Army Corps of Engineers
Seattle District

# SATSOP RIVER FLOODPLAIN RESTORATION PROJECT



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# 1 INTRODUCTION

## 1.1 BACKGROUND

Historic gravel mining activities have impaired floodplain functions and processes of the lower Satsop River in Grays Harbor County, Washington. The floodplain functions and processes are important to the creation and maintenance of complex habitat conditions and long-term health of native fish and wildlife species. The gravel mining activities occurred through the mid-1980s (COE, 2003). The gravel mining created three floodplain ponds and isolated the river from a large area of the floodplain through the placement of riprap along channel banks and the construction of dikes. The U.S. Army Corps of Engineers Seattle District, in cooperation with the Washington State Department of Fish and Wildlife, is working to develop a project to restore the impaired floodplain functions and processes. Detailed hydrologic, hydraulic, geomorphic, and sediment transport studies were conducted to evaluate restoration alternatives and define their potential impacts. A project vicinity map is shown in Figure 1.

The proposed floodplain restoration project is located along the left bank (left is oriented to an observer looking downstream) of the Satsop River between its confluence with the Chehalis River (River Mile 0) and U.S Highway12 (River Mile 5) in Grays Harbor County. The Satsop River has a drainage area of about 300 square miles and has a very wet winter climate. Due to the orographic effects of the Olympic Mountains, average annual precipitation in the basin ranges from less than 70 inches per year near Satsop, WA to about 180 inches per year in headwater areas. The Chehalis River is also tidally influenced at its confluence with the Satsop River.

The project site encompasses 118.5 acres, consisting of pastureland and an abandoned gravel mining operation. A project area map is shown in Figure 2. Three gravel mine ponds, up to 46 ft in depth, totaling approximately 10 acres in surface area, are located on the property. The entire site is located within the historic channel migration zone of the Satsop River. High flow channels are located on the property and are frequently inundated during floods. Riprap and dikes on the property have prevented migration of the river onto the site. Private properties and a variety of infrastructure border the project site.

The left bank of the river adjacent to the northern portion of the site has been reveted with riprap. The southern portion of the site contains three gravel pits; dikes surround two of the pits. The dikes are approximately 10-feet in height and range from about 15-feet in width at their crest to about 60-feet in width at their base. It is also noted that approximately 100,000 cubic yards of spoils from construction excavations for the Duke Energy Satsop Combustion Turbine Project have been stockpiled interior to the dike system in the vicinity of Ponds B and C. In combination, the riprap, dikes and spoils effectively isolate the river from a large area of the floodplain.

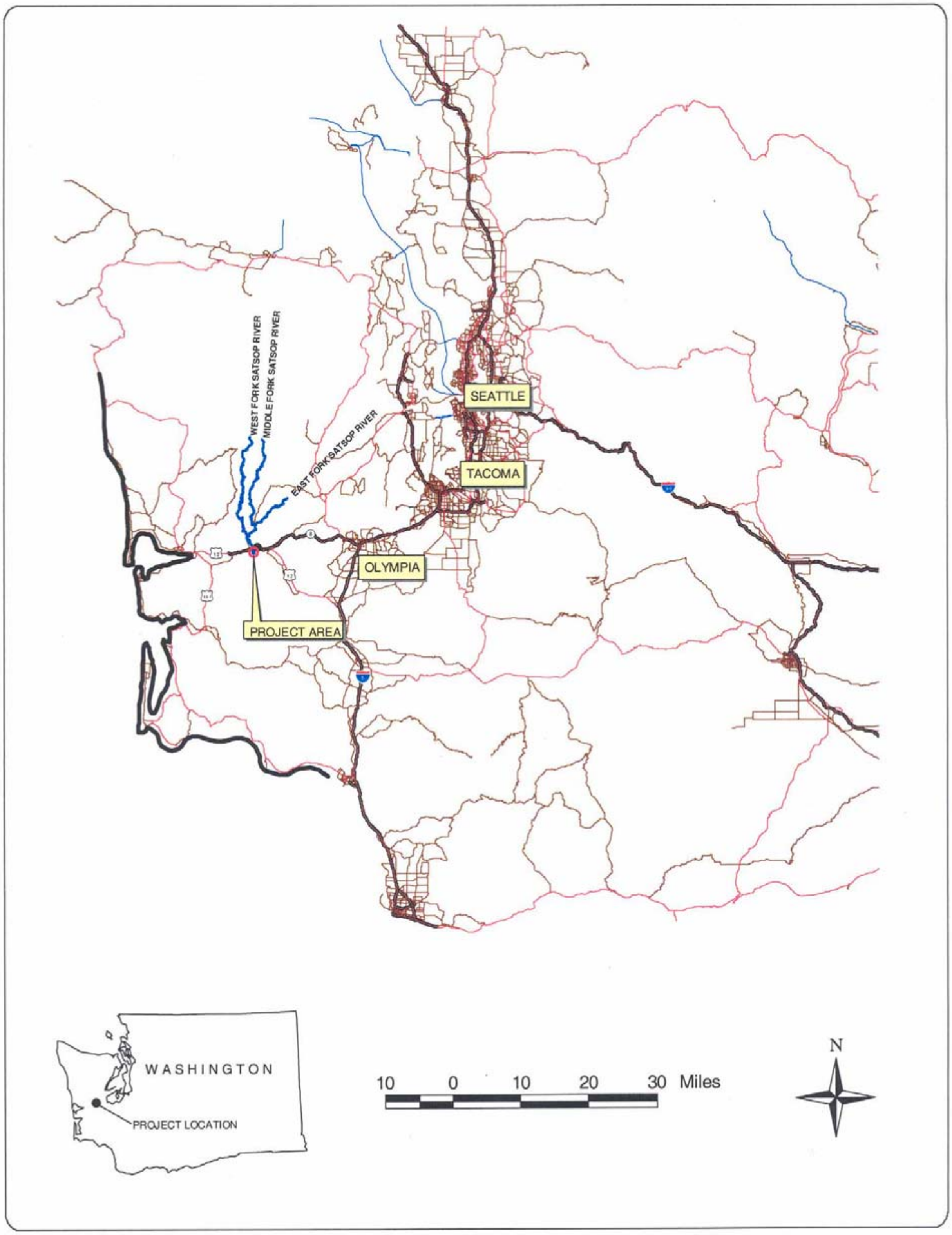



Figure 1. Project vicinity map.

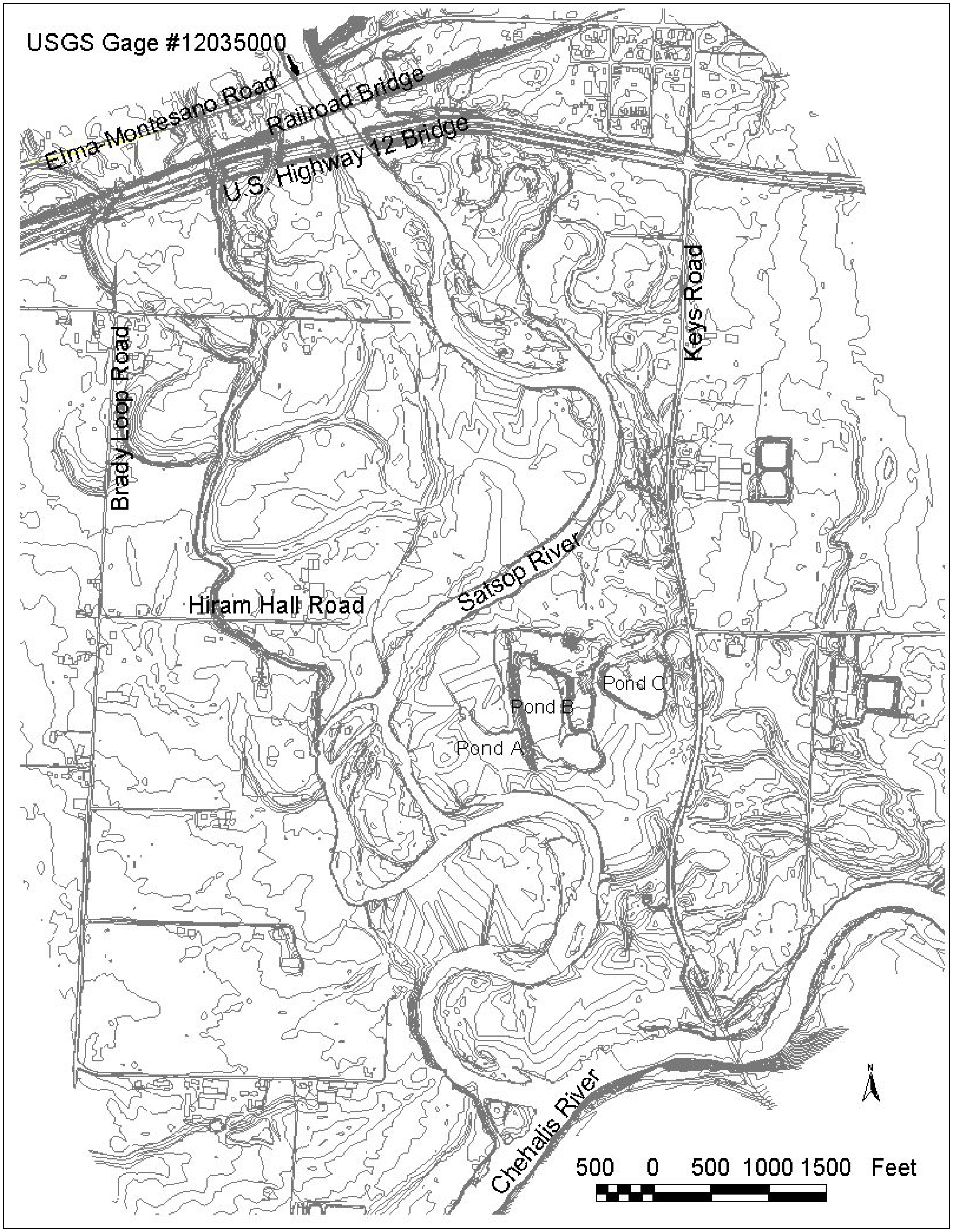



Figure 2. Project area map.

## 1.2 STUDY OBJECTIVES

The overall goal of the restoration project is to reestablish the functions and processes of the floodplain and riparian areas along a reach of the Satsop River for the benefit of native fish and wildlife species and their habitat. The specific goals of this study were to characterize existing conditions and assess potential physical changes and risks that may result from alternative restoration efforts. Three restoration alternatives were evaluated. It is recognized that restoration efforts cannot impose greater risk or negative impacts to adjacent landowners and infrastructure.

## 1.3 STUDY AUTHORITY

The U.S. Army Corps of Engineers (COE), Seattle District, contracted WEST Consultants, Inc. under Engineering Services Contract No. DACW67-03-D-1001, Task Order No. 1, to support design and to evaluate the impacts of the proposed floodplain restoration project. The scope of work for this effort was segmented into the following seven tasks:

1. Review Existing Data
2. Field Reconnaissance and Data Collection
3. Hydrologic Analysis
4. Hydraulic Analysis
5. Geomorphic Analyses Phase One
6. Meetings
7. Report
8. Sedimentation and Geomorphology Evaluation Phase Two (Optional)

Under a modification to the contract, two of the tasks, Task 6 - Public Meeting Presentation and Task 7 – Final Report were deleted. Task 8 was also never implemented. Accordingly, only this draft report for the study was produced. It is also emphasized that a formal Internal Technical Review (ITR) of the work was not conducted.

# 2 DATA

The data and information used in conducting this study are reviewed in the following sections.

## 2.1 PREVIOUS STUDIES

The following prior studies and reports were considered.

### 2.1.1 Hydraulics

A flood insurance study for Grays Harbor County (FEMA, 1990) developed Flood Insurance Rate Maps (FIRMs) for the Satsop River from the confluence with the Chehalis River upstream to River Mile (RM) 8.0. Water surface elevations along the Satsop River were computed through use of the COE HEC-2 step-backwater computer program (COE, 1973) and a 100-year flood peak discharge estimate of 52,300 cfs. The results of a hydraulic analysis for the Chehalis River between RM 1.5 and RM 9.2 were also reported. The Chehalis River water surface elevations for the 100-year flood were based on a COE report, "Suggested Hydraulic Floodway Chehalis River, Aberdeen to Satsop and Vicinity, Grays Harbor County, Washington" (COE, 1978). The COE study indicated that the tidal influence of Grays Harbor extends up the Chehalis River to Satsop. The confluence of the two rivers is at about Chehalis RM 21. The FIRM encompassing the project site shows it to be completely inundated by the 100-year flood. However, the limit of detailed study along the Satsop River shown on the FIRM is near the upstream end of the project site. At that point, the base flood (100-year return period) elevation is indicated to be about 29 ft NGVD. All elevations in this report are referenced to NGVD unless otherwise noted.

A UNET hydraulic model (COE, 1996) of the lower Chehalis River, downstream of Grand Mound, Washington, was developed by Pacific International Engineering, PLLC (PIE) as part of a study for Lewis County and Grays Harbor County (PIE, 1998). The UNET model was a refinement of a hydraulic model originally developed for Lewis County's Chehalis River Basin Flood Control Project. The model was refined by the addition of additional cross sections and calibration and verification to high water marks associated with four major flood events. The model was calibrated to the February 1996 flood and verified against data associated with floods in January and November 1990, and January 1972. The Grays Harbor tidal stage hydrographs registered at Aberdeen were used as the downstream boundary conditions of the UNET model. The UNET model provided calibrated and verified stage-discharge relations for the confluence of the Satsop and Chehalis Rivers.

### 2.1.2 Sediment Transport

Two previous studies of the sediment transport conditions along the Satsop River were identified. Glancy (1971) conducted an analysis of suspended sediment transport measurements collected along streams in the Chehalis River basin over the period October 1961 to September 1965. This study included evaluation of suspended sediment transport conditions along the Satsop River. Collins and Dunne (1986) examined gravel transport and gravel harvesting in the Satsop River. Additional review of these prior studies is made later in Section 5.8.

### 2.1.3 Channel Migration

The Seattle District prepared a channel migration study of the Satsop River (COE, 2002). This project examined the migration characteristics of the mainstem channel along the lower five miles of the river, from the confluence of the east and west forks to the confluence with the Chehalis River. Historical channel locations and human influences were determined through field visits and analysis of historic aerial photographs. Channel migration distances were calculated by georeferencing historical photos with geographic information systems software. The study provides detailed information regarding historical and future meander patterns and rates of migration. Further review of the channel migration study is made in Section 5.5.

### 2.1.4 Groundwater

A specification for the drilling, developing, disinfecting, and testing of a water supply well for the Satsop Nuclear Project was provided by the Seattle District (Chin, 2003). The information included a variety of hydrogeologic data pertinent to the project site. These data included logs of test holes developed in the area, locations of wells used for pump tests of the aquifer, logs of wells used in the pumping tests, pumping test hydrographs, and permeability computations for the pump test.

## 2.2 DATA SOURCES

The basic data used in the study include the following:

### 2.2.1 Topographic Data

The Seattle District provided the following topographic data for use in the study:

- A total of 36 channel cross sections of the Satsop River between the confluence with the Chehalis River and State Route 12 were surveyed (APS Survey & Mapping, 2002).

- Topographic mapping with a 2 ft contour interval was developed for the Satsop River floodplain approximately bounded by Brady Loop Road to the west, Keys Road to the east, U.S. Highway 12 to the north, and the Chehalis River to the south.

- The COE and the Washington Department of Fish and Wildlife (WDFW) conducted supplemental ground surveys of the geometry of high flow channels in the vicinity of the project site.

The WDFW also provided bathymetric information, consisting of depth measurements, for two of the three existing gravel pits on the project site. Staff from the WDFW took depth soundings on July 3, 2003 on Ponds B and C. Pond B was found to have a maximum depth of 46 feet and Pond C a maximum depth of 37 feet. Figure 3 summarizes the bathymetric data available for the ponds.

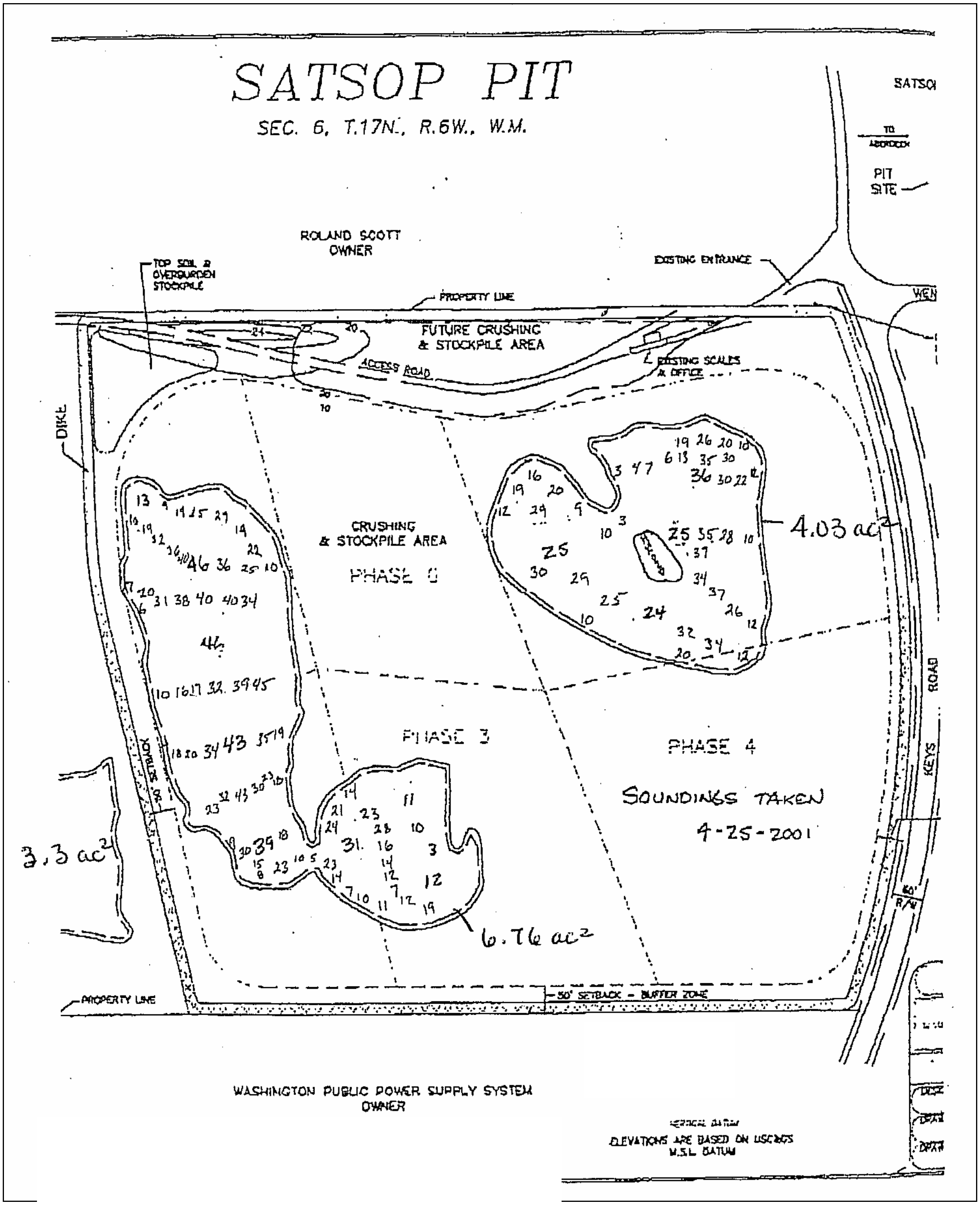



Figure 3. Pond depths surveyed by WDFW.

### 2.2.2 Hydrologic and Hydraulic Data

A record of 72 years of discharge information was obtained for the United States Geological Survey (USGS) Gage "Satsop River near Satsop, WA" (No.12035000). The gage is located in Grays Harbor County, Washington, Hydrologic Unit 17100104 (latitude 47°00'03", longitude 123°29'37" NAD27) about 2.3 miles upstream from the mouth.

Historic high water mark information pertinent to the project area was collected by personnel of the Seattle District in June 2003 (Chin and Knapp, 2003). The high water marks were identified through an interview of local residents. Data for flood events in February 1996 and March 1997 were identified. The February 1996 event was associated with flooding along Chehalis River, whereas the March 1997 was a major flood event on the Satsop River. The Grays Harbor Public Works Division was also contacted to obtain any relevant high water data. All high water data possessed by the County was related to areas upstream of U.S. Highway 12.

### 2.2.3 Structure Data

Construction plans for the U.S. Highway 12 Bridges over the Satsop River were obtained from the Washington Department of Transportation. The plans define the geometry and elevations of the bridge structures. Plans were obtained for both the existing U.S. Highway 12 Bridge and the Elma-Montesano Road.

A 4" steel natural gas pipeline operated by Cascade Natural Gas Company is located along Keys Road adjacent to the east edge of the project site. A general location map for the pipeline was obtained and is shown in Figure 4. However, as the location map is reported to have a horizontal accuracy of plus or minus 50 ft (Personal communication with Clint Mathews; Cascade Natural Gas Company, 2003) the specific location of the pipeline is uncertain and must be field located prior to any construction in the vicinity. No specific data about the depth of burial of the pipeline exist.

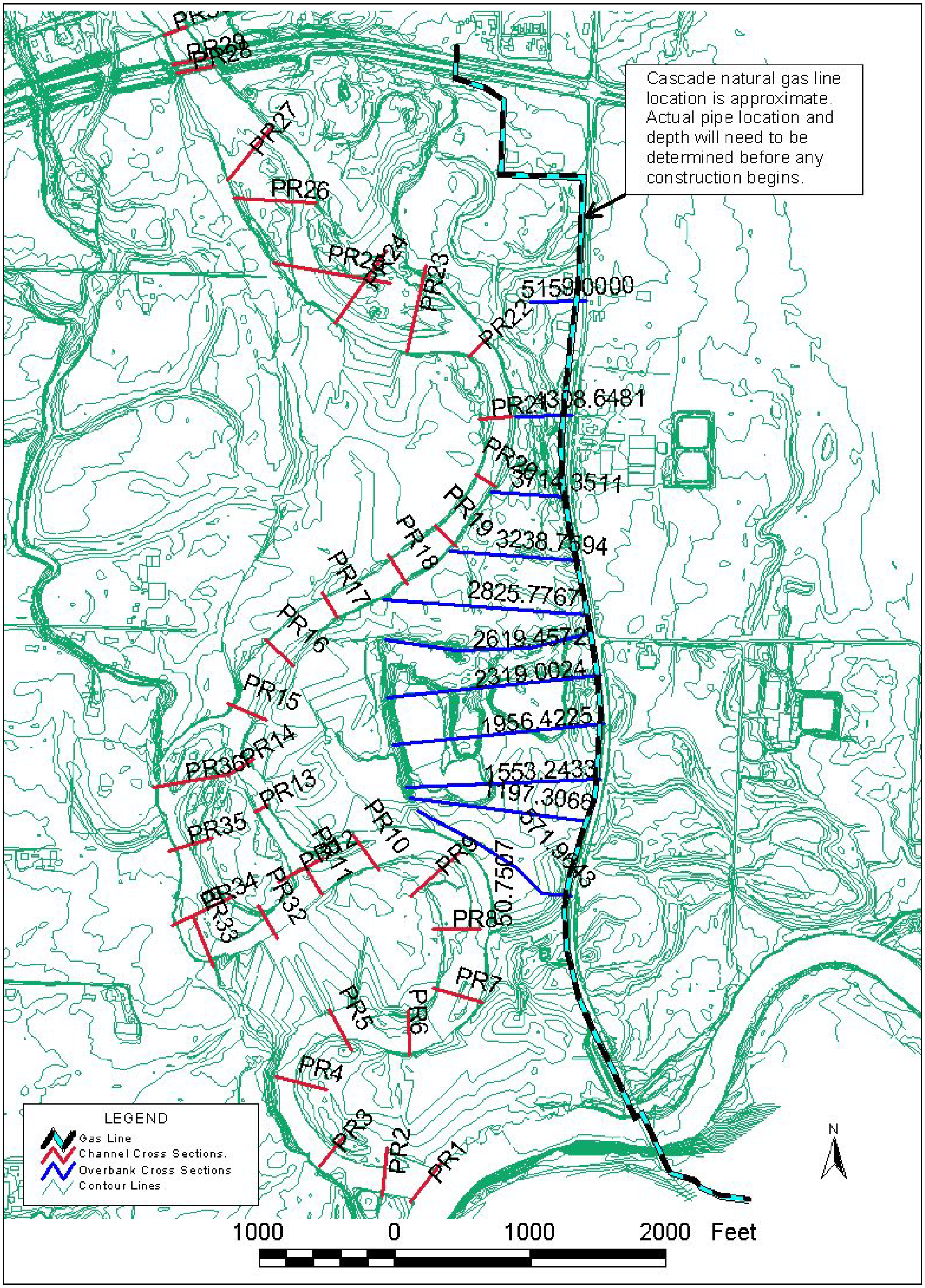



Figure 4. Approximate location of natural gas pipeline.

## 2.3 FIELD RECONNAISSANCE AND DATA COLLECTION

An initial field reconnaissance of the project area was conducted on 2 through 5 June 2003. The field effort was conducted to familiarize team members with the project area and collect data necessary to characterize existing conditions and potential alternatives. In general, the project area considered the lower Satsop River and extended from the Elma-Montesano Road Bridge downstream to the confluence with the Chehalis River. Observations were made of the watershed, bridge crossings, existing bank erosion protection measures, channel characteristics, and locations of significant erosion and sedimentation.

The data collection included a survey of existing bridges and dikes, sediment sampling, placement of staff gages in existing ponds, and observations of channel and floodplain conditions. Specific data collected included sediment samples, the size and distribution of woody debris, locations of existing bank erosion, bankfull delineation, and the type and location of existing bank erosion control measures. Personnel of the WDFW have made approximately weekly readings of the staff gages since their installation. A log of photographs taken during the field reconnaissance and data collection effort is presented in Appendix A.

A second data collection effort was conducted by WEST personnel on July 10, 2003 to collect additional survey information about the dimensions and extent of dikes along the southern boundary of the project site. This work included cross sections of the subject dike, measurements of the length of the dike, and additional reconnaissance of the area surrounding the dike.

A third field reconnaissance was conducted on 21 October 2003 by personnel of WEST and the COE Seattle District to observe conditions in the vicinity of the project associated with a greater than bankfull flow event (COE 2003b). The USGS reported preliminary data that indicated a peak stage of 36.84 occurred at 0600 on 21 October 2003 associated with a discharge of about 36,000 cfs at the Satsop River at Satsop, Washington gage (USGS No. 12035000). Observations of flood conditions were made along the Elma-Montesano Road, Keys Road, Brady Loop Road, and Hiram Hall Road. The field observations of flood conditions were used for qualitative verification of hydraulic modeling results.

## 2.4 Pond, Dike and Spoil Volumes

Estimated volumes of the existing ponds, dikes, and spoils on the project site were developed. The volume estimates were developed to assist in the development of alternative restoration plans. Dike and spoils material may be used as fill to shallow and reshape the existing ponds. The volume estimates were developed by average end area calculations.

### 2.4.1 Existing Pond Volumes

Estimated volumes of the existing ponds on the project site were developed from bathymetric data supplied by the WDFW. The volume of Pond A was developed based on an assumed average depth of approximately 14 feet to the top of bank elevation. A summary of the estimated pond volumes is presented in Table 1. Pond B has the largest volume at 249,617 cubic yards, followed by Pond C at 140,668 cubic yards and Pond A at 80,201 cubic yards. The combined volume of the gravel pits is 470,487 cubic yards, of which, 390,069 cubic yards was filled with water (83%) at the time of the survey. Volume-elevation curves for Ponds B and C are presented in Figure 5. As no specific bathymetric data exist for Pond A, no volume-elevation curve was developed for it.

Table 1 Estimated volumes of existing ponds.

| PONDS | Volume to water surface on July 3, 2003. | | | Volume to top of banks | | |
|---|---|---|---|---|---|---|
| | Cubic Ft | Cubic Yds | Acre-Feet | Cubic Ft | Cubic Yds | Acre-Feet |
| Pond A | 1,940,598 | 71,874 | 45 | 2,165,430 | 80,201 | 50 |
| Pond B | 5,787,350 | 214,346 | 133 | 6,739,672 | 249,617 | 155 |
| Pond C | 2,803,910 | 103,849 | 64 | 3,798,043 | 140,668 | 87 |
| Total | 10,531,858 | 390,069 | 242 | 12,703,144 | 470,487 | 292 |
| *The top of bank elevation for Ponds A and B was assumed to be 18 feet NGVD and the top of bank elevation for Pond C was assumed to be 20 feet NGVD. | | | | | | |

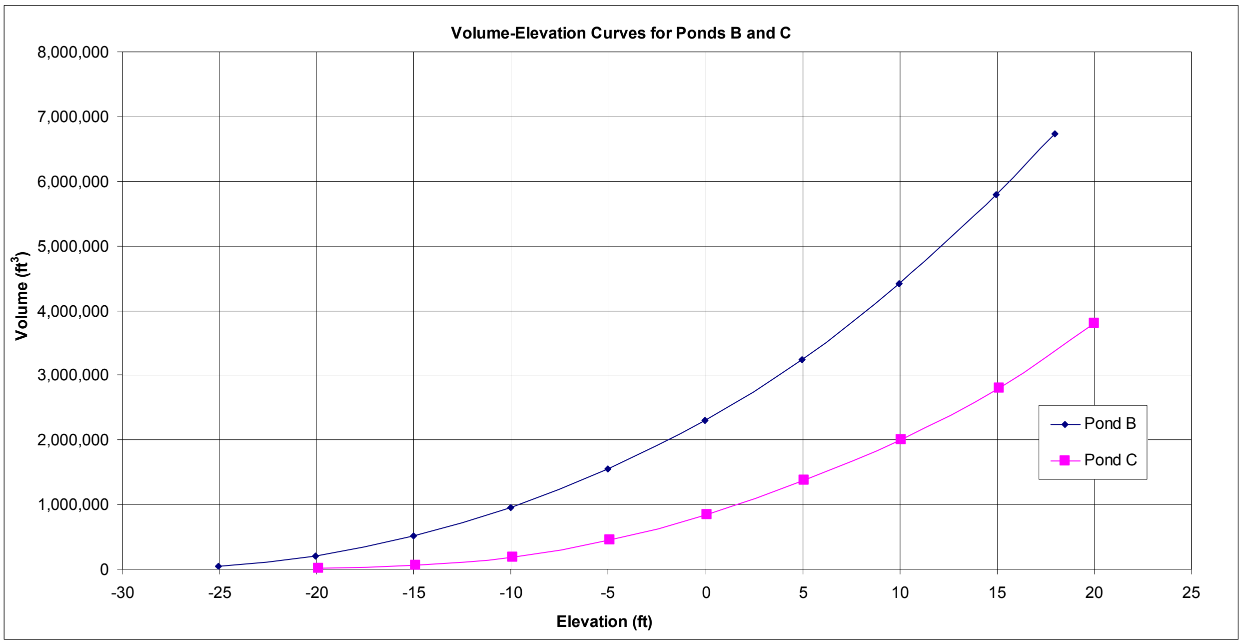



Figure 5. Volume-elevation curves for Ponds B and C.

### 2.4.2 Dike Volumes

Existing dikes are located to the north, west, and south of Gravel Pits B and C. To characterize their geometry and volume, a total of thirteen cross sections of the dikes were surveyed. The surveyed cross section locations are shown in Figure 6. Based on cross sections 1 through 5 and 11 through 13, the estimated volume of the south and west dikes was computed to be about 22,200 cubic yards. The volume of the north dike was estimated as part of the volume of spoils as it is indistinct from the spoils that abut it over much of its length. A summary of the estimated dike volumes is shown in Table 2.

### 2.4.3 Spoils Volume

A large quantity of spoils from construction excavations for the Duke Energy Satsop Combustion Turbine Project has been stockpiled interior to the dike system in the vicinity of

Ponds B and C (COE, 2003). Specifically, the spoils abut the northern dike on the project site. The volume of spoils was estimated from existing topographic mapping of the site to be approximately 100,720 cubic yards.

Table 2. Volume estimates for dikes and spoils on the project site.*

| **Feature** | Cubic Ft | Cubic Yards | Acre-Feet |
|---|---|---|---|
| South Dike | 97,549 | 3,613 | 2.2 |
| West Dike | 501,886 | 18,588 | 11.5 |
| Spoils | 2,719,440 | 100,720 | 62.2 |
| Total | 3,318,875 | 122,921 | 75.9 |

* The volume of the north dike is included in the estimated volume of spoils.

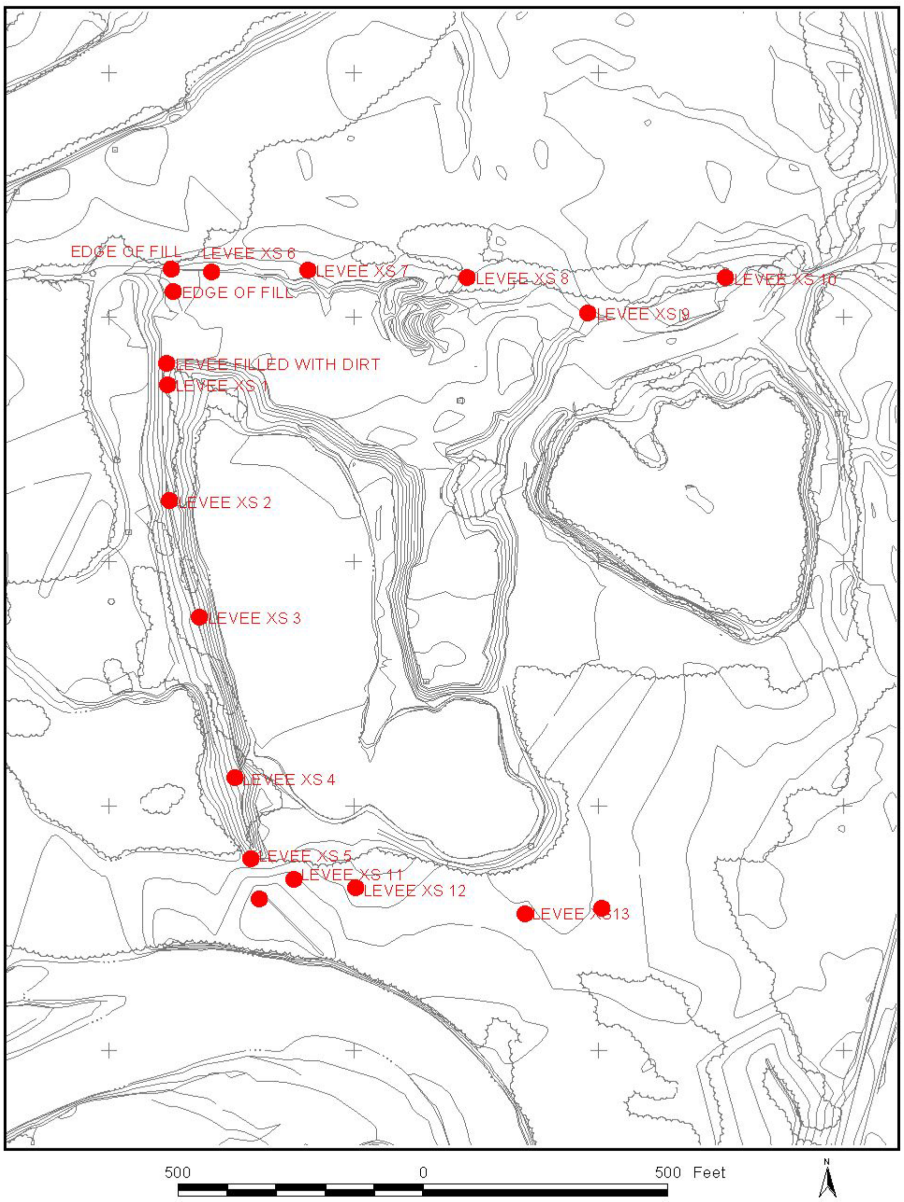



Figure 6. Locations of surveyed dike cross sections.

# 3 HYDROLOGY

An analysis of the hydrology of the Satsop River was conducted. The objective of the analysis was a feasibility level hydrologic study to support the hydraulic analysis for the project.

## 3.1 CLIMATE

The climate of the basin is characterized by relatively warm, wet winters and cool, dry summers. A variable weather pattern within the basin partly due to orographic controls, results in precipitation that ranges from annual averages of less than 70 inches per year near Satsop to about 180 inches per year in the headwater areas of the basin.

## 3.2 GAGE RECORDS/FLOOD HISTORY

Seventy-two years of discharge information are available from the USGS for the Satsop River (Satsop River near Satsop, WA, USGS Gage No.12035000). The gage is located in Grays Harbor County, Washington, Hydrologic Unit 17100104 (latitude 47°00'03", longitude 123°29'37" NAD27), in the west pier of a bridge on old U.S. Highway 410, 0.6 mi west of Satsop, and 2.3 mi upstream from mouth. The general location of the gage is shown in Figure 2. The station covers a drainage area of 299 square miles. The period of record extends from 1929 to current year. The records are good (no estimated daily discharges). There is no regulation or diversion upstream from the station. An average discharge (water years 1930-2001) is 2,040 cfs (92.7 in/yr; 1,476,000 acre-ft/yr). The maximum discharge of 63,600 cfs was observed on March 19, 1997 (elevation 38.87 ft; gage datum is 21 feet above sea level NGVD29). The minimum discharge of 147 cfs was observed on August 31, 1994.

## 3.3 FLOW CHARACTERISTICS

The daily discharge records and peak discharge records for the water years 1930-2001 were obtained from the USGS web site. The observed peak discharges are given in

Table 3 and plotted in Figure 7.  Daily streamflow statistics are given in Table 4.

## 3.4 FLOOD FREQUENCY

An HEC-FFA analysis was performed on the peak flow data to define the flood-frequency relation for the Satsop gage.  The HEC-FFA program assumes the log-Pearson Type III data distribution.  For this analysis, the computed station skew coefficient (founded to the nearest tenth) was used in calculating the frequency curve.  The flood-frequency results are given in Table 5.  The flood-frequency curve is plotted in Figure 8.

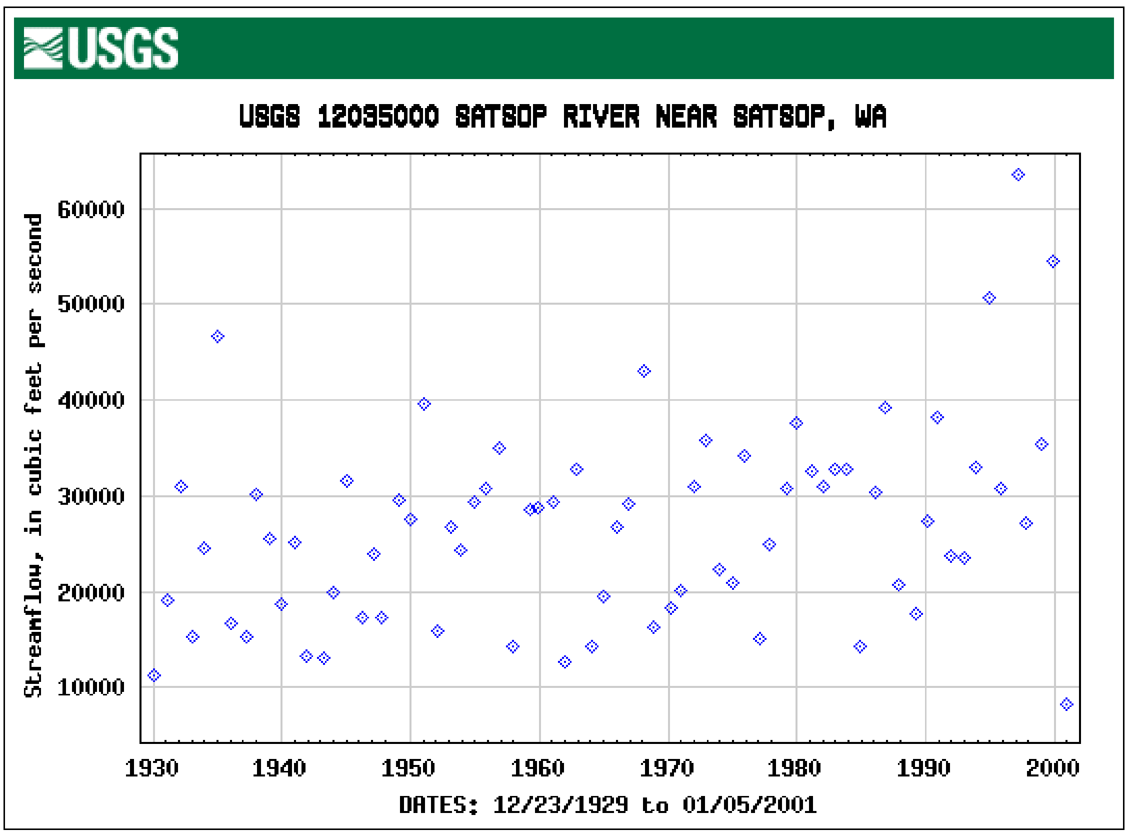



Figure 7.  Record of peak discharge values for the Satsop River.

Table 3. Peak Discharges for the Satsop River.

| Water Year | Date | Gage Height (feet) | Stream-flow (cfs) | Water Year | Date | Gage Height (feet) | Stream-flow (cfs) |
|---|---|---|---|---|---|---|---|
| 1930 | Dec. 23, 1929 | 10.00 | 11,300 | 1966 | Jan. 13, 1966 | 33.92 | 26,700 |
| 1931 | Jan. 23, 1931 | 13.20 | 19,200 | 1967 | Dec. 13, 1966 | 34.54 | 29,200 |
| 1932 | Feb. 26, 1932 | 15.80 | 30,900 | 1968 | Jan. 19, 1968 | 36.43 | 43,100 |
| 1933 | Jan. 08, 1933 | 11.50 | 15,300 | 1969 | Dec. 03, 1968 | 30.64 | 16,200 |
| 1934 | Dec. 21, 1933 | 14.40 | 24,500 | 1970 | Apr. 09, 1970 | 31.24 | 18,200 |
| 1935 | Jan. 22, 1935 | 38.90 | 46,600 | 1971 | Dec. 07, 1970 | 31.83 | 20,200 |
| 1936 | Jan. 04, 1936 | 11.00 | 16,600 | 1972 | Jan. 20, 1972 | 34.30 | 31,000 |
| 1937 | Apr. 14, 1937 | 10.50 | 15,200 | 1973 | Dec. 26, 1972 | 35.23 | 35,900 |
| 1938 | Dec. 28, 1937 | 14.30 | 30,100 | 1974 | Dec. 16, 1973 | 32.46 | 22,400 |
| 1939 | Jan. 01, 1939 | 33.91 | 25,600 | 1975 | Dec. 21, 1974 | 32.10 | 21,000 |
| 1940 | Dec. 15, 1939 | 32.14 | 18,700 | 1976 | Dec. 26, 1975 | 34.95 | 34,200 |
| 1941 | Jan. 18, 1941 | 33.81 | 25,200 | 1977 | Mar. 07, 1977 | 30.41 | 15,100 |
| 1942 | Dec. 19, 1941 | 30.23 | 13,200 | 1978 | Dec. 02, 1977 | 33.10 | 25,000 |
| 1943 | Apr. 01, 1943 | 29.96 | 13,100 | 1979 | Mar. 05, 1979 | 34.24 | 30,700 |
| 1944 | Dec. 03, 1943 | 32.64 | 19,900 | 1980 | Dec. 18, 1979 | 35.54 | 37,700 |
| 1945 | Feb. 07, 1945 | 35.30 | 31,500 | 1981 | Feb. 16, 1981 | 34.62 | 32,600 |
| 1946 | Apr. 11, 1946 | 31.73 | 17,200 | 1982 | Feb. 14, 1982 | 34.31 | 31,000 |
| 1947 | Jan. 25, 1947 | 34.00 | 24,000 | 1983 | Dec. 04, 1982 | 34.66 | 32,800 |
| 1948 | Oct. 19, 1947 | 32.06 | 17,300 | 1984 | Nov. 15, 1983 | 34.66 | 32,800 |
| 1949 | Feb. 22, 1949 | 34.90 | 29,500 | 1985 | Dec. 14, 1984 | 30.13 | 14,200 |
| 1950 | Dec. 28, 1949 | 34.80 | 27,600 | 1986 | Jan. 18, 1986 | 34.16 | 30,300 |
| 1951 | Feb. 09, 1951 | 36.91 | 39,600 | 1987 | Nov. 23, 1986 | 35.93 | 39,300 |
| 1952 | Jan. 30, 1952 | 32.01 | 15,800 | 1988 | Dec. 10, 1987 | 32.11 | 20,800 |
| 1953 | Jan. 23, 1953 | 34.79 | 26,700 | 1989 | Apr. 05, 1989 | 31.19 | 17,600 |
| 1954 | Dec. 12, 1953 | 34.20 | 24,300 | 1990 | Feb. 10, 1990 | 33.68 | 27,300 |
| 1955 | Nov. 18, 1954 | 35.37 | 29,300 | 1991 | Nov. 24, 1990 | 35.75 | 38,200 |
| 1956 | Nov. 03, 1955 | 35.14 | 30,700 | 1992 | Nov. 20, 1991 | 32.86 | 23,700 |
| 1957 | Dec. 10, 1956 | 35.99 | 35,000 | 1993 | Jan. 25, 1993 | 32.81 | 23,500 |
| 1958 | Dec. 26, 1957 | 31.06 | 14,200 | 1994 | Dec. 10, 1993 | 35.38 | 33,000 |
| 1959 | Apr. 30, 1959 | 34.73 | 28,600 | 1995 | Dec. 20, 1994 | 37.28 | 50,600 |
| 1960 | Nov. 20, 1959 | 35.18 | 28,700 | 1996 | Nov. 29, 1995 | 34.27 | 30,800 |
| 1961 | Feb. 21, 1961 | 35.32 | 29,300 | 1997 | Mar. 19, 1997 | 38.87 | 63,600 |
| 1962 | Dec. 23, 1961 | 30.41 | 12,700 | 1998 | Oct. 30, 1997 | 33.68 | 27,200 |
| 1963 | Nov. 20, 1962 | 35.56 | 32,800 | 1999 | Dec. 29, 1998 | 35.08 | 35,400 |
| 1964 | Jan. 25, 1964 | 30.74 | 14,300 | 2000 | Dec. 15, 1999 | 37.78 | 54,500 |
| 1965 | Nov. 30, 1964 | 32.40 | 19,500 | 2001 | Jan. 05, 2001 | 29.83 | 8,190 |

Table 4. Daily Streamflow Statistics for the Satsop River.

| Day of month | Mean of daily mean values for this day for 73 years of record, in cfs | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| **1** | 4162 | 3774 | 3328 | 2703 | 1629 | 829 | 538 | 355 | 379 | 561 | 1922 | 3960 |
| **2** | 4093 | 3713 | 3368 | 2479 | 1580 | 810 | 541 | 357 | 418 | 630 | 2073 | 4709 |
| **3** | 4148 | 3610 | 3273 | 2310 | 1538 | 795 | 518 | 353 | 370 | 586 | 2361 | 4547 |
| **4** | 4182 | 3761 | 3245 | 2311 | 1492 | 792 | 507 | 344 | 381 | 647 | 2407 | 4623 |
| **5** | 4146 | 3671 | 3397 | 2460 | 1462 | 783 | 497 | 336 | 369 | 661 | 2168 | 3938 |
| **6** | 3883 | 3593 | 3138 | 2436 | 1440 | 753 | 485 | 337 | 359 | 681 | 2052 | 4017 |
| **7** | 3996 | 3917 | 2973 | 2288 | 1334 | 751 | 468 | 343 | 350 | 663 | 2068 | 3765 |
| **8** | 3826 | 3832 | 2854 | 2131 | 1282 | 745 | 470 | 339 | 345 | 718 | 2404 | 3497 |
| **9** | 3641 | 3650 | 3062 | 2264 | 1239 | 780 | 505 | 330 | 355 | 801 | 2338 | 3835 |
| **10** | 3428 | 3716 | 3065 | 2172 | 1210 | 762 | 489 | 321 | 379 | 970 | 2654 | 4268 |
| **11** | 3720 | 3479 | 2980 | 2204 | 1192 | 736 | 484 | 317 | 374 | 934 | 2691 | 4246 |
| **12** | 3930 | 3491 | 3147 | 2140 | 1137 | 830 | 508 | 312 | 350 | 892 | 2795 | 4442 |
| **13** | 4006 | 3948 | 3049 | 2177 | 1161 | 749 | 558 | 311 | 337 | 927 | 2980 | 4625 |
| **14** | 4319 | 3814 | 2987 | 2202 | 1190 | 729 | 510 | 309 | 360 | 886 | 3330 | 4344 |
| **15** | 4495 | 3735 | 2977 | 2119 | 1158 | 714 | 484 | 313 | 401 | 909 | 3316 | 4817 |
| **16** | 4500 | 4204 | 2969 | 2084 | 1164 | 702 | 502 | 312 | 419 | 864 | 3125 | 4536 |
| **17** | 4290 | 4222 | 2870 | 2094 | 1171 | 729 | 480 | 307 | 486 | 949 | 2821 | 4632 |
| **18** | 4536 | 4066 | 3186 | 1976 | 1097 | 742 | 462 | 304 | 468 | 1084 | 2810 | 4798 |
| **19** | 5043 | 4307 | 3533 | 1932 | 1052 | 707 | 440 | 302 | 448 | 1128 | 2932 | 4514 |
| **20** | 4382 | 3929 | 3084 | 2083 | 1038 | 685 | 425 | 300 | 500 | 1300 | 3664 | 4511 |
| **21** | 4160 | 3862 | 2781 | 1921 | 993 | 661 | 412 | 297 | 496 | 1206 | 3298 | 4285 |
| **22** | 4472 | 4125 | 2818 | 1775 | 959 | 634 | 410 | 329 | 505 | 1407 | 3204 | 4077 |
| **23** | 4727 | 3709 | 2948 | 1840 | 943 | 641 | 400 | 346 | 603 | 1460 | 3621 | 4246 |
| **24** | 4887 | 3985 | 3015 | 1848 | 958 | 615 | 388 | 352 | 523 | 1559 | 4126 | 4078 |
| **25** | 4720 | 3753 | 2802 | 1711 | 935 | 654 | 380 | 347 | 488 | 1792 | 4149 | 3839 |
| **26** | 4133 | 4049 | 2663 | 1631 | 896 | 634 | 376 | 343 | 488 | 1670 | 3927 | 4515 |
| **27** | 3873 | 3970 | 2650 | 1628 | 867 | 592 | 380 | 325 | 476 | 1860 | 3743 | 4265 |
| **28** | 3788 | 3528 | 2620 | 1660 | 888 | 566 | 375 | 329 | 530 | 1980 | 3658 | 4605 |
| **29** | 3832 | 4048 | 2696 | 1739 | 880 | 551 | 365 | 371 | 511 | 1809 | 3587 | 4144 |
| **30** | 3832 | | 2770 | 1726 | 858 | 534 | 359 | 376 | 561 | 2019 | 3741 | 4397 |
| **31** | 3795 | | 2741 | | 843 | | 358 | 372 | | 2031 | | 3938 |

Table 5. HEC-FFA Flood-Frequency Results for the Satsop River.

| Computed Curve (cfs) | Expected Probability (cfs) | Percent Chance Exceedence | Recurrence Interval (yrs) | Confidence Limits (cfs) | |
|---|---|---|---|---|---|
| | | | | 0.05 | 0.95 |
| 67400. | 69600. | 0.2 | 500 | 80600. | 58500. |
| 61700. | 63300. | 0.5 | 200 | 72900. | 54000. |
| 57200. | 58400. | 1.0 | 100 | 66900. | 50500. |
| 52500. | 53400. | 2.0 | 50 | 60800. | 46800. |
| 46000. | 46500. | 5.0 | 20 | 52300. | 41500. |
| 40700. | 41000. | 10.0 | 10 | 45600. | 37000. |
| 34800. | 35000. | 20.0 | 5 | 38400. | 32000. |
| 25400. | 25400. | 50.0 | 2 | 27400. | 23500. |
| 17900. | 17800. | 80.0 | 1.25 | 19500. | 16300. |
| 14800. | 14700. | 90.0 | 1.11 | 16300. | 13200. |
| 12500. | 12400. | 95.0 | 1.05 | 14000. | 10900. |
| 9070. | 8760. | 99.0 | 1.01 | 10500. | 7570. |

### 3.4.1 Systematic Statistics

| | | | |
|---|---|---|---|
| **Mean** | 4.3954 | **Historic Events** | 0 |
| **Standard Dev** | 0.1720 | **High Outliers** | 0 |
| **Computed Skew** | -0.2844 | **Low Outliers** | 0 |
| **Regional Skew** | -99.0000 | **Zero Or Missing** | 0 |
| **Adopted Skew** | -0.3000 | **Systematic Events** | 72 |

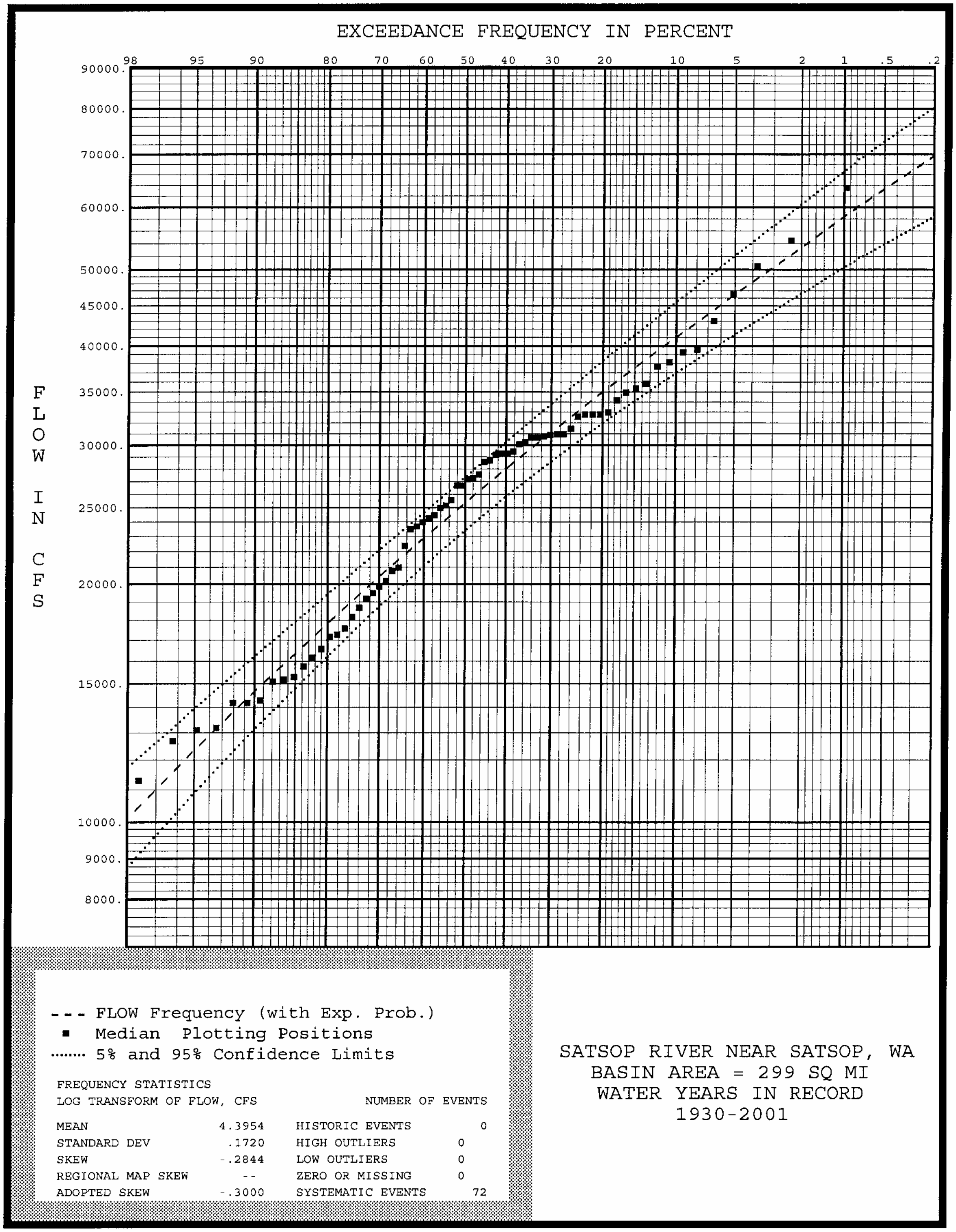



Figure 8. Flood-frequency curve for the Satsop River.

## 3.5 FLOW DURATION

The flow duration analysis was conducted on daily discharges to define "average year" flow distribution and flow duration curves. The summary "average year" hydrograph (based on averaging the 73 years of record for each particular day) is shown in Figure 9. The "maximum" and "minimum year" hydrographs are also plotted in Figure 9. Percentile statistics are shown in Figure 10. The flow duration curve is plotted in Figure 11.

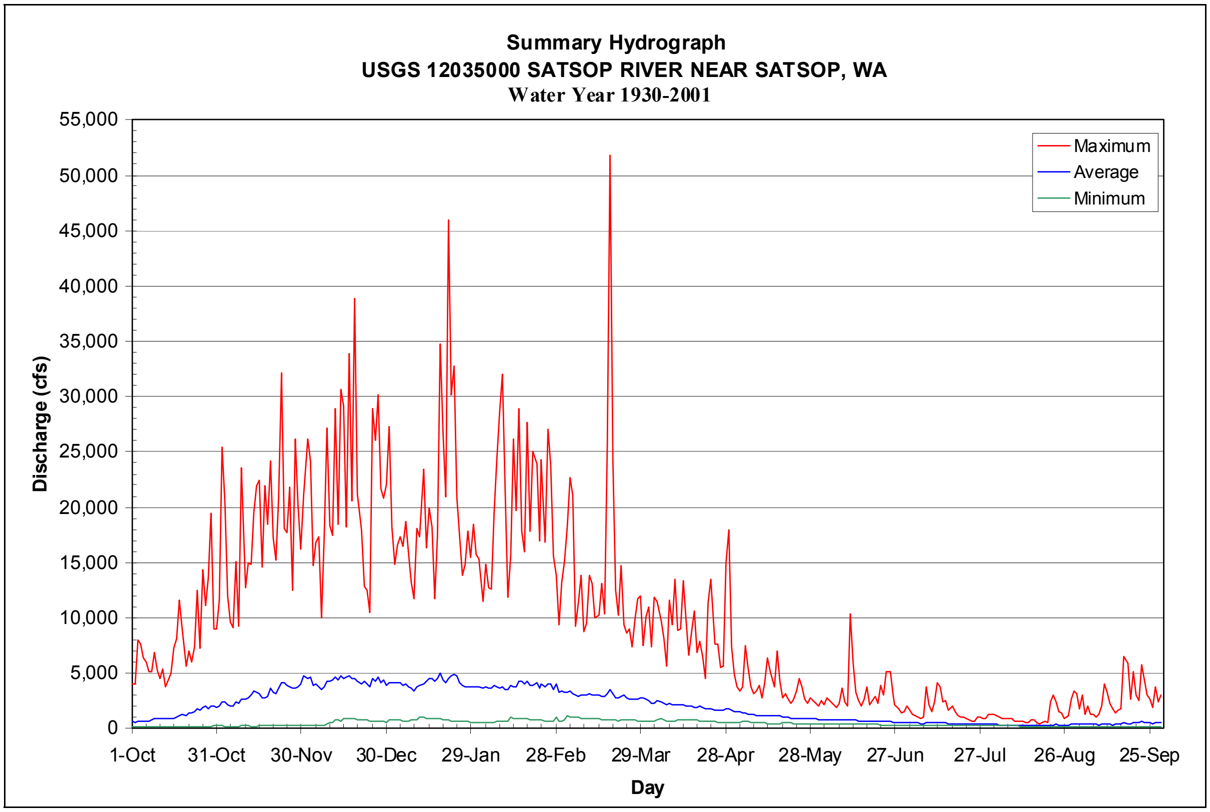



Figure 9. Summary hydrographs for the Satsop River.

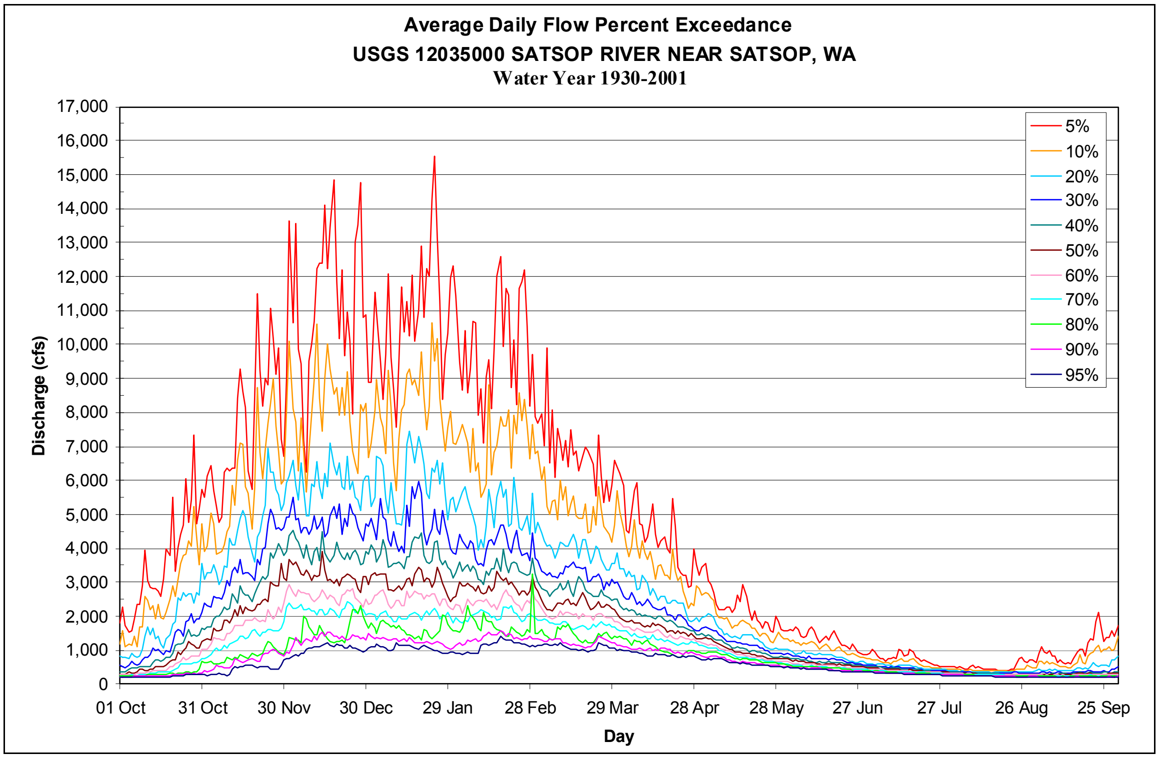



Figure 10. Percentile statistics for the Satsop River.

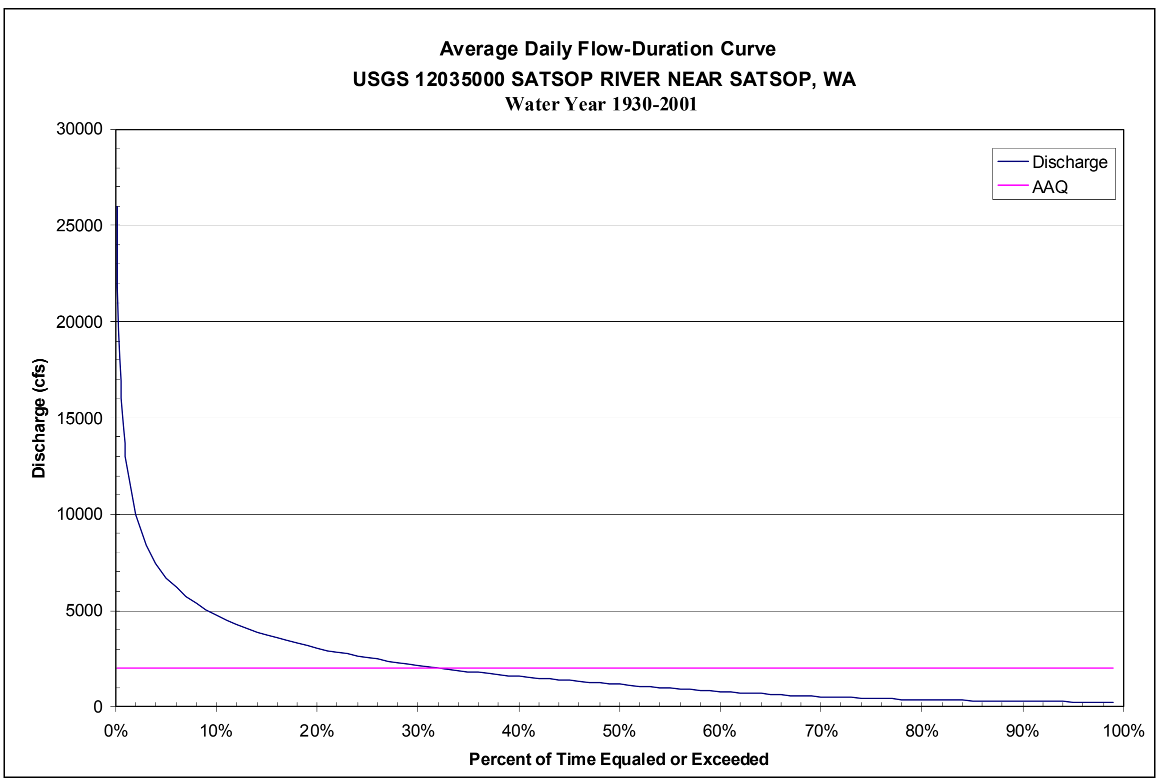



Figure 11. Flow-duration curve for the Satsop River.

## 3.6 MAXIMUMS/MINIMUMS

High flow/low flow hydrologic characteristics were analyzed using the Indicators of Hydrologic Alterations (IHA, 2001) software package. The minimum/maximum flow distribution with the corresponding calendar timing is shown in Figures 12-15.

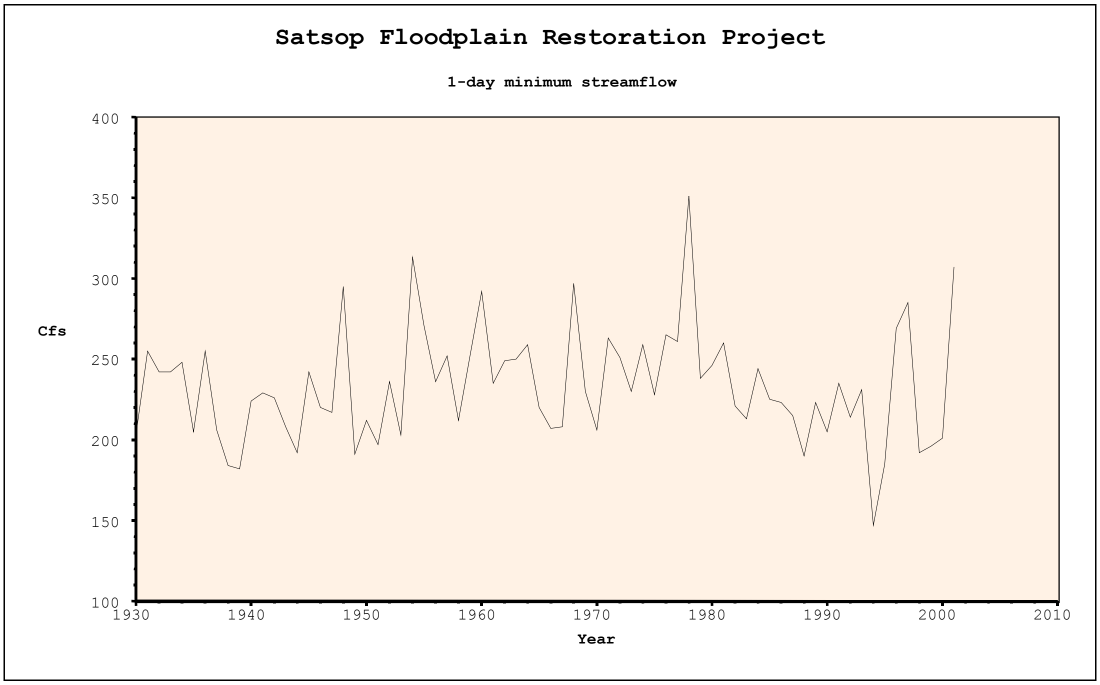



Figure 12. Minimum discharge for the Satsop River.

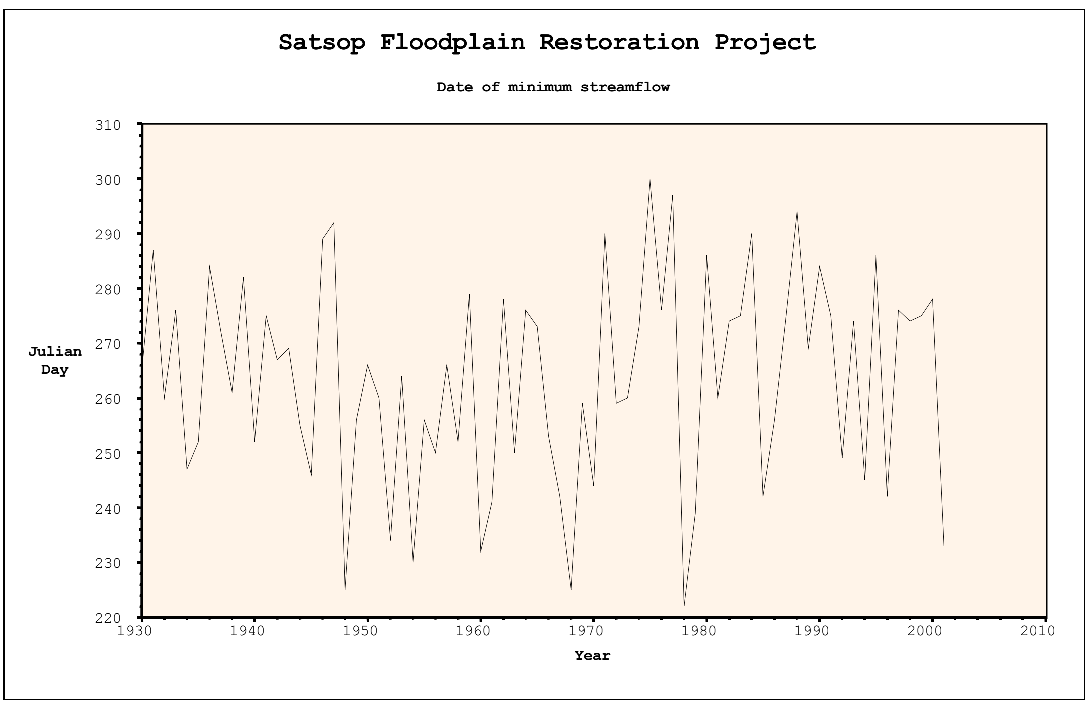



Figure 13. Date of minimum discharge for the Satsop River.

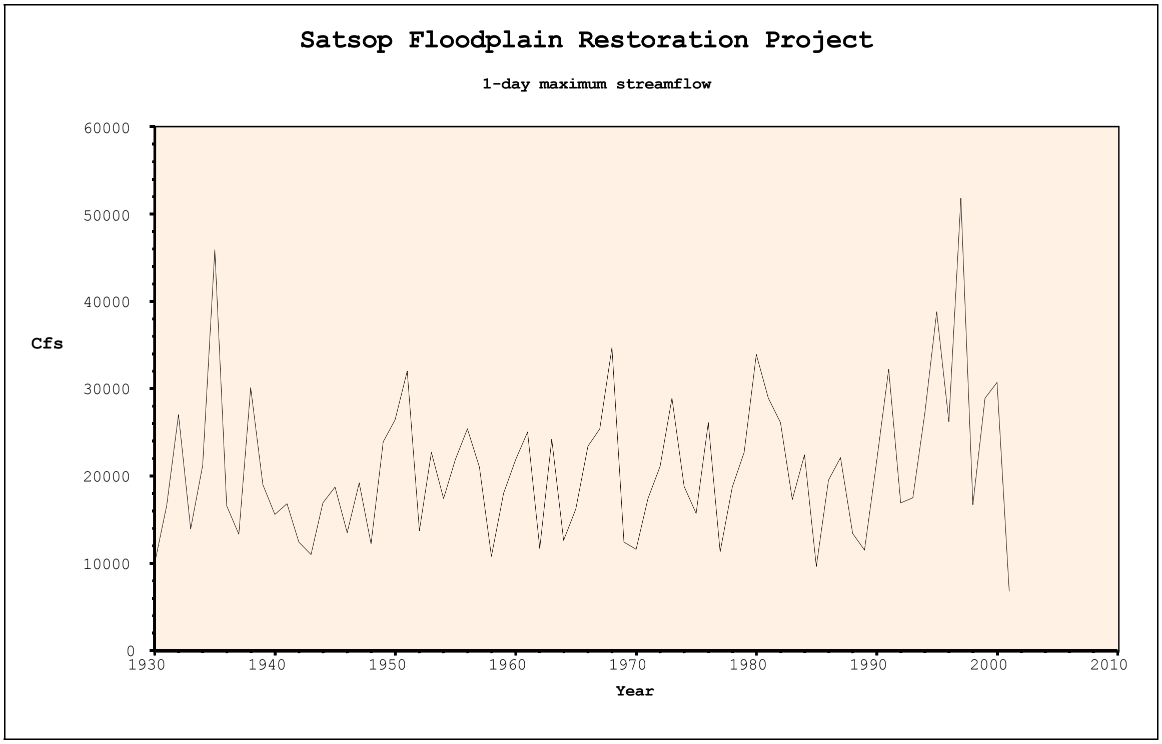



Figure 14. Maximum discharge for the Satsop River.

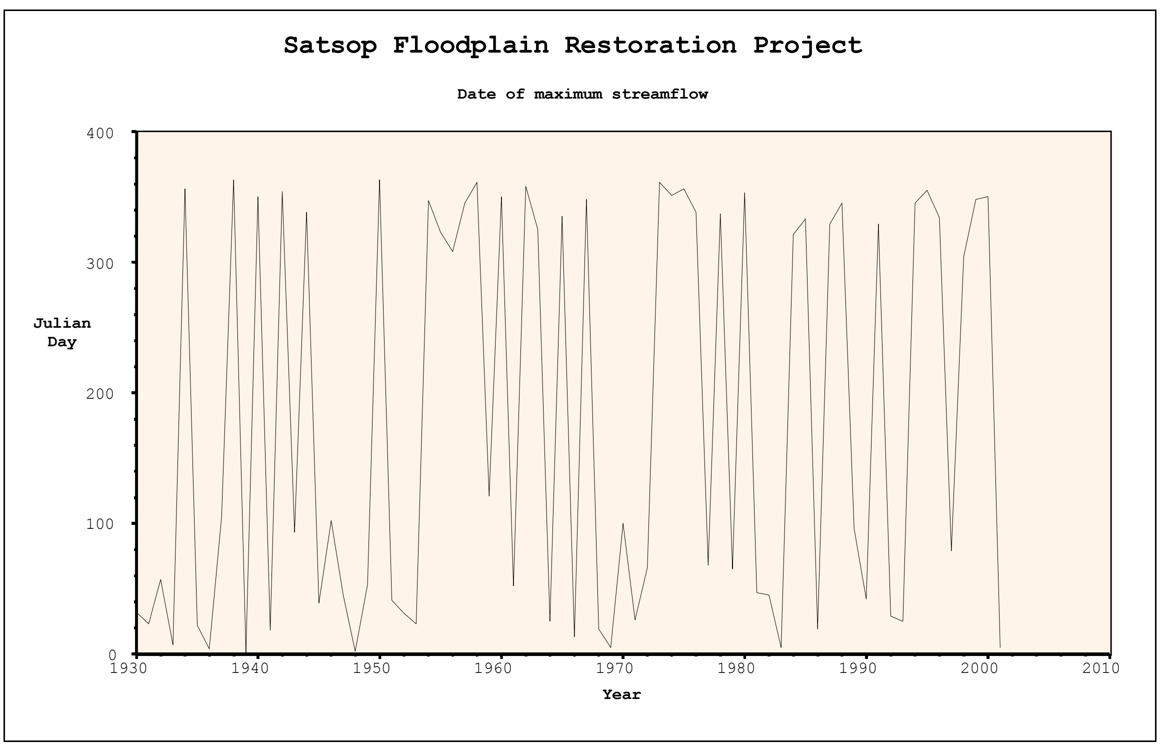



Figure 15. Date of maximum discharge for the Satsop River.

## 3.7 LOW FLOW

Minimum flows averaged over the specified number of days are given in Table 6. The frequency of minimum flows is plotted in Figure 16.

Table 6. Minimum Flows for the Satsop River.

| Water Year | Minimum of Daily Flow Averages (cfs) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1-Day | 3-Day | 7-Day | 14-Day | 30-Day | 60-Day | 90-Day |
| 1930 | 203 | 207 | 212 | 220 | 224 | 242 | 283 |
| 1931 | 255 | 260 | 267 | 281 | 305 | 372 | 462 |
| 1932 | 242 | 242 | 252 | 265 | 273 | 322 | 356 |
| 1933 | 242 | 242 | 242 | 264 | 269 | 304 | 377 |
| 1934 | 248 | 248 | 253 | 261 | 278 | 321 | 369 |
| 1935 | 205 | 205 | 208 | 217 | 228 | 250 | 304 |
| 1936 | 255 | 262 | 268 | 295 | 315 | 344 | 440 |
| 1937 | 206 | 210 | 212 | 220 | 263 | 278 | 388 |
| 1938 | 184 | 187 | 190 | 195 | 208 | 233 | 270 |
| 1939 | 182 | 186 | 191 | 241 | 244 | 266 | 299 |
| 1940 | 224 | 225 | 230 | 235 | 242 | 264 | 281 |
| 1941 | 229 | 230 | 243 | 252 | 270 | 299 | 380 |
| 1942 | 226 | 226 | 229 | 233 | 246 | 294 | 413 |
| 1943 | 208 | 214 | 226 | 229 | 243 | 273 | 320 |
| 1944 | 192 | 193 | 197 | 202 | 209 | 231 | 269 |
| 1945 | 242 | 246 | 252 | 259 | 262 | 295 | 326 |
| 1946 | 220 | 223 | 225 | 230 | 269 | 287 | 380 |
| 1947 | 217 | 219 | 222 | 231 | 269 | 318 | 366 |
| 1948 | 295 | 298 | 307 | 320 | 335 | 359 | 405 |
| 1949 | 191 | 193 | 197 | 207 | 241 | 287 | 317 |
| 1950 | 212 | 216 | 222 | 233 | 280 | 333 | 356 |
| 1951 | 197 | 197 | 197 | 200 | 214 | 225 | 247 |
| 1952 | 236 | 241 | 251 | 257 | 281 | 324 | 327 |
| 1953 | 203 | 205 | 207 | 215 | 233 | 263 | 317 |
| 1954 | 313 | 317 | 322 | 324 | 341 | 368 | 441 |
| 1955 | 271 | 276 | 277 | 288 | 331 | 415 | 464 |
| 1956 | 236 | 236 | 242 | 251 | 275 | 306 | 373 |
| 1957 | 252 | 252 | 255 | 265 | 294 | 358 | 377 |
| 1958 | 212 | 217 | 223 | 232 | 235 | 248 | 276 |
| 1959 | 252 | 255 | 271 | 276 | 290 | 357 | 451 |
| 1960 | 292 | 297 | 301 | 310 | 331 | 345 | 365 |
| 1961 | 235 | 235 | 239 | 246 | 255 | 284 | 312 |

| Water Year | Minimum of Daily Flow Averages (cfs) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1-Day | 3-Day | 7-Day | 14-Day | 30-Day | 60-Day | 90-Day |
| 1962 | 249 | 251 | 267 | 304 | 341 | 389 | 400 |
| 1963 | 250 | 250 | 255 | 264 | 285 | 302 | 354 |
| 1964 | 259 | 265 | 283 | 335 | 370 | 477 | 498 |
| 1965 | 220 | 222 | 224 | 230 | 239 | 264 | 289 |
| 1966 | 207 | 209 | 214 | 223 | 237 | 248 | 285 |
| 1967 | 208 | 209 | 210 | 215 | 225 | 241 | 269 |
| 1968 | 297 | 301 | 312 | 328 | 363 | 451 | 539 |
| 1969 | 230 | 234 | 237 | 247 | 275 | 295 | 359 |
| 1970 | 206 | 206 | 210 | 214 | 232 | 269 | 301 |
| 1971 | 263 | 265 | 276 | 296 | 325 | 432 | 496 |
| 1972 | 251 | 251 | 257 | 272 | 280 | 336 | 468 |
| 1973 | 230 | 231 | 234 | 241 | 252 | 292 | 389 |
| 1974 | 259 | 260 | 264 | 275 | 312 | 348 | 514 |
| 1975 | 228 | 230 | 234 | 237 | 256 | 326 | 386 |
| 1976 | 265 | 291 | 306 | 329 | 344 | 377 | 421 |
| 1977 | 261 | 262 | 264 | 276 | 295 | 358 | 483 |
| 1978 | 351 | 352 | 357 | 370 | 395 | 444 | 558 |
| 1979 | 238 | 238 | 240 | 253 | 256 | 299 | 333 |
| 1980 | 246 | 248 | 251 | 257 | 270 | 291 | 335 |
| 1981 | 260 | 260 | 267 | 277 | 312 | 346 | 429 |
| 1982 | 221 | 222 | 226 | 229 | 244 | 254 | 283 |
| 1983 | 213 | 221 | 266 | 305 | 383 | 456 | 678 |
| 1984 | 244 | 250 | 256 | 268 | 302 | 325 | 371 |
| 1985 | 225 | 227 | 229 | 234 | 250 | 275 | 313 |
| 1986 | 223 | 225 | 226 | 232 | 240 | 265 | 312 |
| 1987 | 215 | 218 | 224 | 231 | 245 | 270 | 327 |
| 1988 | 190 | 190 | 191 | 192 | 200 | 291 | 374 |
| 1989 | 223 | 224 | 225 | 233 | 251 | 303 | 423 |
| 1990 | 205 | 208 | 215 | 241 | 278 | 296 | 342 |
| 1991 | 235 | 265 | 272 | 281 | 303 | 360 | 446 |
| 1992 | 214 | 214 | 218 | 220 | 231 | 242 | 271 |
| 1993 | 231 | 234 | 242 | 251 | 272 | 316 | 375 |
| 1994 | 147 | 149 | 154 | 166 | 187 | 229 | 289 |
| 1995 | 185 | 186 | 194 | 202 | 255 | 298 | 309 |
| 1996 | 269 | 270 | 271 | 276 | 284 | 316 | 347 |
| 1997 | 285 | 293 | 365 | 383 | 415 | 474 | 667 |
| 1998 | 192 | 195 | 198 | 204 | 209 | 229 | 266 |

| Water Year | Minimum of Daily Flow Averages (cfs) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1-Day | 3-Day | 7-Day | 14-Day | 30-Day | 60-Day | 90-Day |
| 1999 | 196 | 208 | 209 | 214 | 228 | 265 | 310 |
| 2000 | 201 | 204 | 285 | 312 | 334 | 359 | 426 |
| 2001 | 307 | 311 | 317 | 332 | 361 | 437 | 503 |

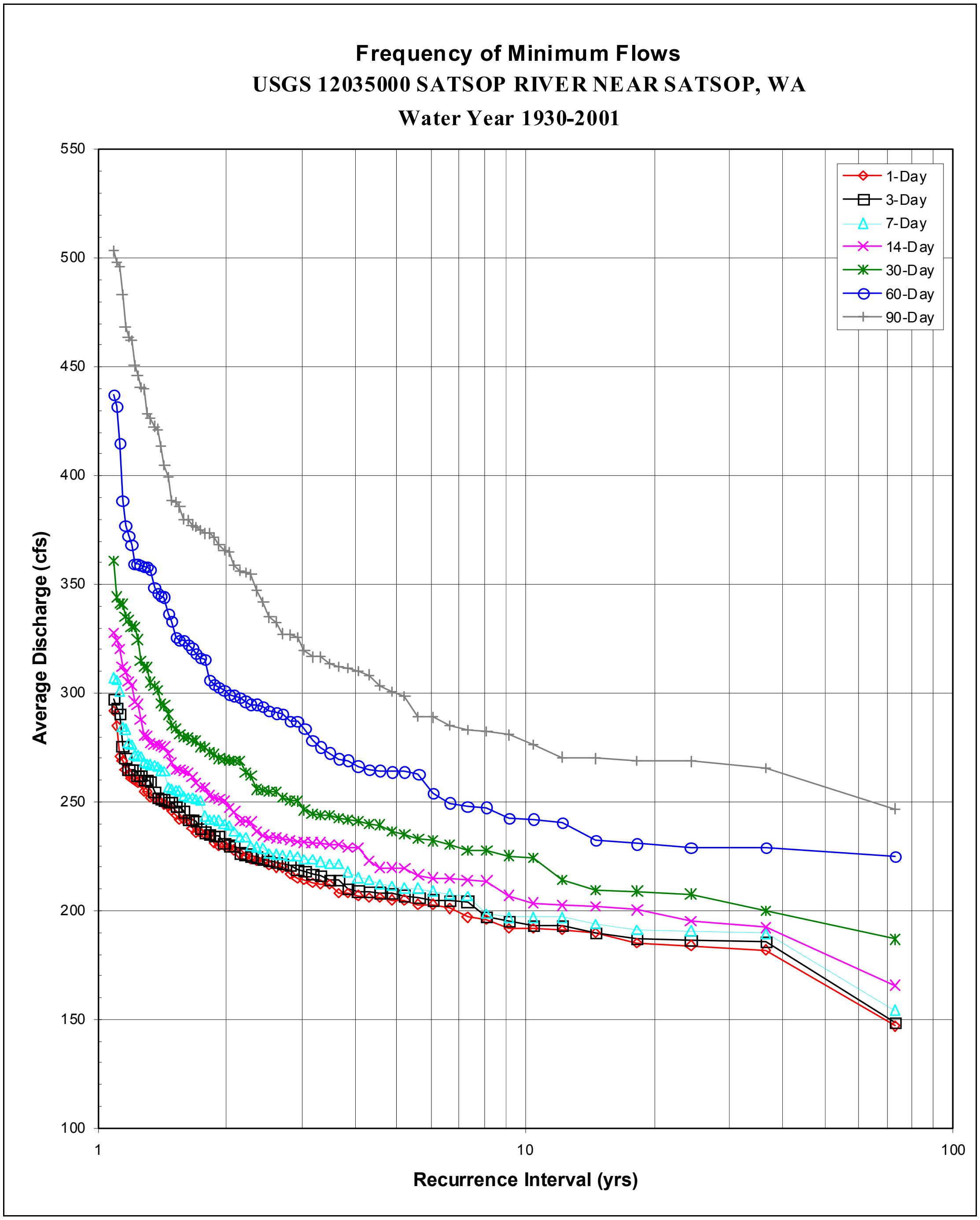



Figure 16. Frequency of minimum flows for the Satsop River.

## 3.8 CHANNEL FORMING DISCHARGE

The channel forming discharge is the one at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or reforming bars, forming or changing bends and meanders results in the average morphologic characteristics of channels (Dunne and Leopold, 1978). It is commonly assumed to be bankfull discharge corresponding to bankfull stream level. The bankfull discharge recurrence interval ($T_a$) in streams has been approximated at a 1.5-year flow event. However, Castro and Jackson (2001) have found patterns of $T_a$ to be significant when stratified by ecoregions in the Pacific Northwest. Their study indicates that a 1.5-year $T_a$ should be applied to streams in Idaho, eastern Washington, and eastern Oregon, while a 1.2-year recurrence interval should be applied to streams in the more humid areas of western Oregon and western Washington. Since the Satsop River belongs to the latter region, its channel forming discharge was estimated at 17,000 cfs with a 1.2-year recurrence interval.

## 3.9 GROUNDWATER

Available data and information from the state of Washington Department of Ecology (WDOE) water well database pertinent to the vicinity of the project were collected and reviewed. The database includes a map of well locations and installation logs for the associated wells. The installation logs describe the depth of the well and the general characteristics of the materials in which the well was completed. A map showing the location of wells in the vicinity of the project is shown in Figure 17. A summary of data and information for select wells in the vicinity of the project site is presented in Table 7. Notably, no information specific to the Satsop Business Park well was identified.

A specification for the development of a water supply well for the Satsop Nuclear Project, now referred to as the Satsop Business Park Water Supply Well, was provided by the Seattle District (Chin, 2003). The specification included a variety of hydrogeologic data pertinent to the project site. The data included logs of test holes and wells developed in the area; locations of wells used for pump tests of the aquifer, pumping test hydrographs, and permeability computations for the pump tests.

As seen from the logs of both the DOE well database and the Nuclear Project test holes, the stratigraphy of the study area generally consists of clays, gravels and bedrock. The surficial material is silt-to-clay (0-20 ft thick) underlain by very coarse gravel (some of it cemented) and then bedrock. The bedrock surface generally slopes downward from east to west, reaching depths of more than 100 feet below the Satsop River. The aquifer is partially confined by the surficial silt and clay layer where they are present.

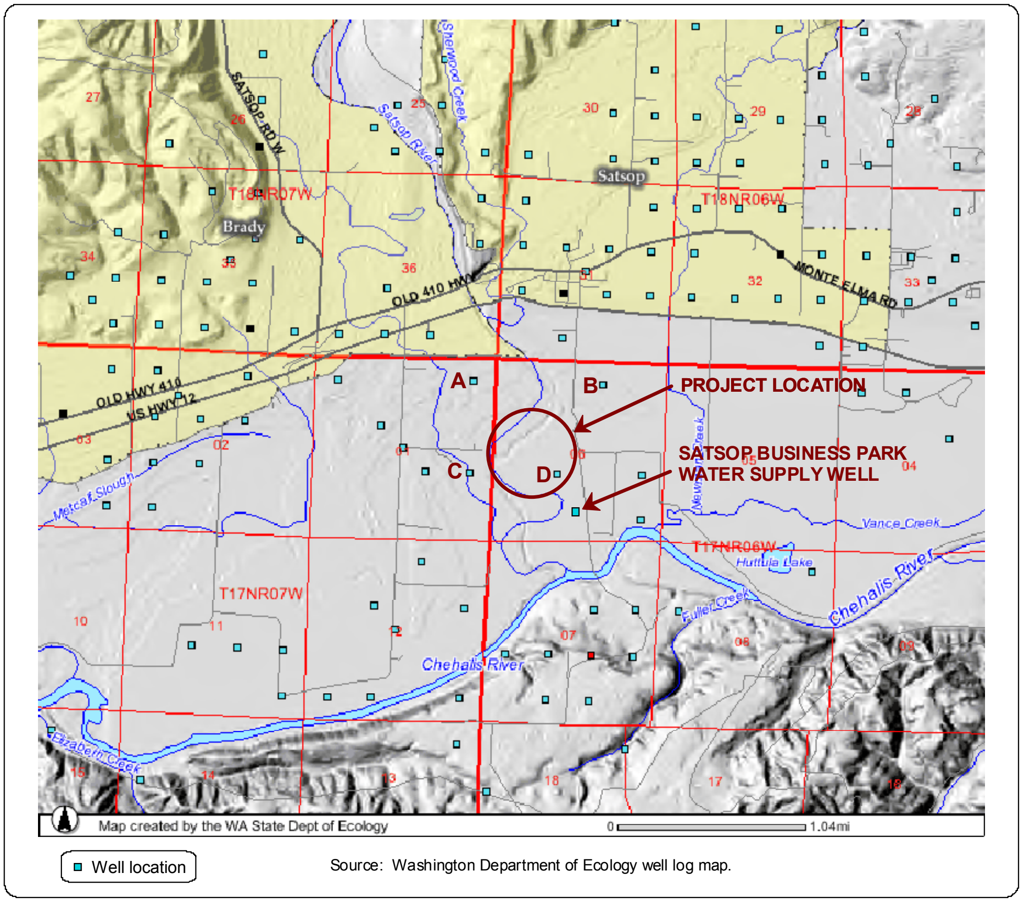



Figure 17. Location of water wells in the project vicinity.

Two aquifer pump tests were conducted in 1974 in the vicinity of the confluence of the Satsop and Chehalis Rivers as part of the development of the Satsop Business Park water supply well. For each test, the wells were pumped at about 1,000 GPD, and only small drawdowns of less than one foot (and often less than 0.4 feet) were measured at the nearby observation wells. The tests yielded extremely high values of transmissivity, giving values of hydraulic conductivity exceeding 2,000 ft/day. Riverbed infiltration rates were estimated to be approximately 100 GPD/sq.ft/ft. These values are extremely large, and indicate a highly conductive aquifer with good communication between the aquifer and the adjacent rivers.

A network of four staff gages was also placed to collect water level data in the gravel ponds and Egress Channel. The data was collected for use in evaluating the relation between river stage-discharge, pond water elevations, and Egress Channel discharge. A staff gage was placed in each of the three ponds and along the Egress Channel as shown on Figure 18. Since their installation in June 2003, personnel of the WDFW have made periodic readings of the water level at the staff gages.

Table 7 Summary of well data.

<table>
<tr><th rowspan="3">Well Identifier Shown on Figure 17</th><th rowspan="3">Owner</th><th rowspan="3">Well Log I.D.</th><th rowspan="3">Well Diameter (inches)</th><th rowspan="3">Well Depth (ft)</th><th rowspan="3">Depth to static water level below top of well</th><th colspan="3">Well Log</th></tr>
<tr><th rowspan="2">Material</th><th colspan="2">Depth (ft)</th></tr>
<tr><th>From</th><th>To</th></tr>
<tr><td rowspan="5">A</td><td rowspan="5">Ayres</td><td rowspan="5">272773</td><td rowspan="5">6</td><td rowspan="5">60</td><td rowspan="5">14 ft 1 in.</td><td>Top soil</td><td>0</td><td>2</td></tr>
<tr><td>Yellow clay</td><td>2</td><td>8</td></tr>
<tr><td>Yellow clay gravel</td><td>8</td><td>22</td></tr>
<tr><td>Gravel w/ red clay binder</td><td>22</td><td>47</td></tr>
<tr><td>Gravel w/ yellow clay binder</td><td>47</td><td>59</td></tr>
<tr><td rowspan="2">B</td><td rowspan="2">Haas</td><td rowspan="2">26817</td><td rowspan="2">6</td><td rowspan="2">39</td><td rowspan="2">9 ft</td><td>Brown silt</td><td>0</td><td>14</td></tr>
<tr><td>Gravel blue</td><td>14</td><td>39</td></tr>
<tr><td rowspan="4">C</td><td rowspan="4">Hensler</td><td rowspan="4">25189</td><td rowspan="4">6</td><td rowspan="4">53</td><td rowspan="4">11 ft</td><td>Top soil</td><td>0</td><td>3</td></tr>
<tr><td>Brown clay</td><td>3</td><td>14</td></tr>
<tr><td>Blue clay</td><td>14</td><td>21</td></tr>
<tr><td>Gravel</td><td>21</td><td>53</td></tr>
<tr><td rowspan="3">D</td><td rowspan="3">Kinsmen</td><td rowspan="3">23278</td><td rowspan="3">6</td><td rowspan="3">32</td><td rowspan="3">11 ft</td><td>Silt & sand brown</td><td>0</td><td>15</td></tr>
<tr><td>Gavel & clay</td><td>15</td><td>20</td></tr>
<tr><td>Gravel</td><td>20</td><td>32</td></tr>
</table>

Notably, the Pond B staff gage was damaged by vandalism in September 2003 and data from that gage after that date are suspect. A comparison of the collected stage data to the average daily discharge at the Satsop River gage is shown in Figure 19. In general, the stage data demonstrate close correspondence between the discharge in the river and the water elevation in the ponds. The pond stages are seen to respond in a similar manner, closely reflecting rising and falling river discharge. The ponds were also observed to be inundated, and the staff gages submerged, by relatively minor flood events. During the dry summer months, the pond stages generally reflect the position of each pond relative to the river channel and likely reflect the regional groundwater water flow pattern. An annual minimum stage in the ponds of about 14 ft NGVD was observed.

In consideration of the broad nature of the Satsop River floodplain, highly conductive aquifer and communication between the aquifer and the adjacent rivers, it is unlikely that placement of fine materials within the existing gravel ponds would have any significant impact to the general groundwater flow pattern in the vicinity of the project. Any barrier to groundwater flow posed by lower permeability materials placed in the pond would be expected to cause minor refraction of groundwater flow lines. This conclusion is important due to the proximity of the Satsop Business Park Water Supply Well to the project site (Figure 17).

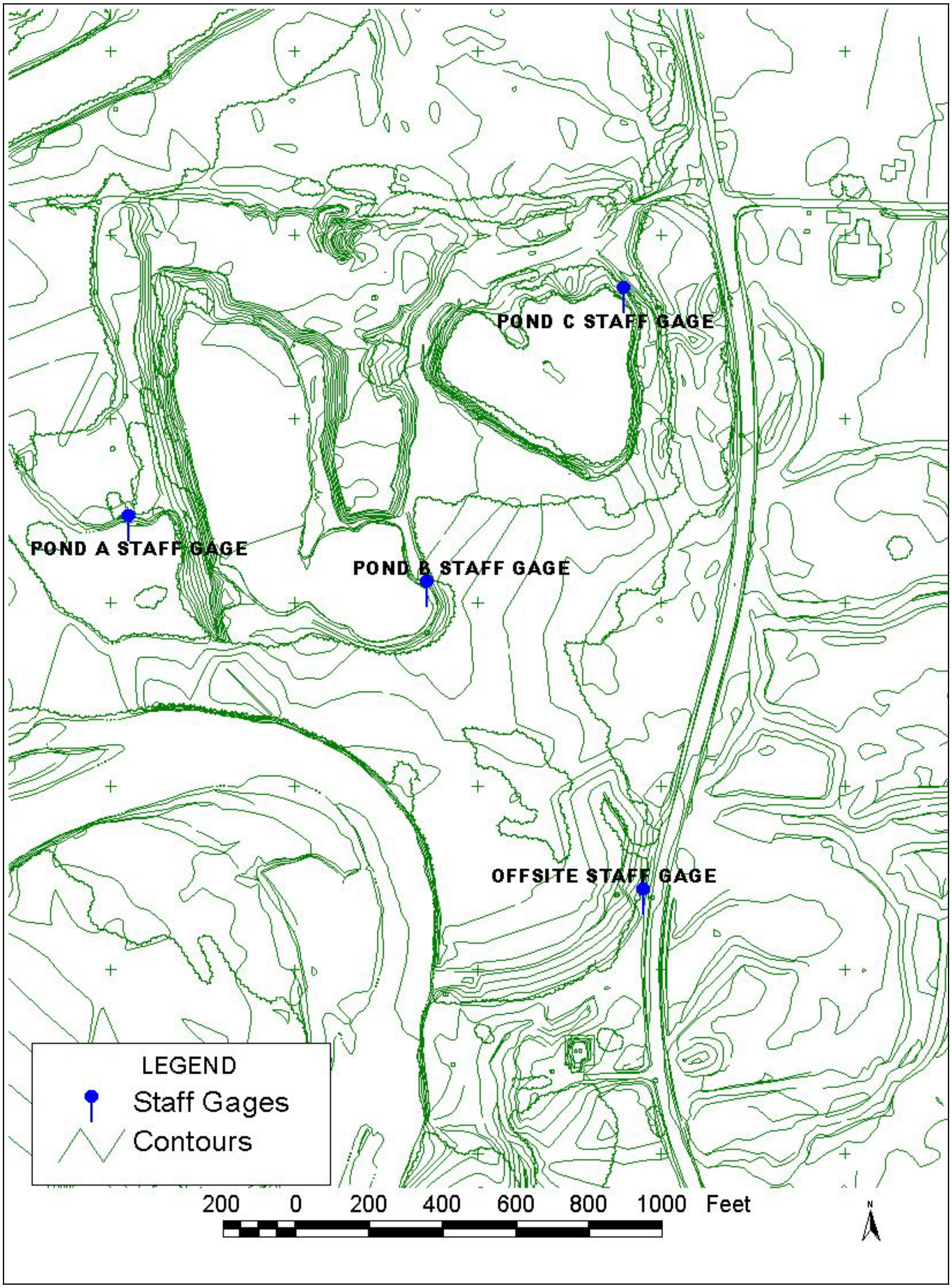



Figure 18. Location of staff gages.

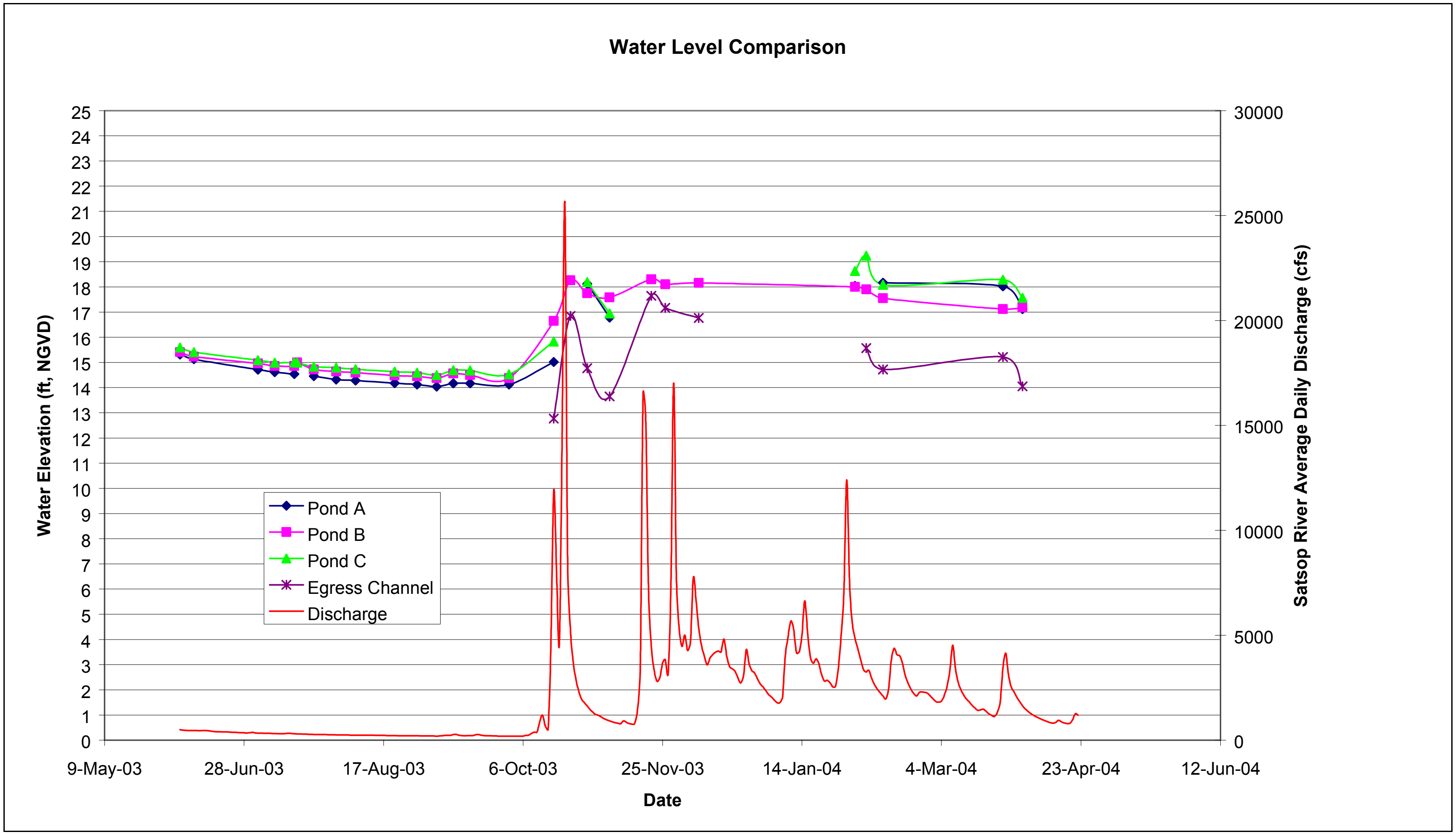



Figure 19. Comparison of staff gage data to Satsop River discharge.

# 4 HYDRAULIC ANALYSIS

A feasibility-level hydraulic analysis of the lower Satsop River was conducted. The objective of the analysis was to provide data and information necessary to characterize existing conditions and allow identification and evaluation of hydraulic impacts associated with three restoration alternatives. The hydraulic analysis used the Corps of Engineers HEC-RAS Version 3.1.1 computer program (COE, 2003c).

## 4.1 HYDRAULIC MODEL DEVELOPMENT

The hydraulic analysis utilized both the unsteady flow and steady flow analysis capabilities of the HEC-RAS computer program. Unsteady flow analysis was conducted to define hydraulic characteristics for several historic flood events that reflect the tidally influenced stage levels at the confluence of the Satsop and Chehalis Rivers. The unsteady analysis also allowed assessment of impacts associated with potential changes in floodplain storage on the project site. Steady flow analysis was used to characterize hydraulic conditions over a range of Satsop River flows for average flow conditions along the Chehalis River. The steady flow analysis was performed in unsteady mode in HEC-RAS by ramping up the flow to the desired peak flow and holding it there for a couple of days. The “steady flow” analysis was necessary since there are no unique hydrographs that correspond to specific flow frequencies, and the downstream tidal influence information is not available for all historic flood events.

### 4.1.1 Geometry Data

The hydraulic model was developed from surveyed channel cross sections provided by the Seattle District, and channel cross sections at the U.S. Highway 12 Bridge, Railroad Bridge, and Elma-Montesano Road Bridge surveyed by WEST Consultants, Inc. The geometric data of the bridge structures was obtained from either field measurement or bridge construction plans. The Seattle District provided a two-foot contour map of the study area from which the surveyed channel sections were extended into overbank areas. The cross section layout of the HEC-RAS model is shown in Figure 20.

### 4.1.2 Flow Network

Based on field observations of the channel network, examination of FEMA floodplain mapping, topographic mapping, high-water data for historic floods, and observations of flood conditions in October 2003, it is apparent that the floodplain of the lower Satsop River is very broad and includes complex hydraulic conditions. Initial hydraulic modeling results confirmed the need to consider multiple flow paths to adequately describe hydraulic conditions over the range of discharge considered. As shown on Figure 20, three reaches were defined (Satsop Main, Overbank Pond, and Satsop Lower) to describe the hydraulic conditions in the vicinity of the project.

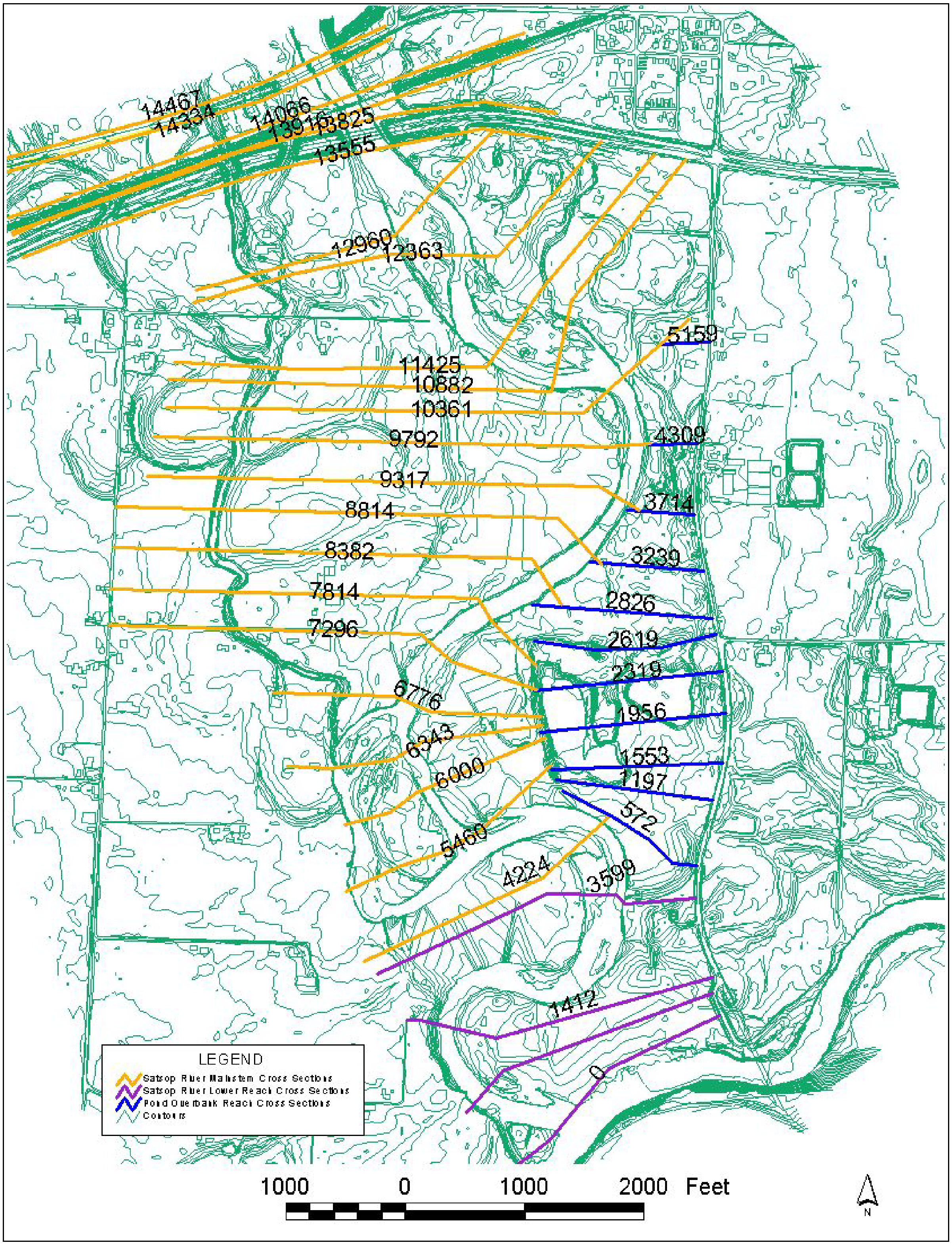



Figure 20. Layout of HEC-RAS model cross sections.

The Pond Reach contains an existing high flow path referred to as the "Egress Channel." The Pond Reach splits from the mainstem channel along the northern half of the project site. Lateral weirs along the left bank of the mainstem channel were used in the model to determine the split of flow from the Satsop Main Reach into the Pond Reach. The Pond Reach ("Egress Channel") connects back to the mainstem Satsop River downstream of the project site at the junction with the Lower Satsop Reach.

In general, Keys Road and Brady Loop Road were considered as lateral boundaries for effective flow along the lower Satsop River. However, it was also recognized that effective flow over the lateral boundaries of the model is dependent on both the discharge along the lower Satsop River as well as the stage of the Chehalis River. In view of the objectives of the study and the available topographic information, the selected lateral limits of the model are considered appropriate.

#### 4.1.3 Hydraulic Roughness

Initial estimates of the hydraulic roughness (Manning's n) values utilized in the model were chosen based on field reconnaissance observations, review of recent color aerial photographs of the study area, published description of Manning's n values (Barnes, 1987 and Chow, 1959), and professional judgment. The Manning's n value for the main channel was estimated at 0.036. The main channel is a meandering gravel bed stream with moderate levels of debris. The value of Manning's n for overbank areas was estimated to range from 0.055 for agricultural fields to 0.15 for heavy brush and trees. As discussed later in this section of the report, the initial estimates of hydraulic roughness were later calibrated to observed water surface elevations.

#### 4.1.4 Boundary Conditions

The boundary conditions in the vicinity of the Satsop River/Chehalis River confluence required for hydraulic analysis were developed from available information.

##### 4.1.4.1 Unsteady Flow Analysis Boundary Conditions

The Chehalis River is tidally influenced at its confluence with the Satsop River (COE, 1978). As seen in the UNET model geometry data for the Chehalis River at RM 20.04, in the vicinity of the confluence with the Satsop River, the thalweg elevation of the Chehalis River is about –5.0 ft NGVD (PIE, 1998). Similarly, the most downstream surveyed channel cross section for the Satsop River has a thalweg elevation of 0 ft NGVD. The overbank ground elevation in the vicinity of the confluence is at about elevation 10 ft NGVD. Records for the Aberdeen, Washington tide gage (Station 9441187) indicate that the Mean Higher High Water (MHHW) elevation is about 4.93 ft NGVD and the Mean Lower Low Water (MLLW) elevation is about –5.18 ft NGVD.

To account for the influence of the Chehalis River on water surface elevations along the Satsop River, the downstream boundary condition of the unsteady flow HEC-RAS model was set equal to stages derived from a stage-discharge relation for the Chehalis River for a cross section at RM 20.04 derived from a previously developed UNET hydraulic model (PIE, 1998). The stage discharge relation (Figure 21) was defined by hydraulic results from the UNET model at RM 20.04 for the February 1996 flood event. At Porter, Washington, the February 1996 flood event was estimated to be a 150-year return period event. The downstream boundary of the UNET model was set equal to the record for the tide gage at Aberdeen, Washington.

Stage hydrographs at the downstream boundary of the Satsop River hydraulic model were developed for two historic flood events, the February 1996 flood and the March 1997 flood. The February 1996 flood event was the largest flood of record along the Chehalis River, and represents a high backwater condition for flow along the Satsop River. The March 1997 flood was the flood of record along the Satsop River. The March 1997 flood peak flow was about 63,600 cfs. The stage was defined for the combined flow of the Chehalis River at Porter, Washington and the Satsop River near Satsop, Washington based on the previously described UNET derived stage discharge relation for the Chehalis River. The records from the USGS gage at the Elma-Montesano Bridge defined flows at the upstream limit of the hydraulic model.

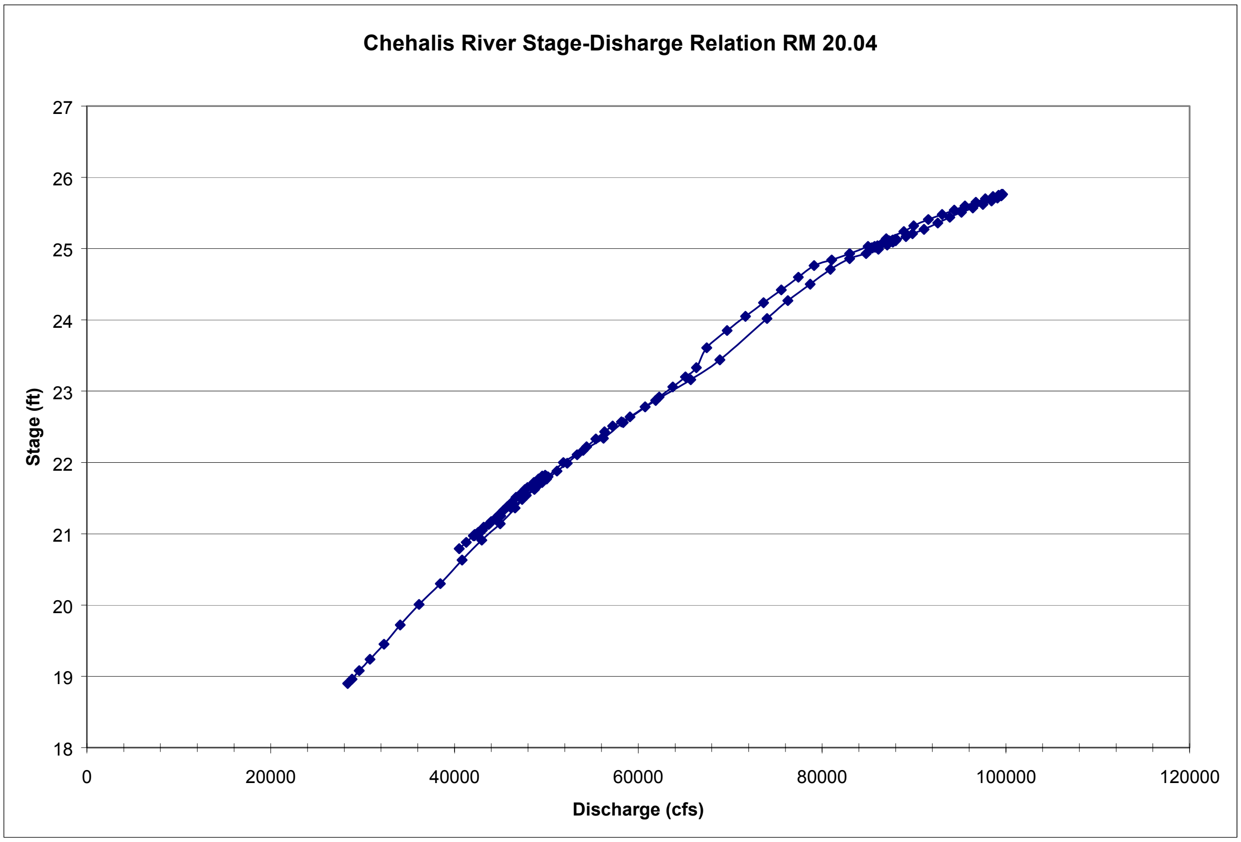



Figure 21. Stage/discharge relationship for the Chehalis River at cross section 20.04.

#### 4.1.4.2 Steady Flow Analysis Boundary Conditions

The potential for coincidence of peak flows along the Chehalis River and Satsop River was examined. The occurrence of peak flows along the Chehalis River measured at Porter, Washington, was plotted against the peak flows recorded at the Satsop River near Satsop, Washington gage as shown in Figure 22. No consistent correspondence can be observed between the timing of peak flows along the two rivers. More detailed examination of flow records indicated that a week or more often separates the occurrence of peak flows along the Chehalis River and Satsop River. Frequently, the timing of annual peaks of the Satsop River and Chehalis River is separated by months. Linear regression of the Satsop River peak flow values against average daily flow values along the Chehalis River for the same day also demonstrated low correlation.

For steady flow analyses, it was assumed that the stage at the downstream limit of the model would be reasonably defined by the combined flow of the Satsop River and the average of mean daily flows for the Chehalis River on the same day as historic Satsop River peak flows (16,400 cfs). The stage corresponding to the resultant discharge was determined from the stage-discharge relation for RM 20.04 derived from a previously developed UNET hydraulic model (PIE, 1998). The resultant stage-discharge relation, in terms of Satsop River flow, is shown in Figure 23. The stage discharge relation encompasses an elevation range of approximately 19.7 to 24.2 ft NGVD at the Chehalis/Satsop confluence for Satsop River flows from 17,000 to 60,000 cfs. It is noted that the ground elevations in the vicinity of the project range from 17 to 25 ft NGVD. The project site is therefore subject to significant inundation by any Satsop River flood event greater than bankfull flow.

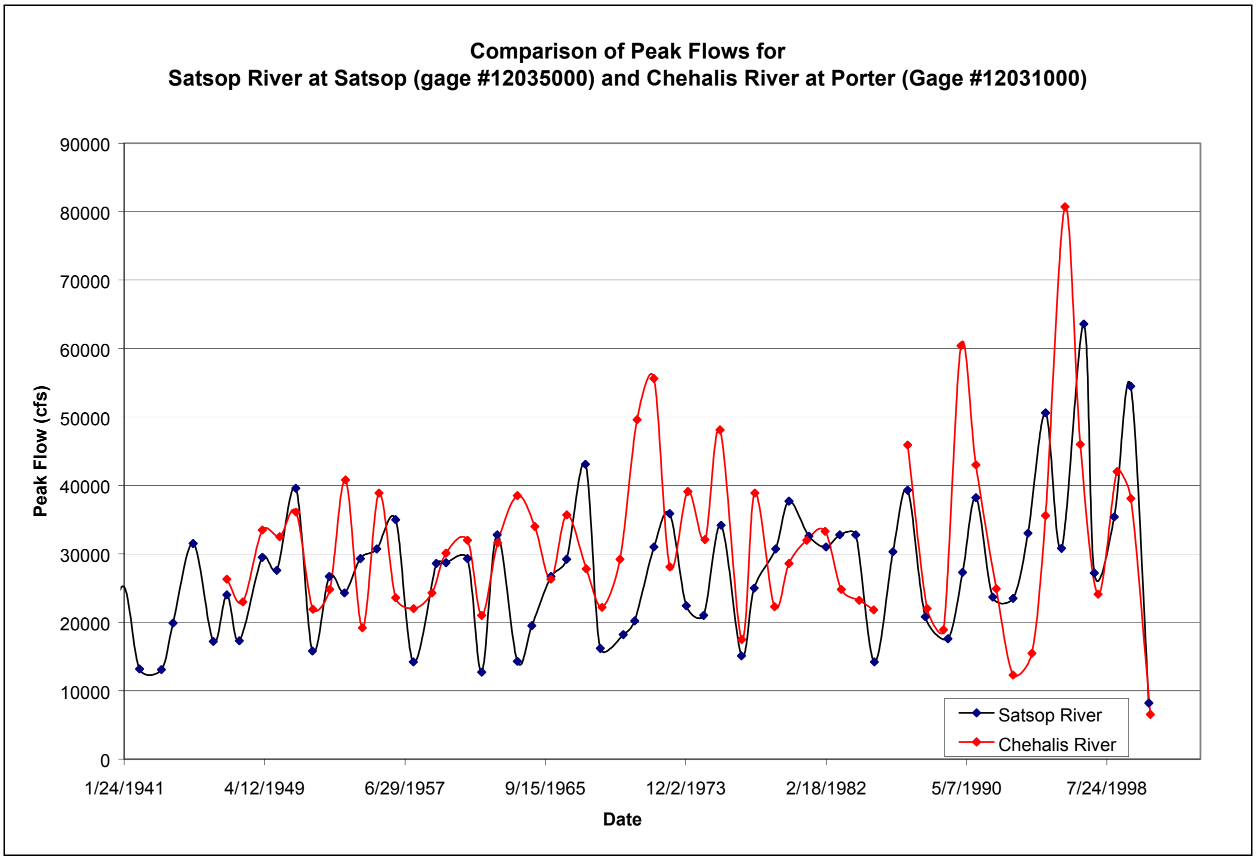



Figure 22. Peak flow comparison between the Satsop River and Chehalis River.

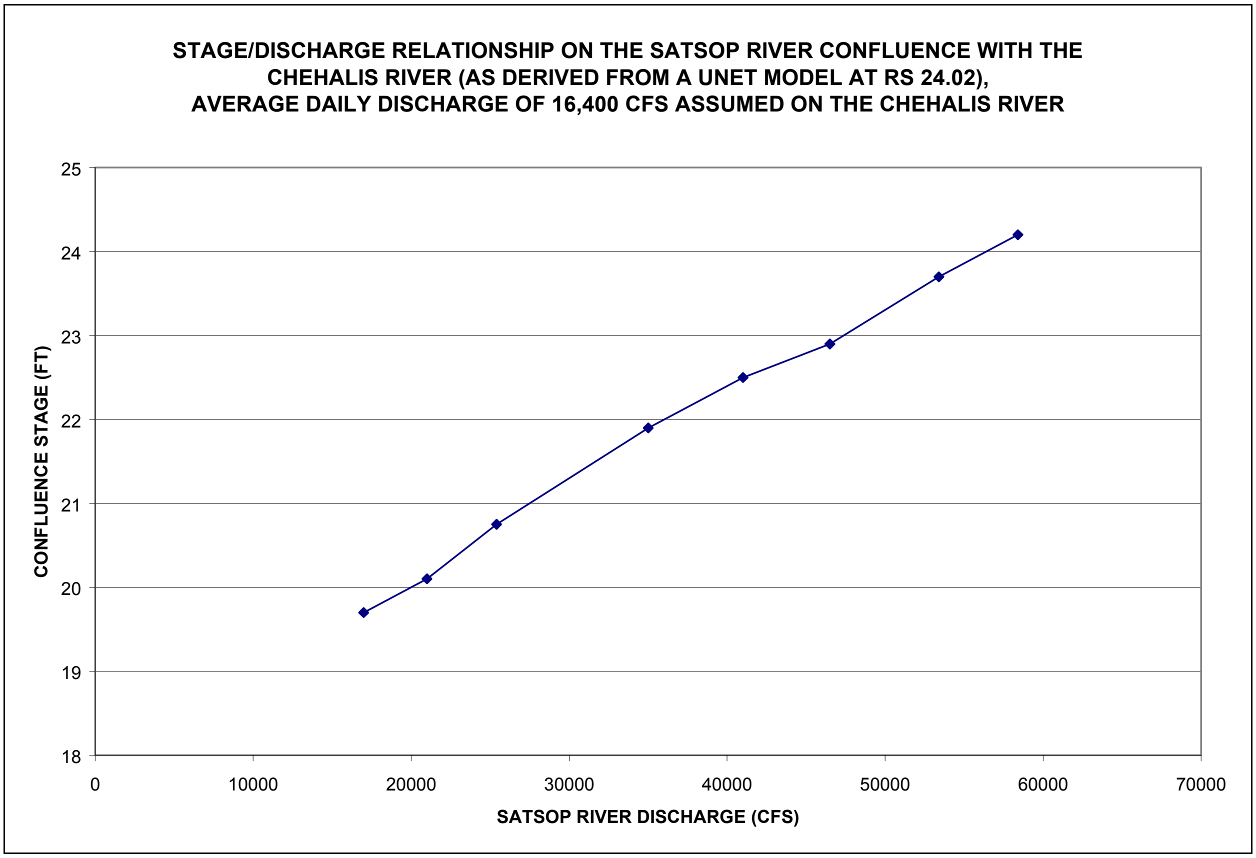



Figure 23. Stage/discharge relationship for the Satsop River.

## 4.2 Model Calibration

The hydraulic model of the Satsop River was calibrated to observed water surface elevations associated with floods in February 1996 and March 1997 and estimated bankfull elevation indicators. The high water mark elevation information was collected by Seattle District personnel (Chin and Knapp, 2003) in June 2003. Stage information for historic flood events was also available from the USGS gage Satsop River near Satsop, Washington. The bankfull elevation indicators were surveyed during field reconnaissance activities in June 2003.

The February 1996 event at 80,700 cfs is the largest recorded flood event for the Chehalis River at the Porter, Washington USGS gage. It represents a high backwater condition for the Satsop River. The peak flow along the Satsop River in water year 1996 actually occurred in November 1995 and was not associated with the February 1996 peak on the Chehalis River. The March 1997 flood event represents a high flow on the Satsop River and relatively low stage on the Chehalis River. The March 1997 flood event was the largest recorded flood event at the Satsop River near Satsop, Washington USGS gage. It had a peak discharge of about 63,600 cfs, which is estimated to be larger than a 200-year return period event. The corresponding flow of the Chehalis River at the time of the Satsop River peak was 20,300 cfs, approximately a 1.2 year event. The Chehalis River peak flow in 1997 was 46,000 cfs on January 2, more than 2 months earlier than the Satsop River peak flow. The locations of the available high water marks are shown in Figure 24.

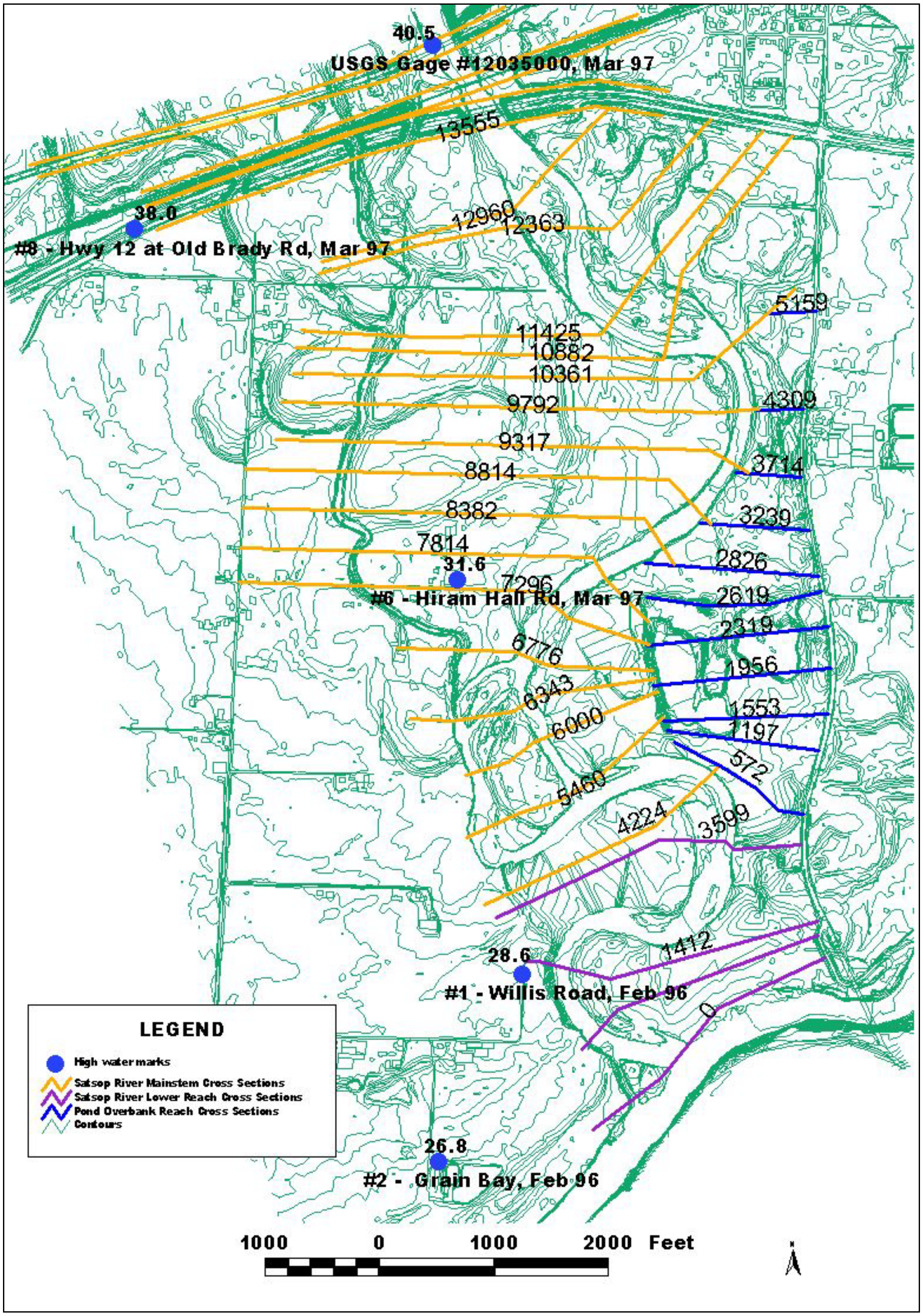



Figure 24. Location of observed high water marks for the February 1996 and March 1997 events.

Calibration of the hydraulic model was accomplished by adjusting the Manning's "n" values for each of the three calibration events to best match the observed high water marks. It was determined from examination of the available topographic data that several of the available high water marks (Nos. 3, 4, 5 and 7) are associated with flow paths that are not associated with flow along the mainstem Satsop River or pertinent to calibration of the hydraulic model. As previously noted, at high stages, the Chehalis River inundates a significant portion of the lower Satsop River.

Table 8 summarizes the results from the calibration. In general, the calibration effort resulted in calculated water surface elevations that are within 1.2 feet of the observed water surface elevations at all locations considered. Calculated water surface profiles for each of the calibration events along both the Satsop Main Reach and Pond Reach are shown in Figure 25. The difference in model results to observed water surface elevations is attributed to uncertainties about the stage at the Chehalis River confluence which can significantly influence the stage of the lower Satsop River.

Table 8. Summary of calibration data.

| LOCATION | EVENT | DISCHARGE (cfs) | OBSERVED WATER SURFACE ELEVATION (ft) | MODEL RESULT (ft) | WS DIFFERENCE (ft) |
|---|---|---|---|---|---|
| USGS GAGE #12035000 | March 1997 | 62,510 | 40.5 | 41.1 | 0.6 |
| OBSERVED PT #8 SR12 near Old Brady Road | March 1997 | 62,510 | 38 | 38.4 | 0.4 |
| OBSERVED PT#6 HIRAM HALL RD | March 1997 | 62,510 | 31.6 | 30.4 | -1.2 |
| | | | | | |
| USGS GAGE #12035000 | February 1996 | 26,780 | 34.9 | 35.7 | 0.8 |
| OBSERVED PT #1 83 Willis Rd | February 1996 | 26,780 | 28.6 | 27.6 | -1 |
| OBSERVED PT #2 Willis Grain Bay | February 1996 | 26,780 | 26.8 | 27.5 | 0.7 |
| | | | | | |
| USGS GAGE #12035000 | Bankfull | 17,000 | 32.7 | 33.7 | 1 |

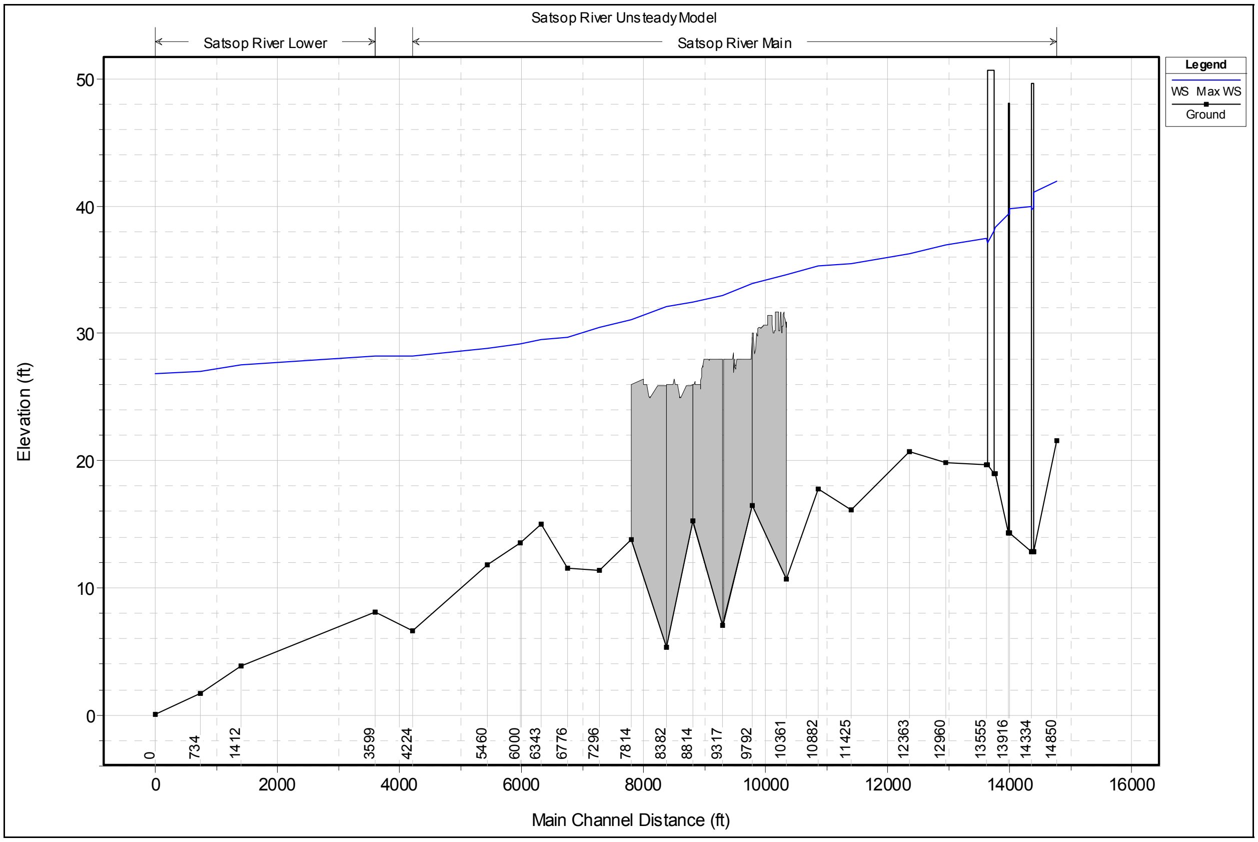



Figure 25. Satsop River March 1997 event water surface comparison for Existing Conditions.

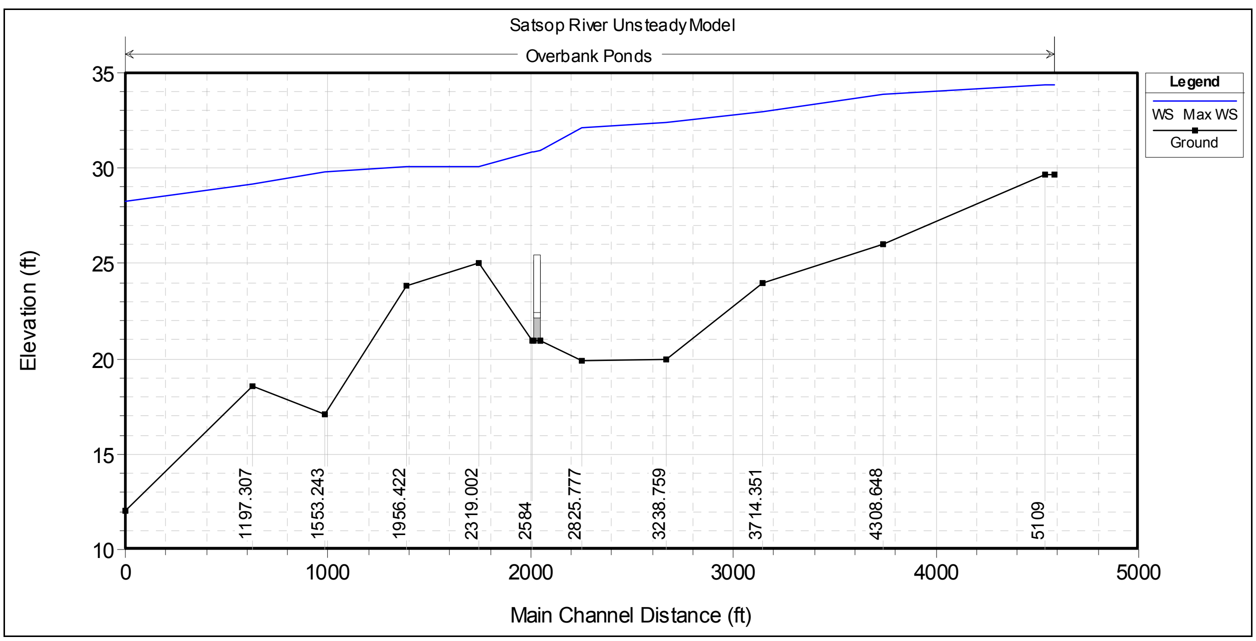



Figure 25 (cont). Pond Reach March 1997 event water surface comparison for Existing Conditions.

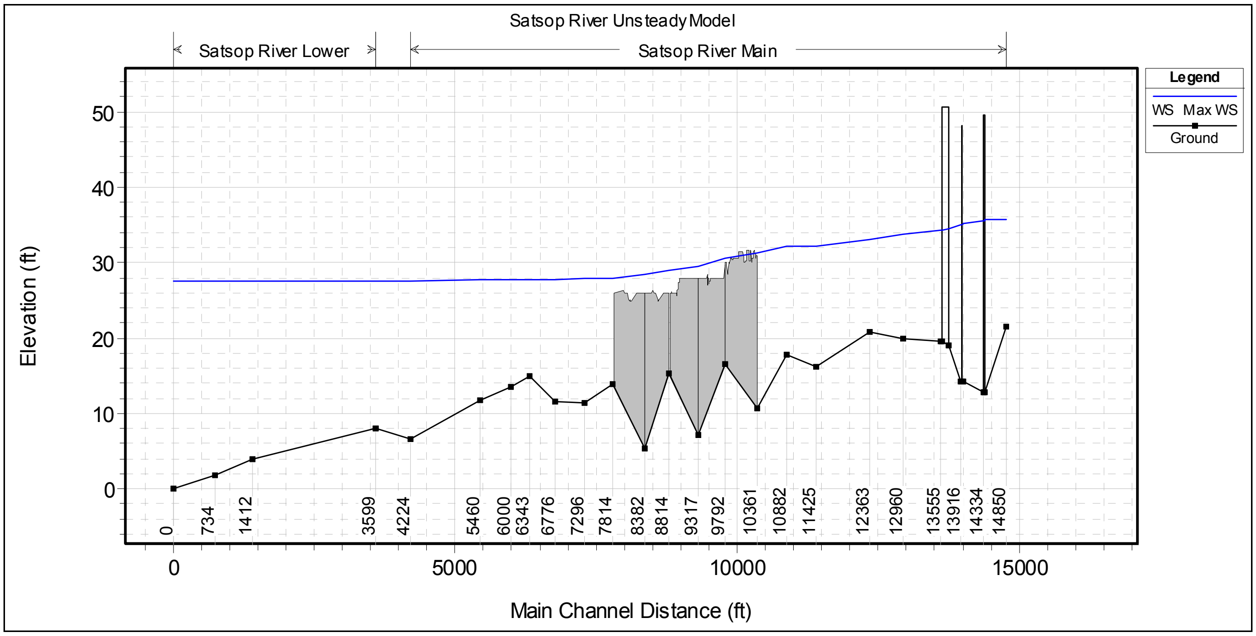



Figure 25 (cont). Satsop River February 1996 event water surface comparison for Existing Conditions.

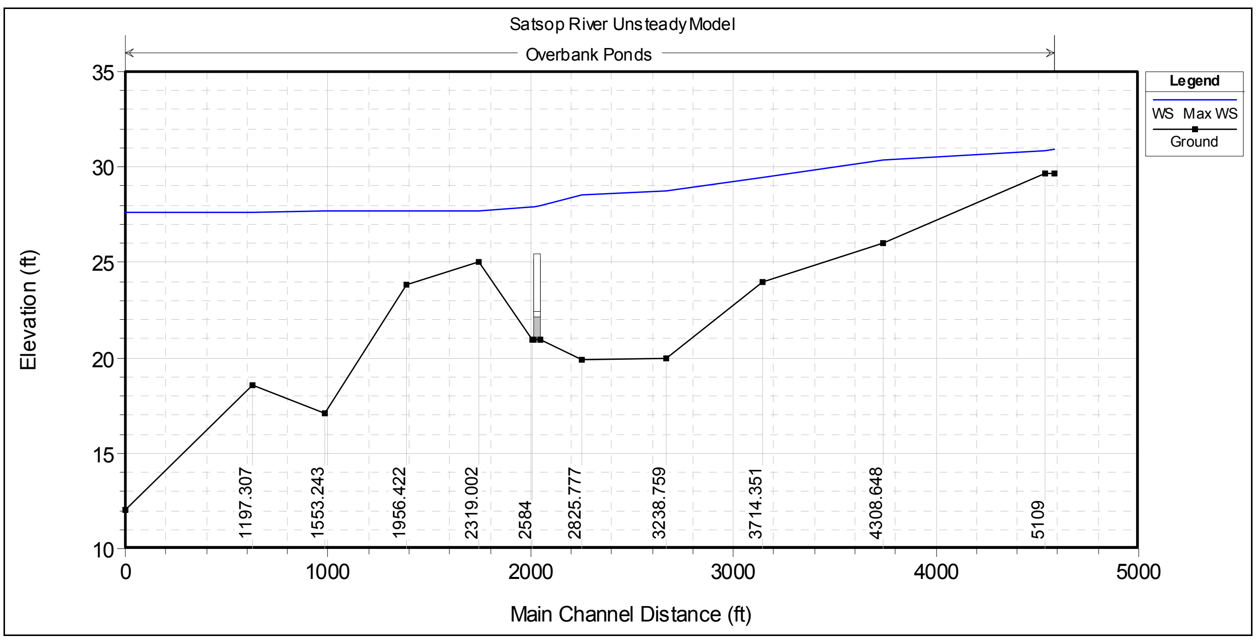



Figure 25 (cont). Pond Reach February 1996 event water surface comparison for Existing Conditions.

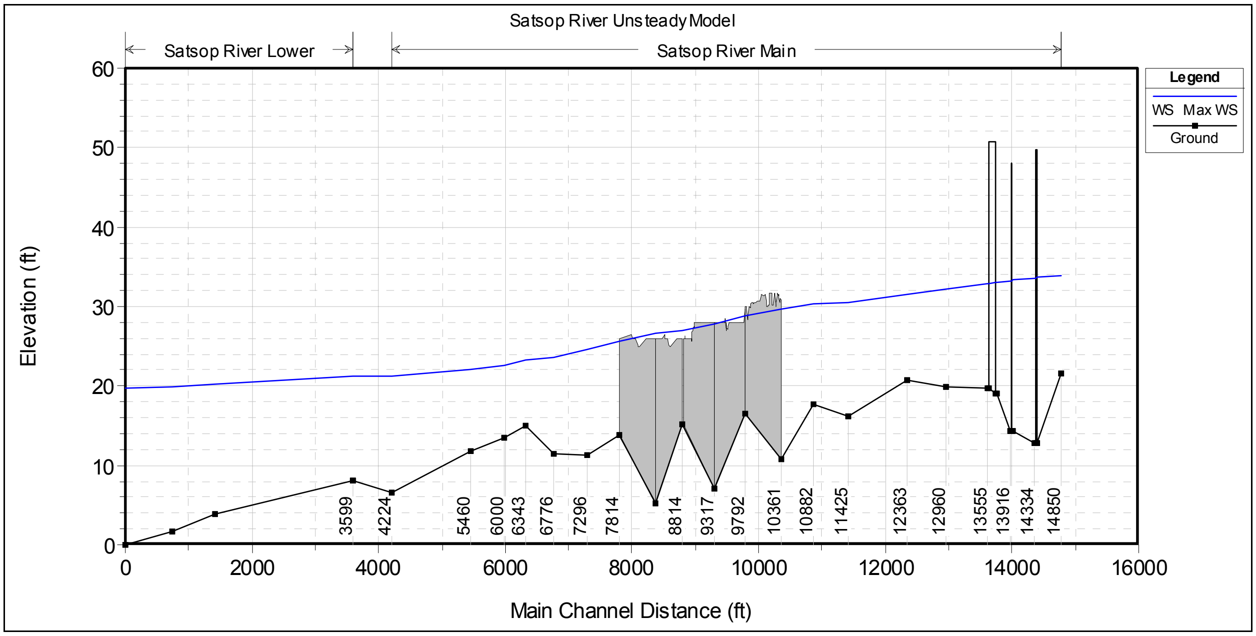



Figure 25 (cont). Water surface profile for bankfull flow on the Mainstem Satsop River for Existing Conditions.

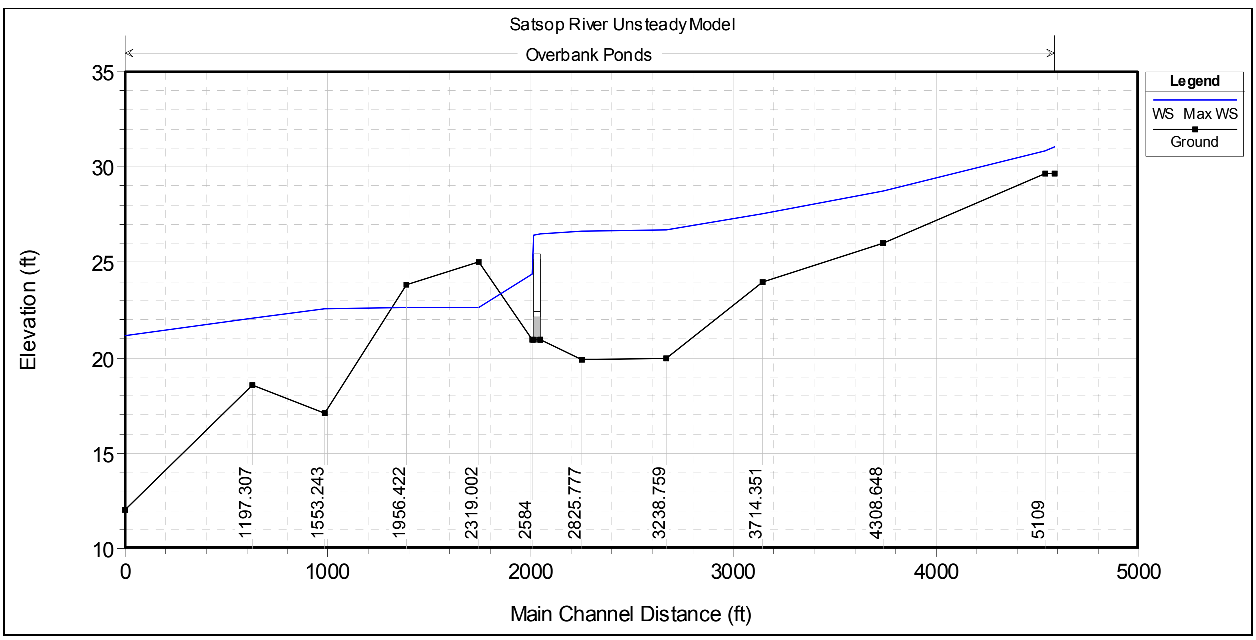



Figure 25 (cont). Water surface profile for the bankfull flow in the Pond Reach area for Existing Conditions.

## 4.3 Analysis Conditions

Hydraulic models for existing conditions and three restoration alternatives were developed. The objective of the analysis was to provide data and information necessary to characterize existing conditions and allow identification and evaluation of hydraulic impacts associated with the alternatives.

### 4.3.1 Existing Conditions

The existing conditions hydraulic model was developed to reflect the natural and manmade features of the project site. This included existing flow paths, dikes, ponds, riprap, spoils piles, and culverts.

### 4.3.2 Alternative 1

Under Alternative 1, all man-made features associated with the project site are to be removed and the existing pond geometry is maintained. As the first restoration concept considered, the preliminary analysis results for Alternative 1 were used to help formulate the conceptual elements of Alternatives 2 and 3. Alternative 1 included the following conceptual elements:

- Removal of all dikes surrounding Ponds B and C.
- Removal of the culverts along the entrance road to the project site.
- Removal of all spoils from the site.
- Removal of all riprap along the left bank of the Satsop River adjacent to the project site

Figure 26 shows a general grading plan and features of Alternative 1.

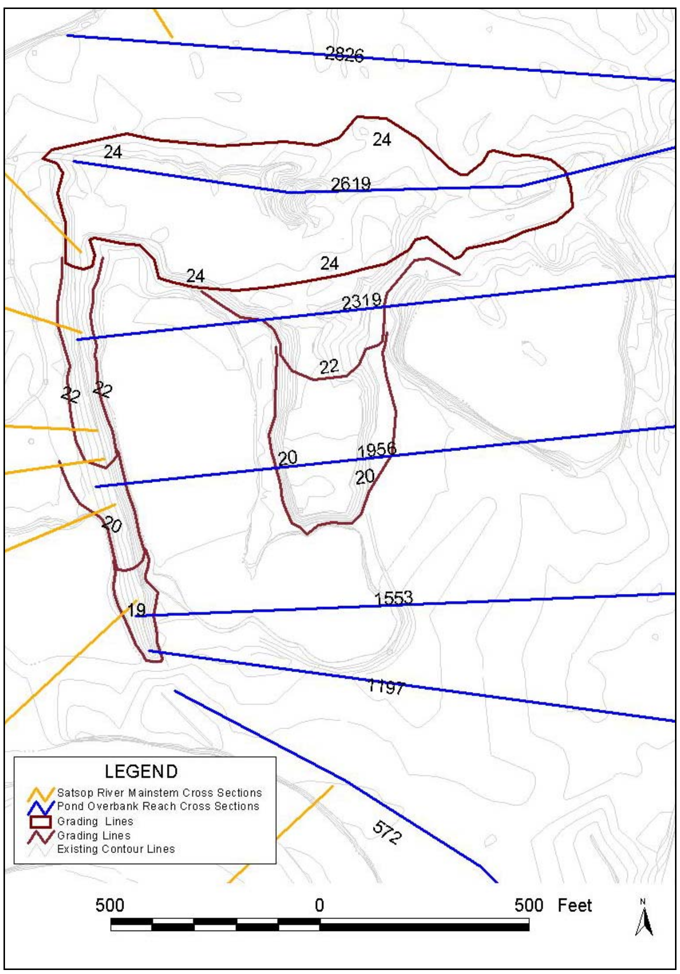



Figure 26. Approximate project site grading plan for Alternative 1.

### 4.3.3 Alternative 2

A general layout of Alternative 2 features is shown in Figure 27. Conceptual descriptions of the Alternative 2 features are as follows:

<u>Dikes/Levees</u>

- Remove northern, western, and southern dikes to natural ground levels and contours.

  The ditch along the northern dike will be redirected by regrading the north dike/stock pile material to connect with 3 low areas to encourage flood flows across the site in a southerly direction and away from the road. The low areas will be located at the current dike breaches and will be graded to elevation 17 ft NGVD with a 40-foot top width. By creating low areas at elevation 17 ft NGVD (assuming the bottom elevation in the adjacent wetland is at elevation 15 ft NGVD), ponded water will be retained in the wetland while directing flood flows away from the road. Material from southern and western dikes/levees will be placed into Ponds B and C.

- Leave eastern dike in place.

  The existing culvert along the access road to the site will be removed. The eastern dike will be reconnected to the access area and a swale created to enhance potential overflows to Pond C. The former culvert location would be filled to elevation 18 ft NGVD and regraded with a 7 horizontal: 1 vertical side slope on the left bank and 3 horizontal: 1 vertical or 4 horizontal: 1 vertical side slope on the right bank to the eastern dike elevation (assumed at elevation 22 ft NGVD).

- If suitable, dike materials may be used for onsite revegetation plantings.

<u>Stockpiled Soil</u>

Onsite stockpiled soil will be placed to create shallow areas in Ponds B and C (approximately equal amounts per pond). Placing fill in the ponds would be expected to reduce any potential impacts due to avulsion. There would be a greater sediment supply available for the sediment budget. Alternatives 2 and 3 reflect this measure. The dikes and spoils were estimated to have a volume of 122,921 cubic yards, which is 26% of the total volume of the ponds.

For Alternatives 2 and 3, the estimated fill volume required to create an island and enlarge the existing peninsula on the north side of Pond C was estimated to be 68,000 cubic yards. The required fill in Pond B was estimated to be about 28,900 cubic yards. An additional 26,000 cubic yards of material would remain for placement in Pond B or C. It is recommended that the extra material be placed at the upstream end of Pond B to help minimize any risk of impacts due to headcutting or avulsion. The fill would be most effective if the dropoff into Pond B at the upstream end were gradual. If the remaining material is placed in Pond B for a total Pond B fill volume of 54,900 cubic yards, the new Pond B volume capacity is 194,717 cubic yards. Table 9 summarizes the expected fill distribution between ponds.

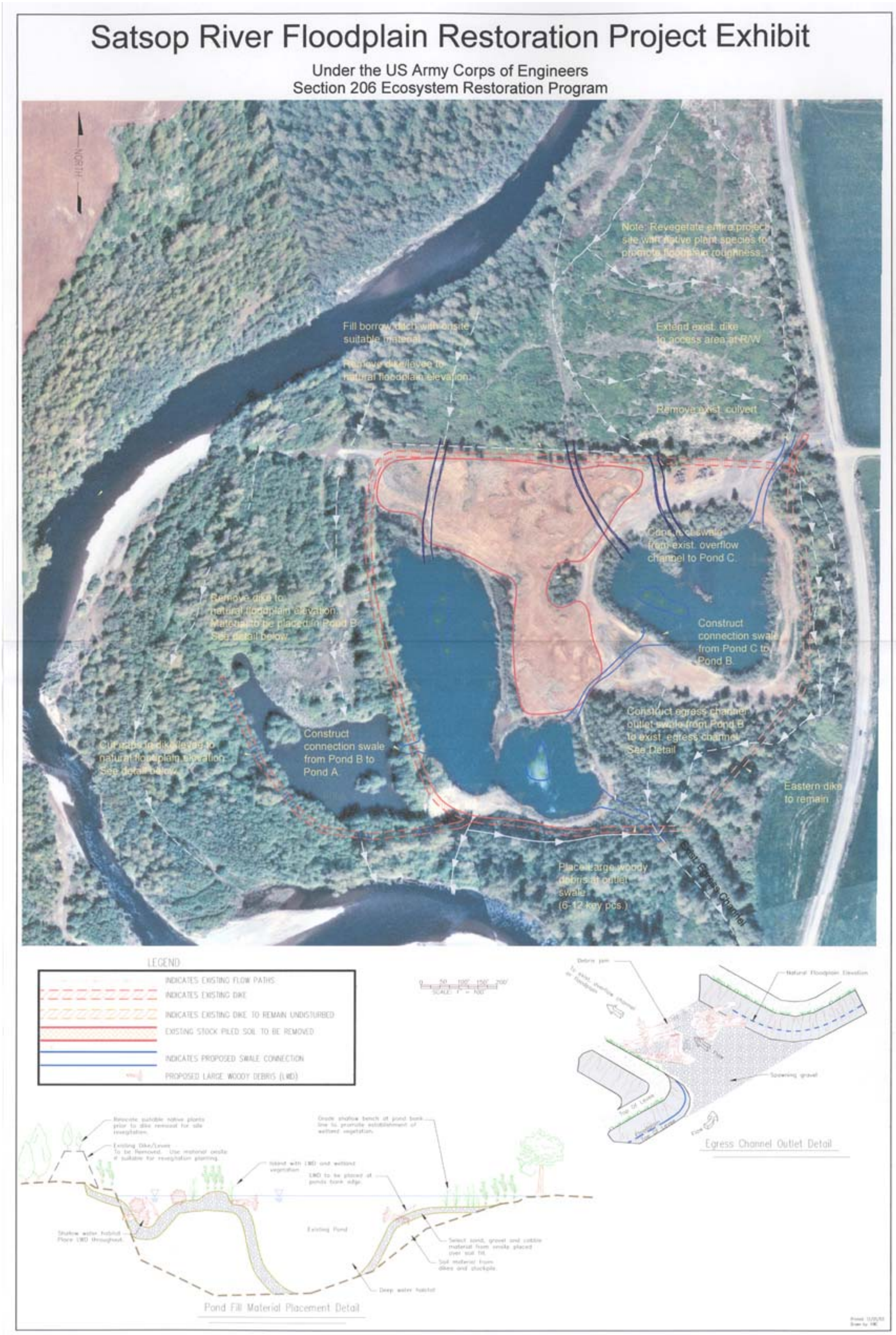



Figure 27.  Alternative 2 layout.

A layer of native onsite material (i.e. mixed sand, gravel, cobble) will be placed over the stockpiled soil placed in the ponds. The pond edges will be amended with appropriate topsoil for planting and establishment of native wetland plants.

Table 9. Fill Volumes for Ponds

| | Existing Volume to Top of Bank (Cubic Yards) | Approximate Fill Volume (Cubic Yards) | New Volume to Top of Bank (Cubic Yards) |
|---|---|---|---|
| Pond B | 249,617 | 28,900 for island | 220,717 |
| | | 26,000 additional | 194,717 |
| Pond C | 140,668 | 68,000 for island and peninsula | 72,668 |

Pond Connectivity

- Pond B will be connected to Pond A with a trapezoidal channel at elevation 13 ft NGVD (about 1 ft below the summer pond water level). The channel will have 4 horizontal: 1 vertical side slopes and a 12-ft bottom width. During the summer, this connection would have a wetted top width of about 20 feet. Above elevation 13 ft NGVD, the channel side slopes would be graded to the natural floodplain elevation of about 20 ft NGVD with a flatter side slope (assumed 6 horizontal: 1 vertical). A schematic of the proposed channel is provided in Figure 28. The channel would be approximately 200 feet long and oriented in a north to south direction. The bottom elevation of this channel would be 1.9 feet below the elevation of the Pond B constructed outlet described below.

- Pond C will be connected to Pond B with a channel at elevation 13 ft NGVD (about 1 ft below the summer pond water level). The channel will have 4 horizontal: 1 vertical side slopes and a 12-ft bottom width. During the summer, this connection would have a wetted top width of about 20 feet. Above elevation 13 ft NGVD the channel side slopes could be graded to the natural floodplain elevation of about 20 ft NGVD with a flatter side slope (assume 6 horizontal: 1 vertical). A proposed schematic of the proposed channel is shown in Figure 28. The channel would be approximately 400 feet long and oriented in a north to south direction.

- The connection from Pond B to the existing Egress Channel located at the SE corner of the project site will be enhanced. The outlet channel from Pond B would be constructed to elevation 14.9 ft NGVD, with a 30 ft bottom width, 4:1 side slope, and 200-ft length to connect with the existing Egress Channel. Excavation and construction of the outlet swale will only be conducted on WDFW property. No construction on adjacent property is proposed but a flow easement is assumed. The dimensions and elevations of the connection channel are based on limited survey information and could be revised as better field information is gathered. It is noted that the natural Egress Channel outlet to the Satsop River is at elevation 14.9 ft NGVD, according to the Corps supplemental survey information, and is not be hydraulically connected to the mainstem until that elevation is reached. It is also assumed that the river will not significantly migrate away from the current Egress Channel outlet location.

- The edges of all the pond connection channels will be planted with a variety of native plants, including trees and shrubs, to provide shade to the channels and moderate summer water temperatures.

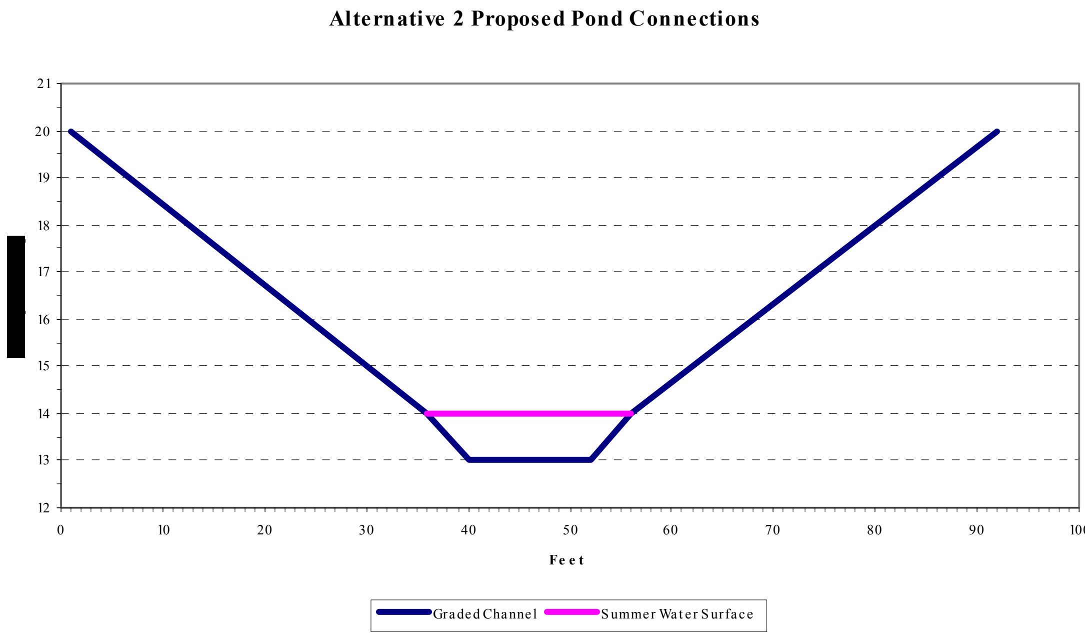



Figure 28. Proposed pond connections for Alternatives 2 and 3.

Pond Fringes

- Identified material (soil) will be placed in shallow areas of Ponds B and C, then pond banks will be graded at a 7 horizontal: 1 vertical side slope in a manner to allow wetland vegetation establishment.

- To provide for juvenile salmonid cover year-round, bottom elevations along the edges of the ponds will have a maximum depth of 5 ft at the toe of the pond bank during the summer (elevation 9 ft NGVD).

- Small islands will be created in the ponds using available stockpile soil or dike material.

LWD Placement

- Place/bury/anchor approximately 6 to12 key pieces of LWD at the entrance of the Egress Channel located in the SE corner of the project site (near property line).

- Place/bury/anchor key pieces of LWD above current access road location in overflow channel (primarily the area immediately to the North of this site).

- Place/bury/anchor remaining LWD pieces along pond edges and in connection channels.

Revegetation

- Revegetate the disturbed/degraded portions of the project site with native plant species (coordinate the details with WDFW engineering). Plant with suitable soil amendment.

- The northern portion of the project site must be planted in a manner that will allow WDFW future construction access to the riprapped reach of the mainstem channel with minimal disturbance to the plantings.

As shown in Figure 29, extra cross sections were added to the existing condition hydraulic model in the Pond Reach to hydraulically define the features associated with Alternatives 2 and 3. Specific features hydraulically modeled in Alternative 2 included the regraded topography, channels connecting the ponds to the floodplain, and woody debris. The northern, western, and southern levees were lowered to the approximate surrounding ground elevation. The cross sections through the Pond Reach were adjusted to reflect the grading plan for the alternative. The bathymetry of Ponds B and C was adjusted to reflect the fill that will be placed in them. Blocked obstructions were used in the HEC-RAS model to represent proposed locations for woody debris.

Two scenarios for hydraulic roughness were evaluated for Alternative 2. Hydraulic conditions before and after vegetation plantings have matured were considered. Manning's n values of 0.040 for the Pond Reach channel and 0.050 for floodplain areas were used in the disturbed portion of the Pond Reach to represent immature vegetation conditions. Manning's n values of 0.055 for the Pond Reach channel and 0.080 for floodplain areas were used in the Pond Reach to represent mature vegetation conditions. As shown in Figure 30 the mature vegetation results in a slight decrease in channel velocity for the 100-year flow.

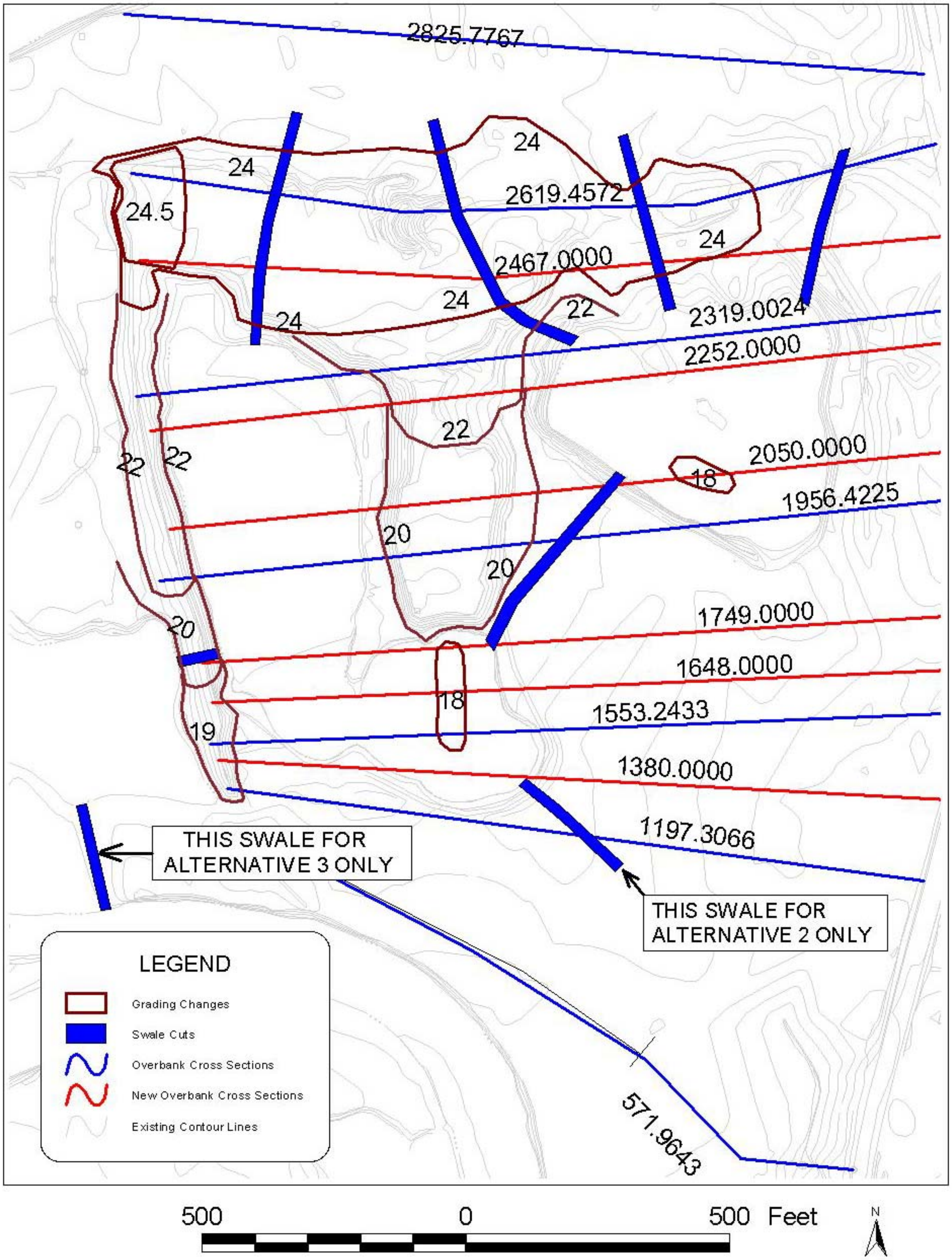



Figure 29. Approximate project site grading plan for Alternative 2 and 3.

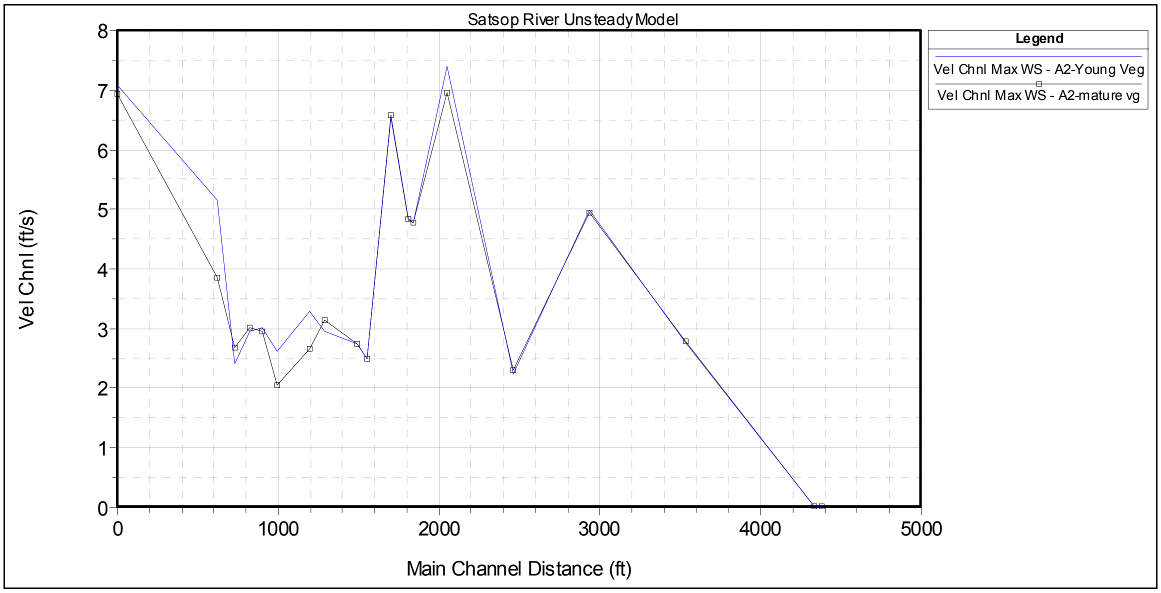



Figure 30. Pond Reach velocity comparison for Alternative 2 at the 100-year flow.

### 4.3.4 Alternative 3

A general layout of the Alternative 3 features is shown in Figure 29. Alternative 3 is the same as Alternative 2 with the exception that no outlet from Pond B to the Egress Channel will be created. Instead, a short outlet channel will be constructed from the southwest corner of Pond A to the river. It is assumed that excavation and construction of the outlet channel will be on adjacent property and an easement or ownership of the involved property will be required. The channel bottom would be excavated to elevation 13 ft NGVD (about 1 foot below the summer pond water level) and will have 4 horizontal: 1 vertical side slopes and a 20 ft bottom width. During the summer, this connection would have a wetted top width of 28 feet, if the pond level water does not drain down to the outlet elevation or river elevation. Above elevation 13 ft NGVD, the channel side slopes could be graded to the natural floodplain elevation of approximately 18 ft NGVD with a flatter side slope (assume 6:1). The channel would be approximately 200 ft in length and oriented in a north to south direction. Approximately 100 ft of this channel would be located on what is currently adjacent property. It is also assumed that the river will not migrate away from the proposed outlet location.

Similar to Alternative 2, two scenarios of hydraulic roughness were evaluated for Alternative 3 (with initial condition n values and mature vegetation n values). For immature vegetation conditions Manning's n values of 0.040 for the Pond Reach channel and 0.050 for floodplain areas were used in the disturbed portion of the Pond Reach. Hydraulic conditions associated with mature conditions of vegetation were represented using Manning's n values of 0.055 for the overflow channel and 0.080 for floodplain areas in the disturbed portion of the Pond Reach. As seen in Figure 31 the mature vegetation results in a slight decrease in channel velocity for the 100-year flow. The mature vegetation, and resultant lower velocities require a smaller riprap size for erosion protection.

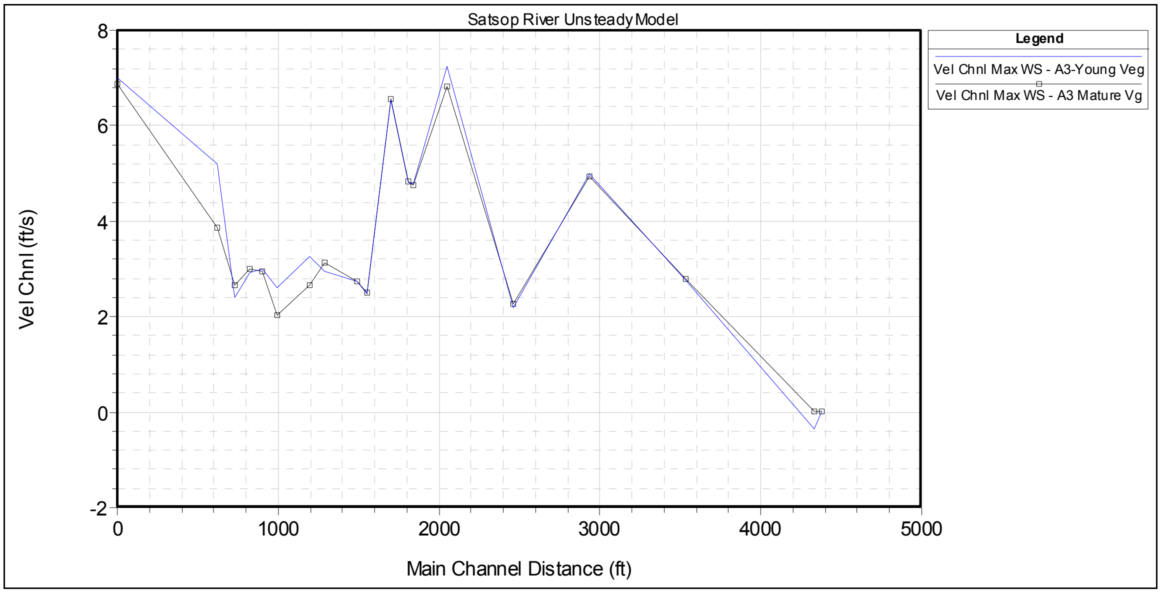



Figure 31. Pond Reach velocity comparison for Alternative 3 with the 100-year flow.

## 4.4 Steady Flow Modeling Results

For all analysis conditions considered the backwater effects of the Chehalis River are a significant influence for all flood events. Under typical bankfull flow conditions, the lower Satsop River floodplain will be inundated to approximately elevation 19.7 ft NGVD. As the elevation of the project site ranges from about 17 to 25 ft NGVD, the majority of the site will be flooded due to backwater at even a nominal flood event.

Additionally, the relatively flat nature of the overbank areas results in a broad floodplain that presents complex flow patterns. For moderate floods, the flow patterns in overbank areas are influenced by relatively subtle changes in the overbank topography, whereas for large floods the boundaries of the floodplain become less confined and less distinct from the broad Chehalis River floodplain. Consequently, the hydraulic modeling effort is subject to the limitations associated with one-dimensional modeling techniques and does not describe two-dimensional flow conditions. Furthermore, it should be recognized that the lower Satsop River is dynamic, continuously eroding and depositing sediment and debris, and the developed hydraulic models can only represent the conditions at the time the involved data was collected.

A summary of hydraulic parameters for each of the analysis conditions is shown in Table 10 for the estimated bankfull flood and in Table 11 for the 100-year flood. Water surface profiles for the bankfull flow are shown in Figure 32, and Figure 33 for the 100-year event.

In the following sections the results of the steady flow hydraulic modeling for each of the analysis conditions are summarized.

### 4.4.1 Existing Conditions

Significant conclusions of the hydraulic modeling for existing conditions include the following:

- Existing dikes on the project site and the Hiram Hall Road create significant obstructions to flow in overbank areas.
- Several low points exist in the northern dike on the project site.
- During the bankfull flood a discharge of approximately 690 cfs flows back into the Satsop River at the downstream end of the Pond Reach.
- Field observations made during an approximate 5-year flood event in October 2003 generally confirm the existing conditions hydraulic modeling results.

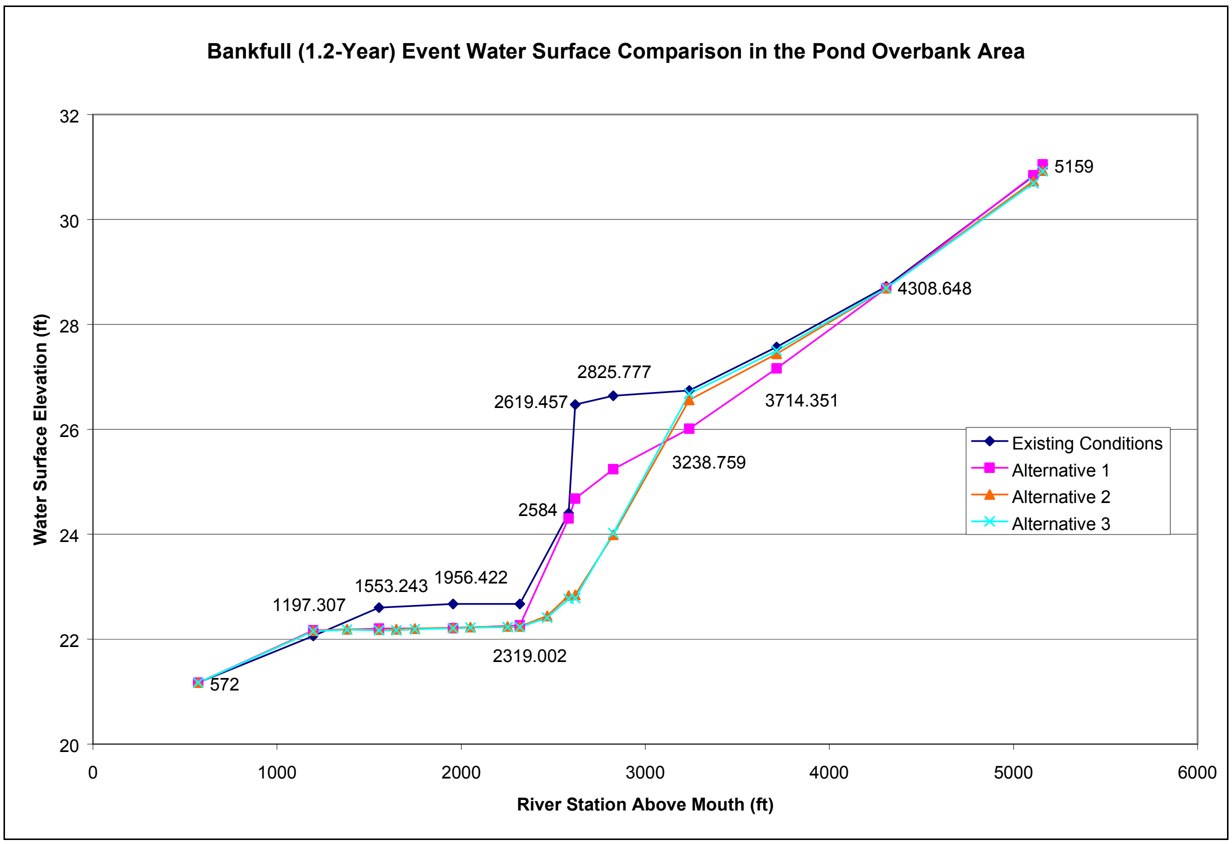



Figure 32. Water surface profile for the bankfull flow in the Pond Overbank Reach area for Existing Conditions, Alternatives 1, 2, and 3.

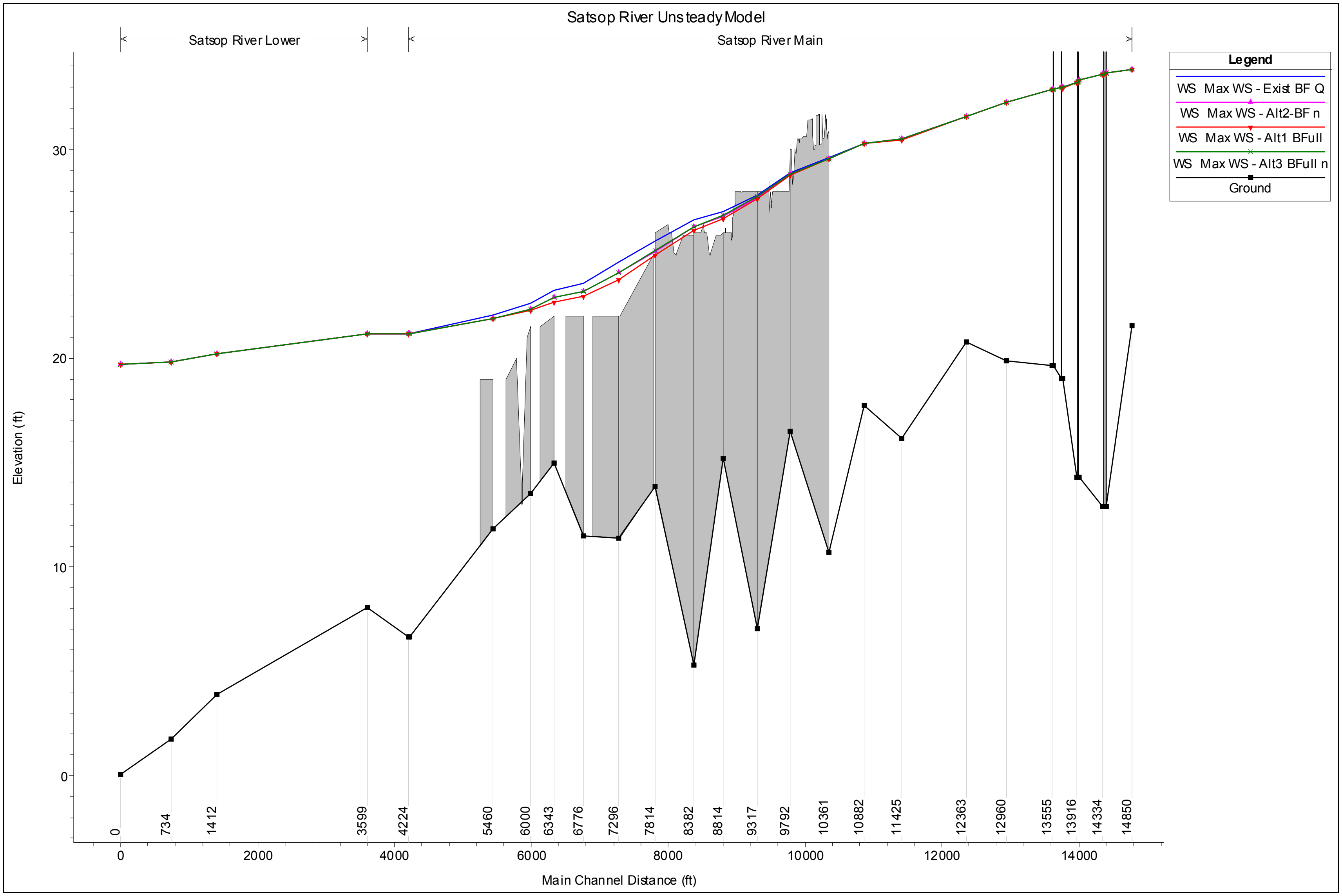



Figure 32 (cont). Water surface profile for bankfull flow on the Mainstem Satsop River for Existing Conditions, Alternatives 1, 2, and 3.

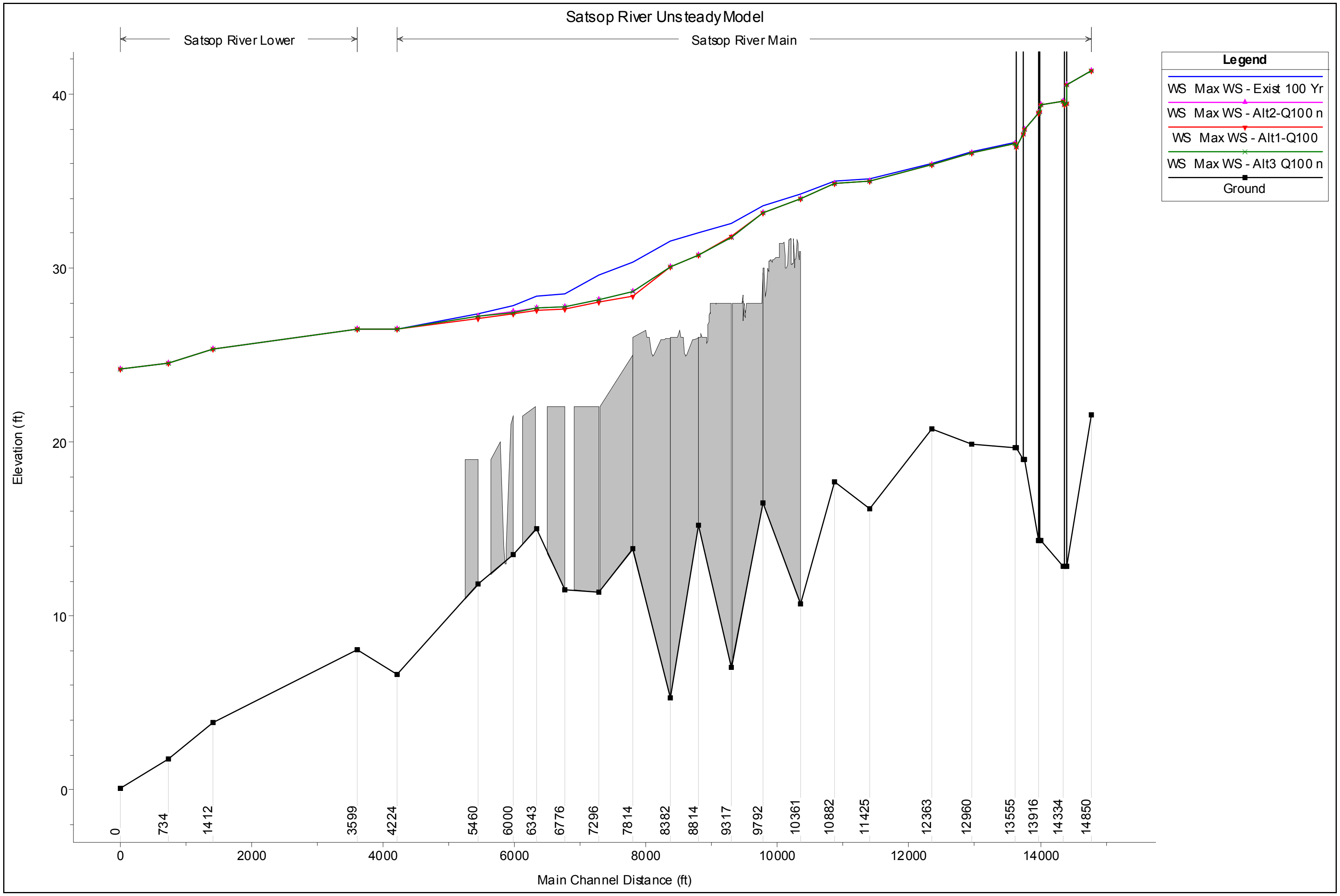



Figure 33. Water surface profile for the 100-year flow on the Mainstem Satsop River for Existing Conditions, and Alternatives 1, 2, and 3.

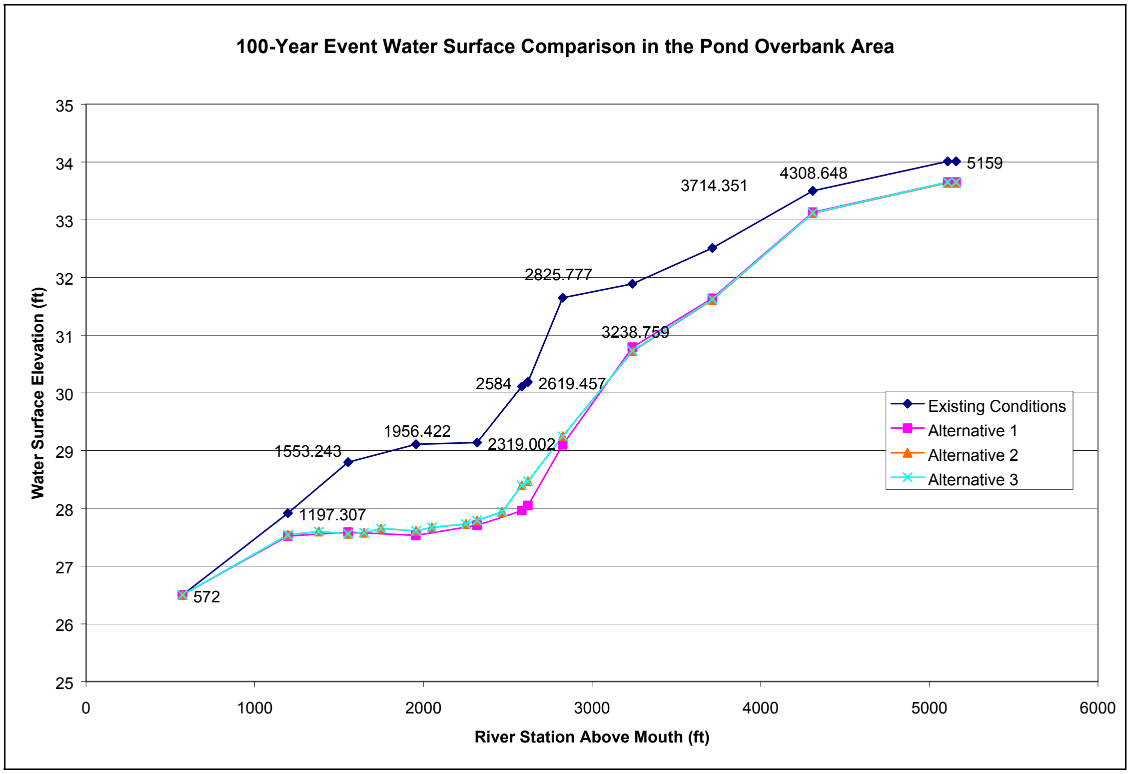



Figure 33 (cont). Water surface profile for the 100-year flow in the Pond Reach area for Existing Conditions, and Alternatives 1, 2, and 3.

Table 10. Satsop River parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 14850 | Max WS | Alt2-BF n | 17000.00 | 33.83 | 0.000915 | 6.06 | 10.78 | 9.59 | 0.61 |
| Main | 14850 | Max WS | Exist BF Q | 17000.00 | 33.83 | 0.000914 | 6.06 | 10.79 | 9.59 | 0.61 |
| Main | 14850 | Max WS | Alt1 BFull | 17000.00 | 33.83 | 0.000915 | 6.06 | 10.78 | 9.59 | 0.61 |
| Main | 14850 | Max WS | Alt3 BFull n | 17000.00 | 33.83 | 0.000915 | 6.06 | 10.79 | 9.59 | 0.61 |
| | | | | | | | | | | |
| Main | 14467 | Max WS | Alt2-BF n | 17000.00 | 33.67 | 0.000600 | 5.32 | 12.57 | 7.58 | 0.45 |
| Main | 14467 | Max WS | Exist BF Q | 17000.00 | 33.68 | 0.000599 | 5.32 | 12.58 | 7.58 | 0.45 |
| Main | 14467 | Max WS | Alt1 BFull | 17000.00 | 33.67 | 0.000600 | 5.32 | 12.57 | 7.58 | 0.45 |
| Main | 14467 | Max WS | Alt3 BFull n | 17000.00 | 33.67 | 0.000600 | 5.32 | 12.57 | 7.58 | 0.45 |
| | | | | | | | | | | |
| Main | 14334 | Max WS | Alt2-BF n | 16999.99 | 33.61 | 0.000613 | 5.36 | 12.51 | 7.46 | 0.46 |
| Main | 14334 | Max WS | Exist BF Q | 17000.00 | 33.62 | 0.000612 | 5.36 | 12.52 | 7.46 | 0.46 |
| Main | 14334 | Max WS | Alt1 BFull | 17000.00 | 33.61 | 0.000613 | 5.36 | 12.51 | 7.46 | 0.46 |
| Main | 14334 | Max WS | Alt3 BFull n | 17000.01 | 33.62 | 0.000613 | 5.36 | 12.51 | 7.46 | 0.46 |
| | | | | | | | | | | |
| Main | 14066 | Max WS | Alt2-BF n | 16999.99 | 33.31 | 0.001077 | 5.53 | 8.53 | 6.73 | 0.55 |
| Main | 14066 | Max WS | Exist BF Q | 17000.00 | 33.31 | 0.001077 | 5.53 | 8.52 | 6.73 | 0.55 |
| Main | 14066 | Max WS | Alt1 BFull | 17000.00 | 33.30 | 0.001077 | 5.53 | 8.53 | 6.73 | 0.55 |
| Main | 14066 | Max WS | Alt3 BFull n | 16999.98 | 33.31 | 0.001077 | 5.53 | 8.53 | 6.73 | 0.55 |
| | | | | | | | | | | |
| Main | 13916 | Max WS | Alt2-BF n | 16999.99 | 33.23 | 0.001088 | 5.59 | 8.61 | 6.77 | 0.56 |
| Main | 13916 | Max WS | Exist BF Q | 16999.99 | 33.23 | 0.001087 | 5.59 | 8.61 | 6.76 | 0.56 |
| Main | 13916 | Max WS | Alt1 BFull | 17000.00 | 33.23 | 0.001088 | 5.59 | 8.61 | 6.77 | 0.57 |
| Main | 13916 | Max WS | Alt3 BFull n | 17000.01 | 33.23 | 0.001088 | 5.59 | 8.61 | 6.77 | 0.56 |
| | | | | | | | | | | |
| Main | 13825 | Max WS | Alt2-BF n | 16999.97 | 32.97 | 0.000920 | 5.81 | 10.19 | 8.43 | 0.57 |
| Main | 13825 | Max WS | Exist BF Q | 16999.99 | 32.97 | 0.000920 | 5.81 | 10.19 | 8.43 | 0.57 |
| Main | 13825 | Max WS | Alt1 BFull | 17000.00 | 32.96 | 0.000921 | 5.81 | 10.19 | 8.43 | 0.57 |
| Main | 13825 | Max WS | Alt3 BFull n | 17000.00 | 32.97 | 0.000920 | 5.81 | 10.19 | 8.43 | 0.57 |
| | | | | | | | | | | |
| Main | 13555 | Max WS | Alt2-BF n | 17000.00 | 32.86 | 0.000984 | 5.84 | 9.77 | 6.08 | 0.59 |
| Main | 13555 | Max WS | Exist BF Q | 16999.99 | 32.86 | 0.000983 | 5.84 | 9.77 | 6.08 | 0.59 |
| Main | 13555 | Max WS | Alt1 BFull | 16999.99 | 32.86 | 0.000985 | 5.84 | 9.77 | 6.08 | 0.59 |
| Main | 13555 | Max WS | Alt3 BFull n | 17000.00 | 32.86 | 0.000984 | 5.84 | 9.77 | 6.08 | 0.59 |
| | | | | | | | | | | |
| Main | 12960 | Max WS | Alt2-BF n | 16999.97 | 32.27 | 0.001175 | 4.79 | 6.38 | 3.32 | 0.46 |
| Main | 12960 | Max WS | Exist BF Q | 16999.96 | 32.27 | 0.001172 | 4.79 | 6.38 | 3.32 | 0.46 |
| Main | 12960 | Max WS | Alt1 BFull | 16999.96 | 32.27 | 0.001177 | 4.79 | 6.38 | 3.32 | 0.46 |
| Main | 12960 | Max WS | Alt3 BFull n | 16999.98 | 32.27 | 0.001174 | 4.79 | 6.38 | 3.32 | 0.46 |
| | | | | | | | | | | |
| Main | 12363 | Max WS | Alt2-BF n | 16999.95 | 31.59 | 0.001377 | 4.68 | 5.38 | 3.27 | 0.46 |
| Main | 12363 | Max WS | Exist BF Q | 16999.94 | 31.59 | 0.001370 | 4.68 | 5.39 | 3.27 | 0.46 |
| Main | 12363 | Max WS | Alt1 BFull | 16999.90 | 31.58 | 0.001382 | 4.69 | 5.38 | 3.27 | 0.46 |
| Main | 12363 | Max WS | Alt3 BFull n | 16999.94 | 31.59 | 0.001375 | 4.68 | 5.39 | 3.27 | 0.46 |

Table 10 (cont). Satsop River parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 11425 | Max WS | Alt2-BF n | 16999.82 | 30.49 | 0.001413 | 4.80 | 5.48 | 3.15 | 0.48 |
| Main | 11425 | Max WS | Exist BF Q | 16999.78 | 30.51 | 0.001391 | 4.77 | 5.50 | 3.17 | 0.47 |
| Main | 11425 | Max WS | Alt1 BFull | 16999.61 | 30.48 | 0.001428 | 4.81 | 5.47 | 3.14 | 0.48 |
| Main | 11425 | Max WS | Alt3 BFull n | 16999.81 | 30.50 | 0.001405 | 4.79 | 5.49 | 3.16 | 0.48 |
| | | | | | | | | | | |
| Main | 10882 | Max WS | Alt2-BF n | 16999.73 | 30.29 | 0.000279 | 2.69 | 7.77 | 4.41 | 0.13 |
| Main | 10882 | Max WS | Exist BF Q | 16999.77 | 30.31 | 0.000276 | 2.67 | 7.79 | 4.40 | 0.13 |
| Main | 10882 | Max WS | Alt1 BFull | 16999.44 | 30.27 | 0.000282 | 2.69 | 7.75 | 4.42 | 0.13 |
| Main | 10882 | Max WS | Alt3 BFull n | 16999.81 | 30.30 | 0.000278 | 2.68 | 7.78 | 4.40 | 0.13 |
| | | | | | | | | | | |
| Main | 10361 | Max WS | Alt2-BF n | 16999.49 | 29.56 | 0.001423 | 7.16 | 10.32 | 2.85 | 0.88 |
| Main | 10361 | Max WS | Exist BF Q | 16999.44 | 29.59 | 0.001415 | 7.12 | 10.27 | 2.84 | 0.87 |
| Main | 10361 | Max WS | Alt1 BFull | 16998.94 | 29.53 | 0.001433 | 7.19 | 10.32 | 2.85 | 0.88 |
| Main | 10361 | Max WS | Alt3 BFull n | 16999.38 | 29.57 | 0.001417 | 7.15 | 10.32 | 2.85 | 0.87 |
| | | | | | | | | | | |
| Main | 9792 | Max WS | Alt2-BF n | 17112.88 | 28.81 | 0.001724 | 6.56 | 7.59 | 2.75 | 0.81 |
| Main | 9792 | Max WS | Exist BF Q | 17071.52 | 28.86 | 0.001668 | 6.48 | 7.64 | 2.78 | 0.78 |
| Main | 9792 | Max WS | Alt1 BFull | 17135.70 | 28.77 | 0.001769 | 6.62 | 7.56 | 2.73 | 0.82 |
| Main | 9792 | Max WS | Alt3 BFull n | 17117.97 | 28.83 | 0.001708 | 6.54 | 7.61 | 2.76 | 0.80 |
| | | | | | | | | | | |
| Main | 9317 | Max WS | Alt2-BF n | 16769.47 | 27.72 | 0.002080 | 8.59 | 10.31 | 2.88 | 1.27 |
| Main | 9317 | Max WS | Exist BF Q | 16739.83 | 27.82 | 0.001996 | 8.42 | 10.32 | 2.91 | 1.22 |
| Main | 9317 | Max WS | Alt1 BFull | 16882.00 | 27.62 | 0.002177 | 8.78 | 10.30 | 2.93 | 1.32 |
| Main | 9317 | Max WS | Alt3 BFull n | 16757.00 | 27.75 | 0.002049 | 8.53 | 10.31 | 2.90 | 1.25 |
| | | | | | | | | | | |
| Main | 8814 | Max WS | Alt2-BF n | 16874.92 | 26.81 | 0.002097 | 7.73 | 8.48 | 1.95 | 1.08 |
| Main | 8814 | Max WS | Exist BF Q | 16659.75 | 27.05 | 0.001781 | 7.22 | 8.65 | 2.11 | 0.94 |
| Main | 8814 | Max WS | Alt1 BFull | 16643.56 | 26.70 | 0.002174 | 7.82 | 8.40 | 1.89 | 1.11 |
| Main | 8814 | Max WS | Alt3 BFull n | 17016.62 | 26.83 | 0.002103 | 7.75 | 8.50 | 1.95 | 1.09 |
| | | | | | | | | | | |
| Main | 8382 | Max WS | Alt2-BF n | 16180.28 | 26.27 | 0.001211 | 6.39 | 9.78 | 3.26 | 0.71 |
| Main | 8382 | Max WS | Exist BF Q | 15807.29 | 26.60 | 0.001000 | 5.91 | 10.04 | 3.29 | 0.60 |
| Main | 8382 | Max WS | Alt1 BFull | 16090.75 | 26.13 | 0.001277 | 6.51 | 9.66 | 3.18 | 0.74 |
| Main | 8382 | Max WS | Alt3 BFull n | 16293.39 | 26.30 | 0.001215 | 6.41 | 9.80 | 3.27 | 0.71 |
| | | | | | | | | | | |
| Main | 7814 | Max WS | Alt2-BF n | 16046.25 | 25.14 | 0.002289 | 8.64 | 9.55 | 3.27 | 1.31 |
| Main | 7814 | Max WS | Exist BF Q | 16410.06 | 25.63 | 0.001900 | 8.12 | 10.01 | 3.82 | 1.14 |
| Main | 7814 | Max WS | Alt1 BFull | 16022.94 | 24.92 | 0.002444 | 8.80 | 9.35 | 3.54 | 1.37 |
| Main | 7814 | Max WS | Alt3 BFull n | 16149.15 | 25.15 | 0.002301 | 8.67 | 9.57 | 3.28 | 1.32 |
| | | | | | | | | | | |
| Main | 7296 | Max WS | Alt2-BF n | 15319.59 | 24.09 | 0.003203 | 8.09 | 6.56 | 3.03 | 1.29 |
| Main | 7296 | Max WS | Exist BF Q | 16410.06 | 24.61 | 0.002956 | 7.91 | 6.72 | 3.11 | 1.22 |
| Main | 7296 | Max WS | Alt1 BFull | 14875.11 | 23.75 | 0.003524 | 8.38 | 6.43 | 3.66 | 1.39 |
| Main | 7296 | Max WS | Alt3 BFull n | 15410.53 | 24.10 | 0.003224 | 8.12 | 6.56 | 3.03 | 1.30 |
| | | | | | | | | | | |

Table 10 (cont). Satsop River parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, and 3.

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 6776 | Max WS | Alt2-BF n | 14300.72 | 23.20 | 0.001854 | 6.84 | 7.66 | 4.67 | 0.87 |
| Main | 6776 | Max WS | Exist BF Q | 16410.06 | 23.59 | 0.002077 | 7.33 | 7.80 | 5.13 | 1.00 |
| Main | 6776 | Max WS | Alt1 BFull | 13203.53 | 22.94 | 0.001752 | 6.60 | 7.56 | 4.71 | 0.82 |
| Main | 6776 | Max WS | Alt3 BFull n | 14384.57 | 23.20 | 0.001874 | 6.88 | 7.66 | 4.67 | 0.88 |
| | | | | | | | | | | |
| Main | 6343 | Max WS | Alt2-BF n | 14111.88 | 22.90 | 0.001236 | 4.23 | 5.03 | 3.63 | 0.38 |
| Main | 6343 | Max WS | Exist BF Q | 16410.06 | 23.26 | 0.001292 | 4.48 | 5.30 | 3.98 | 0.42 |
| Main | 6343 | Max WS | Alt1 BFull | 12517.92 | 22.68 | 0.001135 | 3.97 | 4.87 | 3.59 | 0.34 |
| Main | 6343 | Max WS | Alt3 BFull n | 14195.35 | 22.89 | 0.001251 | 4.26 | 5.03 | 3.63 | 0.39 |
| | | | | | | | | | | |
| Main | 6000 | Max WS | Alt2-BF n | 13872.14 | 22.36 | 0.001689 | 5.72 | 6.24 | 3.13 | 0.65 |
| Main | 6000 | Max WS | Exist BF Q | 16410.05 | 22.65 | 0.001984 | 6.38 | 6.53 | 3.46 | 0.80 |
| Main | 6000 | Max WS | Alt1 BFull | 11457.79 | 22.29 | 0.001200 | 4.78 | 6.17 | 3.12 | 0.46 |
| Main | 6000 | Max WS | Alt3 BFull n | 13957.07 | 22.35 | 0.001721 | 5.76 | 6.23 | 3.12 | 0.66 |
| | | | | | | | | | | |
| Main | 5460 | Max WS | Alt2-BF n | 13355.95 | 21.91 | 0.000444 | 2.71 | 5.56 | 4.64 | 0.15 |
| Main | 5460 | Max WS | Exist BF Q | 16410.05 | 22.09 | 0.000606 | 3.23 | 5.74 | 4.41 | 0.21 |
| Main | 5460 | Max WS | Alt1 BFull | 14115.41 | 21.87 | 0.000511 | 2.89 | 5.52 | 4.64 | 0.17 |
| Main | 5460 | Max WS | Alt3 BFull n | 13407.46 | 21.90 | 0.000416 | 2.62 | 5.55 | 4.70 | 0.14 |
| | | | | | | | | | | |
| Main | 4225 | Max WS | Alt2-BF n | 14685.92 | 21.17 | 0.001024 | 5.78 | 9.41 | 3.94 | 0.59 |
| Main | 4225 | Max WS | Alt3 BFull n | 14728.93 | 21.17 | 0.001030 | 5.80 | 9.41 | 3.94 | 0.59 |
| | | | | | | | | | | |
| Main | 4224 | Max WS | Alt2-BF n | 14685.93 | 21.17 | 0.001024 | 5.78 | 9.41 | 3.94 | 0.59 |
| Main | 4224 | Max WS | Exist BF Q | 16410.04 | 21.17 | 0.001277 | 6.46 | 9.41 | 3.81 | 0.73 |
| Main | 4224 | Max WS | Alt1 BFull | 14114.98 | 21.17 | 0.000945 | 5.56 | 9.41 | 3.81 | 0.54 |
| Main | 4224 | Max WS | Alt3 BFull n | 14728.94 | 21.17 | 0.001030 | 5.80 | 9.41 | 3.94 | 0.59 |
| | | | | | | | | | | |
| Lower | 3599 | Max WS | Alt2-BF n | 17100.01 | 21.17 | 0.001046 | 5.46 | 8.48 | 4.39 | 0.54 |
| Lower | 3599 | Max WS | Exist BF Q | 17100.00 | 21.17 | 0.001046 | 5.46 | 8.48 | 4.39 | 0.54 |
| Lower | 3599 | Max WS | Alt1 BFull | 17100.01 | 21.17 | 0.001046 | 5.46 | 8.48 | 4.39 | 0.54 |
| Lower | 3599 | Max WS | Alt3 BFull n | 17100.01 | 21.17 | 0.001046 | 5.46 | 8.48 | 4.39 | 0.54 |
| | | | | | | | | | | |
| Lower | 1412 | Max WS | Alt2-BF n | 17100.01 | 20.22 | 0.000720 | 5.03 | 9.91 | 3.68 | 0.44 |
| Lower | 1412 | Max WS | Exist BF Q | 17100.00 | 20.22 | 0.000720 | 5.03 | 9.91 | 3.68 | 0.44 |
| Lower | 1412 | Max WS | Alt1 BFull | 17100.01 | 20.22 | 0.000720 | 5.03 | 9.91 | 3.68 | 0.44 |
| Lower | 1412 | Max WS | Alt3 BFull n | 17100.01 | 20.22 | 0.000720 | 5.03 | 9.91 | 3.68 | 0.44 |
| | | | | | | | | | | |
| Lower | 734 | Max WS | Alt2-BF n | 17099.92 | 19.82 | 0.000553 | 5.06 | 12.39 | 4.52 | 0.41 |
| Lower | 734 | Max WS | Exist BF Q | 17099.97 | 19.82 | 0.000553 | 5.06 | 12.39 | 4.52 | 0.41 |
| Lower | 734 | Max WS | Alt1 BFull | 17099.92 | 19.82 | 0.000553 | 5.06 | 12.39 | 4.52 | 0.41 |
| Lower | 734 | Max WS | Alt3 BFull n | 17099.92 | 19.82 | 0.000553 | 5.06 | 12.39 | 4.52 | 0.41 |
| | | | | | | | | | | |
| Lower | 0 | Max WS | Alt2-BF n | 878.14 | 19.70 | 0.000000 | 0.11 | 14.53 | 8.18 | 0.00 |
| Lower | 0 | Max WS | Exist BF Q | 894.70 | 19.70 | 0.000000 | 0.11 | 14.53 | 8.18 | 0.00 |
| Lower | 0 | Max WS | Alt1 BFull | 865.63 | 19.70 | 0.000000 | 0.11 | 14.53 | 8.18 | 0.00 |
| Lower | 0 | Max WS | Alt3 BFull n | 885.90 | 19.70 | 0.000000 | 0.11 | 14.53 | 8.18 | 0.00 |

Table 10 (cont). Pond Reach parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total (cfs) | W.S. Elev (ft) | E.G. Slope (ft/ft) | Vel Chnl (ft/s) | Hydr Depth C (ft) | Hydr Depth (ft) | Shear Chan (lb/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ponds | 5159 | Max WS | Alt2-BF n | 100.00 | 30.93 | 0.003909 | 0.96 | 2.02 | 0.96 | 0.34 |
| Ponds | 5159 | Max WS | Exist BF Q | 100.00 | 31.05 | 0.002532 | 1.56 | 1.23 | 0.76 | 0.19 |
| Ponds | 5159 | Max WS | Alt1 BFull | 100.00 | 31.05 | 0.002518 | 1.55 | 1.23 | 0.76 | 0.19 |
| Ponds | 5159 | Max WS | Alt3 BFull n | 100.00 | 30.92 | 0.003964 | 0.97 | 2.02 | 0.96 | 0.34 |
| | | | | | | | | | | |
| Ponds | 5109 | Max WS | Alt2-BF n | 88.35 | 30.73 | 0.003797 | 1.00 | 1.92 | 0.91 | 0.28 |
| Ponds | 5109 | Max WS | Exist BF Q | 100.00 | 30.83 | 0.005343 | 1.99 | 1.01 | 0.63 | 0.34 |
| Ponds | 5109 | Max WS | Alt1 BFull | 100.62 | 30.84 | 0.005304 | 1.99 | 1.02 | 0.63 | 0.34 |
| Ponds | 5109 | Max WS | Alt3 BFull n | 100.00 | 30.69 | 0.005018 | 1.16 | 1.91 | 0.90 | 0.37 |
| | | | | | | | | | | |
| Ponds | 4308.648 | Max WS | Alt2-BF n | 38.88 | 28.69 | 0.000028 | 0.20 | 1.65 | 1.35 | 0.00 |
| Ponds | 4308.648 | Max WS | Exist BF Q | 28.52 | 28.72 | 0.000014 | 0.14 | 1.69 | 1.37 | 0.00 |
| Ponds | 4308.648 | Max WS | Alt1 BFull | 30.78 | 28.69 | 0.000018 | 0.16 | 1.66 | 1.35 | 0.00 |
| Ponds | 4308.648 | Max WS | Alt3 BFull n | 38.35 | 28.69 | 0.000027 | 0.19 | 1.66 | 1.35 | 0.00 |
| | | | | | | | | | | |
| Ponds | 3714.351 | Max WS | Alt2-BF n | 330.55 | 27.44 | 0.003946 | 2.48 | 1.97 | 1.20 | 0.44 |
| Ponds | 3714.351 | Max WS | Exist BF Q | 360.20 | 27.57 | 0.003632 | 2.45 | 2.06 | 1.28 | 0.42 |
| Ponds | 3714.351 | Max WS | Alt1 BFull | 275.09 | 27.16 | 0.004919 | 2.60 | 1.79 | 1.02 | 0.49 |
| Ponds | 3714.351 | Max WS | Alt3 BFull n | 343.03 | 27.50 | 0.003772 | 2.46 | 2.01 | 1.23 | 0.42 |
| | | | | | | | | | | |
| Ponds | 3238.759 | Max WS | Alt2-BF n | 242.74 | 26.56 | 0.000012 | 0.26 | 4.76 | 2.97 | 0.00 |
| Ponds | 3238.759 | Max WS | Exist BF Q | 494.28 | 26.74 | 0.000040 | 0.50 | 4.94 | 3.11 | 0.01 |
| Ponds | 3238.759 | Max WS | Alt1 BFull | 508.72 | 26.01 | 0.000090 | 0.66 | 4.20 | 2.50 | 0.02 |
| Ponds | 3238.759 | Max WS | Alt3 BFull n | 103.70 | 26.68 | 0.000002 | 0.11 | 4.87 | 3.06 | 0.00 |
| | | | | | | | | | | |
| Ponds | 2825.777 | Max WS | Alt2-BF n | 929.04 | 23.99 | 0.012140 | 5.50 | 2.20 | 0.88 | 1.63 |
| Ponds | 2825.777 | Max WS | Exist BF Q | 1318.46 | 26.64 | 0.000391 | 1.46 | 4.84 | 2.39 | 0.12 |
| Ponds | 2825.777 | Max WS | Alt1 BFull | 1051.58 | 25.24 | 0.003587 | 2.19 | 1.81 | 1.32 | 0.41 |
| Ponds | 2825.777 | Max WS | Alt3 BFull n | 818.09 | 24.02 | 0.013226 | 5.33 | 1.98 | 0.47 | 1.60 |
| | | | | | | | | | | |
| Ponds | 2619.457 | Max WS | Alt2-BF n | 1061.20 | 22.84 | 0.000721 | 1.71 | 3.91 | 2.17 | 0.16 |
| Ponds | 2619.457 | Max WS | Exist BF Q | 691.07 | 26.47 | 0.001128 | 2.37 | 4.30 | 1.35 | 0.30 |
| Ponds | 2619.457 | Max WS | Alt1 BFull | 1116.74 | 24.68 | 0.001873 | 1.10 | 0.79 | 0.78 | 0.09 |
| Ponds | 2619.457 | Max WS | Alt3 BFull n | 959.69 | 22.78 | 0.000618 | 1.58 | 3.88 | 2.19 | 0.14 |
| | | | | | | | | | | |
| Ponds | 2584 | Max WS | Alt2-BF n | 1061.20 | 22.83 | 0.000729 | 1.72 | 3.90 | 2.18 | 0.16 |
| Ponds | 2584 | Max WS | Exist BF Q | 690.75 | 24.40 | 0.014563 | 5.63 | 2.30 | 1.65 | 2.06 |
| Ponds | 2584 | Max WS | Alt1 BFull | 1116.74 | 24.30 | 0.016630 | 2.11 | 0.41 | 0.41 | 0.42 |
| Ponds | 2584 | Max WS | Alt3 BFull n | 959.69 | 22.77 | 0.000625 | 1.58 | 3.87 | 2.20 | 0.14 |
| | | | | | | | | | | |
| Ponds | 2467 | Max WS | Alt2-BF n | 1785.82 | 22.44 | 0.003530 | 3.65 | 3.69 | 2.14 | 0.75 |
| Ponds | 2467 | Max WS | Alt3 BFull n | 1695.62 | 22.41 | 0.003260 | 3.50 | 3.67 | 2.16 | 0.69 |

Table 10 (cont). Pond Reach parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total (cfs) | W.S. Elev (ft) | E.G. Slope (ft/ft) | Vel Chnl (ft/s) | Hydr Depth C (ft) | Hydr Depth (ft) | Shear Chan (lb/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ponds | 2319.002 | Max WS | Alt2-BF n | 1780.42 | 22.24 | 0.000012 | 0.41 | 5.97 | 4.70 | 0.00 |
| Ponds | 2319.002 | Max WS | Exist BF Q | 690.42 | 22.67 | 0.000003 | | | 5.41 | |
| Ponds | 2319.002 | Max WS | Alt1 BFull | 2257.74 | 22.26 | 0.000015 | | | 4.80 | |
| Ponds | 2319.002 | Max WS | Alt3 BFull n | 1689.49 | 22.23 | 0.000011 | 0.39 | 5.96 | 4.69 | 0.00 |
| Ponds | 2252 | Max WS | Alt2-BF n | 2799.31 | 22.24 | 0.000024 | 0.58 | 5.91 | 5.10 | 0.01 |
| Ponds | 2252 | Max WS | Alt3 BFull n | 2715.45 | 22.23 | 0.000023 | 0.56 | 5.90 | 5.09 | 0.01 |
| Ponds | 2050 | Max WS | Alt2-BF n | 2799.30 | 22.23 | 0.000047 | 0.72 | 4.97 | 3.33 | 0.01 |
| Ponds | 2050 | Max WS | Alt3 BFull n | 2715.45 | 22.22 | 0.000044 | 0.70 | 4.96 | 3.32 | 0.01 |
| Ponds | 1956.422 | Max WS | Alt2-BF n | 3227.86 | 22.22 | 0.000081 | 0.08 | 6.18 | 3.60 | 0.03 |
| Ponds | 1956.422 | Max WS | Exist BF Q | 690.42 | 22.67 | 0.000009 | | | 3.81 | |
| Ponds | 1956.422 | Max WS | Alt1 BFull | 4607.49 | 22.21 | 0.000113 | | | 3.53 | |
| Ponds | 1956.422 | Max WS | Alt3 BFull n | 3142.96 | 22.21 | 0.000078 | 0.08 | 6.17 | 3.59 | 0.03 |
| Ponds | 1749 | Max WS | Alt2-BF n | 3744.04 | 22.20 | 0.000068 | 0.78 | 6.62 | 4.23 | 0.03 |
| Ponds | 1749 | Max WS | Alt3 BFull n | 3692.56 | 22.19 | 0.000066 | 0.77 | 6.61 | 4.21 | 0.03 |
| Ponds | 1648 | Max WS | Alt2-BF n | 3744.06 | 22.19 | 0.000107 | 1.14 | 5.67 | 3.74 | 0.04 |
| Ponds | 1648 | Max WS | Alt3 BFull n | 3692.56 | 22.17 | 0.000105 | 1.13 | 5.66 | 3.73 | 0.04 |
| Ponds | 1553.243 | Max WS | Alt2-BF n | 3744.04 | 22.18 | 0.000093 | 1.12 | 5.84 | 4.29 | 0.03 |
| Ponds | 1553.243 | Max WS | Exist BF Q | 690.42 | 22.60 | 0.000285 | 1.34 | 5.05 | 2.69 | 0.09 |
| Ponds | 1553.243 | Max WS | Alt1 BFull | 2985.04 | 22.20 | 0.000038 | 0.46 | 4.64 | 4.45 | 0.01 |
| Ponds | 1553.243 | Max WS | Alt3 BFull n | 3692.56 | 22.17 | 0.000091 | 1.11 | 5.83 | 4.28 | 0.03 |
| Ponds | 1380 | Max WS | Alt2-BF n | 2414.09 | 22.19 | 0.000057 | 0.90 | 6.04 | 4.35 | 0.02 |
| Ponds | 1380 | Max WS | Alt3 BFull n | 2371.07 | 22.18 | 0.000055 | 0.88 | 6.03 | 4.34 | 0.02 |
| Ponds | 1197.307 | Max WS | Alt2-BF n | 2414.08 | 22.16 | 0.000438 | 1.60 | 6.11 | 3.84 | 0.13 |
| Ponds | 1197.307 | Max WS | Exist BF Q | 690.40 | 22.06 | 0.003143 | 2.93 | 2.73 | 1.74 | 0.53 |
| Ponds | 1197.307 | Max WS | Alt1 BFull | 2985.05 | 22.17 | 0.000133 | 0.63 | 2.89 | 3.74 | 0.02 |
| Ponds | 1197.307 | Max WS | Alt3 BFull n | 2371.08 | 22.15 | 0.000509 | 1.50 | 4.25 | 3.72 | 0.12 |
| Ponds | 572 | Max WS | Alt2-BF n | 2414.08 | 21.17 | 0.002993 | 4.78 | 5.84 | 1.64 | 1.09 |
| Ponds | 572 | Max WS | Exist BF Q | 689.96 | 21.17 | 0.000175 | 1.26 | 6.67 | 2.50 | 0.07 |
| Ponds | 572 | Max WS | Alt1 BFull | 2985.04 | 21.17 | 0.003153 | 5.34 | 6.67 | 1.75 | 1.30 |
| Ponds | 572 | Max WS | Alt3 BFull n | 2371.08 | 21.17 | 0.002887 | 4.70 | 5.84 | 1.64 | 1.05 |

Table 11. Satsop River parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 14850 | Max WS | Exist 100 Yr | 58400.00 | 41.36 | 0.000766 | 7.90 | 18.31 | 7.60 | 0.87 |
| Main | 14850 | Max WS | Alt2-Q100 n | 58400.00 | 41.35 | 0.000767 | 7.90 | 18.31 | 7.59 | 0.87 |
| Main | 14850 | Max WS | Alt1-Q100 | 58400.00 | 41.35 | 0.000767 | 7.90 | 18.31 | 7.59 | 0.87 |
| Main | 14850 | Max WS | Alt3 Q100 n | 58400.00 | 41.35 | 0.000767 | 7.90 | 18.31 | 7.59 | 0.87 |
| | | | | | | | | | | |
| Main | 14467 | Max WS | Exist 100 Yr | 58399.98 | 40.52 | 0.001172 | 9.94 | 19.42 | 10.92 | 1.36 |
| Main | 14467 | Max WS | Alt2-Q100 n | 58297.36 | 40.51 | 0.001169 | 9.92 | 19.41 | 10.92 | 1.36 |
| Main | 14467 | Max WS | Alt1-Q100 | 58296.73 | 40.51 | 0.001169 | 9.92 | 19.41 | 10.92 | 1.36 |
| Main | 14467 | Max WS | Alt3 Q100 n | 58295.94 | 40.51 | 0.001169 | 9.92 | 19.41 | 10.92 | 1.36 |
| | | | | | | | | | | |
| Main | 14334 | Max WS | Exist 100 Yr | 58399.99 | 39.61 | 0.001452 | 10.71 | 18.51 | 10.76 | 1.61 |
| Main | 14334 | Max WS | Alt2-Q100 n | 58441.21 | 39.60 | 0.001456 | 10.72 | 18.50 | 10.75 | 1.62 |
| Main | 14334 | Max WS | Alt1-Q100 | 58438.71 | 39.61 | 0.001456 | 10.72 | 18.50 | 10.75 | 1.61 |
| Main | 14334 | Max WS | Alt3 Q100 n | 58439.05 | 39.61 | 0.001456 | 10.72 | 18.50 | 10.75 | 1.61 |
| | | | | | | | | | | |
| Main | 14066 | Max WS | Exist 100 Yr | 58399.98 | 39.41 | 0.001634 | 9.15 | 13.24 | 7.08 | 1.31 |
| Main | 14066 | Max WS | Alt2-Q100 n | 58469.08 | 39.40 | 0.001642 | 9.17 | 13.23 | 7.07 | 1.32 |
| Main | 14066 | Max WS | Alt1-Q100 | 58471.41 | 39.40 | 0.001642 | 9.17 | 13.23 | 7.07 | 1.32 |
| Main | 14066 | Max WS | Alt3 Q100 n | 58472.74 | 39.40 | 0.001642 | 9.17 | 13.23 | 7.07 | 1.32 |
| | | | | | | | | | | |
| Main | 13916 | Max WS | Exist 100 Yr | 58399.98 | 38.94 | 0.001922 | 9.69 | 12.77 | 6.68 | 1.49 |
| Main | 13916 | Max WS | Alt2-Q100 n | 58525.39 | 38.92 | 0.001939 | 9.72 | 12.76 | 6.67 | 1.50 |
| Main | 13916 | Max WS | Alt1-Q100 | 58525.35 | 38.93 | 0.001939 | 9.72 | 12.76 | 6.67 | 1.50 |
| Main | 13916 | Max WS | Alt3 Q100 n | 58526.43 | 38.93 | 0.001939 | 9.72 | 12.76 | 6.67 | 1.50 |
| | | | | | | | | | | |
| Main | 13825 | Max WS | Exist 100 Yr | 58399.98 | 37.99 | 0.002921 | 11.13 | 11.30 | 7.96 | 2.03 |
| Main | 13825 | Max WS | Alt2-Q100 n | 58584.59 | 37.97 | 0.002958 | 11.18 | 11.28 | 7.94 | 2.05 |
| Main | 13825 | Max WS | Alt1-Q100 | 58582.14 | 37.97 | 0.002957 | 11.18 | 11.29 | 7.94 | 2.05 |
| Main | 13825 | Max WS | Alt3 Q100 n | 58583.68 | 37.97 | 0.002958 | 11.18 | 11.28 | 7.94 | 2.05 |
| | | | | | | | | | | |
| Main | 13555 | Max WS | Exist 100 Yr | 58399.98 | 37.20 | 0.002715 | 12.40 | 14.11 | 8.84 | 2.35 |
| Main | 13555 | Max WS | Alt2-Q100 n | 58548.63 | 37.17 | 0.002753 | 12.47 | 14.08 | 8.81 | 2.37 |
| Main | 13555 | Max WS | Alt1-Q100 | 58547.88 | 37.17 | 0.002752 | 12.47 | 14.08 | 8.81 | 2.37 |
| Main | 13555 | Max WS | Alt3 Q100 n | 58544.92 | 37.17 | 0.002752 | 12.47 | 14.08 | 8.81 | 2.37 |
| | | | | | | | | | | |
| Main | 12960 | Max WS | Exist 100 Yr | 58399.95 | 36.67 | 0.001489 | 7.65 | 10.78 | 5.36 | 0.98 |
| Main | 12960 | Max WS | Alt2-Q100 n | 58681.20 | 36.62 | 0.001535 | 7.74 | 10.73 | 5.31 | 1.00 |
| Main | 12960 | Max WS | Alt1-Q100 | 58649.02 | 36.62 | 0.001532 | 7.74 | 10.73 | 5.31 | 1.00 |
| Main | 12960 | Max WS | Alt3 Q100 n | 58680.38 | 36.62 | 0.001534 | 7.74 | 10.73 | 5.31 | 1.00 |
| | | | | | | | | | | |
| Main | 12363 | Max WS | Exist 100 Yr | 58399.94 | 36.00 | 0.001451 | 7.17 | 9.80 | 4.93 | 0.88 |
| Main | 12363 | Max WS | Alt2-Q100 n | 58623.11 | 35.92 | 0.001515 | 7.28 | 9.72 | 4.86 | 0.91 |
| Main | 12363 | Max WS | Alt1-Q100 | 58621.51 | 35.92 | 0.001513 | 7.28 | 9.72 | 4.86 | 0.91 |
| Main | 12363 | Max WS | Alt3 Q100 n | 58622.41 | 35.92 | 0.001514 | 7.28 | 9.72 | 4.86 | 0.91 |

Table 11 (cont). Satsop River parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 11425 | Max WS | Exist 100 Yr | 58399.89 | 35.14 | 0.001238 | 6.75 | 10.12 | 5.05 | 0.77 |
| Main | 11425 | Max WS | Alt2-Q100 n | 58584.99 | 35.01 | 0.001328 | 6.93 | 9.98 | 4.93 | 0.82 |
| Main | 11425 | Max WS | Alt1-Q100 | 58583.82 | 35.01 | 0.001326 | 6.93 | 9.99 | 4.93 | 0.82 |
| Main | 11425 | Max WS | Alt3 Q100 n | 58584.46 | 35.01 | 0.001328 | 6.93 | 9.99 | 4.93 | 0.82 |
| | | | | | | | | | | |
| Main | 10882 | Max WS | Exist 100 Yr | 58399.89 | 35.00 | 0.000419 | 4.48 | 12.37 | 5.89 | 0.32 |
| Main | 10882 | Max WS | Alt2-Q100 n | 58583.35 | 34.86 | 0.000447 | 4.59 | 12.22 | 5.75 | 0.34 |
| Main | 10882 | Max WS | Alt1-Q100 | 58582.02 | 34.86 | 0.000446 | 4.59 | 12.23 | 5.75 | 0.34 |
| Main | 10882 | Max WS | Alt3 Q100 n | 58582.82 | 34.86 | 0.000447 | 4.59 | 12.22 | 5.75 | 0.34 |
| | | | | | | | | | | |
| Main | 10361 | Max WS | Exist 100 Yr | 58399.87 | 34.26 | 0.001849 | 9.82 | 13.56 | 4.22 | 1.50 |
| Main | 10361 | Max WS | Alt2-Q100 n | 58518.19 | 34.01 | 0.002118 | 10.38 | 13.31 | 3.97 | 1.69 |
| Main | 10361 | Max WS | Alt1-Q100 | 58518.12 | 34.02 | 0.002109 | 10.36 | 13.31 | 3.98 | 1.68 |
| Main | 10361 | Max WS | Alt3 Q100 n | 58517.86 | 34.01 | 0.002116 | 10.38 | 13.31 | 3.97 | 1.69 |
| | | | | | | | | | | |
| Main | 9792 | Max WS | Exist 100 Yr | 55571.26 | 33.56 | 0.001427 | 8.22 | 12.29 | 4.88 | 1.08 |
| Main | 9792 | Max WS | Alt2-Q100 n | 55934.26 | 33.15 | 0.001787 | 9.00 | 11.88 | 4.47 | 1.31 |
| Main | 9792 | Max WS | Alt1-Q100 | 55946.73 | 33.16 | 0.001777 | 8.98 | 11.89 | 4.48 | 1.30 |
| Main | 9792 | Max WS | Alt3 Q100 n | 55935.48 | 33.15 | 0.001785 | 8.99 | 11.88 | 4.47 | 1.30 |
| | | | | | | | | | | |
| Main | 9317 | Max WS | Exist 100 Yr | 53212.00 | 32.58 | 0.002207 | 11.02 | 14.30 | 4.52 | 1.87 |
| Main | 9317 | Max WS | Alt2-Q100 n | 53468.02 | 31.78 | 0.003093 | 12.56 | 13.49 | 4.42 | 2.47 |
| Main | 9317 | Max WS | Alt1-Q100 | 53432.82 | 31.81 | 0.003043 | 12.47 | 13.52 | 4.44 | 2.44 |
| Main | 9317 | Max WS | Alt3 Q100 n | 53462.86 | 31.79 | 0.003082 | 12.54 | 13.50 | 4.42 | 2.46 |
| | | | | | | | | | | |
| Main | 8814 | Max WS | Exist 100 Yr | 50546.76 | 32.02 | 0.001171 | 7.89 | 13.53 | 5.26 | 0.96 |
| Main | 8814 | Max WS | Alt2-Q100 n | 52925.87 | 30.75 | 0.002254 | 10.25 | 12.26 | 4.78 | 1.68 |
| Main | 8814 | Max WS | Alt1-Q100 | 53624.15 | 30.75 | 0.002311 | 10.38 | 12.26 | 4.78 | 1.73 |
| Main | 8814 | Max WS | Alt3 Q100 n | 52993.96 | 30.76 | 0.002252 | 10.25 | 12.27 | 4.79 | 1.68 |
| | | | | | | | | | | |
| Main | 8382 | Max WS | Exist 100 Yr | 49228.34 | 31.56 | 0.001060 | 7.57 | 13.92 | 5.11 | 0.88 |
| Main | 8382 | Max WS | Alt2-Q100 n | 44458.78 | 30.08 | 0.001721 | 9.10 | 12.75 | 4.24 | 1.32 |
| Main | 8382 | Max WS | Alt1-Q100 | 44996.84 | 30.06 | 0.001777 | 9.24 | 12.74 | 4.25 | 1.36 |
| Main | 8382 | Max WS | Alt3 Q100 n | 44540.97 | 30.08 | 0.001723 | 9.10 | 12.76 | 4.24 | 1.32 |
| | | | | | | | | | | |
| Main | 7814 | Max WS | Exist 100 Yr | 47747.50 | 30.33 | 0.002644 | 12.20 | 14.48 | 4.40 | 2.28 |
| Main | 7814 | Max WS | Alt2-Q100 n | 38631.48 | 28.63 | 0.003269 | 12.49 | 12.78 | 4.17 | 2.48 |
| Main | 7814 | Max WS | Alt1-Q100 | 38937.78 | 28.39 | 0.003765 | 13.25 | 12.56 | 3.91 | 2.81 |
| Main | 7814 | Max WS | Alt3 Q100 n | 38703.41 | 28.64 | 0.003280 | 12.51 | 12.78 | 4.17 | 2.49 |
| | | | | | | | | | | |
| Main | 7296 | Max WS | Exist 100 Yr | 47747.50 | 29.57 | 0.002365 | 9.99 | 11.28 | 6.35 | 1.64 |
| Main | 7296 | Max WS | Alt2-Q100 n | 33859.84 | 28.20 | 0.002057 | 8.55 | 9.91 | 5.28 | 1.25 |
| Main | 7296 | Max WS | Alt1-Q100 | 32797.54 | 28.05 | 0.002106 | 8.56 | 9.76 | 5.01 | 1.26 |
| Main | 7296 | Max WS | Alt3 Q100 n | 33905.57 | 28.20 | 0.002063 | 8.56 | 9.91 | 5.28 | 1.26 |

Table 11 (cont). Satsop River parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, and 3.

HEC-RAS Profile: Max WS — Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 6776 | Max WS | Exist 100 Yr | 47747.49 | 28.51 | 0.002389 | 10.57 | 12.18 | 5.35 | 1.79 |
| Main | 6776 | Max WS | Alt2-Q100 n | 29048.41 | 27.75 | 0.001161 | 7.06 | 11.42 | 5.49 | 0.81 |
| Main | 6776 | Max WS | Alt1-Q100 | 27055.35 | 27.66 | 0.001062 | 6.71 | 11.33 | 5.40 | 0.74 |
| Main | 6776 | Max WS | Alt3 Q100 n | 29092.40 | 27.75 | 0.001165 | 7.07 | 11.42 | 5.49 | 0.82 |
| | | | | | | | | | | |
| Main | 6343 | Max WS | Exist 100 Yr | 47747.49 | 28.36 | 0.000889 | 5.70 | 10.09 | 7.33 | 0.55 |
| Main | 6343 | Max WS | Alt2-Q100 n | 27910.56 | 27.69 | 0.000387 | 3.60 | 9.42 | 6.80 | 0.23 |
| Main | 6343 | Max WS | Alt1-Q100 | 26304.75 | 27.60 | 0.000360 | 3.45 | 9.34 | 6.69 | 0.21 |
| Main | 6343 | Max WS | Alt3 Q100 n | 27957.27 | 27.68 | 0.000389 | 3.60 | 9.42 | 6.80 | 0.23 |
| | | | | | | | | | | |
| Main | 6000 | Max WS | Exist 100 Yr | 47747.48 | 27.83 | 0.001724 | 8.78 | 11.71 | 8.50 | 1.25 |
| Main | 6000 | Max WS | Alt2-Q100 n | 28496.58 | 27.47 | 0.000679 | 5.40 | 11.35 | 8.22 | 0.48 |
| Main | 6000 | Max WS | Alt1-Q100 | 27092.63 | 27.40 | 0.000640 | 5.22 | 11.28 | 8.09 | 0.45 |
| Main | 6000 | Max WS | Alt3 Q100 n | 28590.36 | 27.47 | 0.000684 | 5.42 | 11.35 | 8.21 | 0.48 |
| | | | | | | | | | | |
| Main | 5460 | Max WS | Exist 100 Yr | 47747.48 | 27.38 | 0.000498 | 4.53 | 11.03 | 9.59 | 0.34 |
| Main | 5460 | Max WS | Alt2-Q100 n | 36612.96 | 27.21 | 0.000306 | 3.51 | 10.86 | 9.51 | 0.21 |
| Main | 5460 | Max WS | Alt1-Q100 | 39144.81 | 27.10 | 0.000367 | 3.82 | 10.75 | 9.31 | 0.24 |
| Main | 5460 | Max WS | Alt3 Q100 n | 36731.07 | 27.21 | 0.000294 | 3.44 | 10.86 | 9.57 | 0.20 |
| | | | | | | | | | | |
| Main | 4225 | Max WS | Alt2-Q100 n | 41436.87 | 26.50 | 0.001042 | 7.87 | 14.74 | 8.03 | 0.93 |
| Main | 4225 | Max WS | Alt3 Q100 n | 41555.06 | 26.50 | 0.001048 | 7.89 | 14.74 | 8.03 | 0.94 |
| | | | | | | | | | | |
| Main | 4224 | Max WS | Exist 100 Yr | 47747.46 | 26.50 | 0.001326 | 8.87 | 14.73 | 7.80 | 1.19 |
| Main | 4224 | Max WS | Alt2-Q100 n | 41436.86 | 26.50 | 0.001043 | 7.87 | 14.74 | 8.03 | 0.93 |
| Main | 4224 | Max WS | Alt1-Q100 | 39141.28 | 26.50 | 0.000891 | 7.27 | 14.74 | 7.80 | 0.80 |
| Main | 4224 | Max WS | Alt3 Q100 n | 41555.59 | 26.50 | 0.001049 | 7.89 | 14.74 | 8.03 | 0.94 |
| | | | | | | | | | | |
| Lower | 3599 | Max WS | Exist 100 Yr | 58409.78 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| Lower | 3599 | Max WS | Alt2-Q100 n | 58413.73 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| Lower | 3599 | Max WS | Alt1-Q100 | 58414.48 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| Lower | 3599 | Max WS | Alt3 Q100 n | 58413.95 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| | | | | | | | | | | |
| Lower | 1412 | Max WS | Exist 100 Yr | 58409.75 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| Lower | 1412 | Max WS | Alt2-Q100 n | 58413.13 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| Lower | 1412 | Max WS | Alt1-Q100 | 58414.02 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| Lower | 1412 | Max WS | Alt3 Q100 n | 58412.66 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| | | | | | | | | | | |
| Lower | 734 | Max WS | Exist 100 Yr | 58409.74 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| Lower | 734 | Max WS | Alt2-Q100 n | 58411.67 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| Lower | 734 | Max WS | Alt1-Q100 | 58412.29 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| Lower | 734 | Max WS | Alt3 Q100 n | 58411.70 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| | | | | | | | | | | |
| Lower | 0 | Max WS | Exist 100 Yr | 979.25 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |
| Lower | 0 | Max WS | Alt2-Q100 n | 982.60 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |
| Lower | 0 | Max WS | Alt1-Q100 | 964.18 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |
| Lower | 0 | Max WS | Alt3 Q100 n | 982.56 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |

Table 11 (cont). Pond Reach parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS | Reload Data

| Reach | River Sta | Profile | Plan | Q Total (cfs) | W.S. Elev (ft) | E.G. Slope (ft/ft) | Vel Chnl (ft/s) | Hydr Depth C (ft) | Hydr Depth (ft) | Shear Chan (lb/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ponds | 5159 | Max WS | Exist 100 Yr | 10.00 | 34.01 | 0.000000 | 0.02 | 4.19 | 2.70 | 0.00 |
| Ponds | 5159 | Max WS | Alt2-Q100 n | 10.00 | 33.64 | 0.000000 | 0.02 | 3.83 | 2.34 | 0.00 |
| Ponds | 5159 | Max WS | Alt1-Q100 | 10.00 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.35 | 0.00 |
| Ponds | 5159 | Max WS | Alt3 Q100 n | 10.00 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.34 | 0.00 |
| | | | | | | | | | | |
| Ponds | 5109 | Max WS | Exist 100 Yr | 10.00 | 34.01 | 0.000000 | 0.02 | 4.19 | 2.70 | 0.00 |
| Ponds | 5109 | Max WS | Alt2-Q100 n | 9.31 | 33.64 | 0.000000 | 0.02 | 3.83 | 2.34 | 0.00 |
| Ponds | 5109 | Max WS | Alt1-Q100 | 9.73 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.35 | 0.00 |
| Ponds | 5109 | Max WS | Alt3 Q100 n | 9.73 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.34 | 0.00 |
| | | | | | | | | | | |
| Ponds | 4308.648 | Max WS | Exist 100 Yr | 2838.59 | 33.50 | 0.000934 | 2.83 | 6.46 | 5.10 | 0.37 |
| Ponds | 4308.648 | Max WS | Alt2-Q100 n | 2588.96 | 33.11 | 0.000977 | 2.78 | 6.08 | 4.71 | 0.37 |
| Ponds | 4308.648 | Max WS | Alt1-Q100 | 2577.98 | 33.13 | 0.000959 | 2.76 | 6.10 | 4.73 | 0.36 |
| Ponds | 4308.648 | Max WS | Alt3 Q100 n | 2589.27 | 33.12 | 0.000975 | 2.78 | 6.08 | 4.72 | 0.36 |
| | | | | | | | | | | |
| Ponds | 3714.351 | Max WS | Exist 100 Yr | 5197.86 | 32.51 | 0.002151 | 4.15 | 6.83 | 5.12 | 0.81 |
| Ponds | 3714.351 | Max WS | Alt2-Q100 n | 5013.47 | 31.61 | 0.003669 | 4.94 | 5.93 | 4.22 | 1.20 |
| Ponds | 3714.351 | Max WS | Alt1-Q100 | 5049.42 | 31.64 | 0.003658 | 4.94 | 5.95 | 4.25 | 1.20 |
| Ponds | 3714.351 | Max WS | Alt3 Q100 n | 5018.78 | 31.62 | 0.003660 | 4.93 | 5.94 | 4.23 | 1.20 |
| | | | | | | | | | | |
| Ponds | 3238.759 | Max WS | Exist 100 Yr | 7863.10 | 31.89 | 0.000485 | 2.76 | 10.09 | 7.71 | 0.30 |
| Ponds | 3238.759 | Max WS | Alt2-Q100 n | 5543.05 | 30.72 | 0.000400 | 2.31 | 8.92 | 6.54 | 0.22 |
| Ponds | 3238.759 | Max WS | Alt1-Q100 | 4853.83 | 30.79 | 0.000298 | 2.00 | 8.98 | 6.60 | 0.17 |
| Ponds | 3238.759 | Max WS | Alt3 Q100 n | 5474.08 | 30.73 | 0.000388 | 2.28 | 8.93 | 6.55 | 0.21 |
| | | | | | | | | | | |
| Ponds | 2825.777 | Max WS | Exist 100 Yr | 9181.48 | 31.65 | 0.000668 | 2.91 | 9.85 | 7.09 | 0.40 |
| Ponds | 2825.777 | Max WS | Alt2-Q100 n | 14003.21 | 29.25 | 0.005363 | 6.95 | 7.45 | 4.81 | 2.44 |
| Ponds | 2825.777 | Max WS | Alt1-Q100 | 13462.51 | 29.10 | 0.006618 | 6.22 | 5.67 | 4.56 | 2.34 |
| Ponds | 2825.777 | Max WS | Alt3 Q100 n | 13924.35 | 29.25 | 0.005437 | 6.83 | 7.21 | 4.80 | 2.40 |
| | | | | | | | | | | |
| Ponds | 2619.457 | Max WS | Exist 100 Yr | 10662.33 | 30.19 | 0.009785 | 10.58 | 8.01 | 2.95 | 4.81 |
| Ponds | 2619.457 | Max WS | Alt2-Q100 n | 19819.07 | 28.47 | 0.001838 | 4.76 | 9.02 | 5.23 | 0.96 |
| Ponds | 2619.457 | Max WS | Alt1-Q100 | 19513.81 | 28.05 | 0.002166 | 3.58 | 4.16 | 4.08 | 0.56 |
| Ponds | 2619.457 | Max WS | Alt3 Q100 n | 19747.11 | 28.47 | 0.001829 | 4.75 | 9.02 | 5.23 | 0.95 |
| | | | | | | | | | | |
| Ponds | 2584 | Max WS | Exist 100 Yr | 10662.33 | 30.11 | 0.010303 | 10.79 | 7.94 | 2.90 | 5.02 |
| Ponds | 2584 | Max WS | Alt2-Q100 n | 19812.81 | 28.40 | 0.001914 | 4.83 | 8.95 | 5.16 | 0.99 |
| Ponds | 2584 | Max WS | Alt1-Q100 | 19512.62 | 27.96 | 0.002331 | 3.66 | 4.07 | 3.99 | 0.59 |
| Ponds | 2584 | Max WS | Alt3 Q100 n | 19740.27 | 28.40 | 0.001903 | 4.82 | 8.95 | 5.16 | 0.98 |
| | | | | | | | | | | |
| Ponds | 2467 | Max WS | Alt2-Q100 n | 24593.15 | 27.94 | 0.003786 | 6.56 | 8.49 | 4.62 | 1.85 |
| Ponds | 2467 | Max WS | Alt3 Q100 n | 24544.70 | 27.94 | 0.003777 | 6.55 | 8.49 | 4.62 | 1.85 |

Table 11 (cont). Pond Reach parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS | Reload Data

| Reach | River Sta | Profile | Plan | Q Total (cfs) | W.S. Elev (ft) | E.G. Slope (ft/ft) | Vel Chnl (ft/s) | Hydr Depth C (ft) | Hydr Depth (ft) | Shear Chan (lb/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ponds | 2319.002 | Max WS | Exist 100 Yr | 10662.33 | 29.14 | 0.000052 | 0.41 | 3.00 | 7.88 | 0.01 |
| Ponds | 2319.002 | Max WS | Alt2-Q100 n | 24579.38 | 27.79 | 0.000186 | 2.49 | 11.52 | 7.92 | 0.13 |
| Ponds | 2319.002 | Max WS | Alt1-Q100 | 25647.27 | 27.71 | 0.000141 | 0.43 | 1.57 | 7.91 | 0.01 |
| Ponds | 2319.002 | Max WS | Alt3 Q100 n | 24528.35 | 27.79 | 0.000185 | 2.49 | 11.52 | 7.92 | 0.13 |
| | | | | | | | | | | |
| Ponds | 2252 | Max WS | Alt2-Q100 n | 29392.28 | 27.73 | 0.000223 | 2.74 | 11.41 | 8.44 | 0.15 |
| Ponds | 2252 | Max WS | Alt3 Q100 n | 29347.60 | 27.73 | 0.000222 | 2.74 | 11.41 | 8.43 | 0.15 |
| | | | | | | | | | | |
| Ponds | 2050 | Max WS | Alt2-Q100 n | 29376.86 | 27.67 | 0.000332 | 3.13 | 10.41 | 8.20 | 0.21 |
| Ponds | 2050 | Max WS | Alt3 Q100 n | 29332.41 | 27.67 | 0.000332 | 3.12 | 10.41 | 8.20 | 0.21 |
| | | | | | | | | | | |
| Ponds | 1956.422 | Max WS | Exist 100 Yr | 10662.32 | 29.11 | 0.000092 | 0.70 | 4.42 | 7.97 | 0.03 |
| Ponds | 1956.422 | Max WS | Alt2-Q100 n | 29931.43 | 27.61 | 0.000447 | 0.29 | 11.57 | 7.95 | 0.32 |
| Ponds | 1956.422 | Max WS | Alt1-Q100 | 32141.88 | 27.53 | 0.000331 | 0.98 | 2.83 | 7.80 | 0.06 |
| Ponds | 1956.422 | Max WS | Alt3 Q100 n | 29837.34 | 27.61 | 0.000445 | 0.29 | 11.57 | 7.95 | 0.32 |
| | | | | | | | | | | |
| Ponds | 1749 | Max WS | Alt2-Q100 n | 21808.29 | 27.65 | 0.000213 | 2.05 | 12.07 | 8.65 | 0.16 |
| Ponds | 1749 | Max WS | Alt3 Q100 n | 21690.22 | 27.65 | 0.000210 | 2.04 | 12.07 | 8.64 | 0.16 |
| | | | | | | | | | | |
| Ponds | 1648 | Max WS | Alt2-Q100 n | 21807.98 | 27.58 | 0.000295 | 2.96 | 11.07 | 8.15 | 0.20 |
| Ponds | 1648 | Max WS | Alt3 Q100 n | 21689.89 | 27.58 | 0.000292 | 2.95 | 11.07 | 8.15 | 0.20 |
| | | | | | | | | | | |
| Ponds | 1553.243 | Max WS | Exist 100 Yr | 10662.32 | 28.80 | 0.001322 | 4.92 | 11.24 | 6.91 | 0.93 |
| Ponds | 1553.243 | Max WS | Alt2-Q100 n | 21807.65 | 27.56 | 0.000283 | 3.01 | 11.23 | 7.87 | 0.19 |
| Ponds | 1553.243 | Max WS | Alt1-Q100 | 19282.82 | 27.59 | 0.000151 | 1.55 | 10.04 | 8.01 | 0.09 |
| Ponds | 1553.243 | Max WS | Alt3 Q100 n | 21689.56 | 27.56 | 0.000280 | 2.99 | 11.23 | 7.87 | 0.19 |
| | | | | | | | | | | |
| Ponds | 1380 | Max WS | Alt2-Q100 n | 16978.76 | 27.60 | 0.000217 | 2.69 | 11.45 | 7.83 | 0.15 |
| Ponds | 1380 | Max WS | Alt3 Q100 n | 16860.41 | 27.60 | 0.000214 | 2.67 | 11.45 | 7.83 | 0.15 |
| | | | | | | | | | | |
| Ponds | 1197.307 | Max WS | Exist 100 Yr | 10662.32 | 27.92 | 0.004033 | 7.14 | 8.59 | 5.60 | 2.14 |
| Ponds | 1197.307 | Max WS | Alt2-Q100 n | 16978.52 | 27.54 | 0.001094 | 3.86 | 11.49 | 7.74 | 0.61 |
| Ponds | 1197.307 | Max WS | Alt1-Q100 | 19279.31 | 27.52 | 0.000305 | 1.92 | 8.24 | 7.64 | 0.16 |
| Ponds | 1197.307 | Max WS | Alt3 Q100 n | 16860.17 | 27.54 | 0.001132 | 3.87 | 9.65 | 7.66 | 0.62 |
| | | | | | | | | | | |
| Ponds | 572 | Max WS | Exist 100 Yr | 10662.31 | 26.50 | 0.001700 | 5.80 | 12.00 | 5.93 | 1.26 |
| Ponds | 572 | Max WS | Alt2-Q100 n | 16976.88 | 26.50 | 0.002650 | 6.93 | 11.17 | 5.54 | 1.84 |
| Ponds | 572 | Max WS | Alt1-Q100 | 19273.20 | 26.50 | 0.003154 | 7.90 | 12.00 | 5.59 | 2.34 |
| Ponds | 572 | Max WS | Alt3 Q100 n | 16858.35 | 26.50 | 0.002613 | 6.88 | 11.17 | 5.54 | 1.82 |

### 4.4.2 Alternatives 1, 2, and 3

Significant conclusions of the hydraulic modeling for Alternatives 1, 2, and 3 include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 25, Figure 33).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 34, Figure 35).
- Due the removal of the dikes, during the bankfull flood significantly more discharge occurs through the Pond Reach compared to existing conditions (Table 12).
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 25, Figure 33).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 34, Figure 35).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 34, Figure 35).
- Flow velocities along the lower Pond Reach increase (Figure 34, Figure 35).

Bankfull flow results for the alternatives are summarized in Table 12.

Table 12. Summary of differences between Existing Conditions and Alternatives 1, 2, and 3 for bankfull flow.

| Analysis Condition | Maximum Mainstem Water Surface Decrease (ft) | Maximum Mainstem Velocity Decrease (ft/s) | Increase in Pond Reach Discharge at Outlet (cfs) |
|---|---|---|---|
| Alternative 1 | 0.86 | 1.6 | 2,300 |
| Alternative 2 | 0.52 | 0.66 | 1,720 |
| Alternative 3 | 0.51 | 0.62 | 1,680 |

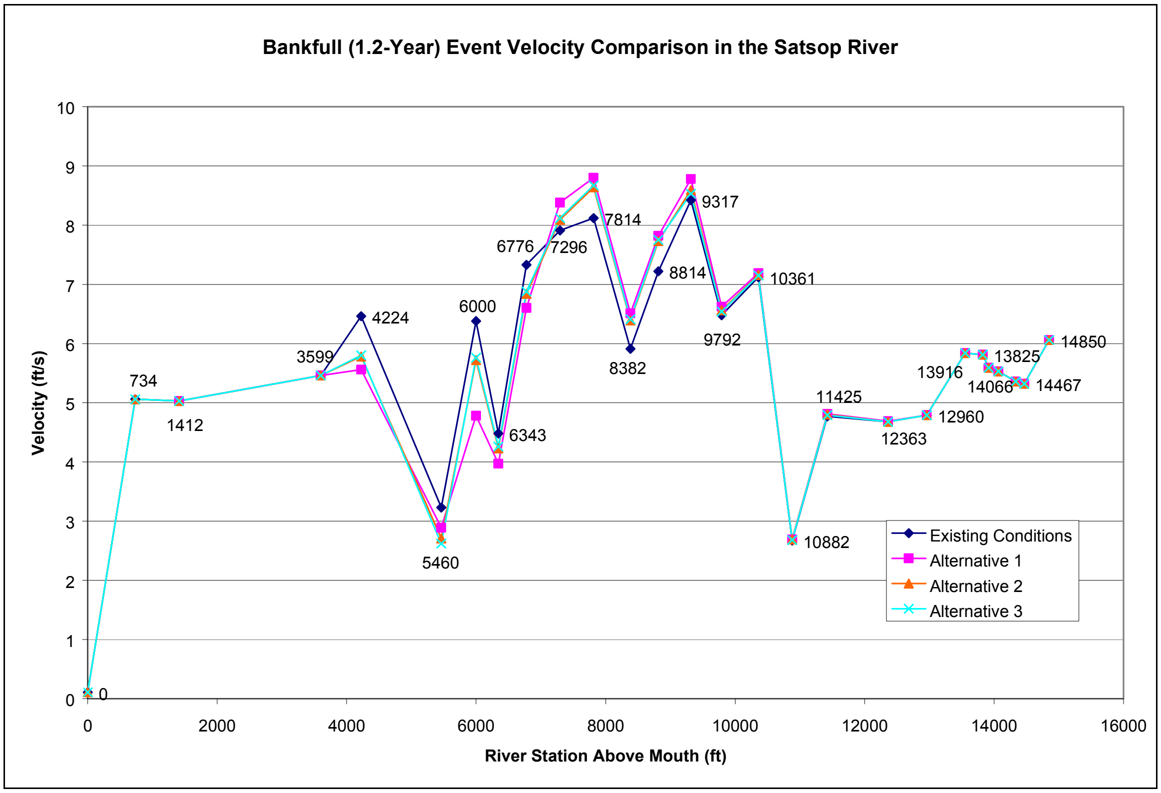



Figure 34. Velocity comparison at bankfull flow in the Satsop River.

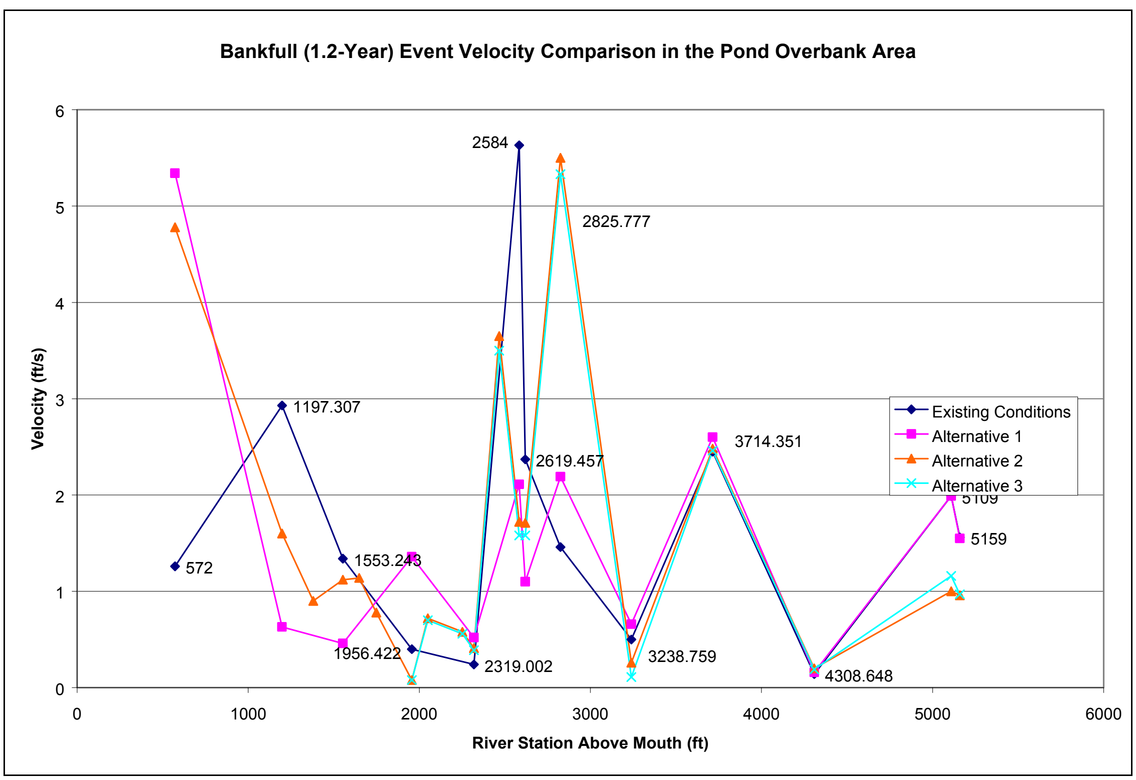



Figure 34 (cont). Velocity comparison at bankfull flow in the Pond Reach area.

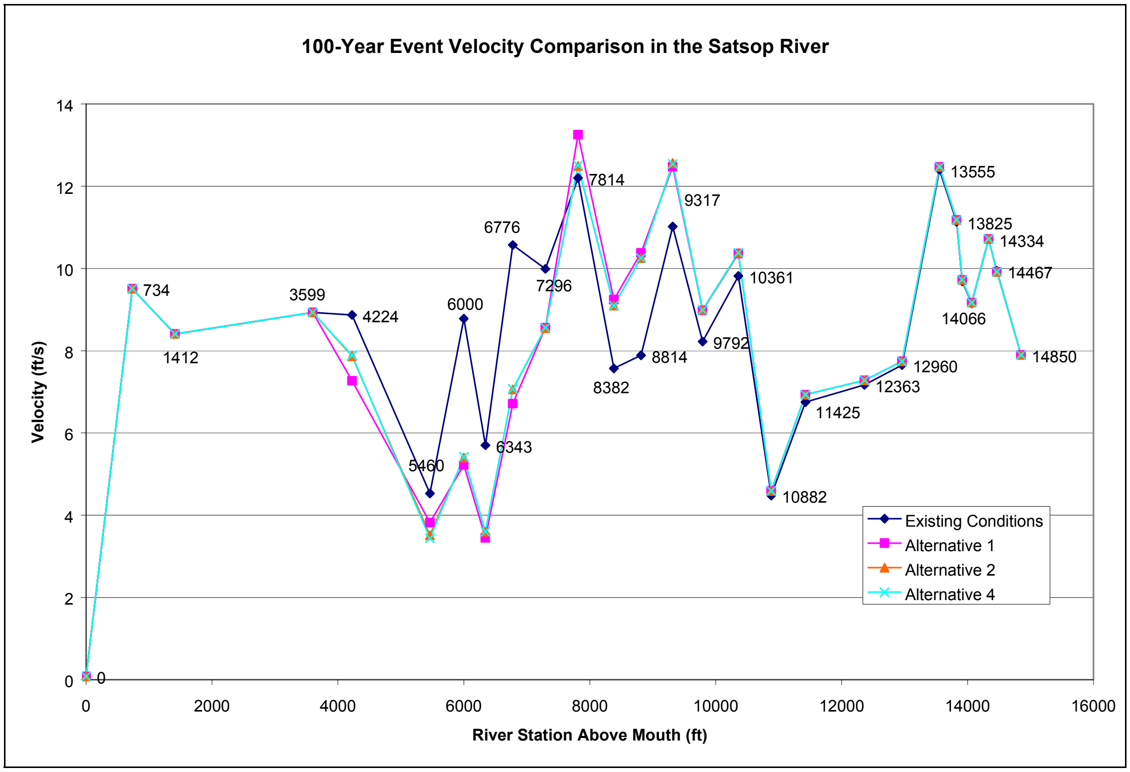



Figure 35. Velocity comparison at the 100-year flow in the Satsop River.

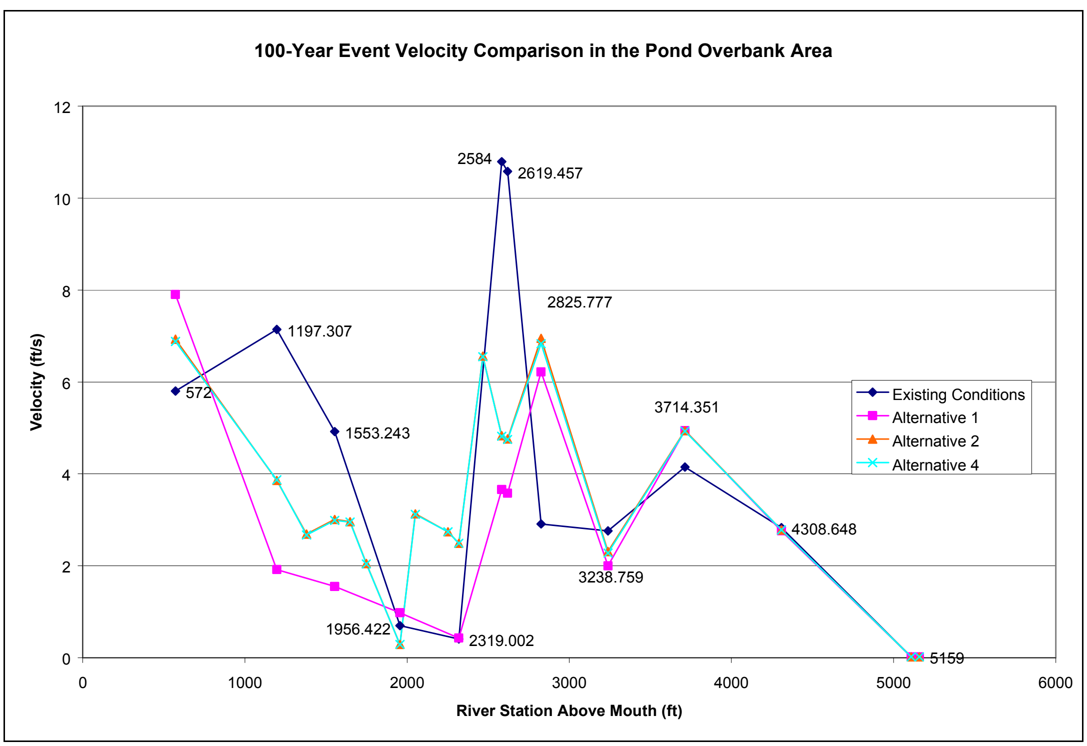



Figure 35 (cont). Velocity comparison at the 100-year flow in the Pond Reach area.

## 4.5 Unsteady Flow Modeling Results

In the following sections the results of the unsteady steady flow hydraulic modeling for each of the analysis conditions are summarized. To assess the influence of the proposed alternatives on the hydraulic characteristics of the Satsop River, unsteady flow analyses were conducted based on the February 1996 and March 1997 flood events. The unsteady flow analysis provides a means of directly analyzing the effect on floodplain storage associated with the proposed alternatives. In general terms, all the alternatives provide hydraulic benefits by decreasing overall water surface elevations in the project vicinity. This is due to the increase in floodplain function in the system that the alternatives provide. The beneficial effects apply to both the February 1996 and March 1997 events. Specific effects of the alternatives are described in the following sections:

### 4.5.1 Alternative 1

Significant conclusions of the hydraulic modeling for Alternative 1 with the March 1997 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 36).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 37).
- Due the removal of the dikes, significantly more discharge (22,430 vs 11,950 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 38).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 37).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 39).
- Flow velocities along the lower Pond Reach (Egress Channel ) increase (Figure 39).

Significant conclusions of the hydraulic modeling for Alternative 1 with the February 1996 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 40).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 41).
- Due the removal of the dikes, significantly more discharge (5,190 vs 1,860 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 42).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main

channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 41).

- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 43).
- Flow velocities along the lower Pond Reach  (Egress Channel ) increase (Figure 43).

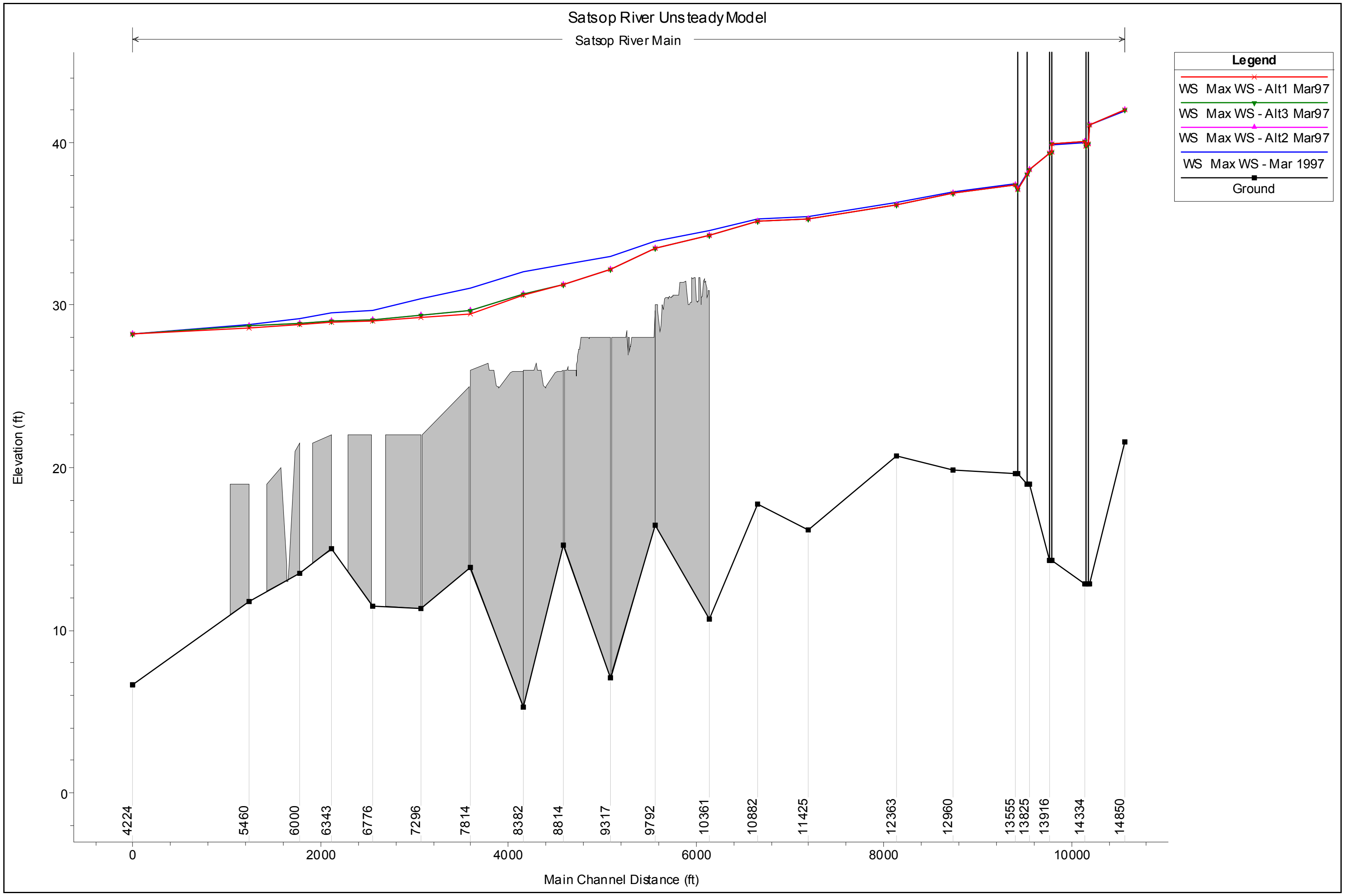



Figure 36. Satsop River March 1997 event water surface comparison for Existing Conditions, and Alternatives 1, 2 and 3.

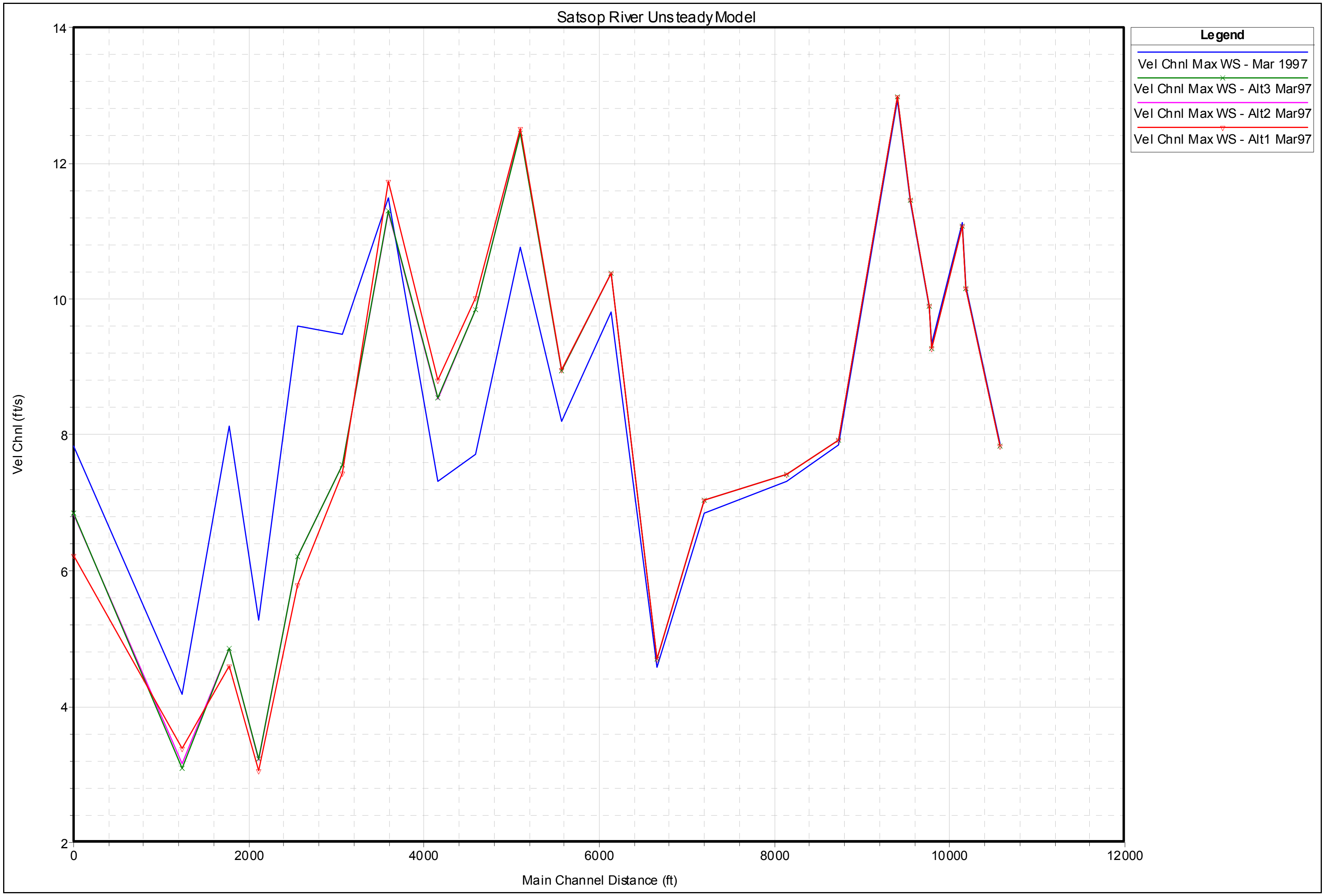



Figure 37. Satsop River March 1997 event velocity comparison for Existing Conditions, and Alternatives 1, 2 and 3.

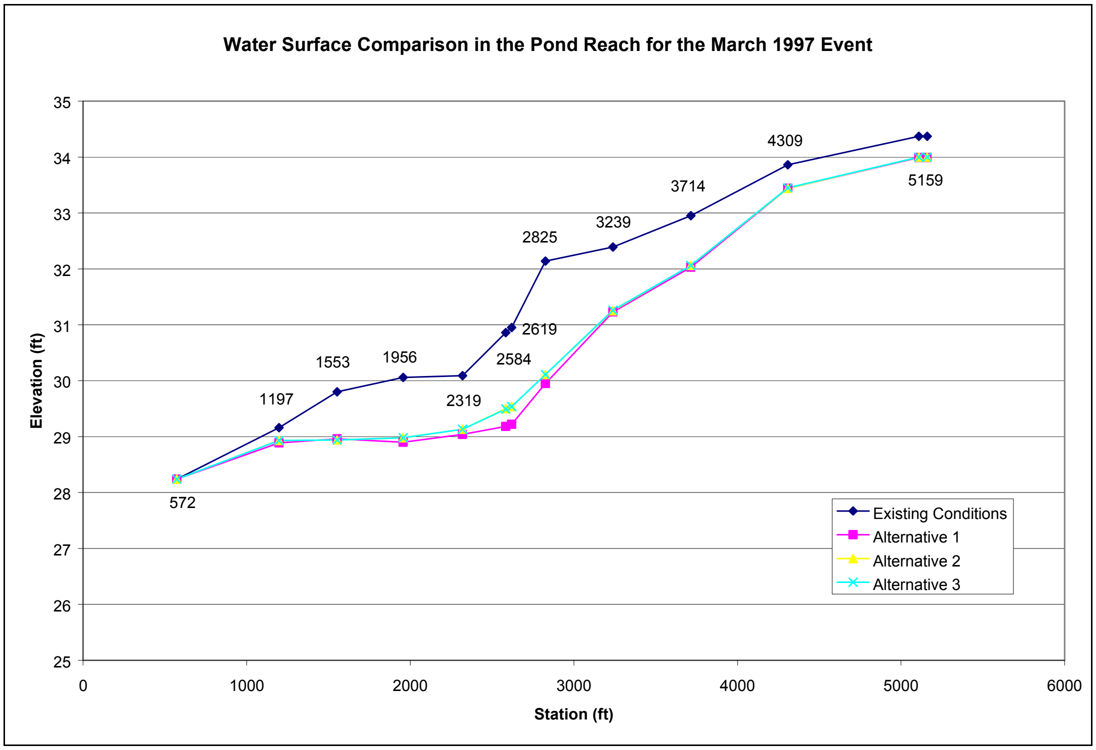



Figure 38. Pond Reach March 1997 event water surface comparison for Existing Conditions, and Alternatives 1, 2 and 3.

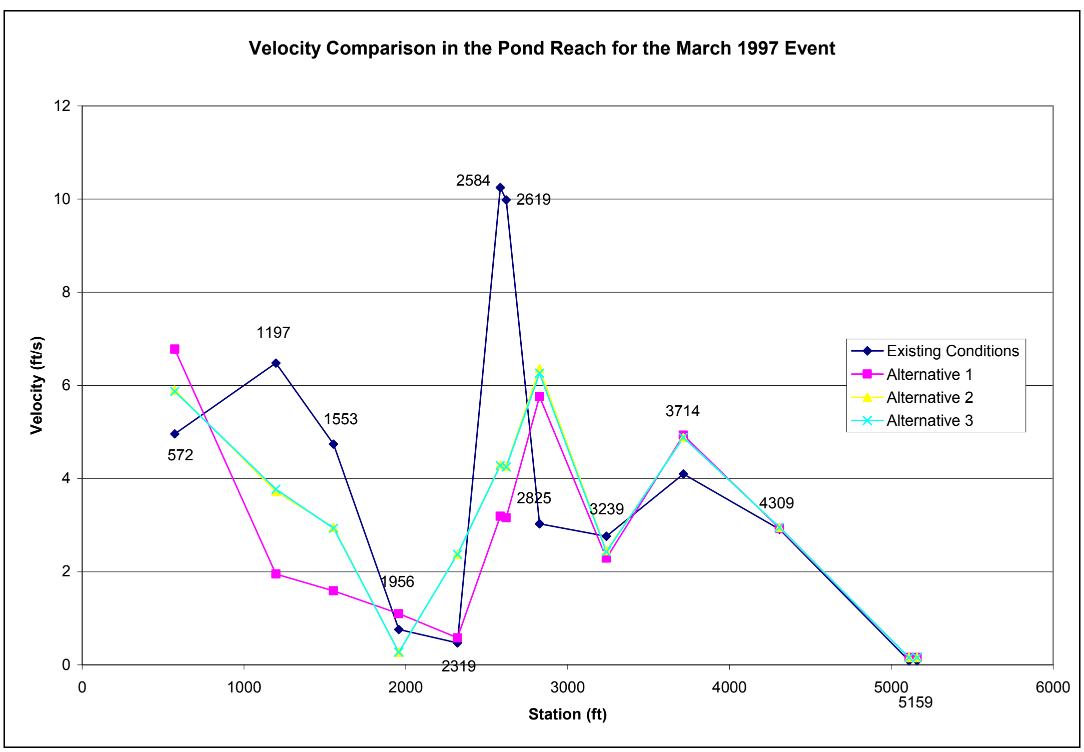



Figure 39. Pond Reach March 1997 event velocity comparison for Existing Conditions, and Alternatives 1, 2 and 3.

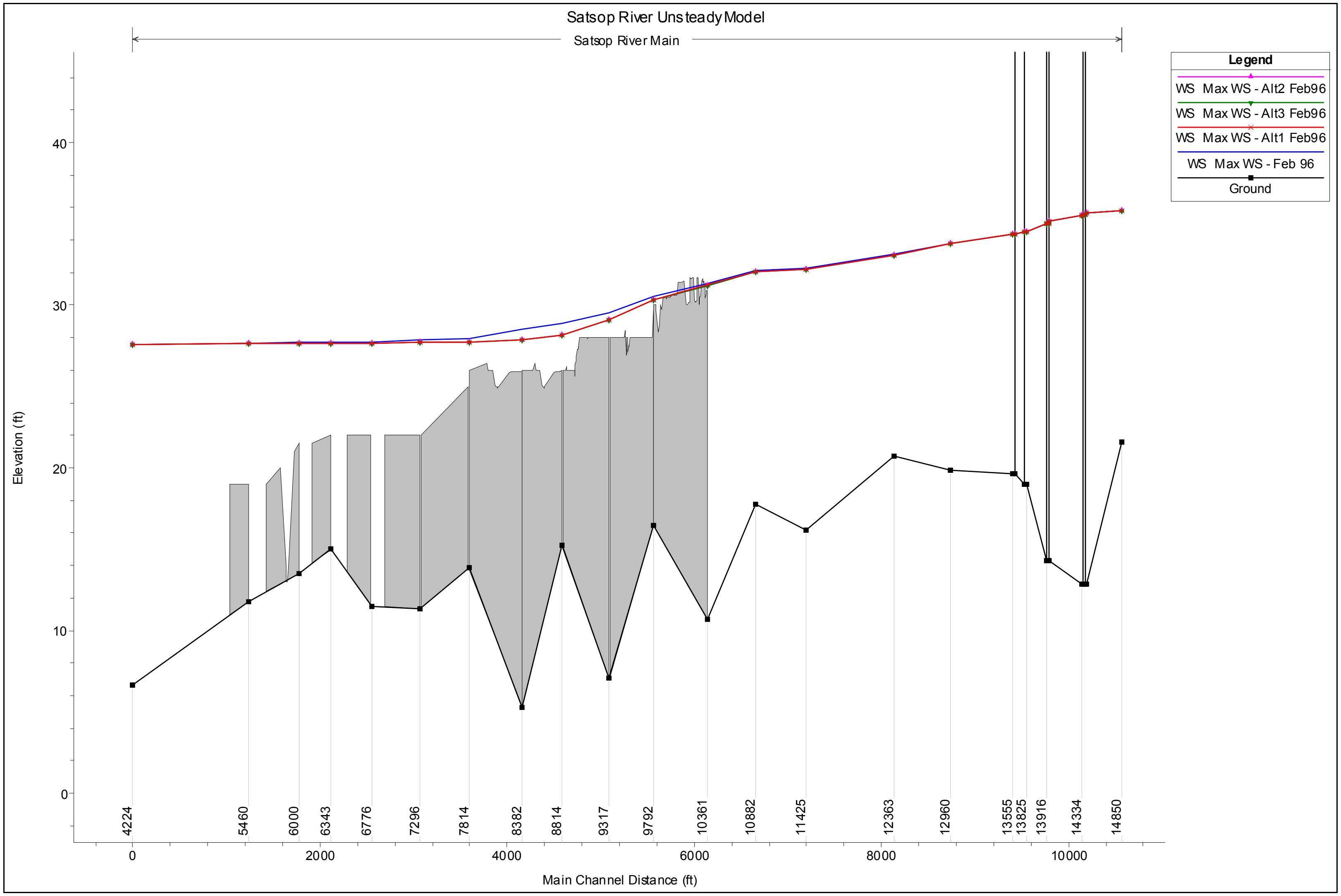


Figure 40. Satsop River February 1996 event water surface comparison for Existing Conditions, and Alternatives 1, 2 and 3.

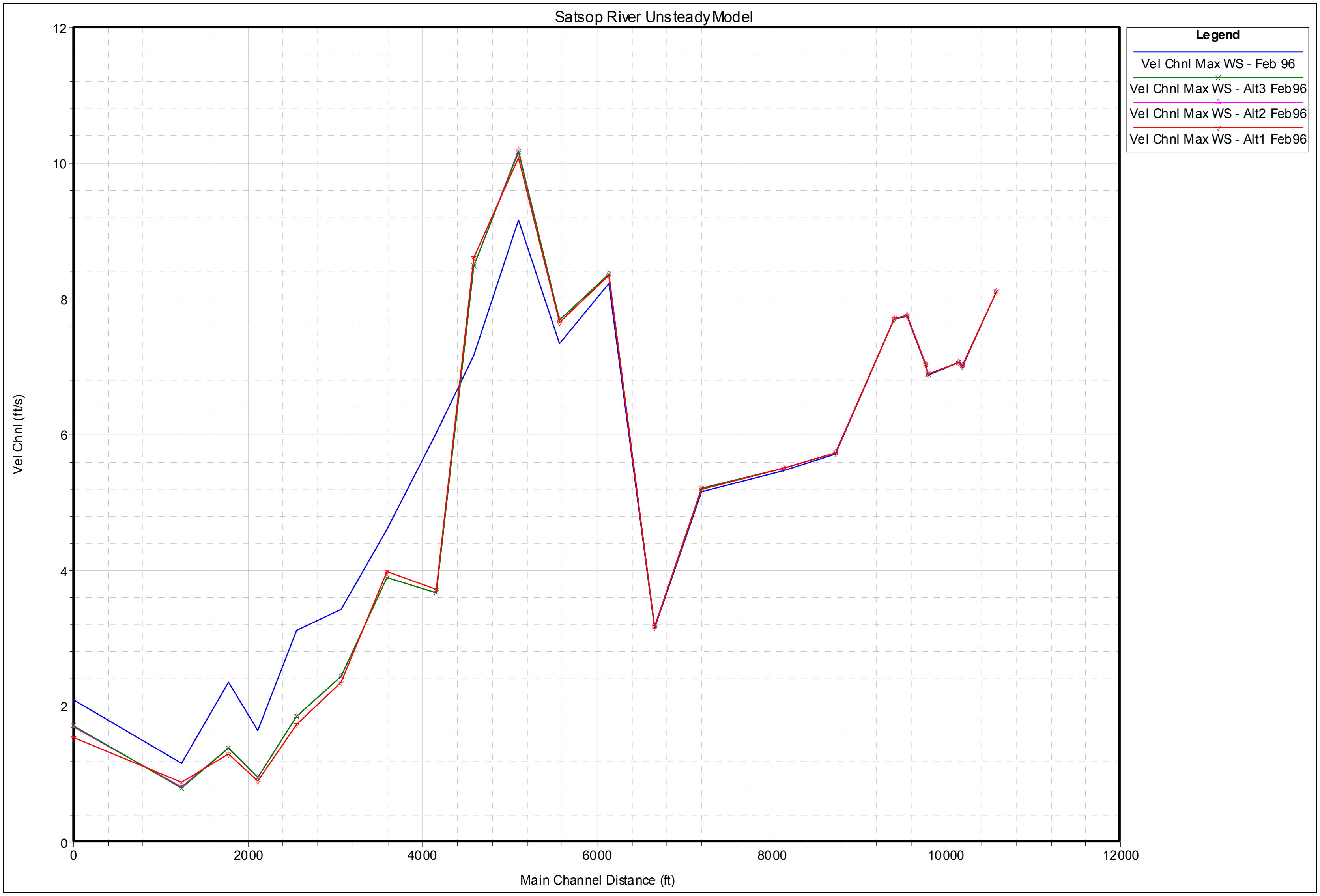



Figure 41. Satsop River February 1996 event velocity comparison for Existing Conditions, and Alternatives 1, 2 and 3.

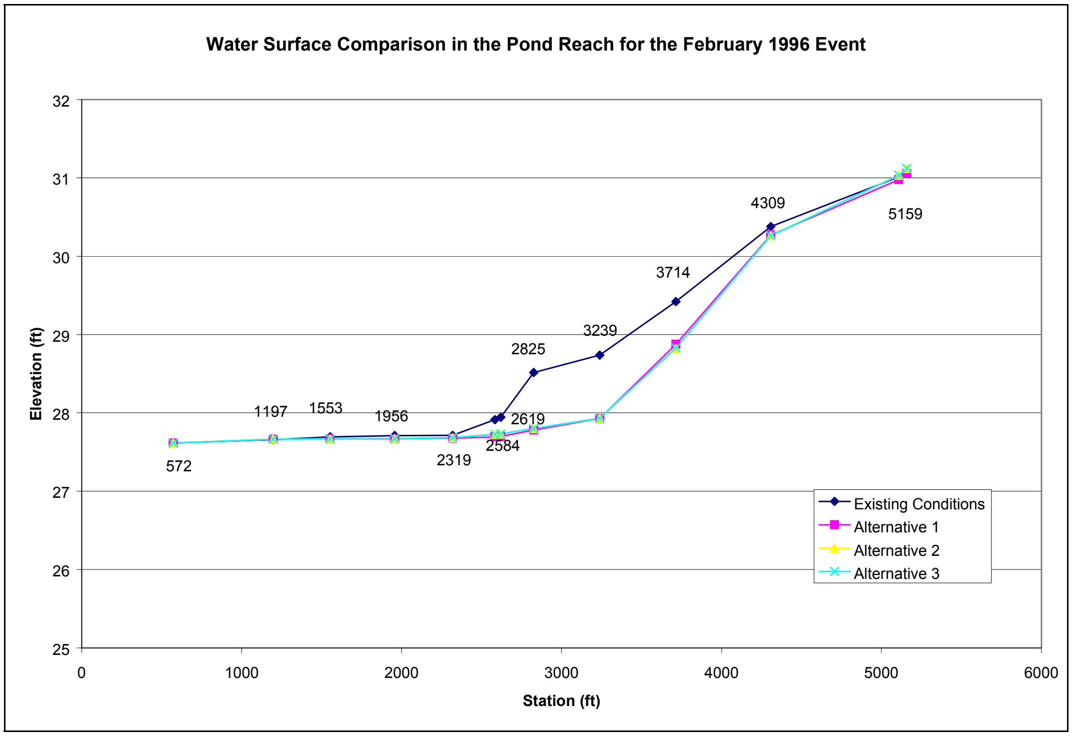



Figure 42. Pond Reach February 1996 event water surface comparison for Existing Conditions and Alternatives 1, 2 and 3.

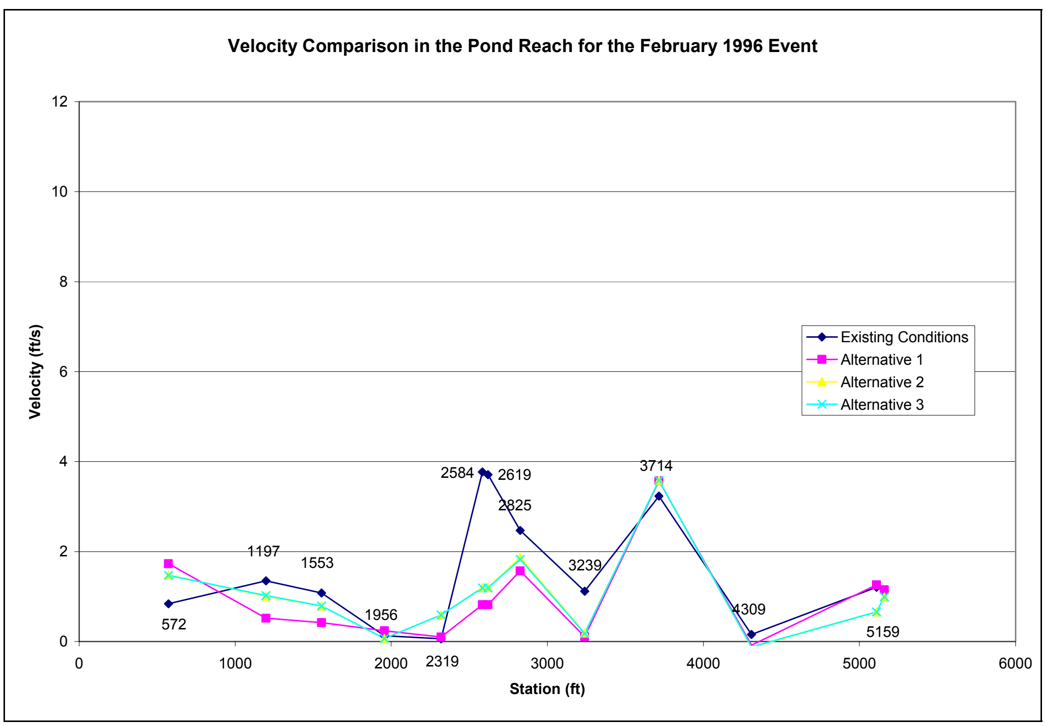



Figure 43. Pond Reach February 1996 event velocity comparison for Existing Conditions and Alternatives 1, 2 and 3.

### 4.5.2 Alternative 2

Significant conclusions of the hydraulic modeling for Alternative 2 with the March 1997 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 38).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 37).
- Due the removal of the dikes, significantly more discharge (19,700, vs 11,950 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 38).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 37).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 39).
- Flow velocities along the lower Pond Reach (Egress Channel ) increase (Figure 39).

Significant conclusions of the hydraulic modeling for Alternative 2 with the February 1996 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 40).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 41).
- Due the removal of the dikes, significantly more discharge (4,460, vs 1,860 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 42).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 41).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 43).
- Flow velocities along the lower Pond Reach (Egress Channel ) increase (Figure 43).

### 4.5.3 Alternative 3

Significant conclusions of the hydraulic modeling for Alternative 3 with the March 1997 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 36).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 37).
- Due the removal of the dikes, significantly more discharge (19,580, vs 11,950 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 38).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 37).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 39).
- Flow velocities along the lower Pond Reach (Egress Channel ) increase (Figure 39).

Significant conclusions of the hydraulic modeling for Alternative 3 with the February 1996 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 40).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 41).
- Due the removal of the dikes, significantly more discharge (4,430 vs 1,860 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 42).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 41).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 43).
- Flow velocities along the lower Pond Reach (Egress Channel ) increase (Figure 43).

## 4.6 Low Flow Conditions

An analysis of low flow hydraulic conditions was conducted to describe how proposed pond outlets might interact with the flow in the Satsop River mainstem. Stage-discharge curves for the mainstem channel were developed for locations in the vicinity of both the Alternative 2 Egress

Channel outlet and the Alternative 3 Pond A outlet channel. Water surface elevations were defined for a range of flows from 140 to 3,000 cfs. The lowest average daily flow of record is 147 cfs in 1994.

As backwater from the Chehalis River would not be expected during low flow periods, the downstream boundary condition for the hydraulic analysis low flow conditions was estimated as normal depth based on an assumed slope of 0.002, the approximate ground slope. This assumption would be expected to give a conservatively low estimate of the stage along the Satsop River. The resultant stage discharge curves for Alternative 2 and Alternative 3 are shown in Figure 44, and Figure 45, respectively.

Notably, under Alternative 2, the Pond B outlet channel is to be set at elevation 14.9 ft NGVD and the outlet of the Egress Channel (Pond Reach) is also at elevation 14.9 ft NGVD. Based on observed pond levels the low flow connection of the ponds to the Satsop River may be interrupted during summer low flow periods. As seen from Figure 44, it would take an approximate flow of 2,350 cfs to reach the 14.9 foot stage to allow the river to hydraulically connect to the Egress Channel.

For Alternative 3, the pond connection from Pond A is set at elevation 13 feet. The corresponding water surface elevation on the Satsop River in that vicinity is 13.4 feet, at 140 cfs, the lowest average daily flow of record (Figure 45). This connection, if implemented, should stay wet year round.

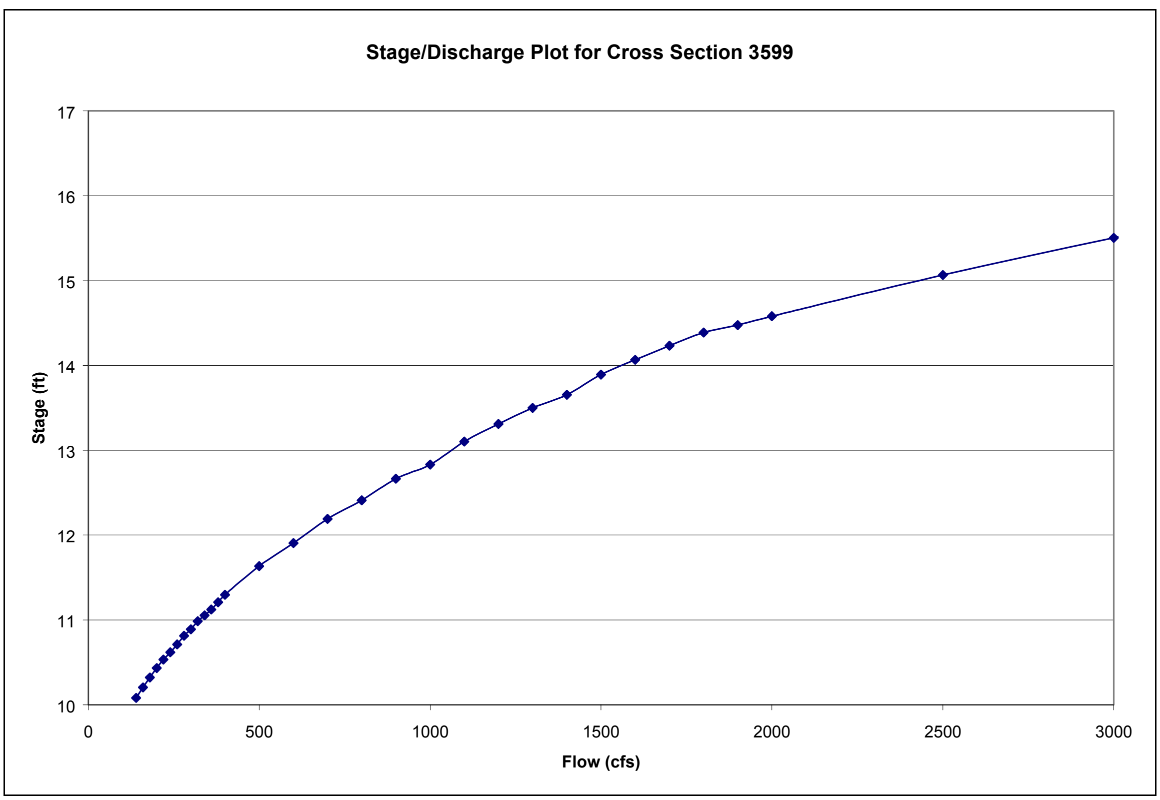



Figure 44. Stage/discharge relationship for cross section 3599 (near Egress outlet).

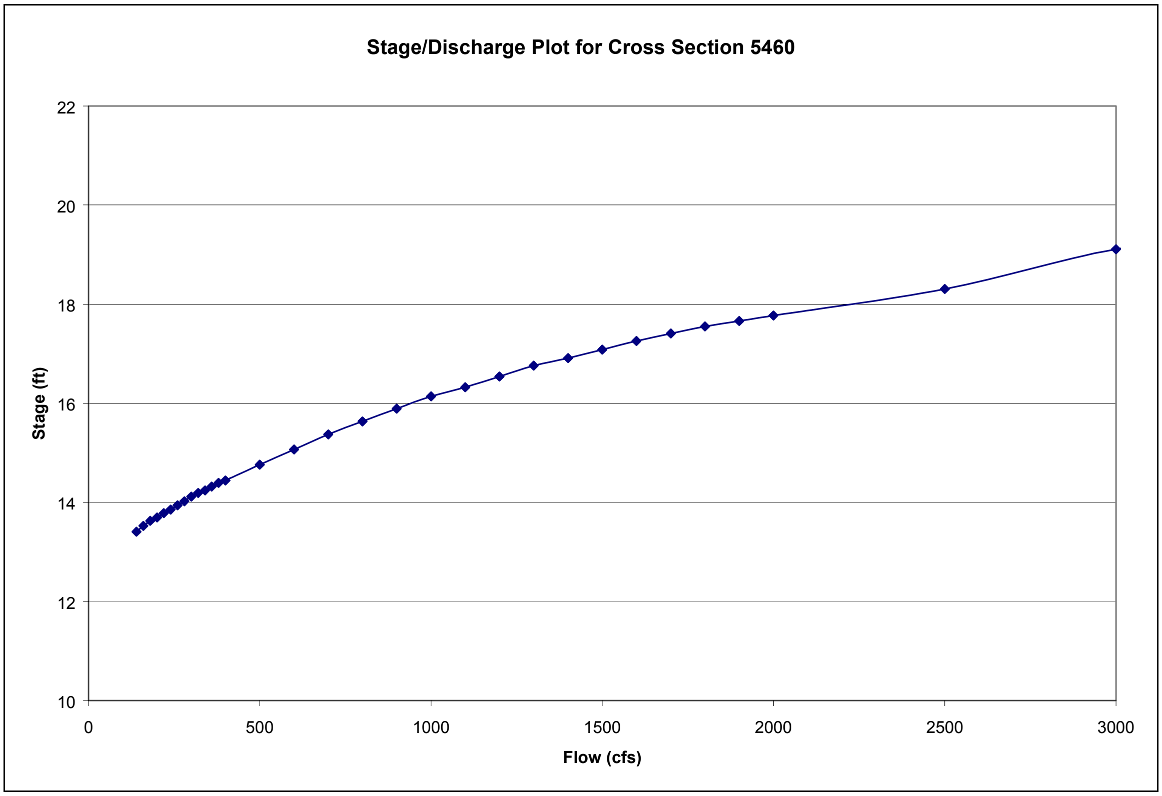



Figure 45. Stage/discharge relationship at cross section 5460 (near Pond A outlet).

## 4.7 Risk and Uncertainty

The risk and uncertainty associated with the hydraulic modeling results is dependent on the ability of the HEC-RAS model to represent the involved physical conditions, the quality of the input data, and the skill of the modeler. Throughout the course of the study, efforts were made to minimize the sources of risk and uncertainty. In the following sections each of the recognized sources of risk and uncertainty is discussed.

### 4.7.1 Representation of Physical Conditions

As discussed previously, the Lower Satsop River floodplain is quite broad and the direction and magnitude of overbank flows are subject to a number of influences including natural topography, man-made structures, and the influence of the Chehalis River. In general, the HEC-RAS hydraulic model is a proven tool that is well regarded for representing the involved issues. Both steady flow and unsteady flow capabilities of the HEC-RAS model were employed to characterize and evaluate the involved physical conditions.

The definition of the lateral limits of effective flow were set in the HEC-RAS model based on existing knowledge about the floodplain, the available topographic data for the project area, and field observations. A potential for flow splits to and from the Satsop River exists in several areas. The specific distribution of flow from the Satsop River upstream of the Montesano-Elma Road it not known and it was necessary to assume that all flow would be retained in the model.

Keys Road was also assumed as a boundary for effective flow, yet field observations show flow may escape in an eastern direction. Similarly, at flood stages, flow from the Chehalis River may potentially enter the Satsop River across Keys Road. Finally, it is possible that flow from the Satsop River escapes to the west between U.S. Highway 12 and Hiram Hall Road. The limits of available topographic data practically limit the extent of the hydraulic modeling. As a result, the magnitude of flow considered in the HEC-RAS model may be overestimated.

#### 4.7.2 Data Limitations

Overall the data available for use in conducting the hydraulic analysis is considered adequate. Recent quality topographic information for the project site and its vicinity were developed for the study. The greatest uncertainties associated with the topographic data lie in areas of dense vegetation. Of particular note is the left bank of the Satsop River along the northern half of the project site and along the Egress Channel. In both areas supplementary surveys were conducted to enhance the available topographic mapping.

Hydrologic data for the hydraulic analysis are considered very good as a long gage record for the river was available. A good understanding of the magnitude, frequency, and duration of the flows was developed. The range of hydraulic variation potentially attributed to hydrology was investigated by considering a range of flows from bankfull to the 100-year flood.

The backwater effect of the Chehalis River is a significant influence on the hydraulic conditions of the Lower Satsop River. Means of estimating the backwater effects of the Chehalis River were developed based on stage-discharge relations from an existing UNET model. Without a specific study of the Chehalis River, further characterization of those backwater conditions is not possible. In general, it is believed that reasonable assumptions were made to address the influence of the Chehalis River and model results generally match observed conditions.

#### 4.7.3 Modeling Error

To minimize risk and uncertainty associated with the application of the HEC-RAS model, only personnel with appropriate training and experience were utilized in the modeling effort. Senior engineers with extensive hydraulic modeling experience reviewed the hydraulic modeling results. Results of the hydraulic analysis were calibrated to the available observations and checked for sensitivity as appropriate.

#### 4.7.4 Hydraulic Roughness Sensitivity Analysis

An analysis of the sensitivity of hydraulic modeling results to the selected Manning's n hydraulic roughness parameter was conducted. A range of Manning's n values for the main channel of the Satsop River was evaluated for the March 1997 event. The March 1997 event was selected for use in the evaluation since it was a relatively recent large flood event on the Satsop River for which high water mark data are available and a relatively low flow condition along the Chehalis River when backwater affects from that watercourse would be least significant.

The sensitivity of the hydraulic results was assessed by running the hydraulic model successively for a range of hydraulic roughness (Manning's n) values for the main channel and overbank areas. The main channel n was varied between values of 0.030 and 0.042. Overbank roughness values were varied over a range of 0.05 to 0.150. The results of the hydraulic model were compared to observed high water mark elevation data to determine differences. The results of the analysis are shown in Figure 46. It is noted that both the USGS Gage and U.S. Highway 12 high water marks are located at the upstream boundary of the study area. A main channel n value of 0.036 was selected for use as it was judged to provide the best representation of conditions in the central portion of the study area.

The hydraulic roughness sensitivity analysis demonstrates that the results of the calibrated existing conditions model are within 0.5 ft of two observed high water mark values and 1.2 ft of a third value. Overall, the evaluation demonstrates that adjustment of hydraulic roughness alone cannot account for the differences between observed and computed water surface elevation. Examination of the topography in the right overbank reveals that a complex network of high flow channels exists in that area and is not specifically represented in the existing conditions hydraulic model. For the purpose of evaluating hydraulic conditions in and around the project site the calibrated model is believed to provide reasonable results based on the available observations.

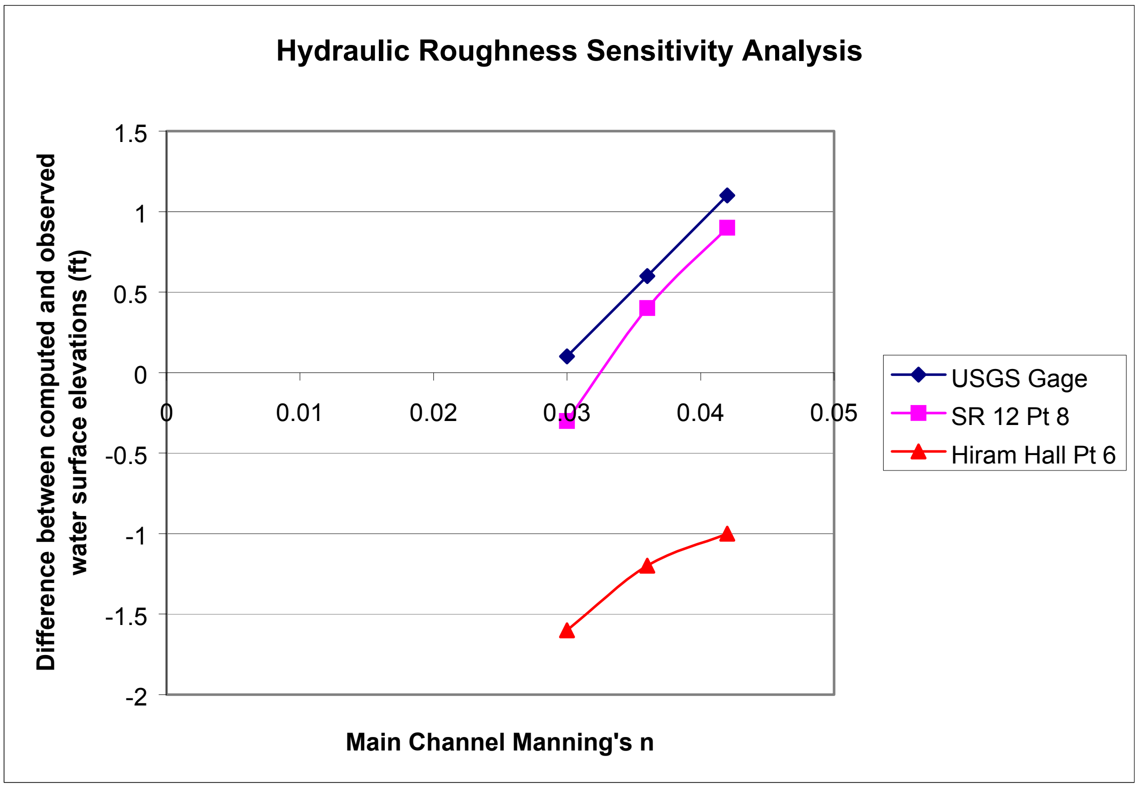



Figure 46. Hydraulic roughness sensitivity analysis results.

### 4.7.5 Overbank Flow Sensitivity Analysis

The hydraulic conditions of the project site represented by the developed hydraulic models are recognized to be dependent on the split of discharge from the mainstem channel determined by lateral weir computations. From field observation, it was recognized that uncertainty may be associated with the elevation of the ground in the vicinity of the assumed weirs due to dense vegetation. It was additionally recognized that the extent and long-term stability of riprap in that

area was uncertain.  To assess the sensitivity of the hydraulic analysis results, the characteristics of the lateral weirs were evaluated by varying the assumed weir elevations.
The elevation of the lateral structures (Nos. 9315, 8812, and 8380) was adjusted up 1 foot, and then down 1 foot, for the Alternative 2 analysis condition model.  The results of the analysis for the bankfull flood indicate that the weirs are not the dominant influence on the magnitude of flow in the Pond Reach.  The major controlling factors for overbank flow in the vicinity of the project are the obstructions created by the existing dikes on the project site and spoil piles.

Table 13 summarizes the weir sensitivity analysis.

Table 13.  Lateral weir sensitivity analysis for the bankfull flood.

| Flow Location | Existing Condition. | Alternative 2 Lateral Structures Minus 1’ | Alternative 2 Lateral Structures at Existing Elevations | Alternative 2 Lateral Structures Plus 1’ |
|---|---|---|---|---|
| Maximum Flow anywhere in Pond Reach (cfs) | 1,318 | 3,940 | 3,744 | 3,678 |
| Flow at Pond Reach outlet (cfs) | 690 | 2,430 | 2,414 | 2,383 |

# 5 GEOMORPHIC ANALYSIS PHASE ONE

A geomorphic assessment of the characteristics of the Satsop River study area was conducted. The objective of the analysis was to characterize existing geomorphic conditions, identify dominant physical processes, and describe potential geomorphic effects of the proposed alternatives. This first analysis phase is intended to assist in defining a preferred alternative based on qualitative geomorphic assessments supported by quantitative calculations. If needed, a second geomorphic analysis phase will be conducted to refine any structural designs and to increase the certainty of results.

## 5.1 Basin Characteristics

The Satsop River basin has a drainage area of about 300 square miles. In general, the basin has an elongated triangular shape that originates in the steep southern Olympic Mountains. Three major tributaries, the East Fork, Middle Fork, and West Fork form the mainstem Satsop River. The Satsop River upper reaches are much steeper than the lower Satsop. Downstream of the tributaries, the gradient of the lower 6 miles of the Satsop River channel flattens considerably but maintains a relatively constant slope of about 9 ft per mile. The reduced slope of the lower Satsop River below the tributaries results in significant sediment deposition and channel migration.

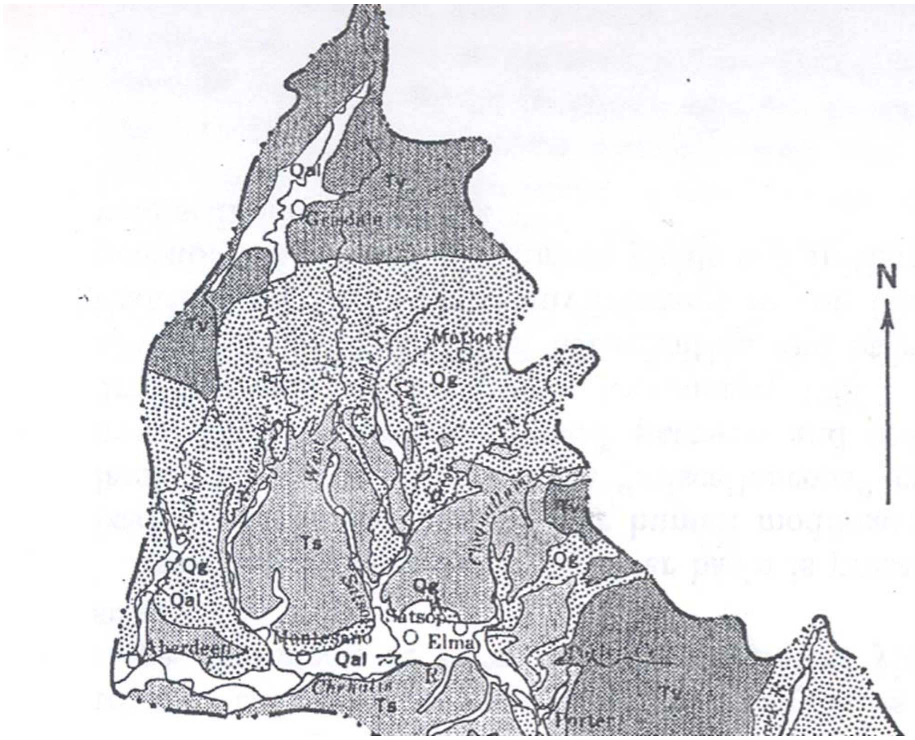
### 5.1.1 Geology

The general surficial geology in the vicinity of the Satsop River is shown in Figure 47. The headwaters of the Satsop River are located within igneous and sedimentary rock of the Olympic Mountains (USGS, 1971). The West Fork is located in extensive deposits of deeply weathered, gravelly alpine glacial outwash that enters the stream through bank erosion. Most of the East Fork and portions of the Middle and West Forks are underlain by gravelly outwash from the continental ice sheet within the Puget Lowland (Collins and Dunne, 1986). These deposits are a major source of gravel to the lower Satsop River.

### 5.1.2 Land Use

According to the USGS (1971), land use in the Satsop River watershed is 87 % woodland, 8 % Idle (rock outcrops, landslide areas, bluffs and other “agriculturally unproductive” lands), 3 % cropland, <1 % pasture, <1 % urban, and 2 % “other” (roads, gravel pits, parks and similar areas). Field reconnaissance observations indicate that current land use conditions are not significantly different from those reported by the USGS.

Instream gravel mining has historically occurred between River Miles 1 and 4 along the Satsop River (Collins and Dunne, 1986). Documented information on the rate of instream gravel mining is limited. The minimum documented rates of instream gravel extraction indicate that natural replenishment rates for gravel were not exceeded except for the period between 1978 and 1982. Unofficial estimates indicate that instream gravel extraction volumes exceeded natural replenishment rates beginning in the 1960s.




SURFICIAL DEPOSITS

*Holocene*

| Qal |
|---|

Alluvium

*Unconsolidated deposits of silt, sand and gravel with some clay; include low-level terrace, marsh, and peat deposits, artificial fill, and some localized glacial and landslide deposits. Easily eroded and in close contact with drainage channels.*

*Pleistocene*

| Qg | Qc |
|---|---|

Unconsolidated glacial and marine terrace deposits and consolidated surficial deposits

Qg, *chiefly unconsolidated to partly consolidated glacial deposits, including fluvial and glaciofluvial sand and gravel, silt and clay, till and outwash. Includes some alluvium. May include marine terrace deposits in the lower Wynoochee and Satsop River drainages possibly as old as late Pliocene. Generally easily eroded except till deposits. In contact with stream channels in many places.*

Qc, *cemented heterogenous mixture of volcanic gravel, sand, silt, and clay; contains some till. Deeply weathered locally. Erodibility varies depending on degree of cementation and weathering.*

QUATERNAR

*Eocene to Pliocene*

BEDROCK

| Ts | Tv |
|---|---|

Marine and nonmarine sedimentary rocks, and volcanic
Rocks with associated sedimentary interbeds.

Ts, *marine and nonmarine sedimentary bedrock consisting of conglomeratic sand, and also silt and clay-size particles. Unit ranges widely in composition and degree of induration.*

Tv, *chiefly extrusive rocks and associated sedimentary interbeds of wide composition and textural range. Contains a few small intrusive bodies. Unit ranges widely in degree of weathering and Erodibility.*

TERTIARY

Figure 47. Surficial geology of the Satsop River basin (USGS, 1971).

## 5.2 Channel Characteristics

The lower Satsop River has a meandering alluvial channel. Historically, extensive channel migration has occurred. In various locations, human developments have created impediments to natural migration processes. The developments include road and bridges, riprap, and dikes. In the following sections the existing characteristics of the Lower Satsop River channel are described based on a variety of collected data.

### 5.2.1 Bank Erosion

The extent of existing bank erosion along the Lower Satsop River was delineated. Eroding banks were defined as channel banks with no vegetative cover. Typically, the eroding banks were found to be located along the outside of channel bends and nearly vertical. The limits of eroding banks were delineated by use of Geographic Positioning System (GPS) equipment. The total distance of bank erosion measured along both the left and right banks in the 14,600 ft long study reach was 9,800 ft. The delineated bank erosion locations are shown in Figure 48. As shown in the figure no significant bank erosion was observed between cross sections PR16 to PR22. It is noted that the left bank is revetted with riprap through this reach. Images of the observed bank erosion are shown Photograph Nos. 16,17, 20, 26, 29, 37, 42, 46, 51, 58, 59, and 67 in Appendix 2.

### 5.2.2 Woody Debris

Large woody debris plays a key role in the morphology of typical west-side Pacific Northwest rivers. Large woody debris can play a key role in main channel/side channel switching dynamics, bar formation, and migration processes. Significant quantities of large woody debris were observed throughout the study area. Typically, the woody debris was found to be collected along the outside bends of the river. The apex of bars and chute cutoffs of meanders were also observed to collect large woody debris piles.

To evaluate the characteristics of the woody debris, a survey of the debris was conducted. In general, the location and approximate diameter of each piece of woody debris along the lower Satsop River equal to or larger than 12 inches in minimum diameter was recorded with a GPS, although some of the collected GPS points are associated with several pieces of woody debris. The diameter of each debris piece was estimated at a distance approximately 5 feet from the rootwad.

A total of 357 individual pieces of woody debris were counted. Counting individual pieces in the larger logjams was not practical. The locations of the observed woody debris and log jams are shown in Figure 49. As shown in the figure, a lower density of woody debris is apparent in the riprap reach between cross sections PR16 to PR22. Images of the observed woody debris are seen in Photograph Nos. 3, 12, 13, 14, 15, 20, 23, 39, 40, 50, 61, 65, and 68 in Appendix A.

Most of the woody debris consisting of a single piece or a group of a few pieces was found to have the rootwad attached. In larger debris piles, a majority of the debris pieces did not have the rootwad attached. A histogram of the surveyed woody debris sizes is shown in Figure 50. The single largest piece of woody debris was observed to be approximately 6 ft in diameter. The majority of woody debris was 1 to 2 ft in diameter.

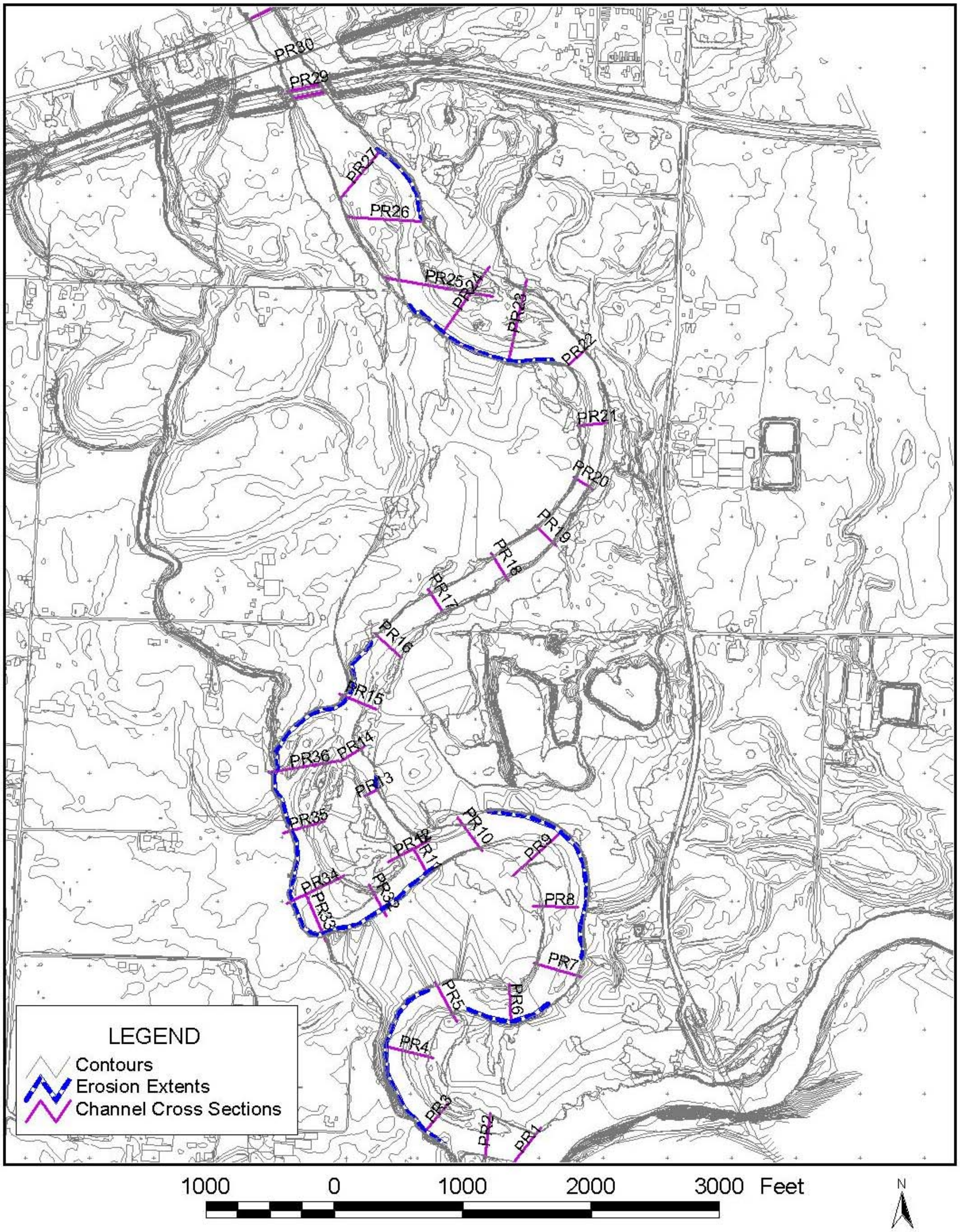



Figure 48. Locations of existing bank erosion.

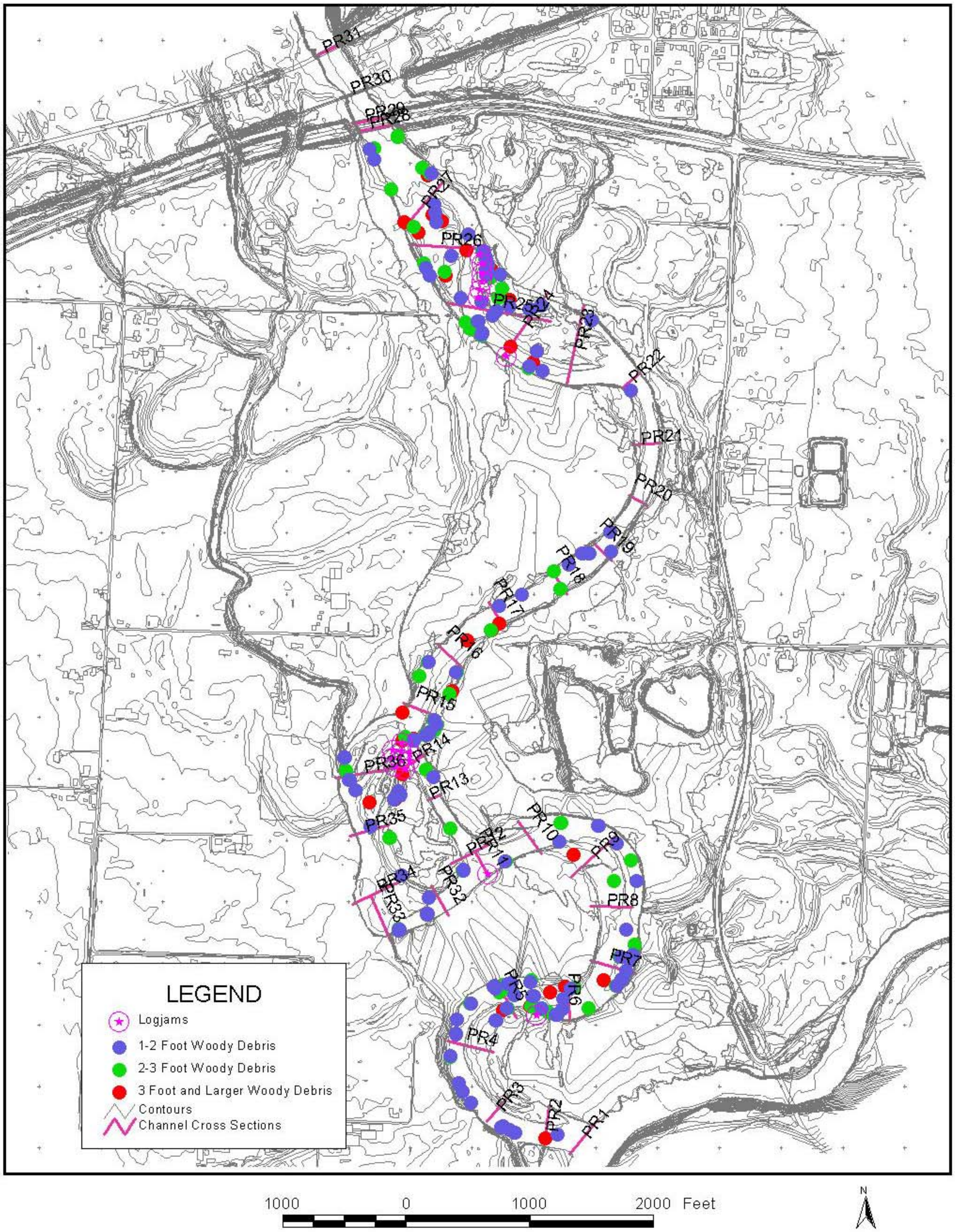



Figure 49. Locations of surveyed woody debris.

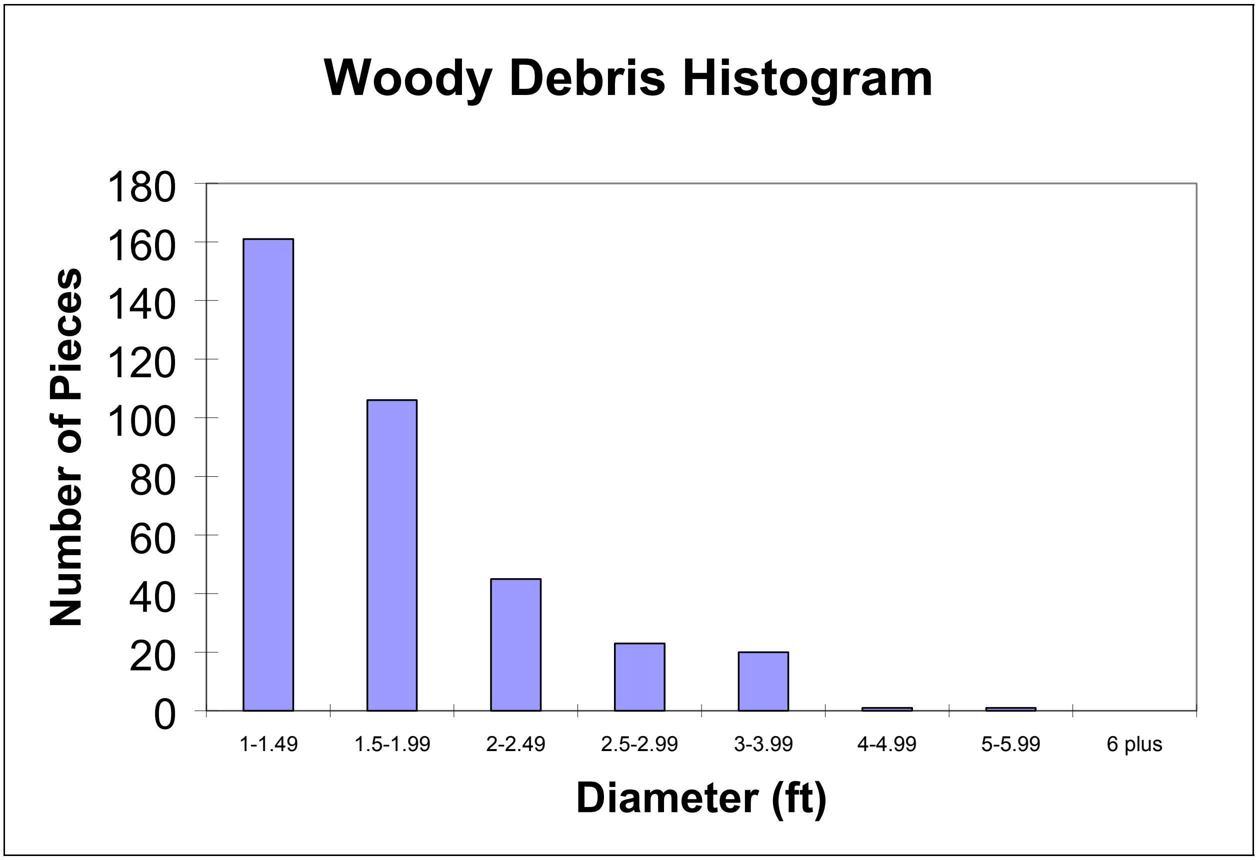



Figure 50.  Histogram of observed woody debris sizes (does not include logjams).

### 5.2.3 Bankfull Delineation

The bankfull width of the Satsop River channel was estimated at several locations through the study area.  Where bankfull indicators were apparent, GPS points were set to define the location. Bankfull indicators considered in the delineation included topographic breaks in channel geometry and vegetation characteristics.  The identified bankfull delineation locations are shown in Figure 51.

Results of the effort were found to vary widely,  estimates of bankfull width range from about 200 to 600 feet.  A plot of the estimated bankfull channel widths is shown in Figure 52.    The bankfull widths are seen to be highest along the portions of the river with multiple channels and unconfined by bank erosion protection measures.  The variability of bankfull width estimates is attributed to difficulties in defining banfull width in the vicinity of multiple channels.

For comparison, regional hydraulic geometry relations (Castro and Jackson, 2001) were used to estimate bankfull width (310 ft) and depth (12 ft).   The discrepancy between the results of field observations and the estimates derived from regional relations is attributed to the extensive bank erosion and channel migration characteristics of the study area.  Hydraulic modeling results for the estimated bankfull discharge (17,000 cfs) derived from regional relations are also shown on Figure 52 and are seen to closely match field estimates of bankfull width.

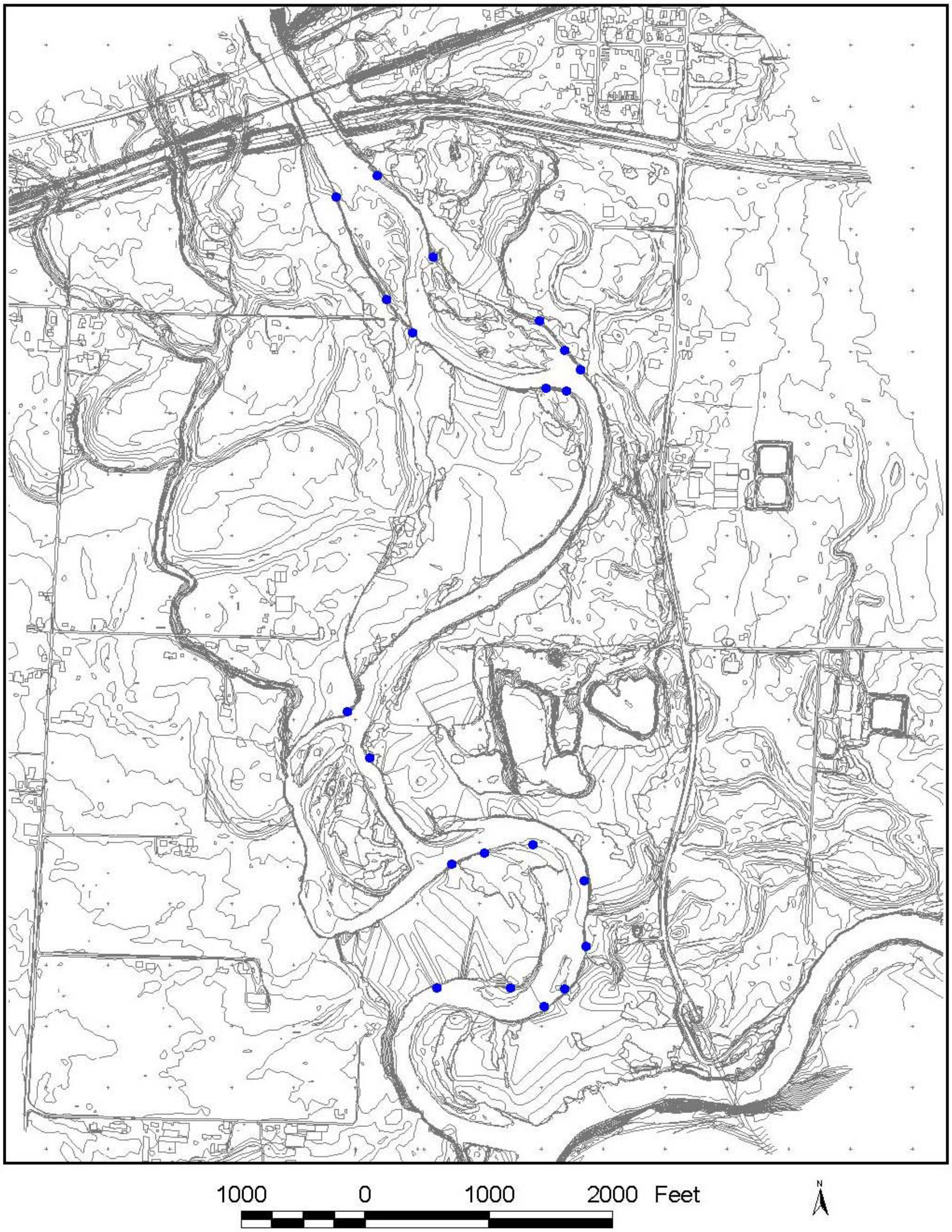



Figure 51. Locations of identified bankfull indicators.

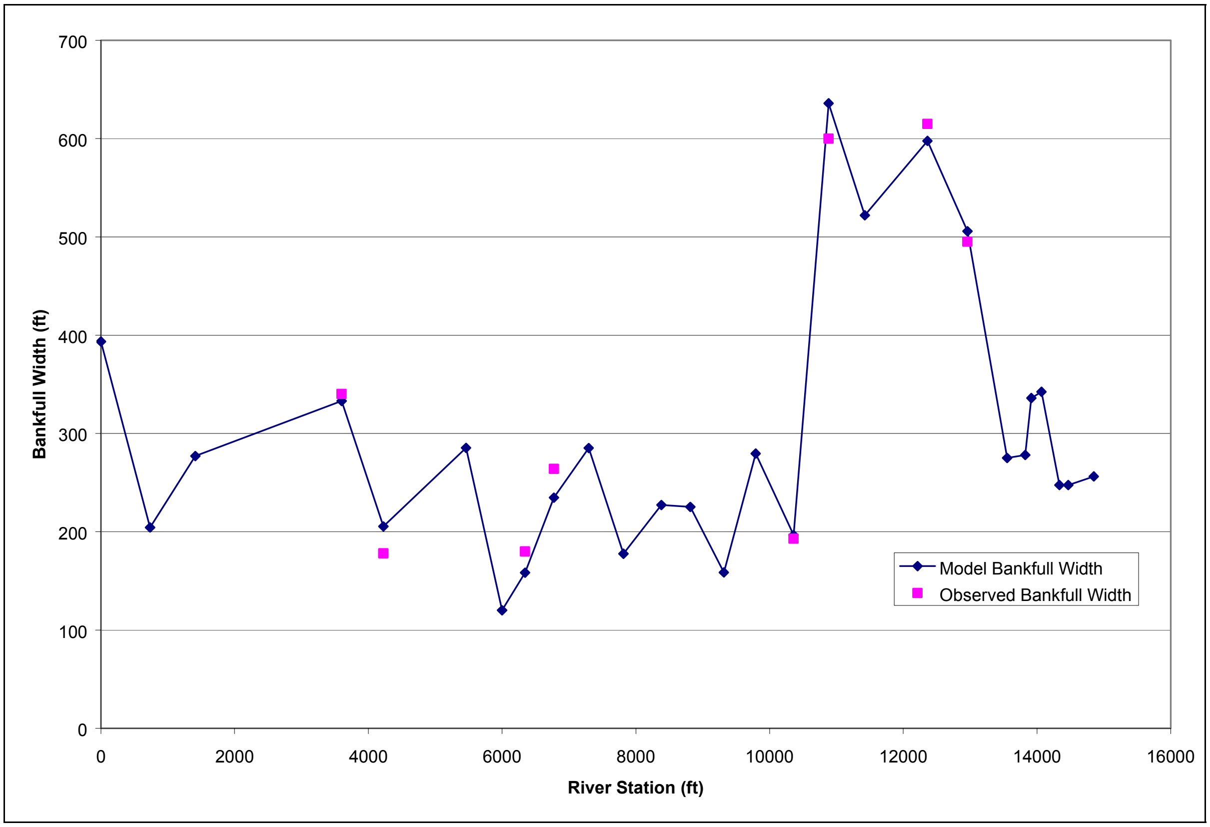



Figure 52. Bankfull width estimates.

### 5.2.4 Pools and Riffles

Several measurements were taken to characterize the general attributes of pools and riffles along the Satsop River. The measurements taken do not provide a complete survey of all pools and riffles along the lower Satsop River. Depth measurements were taken by sounding the pool with a survey rod. Pool depth measurements were taken at four locations. The measured pool depths ranged from 8.5 to 11.0 feet, with an average of 9.9 feet.

### 5.2.5 Riprap

The extent of bank erosion protection was surveyed to identify the type and locations of revetment. Riprap was found to be present along about 3,000 ft of the left bank, a significant portion of the lower Satsop River. This includes the left bank of the river along the northern portion of the project site. About 200 ft of riprap was observed along the right bank of the river. Figure 53 shows the approximate location of observed riprap coverage. The extent of the riprap coverage was observed to vary with location, with few areas having full coverage of the bank. In most areas along the left bank, the riprap was seen to protect the toe of the bank and the upper bank was vegetated by small diameter trees. Notably, in several areas along the left bank adjacent to the project site, the riprap coverage had failed.

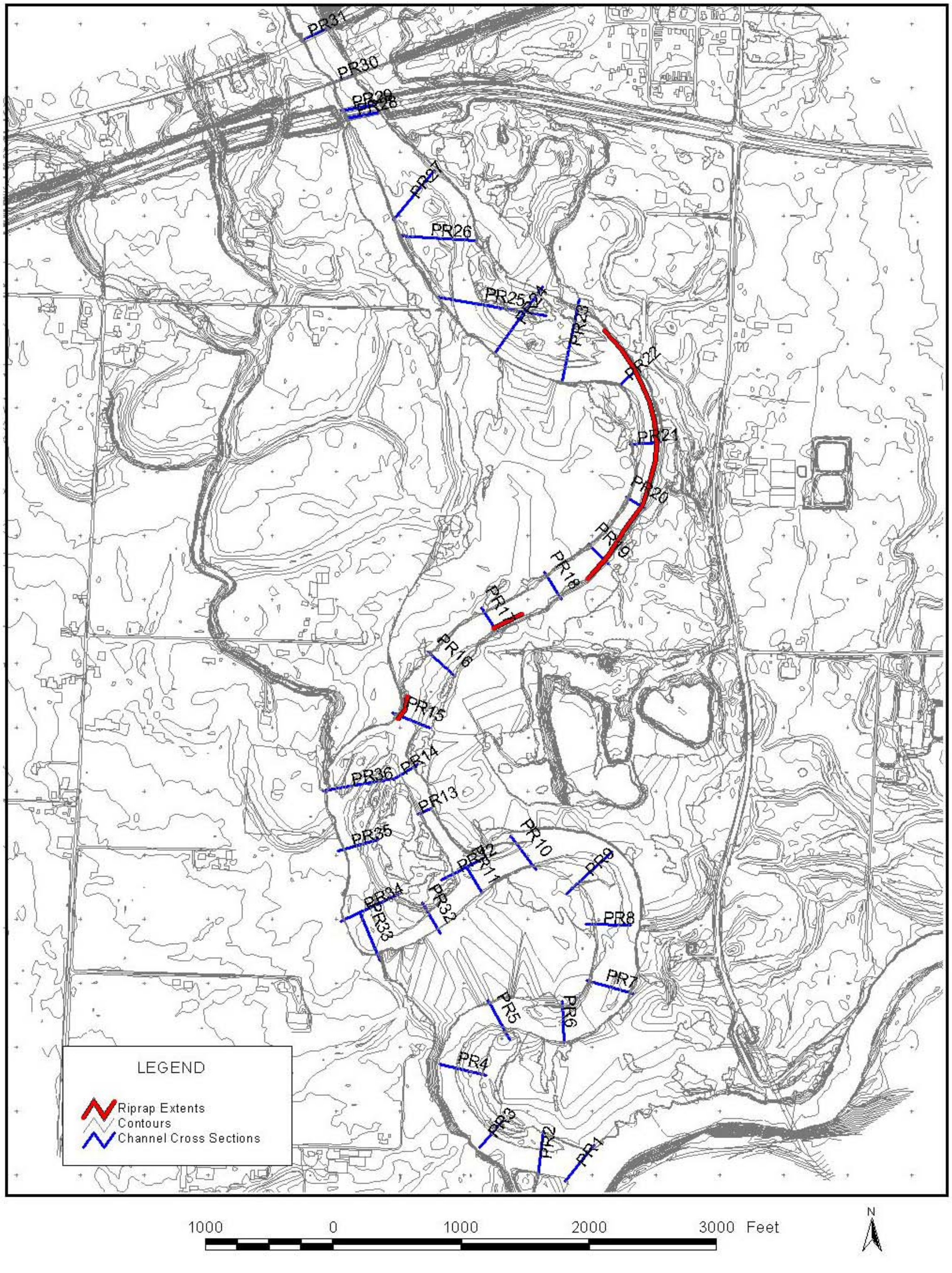



Figure 53. Locations of existing riprap bank protection.

## 5.3 Channel Profile Analysis

An analysis of the profile of the Lower Satsop River was conducted to identify characteristic slopes of the mainstem channel and a side channel through the project site (the Egress Channel). One set of channel profile elevation data exists. It was developed as part of channel cross-section surveys conducted for the current study.

The profile of the mainstem channel thalweg is shown in Figure 54. The overall gradient of the nearly 15,000 ft long lower Satsop River channel is about 0.0015 or 7.7 feet/mile. Also shown on the figure are sub-reaches of similar slope through the study area. In general, three distinct reaches (Upstream Reach, Riprap Reach, and Downstream Reach) with similar slope characteristics can be identified.

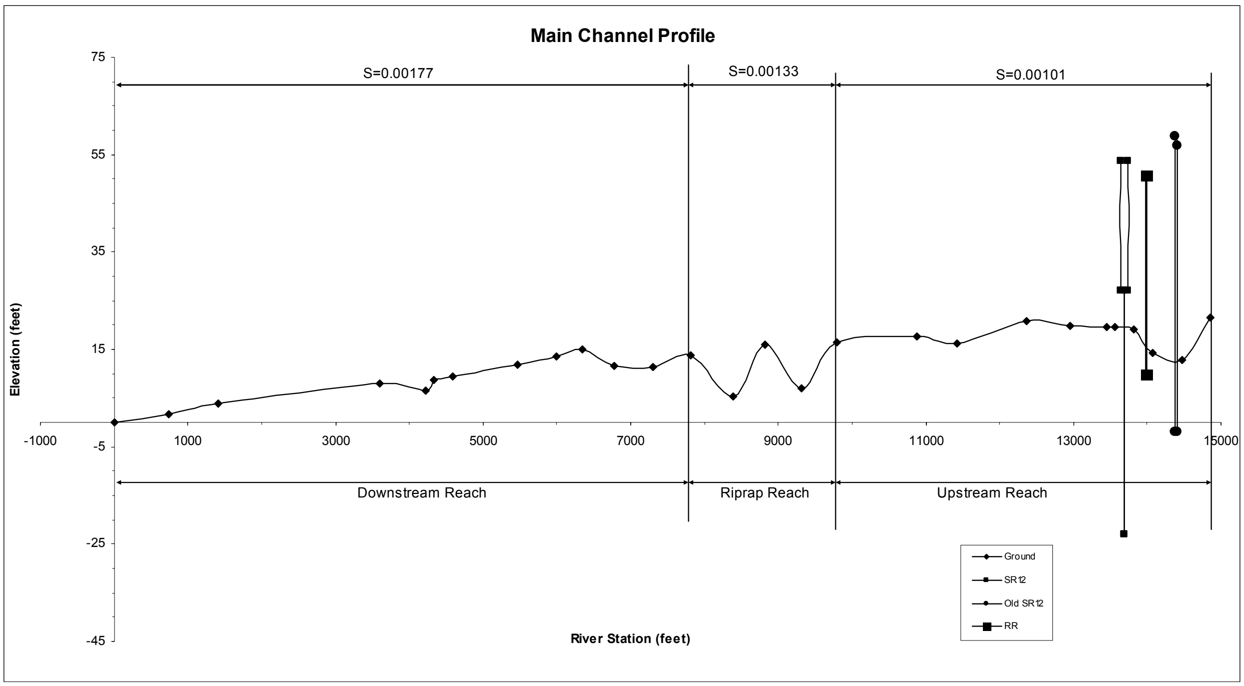



Figure 54. Main channel thalweg profile.

The Upstream Reach extends from about the upstream limit of the study area to the approximate upstream extent of the proposed project. The slope of this reach is approximately 0.001. The influence of scour associated with the existing highway and railroad bridges near the upstream limit of the reach is apparent in the profile. Downstream of the bridges the channel widens significantly and several large alternating bars exist.

The Riprap Reach extends from the large meander upstream of the project site to a point downstream of the riprap along the left bank adjacent to the project site. The channel in this reach also has a slope of approximately 0.001. The bankfull width of the channel in this reach is approximately 200 feet and significantly narrower then the bankfull width observed in the Upstream or Downstream Reaches. Notably, the profile in this reach displays vertical variability of about 10 ft that is consistent with field measurements of pools.

The Downstream Reach extends to the confluence with the Chehalis River. The main channel in this reach has an existing slope of about 0.0018, which is somewhat steeper and more sinuous than either upstream reach. It is an area of extensive historic channel migration, secondary channels and avulsion. It is noted that a significant side channel exists along the right bank of this reach that formed due to the movement of the main channel. If the flow path of the side channel is considered the overall slope of the Downstream Reach is about 0.0014, which is more similar to the other reaches. The hydraulic and sediment transport conditions of this reach are also influenced by the backwater conditions of the Chehalis River. It is noted that the Mean High High Water (MHHW) elevation at the Aberdeen Tidal Gage is elevation 4.93 ft NGVD (NOAA, 2003), which indicates a diurnal tidal influence on the Downstream Reach.

## 5.4 Channel Length Analysis

Over the last 60 years, the lower Satsop River channel length has ranged from 11,421 feet to 15,366 feet. Table 14 lists historic channel lengths. Changes to channel length have occurred due to channel migration, chute cutoffs of meanders and avulsions. The data suggests a 50-year cycle of creating and cutting off bends. This cycle is illustrated graphically in Figure 55. As shown on Figure 56, the study area contains two reaches of river that are free to meander. They are the Upstream Reach, from the bridges to the riprap revetment, and the Downstream Reach, from the riprap revetment to the confluence of the Chehalis River. Of these reaches, the Upstream Reach has had little movement, even before the placement of the riprap adjacent to the project site, until 1997. Since then, two short bends (A and B) have formed (Figure 57). The lower reach maintains three bends (Bend One, Bend Two, and Bend Three) that amplified in length from 1941 to 1951 and then again from 1977 to 1997. The bends cut off between 1953 and 1962.

The river's length appears to be in a state of decline. Between 1997 and 2003, Bend One cutoff, while the downstream two bends (Bend Two and Bend Three) continued to amplify in length, but decreasing the overall length of the channel. A summary of the noted historic channel changes in the study area is presented in Table 15.

Based on the historic record it is expected that Bend Two, Bend Three, A and B will increase in length. Eventually, Bend Three will cut off, followed by Bend Two. The significant bend within the Riprap Reach has remained relatively static for a period of over 40 years due to the erosion control measures along that reach. If the riprap is removed, movement of the bend is expected and could be expected to impact the project site. If the Riprap Reach remains static, Bends A and B are expected to maintain their sinuosity and perhaps transpose in a downstream direction.

Table 14. Historic Satsop River Channel Lengths

| **Historic Satsop Channel Lengths (from Old SR 12 Bridge to confluence)** | |
|---|---|
| Year | Length (ft) |
| 1941 | 13,011 |
| 1951 | 14,659 |
| 1953 | 14,854 |
| 1962 | 11,758 |
| 1967 | 12,170 |
| 1972 | 12,151 |
| 1977 | 11,421 |
| 1981 | 11,633 |
| 1985 | 11,521 |
| 1990 | 12,863 |
| 1997 | 15,366 |
| 2003 | 14,467 |

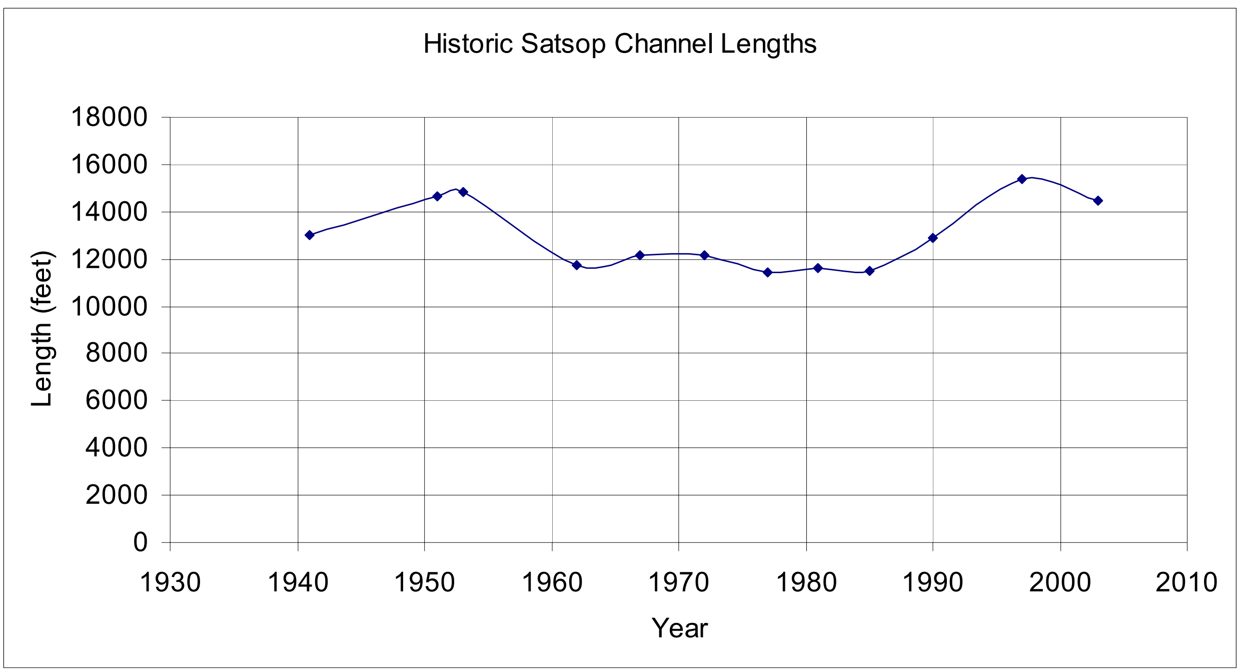



Figure 55. Historic Satsop River main channel lengths.

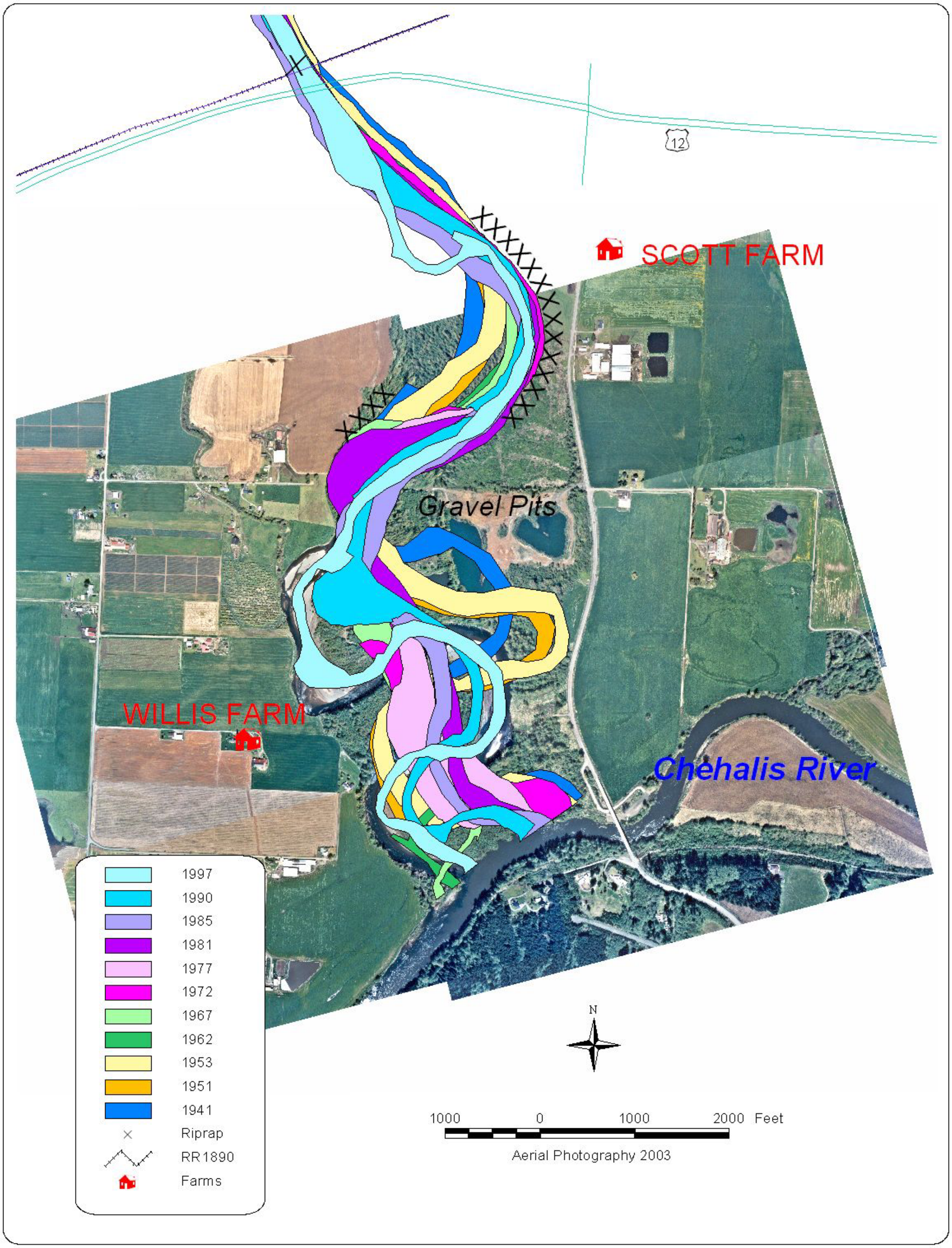



Figure 56. Historical channel locations in the vicinity of the project.

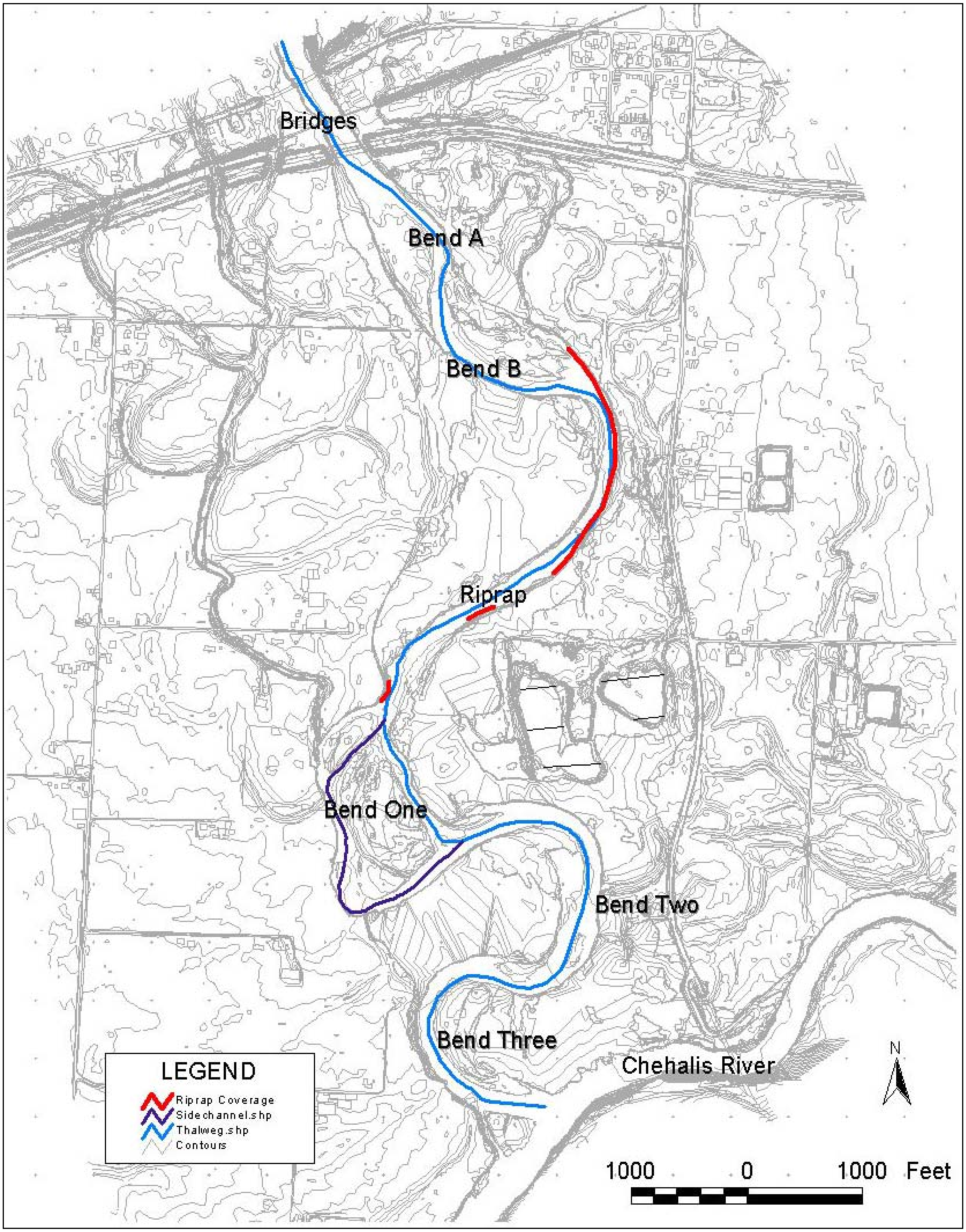



Figure 57. Bend locations along the Satsop River.

Table 15. Historic channel changes in the Satsop River study area.

| Physical Change | | | |
|---|---|---|---|
| Year | Upstream Reach | Downstream Reach | Overall result |
| 1941-1951 | None | All bends amplify | Channel Length Increases |
| 1951-1953 | None | All bends amplify | Channel Length Increases |
| 1953-1962 | None | All Bends cutoff | Channel Length Decreases |
| 1962-1967 | None | Development of third bend and minor second bend | Channel Length Increases |
| 1967-1972 | None | Second and third bend transpose through plain. | Channel Length Unchanged |
| 1972-1977 | None | River straightens through bends two and three, develops bend one | Channel Length Decreases |
| 1977-1981 | None | Bends two and three redevelop with 1972 positioning | Channel Length Increases |
| 1981-1985 | None | Bend one cuts off, bends two and three amplify | Channel Length Decreases |
| 1985-1990 | None | All bends amplify | Channel Length Increases |
| 1990-1997 | Bend B develops just above revetment | Bends one, two, and three amplify | Channel Length Increases |
| 1997-2003 | Bend A develops, B amplifies | Bend one cuts off, bends two and three amplify | Channel Length Decreases |

## 5.5 Channel Migration Analysis

The Satsop River within the study area is an actively meandering river that has been influenced by the placement of riprap along the left bank along the northern portion of the project site. The Seattle District prepared a channel migration study of the Satsop River (COE, 2002), a meander risk analysis (COE, 2003c), and a future conditions assessment (2004). Conclusions of the COE studies included:

- Human influences such as bridges and the rock revetment have effectively prevented channel migration in the vicinity of the project site.
- The historic average annual channel migration rate is 9 ft/yr.
- Historically, avulsion has occurred frequently in the lower portion of the study area.

The historic channel locations identified by the COE study area were overlaid onto 2003 aerial photography as shown in Figure 56. The locations and rates of migration between 1997 and 2003 are seen to be consistent with the historic record. Continued bend amplification and cutoffs can be expected.

Figure 56 illustrates that the river bend in the upstream reach of the project area migrated steadily between 1941 and 1977. Riprap was placed along the left bank of this bend around 1972 and effectively stabilized the bank location. A review of aerial photographs indicate that the 1972 channel shown in Figure 56 is probably located too far to the east and the 1977 channel better represents the bend's meander limit and the riprap location. The river channel continues to be much more active and irregular downstream of the riprap stabilized bend.

The bend along the northern portion of the project site migrated steadily eastward between 1941 and the placement of riprap around 1972. During this 31 year time period, the outside of the bend moved east 550 to 600 feet. This is an average rate of migration of about 18 to 19 ft/year. The entrance to the bend also migrated downstream about 1,000 ft. Since 1972, the bend has been stable and the large point bar on the inside of the bend has been covered with dense vegetation. The existing channel in this area is about 150 feet in width, which is about 25 percent narrower than earlier channels.

The consistency of the bend migration noted between 1941 and 1972 is attributed to the stability of the upstream channel that existed downstream of the U.S.Highway 12 bridges. However, between 1990 and 1997, the approach to the bend along the northern portion of the project site altered. At this time, it is unclear how future conditions of channel migration will influence the riprap reach. However, based on past history, if the riprap along the project site were removed, it is considered likely that the river would continue to migrate eastward at a rate of 18 to 19 ft /year. The river could be expected to encroach on Keys Road in 20 to 30 years, depending on the specific direction of movement. Due to the control provided by upstream bridges, it is considered likely that the direction would be to the southeast as it was prior to 1972. Consequently, the river has a potential to capture the existing gravel ponds.

The riprap reach has been stable, although 2003 field assessments show that portions of the riprap are failing. With no action, the riprap reach can be expected to continue to direct pressure to the west on the right bank of the downstream bend. The river bends below the riprap reach have migrated in a sinuous pattern at a rate of about 40 to 45 feet per year over the 20 years between 1977 and 1997. Between 1997 and 2003, similar erosion rates were noted.

As shown in Figure 58, the COE study also estimated expected future meander limits based on the assumption that the rates and types of migration of the past will be the same in the future. The "Ultimate Unmitigated Channel" meander limits were determined from historic meander belt width, measured bend amplitudes, and potential avulsion sites for each reach. The boundaries for the "Ultimate Mitigated Channel" meander limits were set by constraining the "Ultimate Unmitigated Channel" boundaries to the existing configuration of roads, bridges, and revetments. The project area is seen to be completely encompassed within the "Ultimate Unmitigated Channel" meander limits and partially within the limits of the "Ultimate Mitigated Channel" meander limits.

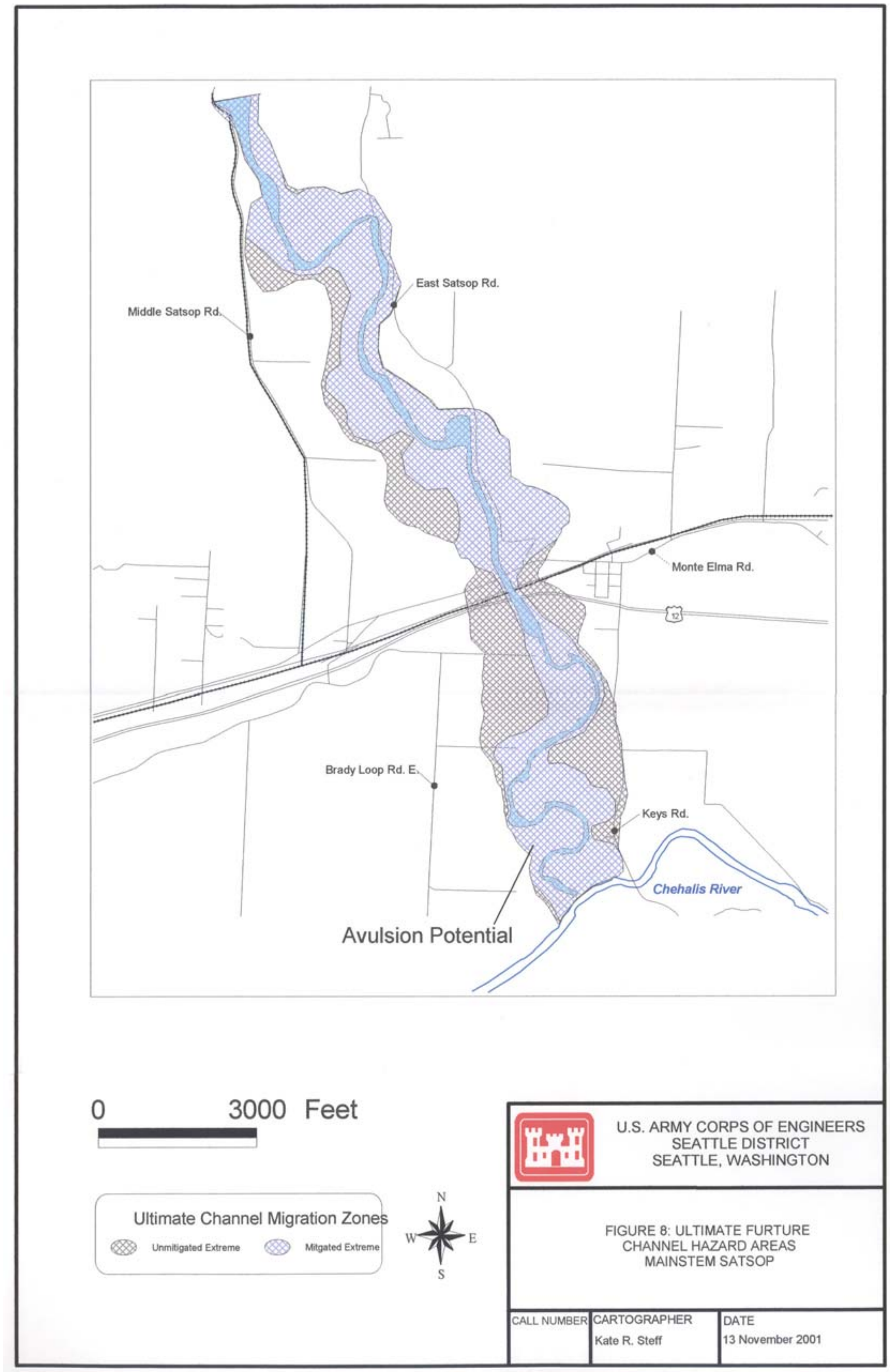



Figure 58. Channel migration hazard areas.

## 5.6 Sediment Characteristics

Sediment samples in the project area were collected to determine the size characteristics of channel bed material, channel bank material, dike materials, and on-site stockpiled soil. Each sampling location was documented by use of Geographic Positioning System (GPS) equipment. The specific sediment sampling locations are shown on Figure 59. Cascade Testing Laboratory, Inc., an accredited laboratory, sieved the collected sediment samples. The resultant size distribution curves are presented in Appendix B.

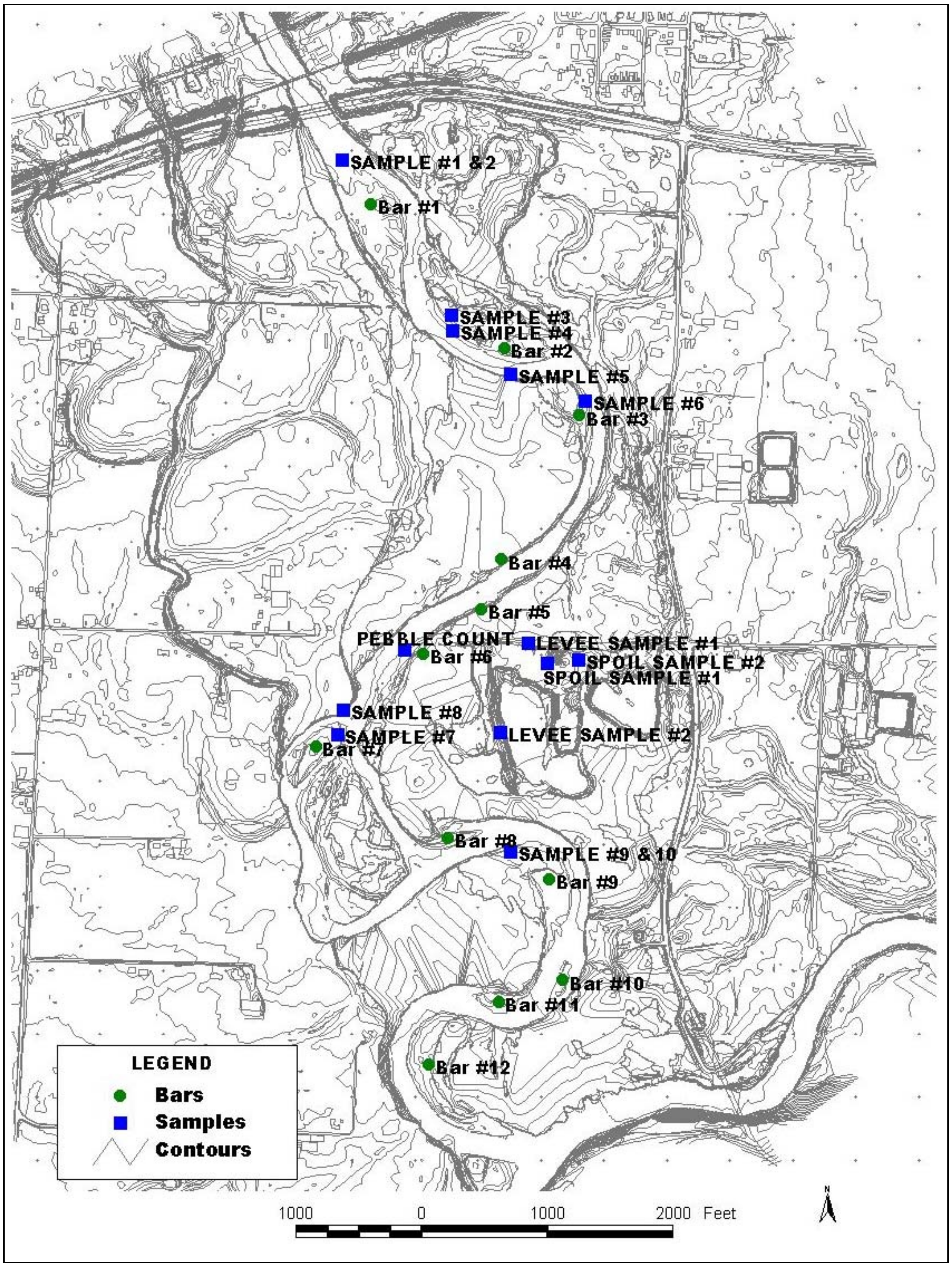



Figure 59. Locations of collected sediment samples.

Multiple sediment samples of the channel bed material were collected to define the size characteristics of both the surface materials and substrate. Surface material samples were taken from a depth no greater than the largest particle size observed ($D_{100}$). Subsurface samples were taken from material at a depth greater than the $D_{100}$ of the surface material. Where no discernable difference between surface and substrate materials was evident a single "Mixed" sample was collected.

Generally, the sediment samples were collected using a five-gallon bucket and a shovel. Samples were typically taken from an area equal to approximately one square foot. Bed material samples were collected from channel bars, near the waters edge, at the approximate mid point of the bar. Bank samples were taken from material that was approximately halfway between the top and bottom limits of the vertical portion of recently eroded banks. Samples of dike and spoil materials were collected at random locations. Approximately 30 pounds of material were collected for each sample.

Table 16 summarizes the general size characteristics for each sample. A summary of size distribution characteristics for each sample is provided in Table 17.

Table 16. Summary of general sediment size characteristics.

| Location/Sample Type | Cobbles (%) | Gravel | | Sand | | | Fines |
|---|---|---|---|---|---|---|---|
| | | Coarse (%) | Fine (%) | Coarse (%) | Medium (%) | Fine (%) | Silt and Clay (%) |
| #1 Levee | 0.0 | 2.4 | 11.6 | 4.5 | 7.2 | 25.6 | 48.7 |
| #2 Levee | 0.0 | 29.0 | 38.3 | 9.2 | 7.2 | 5.1 | 11.2 |
| #1 Spoils | 0.0 | 3.5 | 6.0 | 2.8 | 5.9 | 9.8 | 72.0 |
| #2 Spoils | 0.0 | 3.6 | 7.1 | 1.8 | 3.7 | 6.0 | 77.8 |
| Sample #1- Subsurface | 0.0 | 29.6 | 46.4 | 10.2 | 6.0 | 6.6 | 1.2 |
| Sample #2 – Surface | 15.4 | 65.1 | 12.2 | 3.8 | 1.9 | 1.3 | 0.3 |
| Sample #3 – Mixed | 0.0 | 14.6 | 52.6 | 14.5 | 6.8 | 8.2 | 3.3 |
| Sample #4 – Mixed | 0.0 | 64.1 | 30.3 | 1.5 | 0.7 | 2.8 | 0.6 |
| Sample #5 – Bank | 0.0 | 0.0 | 0.1 | 0.0 | 0.5 | 26.5 | 72.9 |
| Sample #6 – Mixed | 9.9 | 31.7 | 33.0 | 9.6 | 11.4 | 4.0 | 0.4 |
| Sample #7 – Surface | 10.7 | 29.8 | 38.4 | 8.5 | 5.5 | 5.7 | 1.4 |
| Sample #8 – Bank | 0.0 | 0.0 | 0.1 | 0.3 | 0.7 | 42.1 | 56.8 |
| Sample #9 - Subsurface | 0.0 | 39.1 | 30.4 | 11.4 | 15.5 | 2.7 | 0.9 |
| Sample #10 – Surface | 42.4 | 51.5 | 3.5 | 1.1 | 1.0 | 0.4 | 0.4 |

Table 17. Sediment size distribution characteristics.

| Sample Identifier - Sample Type | Sample Location (River Station, feet) | Sediment Size (millimeters)* | | | | | |
|---|---|---|---|---|---|---|---|
| | | $D_{85}$ | $D_{60}$ | $D_{50}$ | $D_{30}$ | $D_{15}$ | $D_{10}$ |
| #1 Levee | 7296 | 4.0 | 0.2 | 0.1 | | | |
| #2 Levee | 6343 | 32.3 | 14.3 | 10.7 | 4.0 | 0.3 | |
| #1 Spoils | 7296 | 0.8 | | | | | |
| #2 Spoils | 7296 | 0.6 | | | | | |
| Sample #1 - Subsurface | 13200 | 43.0 | 15.9 | 13.1 | 6.6 | 2.2 | 1.2 |
| Sample #2 - Surface | 13200 | 76.5 | 60.8 | 54.4 | 30.9 | 13.8 | 8.2 |
| Sample #3 - Mixed | 11425 | 18.8 | 10.4 | 8.1 | 4.2 | 1.2 | 0.3 |
| Sample #4 - Mixed | 11425 | 53.6 | 32.4 | 25.7 | 16.5 | 9.8 | 7.5 |
| Sample #5 - Bank | 10882 | 0.1 | | | | | |
| Sample #6 - Mixed | 10361 | 40.6 | 19.9 | 14.9 | 6.6 | 1.9 | 1.1 |
| Sample #7 - Surface | 6500 | 66.0 | 19.4 | 14.7 | 7.9 | 2.5 | 1.5 |
| Sample #8 - Bank | 6776 | 0.2 | 0.1 | | | | |
| Sample #9 - Subsurface | 4500 | 43.3 | 18.5 | 13.0 | 4.6 | 1.5 | 1.0 |
| Sample #10 - Surface | 4500 | 137.5 | 77.7 | 71.1 | 55.5 | 35.8 | 27.4 |

*$D_x$ is the sediment size (D) that a percentage (x) of the sample size distribution is finer then by weight (e.g., $D_{85}$ is the size for which 85 percent of the sample size distribution is finer then by weight).

### 5.6.1 Bed Material Size Characteristics

As shown in Table 17, the bed material of the lower Satsop River is composed of predominantly gravel-sized material and a smaller percentage of sand. Surface, subsurface, and mixed materials were found to be generally similar. No significant differences in sediment sizes were noted with location through the study area.

As shown in Figure 60, the median particle sizes ($D_{50}$) for surface samples range from 17 to 71 mm with the mean size at 47 mm and median size at 54 mm. In general, the surface samples demonstrate some variability in their size characteristics with location. The surface sample grain size data indicates a general potential for armoring.

As shown on Figure 61, the size characteristics of subsurface samples are generally consistent throughout the study area. The $D_{50}$ particle size of subsurface samples range from 22 to 13 mm with the mean size at 18.5 mm and median size at 13.1mm. The $D_{15}$ of subsurface samples range from1.5 to 3.2mm. Notably, the subsurface sediment size information is also consistent with subsurface sediment sample size distribution information presented by Collins and Dunne (1986).

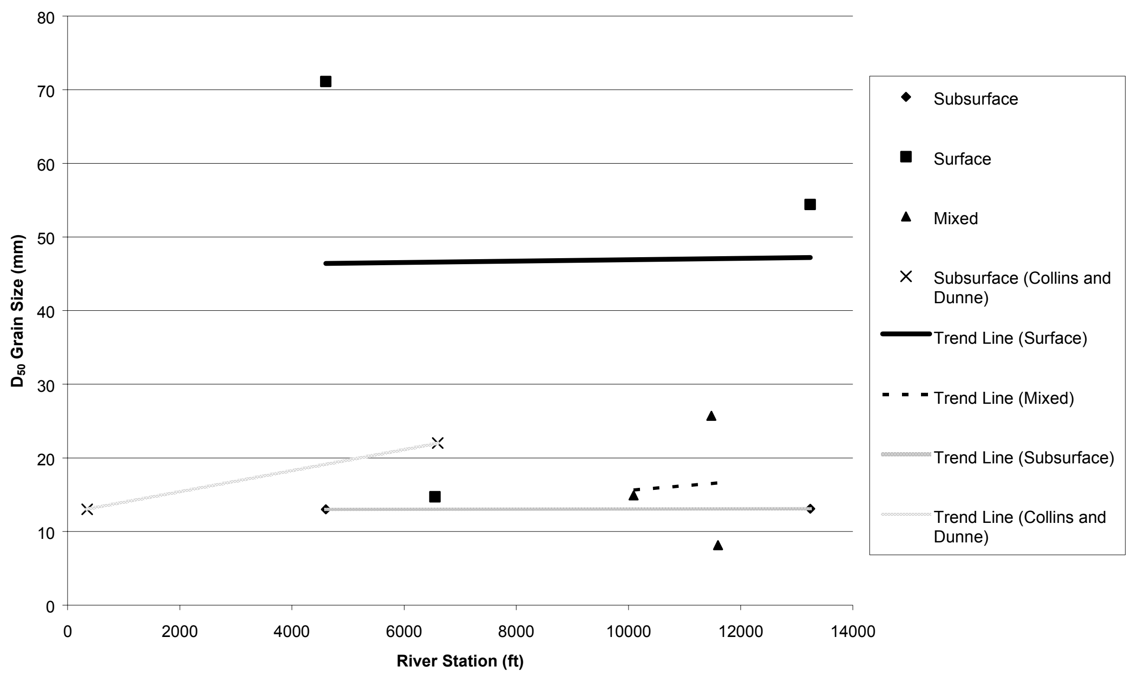



Figure 60. Median sediment size data for all bed material samples.

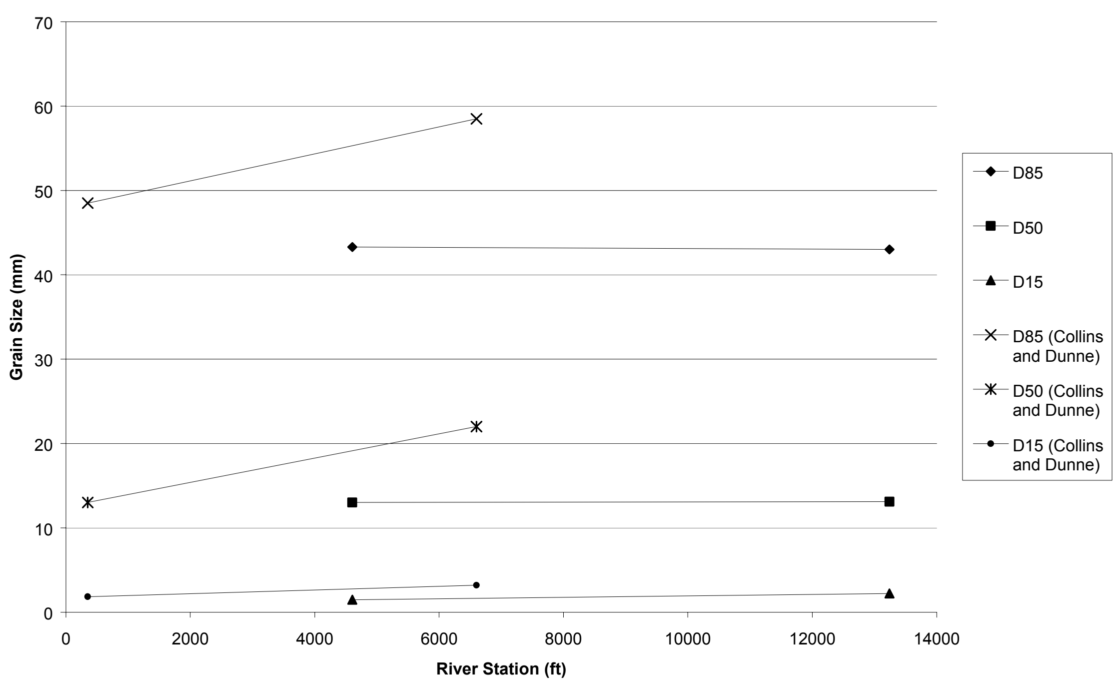



Figure 61. Size characteristics of subsurface bed material samples.

### 5.6.2 Bank Material Size Characteristics

Two samples of bank material were collected and analyzed for size distribution characteristics. The samples were collected from actively eroding banks. At both locations the sampled material extended from the toe of the slope to the top of bank. The sampled bank materials were determined to be predominantly silt- and clay-sized materials. Compared to the coarse bed material of the channel, the bank material would be highly erodible.

### 5.6.3 Dike Material Size Characteristics

Two samples of materials from existing dikes on the project site were collected and analyzed for sediment size distribution characteristics. The dike material samples display significantly different characteristics. Sample Levee #1 was taken along the northern dike and is composed of predominantly sand-, silt- and clay-sized materials. In contrast, the second sample, Levee #2, was determined to be predominantly gravel-sized material. It is understood that the original construction of the dikes may have incorporated topsoil from the locations of the existing gravel ponds.

### 5.6.4 Spoils Size Characteristics

Several samples of the spoils that exist on the project site were collected and analyzed for size distribution characteristics. The spoils were determined to be predominantly silt-and clay-sized material and between 20 to 30 percent by weight sand and gravel sized sediments.

## 5.7 Sediment Transport Analysis

An analysis of sediment transport conditions along the Satsop River within the study area was conducted. The objective of the analysis was to characterize existing sediment transport conditions and define potential impacts associated with the alternative restoration scenarios.

### 5.7.1 Previous Studies

Glancy (1971) conducted an analysis of suspended sediment transport measurements collected along streams in the Chehalis River basin over the period October 1961 to September 1965. This study included evaluation of suspended sediment transport conditions along the Satsop River. The Satsop River was found to contribute about 44 percent of the suspended sediment load to the Chehalis River basin. Measured sediment concentrations range from 1 to 1,030 mg/l. The suspended sediments were found to be 22 percent clay, 45 percent silt, and 33 percent sand. A mean annual suspended-sediment yield of about 790 tons per square mile (240,000 tons/year) was estimated.

Collins and Dunne (1986) examined gravel transport and gravel harvesting in the Satsop River. The average annual bed load transport rate was estimated by three methods: 1) as a percentage (4 percent) of the measured suspended load, 2) an empirical bed load equation (Meyer, Peter-Muller, 1948), and 3) a gravel bar migration assessment. The estimates range from about 3,000 cubic yards/year (2,400 tons/year) to nearly 20,000 cubic yards/year (16,000 tons/year). The best estimate of bed load transport was identified to be 10,000 cubic yards per year (8,000 tons/year). Based on unofficial accounts, annual gravel mining volumes between River Mile 1 and 3 in the Satsop River channel are believed to have significantly exceeded the estimated natural bed load supply during the 1960s and 1970s. A specific gage analysis for the Satsop

River Near Satsop, WA gage was used to demonstrate a trend of channel degradation that extended from the 1950s into the 1980s.

### 5.7.2 Incipient Motion Analysis

An analysis of incipient motion characteristics for each analysis condition was conducted. The incipient motion size was determined at each cross section of both the Mainstem Reach and the Pond Reach based on hydraulic parameters identified for each analysis condition and tractive force calculations. Incipient motion conditions were evaluated for both the bankfull flood (1.2-year return period) and the 100-year flood.

Results of the incipient motion analysis for the bankfull flood are summarized in Figure 62 for the Mainstem Reach and Figure 63 for the Pond Reach. The maximum particle size for incipient motion along the mainstem is between 60 and 70 mm for all alternatives. This size range is consistent with observed sediment sizes. The incipient particle size is noted to increase for Alternatives 1, 2 and 3 upstream of River Station 7296. This is attributed to the increased flow velocities in the mainstem resulting from reduced backwater associated with dike and spoil removal on the site. Similarly, incipient motion sizes for the bankfull condition are observed to reduce slightly downstream of River Station 7296, due to increased flow in the Pond Reach under the proposed alternative conditions compared to existing conditions.

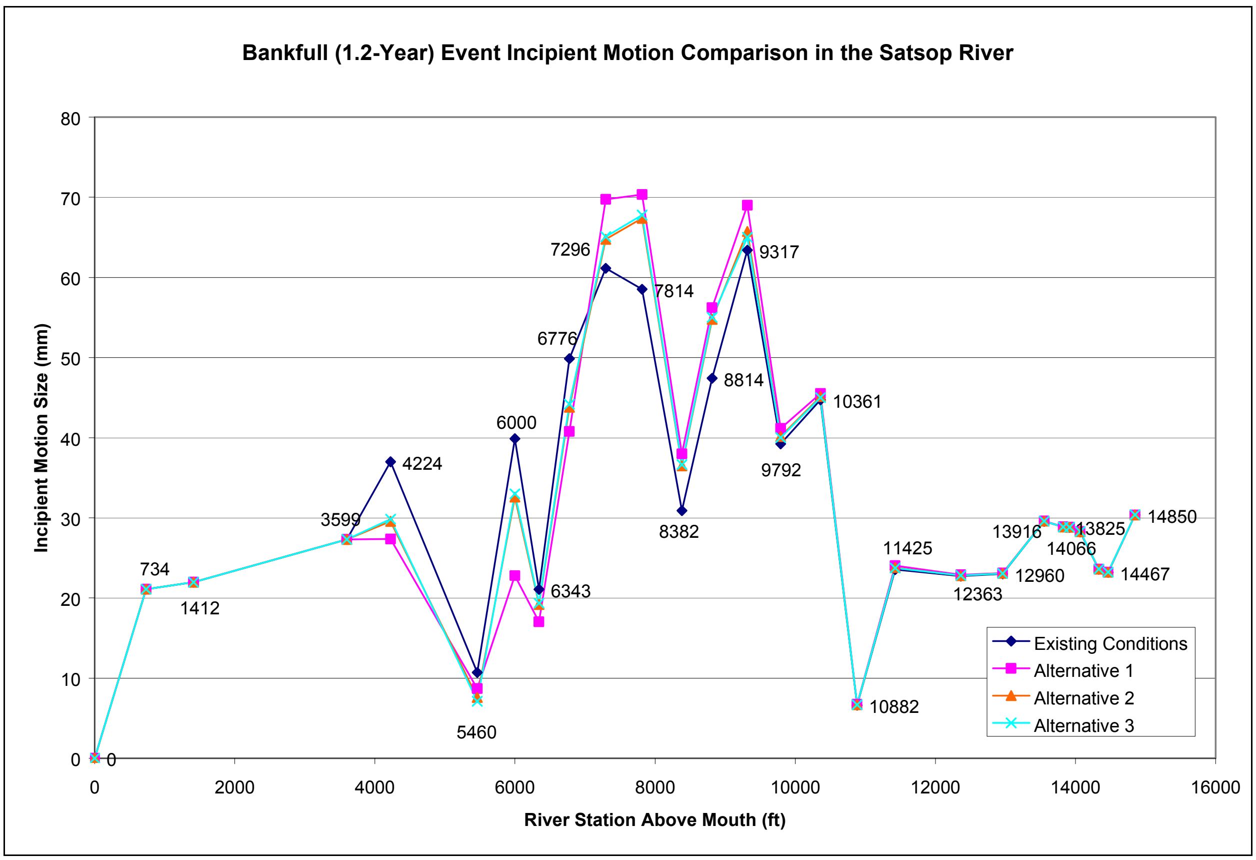



Figure 62. Incipient motion comparison at bankfull flow in the Satsop River.

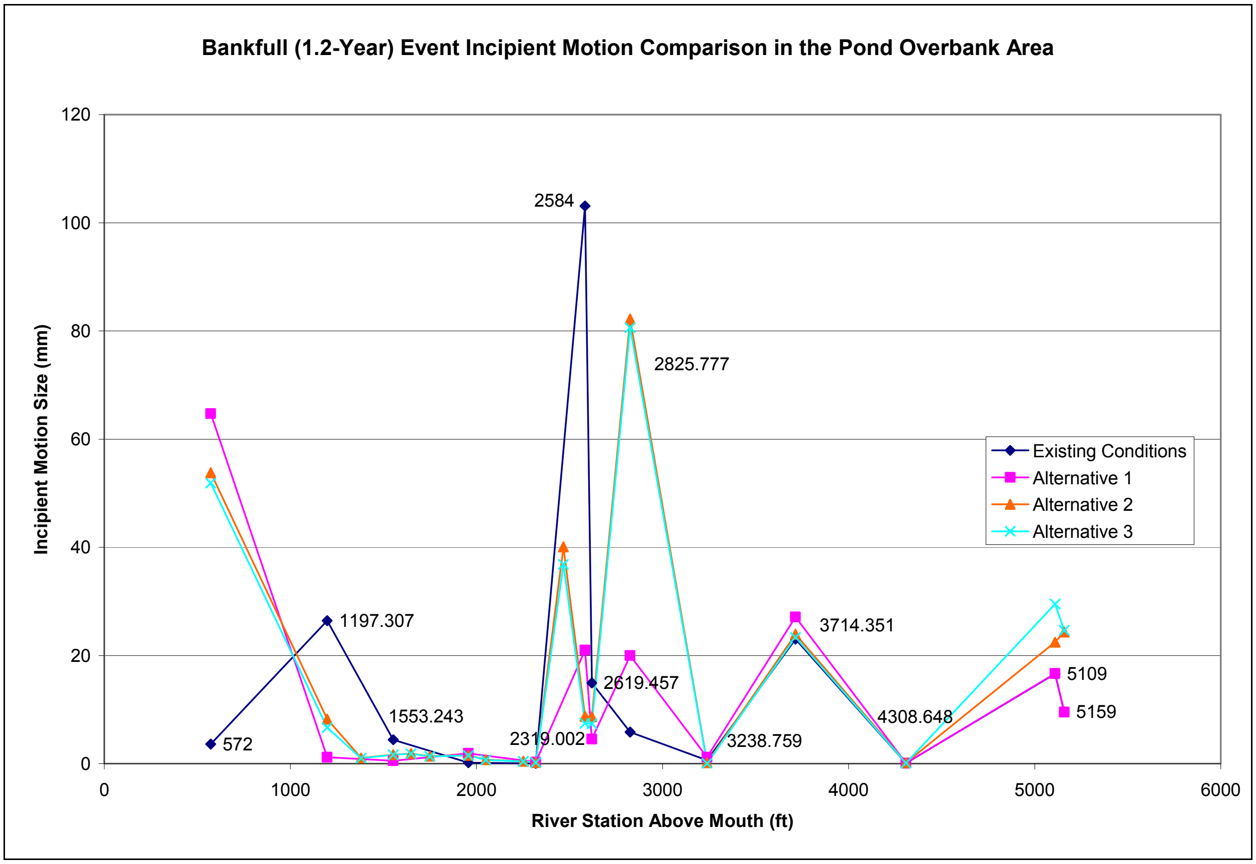



Figure 63. Incipient motion comparison at bankfull flow in the Pond Reach area.

During the Bankfull Flood (1.2 year return period) in the Pond Reach, the incipient motion sizes are generally less than 30 mm in size at most cross sections. At River Station 2584, a significantly larger incipient motion size was defined due to the hydraulic conditions associated with a culvert at that location under existing conditions. Under alternative conditions, the removal of dikes and spoils results in a much higher incipient motion size at River Station 2826. Also at the outlet of the Pond Reach, River Station 572, the incipient motion size is seen to increase significantly for Alternatives 1, 2, and 3 due to increased flow along the Pond Reach.

Results of the incipient motion analysis for the 100-year flood are summarized in Figure 64 for the Mainstem Reach and Figure 65 for the Pond Reach. The maximum particle size for incipient motion along the mainstem is between about 120 and 150 mm for all alternatives. Similar to the results for the Bankfull Flood, the incipient particle size is noted to increase for Alternatives 1, 2 and 3 upstream of River Station 7296. This is attributed to the increased flow velocities in the mainstem resulting from reduced backwater associated with dike and spoil removal on the site. The incipient motion sizes for the 100 year flood area are observed to reduce slightly downstream of River Station 7296, due to increase flow in the Pond Reach under the proposed alternative conditions compared to existing conditions.

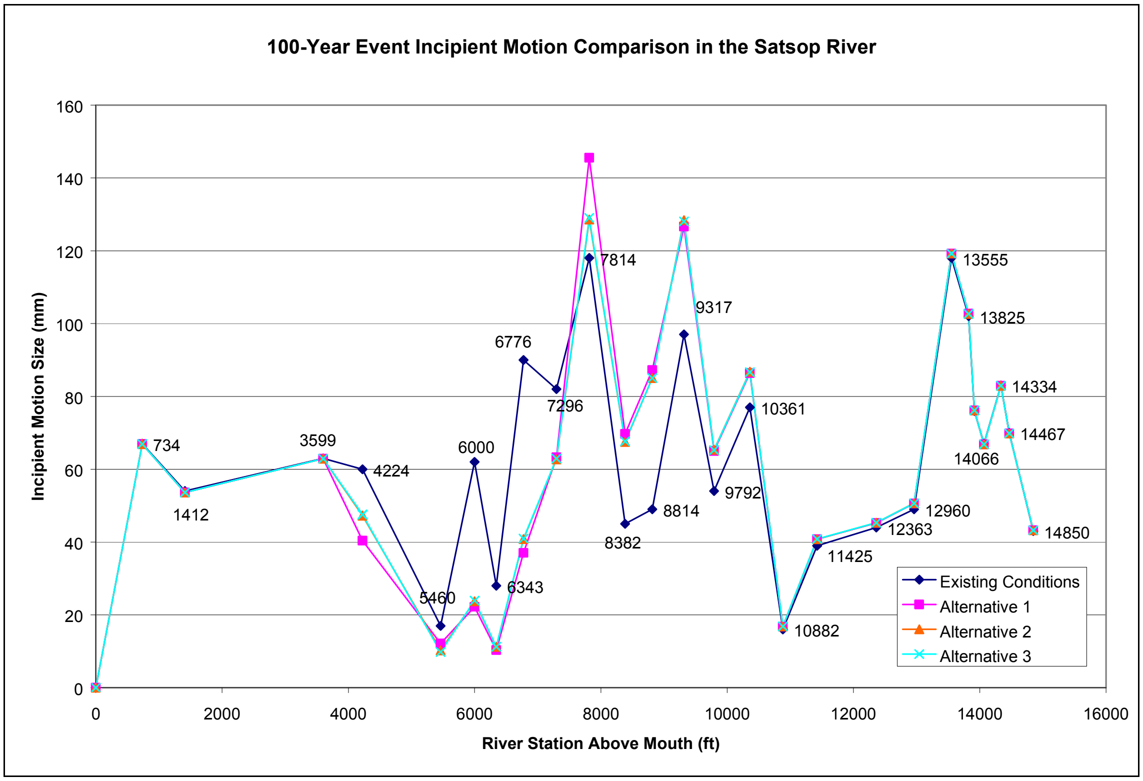



Figure 64. Incipient motion comparison at the 100-year flow in the Satsop River.

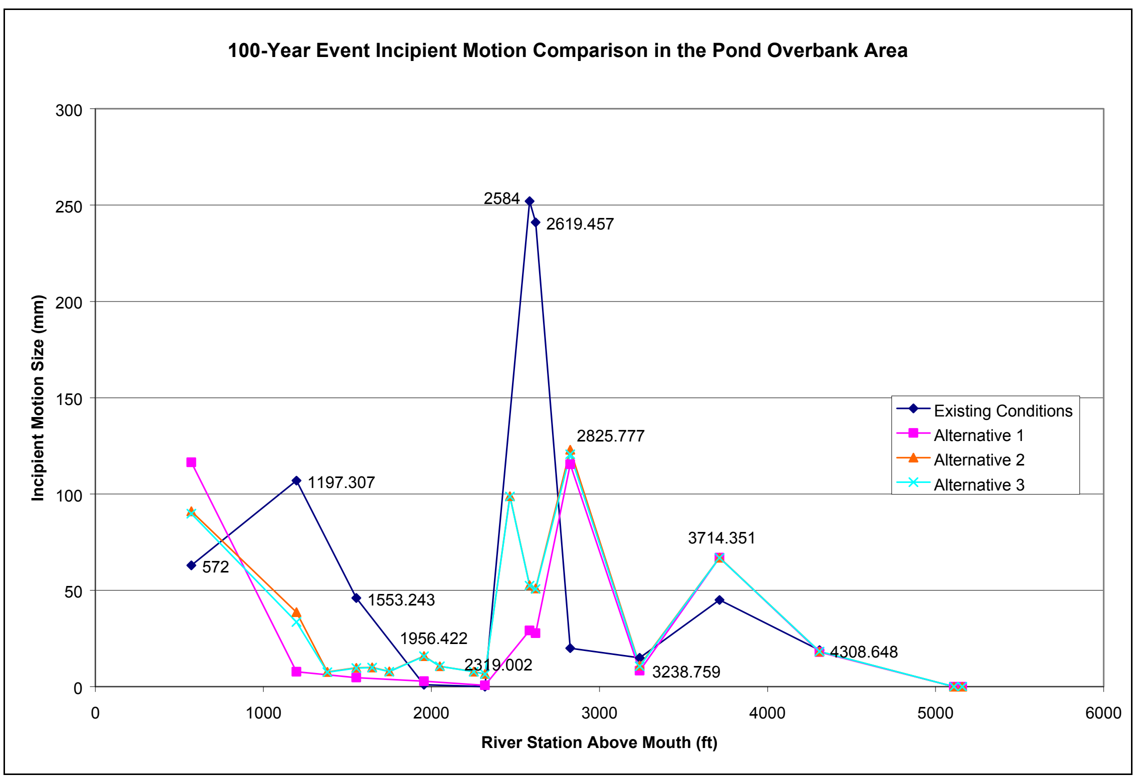



Figure 65. Incipient motion comparison at the 100-year flow in the Pond Reach area.

The estimated incipient motion characteristics for the Pond Reach for the 100-year flood closely resemble the results found for the bankfull flood except that the predicted particle sizes are significantly larger.

### 5.7.3 Bed Load Transport Capacity

The average annual bed load sediment transport capacity for each analysis condition was evaluated at five cross sections located through the study area. The bed load transport rates were calculated based on the SAM Hydraulic Design Package (COE, 1998) and the Meyer-Peter and Muller (1948) bed load formula. The Meyer-Peter and Muller (1948) bed load formula was selected for use since it had been previously applied by Collins and Dunne (1986). Results of the analysis are summarized in Table 18.

The results of the analysis are qualitatively consistent with field conditions and previous studies. Under existing conditions, the average annual bed load transport capacity was estimated to range from approximately 1,400 tons/year to nearly 34,000 tons/year for all sections. The average of annual bed load transport capacity determined for all sections is about 14,000 tons per year. If the values for sections affected by riprap are excluded, the average rate is about 9,700 tons per year, which is very similar to the value of 8,000 tons per year previously estimated by Collins and Dunne (1986) for the lower Satsop River.

The bed load transport estimates for existing conditions demonstrate the variability of sediment transport capacity through the study area. Within the riprap reach adjacent to the project area the bed load transport capacity is much greater than upstream and downstream locations. From field observation, it is apparent that the channel adjacent to the riprap is much narrower and deeper than the upstream and downstream channel where meandering is more pronounced. It is also apparent from surface sediments along the reach that armoring will likely limit the actual bed load transport for commonly occurring flows.

The bed load transport capacities calculated for alternative conditions display similar results. The altered flow distribution caused by removal of dikes and spoils from the project site results in an overall reduction in bed load transport capacity at the section adjacent to Pond A and an increase in bed load transport capacity in the middle portion of the riprap reach. Little change is noted at the sections upstream and downstream of the project site.

Table 18 Summary of average annual bed load transport capacity.

| | Location | Near Confluence | Adjacent to Pond A | Downstream Riprap | Middle Riprap | Upstream Riprap |
|---|---|---|---|---|---|---|
| | River Station | 734 | 6,000 | 7,814 | 8,814 | 10,882 |
| 1 | Existing Conditions (tons/yr) | 7,967 | 11,478 | 41,768 | 24,832 | 1,687 |
| 2 | Alternative 1 (tons/yr) | 7,961 | 2,661 | 57,774 | 43,066 | 1,749 |
| | Difference Row 2-1 (tons/yr) | -6 | -8,817 | 16,006 | 18,234 | 62 |
| | Percent Change (1 to 2) | -0.08 | -76.82 | 38.32 | 73.43 | 3.68 |
| 3 | Alternative 2 (tons/yr) | 8,068 | 4,921 | 51,159 | 40,963 | 1,754 |
| | Difference Row 1-3 (tons/yr) | 101 | -6557 | 9,391 | 16,131 | 67 |
| | Percent Change (1 to 3) | 1.27 | -57.13 | 22.48 | 64.96 | 3.97 |
| 4 | Alternative 3 (tons/yr) | 7,961 | 5,049 | 51,616 | 41,178 | 1,741 |
| | Difference Column 1-4 (tons/yr) | -6 | -6,429 | 9,848 | 16,346 | 54 |
| | Percent Change (1-4) | -0.08 | -56.01 | 23.58 | 66.00 | 3.20 |

## 5.8 Time to Fill Ponds

If it is assumed that the mainstem Satsop River channel may capture the existing gravel mine ponds, the time to fill the ponds through natural sediment transport processes can be estimated. The potential supply of sediment to the ponds was assumed to vary from 100 percent of the estimated bed load to a fraction of the total load (suspended load + bed load). The bed load of the lower Satsop River was previously estimated by Collins & Dunne (1986) to be about 10,000 cubic yards/year. The suspended load of the Satsop River was estimated by Glancy (1971) to be about 240,000 tons/year, of which 33 percent was comprised of sand sized material. Assuming that silt and clay sized materials are carried as wash load through the pond, and the long-term trap efficiency of the ponds for sand sized materials would be about 20 percent, the suspended sand load that could be trapped by the ponds would be 15,840 tons/year, or 12,754 cubic yards/year, assuming a density for sand of 92 #/cubic foot.

A summary of the estimates is shown in Table 19. The time required to fill the ponds is seen to vary from nearly 30 years under existing conditions to about 7 years if their volume is reduced by the placement of spoils in Ponds B and C. Practically, the time to fill the ponds will be dependent on the manner in which the mainstem channel interacts with the ponds and the hydrologic sequence that occurs. In any event, it is apparent that the time required to fill the ponds through natural sediment replenishment will be significant.

Table 19 Estimated time required to fill existing gravel ponds

| Analysis Condition | | Volume* (CY) | 100 % of Bed Load (years) | Fraction of Total Load (20% of Suspend Sand Load + Bed Load) (years) |
|---|---|---|---|---|
| Existing | Pond A | 22,448 | 2.25 | 0.99 |
| | Pond B | 170,370 | 17.04 | 7.49 |
| | Pond C | 85,182 | 8.52 | 3.74 |
| | Total | 278,000 | 27.80 | 12.22 |
| | | | | |
| Alternative 1 | Pond A | 22,448 | 2.25 | 0.99 |
| | Pond B | 170,370 | 17.04 | 7.49 |
| | Pond C | 85,182 | 8.52 | 3.74 |
| | Total | 278,000 | 27.80 | 12.22 |
| | | | | |
| Alternatives 2& 3 ** | Pond A | 22,448 | 2.25 | 0.99 |
| | Pond B | 108,910 | 10.89 | 4.79 |
| | Pond C | 23,722 | 2.37 | 1.04 |
| | Total | 155,080 | 15.51 | 6.82 |
| | | | | |

* Volume at elevation 11 ft NGVD, the approximate thalweg elevation.
** Assumes spoils are equally placed in Ponds B & C.
.

## 5.9 Headcut Analysis

During floods, flow may spill into floodplain gravel ponds from either upstream or lateral directions. While the floodwaters fill the ponds, headcutting may occur due to steep hydraulic gradients, increased velocities, and erosion. Once the pond is filled, short-term headcutting processes generally cease. Over the longer term, headcutting will be influenced by both the frequency of flow accessing the ponds and the response of the upstream channel. Potentially, floodplain gravel ponds may be captured by the mainstem through either channel migration or avulsion processes. Headcutting processes may accelerate the potential for avulsion and pit capture by steepening and enlargement of flow paths to the ponds. Potential avulsion routes to Ponds A, B, and C are shown in Figure 66.

A qualitative evaluation of the effects of headcuts that would develop due to the capture of existing gravel ponds was conducted. Qualitative methods were employed for the analysis due to the uncertainty regarding the potential conditions under which the river may become

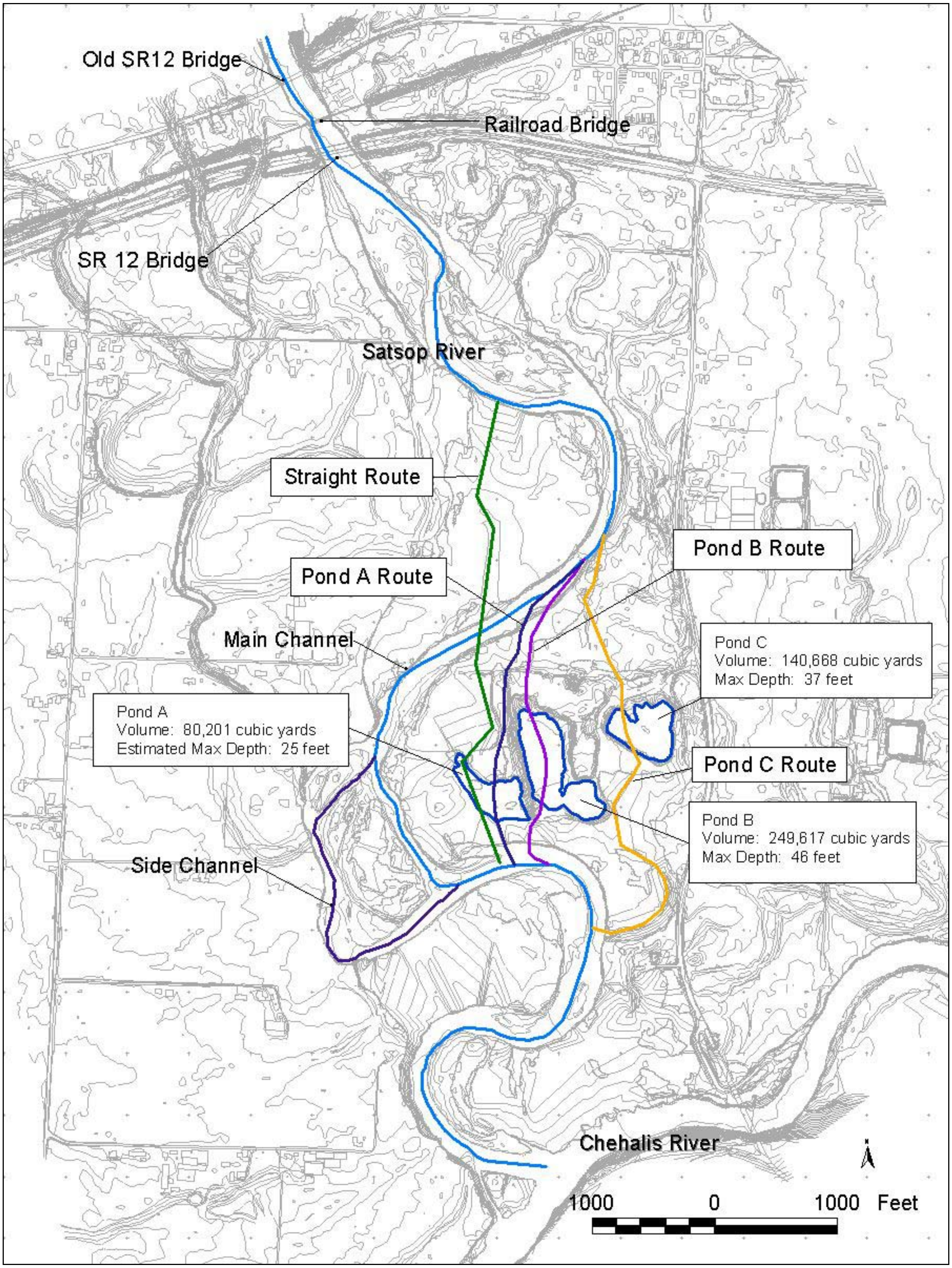



Figure 66. Potential avulsion routes.

connected to the ponds. Ponds may become connected to the river under a variety of circumstances. If warranted, more detailed quantitative assessments may be conducted under later Phase II analysis efforts.

Three methods were employed to evaluate potential short-term headcut conditions:

- Regression equations developed for the Arizona Department of Transportation (Cotton, Ottozawa-Chatupron, 1990)
- Generalized headcut relations developed from sediment routing studies for a specific gravel mine operation (Simons, Li & Associates, 1982)
- A Rule of Thumb that the maximum headcut slope is equal to twice the natural channel slope and the headcut depth is equal to one-half the excavation depth (Hu et al., 2001).

Table 20 summarizes the results of the short-term headcut estimates. For all analysis conditions, the estimated headcut depths range from 3 to 5 feet and the upstream headcut distances range from 44 feet to nearly 1,400 feet. The drown out time for the ponds during the bankfull flood event is noted to be less than 16 minutes which does not allow the peak flow of 17,000 cfs to influence the headcut. The largest estimates were found to be associated with the rule-of –thumb methodology for existing conditions. In general, somewhat reduced headcut distances are associated with the alternative conditions due to flatter gradients caused by the removal of material surrounding the ponds.

It is noted that the existing bridges in the project area are located over 5,800 feet upstream from the upstream limit of the existing ponds. It is considered unlikely that the bridges would be affected by short-term impacts of headcuts from the ponds. Over the long term, if the river captures the ponds, the profile and gradient of the river upstream and downstream of the pond will adjust. The degree of adjustment will be dependent on the specific manner in which the river captures the ponds and the hydrologic sequence experienced after that time.

## 5.10 Bridge Scour

Using Laursen's live bed scour equation (FHWA, 1995) for the 100-year flow, contraction scour depth was calculated for each bridge in the study vicinity. It was assumed that the channel thalweg could migrate across the channel for pier scour calculations. A bed material $D_{50}$ of 51 mm was used in the scour calculations. Pier scour was calculated using the CSU equation (FHWA, 1995). There is essentially no difference in scour at the bridges for Alternative 1, 2, or 3 compared to existing conditions. Long-term degradation was not considered for the total scour, but it can be assumed to be the same for all alternatives. The results of the scour calculations are shown in Table 21. No significant changes in bridge scour conditions were identified for the alternative conditions.

Table 20. Summary of short term headcut estimates.

| Pond | Available Pit Volume ($yd^3$)* | Fill Time (s)** | Method | Headcut Distance (ft) | Headcut depth (ft) | Head cut at Hwy 12 (ft) | Headcut at Elma-Montesano Rd (ft) | Headcut at RR (ft) |
|---|---|---|---|---|---|---|---|---|
| A (Alt 1, 2, 3) | 20,676 | 121 | Regression | 73 | 4.0 | 0 | 0 | 0 |
| A (Alt 1, 2, 3) | | | SLA | 93 | 2.9 | 0 | 0 | 0 |
| A (Alt 1, 2, 3) | | | Rule of Thumb | 535 | 4.0 | 0 | 0 | 0 |
| A (Existing) | | 423 | Regression | 44 | 3.2 | 0 | 0 | 0 |
| A (Existing) | | | SLA | 93 | 2.9 | 0 | 0 | 0 |
| A (Existing) | | | Rule of Thumb | 766 | 4.0 | 0 | 0 | 0 |
| B (Alt 1, 2, 3) | 45,914 | 270 | Regression | 237 | 5.0 | 0 | 0 | 0 |
| B (Alt 1, 2, 3) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| B (Alt 1, 2, 3) | | | Rule of Thumb | 705 | 5.0 | 0 | 0 | 0 |
| B (Existing) | | 939 | Regression | 140 | 4.3 | 0 | 0 | 0 |
| B (Existing) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| B (Existing) | | | Rule of Thumb | 871 | 5.0 | 0 | 0 | 0 |
| C (Alt 1, 2, 3) | 43,446 | 255 | Regression | 86 | 5.0 | 0 | 0 | 0 |
| C (Alt 1, 2, 3) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| C (Alt 1, 2, 3) | | | Rule of Thumb | 593 | 5.0 | 0 | 0 | 0 |
| C (Existing) | | 887 | Regression | 51 | 3.4 | 0 | 0 | 0 |
| C (Existing) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| C (Existing) | | | Rule of Thumb | 1351 | 5.0 | 0 | 0 | 0 |

*Volume available is based on an assumed water surface elevation of 14 feet
**based on bankfull flow hydrograph

Table 21. Summary of bridge scour calculations.

| | Scour Type | Existing Conditions | Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|---|---|---|
| Elma-Montesano Road | Contraction Scour (ft) | 7.09 | 7.13 | 7.09 | 7.12 |
| | 3' Pier, Scour | 5.40 | 5.40 | 5.40 | 5.40 |
| | 5' Pier, Scour | 7.12 | 7.13 | 7.12 | 7.13 |
| | Total Scour | 14.21 | 14.26 | 14.21 | 14.25 |
| Railroad Bridge | Contraction Scour (ft) | 1.38 | 1.35 | 1.38 | 1.37 |
| | 1.25' Pier, Scour | 3.59 | 3.59 | 3.59 | 3.59 |
| | 6.4' Pier, Scour | 7.95 | 7.94 | 7.95 | 7.94 |
| | Total Scour | 9.33 | 9.29 | 9.33 | 9.31 |
| U.S. Hwy 12 Bridge | Contraction Scour (ft) | 2.57 | 2.56 | 2.55 | 2.55 |
| | 4.5' Pier, Scour | 15.91 | 15.88 | 15.91 | 15.90 |
| | Total Scour | 18.48 | 18.44 | 18.46 | 18.45 |

## 5.11 Risk and Uncertainty

The risk and uncertainty associated with the results of the geomorphic analysis is dependent on a variety of factors related to the understanding of the physical system, the quality of available data, and available analysis tools. Efforts to minimize risk and uncertainty in the geomorphic analysis included thorough consideration of relevant prior studies, qualitative assessment of consistency between field conditions and the results of quantitative calculations, and utilization of personnel trained and experienced in conducting the involved assessments. In the following sections, each of the sources of risk and uncertainty are discussed.

### 5.11.1 Understanding the Fluvial System

A multi-level approach to understanding the Satsop River study area was conducted. Qualitative assessments were conducted to collect pertinent data, identify controlling physical processes, and define expected impacts. Quantitative analysis methods were used to describe the hydrology, hydraulics, and sediment transport of the system. Results of the qualitative and quantitative efforts were compared to ensure consistency, identify impacts of proposed alternatives, and define required mitigation measures.

### 5.11.2 Data

A wide variety of the data was used in the geomorphic analysis. This included hydrologic, hydraulic, topographic, geologic, and sediment transport data and information. In general, the available data is considered adequate for the purposes of the study. The available hydrologic data is very good as a long gage record was available for the river. The hydraulic data developed by this study is also considered good, within the limitations of risk and uncertainty previously discussed. The topographic data for the site is considered adequate but limited by dense vegetation in many areas. The geology of the areas has been thoroughly described by previous investigators. Similarly, the available sediment transport data for the project area is considered good. A limited record of specific suspended sediment measurement data is available for the study area, which is unusual for most studies of this type. A prior study was also available that provided a thorough investigation of bed load transport characteristics.

Much of the data used in the geomorphic analysis is recognized to be temporally dependent and a concern exists that historic conditions adequately represent potential future conditions. Hydrologic data can be affected by short and long term climate variability and sediment data can be highly influenced by historic watershed conditions and land use practices. It is recognized that influences such as logging and instream gravel mining have occurred in the basin and influenced the channel, yet little specific information is available to place the historic conditions in perspective of existing and future conditions. Previous investigators of sediment transport for the basin have also recognized this limitation.

### 5.11.3 Analysis Methods

The available tools for prediction of future channel migration and avulsion conditions are in general not very sophisticated. The state of the art for this subject is largely based on extrapolation of historic channel profile and planform information. Consequently, the accuracy of predictions for the future is dependent on the assumption that historic trends will continue into the future. It should be recognized that this assumption may or may not be valid for many reasons.

Similarly, the use of analytical sediment transport methods as a predictive tool for channel migration and avulsion are limited due to incomplete knowledge of sediment transport processes, the inherent complexity of the natural environment, and unpredictable influences such as debris. Consequently, quantitative results of empirical sediment transport equations must be considered approximate unless verified by actual measurements. Unfortunately, measurement of the sediment transport of a river may also be imprecise unless completely trapped by an impoundment where resultant sediment deposits can be accurately measured. No such data exists for the Satsop River.

Methods for evaluating the evolution of potential headcuts into the existing ponds over the long term are also limited. The analysis presented only represents potential short-term headcut conditions. If the ponds are captured, it is recognized that over the long-term the river channel will adjust in both profile and planform. Significant uncertainty exists about exactly how and when such pond capture will occur and the specific impacts that will occur. However, due to the location of the project area within the historic channel migration area, a significant probability exists that pond capture will ultimately occur with or without the current project. The only available analytical means of evaluating the long-term evolution a potential headcut route would be to conduct a long-term sediment routing simulation. This requires selecting an assumed headcut route and available models, such as HEC-6, do not accommodate lateral migration. Consequently, a high level of uncertainty may be associated with such an approach. Alternatively, thorough monitoring programs for headcut development could be conducted to adaptively manage any risk of long-term impacts due to the headcut formation.

# 6 MITIGATION DESIGN

In the preceding sections, the hydraulic and geomorphic characteristics of existing and alternative restoration conditions for the project area were evaluated. The impacts associated with each of the proposed alternatives were identified. Based on the prior analysis the following mitigation measures are defined. It is recognized that alternative methods of erosion protection such as those described in the Integrated Streambank Protection Guidelines (Washington State Aquatic Habitat Guidelines Program, 2002) could also be considered for this project. It is noted that the Corps supports the application of alternative erosion control techniques in suitable locations when practicable.

## 6.1 Keys Road Erosion Protection

Erosion protection for Keys Road and the existing natural gas pipeline was designed for two conditions,

1.) If existing riprap along the left bank of the mainstem is removed.
2.) If existing riprap remains in place.

### 6.1.1 Riprap Design With Migration of Mainstem Channel

If existing riprap along the mainstem channel is removed, migration of the channel that would influence Keys Road is expected. Riprap erosion control along Keys Road would be required. The U.S. Army Corps of Engineers (1994) method for riprap sizing was used to hydraulically design riprap erosion protection for the natural gas pipeline and Keys Road upstream of the project site entrance.

#### 6.1.1.1 Rock Size

The median diameter riprap size was determined based on the Corps of Engineer's methodology for riprap design found in EM 1110-2-1601, Hydraulic Design of Flood Control Channels (June 1994). Assumptions of the design included the following:

- The main channel of the Satsop River can migrate to Keys Road.
- Riprap sized based on hydraulic conditions of the main channel for a 100-year flood.
- Average radius of curvature for channel assumed equal to 1,000 ft.
- 2:1 bank slope.
- Rock stability factor of safety = 1.2 for existing conditions, 1.5 for the alternatives due to uncertainty associated with future conditions.

For Existing Conditions the $D_{50}$ rock size was estimated to be 1.2 feet. The median diameter rock size ($D_{50}$) was estimated to be 2.2 ft for Alternatives 1, 2, and 3. The larger rock size required for Alternatives 1, 2, and 3 is due to the removal of significant flow obstructions in the overbank, an increase in water surface gradient on the main stem of the Satsop River (increasing velocity), and a larger factor of safety. It is noted that existing riprap along the Satsop River varies in size from cobbles to 3 ft diameter rock.

#### 6.1.1.2 Toe Down Depth

The toe down depth requirement for the riprap was determined based on an evaluation of the following components:

- Long-term Degradation Potential – This was assumed equal to zero as the project is located in the lower portion of the Satsop River basin which suggests a depositional environment.

- General Scour – This was estimated based on the largest depth estimated by the empirical Neil, Lacey, and Blench scour equations (USBR, 1984). These methods include bend scour and thalweg formation.
- Local Scour Due to Bedforms - This was assumed equal to zero as the Satsop River is a gravel bed stream.

- Factor of Safety – A factor of safety of 1.2 was used to define the maximum toe down depth for the 100-year flood.

A toe down depth of 12.41 ft was defined. Toe protection may be provided by extending the protection to the maximum scour depth or placing sufficient launchable material at the toe of the revetment.

#### 6.1.1.3 Rock Quantity

The volume of riprap required per foot of stream length was estimated based on the assumed geometry or 2H:1V sideslope, a median rock size of 2.2 ft, a riprap thickness of 4.5 ft, a toe down depth of 12.41 ft, and an estimated bankfull depth of 9.1 ft. These rock quantities are based on the calculations for Alternatives 1, 2, and 3, since protection of Keys Road and the gas line would probably not be a project requirement if the riprap on the main stem of the Satsop Rriver is not removed. The volume of riprap was estimated to be 10.4 CY/ft of bank.

#### 6.1.1.4 Length of Required Bank Protection

It is assumed that bank protection would be required from the existing entrance road to the upstream limit of the property. Bank erosion protection must also be tied into the existing riprap revetment along the adjacent upstream property. The total length of required erosion protection was estimated to be approximately 2,180 ft. Figure 67 shows the approximate location of recommended riprap protection.

### 6.1.2 Riprap Design Without Mainstem Migration

If the existing riprap along the Satsop River is not removed, the mainstem channel will likely continue to be stable for an extended period even though portions of the riprap have failed. If it is assumed that the main channel is restricted from migration to Keys Road, the required riprap size to protect Keys Road and the natural gas pipeline from potential would be substantially less. Under this scenario the riprap was sized based on a factor of safety of 1.5, and a 2:1 sideslope. The required toe down depth was estimated to be 6 feet. Protection is assumed from the toe of the bank up to bankfull depth. The design utilized overbank hydraulic conditions for the 100-year flood. As shown in Table 22, riprap requirements for both immature and mature vegetation conditions in the overbank were evaluated. Increased hydraulic roughness associated with mature overbank vegetation results in a decreased riprap size.

Table 22. Riprap sizes for the Pond Reach assuming no mainstem migration.

| Model | Calculated $D_{50}$ (ft) | Layer thickness (ft) | Rock Quantity ($yd^3/ft$) |
|---|---|---|---|
| Existing Conditions | 0.1 | 0.75 | 1.5 |
| Alternative 1 | 0.4 | 0.75 | 1.5 |
| Alternative 2 Young Vegetation | 0.6 | 1.00 | 2.0 |
| Alternative 2 Mature Vegetation | 0.5 | 1.00 | 2.0 |
| Alternative 3 Young Vegetation | 0.6 | 1.00 | 2.0 |
| Alternative 3 Mature Vegetation | 0.5 | 1.00 | 2.0 |

#### 6.1.3 Alternative Keys Road Protection Without Mainstem Migration

Shear stress is most prominent near Pond Reach cross section 2825. In general, shear stress away from cross section 2825 is approximately half or less. Table 23 summarizes the shear stress upstream of the existing access road. The first 400 feet from the existing access road upstream past cross section 2825 could be protected with riprap or heavy vegetation and engineered log jams. The remaining portion to the upstream end of the project property could be protected by heavy vegetation.

#### 6.1.4 Alternative Measures

Alternative protection measures could be used to protect Keys Road and the nearby natural gas pipeline. It is noted the overflow channel is in close proximity to the road in many locations north of the existing access road. Protection of the road with vegetative covers could be used where adequate separation between the road and the channel exists. Relocation of the existing overflow channel away from Keys Road between the existing access road and the upstream end of the property could also be used to provide adequate protection. The area between the overflow path and Keys Road would be heavily planted with woody vegetation and engineered log jam type structures could be used as flow training devices along the channel. Figure 68 shows the approximate location of protection. The overflow path should be a minimum of 100 feet away from Keys Road.

## 6.2 Erosion Protection for Satsop Business Park Well

As previously discussed in 4.4.2, there will be an increase in overbank flow for all the alternatives (2,370 to 2,990 cfs) versus existing conditions (690 cfs) for the bankfull event. This increase in flow at the overbank outlet creates a potentially more erosive flow condition near the Satsop Business Park Well. A summary of the expected overflow channel shear stresses in the vicinity of the well is shown in Table 24.

The required riprap size for erosion protection was calculated to have a $D_{50}$ size for existing conditions of 0.4 feet. 1.0 ft for Alternative 1 and 0.7 feet for Alternatives 2 and 3. The riprap sizes were calculated based on a safety factor of 1.2 for existing conditions, and 1.5 for all the alternatives. The bend radius used for the design was 450 feet, and the sideslope 2 horizontal: 1 vertical. The defined riprap sizes for the Egress Channel do not anticipate migration of the main channel to that location. However, it is noted that historic channel migration information indicates that the mainstem channel was in close proximity in 1953. Therefore, with or without the current project, it is likely that the well location will be influenced by the mainstem channel again in the future.

Table 23 Shear stress along the Egress Channel between the existing access road and the upstream limit of the property, assuming no channel migration.

| **Discharge** | **Analysis Condition** | **Average Shear Stress (#/ft$^2$)** | **Maximum Shear Stress* (#/ft$^2$)** |
|---|---|---|---|
| Bankfull XS 3714 | Existing | 0.00 | 0.00 |
| | Alternative 1 | 0.00 | 0.00 |
| | Alternative 2 | 0.00 | 0.00 |
| | Alternative 3 | 0.00 | 0.00 |
| Bankfull XS 3714 | Existing | 0.42 | 0.84 |
| | Alternative 1 | 0.49 | 0.98 |
| | Alternative 2 | 0.44 | 0.88 |
| | Alternative 3 | 0.42 | 0.84 |
| Bankfull XS 3238 | Existing | 0.00 | 0.00 |
| | Alternative 1 | 0.02 | 0.04 |
| | Alternative 2 | 0.00 | 0.00 |
| | Alternative 3 | 0.00 | 0.00 |
| Bankfull XS 2825 | Existing | 0.12 | 0.24 |
| | Alternative 1 | 0.41 | 0.82 |
| | Alternative 2 | 1.63 | 3.26 |
| | Alternative 3 | 1.60 | 3.20 |
| 100-year XS 4308 | Existing | 0.37 | 0.74 |
| | Alternative 1 | 0.36 | 0.72 |
| | Alternative 2 | 0.37 | 0.74 |
| | Alternative 3 | 0.36 | 0.72 |
| 100-year XS 3714 | Existing | 0.81 | 1.62 |
| | Alternative 1 | 1.20 | 2.40 |
| | Alternative 2 | 1.20 | 2.40 |
| | Alternative 3 | 1.20 | 2.40 |
| 100-year XS 3238 | Existing | 0.30 | 0.60 |
| | Alternative 1 | 0.17 | 0.34 |
| | Alternative 2 | 0.22 | 0.44 |
| | Alternative 3 | 0.21 | 0.42 |
| 100-year XS 2825 | Existing | 0.81 | 1.62 |
| | Alternative 1 | 2.34 | 4.68 |
| | Alternative 2 | 2.44 | 4.88 |
| | Alternative 3 | 2.40 | 4.80 |

* Based on an assumed bend correction factor of 2.0.

### 6.2.1 Alternative Measures

It is noted that alternative bank protection measures may be appropriate in the vicinity of the Satsop Business Park Well. The expected maximum shear stress in the vicinity of the well is relatively mild for both bankfull and 100-year conditions; a well developed vegetative cover could provide adequate erosion protection. The recommended extent of protection is shown in Figure 68. It is noted that the existing Egress Channel is very heavily vegetated in the vicinity of the well.

Table 24 Shear stress along the Egress Channel near the Satsop Business Park Well.

| Discharge | Analysis Condition | Average Shear Stress (#/ft$^2$) | Maximum Shear Stress* (#/ft$^2$) |
|---|---|---|---|
| Bankfull | Existing | 0.07 | 0.14 |
| | Alternative 1 | 1.30 | 2.60 |
| | Alternative 2 | 1.09 | 2.18 |
| | Alternative 3 | 1.05 | 2.10 |
| 100-year | Existing | 1.26 | 2.52 |
| | Alternative 1 | 2.34 | 4.68 |
| | Alternative 2 | 1.84 | 3.68 |
| | Alternative 3 | 1.82 | 3.64 |

* Based on an assumed bend correction factor of 2.0.

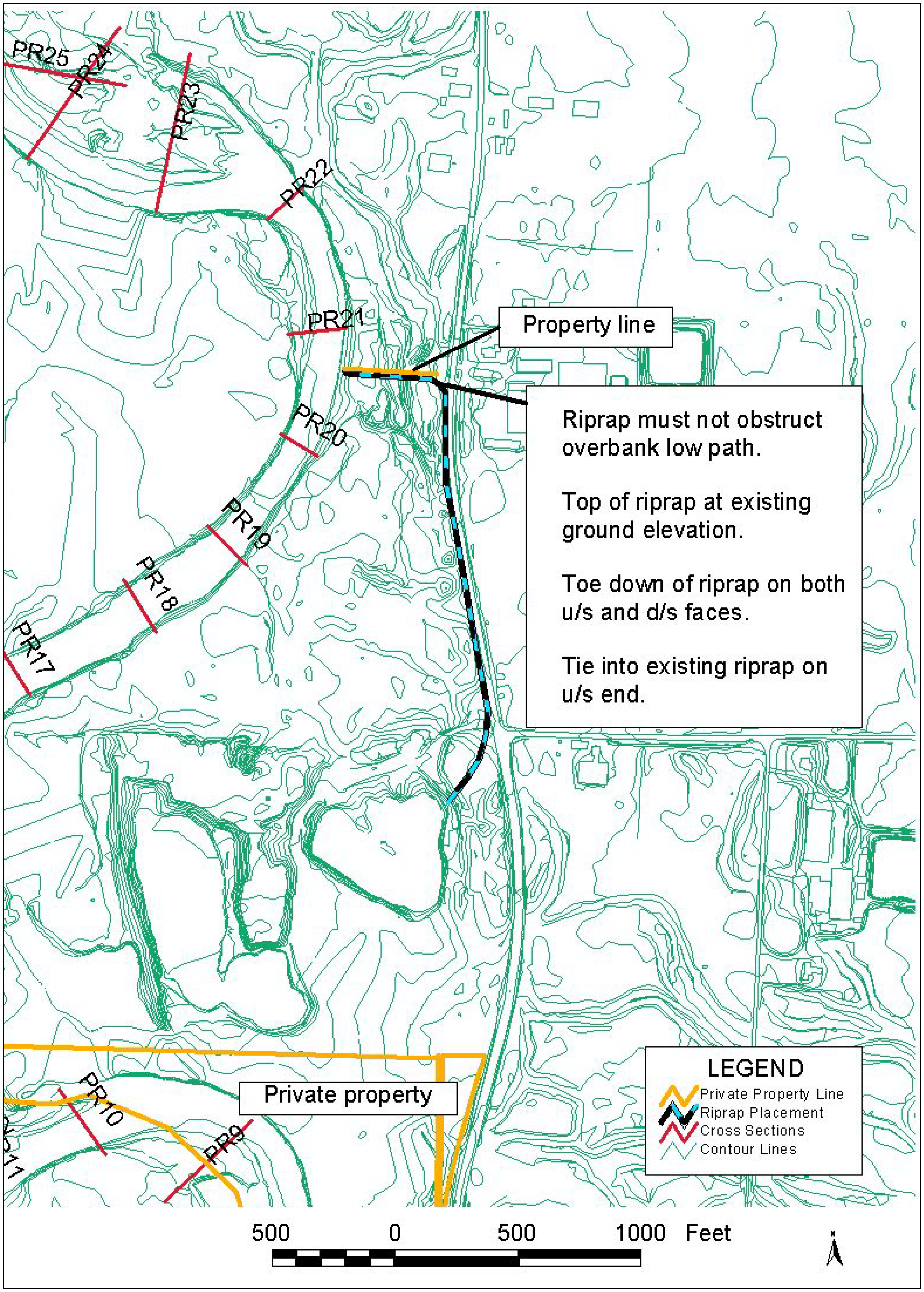



Figure 67. Location of required riprap protection for Keys Road.

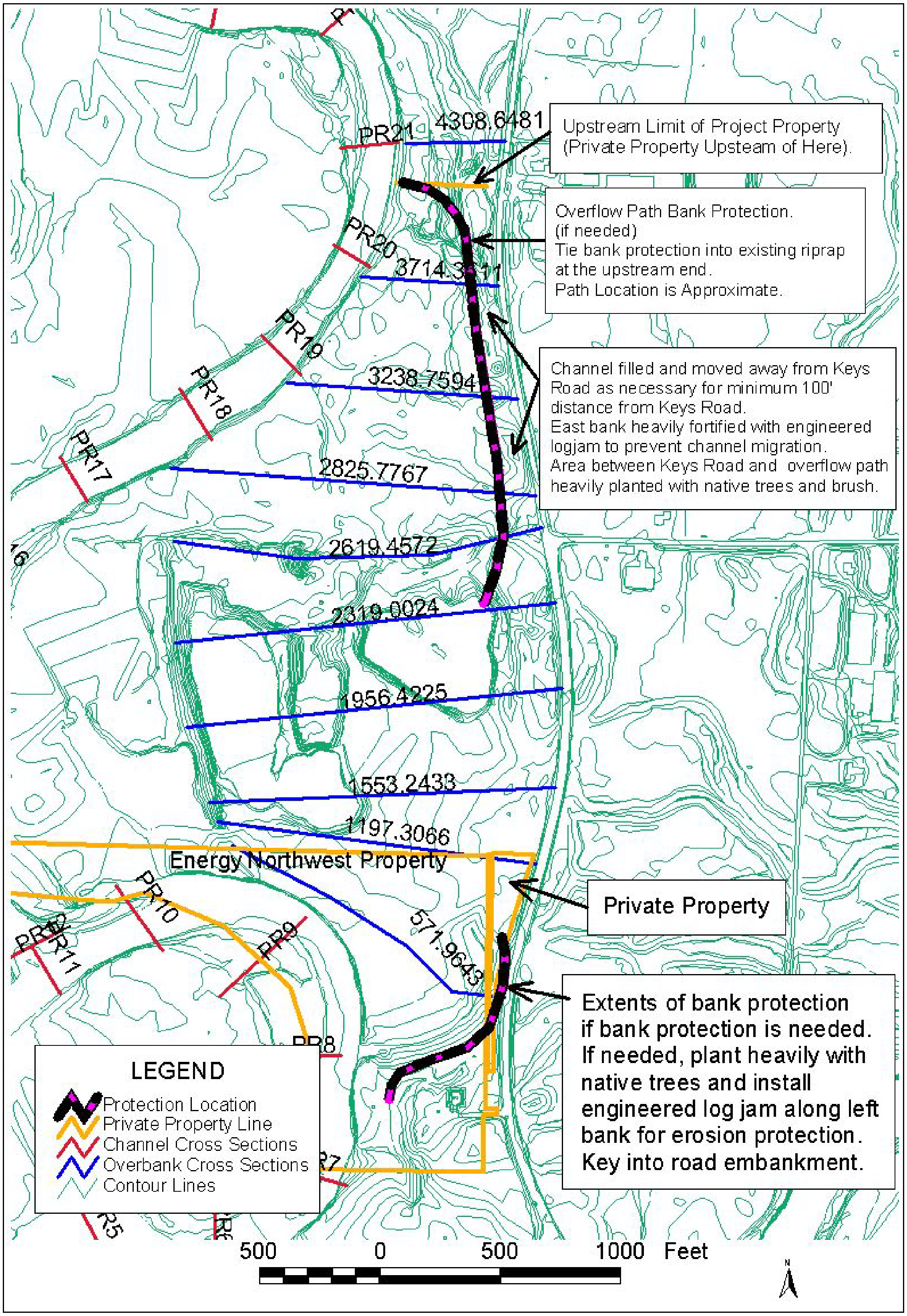



Figure 68. Alternative infrastructure protection measures.

# 7 CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the analysis include the following:

- The floodplain functions of the lower Satsop River have been altered by historic floodplain gravel mining through the excavation of 3 ponds (Ponds A, B and C) with a total volume of approximately 500,000 cubic yards (300 acre feet), construction of dikes that isolate two of the ponds from the main channel, and placement of riprap bank protection along approximately 3,000 ft of the left bank of the mainstem channel.

- The existing dikes and spoils on the project site represent approximately 123,000 cubic yards (76 acre-feet) of material.

- The discharge of the Satsop River has been gaged since 1929. The largest flood of record of 63,600 cfs occurred in March 1997 and the minimum discharge observed was 147 cfs occurred in August 1994. The bankfull discharge for the river was estimated to be 17,000 cfs and has a return period of 1.2 years.

- The broad nature of the Satsop River floodplain, highly conductive aquifer and communication between the aquifer and the adjacent Satsop and Chehalis Rivers, makes it unlikely that placement of fine materials within the existing gravel ponds would have any significant impact to the general groundwater flow pattern in the vicinity of the project.

- Hydraulic analysis of existing conditions demonstrated that the project site is subject to frequent inundation. At bankfull stage, significant flow occurs along an overflow channel along the eastern boundary of the property. During the bankfull flood, a discharge of approximately 690 cfs occurs along the overflow channel. The existing dikes on the project site and Hiram Hall Road were found to create significant obstructions to flow in overbank areas. Several low points exist in the northern dike on the project site that allow overbank flow to enter the existing ponds.

- Three alternatives for restoring floodplain functions were conceptualized. Alternative 1 consists of removal of all man-made features from the site including riprap, dikes, spoils, and culverts. Alternatives 2 and 3 include the features of Alternative 1 and additional hydraulic connections between the existing ponds and the floodplain, and between the ponds. Additionally, under both Alternatives 2 and 3, spoils are to be placed within Ponds B and C.

- Under Alternative 2 an outlet will be constructed between Pond B and the existing Egress Channel. Construction of this outlet will require a flow easement, as the Egress Channel is located on private property.
- Under Alternative 3, the outlet will connect Pond A to the mainstem channel. The construction of the outlet channel for this alternative will require an easement, as it will cross private property.

- Steady flow hydraulic analysis results for Alternatives 1, 2 and 3 are similar. The following conclusions were identified:
    - For the bankfull flow, water surface elevations will decrease along the mainstem Satsop River channel between River Stations 4224 and 9792, by as much as 0.86 feet.
    - For the 100-year flood, water surface elevations will decrease along the mainstem of up to a maximum of 2 feet between River Stations 4224 and 13555.
    - For the bankfull flow, flow velocities along the mainstem Satsop River channel adjacent to the ponds will decrease up to a maximum of 1.60 feet/second. Adjacent to the existing riprap along the left bank of the river on the project site, flow velocities along the mainstem channel will increase a maximum of 2 feet/second. Notably, velocity increases for the bankfull flow will not extend upstream of the project site.
    - For the 100-year flood, flow velocities along the mainstem channel adjacent to the ponds will reduce a maximum of 3.6 feet/second. Adjacent to the existing riprap along the left bank of the river on the project site flow velocities will increase along the mainstem channel a maximum of 2.5 feet/second. Notably, velocity increases for the 100-year flood will not extend upstream of the project site.
    - Water surface elevations will decrease for both the bankfull flow and 100-year flood upstream of the dikes to be removed.
    - Flow velocities will decreases for both the bankfull flow and 100-year flood through the portion of the Pond Reach influenced by the ponds,
    - Flow will increase along the Egress Channel portion of the Pond Reach will occur that ranges from 1,680 cfs to 2,300 cfs for the bankfull flow and 6,196 to 8,611 cfs for the 100-year flood.
    - Flow velocities will increase along the Egress Channel portion of the Pond Reach as much as 4.1 feet/second for the bankfull flow to 2.1 feet/second for the 100-year flood. Backwater conditions for the 100-year flood moderate the flow velocities along the Egress Channel.

- Unsteady flow analysis results for Alternatives 1, 2 and 3 are also similar. For the March 1997 event, the following conclusions were identified:
    - Water surface elevations along the mainstem Satsop River channel adjacent to the ponds were reduced up to 2.0 feet.
    - Flow velocities along the mainstem Satsop River channel adjacent to the ponds up were reduced up to 3 feet/second. Increased flow velocities along the mainstem channel adjacent to the existing riprap of up to 2 feet per second.
    - Flow at the Egress Channel outlet increase from 11,950 cfs under existing conditions to a maximum of 22,430 for Alternative 1.
    - An increase in the flow velocity at the outlet of the Egress Channel portion of the Pond Reach of about 1 feet/second.

- From developed stage-discharge relation and flow duration information, it is expected that the proposed hydraulic connection of Alternative 2 from Pond B to the mainstem would be interrupted during the low flow portion of the annual hydrograph. A mainstem minimum flow of 2,350 cfs is required to maintain the hydraulic connection, based on the proposed outlet elevation of 14.9 ft NGVD. A flow of 2,350 cfs is exceeded only about 25 percent of the time. However, it is noted that groundwater from the ponds can be expected to contribute flow to the outlet until the water table seasonally subsides below the outlet elevation.

- The proposed outlet from Pond A associated with Alternative 3 is expected to maintain a hydraulic connection to the mainstem throughout the year. The 13.0 ft elevation of the outlet is noted to be lower than the stage associated with the lowest observed flow of record (147 cfs).

- Significant lengths of the banks within the study area are eroding. Typically, the erosion is located along the outside of the numerous meander bends. The notable exception to the bank erosion was the approximate 3,000 ft length of riprap reveted portion of the channel along the left bank adjacent to the project area. The toe of the bank in that location is armored and dense small diameter trees were established on the overbank above the riprap. However, several sections of the riprap were found to have failed and were missing.

- Significant quantities of large woody debris exist through the study area and were observed to collect along the outside of bends, at the apex of bars and within meander cutoff channels. The debris is a significant influence on the occurrence of bank erosion, channel switching, and cutoff of meanders.

- The mainstem channel through the study area was determined to have a relatively uniform channel profile slope of about 0.0015 or 7.7 feet per mile. The bridges at the upstream limit of the study area were observed to have a significant influence on the profile due to flow contraction and scour. The greatest variability of approximately 10 feet in the channel profile was noted to be adjacent to the riprap along the left bank adjacent to the project site. Pools in the study area were also measured to have a maximum depth of about 10 feet.

- The length of the river within the study area has varied considerably through time due to meander development and avulsions. The available data suggests a 50 year cycle of meander creation and cutoff. Despite the control of upstream bridges, several large bends are noted to be developing upstream of the project site and downstream of existing bridges. Further enlargement of these bends may occur and could result in a westward relocation of the mainstem channel. Future cutoffs of several large bends near the confluence of the Chehalis River can also be expected.

- Historic channel location data shows the Lower Satsop River to be an actively meandering river that has been significantly influenced by the placement of riprap on the project site. Comparison of 2003 aerial photography to prior channel migration data demonstrate that trends and rates of migration since 1997 are similar to those observed before 1997. Rates of migration of 40 to 50 ft per year were noted along the lower half of the study area. The entire project area is noted to be within the unmitigated extreme channel migration area of the river. Removal of existing riprap along the left bank of the channel on the project site can be expected to result in the migration of the mainstem river to Keys Road and capture of the existing gravel mine ponds.

- Bed material size characteristics in the study area were found to relatively uniform comprised of predominantly gravel-sized material and a smaller percentage of sand.

- Suspended sediment transport measurements along the Satsop River indicate a mean annual suspended sediment yield of about 240,000 tons/year.

- Bed load transport estimates based on various methods indicate an annual rate of about 10,000 cubic yards/year (8,000 tons/year). Bed load transport calculations for the proposed alternatives show that the removal of dikes and other obstructions in the floodplain will increase bed load transport capacity of the river adjacent to the existing riprap adjacent to the project, downstream of the riprap the bed load transport capacity will be reduced. Armoring of the channel is expected to limit the actual bed load transport ability of the river, and associated degradation or aggradation.

- Consistent with the bed load transport analysis results, incipient motion calculations for the various analysis conditions indicate that slight increases in the maximum incipient particle size will occur along the mainstem channel along the riprap adjacent to the project site for the bankfull flow and 100-year flood. Decreases in the incipient particle size are expected along the mainstem adjacent to the existing ponds due to the expanded flow area.

- Assuming the ponds on the project site are captured by the river, the time to fill the existing ponds to the elevation of the existing channel thalweg was estimated to range from approximately 7 years to nearly 30 years based on a range of assumed sediment supplies. Reducing the volume of the ponds by the placement of spoils within them substantially reduces the expected time to fill the pond with natural sediment supplies.

- For all analysis conditions, the short-term headcut depths were estimated to range from 3 to 5 feet and upstream headcut distances were estimated to range from 44 to 1,400 feet, if captured by the river. The existing bridges are nearly 5,800 feet upstream from the existing ponds.
- Over the long-term, capture of the ponds by the river will induce a variety of adjustments to the upstream and downstream river profile, plan form, and bank stability characteristics. The specific impacts will be dependent on the manner in which the ponds are captured and the hydrologic sequence that occurs after that time.

- No significant difference in scour conditions at the upstream bridges was identified for the various analysis conditions considered.

Recommendations of the study include the following:

- Alternative 3 is recommended as the preferred alternative since the outlet from the existing pond system will connect directly to the mainstem Satsop River, a year round hydraulic connection to the mainstem channel can be maintained, and the lowest increase of flow along the Egress Channel will occur under this plan.

- If the existing riprap is removed from the left bank of the river along the project site, a riprap revetment should be constructed along Keys Road to protect the road and natural gas pipeline along it. Size requirements for the riprap revetment are defined based on main channel hydraulic conditions. Alternative erosion protection measures including vegetative plantings and engineered log jam structures could also be utilized. Due to the proximity of the existing overflow channel to the Keys Road embankment, the overflow channel should be relocated to the west if alternative erosion control measures are used.

- If the riprap along the main channel is not removed, migration of the mainstem to Keys Road is not expected in the short-term and riprap erosion protection requirements are determined based on overbank hydraulic conditions. Alternative erosion protection measures, including vegetative plantings and engineered log jam structures could also be utilized.

- Flow increases along the Egress Channel associated with alternative conditions require consideration of erosion protection measures for the Satsop Business Park Well. Riprap size requirements were identified, assuming that the riprap along the mainstem will not be removed, and the mainstem will not migrate to the Egress Channel. Alternative erosion control measures could also be utilized in place of riprap. A well-developed vegetative cover would provide adequate erosion protection. It is noted that under existing conditions, the Egress Channel is already heavily vegetated in the vicinity of the well. Maintenance of the existing conditions of vegetation should provide adequate protection for the well.

- If the riprap along the mainstem channel is removed, or fails, migration of the mainstem channel to the Egress Channel is possible. Protection of the Satsop Business Park Well would require a revetment designed for mainstem hydraulic conditions, similar to those defined for Keys Road or relocation of the well.
- A detailed monitoring plan for the hydrologic, hydraulic, geomorphic, and water quality characteristics of the project area should be developed to provide a basis for assessing project success, documenting project impacts, and adaptively managing any unforeseen circumstances. Suggestions for monitoring include:

    - Collection, review, and comparison of aerial photography for the lower Satsop River.
    - Photographic documentation of specific viewpoints within the vicinity of the project.

- Establishment of sedimentation ranges through the study area that could be periodically resurveyed to define channel aggradation or degradation, headcuts, bank stability, and possible channel development in overbank areas.
- Pond water level data should continue to be collected to understand groundwater table variability.
- Survey and assessment of erosion control measures for stability and effectiveness
- Water quality data for the Satsop Business Park Well.

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Seattle District

# ADDENDUM TO SATSOP RIVER FLOODPLAIN RESTORATION PROJECT


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June 15, 2004

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# 1 INTRODUCTION

A study to characterize existing conditions along the lower Satsop River and assess potential physical changes and risks associated with three floodplain restoration alternatives (Alternatives 1, 2 and 3) was previously conducted (WEST, 2004). This addendum evaluates a fourth restoration alternative (Alternative 3B) for the Satsop River project site. Alternative 3B is the same as Alternative 3 with the exception that the existing southern dike on the project site is retained.

# 2 HYDRAULIC ANALYSIS

A feasibility-level hydraulic analysis of the lower Satsop River was conducted. Details of hydraulic model development and calibration were previously described (WEST, 2004). The hydraulic analysis used the Corps of Engineers HEC-RAS Version 3.1.1 computer program (COE, 2003c).

## 2.1 Analysis Conditions

Hydraulic models for existing conditions and four restoration alternatives were developed. The objective of the analysis was to provide data and information necessary to characterize existing conditions and allow identification and evaluation of hydraulic impacts associated with the alternatives. Descriptions of Existing and Alternative 1, 2, and 3 analysis conditions were previously presented (WEST, 2004).

### 2.1.1 Alternative 3B

Alternative 3B is the same as Alternative 3 except that the south levee is left in place, as it is for existing conditions. The south levee is located south of Pond C and the eastern lobe of Pond B.

## 2.2 Steady Flow Modeling Results

For all analysis conditions considered the backwater effects of the Chehalis River are a significant influence for all flood events. Under typical bankfull flow conditions, the lower Satsop River floodplain will be inundated to approximately elevation 19.7 ft NGVD. As the elevation of the project site ranges from about 17 to 25 ft NGVD, the majority of the site will be flooded due to backwater for even a nominal flood event.

Additionally, the relatively flat nature of the overbank areas results in a broad floodplain that presents complex flow patterns. For moderate floods, the flow patterns in overbank areas are influenced by relatively subtle changes in the overbank topography, whereas for large floods the boundaries of the floodplain become less confined and less distinct from the broad Chehalis River floodplain. Consequently, the hydraulic modeling effort is subject to the limitations associated with one-dimensional modeling techniques and does not describe two-dimensional flow conditions. Furthermore, it should be recognized that the lower Satsop River is dynamic, continuously eroding and depositing sediment and debris, and the developed hydraulic models can only represent the conditions at the time the involved data were collected.

A summary of hydraulic parameters for each of the analysis conditions is shown in Table 1 for the bankfull flood and in Table 2 for the 100-year flood. Water surface profiles are shown in Figure 1 and Figure 2 for the bankfull flow and Figure 3 and Figure 4 for the 100-year flood.

In the following sections the results of the steady flow hydraulic modeling for each of the analysis conditions are summarized.

### 2.2.1 Existing Conditions

Significant conclusions of the hydraulic modeling for existing conditions include the following:

- Existing dikes on the project site and the Hiram Hall Road create significant obstructions to flow in overbank areas.
- Several low points exist in the northern dike on the project site.
- During the bankfull flood a discharge of approximately 690 cfs flows back into the Satsop River at the downstream end of the Pond Reach.
- Field observations made during an approximate 5-year flood event in October 2003 generally confirm the existing conditions hydraulic modeling results.

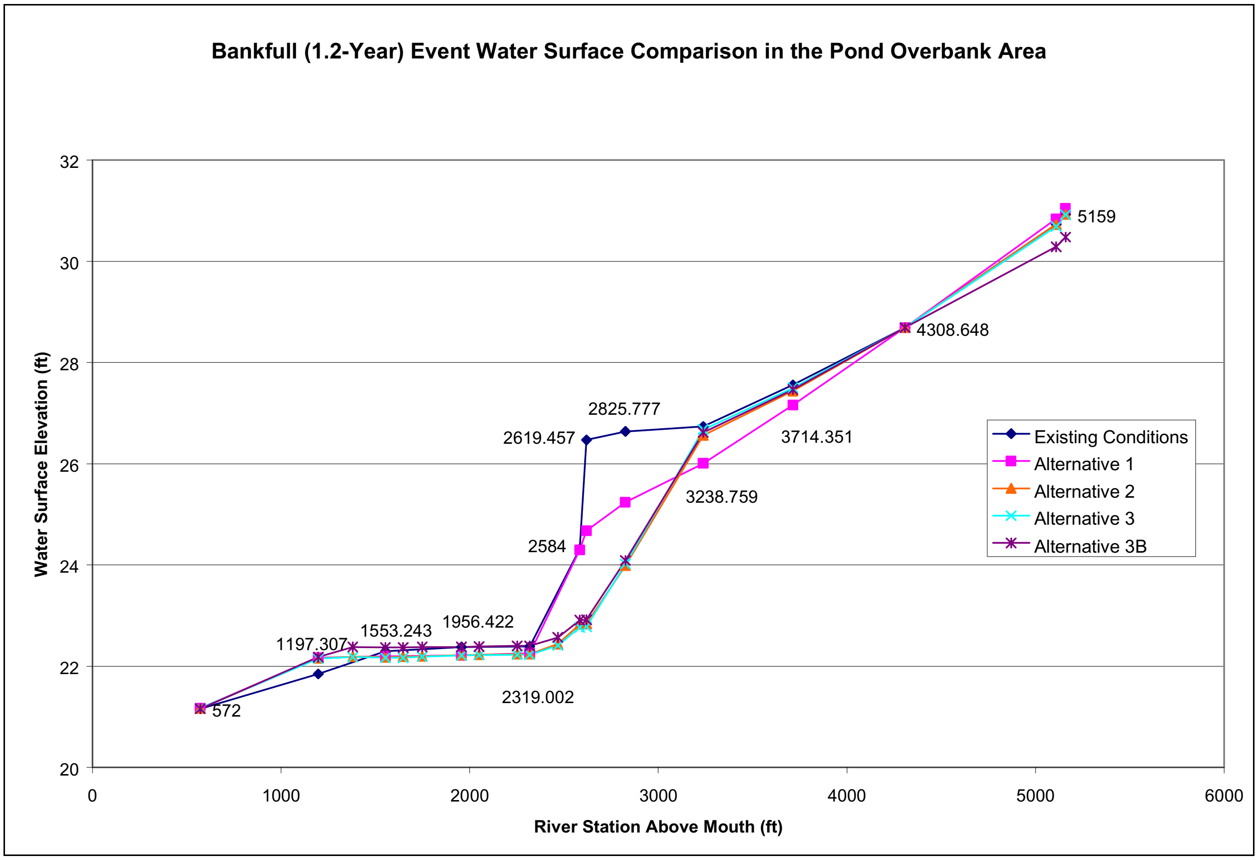


Figure 1 Water surface profile for the bankfull flow in the Pond Overbank Reach area for Existing Conditions, Alternatives 1, 2, 3, and 3B.

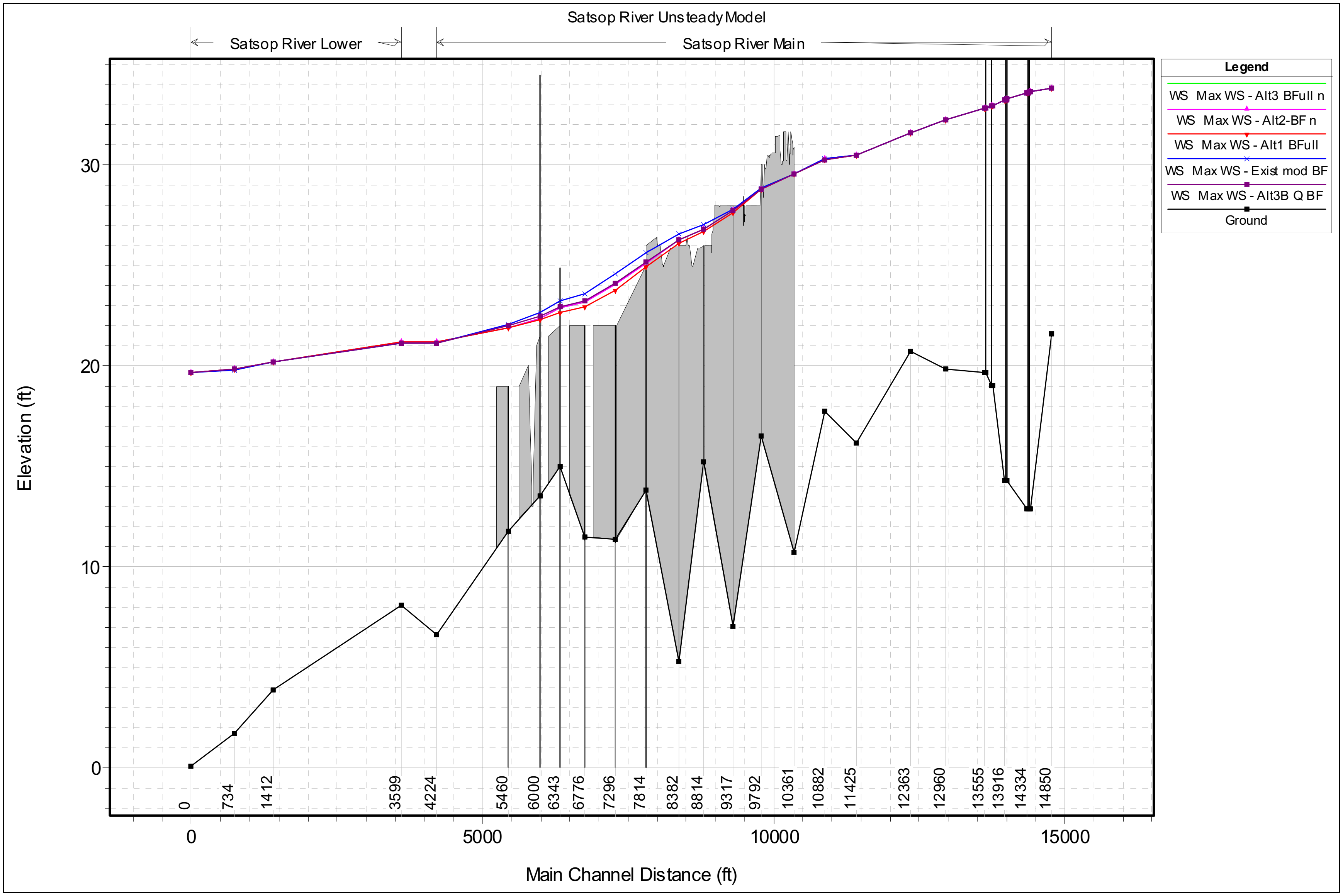


Figure 2 Water surface profile for bankfull flow on the Mainstem Satsop River for Existing Conditions, Alternatives 1, 2, 3, and 3B.

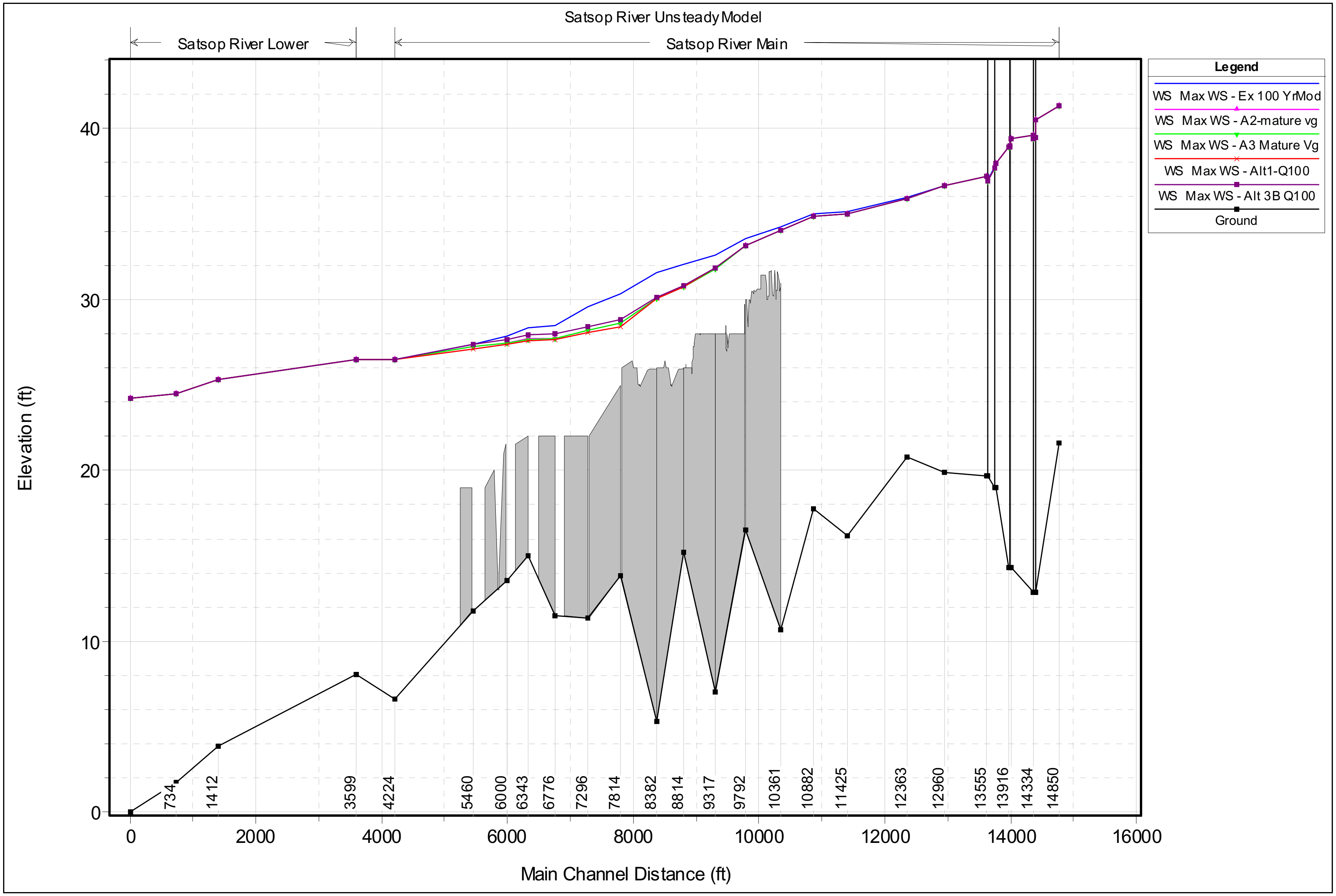


Figure 3

Water surface profile for the 100-year flow on the Mainstem Satsop River for Existing Conditions, and Alternatives 1, 2, 3, and 3B.

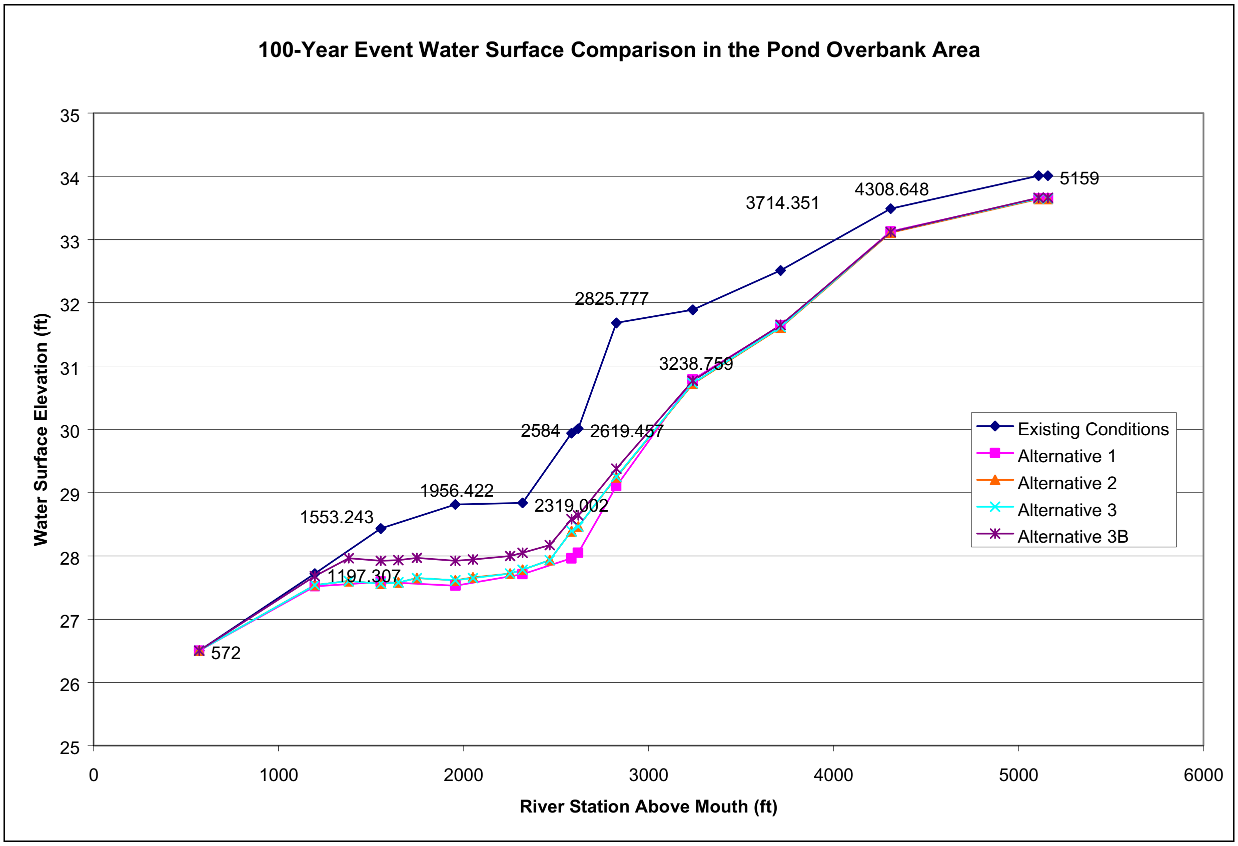


Figure 4 Water surface profiles for the 100-year flow in the Pond Reach area for Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Table 1 Satsop River parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 14850 | Max WS | Alt3 BFull n | 17000.00 | 33.83 | 0.000915 | 6.06 | 10.79 | 9.59 | 0.61 |
| Main | 14850 | Max WS | Alt2-BF n | 17000.00 | 33.83 | 0.000915 | 6.06 | 10.78 | 9.59 | 0.61 |
| Main | 14850 | Max WS | Alt1 BFull | 17000.00 | 33.83 | 0.000915 | 6.06 | 10.78 | 9.59 | 0.61 |
| Main | 14850 | Max WS | Exist mod BF | 17000.00 | 33.83 | 0.000914 | 6.06 | 10.79 | 9.59 | 0.61 |
| Main | 14850 | Max WS | Alt3B Q BF | 17000.00 | 33.83 | 0.000915 | 6.06 | 10.78 | 9.59 | 0.61 |
| | | | | | | | | | | |
| Main | 14467 | Max WS | Alt3 BFull n | 16999.99 | 33.67 | 0.000600 | 5.32 | 12.57 | 7.58 | 0.45 |
| Main | 14467 | Max WS | Alt2-BF n | 17000.00 | 33.67 | 0.000600 | 5.32 | 12.57 | 7.58 | 0.45 |
| Main | 14467 | Max WS | Alt1 BFull | 17000.00 | 33.67 | 0.000600 | 5.32 | 12.57 | 7.58 | 0.45 |
| Main | 14467 | Max WS | Exist mod BF | 17000.00 | 33.67 | 0.000599 | 5.32 | 12.57 | 7.58 | 0.45 |
| Main | 14467 | Max WS | Alt3B Q BF | 16999.99 | 33.67 | 0.000600 | 5.32 | 12.57 | 7.58 | 0.45 |
| | | | | | | | | | | |
| Main | 14334 | Max WS | Alt3 BFull n | 17000.00 | 33.62 | 0.000613 | 5.36 | 12.51 | 7.46 | 0.46 |
| Main | 14334 | Max WS | Alt2-BF n | 17000.00 | 33.61 | 0.000613 | 5.36 | 12.51 | 7.46 | 0.46 |
| Main | 14334 | Max WS | Alt1 BFull | 17000.00 | 33.61 | 0.000613 | 5.36 | 12.51 | 7.46 | 0.46 |
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| Main | 14334 | Max WS | Alt3B Q BF | 16999.99 | 33.61 | 0.000613 | 5.36 | 12.51 | 7.46 | 0.46 |
| | | | | | | | | | | |
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| Main | 14066 | Max WS | Alt1 BFull | 17000.00 | 33.30 | 0.001077 | 5.53 | 8.53 | 6.73 | 0.55 |
| Main | 14066 | Max WS | Exist mod BF | 16999.99 | 33.31 | 0.001077 | 5.53 | 8.53 | 6.73 | 0.55 |
| Main | 14066 | Max WS | Alt3B Q BF | 16999.99 | 33.31 | 0.001077 | 5.53 | 8.53 | 6.73 | 0.55 |
| | | | | | | | | | | |
| Main | 13916 | Max WS | Alt3 BFull n | 16999.99 | 33.23 | 0.001088 | 5.59 | 8.61 | 6.77 | 0.56 |
| Main | 13916 | Max WS | Alt2-BF n | 17000.00 | 33.23 | 0.001088 | 5.59 | 8.61 | 6.77 | 0.56 |
| Main | 13916 | Max WS | Alt1 BFull | 17000.00 | 33.23 | 0.001088 | 5.59 | 8.61 | 6.77 | 0.57 |
| Main | 13916 | Max WS | Exist mod BF | 16999.99 | 33.23 | 0.001087 | 5.59 | 8.61 | 6.76 | 0.56 |
| Main | 13916 | Max WS | Alt3B Q BF | 16999.99 | 33.23 | 0.001088 | 5.59 | 8.61 | 6.77 | 0.56 |
| | | | | | | | | | | |
| Main | 13825 | Max WS | Alt3 BFull n | 16999.99 | 32.97 | 0.000920 | 5.81 | 10.19 | 8.43 | 0.57 |
| Main | 13825 | Max WS | Alt2-BF n | 16999.99 | 32.97 | 0.000920 | 5.81 | 10.19 | 8.43 | 0.57 |
| Main | 13825 | Max WS | Alt1 BFull | 17000.00 | 32.96 | 0.000921 | 5.81 | 10.19 | 8.43 | 0.57 |
| Main | 13825 | Max WS | Exist mod BF | 16999.99 | 32.97 | 0.000920 | 5.81 | 10.19 | 8.43 | 0.57 |
| Main | 13825 | Max WS | Alt3B Q BF | 16999.98 | 32.96 | 0.000921 | 5.81 | 10.19 | 8.43 | 0.57 |
| | | | | | | | | | | |
| Main | 13555 | Max WS | Alt3 BFull n | 16999.99 | 32.86 | 0.000984 | 5.84 | 9.77 | 6.08 | 0.59 |
| Main | 13555 | Max WS | Alt2-BF n | 17000.00 | 32.86 | 0.000984 | 5.84 | 9.77 | 6.08 | 0.59 |
| Main | 13555 | Max WS | Alt1 BFull | 16999.99 | 32.86 | 0.000985 | 5.84 | 9.77 | 6.08 | 0.59 |
| Main | 13555 | Max WS | Exist mod BF | 16999.99 | 32.86 | 0.000983 | 5.84 | 9.77 | 6.08 | 0.59 |
| Main | 13555 | Max WS | Alt3B Q BF | 16999.98 | 32.86 | 0.000984 | 5.84 | 9.77 | 6.08 | 0.59 |

Table 1 (cont). Satsop River parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 12960 | Max WS | Alt3 BFull n | 16999.99 | 32.27 | 0.001174 | 4.79 | 6.38 | 3.32 | 0.46 |
| Main | 12960 | Max WS | Alt2-BF n | 17000.01 | 32.27 | 0.001175 | 4.79 | 6.38 | 3.32 | 0.46 |
| Main | 12960 | Max WS | Alt1 BFull | 16999.96 | 32.27 | 0.001177 | 4.79 | 6.38 | 3.32 | 0.46 |
| Main | 12960 | Max WS | Exist mod BF | 16999.96 | 32.27 | 0.001173 | 4.79 | 6.38 | 3.32 | 0.46 |
| Main | 12960 | Max WS | Alt3B Q BF | 16999.96 | 32.27 | 0.001176 | 4.79 | 6.38 | 3.32 | 0.46 |
| | | | | | | | | | | |
| Main | 12363 | Max WS | Alt3 BFull n | 16999.96 | 31.59 | 0.001375 | 4.68 | 5.39 | 3.27 | 0.46 |
| Main | 12363 | Max WS | Alt2-BF n | 16999.98 | 31.59 | 0.001377 | 4.68 | 5.38 | 3.27 | 0.46 |
| Main | 12363 | Max WS | Alt1 BFull | 16999.90 | 31.58 | 0.001382 | 4.69 | 5.38 | 3.27 | 0.46 |
| Main | 12363 | Max WS | Exist mod BF | 16999.95 | 31.59 | 0.001371 | 4.68 | 5.39 | 3.27 | 0.46 |
| Main | 12363 | Max WS | Alt3B Q BF | 16999.96 | 31.59 | 0.001377 | 4.68 | 5.38 | 3.27 | 0.46 |
| | | | | | | | | | | |
| Main | 11425 | Max WS | Alt3 BFull n | 16999.83 | 30.50 | 0.001405 | 4.79 | 5.49 | 3.16 | 0.48 |
| Main | 11425 | Max WS | Alt2-BF n | 16999.81 | 30.49 | 0.001413 | 4.80 | 5.48 | 3.15 | 0.48 |
| Main | 11425 | Max WS | Alt1 BFull | 16999.61 | 30.48 | 0.001428 | 4.81 | 5.47 | 3.14 | 0.48 |
| Main | 11425 | Max WS | Exist mod BF | 16999.86 | 30.51 | 0.001394 | 4.78 | 5.50 | 3.17 | 0.47 |
| Main | 11425 | Max WS | Alt3B Q BF | 16999.88 | 30.49 | 0.001414 | 4.80 | 5.48 | 3.15 | 0.48 |
| | | | | | | | | | | |
| Main | 10882 | Max WS | Alt3 BFull n | 16999.81 | 30.30 | 0.000278 | 2.68 | 7.78 | 4.40 | 0.13 |
| Main | 10882 | Max WS | Alt2-BF n | 16999.74 | 30.29 | 0.000279 | 2.69 | 7.77 | 4.41 | 0.13 |
| Main | 10882 | Max WS | Alt1 BFull | 16999.44 | 30.27 | 0.000282 | 2.69 | 7.75 | 4.42 | 0.13 |
| Main | 10882 | Max WS | Exist mod BF | 16999.79 | 30.31 | 0.000276 | 2.68 | 7.79 | 4.40 | 0.13 |
| Main | 10882 | Max WS | Alt3B Q BF | 16999.84 | 30.29 | 0.000280 | 2.69 | 7.77 | 4.41 | 0.13 |
| | | | | | | | | | | |
| Main | 10361 | Max WS | Alt3 BFull n | 16999.38 | 29.57 | 0.001417 | 7.15 | 10.32 | 2.85 | 0.87 |
| Main | 10361 | Max WS | Alt2-BF n | 16999.51 | 29.56 | 0.001423 | 7.16 | 10.32 | 2.85 | 0.88 |
| Main | 10361 | Max WS | Alt1 BFull | 16998.94 | 29.53 | 0.001433 | 7.19 | 10.32 | 2.85 | 0.88 |
| Main | 10361 | Max WS | Exist mod BF | 16999.60 | 29.59 | 0.001416 | 7.13 | 10.28 | 2.84 | 0.87 |
| Main | 10361 | Max WS | Alt3B Q BF | 16999.61 | 29.55 | 0.001423 | 7.16 | 10.32 | 2.85 | 0.88 |
| | | | | | | | | | | |
| Main | 9792 | Max WS | Alt3 BFull n | 17118.02 | 28.83 | 0.001708 | 6.54 | 7.61 | 2.76 | 0.80 |
| Main | 9792 | Max WS | Alt2-BF n | 17113.26 | 28.81 | 0.001724 | 6.56 | 7.59 | 2.75 | 0.81 |
| Main | 9792 | Max WS | Alt1 BFull | 17135.70 | 28.77 | 0.001769 | 6.62 | 7.56 | 2.73 | 0.82 |
| Main | 9792 | Max WS | Exist mod BF | 17063.65 | 28.86 | 0.001671 | 6.48 | 7.63 | 2.78 | 0.79 |
| Main | 9792 | Max WS | Alt3B Q BF | 17041.67 | 28.82 | 0.001703 | 6.52 | 7.60 | 2.76 | 0.80 |
| | | | | | | | | | | |
| Main | 9317 | Max WS | Alt3 BFull n | 16756.92 | 27.75 | 0.002049 | 8.53 | 10.31 | 2.90 | 1.25 |
| Main | 9317 | Max WS | Alt2-BF n | 16769.42 | 27.72 | 0.002080 | 8.59 | 10.31 | 2.88 | 1.27 |
| Main | 9317 | Max WS | Alt1 BFull | 16882.00 | 27.62 | 0.002177 | 8.78 | 10.30 | 2.93 | 1.32 |
| Main | 9317 | Max WS | Exist mod BF | 16727.11 | 27.81 | 0.001997 | 8.42 | 10.32 | 2.91 | 1.22 |
| Main | 9317 | Max WS | Alt3B Q BF | 16742.79 | 27.74 | 0.002058 | 8.54 | 10.31 | 2.89 | 1.25 |

Table 1 (cont). Satsop River parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 8814 | Max WS | Alt3 BFull n | 17017.25 | 26.83 | 0.002103 | 7.75 | 8.50 | 1.95 | 1.09 |
| Main | 8814 | Max WS | Alt2-BF n | 16875.47 | 26.81 | 0.002097 | 7.73 | 8.48 | 1.95 | 1.08 |
| Main | 8814 | Max WS | Alt1 BFull | 16643.56 | 26.70 | 0.002174 | 7.82 | 8.40 | 1.89 | 1.11 |
| Main | 8814 | Max WS | Exist mod BF | 16635.12 | 27.05 | 0.001781 | 7.21 | 8.65 | 2.10 | 0.94 |
| Main | 8814 | Max WS | Alt3B Q BF | 16947.17 | 26.82 | 0.002097 | 7.74 | 8.49 | 1.95 | 1.08 |
| | | | | | | | | | | |
| Main | 8382 | Max WS | Alt3 BFull n | 16293.90 | 26.30 | 0.001215 | 6.41 | 9.80 | 3.27 | 0.71 |
| Main | 8382 | Max WS | Alt2-BF n | 16180.71 | 26.27 | 0.001211 | 6.39 | 9.78 | 3.26 | 0.71 |
| Main | 8382 | Max WS | Alt1 BFull | 16090.75 | 26.13 | 0.001277 | 6.51 | 9.66 | 3.18 | 0.74 |
| Main | 8382 | Max WS | Exist mod BF | 15789.10 | 26.60 | 0.000999 | 5.91 | 10.04 | 3.29 | 0.60 |
| Main | 8382 | Max WS | Alt3B Q BF | 16234.20 | 26.29 | 0.001210 | 6.39 | 9.79 | 3.26 | 0.71 |
| | | | | | | | | | | |
| Main | 7814 | Max WS | Alt3 BFull n | 16149.61 | 25.15 | 0.002301 | 8.67 | 9.57 | 3.28 | 1.32 |
| Main | 7814 | Max WS | Alt2-BF n | 16046.64 | 25.14 | 0.002289 | 8.64 | 9.55 | 3.27 | 1.31 |
| Main | 7814 | Max WS | Alt1 BFull | 16022.94 | 24.92 | 0.002444 | 8.80 | 9.35 | 3.54 | 1.37 |
| Main | 7814 | Max WS | Exist mod BF | 16391.89 | 25.63 | 0.001899 | 8.11 | 10.01 | 3.82 | 1.14 |
| Main | 7814 | Max WS | Alt3B Q BF | 16092.31 | 25.15 | 0.002284 | 8.64 | 9.57 | 3.28 | 1.31 |
| | | | | | | | | | | |
| Main | 7296 | Max WS | Alt3 BFull n | 15410.92 | 24.10 | 0.003224 | 8.12 | 6.56 | 3.03 | 1.30 |
| Main | 7296 | Max WS | Alt2-BF n | 15319.93 | 24.09 | 0.003203 | 8.09 | 6.56 | 3.03 | 1.29 |
| Main | 7296 | Max WS | Alt1 BFull | 14875.11 | 23.75 | 0.003524 | 8.38 | 6.43 | 3.66 | 1.39 |
| Main | 7296 | Max WS | Exist mod BF | 16391.89 | 24.61 | 0.002955 | 7.90 | 6.72 | 3.11 | 1.22 |
| Main | 7296 | Max WS | Alt3B Q BF | 15342.00 | 24.12 | 0.003162 | 8.05 | 6.57 | 3.04 | 1.28 |
| | | | | | | | | | | |
| Main | 6776 | Max WS | Alt3 BFull n | 14384.91 | 23.20 | 0.001874 | 6.88 | 7.66 | 4.67 | 0.88 |
| Main | 6776 | Max WS | Alt2-BF n | 14301.01 | 23.20 | 0.001854 | 6.84 | 7.66 | 4.67 | 0.87 |
| Main | 6776 | Max WS | Alt1 BFull | 13203.53 | 22.94 | 0.001752 | 6.60 | 7.56 | 4.71 | 0.82 |
| Main | 6776 | Max WS | Exist mod BF | 16391.88 | 23.59 | 0.002075 | 7.33 | 7.80 | 5.13 | 1.00 |
| Main | 6776 | Max WS | Alt3B Q BF | 14285.80 | 23.26 | 0.001805 | 6.77 | 7.68 | 4.72 | 0.85 |
| | | | | | | | | | | |
| Main | 6343 | Max WS | Alt3 BFull n | 14195.68 | 22.89 | 0.001251 | 4.26 | 5.03 | 3.63 | 0.39 |
| Main | 6343 | Max WS | Alt2-BF n | 14112.17 | 22.90 | 0.001236 | 4.23 | 5.03 | 3.63 | 0.38 |
| Main | 6343 | Max WS | Alt1 BFull | 12517.92 | 22.68 | 0.001135 | 3.97 | 4.87 | 3.59 | 0.34 |
| Main | 6343 | Max WS | Exist mod BF | 16391.88 | 23.26 | 0.001292 | 4.48 | 5.30 | 3.98 | 0.42 |
| Main | 6343 | Max WS | Alt3B Q BF | 14080.39 | 22.97 | 0.001165 | 4.14 | 5.09 | 3.68 | 0.37 |
| | | | | | | | | | | |
| Main | 6000 | Max WS | Alt3 BFull n | 13957.37 | 22.35 | 0.001721 | 5.76 | 6.23 | 3.12 | 0.66 |
| Main | 6000 | Max WS | Alt2-BF n | 13872.44 | 22.36 | 0.001689 | 5.72 | 6.24 | 3.13 | 0.65 |
| Main | 6000 | Max WS | Alt1 BFull | 11457.79 | 22.29 | 0.001200 | 4.78 | 6.17 | 3.12 | 0.46 |
| Main | 6000 | Max WS | Exist mod BF | 16391.88 | 22.65 | 0.001984 | 6.38 | 6.53 | 3.46 | 0.80 |
| Main | 6000 | Max WS | Alt3B Q BF | 13808.20 | 22.48 | 0.001568 | 5.57 | 6.36 | 3.23 | 0.62 |

Table 1 (cont). Satsop River parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 5460 | Max WS | Alt3 BFull n | 13407.39 | 21.90 | 0.000416 | 2.62 | 5.55 | 4.70 | 0.14 |
| Main | 5460 | Max WS | Alt2-BF n | 13355.91 | 21.91 | 0.000444 | 2.71 | 5.56 | 4.64 | 0.15 |
| Main | 5460 | Max WS | Alt1 BFull | 14115.41 | 21.87 | 0.000511 | 2.89 | 5.52 | 4.64 | 0.17 |
| Main | 5460 | Max WS | Exist mod BF | 16391.88 | 22.09 | 0.000606 | 3.23 | 5.74 | 4.40 | 0.21 |
| Main | 5460 | Max WS | Alt3B Q BF | 14602.32 | 22.03 | 0.000459 | 2.79 | 5.68 | 4.40 | 0.16 |
| | | | | | | | | | | |
| Main | 4225 | Max WS | Alt3 BFull n | 14728.89 | 21.17 | 0.001030 | 5.80 | 9.41 | 3.94 | 0.59 |
| Main | 4225 | Max WS | Alt2-BF n | 14685.89 | 21.17 | 0.001024 | 5.78 | 9.41 | 3.94 | 0.59 |
| Main | 4225 | Max WS | Alt3B Q BF | 16093.29 | 21.16 | 0.001230 | 6.34 | 9.41 | 3.94 | 0.70 |
| | | | | | | | | | | |
| Main | 4224 | Max WS | Alt3 BFull n | 14728.90 | 21.17 | 0.001030 | 5.80 | 9.41 | 3.94 | 0.59 |
| Main | 4224 | Max WS | Alt2-BF n | 14685.91 | 21.17 | 0.001024 | 5.78 | 9.41 | 3.94 | 0.59 |
| Main | 4224 | Max WS | Alt1 BFull | 14114.98 | 21.17 | 0.000945 | 5.56 | 9.41 | 3.81 | 0.54 |
| Main | 4224 | Max WS | Exist mod BF | 16391.88 | 21.16 | 0.001276 | 6.46 | 9.41 | 3.81 | 0.73 |
| Main | 4224 | Max WS | Alt3B Q BF | 16093.28 | 21.16 | 0.001231 | 6.34 | 9.41 | 3.94 | 0.70 |
| | | | | | | | | | | |
| Lower | 3599 | Max WS | Alt3 BFull n | 17099.99 | 21.17 | 0.001046 | 5.46 | 8.48 | 4.39 | 0.54 |
| Lower | 3599 | Max WS | Alt2-BF n | 17100.01 | 21.17 | 0.001046 | 5.46 | 8.48 | 4.39 | 0.54 |
| Lower | 3599 | Max WS | Alt1 BFull | 17100.01 | 21.17 | 0.001046 | 5.46 | 8.48 | 4.39 | 0.54 |
| Lower | 3599 | Max WS | Exist mod BF | 17080.00 | 21.16 | 0.001045 | 5.45 | 8.48 | 4.38 | 0.54 |
| Lower | 3599 | Max WS | Alt3B Q BF | 17080.01 | 21.16 | 0.001045 | 5.45 | 8.48 | 4.38 | 0.54 |
| | | | | | | | | | | |
| Lower | 1412 | Max WS | Alt3 BFull n | 17099.97 | 20.22 | 0.000720 | 5.03 | 9.91 | 3.68 | 0.44 |
| Lower | 1412 | Max WS | Alt2-BF n | 17100.01 | 20.22 | 0.000720 | 5.03 | 9.91 | 3.68 | 0.44 |
| Lower | 1412 | Max WS | Alt1 BFull | 17100.01 | 20.22 | 0.000720 | 5.03 | 9.91 | 3.68 | 0.44 |
| Lower | 1412 | Max WS | Exist mod BF | 17079.96 | 20.21 | 0.000719 | 5.03 | 9.91 | 3.67 | 0.43 |
| Lower | 1412 | Max WS | Alt3B Q BF | 17079.98 | 20.22 | 0.000718 | 5.03 | 9.91 | 3.67 | 0.43 |
| | | | | | | | | | | |
| Lower | 734 | Max WS | Alt3 BFull n | 17099.92 | 19.82 | 0.000553 | 5.06 | 12.39 | 4.52 | 0.41 |
| Lower | 734 | Max WS | Alt2-BF n | 17099.92 | 19.82 | 0.000553 | 5.06 | 12.39 | 4.52 | 0.41 |
| Lower | 734 | Max WS | Alt1 BFull | 17099.92 | 19.82 | 0.000553 | 5.06 | 12.39 | 4.52 | 0.41 |
| Lower | 734 | Max WS | Exist mod BF | 17079.91 | 19.82 | 0.000550 | 5.05 | 12.39 | 4.53 | 0.41 |
| Lower | 734 | Max WS | Alt3B Q BF | 17079.88 | 19.82 | 0.000552 | 5.05 | 12.39 | 4.52 | 0.41 |
| | | | | | | | | | | |
| Lower | 0 | Max WS | Alt3 BFull n | 885.89 | 19.70 | 0.000000 | 0.11 | 14.53 | 8.18 | 0.00 |
| Lower | 0 | Max WS | Alt2-BF n | 878.14 | 19.70 | 0.000000 | 0.11 | 14.53 | 8.18 | 0.00 |
| Lower | 0 | Max WS | Alt1 BFull | 865.63 | 19.70 | 0.000000 | 0.11 | 14.53 | 8.18 | 0.00 |
| Lower | 0 | Max WS | Exist mod BF | 909.57 | 19.70 | 0.000000 | 0.12 | 14.53 | 8.18 | 0.00 |
| Lower | 0 | Max WS | Alt3B Q BF | 982.67 | 19.70 | 0.000000 | 0.12 | 14.53 | 8.18 | 0.00 |

Table 1 (cont). Pond Reach parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Ponds | 5159 | Max WS | Alt3 BFull n | 100.00 | 30.92 | 0.003964 | 0.97 | 2.02 | 0.96 | 0.34 |
| Ponds | 5159 | Max WS | Alt2-BF n | 100.00 | 30.93 | 0.003909 | 0.96 | 2.02 | 0.96 | 0.34 |
| Ponds | 5159 | Max WS | Alt1 BFull | 100.00 | 31.05 | 0.002518 | 1.55 | 1.23 | 0.76 | 0.19 |
| Ponds | 5159 | Max WS | Exist mod BF | 80.00 | 30.93 | 0.002363 | 1.41 | 1.11 | 0.69 | 0.16 |
| Ponds | 5159 | Max WS | Alt3B Q BF | 80.00 | 30.48 | 0.003757 | 1.06 | 1.80 | 0.88 | 0.24 |
| | | | | | | | | | | |
| Ponds | 5109 | Max WS | Alt3 BFull n | 100.00 | 30.69 | 0.005018 | 1.16 | 1.91 | 0.90 | 0.37 |
| Ponds | 5109 | Max WS | Alt2-BF n | 88.36 | 30.73 | 0.003797 | 1.00 | 1.92 | 0.91 | 0.28 |
| Ponds | 5109 | Max WS | Alt1 BFull | 100.62 | 30.84 | 0.005304 | 1.99 | 1.02 | 0.63 | 0.34 |
| Ponds | 5109 | Max WS | Exist mod BF | 80.00 | 30.73 | 0.005175 | 1.83 | 0.91 | 0.57 | 0.29 |
| Ponds | 5109 | Max WS | Alt3B Q BF | 80.00 | 30.29 | 0.004010 | 1.16 | 1.70 | 1.01 | 0.23 |
| | | | | | | | | | | |
| Ponds | 4308.648 | Max WS | Alt3 BFull n | 38.35 | 28.69 | 0.000027 | 0.19 | 1.66 | 1.35 | 0.00 |
| Ponds | 4308.648 | Max WS | Alt2-BF n | 38.88 | 28.69 | 0.000028 | 0.20 | 1.65 | 1.35 | 0.00 |
| Ponds | 4308.648 | Max WS | Alt1 BFull | 30.78 | 28.69 | 0.000018 | 0.16 | 1.66 | 1.35 | 0.00 |
| Ponds | 4308.648 | Max WS | Exist mod BF | 16.40 | 28.69 | 0.000005 | 0.08 | 1.66 | 1.35 | 0.00 |
| Ponds | 4308.648 | Max WS | Alt3B Q BF | 38.71 | 28.69 | 0.000028 | 0.20 | 1.65 | 1.35 | 0.00 |
| | | | | | | | | | | |
| Ponds | 3714.351 | Max WS | Alt3 BFull n | 343.08 | 27.50 | 0.003771 | 2.46 | 2.01 | 1.23 | 0.42 |
| Ponds | 3714.351 | Max WS | Alt2-BF n | 330.61 | 27.44 | 0.003944 | 2.48 | 1.97 | 1.20 | 0.44 |
| Ponds | 3714.351 | Max WS | Alt1 BFull | 275.09 | 27.16 | 0.004919 | 2.60 | 1.79 | 1.02 | 0.49 |
| Ponds | 3714.351 | Max WS | Exist mod BF | 352.91 | 27.56 | 0.003584 | 2.42 | 2.05 | 1.27 | 0.41 |
| Ponds | 3714.351 | Max WS | Alt3B Q BF | 337.24 | 27.47 | 0.003841 | 2.47 | 2.00 | 1.22 | 0.43 |
| | | | | | | | | | | |
| Ponds | 3238.759 | Max WS | Alt3 BFull n | 102.93 | 26.68 | 0.000002 | 0.11 | 4.87 | 3.06 | 0.00 |
| Ponds | 3238.759 | Max WS | Alt2-BF n | 242.02 | 26.57 | 0.000011 | 0.26 | 4.76 | 2.97 | 0.00 |
| Ponds | 3238.759 | Max WS | Alt1 BFull | 508.72 | 26.01 | 0.000090 | 0.66 | 4.20 | 2.50 | 0.02 |
| Ponds | 3238.759 | Max WS | Exist mod BF | 493.74 | 26.74 | 0.000041 | 0.50 | 4.93 | 3.11 | 0.01 |
| Ponds | 3238.759 | Max WS | Alt3B Q BF | 148.99 | 26.62 | 0.000004 | 0.16 | 4.82 | 3.01 | 0.00 |
| | | | | | | | | | | |
| Ponds | 2825.777 | Max WS | Alt3 BFull n | 817.48 | 24.02 | 0.013241 | 5.33 | 1.98 | 0.46 | 1.60 |
| Ponds | 2825.777 | Max WS | Alt2-BF n | 928.55 | 23.99 | 0.012148 | 5.51 | 2.20 | 0.88 | 1.63 |
| Ponds | 2825.777 | Max WS | Alt1 BFull | 1051.58 | 25.24 | 0.003587 | 2.19 | 1.81 | 1.32 | 0.41 |
| Ponds | 2825.777 | Max WS | Exist mod BF | 1314.32 | 26.64 | 0.000390 | 1.46 | 4.84 | 2.39 | 0.12 |
| Ponds | 2825.777 | Max WS | Alt3B Q BF | 858.48 | 24.09 | 0.012121 | 5.18 | 2.05 | 0.54 | 1.52 |
| | | | | | | | | | | |
| Ponds | 2619.457 | Max WS | Alt3 BFull n | 959.04 | 22.78 | 0.000618 | 1.58 | 3.88 | 2.19 | 0.14 |
| Ponds | 2619.457 | Max WS | Alt2-BF n | 1060.75 | 22.84 | 0.000721 | 1.71 | 3.91 | 2.17 | 0.16 |
| Ponds | 2619.457 | Max WS | Alt1 BFull | 1116.74 | 24.68 | 0.001873 | 1.10 | 0.79 | 0.78 | 0.09 |
| Ponds | 2619.457 | Max WS | Exist mod BF | 689.21 | 26.47 | 0.001127 | 2.37 | 4.29 | 1.35 | 0.30 |
| Ponds | 2619.457 | Max WS | Alt3B Q BF | 998.59 | 22.92 | 0.000597 | 1.57 | 3.96 | 2.15 | 0.14 |

Table 1 (cont). Pond Reach parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS Reload Data

| Reach | River Sta | Profile | Plan | Q Total (cfs) | W.S. Elev (ft) | E.G. Slope (ft/ft) | Vel Chnl (ft/s) | Hydr Depth C (ft) | Hydr Depth (ft) | Shear Chan (lb/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ponds | 2584 | Max WS | Alt3 BFull n | 959.04 | 22.77 | 0.000625 | 1.58 | 3.87 | 2.20 | 0.14 |
| Ponds | 2584 | Max WS | Alt2-BF n | 1060.69 | 22.82 | 0.000730 | 1.72 | 3.90 | 2.18 | 0.16 |
| Ponds | 2584 | Max WS | Alt1 BFull | 1116.74 | 24.30 | 0.016630 | 2.11 | 0.41 | 0.41 | 0.42 |
| Ponds | 2584 | Max WS | Exist mod BF | 689.05 | 24.32 | 0.016260 | 5.83 | 2.24 | 1.66 | 2.24 |
| Ponds | 2584 | Max WS | Alt3B Q BF | 998.59 | 22.91 | 0.000603 | 1.58 | 3.95 | 2.15 | 0.14 |
| | | | | | | | | | | |
| Ponds | 2467 | Max WS | Alt3 BFull n | 1695.13 | 22.41 | 0.003265 | 3.50 | 3.67 | 2.16 | 0.70 |
| Ponds | 2467 | Max WS | Alt2-BF n | 1785.43 | 22.44 | 0.003535 | 3.65 | 3.68 | 2.14 | 0.76 |
| Ponds | 2467 | Max WS | Alt3B Q BF | 1746.86 | 22.57 | 0.003002 | 3.41 | 3.76 | 2.06 | 0.65 |
| | | | | | | | | | | |
| Ponds | 2319.002 | Max WS | Alt3 BFull n | 1689.11 | 22.23 | 0.000011 | 0.39 | 5.96 | 4.69 | 0.00 |
| Ponds | 2319.002 | Max WS | Alt2-BF n | 1780.07 | 22.24 | 0.000012 | 0.41 | 5.97 | 4.70 | 0.00 |
| Ponds | 2319.002 | Max WS | Alt1 BFull | 2257.74 | 22.26 | 0.000015 | | | 4.80 | |
| Ponds | 2319.002 | Max WS | Exist mod BF | 688.67 | 22.39 | 0.000004 | | | 5.19 | |
| Ponds | 2319.002 | Max WS | Alt3B Q BF | 1745.59 | 22.40 | 0.000011 | 0.39 | 6.13 | 4.81 | 0.00 |
| | | | | | | | | | | |
| Ponds | 2252 | Max WS | Alt3 BFull n | 2715.11 | 22.22 | 0.000023 | 0.56 | 5.90 | 5.08 | 0.01 |
| Ponds | 2252 | Max WS | Alt2-BF n | 2798.98 | 22.23 | 0.000024 | 0.58 | 5.91 | 5.09 | 0.01 |
| Ponds | 2252 | Max WS | Alt3B Q BF | 2800.73 | 22.40 | 0.000022 | 0.56 | 6.07 | 5.23 | 0.01 |
| | | | | | | | | | | |
| Ponds | 2050 | Max WS | Alt3 BFull n | 2715.11 | 22.21 | 0.000044 | 0.70 | 4.96 | 3.32 | 0.01 |
| Ponds | 2050 | Max WS | Alt2-BF n | 2798.97 | 22.23 | 0.000047 | 0.72 | 4.97 | 3.33 | 0.01 |
| Ponds | 2050 | Max WS | Alt3B Q BF | 2799.20 | 22.39 | 0.000042 | 0.69 | 5.13 | 3.47 | 0.01 |
| | | | | | | | | | | |
| Ponds | 1956.422 | Max WS | Alt3 BFull n | 3142.63 | 22.21 | 0.000061 | 0.70 | 6.17 | 3.59 | 0.02 |
| Ponds | 1956.422 | Max WS | Alt2-BF n | 3227.55 | 22.22 | 0.000064 | 0.72 | 6.18 | 3.60 | 0.02 |
| Ponds | 1956.422 | Max WS | Alt1 BFull | 4607.49 | 22.21 | 0.000113 | | | 3.53 | |
| Ponds | 1956.422 | Max WS | Exist mod BF | 688.67 | 22.38 | 0.000011 | | | 3.55 | |
| Ponds | 1956.422 | Max WS | Alt3B Q BF | 3276.38 | 22.38 | 0.000058 | 0.70 | 6.35 | 3.76 | 0.02 |
| | | | | | | | | | | |
| Ponds | 1749 | Max WS | Alt3 BFull n | 3692.61 | 22.19 | 0.000066 | 0.77 | 6.61 | 4.21 | 0.03 |
| Ponds | 1749 | Max WS | Alt2-BF n | 3744.10 | 22.20 | 0.000068 | 0.78 | 6.62 | 4.23 | 0.03 |
| Ponds | 1749 | Max WS | Alt3B Q BF | 2477.90 | 22.38 | 0.000027 | 0.50 | 6.80 | 4.39 | 0.01 |
| | | | | | | | | | | |
| Ponds | 1648 | Max WS | Alt3 BFull n | 3692.61 | 22.17 | 0.000105 | 1.13 | 5.66 | 3.73 | 0.04 |
| Ponds | 1648 | Max WS | Alt2-BF n | 3744.10 | 22.19 | 0.000107 | 1.14 | 5.67 | 3.74 | 0.04 |
| Ponds | 1648 | Max WS | Alt3B Q BF | 2477.90 | 22.37 | 0.000041 | 0.73 | 5.86 | 3.89 | 0.01 |
| | | | | | | | | | | |
| Ponds | 1553.243 | Max WS | Alt3 BFull n | 3692.60 | 22.17 | 0.000091 | 1.11 | 5.83 | 4.28 | 0.03 |
| Ponds | 1553.243 | Max WS | Alt2-BF n | 3744.09 | 22.18 | 0.000093 | 1.12 | 5.84 | 4.29 | 0.03 |
| Ponds | 1553.243 | Max WS | Alt1 BFull | 2985.04 | 22.20 | 0.000038 | 0.46 | 4.64 | 4.45 | 0.01 |
| Ponds | 1553.243 | Max WS | Exist mod BF | 688.65 | 22.30 | 0.000369 | 1.46 | 4.75 | 2.59 | 0.11 |
| Ponds | 1553.243 | Max WS | Alt3B Q BF | 2477.93 | 22.37 | 0.000036 | 0.72 | 6.04 | 4.37 | 0.01 |

Table 1 (cont). Pond Reach parameter comparison for bankfull flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| | | | | | | | | | | |
| Ponds | 1380 | Max WS | Alt3 BFull n | 2371.09 | 22.18 | 0.000055 | 0.88 | 6.03 | 4.34 | 0.02 |
| Ponds | 1380 | Max WS | Alt2-BF n | 2414.11 | 22.19 | 0.000057 | 0.90 | 6.04 | 4.35 | 0.02 |
| Ponds | 1380 | Max WS | Alt3B Q BF | 986.80 | 22.38 | 0.000008 | 0.35 | 6.23 | 4.49 | 0.00 |
| | | | | | | | | | | |
| Ponds | 1197.307 | Max WS | Alt3 BFull n | 2371.10 | 22.15 | 0.000509 | 1.50 | 4.25 | 3.72 | 0.12 |
| Ponds | 1197.307 | Max WS | Alt2-BF n | 2414.10 | 22.16 | 0.000438 | 1.60 | 6.11 | 3.84 | 0.13 |
| Ponds | 1197.307 | Max WS | Alt1 BFull | 2985.05 | 22.17 | 0.000133 | 0.63 | 2.89 | 3.74 | 0.02 |
| Ponds | 1197.307 | Max WS | Exist mod BF | 688.64 | 21.85 | 0.002402 | 2.74 | 3.02 | 1.83 | 0.45 |
| Ponds | 1197.307 | Max WS | Alt3B Q BF | 986.80 | 22.18 | 0.003354 | 3.46 | 3.35 | 1.98 | 0.69 |
| | | | | | | | | | | |
| Ponds | 572 | Max WS | Alt3 BFull n | 2371.09 | 21.17 | 0.002887 | 4.70 | 5.84 | 1.64 | 1.05 |
| Ponds | 572 | Max WS | Alt2-BF n | 2414.10 | 21.17 | 0.002993 | 4.78 | 5.84 | 1.64 | 1.09 |
| Ponds | 572 | Max WS | Alt1 BFull | 2985.04 | 21.17 | 0.003153 | 5.34 | 6.67 | 1.75 | 1.30 |
| Ponds | 572 | Max WS | Exist mod BF | 688.12 | 21.16 | 0.000175 | 1.26 | 6.66 | 2.50 | 0.07 |
| Ponds | 572 | Max WS | Alt3B Q BF | 986.73 | 21.16 | 0.000501 | 1.96 | 5.84 | 1.64 | 0.18 |

Table 2 Satsop River parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, and 3.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 14850 | Max WS | Ex 100 YrMod | 58400.00 | 41.36 | 0.000766 | 7.90 | 18.31 | 7.60 | 0.87 |
| Main | 14850 | Max WS | A2-mature vg | 58400.00 | 41.35 | 0.000767 | 7.90 | 18.31 | 7.59 | 0.87 |
| Main | 14850 | Max WS | A3 Mature Vg | 58400.00 | 41.35 | 0.000767 | 7.90 | 18.31 | 7.59 | 0.87 |
| Main | 14850 | Max WS | Alt1-Q100 | 58400.00 | 41.35 | 0.000767 | 7.90 | 18.31 | 7.59 | 0.87 |
| Main | 14850 | Max WS | Alt 3B Q100 | 58400.00 | 41.35 | 0.000767 | 7.90 | 18.31 | 7.59 | 0.87 |
| | | | | | | | | | | |
| Main | 14467 | Max WS | Ex 100 YrMod | 58399.98 | 40.52 | 0.001172 | 9.94 | 19.42 | 10.92 | 1.36 |
| Main | 14467 | Max WS | A2-mature vg | 58297.19 | 40.51 | 0.001169 | 9.92 | 19.41 | 10.92 | 1.36 |
| Main | 14467 | Max WS | A3 Mature Vg | 58295.93 | 40.51 | 0.001169 | 9.92 | 19.41 | 10.92 | 1.36 |
| Main | 14467 | Max WS | Alt1-Q100 | 58296.73 | 40.51 | 0.001169 | 9.92 | 19.41 | 10.92 | 1.36 |
| Main | 14467 | Max WS | Alt 3B Q100 | 58296.28 | 40.51 | 0.001169 | 9.92 | 19.41 | 10.92 | 1.36 |
| | | | | | | | | | | |
| Main | 14334 | Max WS | Ex 100 YrMod | 58399.99 | 39.61 | 0.001452 | 10.71 | 18.51 | 10.76 | 1.61 |
| Main | 14334 | Max WS | A2-mature vg | 58441.31 | 39.60 | 0.001456 | 10.72 | 18.50 | 10.75 | 1.62 |
| Main | 14334 | Max WS | A3 Mature Vg | 58439.05 | 39.61 | 0.001456 | 10.72 | 18.50 | 10.75 | 1.61 |
| Main | 14334 | Max WS | Alt1-Q100 | 58438.71 | 39.61 | 0.001456 | 10.72 | 18.50 | 10.75 | 1.61 |
| Main | 14334 | Max WS | Alt 3B Q100 | 58438.94 | 39.61 | 0.001456 | 10.72 | 18.50 | 10.75 | 1.61 |
| | | | | | | | | | | |
| Main | 14066 | Max WS | Ex 100 YrMod | 58399.98 | 39.41 | 0.001634 | 9.15 | 13.24 | 7.08 | 1.31 |
| Main | 14066 | Max WS | A2-mature vg | 58470.48 | 39.40 | 0.001642 | 9.17 | 13.23 | 7.07 | 1.32 |
| Main | 14066 | Max WS | A3 Mature Vg | 58470.25 | 39.40 | 0.001642 | 9.17 | 13.23 | 7.07 | 1.32 |
| Main | 14066 | Max WS | Alt1-Q100 | 58471.41 | 39.40 | 0.001642 | 9.17 | 13.23 | 7.07 | 1.32 |
| Main | 14066 | Max WS | Alt 3B Q100 | 58469.68 | 39.40 | 0.001642 | 9.17 | 13.23 | 7.07 | 1.32 |
| | | | | | | | | | | |
| Main | 13916 | Max WS | Ex 100 YrMod | 58399.98 | 38.94 | 0.001922 | 9.69 | 12.77 | 6.68 | 1.49 |
| Main | 13916 | Max WS | A2-mature vg | 58526.98 | 38.92 | 0.001939 | 9.72 | 12.76 | 6.67 | 1.50 |
| Main | 13916 | Max WS | A3 Mature Vg | 58526.25 | 38.93 | 0.001939 | 9.72 | 12.76 | 6.67 | 1.50 |
| Main | 13916 | Max WS | Alt1-Q100 | 58525.35 | 38.93 | 0.001939 | 9.72 | 12.76 | 6.67 | 1.50 |
| Main | 13916 | Max WS | Alt 3B Q100 | 58525.72 | 38.93 | 0.001939 | 9.72 | 12.76 | 6.67 | 1.50 |
| | | | | | | | | | | |
| Main | 13825 | Max WS | Ex 100 YrMod | 58399.98 | 37.99 | 0.002921 | 11.13 | 11.30 | 7.96 | 2.03 |
| Main | 13825 | Max WS | A2-mature vg | 58584.68 | 37.97 | 0.002958 | 11.18 | 11.28 | 7.94 | 2.05 |
| Main | 13825 | Max WS | A3 Mature Vg | 58583.68 | 37.97 | 0.002958 | 11.18 | 11.28 | 7.94 | 2.05 |
| Main | 13825 | Max WS | Alt1-Q100 | 58582.14 | 37.97 | 0.002957 | 11.18 | 11.29 | 7.94 | 2.05 |
| Main | 13825 | Max WS | Alt 3B Q100 | 58582.75 | 37.97 | 0.002957 | 11.18 | 11.29 | 7.94 | 2.05 |
| | | | | | | | | | | |
| Main | 13555 | Max WS | Ex 100 YrMod | 58399.98 | 37.20 | 0.002715 | 12.40 | 14.11 | 8.84 | 2.35 |
| Main | 13555 | Max WS | A2-mature vg | 58548.71 | 37.17 | 0.002753 | 12.47 | 14.08 | 8.81 | 2.37 |
| Main | 13555 | Max WS | A3 Mature Vg | 58544.98 | 37.17 | 0.002752 | 12.47 | 14.08 | 8.81 | 2.37 |
| Main | 13555 | Max WS | Alt1-Q100 | 58547.88 | 37.17 | 0.002752 | 12.47 | 14.08 | 8.81 | 2.37 |
| Main | 13555 | Max WS | Alt 3B Q100 | 58547.93 | 37.17 | 0.002752 | 12.47 | 14.08 | 8.81 | 2.37 |

Table 2 (cont). Satsop River parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 12960 | Max WS | Ex 100 YrMod | 58399.95 | 36.67 | 0.001489 | 7.65 | 10.78 | 5.36 | 0.98 |
| Main | 12960 | Max WS | A2-mature vg | 58681.79 | 36.62 | 0.001535 | 7.74 | 10.73 | 5.31 | 1.00 |
| Main | 12960 | Max WS | A3 Mature Vg | 58681.09 | 36.62 | 0.001534 | 7.74 | 10.73 | 5.31 | 1.00 |
| Main | 12960 | Max WS | Alt1-Q100 | 58649.02 | 36.62 | 0.001532 | 7.74 | 10.73 | 5.31 | 1.00 |
| Main | 12960 | Max WS | Alt 3B Q100 | 58635.16 | 36.62 | 0.001531 | 7.74 | 10.73 | 5.31 | 1.00 |
| | | | | | | | | | | |
| Main | 12363 | Max WS | Ex 100 YrMod | 58399.93 | 36.00 | 0.001451 | 7.17 | 9.80 | 4.93 | 0.88 |
| Main | 12363 | Max WS | A2-mature vg | 58623.77 | 35.92 | 0.001515 | 7.28 | 9.72 | 4.86 | 0.91 |
| Main | 12363 | Max WS | A3 Mature Vg | 58623.07 | 35.92 | 0.001515 | 7.28 | 9.72 | 4.86 | 0.91 |
| Main | 12363 | Max WS | Alt1-Q100 | 58621.51 | 35.92 | 0.001513 | 7.28 | 9.72 | 4.86 | 0.91 |
| Main | 12363 | Max WS | Alt 3B Q100 | 58621.72 | 35.92 | 0.001513 | 7.28 | 9.72 | 4.86 | 0.91 |
| | | | | | | | | | | |
| Main | 11425 | Max WS | Ex 100 YrMod | 58399.89 | 35.14 | 0.001238 | 6.75 | 10.12 | 5.05 | 0.77 |
| Main | 11425 | Max WS | A2-mature vg | 58585.52 | 35.01 | 0.001328 | 6.93 | 9.98 | 4.93 | 0.82 |
| Main | 11425 | Max WS | A3 Mature Vg | 58584.93 | 35.01 | 0.001328 | 6.93 | 9.99 | 4.93 | 0.82 |
| Main | 11425 | Max WS | Alt1-Q100 | 58583.82 | 35.01 | 0.001326 | 6.93 | 9.99 | 4.93 | 0.82 |
| Main | 11425 | Max WS | Alt 3B Q100 | 58583.93 | 35.01 | 0.001326 | 6.93 | 9.99 | 4.93 | 0.82 |
| | | | | | | | | | | |
| Main | 10882 | Max WS | Ex 100 YrMod | 58399.89 | 35.00 | 0.000419 | 4.48 | 12.37 | 5.89 | 0.32 |
| Main | 10882 | Max WS | A2-mature vg | 58583.73 | 34.86 | 0.000447 | 4.59 | 12.22 | 5.75 | 0.34 |
| Main | 10882 | Max WS | A3 Mature Vg | 58583.15 | 34.86 | 0.000447 | 4.59 | 12.22 | 5.75 | 0.34 |
| Main | 10882 | Max WS | Alt1-Q100 | 58582.02 | 34.86 | 0.000446 | 4.59 | 12.23 | 5.75 | 0.34 |
| Main | 10882 | Max WS | Alt 3B Q100 | 58582.01 | 34.86 | 0.000447 | 4.59 | 12.23 | 5.75 | 0.34 |
| | | | | | | | | | | |
| Main | 10361 | Max WS | Ex 100 YrMod | 58399.90 | 34.26 | 0.001849 | 9.82 | 13.56 | 4.22 | 1.50 |
| Main | 10361 | Max WS | A2-mature vg | 58518.23 | 34.01 | 0.002118 | 10.38 | 13.31 | 3.97 | 1.69 |
| Main | 10361 | Max WS | A3 Mature Vg | 58518.10 | 34.01 | 0.002116 | 10.38 | 13.31 | 3.97 | 1.69 |
| Main | 10361 | Max WS | Alt1-Q100 | 58518.12 | 34.02 | 0.002109 | 10.36 | 13.31 | 3.98 | 1.68 |
| Main | 10361 | Max WS | Alt 3B Q100 | 58518.44 | 34.02 | 0.002110 | 10.37 | 13.31 | 3.98 | 1.68 |
| | | | | | | | | | | |
| Main | 9792 | Max WS | Ex 100 YrMod | 55566.47 | 33.56 | 0.001427 | 8.22 | 12.29 | 4.88 | 1.08 |
| Main | 9792 | Max WS | A2-mature vg | 55934.83 | 33.15 | 0.001788 | 9.00 | 11.88 | 4.47 | 1.31 |
| Main | 9792 | Max WS | A3 Mature Vg | 55935.87 | 33.15 | 0.001785 | 8.99 | 11.88 | 4.47 | 1.31 |
| Main | 9792 | Max WS | Alt1-Q100 | 55946.73 | 33.16 | 0.001777 | 8.98 | 11.89 | 4.48 | 1.30 |
| Main | 9792 | Max WS | Alt 3B Q100 | 55923.37 | 33.16 | 0.001775 | 8.97 | 11.89 | 4.48 | 1.30 |
| | | | | | | | | | | |
| Main | 9317 | Max WS | Ex 100 YrMod | 53221.61 | 32.58 | 0.002208 | 11.03 | 14.30 | 4.52 | 1.87 |
| Main | 9317 | Max WS | A2-mature vg | 53468.22 | 31.78 | 0.003094 | 12.56 | 13.49 | 4.41 | 2.47 |
| Main | 9317 | Max WS | A3 Mature Vg | 53463.00 | 31.79 | 0.003083 | 12.54 | 13.50 | 4.42 | 2.46 |
| Main | 9317 | Max WS | Alt1-Q100 | 53432.82 | 31.81 | 0.003043 | 12.47 | 13.52 | 4.44 | 2.44 |
| Main | 9317 | Max WS | Alt 3B Q100 | 53458.34 | 31.81 | 0.003049 | 12.49 | 13.52 | 4.44 | 2.44 |

Table 2 (cont).  Satsop River parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 8814 | Max WS | Ex 100 YrMod | 50374.01 | 32.03 | 0.001160 | 7.85 | 13.54 | 5.26 | 0.96 |
| Main | 8814 | Max WS | A2-mature vg | 52927.67 | 30.75 | 0.002256 | 10.25 | 12.26 | 4.78 | 1.68 |
| Main | 8814 | Max WS | A3 Mature Vg | 52996.47 | 30.75 | 0.002254 | 10.25 | 12.27 | 4.79 | 1.68 |
| Main | 8814 | Max WS | Alt1-Q100 | 53624.15 | 30.75 | 0.002311 | 10.38 | 12.26 | 4.78 | 1.73 |
| Main | 8814 | Max WS | Alt 3B Q100 | 52914.66 | 30.80 | 0.002195 | 10.14 | 12.31 | 4.82 | 1.65 |
| | | | | | | | | | | |
| Main | 8382 | Max WS | Ex 100 YrMod | 50170.52 | 31.53 | 0.001113 | 7.75 | 13.90 | 5.09 | 0.93 |
| Main | 8382 | Max WS | A2-mature vg | 44457.57 | 30.08 | 0.001723 | 9.10 | 12.75 | 4.24 | 1.32 |
| Main | 8382 | Max WS | A3 Mature Vg | 44534.82 | 30.08 | 0.001724 | 9.11 | 12.76 | 4.24 | 1.32 |
| Main | 8382 | Max WS | Alt1-Q100 | 44996.84 | 30.06 | 0.001777 | 9.24 | 12.74 | 4.25 | 1.36 |
| Main | 8382 | Max WS | Alt 3B Q100 | 44469.44 | 30.14 | 0.001671 | 8.99 | 12.80 | 4.22 | 1.28 |
| | | | | | | | | | | |
| Main | 7814 | Max WS | Ex 100 YrMod | 47611.61 | 30.32 | 0.002642 | 12.19 | 14.46 | 4.40 | 2.27 |
| Main | 7814 | Max WS | A2-mature vg | 38632.10 | 28.63 | 0.003275 | 12.50 | 12.78 | 4.17 | 2.49 |
| Main | 7814 | Max WS | A3 Mature Vg | 38702.64 | 28.63 | 0.003286 | 12.52 | 12.78 | 4.17 | 2.50 |
| Main | 7814 | Max WS | Alt1-Q100 | 38937.78 | 28.39 | 0.003765 | 13.25 | 12.56 | 3.91 | 2.81 |
| Main | 7814 | Max WS | Alt 3B Q100 | 38627.71 | 28.79 | 0.003069 | 12.20 | 12.94 | 4.28 | 2.36 |
| | | | | | | | | | | |
| Main | 7296 | Max WS | Ex 100 YrMod | 47611.61 | 29.56 | 0.002362 | 9.98 | 11.27 | 6.34 | 1.63 |
| Main | 7296 | Max WS | A2-mature vg | 33841.37 | 28.20 | 0.002058 | 8.55 | 9.90 | 5.28 | 1.25 |
| Main | 7296 | Max WS | A3 Mature Vg | 33899.21 | 28.20 | 0.002065 | 8.56 | 9.90 | 5.28 | 1.26 |
| Main | 7296 | Max WS | Alt1-Q100 | 32797.54 | 28.05 | 0.002106 | 8.56 | 9.76 | 5.01 | 1.26 |
| Main | 7296 | Max WS | Alt 3B Q100 | 33872.55 | 28.40 | 0.001890 | 8.30 | 10.10 | 5.45 | 1.17 |
| | | | | | | | | | | |
| Main | 6776 | Max WS | Ex 100 YrMod | 47611.60 | 28.50 | 0.002384 | 10.55 | 12.17 | 5.35 | 1.78 |
| Main | 6776 | Max WS | A2-mature vg | 28998.60 | 27.75 | 0.001158 | 7.04 | 11.42 | 5.49 | 0.81 |
| Main | 6776 | Max WS | A3 Mature Vg | 29043.06 | 27.74 | 0.001162 | 7.06 | 11.41 | 5.49 | 0.81 |
| Main | 6776 | Max WS | Alt1-Q100 | 27055.35 | 27.66 | 0.001062 | 6.71 | 11.33 | 5.40 | 0.74 |
| Main | 6776 | Max WS | Alt 3B Q100 | 29255.05 | 27.97 | 0.001081 | 6.90 | 11.64 | 5.49 | 0.77 |
| | | | | | | | | | | |
| Main | 6343 | Max WS | Ex 100 YrMod | 47611.60 | 28.35 | 0.000887 | 5.69 | 10.08 | 7.32 | 0.55 |
| Main | 6343 | Max WS | A2-mature vg | 27861.15 | 27.68 | 0.000386 | 3.59 | 9.42 | 6.80 | 0.22 |
| Main | 6343 | Max WS | A3 Mature Vg | 27908.07 | 27.68 | 0.000388 | 3.60 | 9.42 | 6.80 | 0.23 |
| Main | 6343 | Max WS | Alt1-Q100 | 26304.75 | 27.60 | 0.000360 | 3.45 | 9.34 | 6.69 | 0.21 |
| Main | 6343 | Max WS | Alt 3B Q100 | 28754.25 | 27.90 | 0.000377 | 3.61 | 9.64 | 6.97 | 0.22 |
| | | | | | | | | | | |
| Main | 6000 | Max WS | Ex 100 YrMod | 47611.59 | 27.82 | 0.001718 | 8.76 | 11.70 | 8.49 | 1.24 |
| Main | 6000 | Max WS | A2-mature vg | 28427.53 | 27.47 | 0.000676 | 5.39 | 11.35 | 8.21 | 0.47 |
| Main | 6000 | Max WS | A3 Mature Vg | 28521.72 | 27.47 | 0.000681 | 5.41 | 11.35 | 8.21 | 0.48 |
| Main | 6000 | Max WS | Alt1-Q100 | 27092.63 | 27.40 | 0.000640 | 5.22 | 11.28 | 8.09 | 0.45 |
| Main | 6000 | Max WS | Alt 3B Q100 | 30656.36 | 27.67 | 0.000736 | 5.69 | 11.55 | 8.41 | 0.53 |

Table 2 (cont). Satsop River parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS Profile: Max WS Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Main | 5460 | Max WS | Ex 100 YrMod | 47611.59 | 27.38 | 0.000496 | 4.52 | 11.03 | 9.58 | 0.34 |
| Main | 5460 | Max WS | A2-mature vg | 36606.08 | 27.21 | 0.000306 | 3.51 | 10.86 | 9.51 | 0.21 |
| Main | 5460 | Max WS | A3 Mature Vg | 36724.19 | 27.21 | 0.000294 | 3.44 | 10.86 | 9.57 | 0.20 |
| Main | 5460 | Max WS | Alt1-Q100 | 39144.81 | 27.10 | 0.000367 | 3.82 | 10.75 | 9.31 | 0.24 |
| Main | 5460 | Max WS | Alt 3B Q100 | 40506.77 | 27.38 | 0.000339 | 3.74 | 11.03 | 9.73 | 0.23 |
| | | | | | | | | | | |
| Main | 4225 | Max WS | A2-mature vg | 41432.54 | 26.50 | 0.001042 | 7.87 | 14.74 | 8.03 | 0.93 |
| Main | 4225 | Max WS | A3 Mature Vg | 41550.88 | 26.50 | 0.001048 | 7.89 | 14.74 | 8.03 | 0.94 |
| Main | 4225 | Max WS | Alt 3B Q100 | 46203.24 | 26.50 | 0.001296 | 8.77 | 14.74 | 8.03 | 1.16 |
| | | | | | | | | | | |
| Main | 4224 | Max WS | Ex 100 YrMod | 47611.59 | 26.50 | 0.001318 | 8.85 | 14.73 | 7.80 | 1.18 |
| Main | 4224 | Max WS | A2-mature vg | 41432.52 | 26.50 | 0.001042 | 7.87 | 14.74 | 8.03 | 0.93 |
| Main | 4224 | Max WS | A3 Mature Vg | 41550.87 | 26.50 | 0.001048 | 7.89 | 14.74 | 8.03 | 0.94 |
| Main | 4224 | Max WS | Alt1-Q100 | 39141.28 | 26.50 | 0.000891 | 7.27 | 14.74 | 7.80 | 0.80 |
| Main | 4224 | Max WS | Alt 3B Q100 | 46203.24 | 26.50 | 0.001296 | 8.77 | 14.74 | 8.03 | 1.16 |
| | | | | | | | | | | |
| Lower | 3599 | Max WS | Ex 100 YrMod | 58409.78 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| Lower | 3599 | Max WS | A2-mature vg | 58413.68 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| Lower | 3599 | Max WS | A3 Mature Vg | 58413.71 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| Lower | 3599 | Max WS | Alt1-Q100 | 58414.48 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| Lower | 3599 | Max WS | Alt 3B Q100 | 58412.80 | 26.50 | 0.001480 | 8.93 | 13.80 | 7.71 | 1.23 |
| | | | | | | | | | | |
| Lower | 1412 | Max WS | Ex 100 YrMod | 58409.76 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| Lower | 1412 | Max WS | A2-mature vg | 58412.66 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| Lower | 1412 | Max WS | A3 Mature Vg | 58413.33 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| Lower | 1412 | Max WS | Alt1-Q100 | 58414.02 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| Lower | 1412 | Max WS | Alt 3B Q100 | 58412.31 | 25.34 | 0.001162 | 8.41 | 14.99 | 8.48 | 1.06 |
| | | | | | | | | | | |
| Lower | 734 | Max WS | Ex 100 YrMod | 58409.78 | 24.52 | 0.001270 | 9.51 | 17.09 | 9.16 | 1.30 |
| Lower | 734 | Max WS | A2-mature vg | 58411.64 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| Lower | 734 | Max WS | A3 Mature Vg | 58411.62 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| Lower | 734 | Max WS | Alt1-Q100 | 58412.29 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| Lower | 734 | Max WS | Alt 3B Q100 | 58411.30 | 24.52 | 0.001272 | 9.51 | 17.09 | 9.16 | 1.30 |
| | | | | | | | | | | |
| Lower | 0 | Max WS | Ex 100 YrMod | 979.35 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |
| Lower | 0 | Max WS | A2-mature vg | 982.60 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |
| Lower | 0 | Max WS | A3 Mature Vg | 982.56 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |
| Lower | 0 | Max WS | Alt1-Q100 | 964.18 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |
| Lower | 0 | Max WS | Alt 3B Q100 | 982.66 | 24.20 | 0.000000 | 0.08 | 19.03 | 12.61 | 0.00 |

Table 2 (cont). Pond Reach parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Ponds | 5159 | Max WS | Ex 100 YrMod | 10.00 | 34.01 | 0.000000 | 0.02 | 4.19 | 2.71 | 0.00 |
| Ponds | 5159 | Max WS | A2-mature vg | 10.00 | 33.64 | 0.000000 | 0.02 | 3.82 | 2.34 | 0.00 |
| Ponds | 5159 | Max WS | A3 Mature Vg | 10.00 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.34 | 0.00 |
| Ponds | 5159 | Max WS | Alt1-Q100 | 10.00 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.35 | 0.00 |
| Ponds | 5159 | Max WS | Alt 3B Q100 | 10.00 | 33.66 | 0.000000 | 0.02 | 3.84 | 2.35 | 0.00 |
| | | | | | | | | | | |
| Ponds | 5109 | Max WS | Ex 100 YrMod | 10.00 | 34.01 | 0.000000 | 0.02 | 4.19 | 2.71 | 0.00 |
| Ponds | 5109 | Max WS | A2-mature vg | 9.31 | 33.64 | 0.000000 | 0.02 | 3.82 | 2.34 | 0.00 |
| Ponds | 5109 | Max WS | A3 Mature Vg | 9.73 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.34 | 0.00 |
| Ponds | 5109 | Max WS | Alt1-Q100 | 9.73 | 33.65 | 0.000000 | 0.02 | 3.83 | 2.35 | 0.00 |
| Ponds | 5109 | Max WS | Alt 3B Q100 | 8.31 | 33.66 | 0.000000 | 0.02 | 3.84 | 2.35 | 0.00 |
| | | | | | | | | | | |
| Ponds | 4308.648 | Max WS | Ex 100 YrMod | 2843.40 | 33.49 | 0.000937 | 2.84 | 6.46 | 5.09 | 0.37 |
| Ponds | 4308.648 | Max WS | A2-mature vg | 2588.57 | 33.11 | 0.000977 | 2.78 | 6.08 | 4.71 | 0.37 |
| Ponds | 4308.648 | Max WS | A3 Mature Vg | 2588.88 | 33.12 | 0.000975 | 2.78 | 6.08 | 4.72 | 0.36 |
| Ponds | 4308.648 | Max WS | Alt1-Q100 | 2577.98 | 33.13 | 0.000959 | 2.76 | 6.10 | 4.73 | 0.36 |
| Ponds | 4308.648 | Max WS | Alt 3B Q100 | 2602.13 | 33.12 | 0.000981 | 2.79 | 6.09 | 4.72 | 0.37 |
| | | | | | | | | | | |
| Ponds | 3714.351 | Max WS | Ex 100 YrMod | 5188.23 | 32.51 | 0.002140 | 4.14 | 6.83 | 5.12 | 0.81 |
| Ponds | 3714.351 | Max WS | A2-mature vg | 5013.34 | 31.61 | 0.003671 | 4.94 | 5.93 | 4.22 | 1.20 |
| Ponds | 3714.351 | Max WS | A3 Mature Vg | 5018.66 | 31.62 | 0.003661 | 4.93 | 5.94 | 4.23 | 1.20 |
| Ponds | 3714.351 | Max WS | Alt1-Q100 | 5049.42 | 31.64 | 0.003658 | 4.94 | 5.95 | 4.25 | 1.20 |
| Ponds | 3714.351 | Max WS | Alt 3B Q100 | 5020.38 | 31.65 | 0.003587 | 4.90 | 5.97 | 4.26 | 1.18 |
| | | | | | | | | | | |
| Ponds | 3238.759 | Max WS | Ex 100 YrMod | 8035.83 | 31.89 | 0.000508 | 2.83 | 10.08 | 7.70 | 0.32 |
| Ponds | 3238.759 | Max WS | A2-mature vg | 5540.74 | 30.72 | 0.000400 | 2.31 | 8.91 | 6.54 | 0.22 |
| Ponds | 3238.759 | Max WS | A3 Mature Vg | 5471.67 | 30.73 | 0.000388 | 2.28 | 8.93 | 6.55 | 0.21 |
| Ponds | 3238.759 | Max WS | Alt1-Q100 | 4853.83 | 30.79 | 0.000298 | 2.00 | 8.98 | 6.60 | 0.17 |
| Ponds | 3238.759 | Max WS | Alt 3B Q100 | 5553.09 | 30.77 | 0.000392 | 2.30 | 8.97 | 6.59 | 0.22 |
| | | | | | | | | | | |
| Ponds | 2825.777 | Max WS | Ex 100 YrMod | 8239.34 | 31.68 | 0.000530 | 2.60 | 9.89 | 7.13 | 0.32 |
| Ponds | 2825.777 | Max WS | A2-mature vg | 14001.42 | 29.24 | 0.005373 | 6.96 | 7.45 | 4.81 | 2.44 |
| Ponds | 2825.777 | Max WS | A3 Mature Vg | 13918.88 | 29.25 | 0.005444 | 6.83 | 7.21 | 4.80 | 2.41 |
| Ponds | 2825.777 | Max WS | Alt1-Q100 | 13462.51 | 29.10 | 0.006618 | 6.22 | 5.67 | 4.56 | 2.34 |
| Ponds | 2825.777 | Max WS | Alt 3B Q100 | 13956.54 | 29.38 | 0.005079 | 6.67 | 7.33 | 4.90 | 2.28 |
| | | | | | | | | | | |
| Ponds | 2619.457 | Max WS | Ex 100 YrMod | 10798.21 | 30.01 | 0.011276 | 11.18 | 7.83 | 2.85 | 5.42 |
| Ponds | 2619.457 | Max WS | A2-mature vg | 19818.56 | 28.46 | 0.001844 | 4.77 | 9.01 | 5.23 | 0.96 |
| Ponds | 2619.457 | Max WS | A3 Mature Vg | 19746.57 | 28.46 | 0.001834 | 4.75 | 9.01 | 5.22 | 0.95 |
| Ponds | 2619.457 | Max WS | Alt1-Q100 | 19513.81 | 28.05 | 0.002166 | 3.58 | 4.16 | 4.08 | 0.56 |
| Ponds | 2619.457 | Max WS | Alt 3B Q100 | 19850.35 | 28.64 | 0.001672 | 4.60 | 9.19 | 5.40 | 0.89 |

Table 2 (cont). Pond Reach parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

File Options Std. Tables User Tables Locations Help

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS

Reload Data

| Reach | River Sta | Profile | Plan | Q Total (cfs) | W.S. Elev (ft) | E.G. Slope (ft/ft) | Vel Chnl (ft/s) | Hydr Depth C (ft) | Hydr Depth (ft) | Shear Chan (lb/sq ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ponds | 2584 | Max WS | Ex 100 YrMod | 10798.21 | 29.94 | 0.011659 | 11.31 | 7.77 | 2.91 | 5.56 |
| Ponds | 2584 | Max WS | A2-mature vg | 19812.19 | 28.39 | 0.001920 | 4.84 | 8.94 | 5.16 | 0.99 |
| Ponds | 2584 | Max WS | A3 Mature Vg | 19740.55 | 28.39 | 0.001909 | 4.82 | 8.94 | 5.15 | 0.98 |
| Ponds | 2584 | Max WS | Alt1-Q100 | 19512.62 | 27.96 | 0.002331 | 3.66 | 4.07 | 3.99 | 0.59 |
| Ponds | 2584 | Max WS | Alt 3B Q100 | 19839.74 | 28.58 | 0.001732 | 4.66 | 9.13 | 5.34 | 0.91 |
| | | | | | | | | | | |
| Ponds | 2467 | Max WS | A2-mature vg | 24608.17 | 27.93 | 0.003811 | 6.58 | 8.48 | 4.61 | 1.86 |
| Ponds | 2467 | Max WS | A3 Mature Vg | 24561.01 | 27.93 | 0.003802 | 6.57 | 8.48 | 4.61 | 1.86 |
| Ponds | 2467 | Max WS | Alt 3B Q100 | 24586.80 | 28.17 | 0.003268 | 6.21 | 8.72 | 4.85 | 1.64 |
| | | | | | | | | | | |
| Ponds | 2319.002 | Max WS | Ex 100 YrMod | 10798.21 | 28.84 | 0.000059 | 0.40 | 2.70 | 7.62 | 0.01 |
| Ponds | 2319.002 | Max WS | A2-mature vg | 24600.81 | 27.78 | 0.000187 | 2.50 | 11.51 | 7.91 | 0.13 |
| Ponds | 2319.002 | Max WS | A3 Mature Vg | 24543.42 | 27.78 | 0.000186 | 2.49 | 11.51 | 7.91 | 0.13 |
| Ponds | 2319.002 | Max WS | Alt1-Q100 | 25647.27 | 27.71 | 0.000141 | 0.43 | 1.57 | 7.91 | 0.01 |
| Ponds | 2319.002 | Max WS | Alt 3B Q100 | 24579.49 | 28.05 | 0.000170 | 2.42 | 11.78 | 8.16 | 0.12 |
| | | | | | | | | | | |
| Ponds | 2252 | Max WS | A2-mature vg | 29441.97 | 27.72 | 0.000225 | 2.75 | 11.40 | 8.43 | 0.15 |
| Ponds | 2252 | Max WS | A3 Mature Vg | 29397.18 | 27.72 | 0.000224 | 2.75 | 11.40 | 8.42 | 0.15 |
| Ponds | 2252 | Max WS | Alt 3B Q100 | 29181.72 | 28.00 | 0.000202 | 2.65 | 11.67 | 8.70 | 0.14 |
| | | | | | | | | | | |
| Ponds | 2050 | Max WS | A2-mature vg | 29427.01 | 27.66 | 0.000335 | 3.14 | 10.40 | 8.19 | 0.21 |
| Ponds | 2050 | Max WS | A3 Mature Vg | 29382.07 | 27.65 | 0.000334 | 3.13 | 10.40 | 8.19 | 0.21 |
| Ponds | 2050 | Max WS | Alt 3B Q100 | 29169.48 | 27.94 | 0.000298 | 3.01 | 10.68 | 8.47 | 0.19 |
| | | | | | | | | | | |
| Ponds | 1956.422 | Max WS | Ex 100 YrMod | 10798.21 | 28.81 | 0.000104 | 0.71 | 4.11 | 7.74 | 0.03 |
| Ponds | 1956.422 | Max WS | A2-mature vg | 30000.23 | 27.61 | 0.000375 | 2.66 | 11.58 | 7.95 | 0.27 |
| Ponds | 1956.422 | Max WS | A3 Mature Vg | 29905.63 | 27.61 | 0.000373 | 2.65 | 11.58 | 7.95 | 0.27 |
| Ponds | 1956.422 | Max WS | Alt1-Q100 | 32141.88 | 27.53 | 0.000331 | 0.98 | 2.83 | 7.80 | 0.06 |
| Ponds | 1956.422 | Max WS | Alt 3B Q100 | 27779.50 | 27.92 | 0.000288 | 2.37 | 11.89 | 8.22 | 0.21 |
| | | | | | | | | | | |
| Ponds | 1749 | Max WS | A2-mature vg | 21814.94 | 27.65 | 0.000213 | 2.05 | 12.07 | 8.65 | 0.16 |
| Ponds | 1749 | Max WS | A3 Mature Vg | 21696.78 | 27.65 | 0.000210 | 2.04 | 12.07 | 8.64 | 0.16 |
| Ponds | 1749 | Max WS | Alt 3B Q100 | 17919.06 | 27.97 | 0.000129 | 1.63 | 12.40 | 8.97 | 0.10 |
| | | | | | | | | | | |
| Ponds | 1648 | Max WS | A2-mature vg | 21814.67 | 27.58 | 0.000295 | 2.96 | 11.07 | 8.16 | 0.20 |
| Ponds | 1648 | Max WS | A3 Mature Vg | 21696.49 | 27.58 | 0.000292 | 2.95 | 11.07 | 8.16 | 0.20 |
| Ponds | 1648 | Max WS | Alt 3B Q100 | 17919.62 | 27.93 | 0.000177 | 2.34 | 11.42 | 8.50 | 0.12 |
| | | | | | | | | | | |
| Ponds | 1553.243 | Max WS | Ex 100 YrMod | 10798.20 | 28.43 | 0.001604 | 5.31 | 10.87 | 6.54 | 1.09 |
| Ponds | 1553.243 | Max WS | A2-mature vg | 21814.38 | 27.56 | 0.000283 | 3.01 | 11.23 | 7.87 | 0.19 |
| Ponds | 1553.243 | Max WS | A3 Mature Vg | 21696.18 | 27.56 | 0.000280 | 2.99 | 11.23 | 7.87 | 0.19 |
| Ponds | 1553.243 | Max WS | Alt1-Q100 | 19282.82 | 27.59 | 0.000151 | 1.55 | 10.04 | 8.01 | 0.09 |
| Ponds | 1553.243 | Max WS | Alt 3B Q100 | 17918.61 | 27.92 | 0.000170 | 2.37 | 11.58 | 8.23 | 0.12 |

Table 2 (cont). Pond Reach parameter comparison for 100-year flow with Existing Conditions, and Alternatives 1, 2, 3, and 3B.

Profile Output Table - Shear

HEC-RAS River: Overbank Reach: Ponds Profile: Max WS

| Reach | River Sta | Profile | Plan | Q Total | W.S. Elev | E.G. Slope | Vel Chnl | Hydr Depth C | Hydr Depth | Shear Chan |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft/ft) | (ft/s) | (ft) | (ft) | (lb/sq ft) |
| Ponds | 1380 | Max WS | A2-mature vg | 16982.98 | 27.60 | 0.000217 | 2.69 | 11.45 | 7.83 | 0.15 |
| Ponds | 1380 | Max WS | A3 Mature Vg | 16864.60 | 27.60 | 0.000214 | 2.67 | 11.45 | 7.83 | 0.15 |
| Ponds | 1380 | Max WS | Alt 3B Q100 | 12214.10 | 27.96 | 0.000099 | 1.85 | 11.81 | 8.19 | 0.07 |
| | | | | | | | | | | |
| Ponds | 1197.307 | Max WS | Ex 100 YrMod | 10798.20 | 27.72 | 0.003013 | 6.29 | 8.90 | 5.32 | 1.64 |
| Ponds | 1197.307 | Max WS | A2-mature vg | 16982.77 | 27.54 | 0.001094 | 3.86 | 11.49 | 7.74 | 0.61 |
| Ponds | 1197.307 | Max WS | A3 Mature Vg | 16864.38 | 27.54 | 0.001132 | 3.87 | 9.65 | 7.66 | 0.62 |
| Ponds | 1197.307 | Max WS | Alt1-Q100 | 19279.31 | 27.52 | 0.000305 | 1.92 | 8.24 | 7.64 | 0.16 |
| Ponds | 1197.307 | Max WS | Alt 3B Q100 | 12212.10 | 27.68 | 0.003537 | 6.80 | 8.85 | 4.39 | 1.92 |
| | | | | | | | | | | |
| Ponds | 572 | Max WS | Ex 100 YrMod | 10798.19 | 26.50 | 0.001744 | 5.87 | 12.00 | 5.93 | 1.29 |
| Ponds | 572 | Max WS | A2-mature vg | 16981.16 | 26.50 | 0.002652 | 6.93 | 11.17 | 5.54 | 1.84 |
| Ponds | 572 | Max WS | A3 Mature Vg | 16862.84 | 26.50 | 0.002615 | 6.88 | 11.17 | 5.54 | 1.82 |
| Ponds | 572 | Max WS | Alt1-Q100 | 19273.20 | 26.50 | 0.003154 | 7.90 | 12.00 | 5.59 | 2.34 |
| Ponds | 572 | Max WS | Alt 3B Q100 | 12209.56 | 26.50 | 0.001371 | 4.98 | 11.17 | 5.54 | 0.95 |

### 2.2.2 Alternatives 1, 2, 3, and 3B

Significant conclusions of the hydraulic modeling for Alternatives 1, 2, and 3 include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 2 and Figure 3).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 5, Figure 7).
- Due the removal of the dikes, during the bankfull flood significantly more discharge occurs through the Pond Reach compared to existing conditions, although the increase in flow is not as pronounced for Alternative 3B (Table 3).
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations. There is a nominal increase in water surface elevation in the vicinity of cross section 1197 due to the increase in overbank flow at the bankfull flow (Figure 1). At higher flows, the slight increase in water surface elevation at the bankfull flow becomes a decrease in water surface elevation.
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 5, Figure 7).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 6, Figure 8).
- Flow velocities near the Pond Reach outlet increase (Figure 6, Figure 8).

Bankfull flow results for the alternatives are summarized in Table 1.

Table 3 Summary of differences between Existing Conditions and Alternatives 1, 2, 3, and 3B for bankfull flow.

| Analysis Condition | Maximum Mainstem Water Surface Decrease (ft) | Maximum Mainstem Velocity Decrease (ft/s) | Increase in Pond Reach Discharge at Outlet (cfs) |
|---|---|---|---|
| Alternative 1 | 0.86 | 1.6 | 2,300 |
| Alternative 2 | 0.52 | 0.66 | 1,730 |
| Alternative 3 | 0.51 | 0.62 | 1,680 |
| Alternative 3B | 0.49 | 0.81 | 300 |

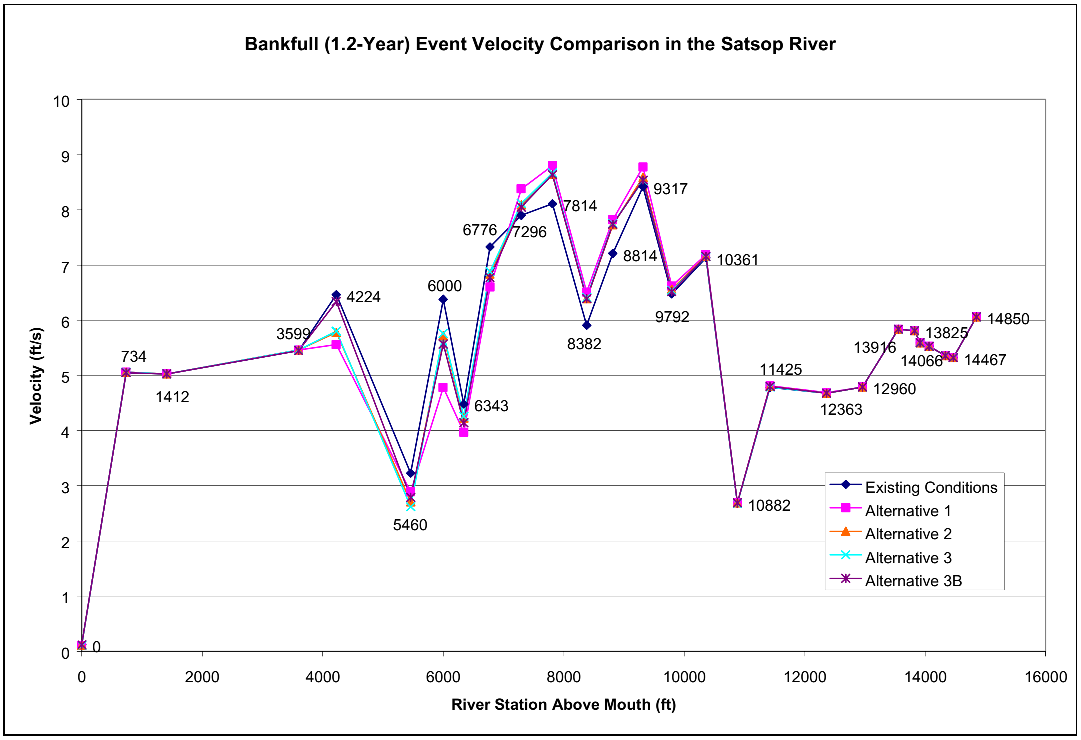


Figure 5 Velocity comparison at bankfull flow in the Satsop River.

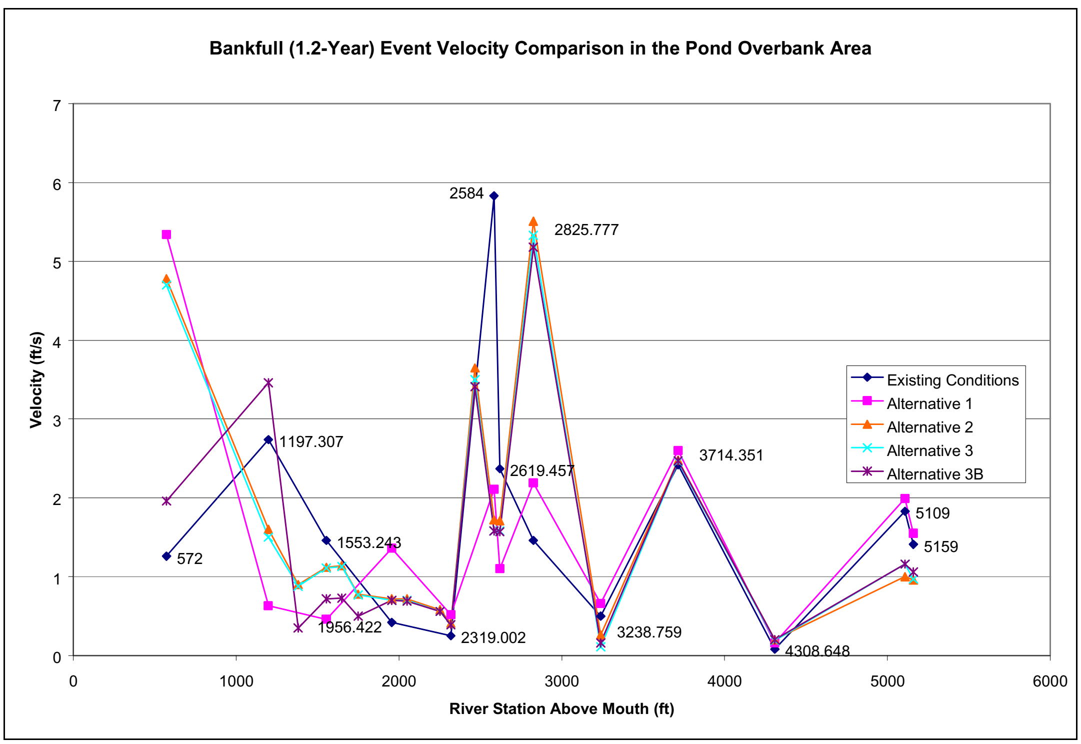


Figure 6 Velocity comparison at bankfull flow in the Pond Reach area.

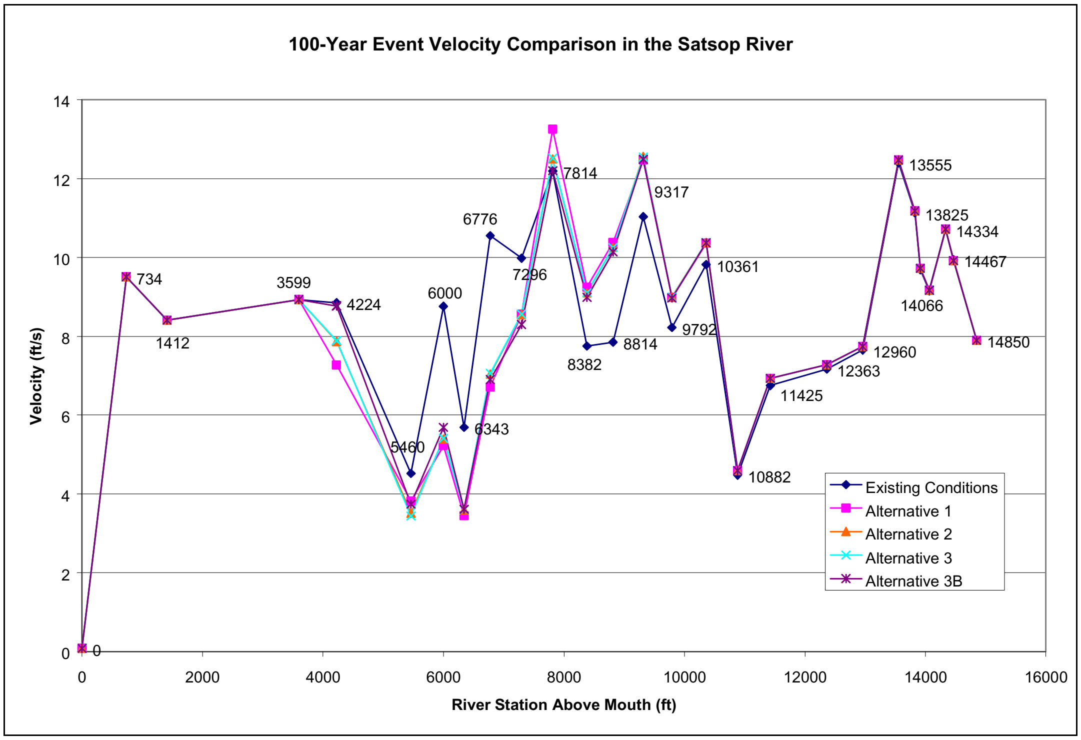


Figure 7. Velocity comparison at the 100-year flow in the Satsop River.

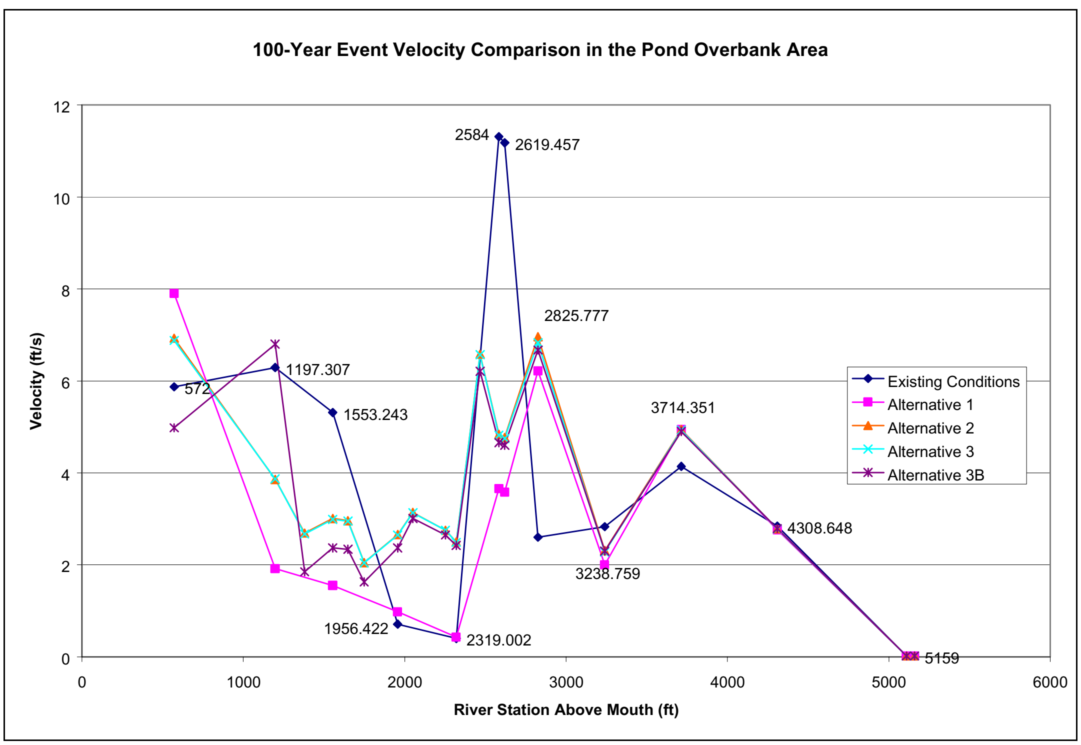


Figure 8. Velocity comparison at the 100-year flow in the Pond Reach area.

## 2.3 Unsteady Flow Modeling Results

In the following sections the results of the unsteady steady flow hydraulic modeling for each of the analysis conditions are summarized. To assess the influence of the proposed alternatives on the hydraulic characteristics of the Satsop River, unsteady flow analyses were conducted based on the February 1996 and March 1997 flood events. The unsteady flow analysis provides a means of directly analyzing the effect on floodplain storage associated with the proposed alternatives. In general terms, all the alternatives provide hydraulic benefits by decreasing overall water surface elevations in the project vicinity. This is due to the increase in floodplain function in the system that the alternatives provide. The beneficial effects apply to both the February 1996 and March 1997 events. Specific effects of the alternatives are described in the following sections:

### 2.3.1 Alternative 1

Significant conclusions of the hydraulic modeling for Alternative 1 with the March 1997 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 9).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 10).
- Due the removal of the dikes, significantly more discharge (22,430 vs 12,000 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 11).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 10).
- Velocities decrease through the portion of the Pond Reach representing the ponds (Figure 12).
- Flow velocities at the lower Pond Reach outlet (Egress Channel ) increase (Figure 12).

Significant conclusions of the hydraulic modeling for Alternative 1 with the February 1996 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 13).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 14).
- Due the removal of the dikes, significantly more discharge (5,190 vs 1,880 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 15).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main

channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 14).

- Flow velocities at the lower Pond Reach outlet (Egress Channel ) increase (Figure 16).

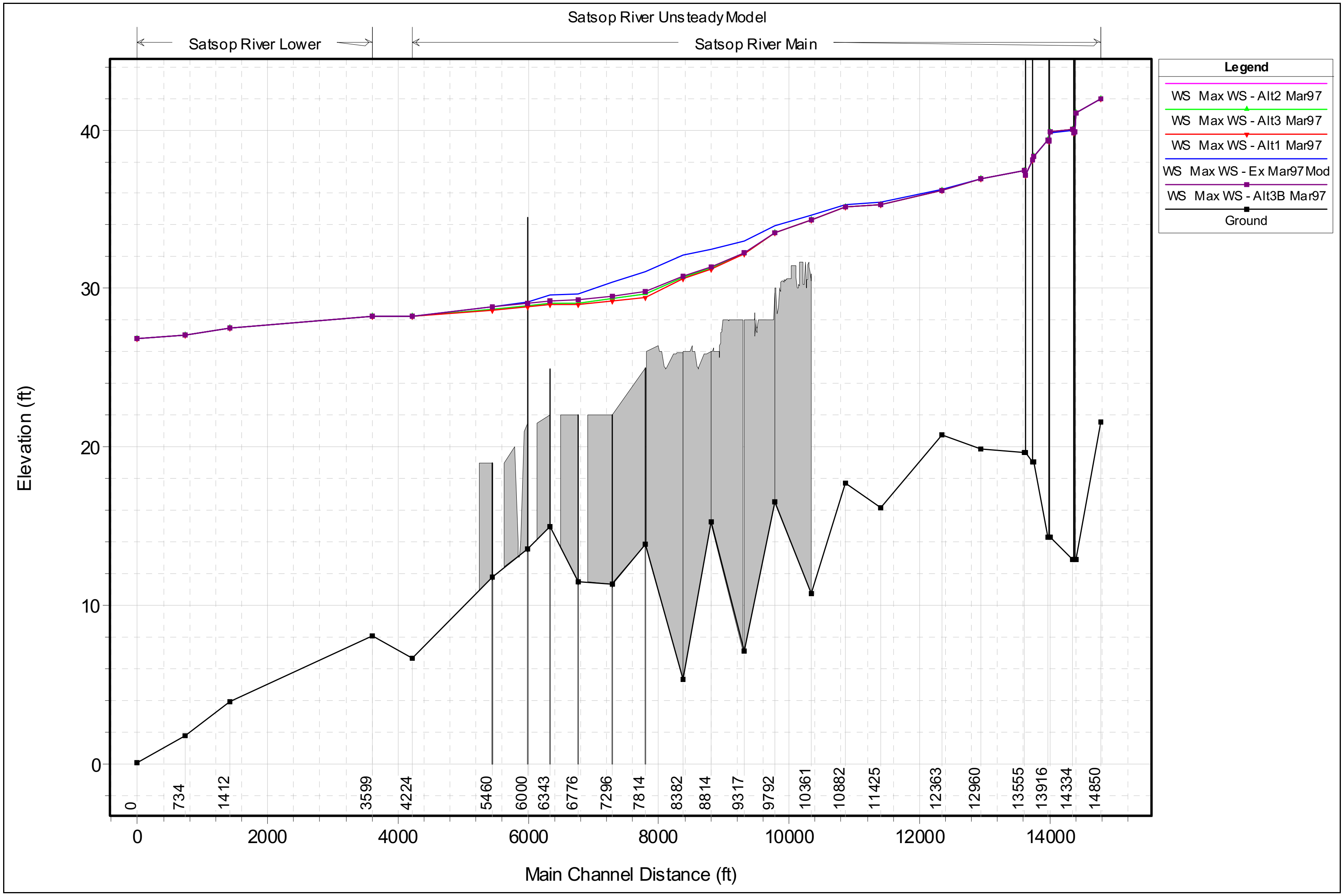


Figure 9. Satsop River March 1997 event water surface comparison for Existing Conditions, and Alternatives 1, 2 3, and 3B.


Figure 10. Satsop River March 1997 event velocity comparison for Existing Conditions, and Alternatives 1, 2 3, and 3B.

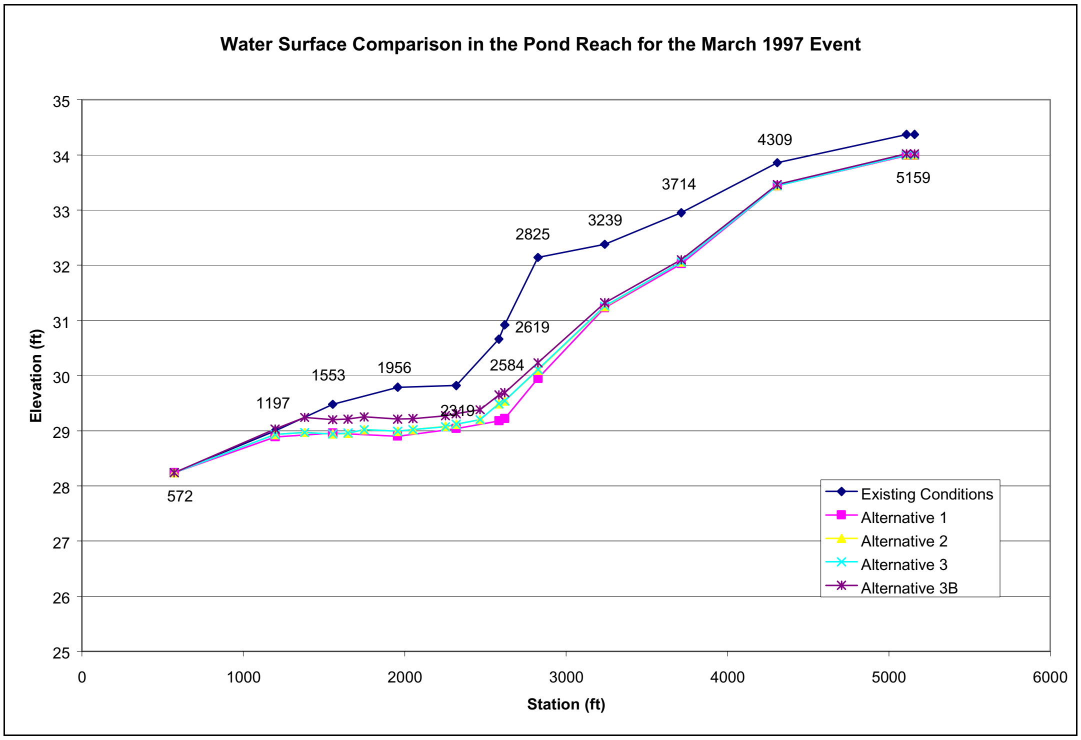


Figure 11. Pond Reach March 1997 event water surface comparison for Existing Conditions, and Alternatives 1, 2 3, and 3B.

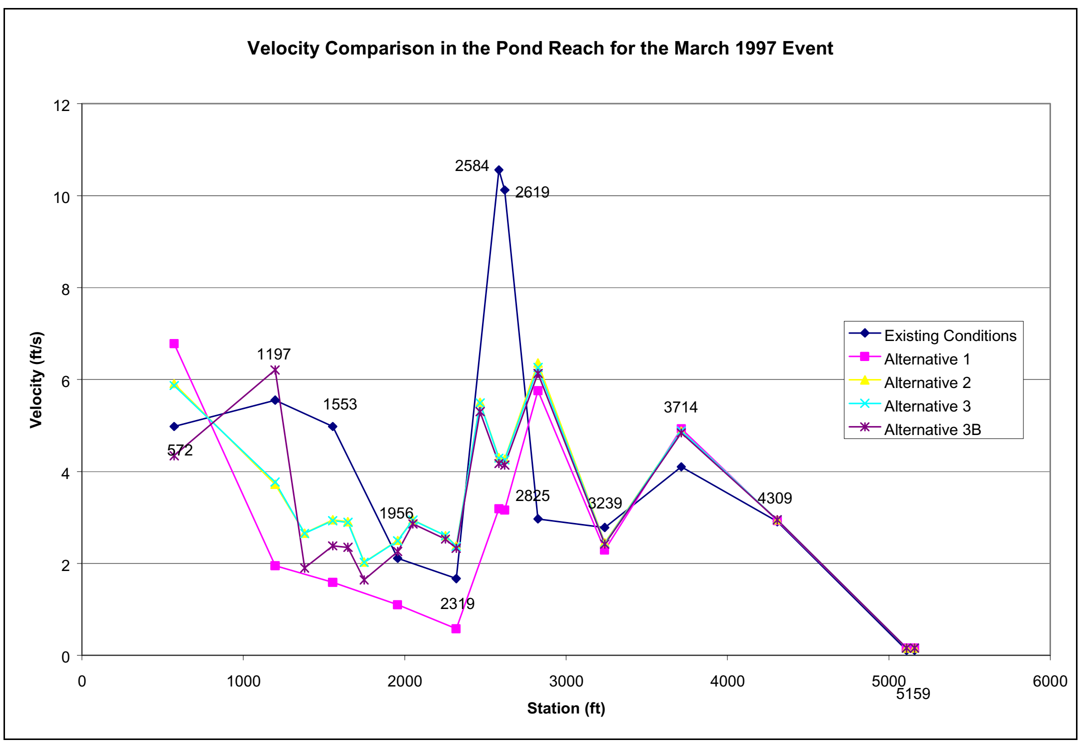


Figure 12. Pond Reach March 1997 event velocity comparison for Existing Conditions, and Alternatives 1, 2 3, and 3B.

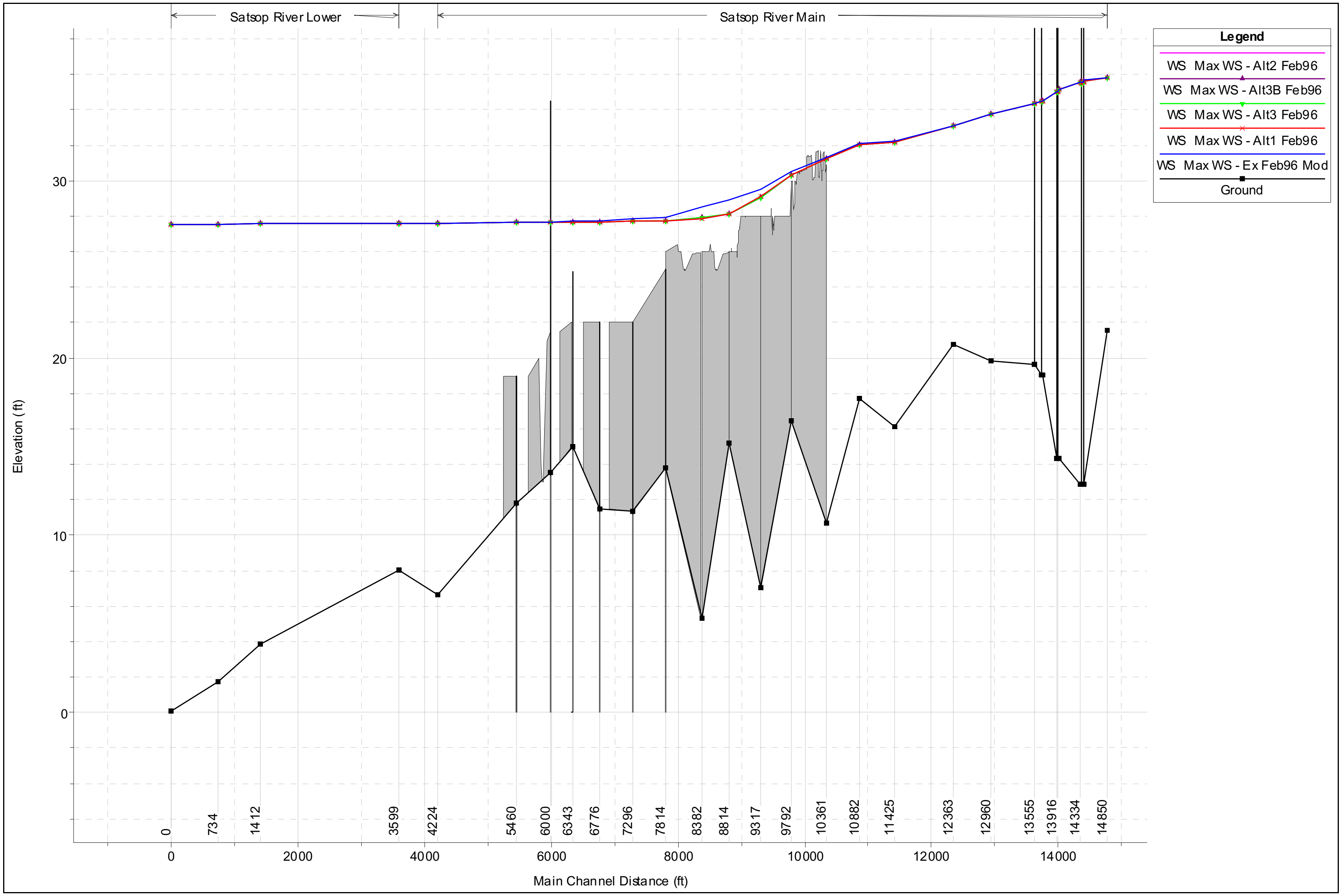


Figure 13. Satsop River February 1996 event water surface comparison for Existing Conditions, and Alternatives 1, 2 3, and 3B.

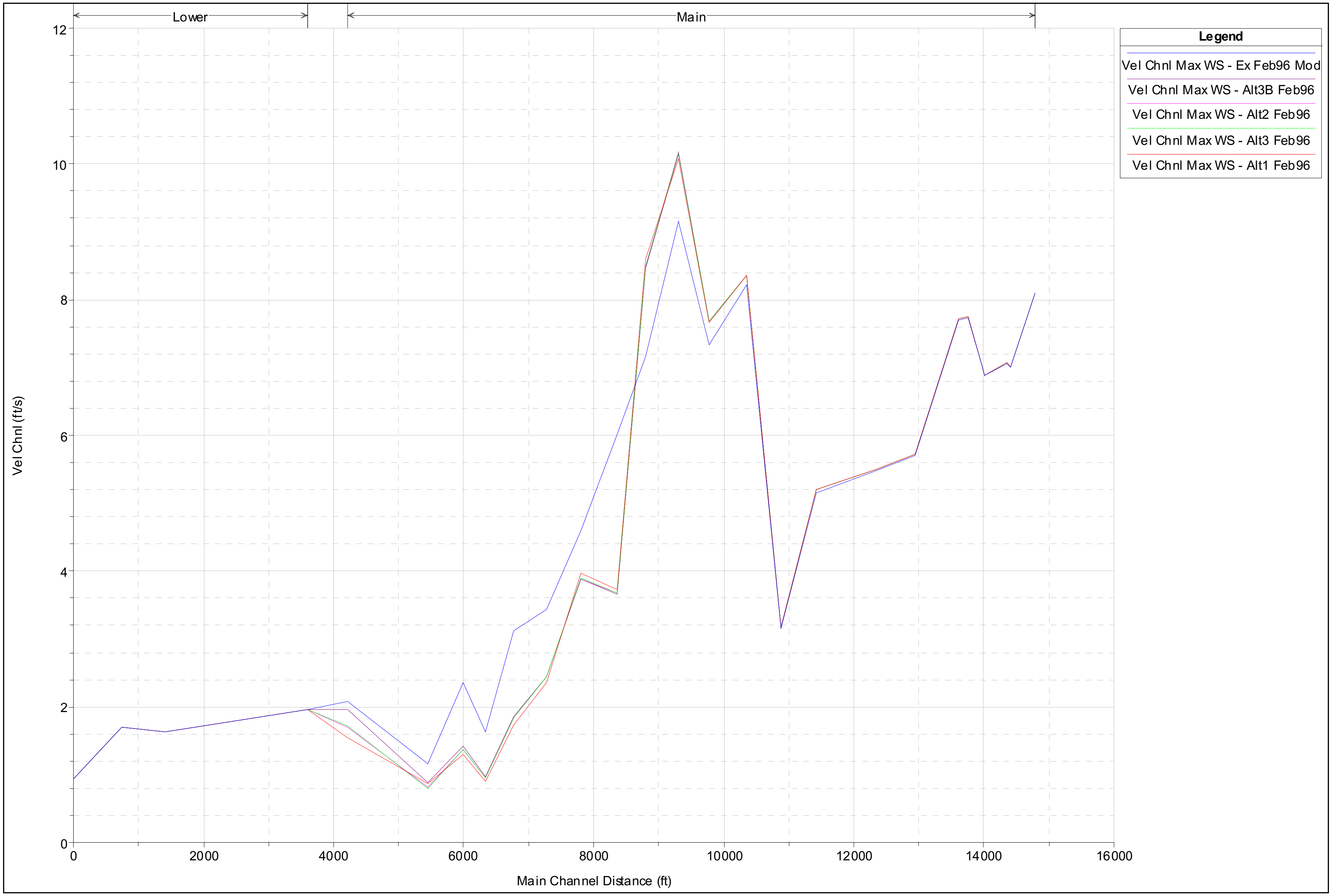


Figure 14. Satsop River February 1996 event velocity comparison for Existing Conditions, and Alternatives 1, 2 3, and 3B.

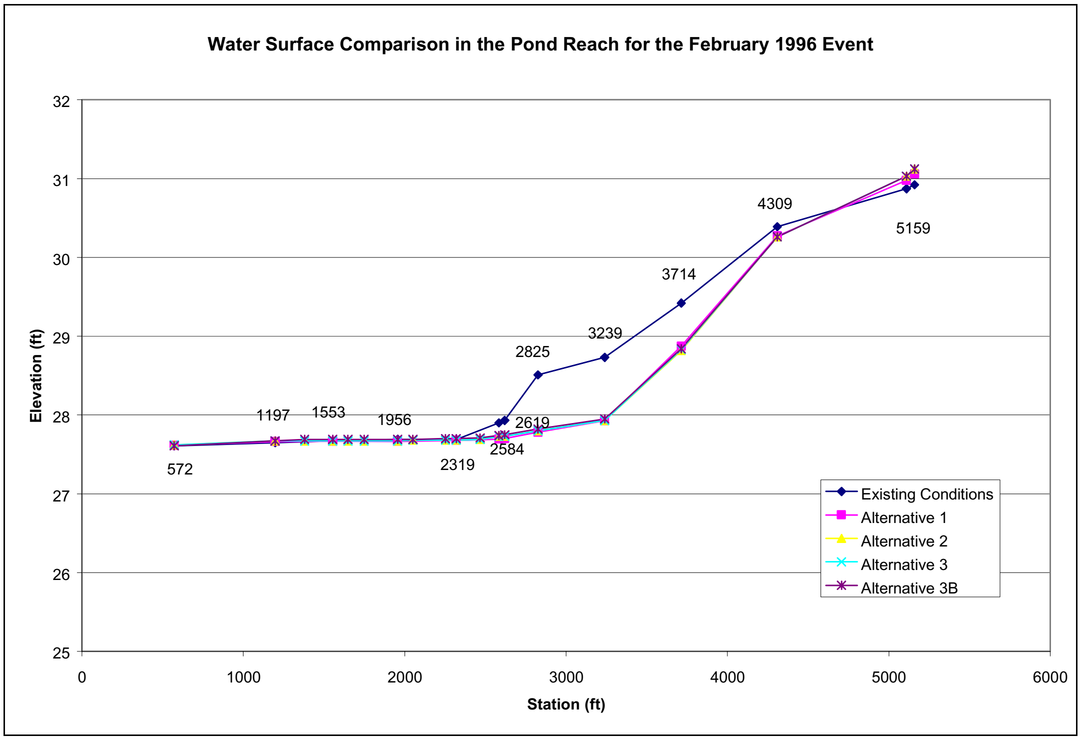


Figure 15. Pond Reach February 1996 event water surface comparison for Existing Conditions and Alternatives 1, 2 3, and 3B.

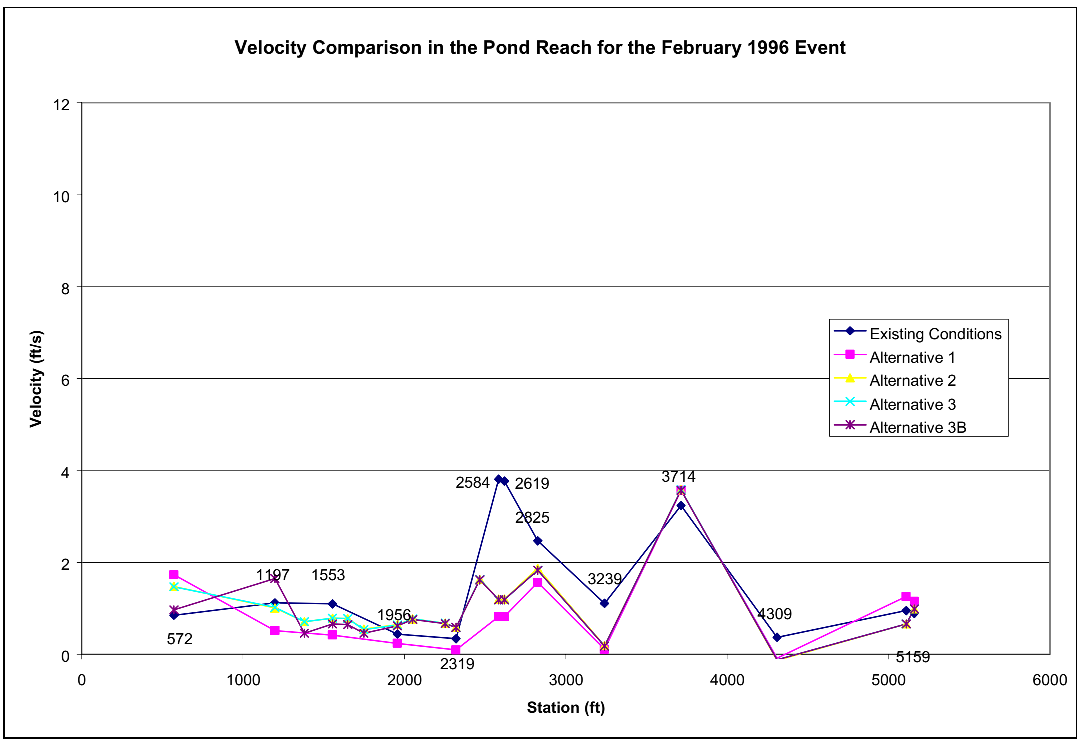


Figure 16. Pond Reach February 1996 event velocity comparison for Existing Conditions and Alternatives 1, 2 3, and 3B.

### 2.3.2 Alternative 2

Significant conclusions of the hydraulic modeling for Alternative 2 with the March 1997 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 9).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 10).
- Due the removal of the dikes, significantly more discharge (19,700, vs 12,000 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 11).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 10).
- Velocities decrease through the lower portion of the Pond Reach (Figure 12).
- Flow velocities along the lower Pond Reach (Egress Channel ) increase (Figure 12).

Significant conclusions of the hydraulic modeling for Alternative 2 with the February 1996 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 13).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 14).
- Due the removal of the dikes, significantly more discharge (4,460, vs 1,880 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 15).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 14).
- Velocities decrease through the lower portion of the Pond Reach (Figure 16).
- Flow velocities at the Pond Reach outlet (Egress Channel ) increase (Figure 16).

### 2.3.3 Alternative 3

Significant conclusions of the hydraulic modeling for Alternative 3 with the March 1997 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 9).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 10).
- Due the removal of the dikes, significantly more discharge (19,580, vs 12,000 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 11).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 10).
- Velocities decrease through the lower portion of the Pond Reach (Figure 12).
- Flow velocities at the Pond Reach outlet (Egress Channel ) increase (Figure 12).

Significant conclusions of the hydraulic modeling for Alternative 3 with the February 1996 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 13).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 14).
- Due the removal of the dikes, significantly more discharge (4,430 vs 1,880 cfs) occurs through the Pond Reach compared to existing conditions.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 15).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 14).
- Velocities decrease through the lower portion of the Pond Reach (Figure 16).
- Flow velocities at the lower Pond Reach outlet (Egress Channel ) increase (Figure 16).

### 4.5.4 Alternative 3B

Significant conclusions of the hydraulic modeling for Alternative 3B with the March 1997 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 9).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 10).
- Due the removal of the northern and western dikes, significantly more discharge (14,480, vs 12,000 cfs) occurs through the Pond Reach compared to existing conditions. The discharge at the Pond Reach outlet is less than Alternatives 1, 2, and 3 due to more flow being diverted out of the Pond reach by the south dike flow obstruction.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 11).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 10).
- Velocities decrease through most of the lower portion of the Pond Reach (Figure 12).
- Flow velocities near cross section 1197 in the lower Pond Reach (Egress Channel ) increase (Figure 12).

Significant conclusions of the hydraulic modeling for Alternative 3B with the February 1996 event include the following:

- Compared to existing conditions, water surface elevations decreased along the mainstem Satsop River channel adjacent to the ponds (Figure 13).
- Compared to existing conditions, flow velocities decreased along the Satsop River adjacent to the ponds (Figure 14).
- Due the removal of the dikes, significantly more discharge (2,910 vs 1,880 cfs) occurs through the Pond Reach compared to existing conditions. Similar to the March 1997 event, the discharge at the Pond Reach outlet is less than Alternatives 1, 2, and 3 due to more flow being diverted out of the Pond reach by the south dike flow obstruction.
- Water surface elevations along the Pond Reach are lower upstream of the former dike locations (Figure 15).
- Channel velocities along the mainstem increase slightly in the area of existing riprap. This is attributed to the removal of flow obstructions and a greater gradient in the main channel created by a decrease in the downstream water surface elevation due to less main channel flow (Figure 14).
- Flow velocities at the Pond Reach outlet (Egress Channel ) increase (Figure 16).

## 2.4 Low Flow Conditions

An analysis of low flow hydraulic conditions was conducted to describe how proposed pond outlets might interact with the flow in the Satsop River mainstem. Stage-discharge curves for the mainstem channel were developed for locations in the vicinity of both the Alternative 2 Egress Channel outlet and the Alternative 3 and 3B Pond A outlet channel. Water surface elevations were defined for a range of flows from 140 to 3,000 cfs. The lowest average daily flow of record is 147 cfs in 1994.

As backwater from the Chehalis River would not be expected during low flow periods, the downstream boundary condition for the hydraulic analysis low flow conditions was estimated as normal depth based on an assumed slope of 0.002, the approximate ground slope. This assumption would be expected to give a conservatively low estimate of the stage along the Satsop River. The resultant stage discharge curves for Alternative 2 and Alternative 3 are shown in Figure 17, and Figure 18, respectively.

Notably, under Alternative 2, the Pond B outlet channel is to be set at elevation 14.9 ft NGVD and the outlet of the Egress Channel (Pond Reach) is also at elevation 14.9 ft NGVD. Based on observed pond levels the low flow connection of the ponds to the Satsop River may be interrupted during summer low flow periods. As seen from Figure 17, it would take an approximate flow of 2,350 cfs to reach the 14.9 foot stage to allow the river to hydraulically connect to the Egress Channel.

For Alternative 3 and Alternative 3B, the pond connection from Pond A is set at elevation 13 feet. The corresponding water surface elevation on the Satsop River in that vicinity is 13.4 feet, at 140 cfs, the lowest average daily flow of record (Figure 18). This connection, if implemented, should stay wet year round for both alternatives.

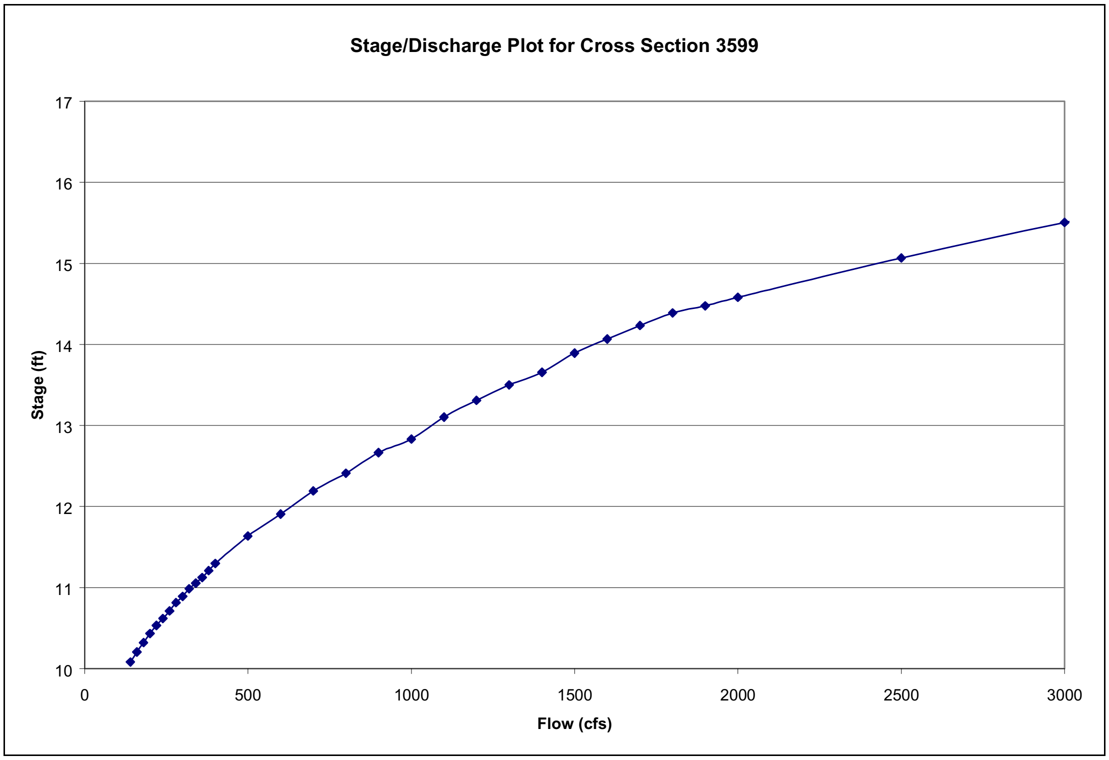


Figure 17. Stage/discharge relationship for cross section 3599 (near Egress outlet).

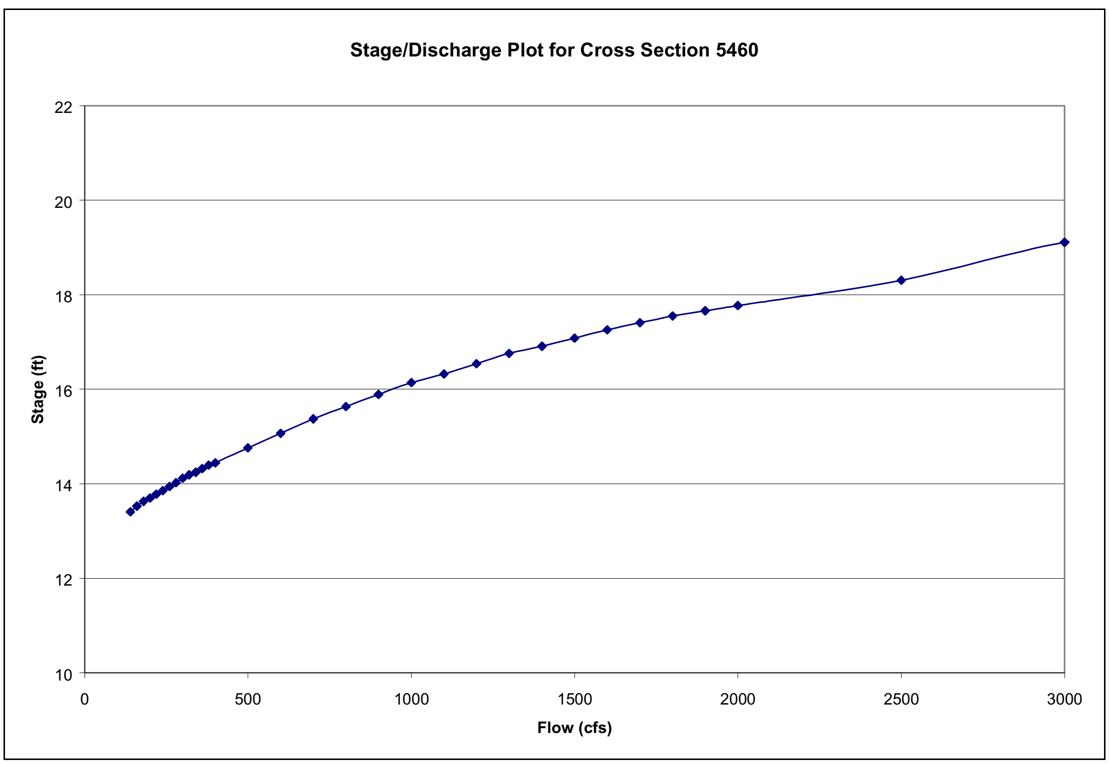


Figure 18. Stage/discharge relationship at cross section 5460 (near Pond A outlet).

# 3 GEOMORPHIC ANALYSIS PHASE ONE

## 3.1 Sediment Transport Analysis

### 3.1.1 Incipient Motion Analysis

An analysis of incipient motion characteristics for each analysis condition was conducted. The incipient motion size was determined at each cross section of both the Mainstem Reach and the Pond Reach based on hydraulic parameters identified for each analysis condition and tractive force calculations. Incipient motion conditions were evaluated for both the bankfull flood (1.2-year return period) and the 100-year flood.

Results of the incipient motion analysis for the bankfull flood are summarized in Figure 19 for the Mainstem Reach and Figure 20 for the Pond Reach. The maximum particle size for incipient motion along the mainstem is between 60 and 70 mm for all alternatives. This size range is consistent with observed sediment sizes. The incipient particle size is noted to increase for Alternatives 1, 2 and 3 upstream of River Station 7296. This is attributed to the increased flow velocities in the mainstem resulting from reduced backwater associated with dike and spoil removal on the site. Similarly, incipient motion sizes for the bankfull condition are observed to reduce slightly downstream of River Station 7296, due to increased flow in the Pond Reach under the proposed alternative conditions compared to existing conditions.

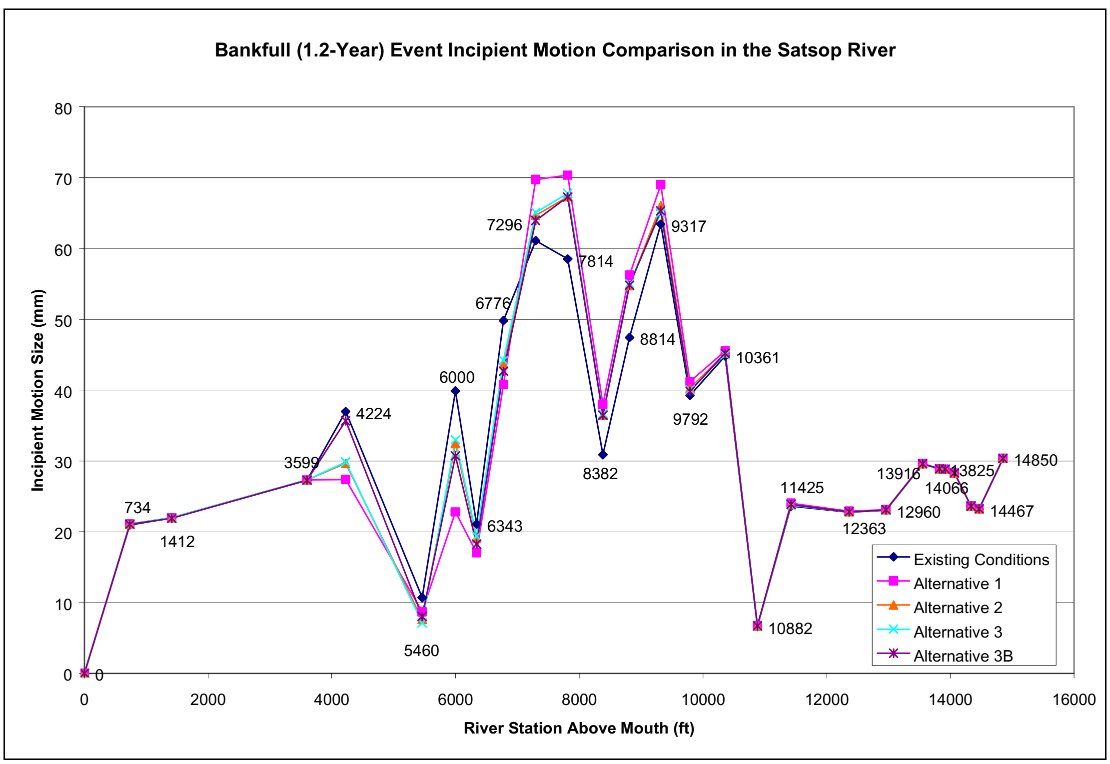


Figure 19. Incipient motion comparison at bankfull flow in the Satsop River.

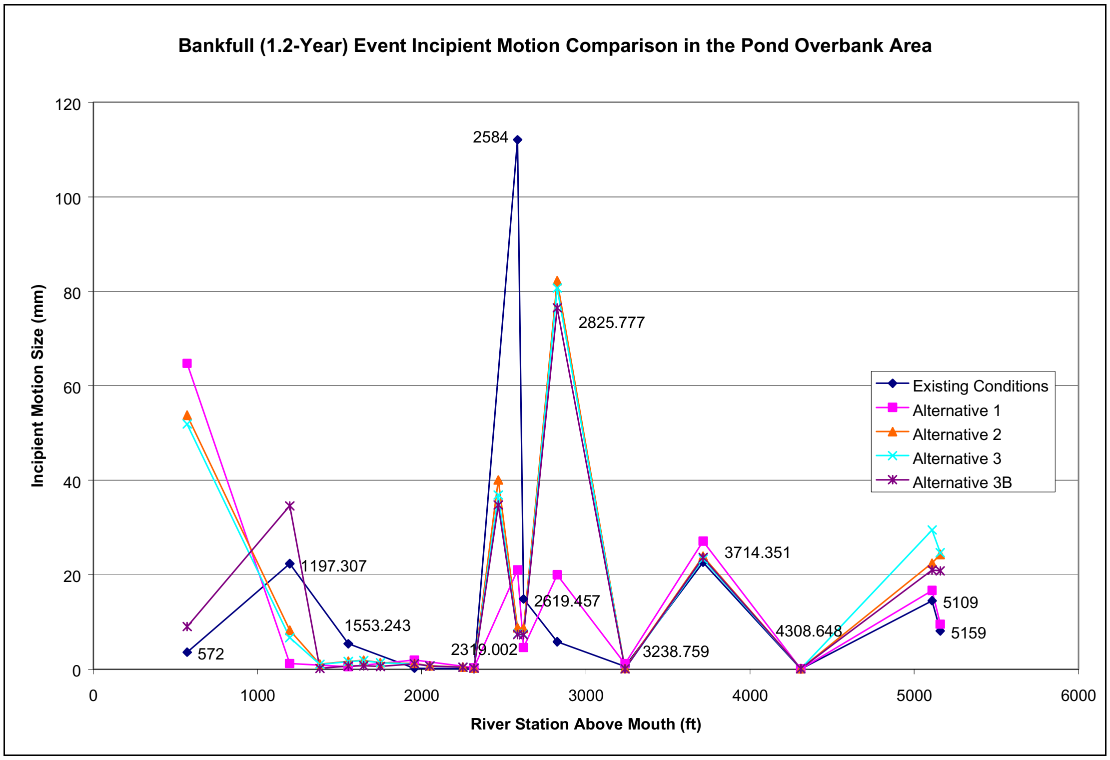


Figure 20. Incipient motion comparison at bankfull flow in the Pond Reach area.

During the Bankfull Flood (1.2 year return period) in the Pond Reach, the incipient motion sizes are generally less than 30 mm in size at most cross sections. At River Station 2584, a significantly larger incipient motion size was defined due to the hydraulic conditions associated with a culvert at that location under existing conditions. Under alternative conditions, the removal of dikes and spoils results in a much higher incipient motion size at River Station 2826. Also at the outlet of the Pond Reach, River Station 572, the incipient motion size is seen to increase significantly for Alternatives 1, 2, and 3 due to increased flow along the Pond Reach, and at a lesser extent, Alternative 3B.

Results of the incipient motion analysis for the 100-year flood are summarized in Figure 21 for the Mainstem Reach and Figure 22 for the Pond Reach. The maximum particle size for incipient motion along the mainstem is between about 120 and 150 mm for all alternatives. Similar to the results for the Bankfull Flood, the incipient particle size is noted to increase for Alternatives 1, 2 and 3 upstream of River Station 7296. This is attributed to the increased flow velocities in the mainstem resulting from reduced backwater associated with dike and spoil removal on the site. The incipient motion sizes for the 100 year flood area are observed to reduce slightly downstream of River Station 7296, due to increase flow in the Pond Reach under the proposed alternative conditions compared to existing conditions.

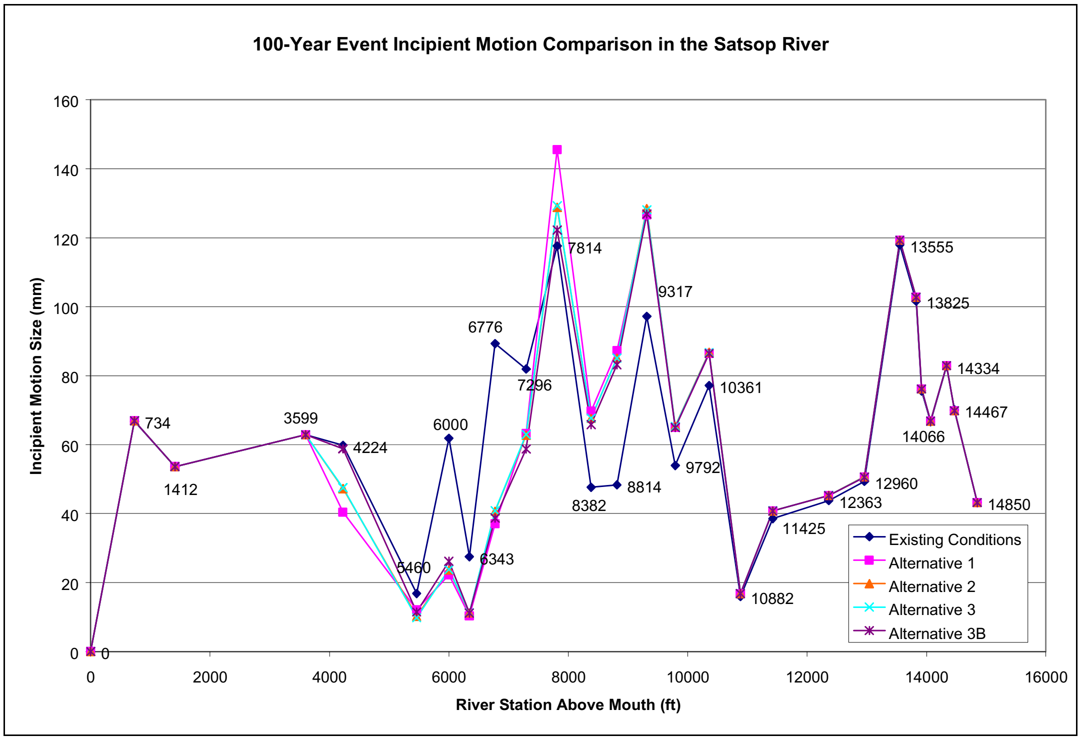


Figure 21. Incipient motion comparison at the 100-year flow in the Satsop River.

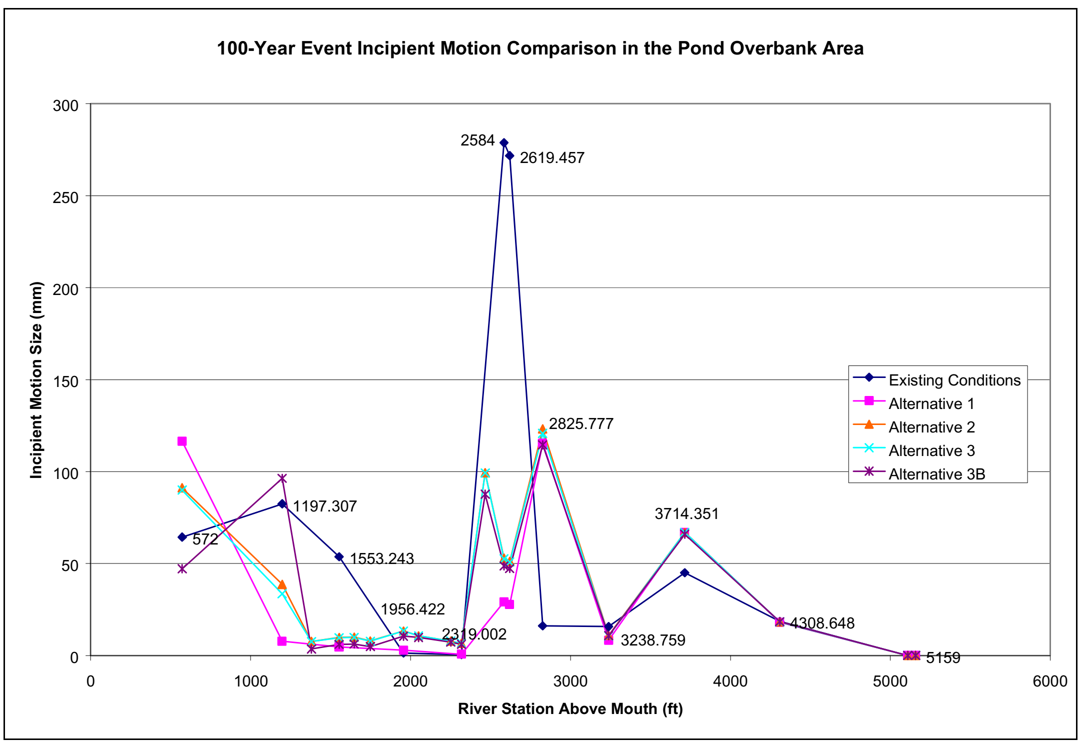


Figure 22. Incipient motion comparison at the 100-year flow in the Pond Reach area.

The estimated incipient motion characteristics for the Pond Reach for the 100-year flood closely resemble the results found for the bankfull flood except that the predicted particle sizes are significantly larger. An exception is at the Pond Reach outlet where the incipient motion size is slightly smaller for Alternative 3B compared to existing conditions due to a more effective flow area at the outlet, which is created by multiple flow paths in the overbank.

### 3.1.2 Bed Load Transport Capacity

The average annual bed load sediment transport capacity for each analysis condition was evaluated at five cross sections located through the study area. The bed load transport rates were calculated based on the SAM Hydraulic Design Package (COE, 1998) and the Meyer-Peter and Muller (1948) bed load formula. The Meyer-Peter and Muller (1948) bed load formula was selected for use since it had been previously applied by Collins and Dunne (1986). Results of the analysis are summarized in

Table 4.

The results of the analysis are qualitatively consistent with field conditions and previous studies. Under existing conditions, the average annual bed load transport capacity was estimated to range from approximately 1,400 tons/year to nearly 34,000 tons/year for all sections. The average of annual bed load transport capacity determined for all sections is about 14,000 tons per year. If the values for sections affected by riprap are excluded, the average rate is about 9,700 tons per year, which is very similar to the value of 8,000 tons per year previously estimated by Collins and Dunne (1986) for the lower Satsop River.

The bed load transport estimates for existing conditions demonstrate the variability of sediment transport capacity through the study area. Within the riprap reach adjacent to the project area the bed load transport capacity is much greater than upstream and downstream locations. From field observation, it is apparent that the channel adjacent to the riprap is much narrower and deeper than the upstream and downstream channel where meandering is more pronounced. It is also apparent from surface sediments along the reach that armoring will likely limit the actual bed load transport for commonly occurring flows.

The bed load transport capacities calculated for alternative conditions display similar results. The altered flow distribution caused by removal of dikes and spoils from the project site results in an overall reduction in bed load transport capacity at the section adjacent to Pond A and an increase in bed load transport capacity in the middle portion of the riprap reach. Little change is noted at the sections upstream and downstream of the project site.

Table 4. Summary of average annual bed load transport capacity.

| | Location | Near Confluence | Adjacent to Pond A | Downstream Riprap | Middle Riprap | Upstream Riprap |
|---|---|---|---|---|---|---|
| | River Station | 734 | 6,000 | 7,814 | 8,814 | 10,882 |
| 1 | Existing Conditions (tons/yr) | 7,967 | 11,478 | 41,768 | 24,832 | 1,687 |
| 2 | Alternative 1 (tons/yr) | 7,961 | 2,661 | 57,774 | 43,066 | 1,749 |
| | Difference Row 2-1 (tons/yr) | -6 | -8,817 | 16,006 | 18,234 | 62 |
| | Percent Change (1 to 2) | -0.08 | -76.82 | 38.32 | 73.43 | 3.68 |
| 3 | Alternative 2 (tons/yr) | 8,068 | 4,921 | 51,159 | 40,963 | 1,754 |
| | Difference Row 1-3 (tons/yr) | 101 | -6557 | 9,391 | 16,131 | 67 |
| | Percent Change (1 to 3) | 1.27 | -57.13 | 22.48 | 64.96 | 3.97 |
| 4 | Alternative 3 (tons/yr) | 7,961 | 5,049 | 51,616 | 41,178 | 1,741 |
| | Difference Row 1-4 (tons/yr) | -6 | -6,429 | 9,848 | 16,346 | 54 |
| | Percent Change (1-4) | -0.08 | -56.01 | 23.58 | 66.00 | 3.20 |
| 5 | Alternative 3B (tons/yr) | 7,967 | 4,402 | 50,937 | 41,009 | 1,747 |
| | Difference Row 1-5 (tons/yr) | 0 | -7,076 | 9,169 | 16,177 | 60 |
| | Percent Change (1-5) | 0 | -61.65 | 21.95 | 65.14 | 3.56 |

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## 3.2 Headcut Analysis

A summary of short-term headcut potential estimates is shown in Table 5.

Table 5. Summary of short term headcut estimates.

| Pond | Available Pit Volume ($yd^3$)* | Fill Time (s)** | Method | Headcut Distance (ft) | Headcut depth (ft) | Head cut at Hwy 12 (ft) | Headcut at Elma-Montesano Rd (ft) | Headcut at RR (ft) |
|---|---|---|---|---|---|---|---|---|
| A (Alt 1) | 20,676 | 121 | Regression | 73 | 4.0 | 0 | 0 | 0 |
| A (Alt 1) | | | SLA | 93 | 2.9 | 0 | 0 | 0 |
| A (Alt 1) | | | Rule of Thumb | 535 | 4.0 | 0 | 0 | 0 |
| A (Alt 2, 3, 3B) | | 169 | Regression | 64 | 4.0 | 0 | 0 | 0 |
| A (Alt 2, 3, 3B) | | | SLA | 93 | 2.9 | 0 | 0 | 0 |
| A (Alt 2, 3, 3B) | | | Rule of Thumb | 535 | 4.0 | 0 | 0 | 0 |
| A (Existing) | | 423 | Regression | 44 | 3.2 | 0 | 0 | 0 |
| A (Existing) | | | SLA | 93 | 2.9 | 0 | 0 | 0 |
| A (Existing) | | | Rule of Thumb | 766 | 4.0 | 0 | 0 | 0 |
| B (Alt 1) | 45,914 | 270 | Regression | 237 | 5.0 | 0 | 0 | 0 |
| B (Alt 1) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| B (Alt 1) | | | Rule of Thumb | 705 | 5.0 | 0 | 0 | 0 |
| B (Alt 2, 3, 3B) | | 376 | Regression | 207 | 5.0 | 0 | 0 | 0 |
| B (Alt 2, 3, 3B) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| B (Alt 2, 3, 3B) | | | Rule of Thumb | 705 | 5.0 | 0 | 0 | 0 |
| B (Existing) | | 939 | Regression | 140 | 4.3 | 0 | 0 | 0 |
| B (Existing) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| B (Existing) | | | Rule of Thumb | 871 | 5.0 | 0 | 0 | 0 |
| C (Alt 1) | 43,446 | 255 | Regression | 86 | 5.0 | 0 | 0 | 0 |
| C (Alt 1) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| C (Alt 1) | | | Rule of Thumb | 593 | 5.0 | 0 | 0 | 0 |
| C (Alt 2, 3, 3B) | | 356 | Regression | 74 | 5.0 | 0 | 0 | 0 |
| C (Alt 2, 3, 3B) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| C (Alt 2, 3, 3B) | | | Rule of Thumb | 593 | 5.0 | 0 | 0 | 0 |
| C (Existing) | | 887 | Regression | 51 | 3.4 | 0 | 0 | 0 |
| C (Existing) | | | SLA | 102 | 3.2 | 0 | 0 | 0 |
| C (Existing) | | | Rule of Thumb | 1351 | 5.0 | 0 | 0 | 0 |

*Volume available is based on an assumed water surface elevation of 14 feet
**based on bankfull flow hydrograph

## 3.3 Bridge Scour

Using Laursen's live bed scour equation (FHWA, 1995) for the 100-year flow, contraction scour depth was calculated for each bridge in the study vicinity. It was assumed that the channel thalweg could migrate across the channel for pier scour calculations. A bed material $D_{50}$ of 51 mm was used in the scour calculations. Pier scour was calculated using the CSU equation (FHWA, 1995). There is essentially no difference in scour at the bridges for Alternative 1, 2, 3, or 3B compared to existing conditions. Long-term degradation was not considered for the total scour, but it can be assumed to be the same for all alternatives. The results of the scour calculations are shown in Table 6. No significant changes in bridge scour conditions were identified for the alternative conditions.

Table 6. Summary of bridge scour calculations.

| | Scour Type | Existing Conditions | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 3B |
|---|---|---|---|---|---|---|
| Elma-Montesano Road | Contraction Scour (ft) | 7.13 | 7.13 | 7.09 | 7.12 | 7.09 |
| | 3' Pier, Scour | 5.40 | 5.40 | 5.40 | 5.40 | 5.40 |
| | 5' Pier, Scour | 7.13 | 7.13 | 7.12 | 7.13 | 7.12 |
| | Total Scour | 14.26 | 14.26 | 14.21 | 14.25 | 14.21 |
| Railroad Bridge | Contraction Scour (ft) | 1.35 | 1.35 | 1.38 | 1.37 | 1.38 |
| | 1.25' Pier, Scour | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| | 6.4' Pier, Scour | 15.27 | 15.28 | 15.28 | 15.28 | 15.28 |
| | Total Scour | 16.62 | 16.63 | 16.66 | 16.65 | 16.66 |
| U.S. Hwy 12 Bridge | Contraction Scour (ft) | 2.56 | 2.56 | 2.55 | 2.55 | 2.57 |
| | 4.5' Pier, Scour | 15.88 | 15.88 | 15.91 | 15.90 | 15.91 |
| | Total Scour | 18.44 | 18.44 | 18.46 | 18.45 | 18.45 |

# 4 MITIGATION DESIGN

The impacts associated with each of the proposed alternatives were identified. Based on the prior analysis the following mitigation measures are defined. It is recognized that alternative methods of erosion protection such as those described in the Integrated Streambank Protection Guidelines (Washington State Aquatic Habitat Guidelines Program, 2002) could also be considered for this project. It is noted that the Corps supports the application of alternative erosion control techniques in suitable locations when practicable.

## 4.1 Keys Road Erosion Protection

Erosion protection for Keys Road and the existing natural gas pipeline was designed for two conditions,

1.) If existing riprap along the left bank of the mainstem is removed.
2.) If existing riprap remains in place.

### 4.1.1 Riprap Design With Migration of Mainstem Channel

If existing riprap along the mainstem channel is removed, migration of the channel that would influence Keys Road is expected. Riprap erosion control along Keys Road would be required. The U.S. Army Corps of Engineers (1994) method for riprap sizing was used to hydraulically design riprap erosion protection for the natural gas pipeline and Keys Road upstream of the project site entrance.

#### 4.1.1.1 Rock Size

The median diameter riprap size was determined based on the Corps of Engineer's methodology for riprap design found in EM 1110-2-1601, Hydraulic Design of Flood Control Channels (June 1994). Assumptions of the design included the following:

- The main channel of the Satsop River can migrate to Keys Road.
- Riprap sized based on hydraulic conditions of the main channel for a 100-year flood.
- Average radius of curvature for channel assumed equal to 1,000 ft.
- 2:1 bank slope.
- Rock stability factor of safety = 1.2 for existing conditions, 1.5 for the alternatives due to uncertainty associated with future conditions.

For Existing Conditions the $D_{50}$ rock size was estimated to be 1.2 feet. The median diameter rock size ($D_{50}$) was estimated to be 2.2 ft for Alternatives 1, 2, 3, and 3B. The larger rock size required for Alternatives 1, 2, 3, and 3B is due to the removal of significant flow obstructions in the overbank, an increase in water surface gradient on the main stem of the Satsop River (increasing velocity), and a larger factor of safety. It is noted that existing riprap along the Satsop River varies in size from cobbles to 3 ft diameter rock.

#### 4.1.1.2 Toe Down Depth

The toe down depth requirement for the riprap was determined based on an evaluation of the following components:

- Long-term Degradation Potential – This was assumed equal to zero as the project is located in the lower portion of the Satsop River basin which suggests a depositional environment.

- General Scour – This was estimated based on the largest depth estimated by the empirical Neil, Lacey, and Blench scour equations (USBR, 1984). These methods include bend scour and thalweg formation.
- Local Scour Due to Bedforms - This was assumed equal to zero as the Satsop River is a gravel bed stream.

- Factor of Safety – A factor of safety of 1.2 was used to define the maximum toe down depth for the 100-year flood.

A toe down depth of 12.41 ft was defined. Toe protection may be provided by extending the protection to the maximum scour depth or placing sufficient launchable material at the toe of the revetment.

#### 4.1.1.3 Rock Quantity

The volume of riprap required per foot of stream length was estimated based on the assumed geometry or 2H:1V sideslope, a median rock size of 2.2 ft, a riprap thickness of 4.5 ft, a toe down depth of 12.41 ft, and an estimated bankfull depth of 9.1 ft. These rock quantities are based on the calculations for Alternatives 1, 2, 3, and 3B, since protection of Keys Road and the gas line would probably not be a project requirement if the riprap on the main stem of the Satsop Rriver is not removed. The volume of riprap was estimated to be 10.4 CY/ft of bank.

#### 4.1.1.4 Length of Required Bank Protection

It is assumed that bank protection would be required from the existing entrance road to the upstream limit of the property. Bank erosion protection must also be tied into the existing riprap revetment along the adjacent upstream property. The total length of required erosion protection was estimated to be approximately 2,180 ft. Figure 23 shows the approximate location of recommended riprap protection.

### 4.1.2 Riprap Design Without Mainstem Migration

If the existing riprap along the Satsop River is not removed, the mainstem channel will likely continue to be stable for an extended period even though portions of the riprap have failed. If it is assumed that the main channel is restricted from migration to Keys Road, the required riprap size to protect Keys Road and the natural gas pipeline from potential would be substantially less. Under this scenario the riprap was sized based on a factor of safety of 1.5, and a 2:1 sideslope. The required toe down depth was estimated to be 6 feet. Protection is assumed from the toe of the bank up to bankfull depth. The design utilized overbank hydraulic conditions for the 100-year flood. As shown in Table 7, riprap requirements for both immature and mature vegetation conditions in the overbank were evaluated. In general, increased hydraulic roughness associated with mature overbank vegetation results in a decreased riprap size.

Table 7. Riprap sizes for the Pond Reach assuming no mainstem migration.

| Model | Calculated $D_{50}$ (ft) | Layer thickness (ft) | Rock Quantity ($yd^3/ft$) |
|---|---|---|---|
| Existing Conditions | 0.1 | 0.75 | 1.2 |
| Alternative 1 | 0.4 | 0.75 | 1.2 |
| Alternative 2 Young Vegetation | 0.6 | 1.00 | 1.5 |
| Alternative 2 Mature Vegetation | 0.5 | 1.00 | 1.5 |
| Alternative 3 Young Vegetation | 0.6 | 1.00 | 1.5 |
| Alternative 3 Mature Vegetation | 0.5 | 1.00 | 1.5 |
| Alternative 3B Young Vegetation | 0.5 | 1.00 | 1.5 |
| Alternative 3B Mature Vegetation | 0.5 | 1.00 | 1.5 |

#### 4.1.3 Alternative Keys Road Protection Without Mainstem Migration

Shear stress is most prominent near Pond Reach cross section 2825. In general, shear stress away from cross section 2825 is approximately half or less. Table 8 summarizes the shear stress upstream of the existing access road. The first 400 feet from the existing access road upstream past cross section 2825 could be protected with riprap or heavy vegetation and engineered log jams. The remaining upstream portion of the flow path could be protected by heavy vegetation.

#### 4.1.4 Alternative Measures

Alternative protection measures could be used to protect Keys Road and the nearby natural gas pipeline. It is noted the overflow channel is in close proximity to the road in many locations north of the existing access road. Protection of the road with vegetative covers could be used where adequate separation between the road and the channel exists. Relocation of the existing overflow channel away from Keys Road between the existing access road and the upstream end of the property could also be used to provide adequate protection. The area between the overflow path and Keys Road would be heavily planted with woody vegetation and engineered log jam type structures could be used as flow training devices along the channel. Figure 24 shows the approximate location of protection. The overflow path should be a minimum of 100 feet away from Keys Road.

## 4.2 Erosion Protection for Satsop Business Park Well

As previously discussed in 4.4.2, there will be an increase in overbank flow for all the alternatives (300 to 2,990 cfs) versus existing conditions (690 cfs) for the bankfull event. This increase in flow at the overbank outlet creates a potentially more erosive flow condition near the Satsop Business Park Well. A summary of the expected overflow channel shear stresses in the vicinity of the well is shown in

Table 9.

The required riprap size for erosion protection was calculated to have a $D_{50}$ size for existing conditions of 0.4 feet. The riprap $D_{50}$was sized at 1.0 ft for Alternative 1 and 0.7 feet for Alternatives 2 and 3, and 0.3 feet for Alternative 3B. The riprap sizes were calculated based on a safety factor of 1.2 for existing conditions, and 1.5 for all the alternatives. The bend radius used for the design was 450 feet, and the sideslope 2 horizontal: 1 vertical. The defined riprap sizes for the Egress Channel do not anticipate migration of the main channel to that location.

However, it is noted that historic channel migration information indicates that the mainstem channel was in close proximity in 1953. Therefore, with or without the current project, it is likely that the well location will be influenced by the mainstem channel again in the future.

Table 8. Shear stress along the Egress Channel between the existing access road and the upstream limit of the property, assuming no channel migration.

| Discharge | Analysis Condition | Average Shear Stress ($\#/ft^2$) | Maximum Shear Stress* ($\#/ft^2$) |
|---|---|---|---|
| Bankfull XS 3714 | Existing | 0.00 | 0.00 |
| | Alternative 1 | 0.00 | 0.00 |
| | Alternative 2 | 0.00 | 0.00 |
| | Alternative 3 | 0.00 | 0.00 |
| | Alternative 3B | 0.00 | 0.00 |
| Bankfull XS 3714 | Existing | 0.41 | 0.82 |
| | Alternative 1 | 0.49 | 0.98 |
| | Alternative 2 | 0.44 | 0.88 |
| | Alternative 3 | 0.42 | 0.84 |
| | Alternative 3B | 0.43 | 0.86 |
| Bankfull XS 3238 | Existing | 0.01 | 0.02 |
| | Alternative 1 | 0.02 | 0.04 |
| | Alternative 2 | 0.00 | 0.00 |
| | Alternative 3 | 0.00 | 0.00 |
| | Alternative 3B | 0.00 | 0.00 |
| Bankfull XS 2825 | Existing | 0.12 | 0.24 |
| | Alternative 1 | 0.41 | 0.82 |
| | Alternative 2 | 1.63 | 3.26 |
| | Alternative 3 | 1.60 | 3.20 |
| | Alternative 3B | 1.52 | 3.04 |
| 100-year XS 4308 | Existing | 0.37 | 0.74 |
| | Alternative 1 | 0.36 | 0.72 |
| | Alternative 2 | 0.37 | 0.74 |
| | Alternative 3 | 0.36 | 0.72 |
| | Alternative 3B | 0.37 | 0.74 |
| 100-year XS 3714 | Existing | 0.81 | 1.62 |
| | Alternative 1 | 1.20 | 2.40 |
| | Alternative 2 | 1.20 | 2.40 |
| | Alternative 3 | 1.20 | 2.40 |
| | Alternative 3B | 1.18 | 2.36 |
| 100-year XS 3238 | Existing | 0.32 | 0.64 |
| | Alternative 1 | 0.17 | 0.34 |
| | Alternative 2 | 0.22 | 0.44 |
| | Alternative 3 | 0.21 | 0.42 |
| | Alternative 3B | 0.22 | 0.44 |
| 100-year XS 2825 | Existing | 0.32 | 0.64 |
| | Alternative 1 | 2.34 | 4.68 |
| | Alternative 2 | 2.44 | 4.88 |
| | Alternative 3 | 2.40 | 4.80 |
| | Alternative 3B | 2.28 | 4.56 |

* Based on an assumed bend correction factor of 2.0.

### 4.2.1 Alternative Measures

It is noted that alternative bank protection measures may be appropriate in the vicinity of the Satsop Business Park Well. The expected maximum shear stress in the vicinity of the well is relatively mild for both bankfull and 100-year conditions; a well developed vegetative cover could provide adequate erosion protection. The recommended extent of protection is shown in Figure 24. It is noted that the existing Egress Channel is very heavily vegetated in the vicinity of the well.

Table 9. Shear stress along the Egress Channel near the Satsop Business Park Well.

| Discharge | Analysis Condition | Average Shear Stress (#/ft$^2$) | Maximum Shear Stress* (#/ft$^2$) |
|---|---|---|---|
| Bankfull | Existing | 0.07 | 0.14 |
| | Alternative 1 | 1.30 | 2.60 |
| | Alternative 2 | 1.09 | 2.18 |
| | Alternative 3 | 1.05 | 2.10 |
| | Alternative 3B | 0.18 | 0.36 |
| 100-year | Existing | 1.29 | 2.58 |
| | Alternative 1 | 2.34 | 4.68 |
| | Alternative 2 | 1.84 | 3.68 |
| | Alternative 3 | 1.82 | 3.64 |
| | Alternative 3B | 0.95 | 1.90 |

* Based on an assumed bend correction factor of 2.0.

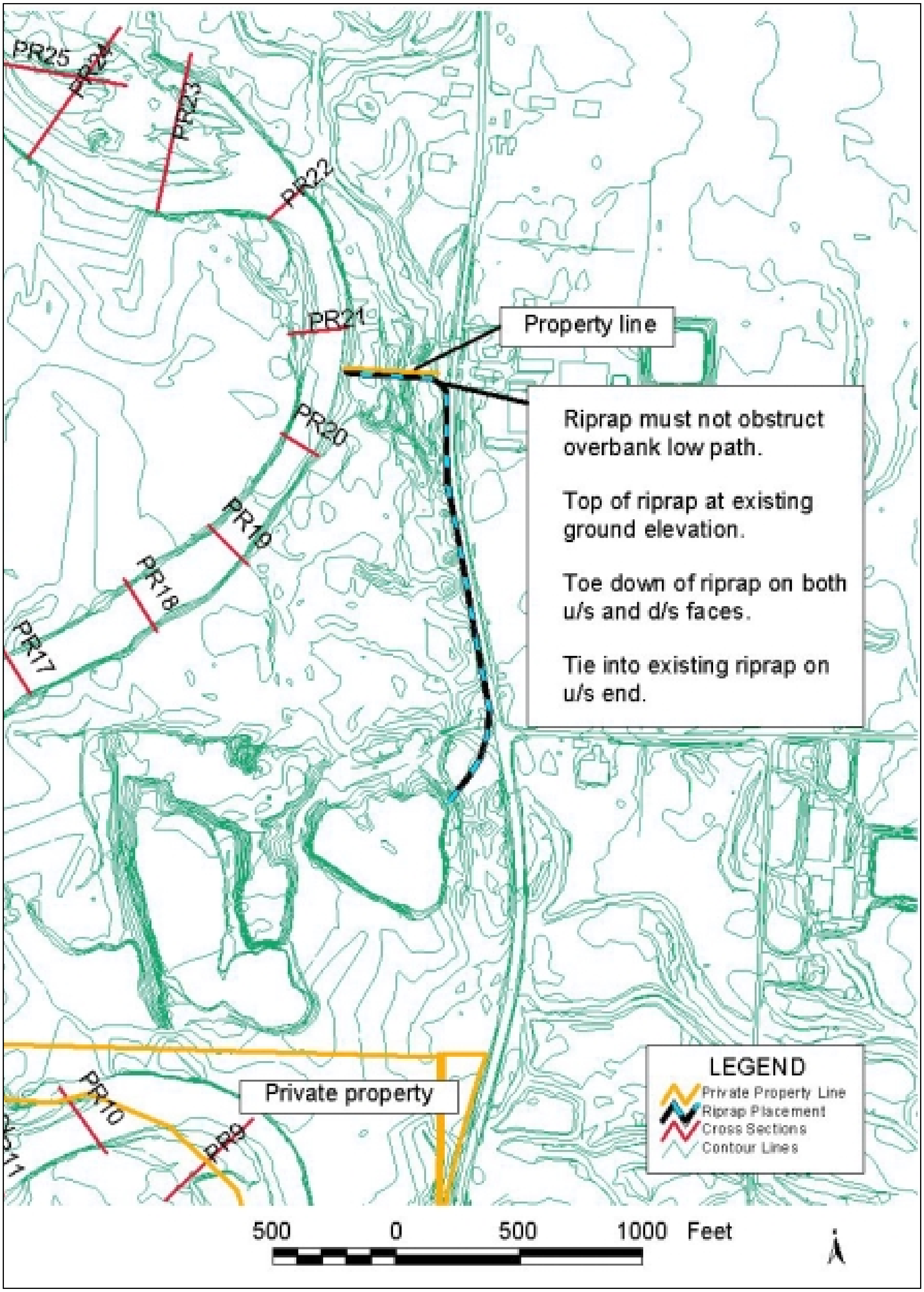


Figure 23. Location of required riprap protection for Keys Road.

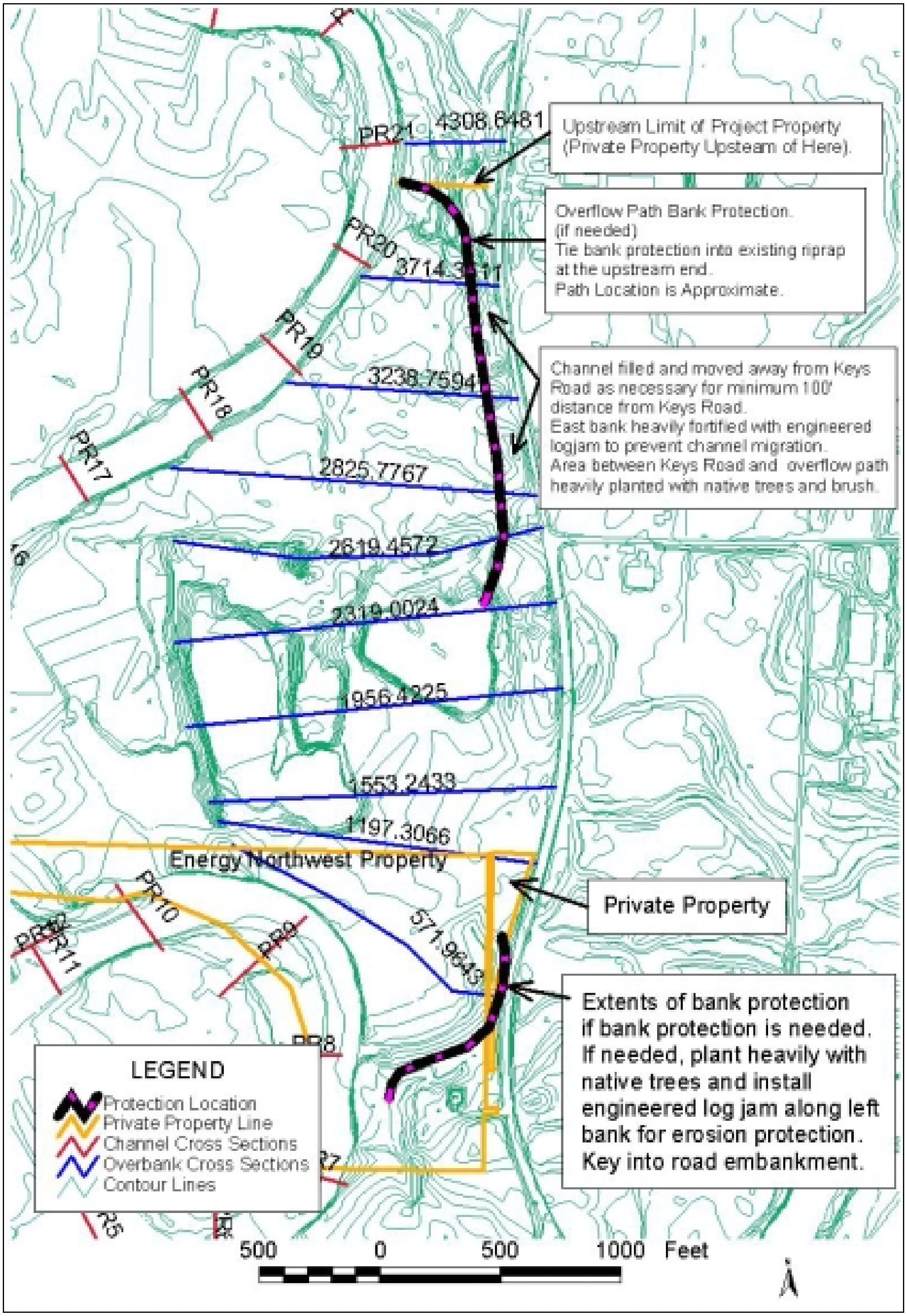


Figure 24. Alternative infrastructure protection measures.

# 5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions from the analysis include the following:

- Four alternatives for restoring floodplain functions were conceptualized. Alternative 1 consists of removal of all man-made features from the site including riprap, dikes, spoils, and culverts. Alternatives 2, 3, and 3B include the features of Alternative 1 and additional hydraulic connections between the existing ponds and the floodplain, and between the ponds. Additionally, under Alternatives 2, 3 and 3B, spoils are to be placed within Ponds B and C.

- Under Alternative 2 an outlet will be constructed between Pond B and the existing Egress Channel. Construction of this outlet will require a flow easement, as the Egress Channel is located on private property.

- Under Alternatives 3 and 3B, the outlet will connect Pond A to the mainstem channel. The construction of the outlet channel for this alternative will require an easement, as it will cross private property. Under Alternative 3B, the existing southern dike will be retained.

- Steady flow hydraulic analysis results for Alternatives 1, 2, 3, and 3B are similar. The following conclusions were identified:
    - For the bankfull flow, water surface elevations will decrease along the mainstem Satsop River channel between River Stations 4224 and 9792, by as much as 0.86 feet.
    - For the 100-year flood, water surface elevations will decrease along the mainstem of up to a maximum of 2 feet between River Stations 4224 and 13555.
    - For the bankfull flow, flow velocities along the mainstem Satsop River channel adjacent to the ponds will decrease up to a maximum of 1.60 feet/second. Adjacent to the existing riprap along the left bank of the river on the project site, flow velocities along the mainstem channel will increase a maximum of 2 feet/second. Notably, velocity increases for the bankfull flow will not extend upstream of the project site.
    - For the 100-year flood, flow velocities along the mainstem channel adjacent to the ponds will reduce a maximum of 3.6 feet/second. Adjacent to the existing riprap along the left bank of the river on the project site flow velocities will increase along the mainstem channel a maximum of 2.5 feet/second. Notably, velocity increases for the 100-year flood will not extend upstream of the project site.
    - Water surface elevations will decrease for both the bankfull flow and 100-year flood upstream of the dikes to be removed.
    - Flow velocities will decreases for both the bankfull flow and 100-year flood through the portion of the Pond Reach influenced by the ponds,
    - Flow will increase at the Egress Channel outlet of the Pond Reach that ranges from 300 cfs to 2,300 cfs for the bankfull flow and 1,410 to 8,480 cfs for the 100-year flood.

    - Flow velocities will increase along the Egress Channel portion of the Pond Reach as much as 4.1 feet/second for the bankfull flow to 2.0 feet/second for the 100-year flood. Backwater conditions for the 100-year flood moderate the flow velocities along the Egress Channel.

- Unsteady flow analysis results for Alternatives 1, 2 3, and 3B are also similar. For the March 1997 event, the following conclusions were identified:
    - Water surface elevations along the mainstem Satsop River channel adjacent to the ponds were reduced up to 1.6 feet.
    - Flow velocities along the mainstem Satsop River channel adjacent to the ponds up were reduced up to 3 feet/second. Increased flow velocities along the mainstem channel adjacent to the existing riprap of up to 2 feet per second.
    - Flow at the Egress Channel outlet increase from 12,000 cfs under existing conditions to a maximum of 22,430 for Alternative 1.
    - An increase in the flow velocity in the Egress Channel portion of the Pond Reach of about 1 feet/second.

- The proposed outlet from Pond A associated with Alternatives 3 and 3B are expected to maintain a hydraulic connection to the mainstem throughout the year. The 13.0 ft elevation of the outlet is noted to be lower than the stage associated with the lowest observed flow of record (147 cfs).

- Assuming the ponds on the project site are captured by the river, the time to fill the existing ponds to the elevation of the existing channel thalweg was estimated to range from approximately 7 years to nearly 30 years based on a range of assumed sediment supplies. Reducing the volume of the ponds by the placement of spoils within them substantially reduces the expected time to fill the pond with natural sediment supplies.

- For all analysis conditions, the short-term headcut depths were estimated to range from 3 to 5 feet and upstream headcut distances were estimated to range from 44 to 1,400 feet, if captured by the river. The existing bridges are nearly 5,800 feet upstream from the existing ponds.

An additional recommendation of the study includes the following:

- Alternative 3B is recommended as the preferred alternative since the outlet from the existing pond system will connect directly to the mainstem Satsop River, a year round hydraulic connection to the mainstem channel can be maintained, and the lowest increase of flow along the Egress Channel will occur under this plan.

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