PHYSICAL PROCESSES, HUMAN IMPACTS, AND RESTORATION ISSUES OF THE LOWER DUNGENESS RIVER

Clallam County, Washington

Prepared for Jamestown S'Klallam Tribe
by the
U.S. Department of the Interior
Bureau of Reclamation
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Report Prepared By

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EXECUTIVE SUMMARY
Lower Dungeness River Study

For the last five years, a study team from the Bureau of Reclamation has worked cooperatively with the Jamestown S'Klallam Tribe and the Dungeness River Management Team to develop an understanding of the natural processes and human impacts in the lower 10.5 miles of Dungeness River. The following text and photographic log provides a brief summary of the analysis and conclusions from this study, along with potential restoration options that could be considered.

What was the objective of this study?

The Dungeness River is a gravel- and cobble-bed stream located on the north end of the Olympic Peninsula of northwestern Washington State. The river is steep, falling about 3,300 feet (1005 m) from the headwaters to the mouth. Human activities along the lower 10.5 mi of the Dungeness River have been identified as a major cause of altering natural river processes in ways that have caused or contributed to a decline in fish populations. Levees, bank protection, bridges, and removal of woody debris and vegetation are all examples of human impacts that have been considered. In 1996, the Jamestown S'Klallam Tribe requested technical assistance from the Bureau of Reclamation to undertake a geomorphological investigation of the lower 10.5 mi of the Dungeness River. The goal of the cooperative effort was to describe the existing physical river processes, determine how the natural processes have been affected by human activity, and develop potential restoration options that could be considered. The study focuses on physical river processes and human impacts that result in channel changes such as bank erosion, aggradation of the riverbed, loss of flood plain, or cutting off access to important fish habitat in side channels.

What natural processes are present in the lower Dungeness River?

The Dungeness River has always been a complex and dynamic system that naturally migrated across the flood plain throughout the lower 10.5 miles. The majority of sediment transport and subsequent channel change occur during flood flows, which occur during late fall and winter. The river is wide, shallow, and has a straight alignment with active (unvegetated) river channel sinuosity (ratio of river length to valley length) ranging between 1 and 1.3. However, the alignment of the low-flow river channel does have meandering or sinuous characteristics. River bank erosion naturally tends to occur along the outside of meander bends while sand, gravel, and cobbles are deposited along the inside of meander bends. Riparian vegetation and the resulting woody debris tend to limit the rates of bank erosion, but ultimately the river bends can and do migrate across the flood plain and downstream over time. If the meander bends migrate too far and become elongated, then meander cut off channels will form during floods and the low flow channel will become straighter. After this change, the channel meandering and migration processes begin again.

Riparian vegetation and woody debris are important components of the river that maintain scour pools, side channels, and diverse habitats utilized by fish and other species. During the summer-low flow period, the deeper depths associated with scour pools provide slower velocities and cooler water temperatures. During floods in the winter or spring snowmelt periods, riparian vegetation, log jams, and side channels provide refuge areas where fish can escape turbulent, high velocity areas of the river.

How have human impacts affected the natural processes the most?

Five reaches were identified in the lower Dungeness River based on significant changes in physical characteristics (e.g., width, depth, slope, alignment, and geology). In each of these reaches, the magnitude of impact on natural processes varies by the type and duration of human activity. The construction of levees has had the greatest impact on the river because of the number of natural processes affected and the length of the river impacted. The levees cause the main river channel to have coarser sediments on the bed, elevated gravel bars, less woody debris, and fewer stable pools. The levees also cut off side channels and result in higher velocities and depths during floods. Finally, the levees at the mouth force the river and sediment into one location in Dungeness Bay preventing a natural delta that would otherwise be present. All of these effects alter fish habitat conditions including water depth, velocity, sediment substrate, and vegetative cover.

In other areas, bridges and clearing of woody debris and the riparian vegetation have impacted natural processes. Bridges can often impact a river by both constricting the river channel and cutting off floodplain and side channels important for fish habitat. Since Burlingame Bridge was replaced, Woodcock Bridge now poses the largest constriction on the river and, in combination with Ward Road, cuts off a portion of the flood plain. The east embankment of the Railroad Bridge also cuts off a portion of the floodplain, but the bridge opening does not cause a constriction or resulting backwater effect upstream.

While bank erosion is part of the natural river migration process, clearing of the riparian zone has accelerated this process and resulted in significant amounts of bank erosion such as on the west bank downstream of the Railroad Bridge and on the east bank downstream of the Highway 101 Bridge.

What restoration options could be considered to restore natural processes on the lower Dungeness River?

Restoration options are discussed in this report that would help restore natural processes where they have been impacted the greatest from human activity. Each of these restoration options have several management implications which need to be evaluated before actions are taken.

Setting back or removing the levees present on the lower Dungeness River restores a whole chain of natural processes. Where possible, levee setback or removal may be one of the most powerful management tools available for restoring fish habitat. The natural processes or linkages include allowing room for natural channel migration to occur, restored access to side channels and flood plains which reduce velocities and water depths in the main river channel. The lower depths and velocities will allow gravel-sized sediments to accumulate over coarser bed material increasing potential spawning areas. The lower depths and velocities will also allow for more recruitment of large woody debris. This will, in turn, increase the number of local scour holes which can become pools during periods of low flow. High elevation bars and, in some places, the aggraded channel bed would have to be removed or lowered in order to prevent channel avulsions into areas the river would not naturally flow. Finally, encouraging the growth of riparian vegetation would provide habitat cover for fish. The riparian vegetation would also create a buffer zone along the river to prevent unnatural bank erosion.

Currently residents of River's End and Kinkade Island are subject to frequent flooding. Relocating these residents would eliminate a safety hazard and help restore floodplain processes. In areas where bank protection is needed, restoration of riparian vegetation could be incorporated into the bank protection design.

Large woody debris could also be used as a restoration tool to limit erosion of old river banks while at the same time providing scour pool and cover habitat for fish. In this case, the engineered log jams would simulate the natural roughness and cover of trees falling into the river channel from naturally eroding banks. Engineered log jams could be constructed to simulate natural log jams that create scour holes during floods and stable pools during low flows. If these types of jams are to be effective, they must be constructed in the low flow channel. A system of engineered log jams may be needed to accommodate lateral migration of the low-flow channel over time. Engineered log jams could be constructed to better align flows under bridges and provide a means of collecting woody debris and limiting the amount of wood being captured on bridge piers. Engineered log jams could be effective along eroding river banks where riparian vegetation has been cleared. Engineered log jams could also be used as mitigation for the effects of existing riprap (high velocity, coarse substrate, and no vegetation cover). Log jams constructed as part of a riprap bank would create gravel bars downstream of the log jam and provide a substrate for vegetation.

Woodcock Bridge could be modified to lengthen its span across the Dungeness River and flood plain to reduce or eliminate the impacts of the bridge. Ward Road could also be setback farther to the west to eliminate impacts to the flood plain. The east embankment of the Railroad Bridge could also be removed to eliminate its impact on the east flood plain. Even though these bridges do locally cut off portions of the flood plain, levee setback and removal activities would restore a whole chain of natural processes over a larger reach of river.

Dungeness River Natural Processes

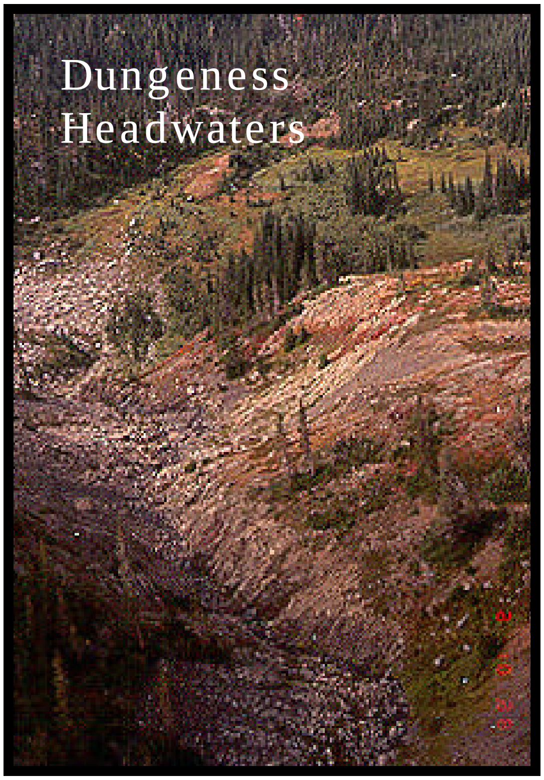


Photo 1:
The headwaters of the Dungeness River begin in the steep alpine watershed of Olympic National Park. The total drainage area for the Dungeness River watershed is 200 square miles.

Photo taken 9-10-98.

Photo 2: The Dungeness River flows north for about 32 miles from the mountains into Dungeness Bay. The Dungeness Spit separates Dungeness Bay from the Strait of Juan de Fuca. The spit is formed by long shore drift currents in the Strait. Photo taken 9-10-98.

Dungeness River Natural Processes

Photo 3: In the upper Dungeness River watershed, the channel slope becomes steeper with elevation. At lower elevations where the channel is less steep, a narrow floodplain is evident. The majority of the upper watershed is heavily forested.

Photo taken 9-10-98.

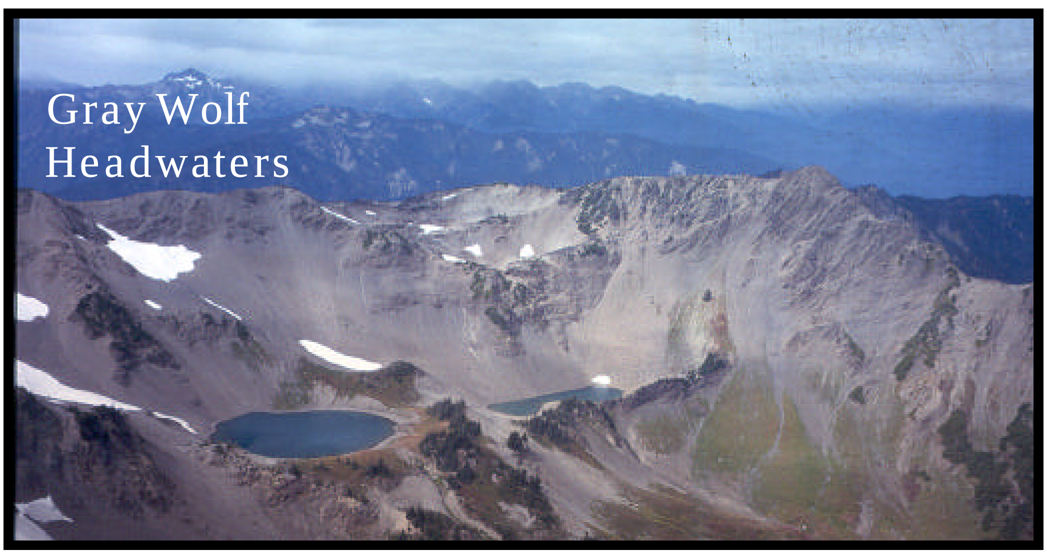
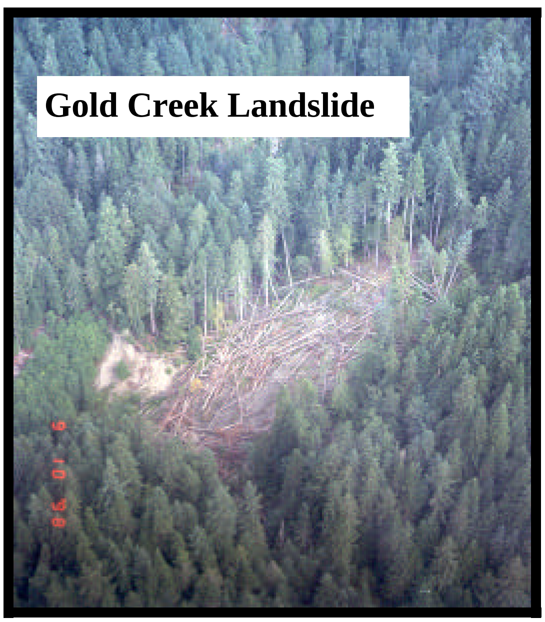


Photo 4: The Gray Wolf is the largest tributary to the Dungeness River. The high elevations of the Gray Wolf drainage are above timberline. Photo taken 9-10-98.

Dungeness River Natural Processes

Photo 5: Large quantities of sediment were observed to be stored along the high alpine slopes above timberline in the Gray Wolf watershed.
Photo taken 9-10-98.



Photos 6A and 6B: Landslides are part of the natural process in the Dungeness watershed. However, in many areas of the watershed logging practices may initiate or reactivate landslides that would otherwise not occur. The landslides contribute fine sediment (silt and clay) to the river channel, but the percentage of coarse sediment (sand and gravel) is likely small. Photos taken 9-10-98.

Dungeness River Natural Processes

Photo 7: In the lower 10.5 miles of the Dungeness River, the main river channel passes through a forested floodplain. The forested floodplain often contains smaller side and overflow channels which are not readily visible from the air. The river is dynamic and can migrate over time throughout the forested floodplain. Photo taken 9-10-98.

Photo 8: Side channels in the forested floodplain such as this one can provide important fish habitat. Log jams often exist at the upstream entrance to these side channels. The log jams limit the flow velocity and coarse sediment entering the side channel which in turn leads to stability of the side channel and fish habitat. Photo taken 5-18-99.

Dungeness River Natural Processes

Photo 9: Where log jams do exist in the main channel, they form stable scour pools as flow accelerates around the wood. These scour pools provide excellent fish habitat and are a natural part of physical processes on the Dungeness River. Removal of log jams from the channel has reduced the number of log jams and pools present in the river today. The construction of levees increases water depth and velocity and the river's capacity to transport wood through the system. Photo taken 6-28-01.

Photo 10: As the river migrates, sediment from the bank is eroded and added to the total sediment load. The majority of bank materials are formed of river sediment deposits (sand and gravel) with a layer of silt on the surface. Photo taken 9-10-98.

Dungeness River Data Collection

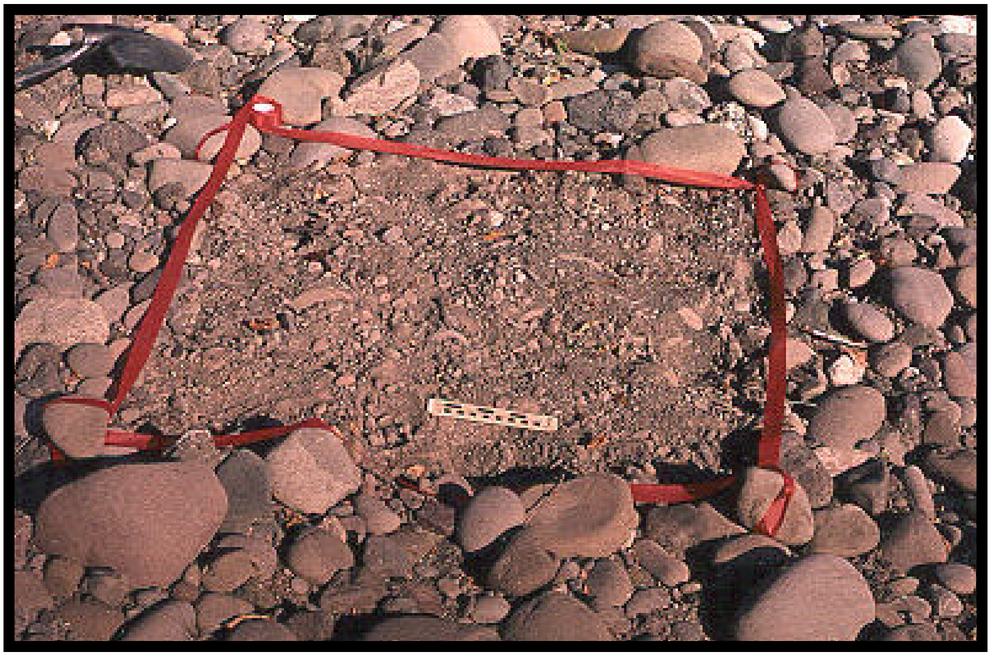


Photo 11: Bed-material samples in gravel bars were taken in 3-ft (1-m) squares to determine the sizes of sediment present in the river channel. Analysis of the samples showed that the channel bed of the Dungeness River is typically composed of sand, gravel, and cobble-sized material. The sand-sized particles are typically present beneath a pavement layer of cobbles. In general, the size of the bed-material decreases in the downstream direction. Photo taken 9-9-98.

Photo 12: A permanent network of 60 cross sections was established in 1997 to monitor channel change over time. Past survey work was also used for comparison where possible. For example, between 1997 and 1999 the channel upstream from the Railroad Bridge (RM 5.5) straightened its course and eroded 5 ft of the channel bed. Deposition of a similar amount was observed downstream of the Railroad Bridge. Photo taken 10-98.

Dungeness River Data Collection

Photo 13: Natural exposures were excavated and used describe soil development. Where present, charcoal was collected and analyzed by radiocarbon dating. These dates along with soil development and geologic mapping helped identify the ages of terraces along the Dungeness River and establish the natural boundaries of the active river channel over the last several thousand years. Photo taken 9-13-98.

Dungeness River Data Collection

Photo 14A and 14B: At this location near RM 8.5 , time-lapse photography during the 1998-99 winter revealed a strong interaction between large woody debris and the formation of gravel bars. In Photo 14A the channel is relatively free of large woody debris of mid-channel gravel bars. In Photo 14B after the winter flood season, several winter floods deposited large woody debris and mid-channel gravel bars. Gravel bar deposition accelerated following the initial deposit of woody debris.

Dungeness River Human Impacts and Management Issues

Photo 15: Numerous human impacts have affected the Dungeness River throughout the watershed. Several logging roads have been constructed in the upper watershed. Rainfall runoff can concentrate where a drainage crosses these logging roads. This concentrated flow can accelerate erosion processes including landslides such as shown here. These types of landslides can be a significant source of fine (silt and clay) sediment to the river channel. While these sizes of sediment do not cause channel change, they can increase turbidity in the river channel affecting fish feeding and spawning. Photo taken 5-17-00.

Photos 16: Five bridges cross the lower Dungeness River. The Railroad Bridge (RM 5.7) is heavily used for recreation and a newly developed River Center was built on the east side. A dike (built in 1961) and recently added cabled logs (visible at right) have been built to protect the new River Center. While the bridge does not constrict the active river channel, the dike does cut off the east floodplain.

Dungeness River Human Impacts and Management Issues

Old Burlingame Bridge

Photo 17: The Burlingame Bridge on Old Olympic Highway (RM 4) was replaced in 1998-99. The old bridge had a span of 130 ft which constricted the active river channel and cut off access to side channels and floodplain. Photo taken 5-21-98.

Photo 18A taken 6-27-01

New Burlingame Bridge

Photo 18B taken 6-27-01

Photos 18A and 18B: The new Burlingame Bridge was built with an increased opening of 430 ft and no longer cuts off access to the wooded floodplain. During a recent site visit, woody debris and gravel bar deposition was observed under the bridge. Future changes in channel bed elevation and woody debris accumulation should be monitored to ensure the safety of the bridge.

Dungeness River Human Impacts and Management Issues

Photo 19: Woodcock Bridge, located at RM 3.3, has a span of 405 ft. This bridge cuts off access to the historic floodplain, constricts the channel migration zone, and causes sediment deposition upstream of the bridge.
Photo taken 5-20-98.

Photo 20: The fish hatchery is near the upstream end of the study reach (RM 10.5). Just upstream of the hatchery is the confluence with Canyon Creek, and just downstream of the hatchery is Kinkade Island & Creek. Photo taken 9-10-98.

Dungeness River Human Impacts and Management Issues

Photo 21: On the west side of Kinkade Island, the main channel has migrated to and eroded a portion of a high glacial deposit. This erosion forced Clallam County to setback the road. Further erosion was prevented by the placement of large angular boulders at the base of the slope. Photo taken 9-10-98.

Photo 22A: Looking upstream at new entrance to Kinkade Creek.

Photo 22B: Looking from main channel at side channel entrance on Kinkade Island.

Photos 22A and B: At the location of Kinkade Island (RM 10), many side channels have developed that pass around and through the island. Kinkade Creek (shown in Photo 22A) is the largest side channel in this area and flows to the east creating the island. Currently, there are three entrances to Kinkade Creek from the main channel. Each of these entrances have log jams that limit the amount of flow and coarse sediment entering the channel. However, recent flooding has widened the upstream-most entrance and the amount of flow entering this path is increasing. As the main channel continues to migrate towards the outside of a bend (shown in Photo 22B), the river has the potential to remove these log jams and the side channels would capture an even larger portion of the total flow (currently estimated at about 50% of the main channel flow). If the log jams were enlarged, the rate at which the main channel may overtake the side channel would be slowed. However, the risk of flooding would still exist on the island because of the numerous side channels throughout the island. Photos taken 10-2000.

Dungeness River Human Impacts and Management Issues

Photo 23: Levees have a large impact in the lower Dungeness River. The Dungeness Meadows levee (shown above) cuts off not only historic floodplain but also historic active channel (RM 7.5 to 8.5). The levees also increase flow depth, velocity, slope, and sediment transport capacity. This also results in the removal of large woody debris that could otherwise form stable log jams and scour pools. Bars are elevated in this reach due to the higher river stage caused by the levee. The Dungeness Meadows levee was extended downstream to block the entrance to a side channel and prevent flooding in the subdivision. To increase fish utilization while still protecting homes from flooding, the lower portion of the levee could be setback to the east side of Spring Creek. Another option would be to create a small opening in the levee that would limit flows but allow fish passage. Photo taken 9-10-98.

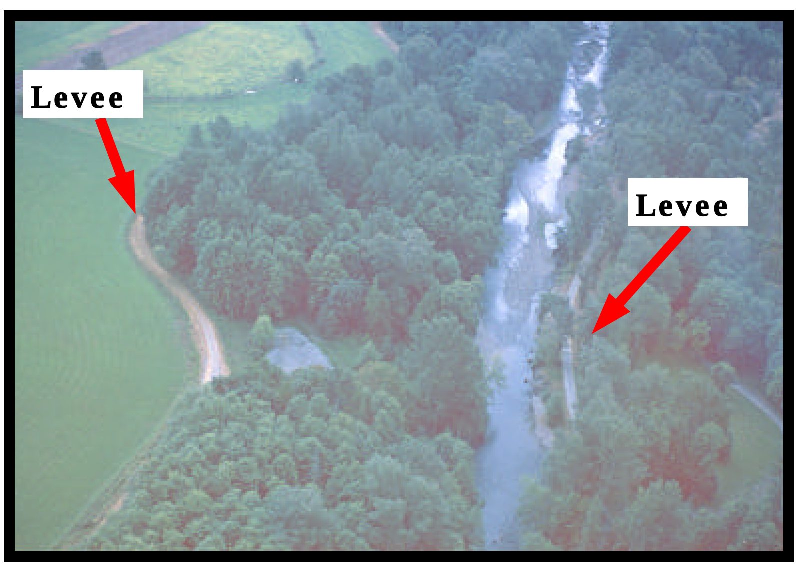


Photo 24: Downstream of RM 2.7, the ACOE and Olympic Game Farm Levees constrict the river channel and cut off portions of the floodplain. At several locations the levee constriction is enough to create a backwater upstream. Sediment deposits have raised the channel bed in these backwater areas as much as 8 feet. Presently, some of these backwater areas are higher in elevation than the surrounding floodplain. Photo taken 9-10-98.

Dungeness River Human Impacts and Management Issues

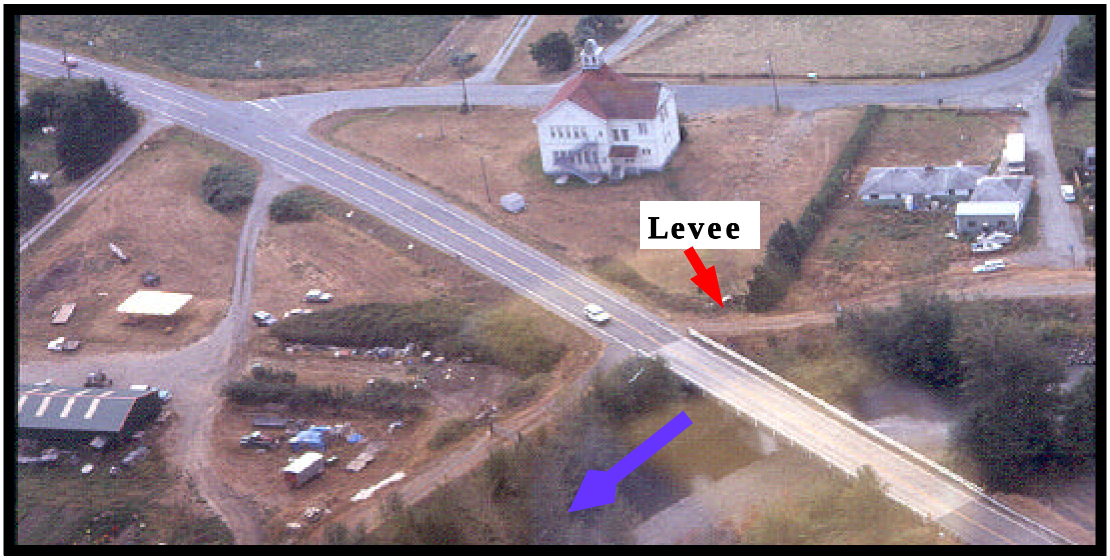


Photo 25: Schoolhouse Bridge (RM 0.8) is located at a natural constriction formed by glacial knobs. The river has likely flowed through these knobs for thousands of years. Prior to levee construction upstream of the bridge, flood flows would spill over river banks onto the floodplain. A portion of these flows would enter Meadowbrook Creek which flows into Dungeness Bay. Today, levees force all the water to pass under Schoolhouse Bridge. Photo taken 9-10-98.

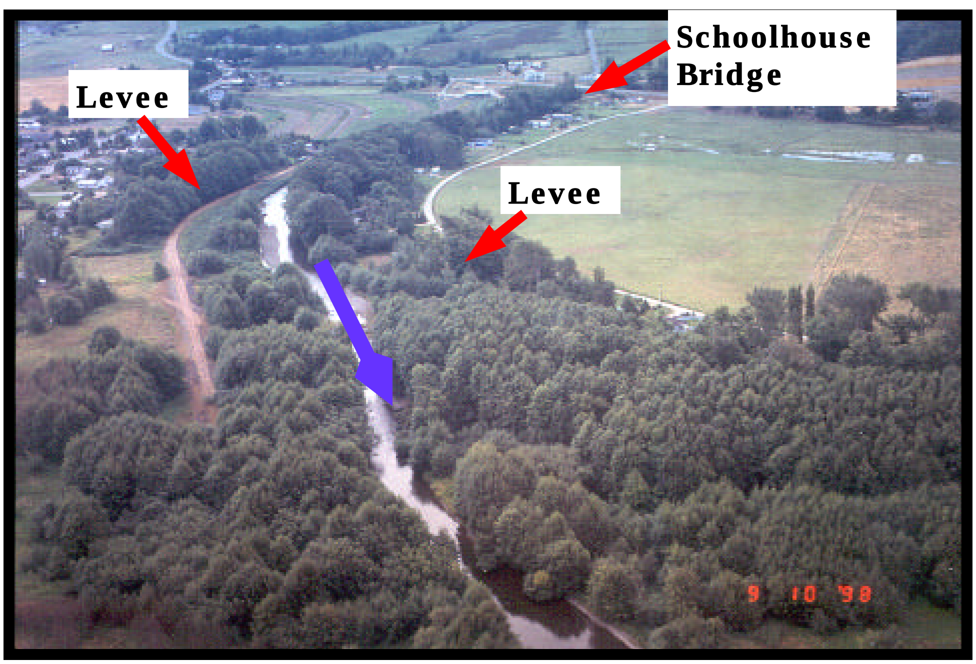


Photo 26: Levees on either side of the river downstream of Schoolhouse Bridge force the river into a fixed alignment all the way to the mouth. Presently, the upstream extent of tidal influence from Dungeness Bay is estimated to be just downstream of Schoolhouse Bridge. The levees have caused an additional backwater effect that has resulted in flooding on the upstream side of Schoolhouse Bridge. Removal of either levee would significantly reduce the backwater effect. Removal of both levees would completely eliminate any upstream impacts. Photo taken 9-10-98.

Dungeness River Human Impacts and Management Issues

Photo 27: Historically, the Dungeness River formed a delta at its mouth and migrated back and forth over time. Historical levee development in the 1800's may have contributed to aggradation in the bay which resulted in moving the town of Dungeness to the east. The present levee development downstream of Schoolhouse Bridge has forced the river to flow into Dungeness Bay at one location. This also forces all of the sediment transported by the river to deposit in one location in the bay. Photo taken 9-10-98.

Photo 28: In addition to bridges and levees, irrigation diversions and bank protection as shown above are common features along the study reach. Bank protection does impact natural processes by preventing natural channel migration and recruitment of large woody debris. In some areas, rock has been placed on the banks of river terraces that are hundreds to thousands of years old. Although erosion of river terraces can be a natural process, the erosion can be accelerated by human impacts to the river. In some cases, protection of terraces can be considered a mitigation for one or more human impacts. Photo taken 6-28-01.

Dungeness River Human Impacts and Management Issues

Photo 29: Clearing of riparian vegetation can reduce the strength of river bank materials and lead to accelerated channel migration and bank erosion. In this location just downstream of the Railroad Bridge, the vegetation on the west terrace was cleared sometime prior to the 1942-43 aerial photograph. Between 1942-43 and 2000, a maximum width of 760 feet of the left bank was eroded by the river. Photo taken 9-10-98.

Photo 30: While development in the floodplain can impact natural processes, the river can also impact development in the flood plain (such as at RM 9.2 in photo 30). Management decisions to implement river restoration have the tough task of balancing natural river processes with the protection of existing infrastructure. Photo taken 9-10-98.

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1.0 INTRODUCTION

1.1 Background

The Dungeness River is a gravel and cobble-bed stream located on the Olympic Peninsula of northwestern Washington State (Figure 1). The river flows northward about 30 river miles (RM) (48 km) from the base of Mount Deception in the Olympic Mountains to the Strait of Juan de Fuca (Strait) near the town of Sequim, Washington. The upper part of the drainage basin has a steep slope averaging around 0.03 and generally flows northeast (Figure 2). The lower 10.5 mi (17 km) of the river has a flatter slope averaging around 0.01 and generally flows northward. Human activities along the lower 10.5 mi have been identified as a major cause of altering natural river processes and channel morphology in ways that have caused or contributed to a decline in fish populations. Levees, bank modifications, bridges, removal of woody debris and vegetation, and gravel mining are all examples of human impacts that have been considered.

In 1988, the Dungeness River Management Team was formed by Clallam County and the Jamestown S'Klallam Tribe (Tribe) to begin a long-term effort to manage and restore the Dungeness River Watershed. After several iterations, in May 1995, the Tribe and Clallam County helped reform the Dungeness River Management Team (DRMT). The DRMT comprises a spectrum of governmental representatives, agency personnel, and citizens that have an interest in or influence on the long-term management of the Dungeness River watershed. The purpose of the DRMT is to address management issues in the watershed and to provide a framework for coordination and cooperation among key interests. Issues of concern include degraded fish habitat, especially as related to salmonid species listed as threatened or endangered under the Endangered Species Act, flooding, bank erosion and property damage, sediment supply and transport, water quality, and water supply. In 1996, the Tribe requested technical assistance from the Bureau of Reclamation (Reclamation) to undertake a geomorphological investigation of the Dungeness River.

1.2 Report Organization

Because this report is organized to meet the needs of a wide variety of readers, this section was written to help direct the reader to areas of interest. An executive summary and photographic overview of the Dungeness River Study are provided at the front of this report. The photographs are referred throughout this report. In addition, aerial photographs, taken in March 2000, are included immediately following the main report figures. Section 1 provides a general overview of the study components and issues addressed in this study. Section 2 contains an overview of the physical setting of the Dungeness Watershed. A brief literature review of past studies related to morphology and physical processes of the Dungeness River is listed in Section 3. Section 4 describes the types of data collected for this study and the purposes for which the data were used. Section 5 contains the details of the methodology used in the geomorphic, hydraulic, and sediment analyses for this project. A brief discussion of the upper watershed is provided in Section 6 to help readers put physical processes discussed for the lower 10.5 mi in context with the entire watershed. An extensive reach analysis was performed for the lower 10.5 mi that investigates natural processes and human impacts using the data collection and analyses methods mentioned in Sections 4 and 5. Section 7 provides the results of those analyses and corresponding time-sequence mapping on aerial photography. Section 8 is a summary of conclusions from this study and recommendations on potential management actions related to river restoration. Section 9 lists suggestions for proposed future studies that would further assist management with river restoration plans by building on information provided in this report. Several appendices have been bound in a separate attachment that provide detailed information about data collected for this study, two focus reports detailing analyses on levee setbacks in the lower 2.7 river miles, and a hydrology report based on USGS gaging station data.

1.3 Study Objectives and Scope

The Dungeness River Restoration Work Group prepared a report (July 1, 1997) entitled: "Recommended Restoration Projects for the Dungeness River." The report recommends several restoration projects for the lower reach of river including:

- Reestablish a functional channel and flood plain in the lower 2.6 mi (4.2 km) of river through dike management and constriction abatement.
- Abate man-made constrictions upstream of the ACOE Levee.
- Create numerous stable log jams.
- Manage sediment to stabilize the channel and reduce the risk of flooding.
- Construct and protect side channels.
- Restore suitable riparian vegetation and riparian-adjacent upland vegetation.
- Conserve instream flows.

The objectives of Reclamation's study were to describe the existing physical river processes through geomorphic investigations, determine how these processes have been affected by human activity, and develop predictive tools to evaluate management actions such as the restoration projects listed above. Where possible, physical processes were measured such as in the determination of sediment load during floods. However, in many cases the physical processes were inferred from the existing stream morphology or other physical characteristics such as aerial photography, terrace identification, bed material and cross section measurements. The study focuses on physical river processes and human impacts that result in channel changing events, such as aggradation of the riverbed, river bank erosion, or loss of flood plain and side channel access. Therefore, analyses focused on coarse sediment processes (sand, gravel, and cobble) rather than fine sediment processes (silt and clay) associated with issues such as water quality. However, some discussion regarding the sediment sources of both fine and coarse sediment sizes to the Dungeness River has been included.

Because this report focuses on channel changing events, hydraulic modeling focused on higher than average flows (see Section 5.0). The topic of flow attenuation along the Dungeness due to irrigation withdrawals, groundwater interaction, runoff, and other potential impacts is an ongoing study being addressed by the Washington State Department of

Ecology. In addition, the United States Geological Survey (USGS) is currently working on a study of the groundwater interaction in the lower Dungeness River and is operating gages to monitor suspended sediment transport and water temperature.

1.4 Study Reaches

This study focused on the lower 10.5 mi of the Dungeness River from near the tributary of Canyon Creek to the mouth at the Straight of Juan de Fuca (Figures 3A and 3B). The study area was subdivided into 5 reaches based on differences in channel and flood plain morphology, both natural and human induced (see Section 7.0). Because the lower river processes are directly related to sediment sources and transport in the upper Dungeness River basin, initial observations and hypothesis for the upper watershed are presented.

2.0 PHYSICAL SETTING OF THE DUNGENESS RIVER WATERSHED

2.1 Topography and Geology

The majority of the lower Dungeness River basin is located within Clallam County; the upper part of the basin is located in Jefferson County. The Dungeness River and its tributaries drain about 200 mi^2 (322 km^2) and contain over 546 mi (879 km) of river (Thomas et al., 1999). The largest tributary to the Dungeness River is the Gray Wolf River, which joins the main stem near Schmith Knob at RM 16 (see Figure 1).

The headwaters of the Dungeness and the Gray Wolf River are in the rugged high peaks of the eastern Olympic Mountains in Olympic National Park (Photos 1, 3, 4, and 5 – Photographic Overview). The Dungeness drains from Obstruction Peak, Mt. Cameron, Mt. Deception, Mt. Constance, Buckhorn Mountain and Mount Townsend, which is the highest point in the drainage basin at 7,788 ft (2,374 m). The upper Dungeness River flows through the Buckhorn Wilderness and the Olympic National Forest. The three streams that make up the Gray Wolf River drain. Much of the upper Gray Wolf River flows within Olympic National Park. The lower 7 mi (11 km) of the Gray Wolf River flow through the Buckhorn Wilderness and the Olympic National Forest. Gray Wolf Ridge separates the main stem of the Dungeness River from the Gray Wolf River.

The Dungeness River and its tributaries flow through sedimentary, metamorphic, and volcanic rocks that compose the Olympic Mountains and adjacent foothills. At higher elevations, the drainages have incised steep, narrow canyons into these rocks. The topography of the basin was modified by ice from the Cordillaran ice sheet, which extended southward from Canada and filled a drainage system that was probably similar to the present Dungeness River to an altitude of about 3,200 ft (975 m; Cady et al., 1972). The continental ice reached its maximum extent some time between about 14,000 years ago (Thorson,1980) and 17,000 years ago (Porter and Swanson, 1998) based on radiocarbon dates from the Puget Lowland near Seattle. The ice left widespread deposits of loose, unsorted till that includes rocks foreign to the Olympic Peninsula. The ice sheet retreated northward to the Strait of Juan de Fuca as early as about 16,000 years ago (Porter and Swanson, 1998) or as late as 12,000 to 13,000 years ago (Thorson, 1980). The upper watershed was carved by alpine glaciers, which formed in the high mountain peaks of the Olympic Range and moved downstream into the Dungeness River drainage. Remnants of the alpine glaciers are still present in the cirques at the headwaters of the Dungeness River and its tributaries. In contrast, the lower 10.5 mi of the Dungeness River flows on a gently sloping plain of glacial till and outwash that were deposited as the continental ice sheet retreated.

2.2 Climate

The climate of the Dungeness River drainage basin is mild at the lower elevations and dry relative to the rest of the Olympic Peninsula. Climatic conditions have only been recorded continuously in the watershed at Sequim (Halloin, 1987; Sequim Chamber of Commerce, 1998). The average annual precipitation of about 16 inches per year (41 cm per year) in Sequim contrasts with an average annual precipitation of about 118 inches per year (300 cm per year) at Forks on the west side of the Olympic Peninsula (Halloin, 1987). The prevailing wind direction across the Olympic Peninsula from the southwest means that storms frequently drop their moisture on the west side of the high Olympic Mountains. Thus, the relatively low precipitation at Sequim is the result of its location in the rain shadow of the Olympic Mountains.

The average summer temperature at Sequim (elevation about 200 ft [60 m]) is about 60^{o}F (16^{o}C) (Halloin, 1987; Figure 4A). During the summer, the average daily maximum temperature is 70^{o}F (21^{o}C) and the average daily minimum temperature is about 50^{o}F (10^{o}C). The average total precipitation at Sequim between the first of May and the end of September, the main agricultural season, is about 4.5 inches (11.4 cm). The driest months are July, August, and September, when an average of only about 2.3 inches (5.8 cm) for the three-month period of precipitation falls.

The average winter temperature at Sequim is about 40^{o}F (4^{o}C) (Halloin, 1987). The average daily maximum temperature in the winter is 48^{o}F (9^{o}C); the average daily minimum temperature is 34^{o}F (1^{o}C). Rain is frequent in the late fall and winter (Figure 4B). The wettest months are November, December, and January, when about 6.8 inches (17.3 cm) of rain fall during the three-month period. The average annual snowfall at Sequim is 6 to 8 inches per year (15 to 20 cm). The first occurrence of freezing temperatures is usually the middle of October. The latest occurrence of temperatures below 32^{o}F (0^{o}C) is usually the last week of April or the first week of May for the lower valley (Halloin, 1987).

Larger amounts of snow fall in the upper part of the Dungeness River drainage basin. This snow, along with glacier ice, is a major source of water to the Dungeness River system. The majority of the snow and ice melts during the summer and early fall and results in diurnal changes in the flows in the river. The average annual precipitation in the upper Dungeness River basin is about 63 inches per year (160 cm per year) (Clark et al., 1995), which is about two and a half times the annual precipitation at Sequim.

2.3 Ground Water

In the lower Dungeness River, ground water and surface water are closely related especially during low-flow periods. Drainages connected or adjacent to the Dungeness River have two different primary sources of flow - dependent upon their size and the location of their headwaters (Thomas et al., 1999). The larger drainages begin in the Olympic Mountains and foothills and their flow is primarily from snowmelt and precipitation. Examples of this type of drainage, other than the Dungeness River itself, are Siebert Creek and McDonald Creek (see Figure 1). In these drainages, flows are highest in the winter and spring. The smaller drainages begin in the lower foothills or piedmont and their flow is primarily from groundwater recharge and irrigation return flow. Examples of this type of drainage are Bell Creek, Cassalery Creek, Gierin Creek, Hurd Creek, and Meadowbrook Creek (see Figure 1). The flows in these drainages are relatively constant throughout the year.

2.4 Forest Fires

The watershed of the Dungeness River has experienced repeated large, intense wildfires prehistorically as a result of a number of climatic patterns, including long-term temperature cycles, a “rainshadow” effect from the adjacent Olympic Mountains, jet stream patterns, and prevailing west-to-east winds (Dungeness Area Watershed Analysis Cooperative Team, 1995). Large, intense, stand-replacement wildfires have swept across the watershed at intervals of approximately 200 years with surviving older trees generally restricted to higher elevations and along riparian corridors. Present data indicate that large, stand-replacing fires occurred in A.D. 1308, 1508, and 1701 in the Dungeness watershed. The intervals between these fires is long enough to permit growth of a replacement stand and accumulation of both ground and ladder fuels within the forest. This history provided an opportunity for correlation with numerous charcoal horizons observed in the exposed banks along the margins of the river corridor (Appendix Q).

A large, human-caused fire occurred in 1890 in the foothills between Port Angeles and Sequim, smoldered over the winter, and flared up again in 1891. Although not as extensive as the pre-historic fires, the 1890-1891 fire burned large areas of the lower Dungeness watershed. Numerous smaller fires have also occurred in the watershed with significant ones reported in 1860, 1880, 1896, 1902, 1917 and 1925 (Dungeness Area Watershed Analysis Cooperative Team, 1995). Few fires have occurred in the watershed since 1930, largely as a result of improved fire prevention techniques and increased levels of summer precipitation (Dungeness Area Watershed Analysis Cooperative Team, 1995).

2.5 Recent Human Development

The history of water and land use in the Dungeness River drainage basin is compiled from published and unpublished literature, museum information, old maps, interviews with long-term residents of the valley, and newspaper articles. Information on irrigation practices, logging, and modifications to the Dungeness River and flood plain were of particular interest. A detailed documentation compiled for this study is attached in Appendix A.

2.5.1 Habitation and Water Use

The Dungeness River valley has a long history of human habitation. The earliest known archaeology site in the Sequim area has been dated at 12,500 years ago (10,500 BP) (Duncan, 2002 written communication). In more recent history, Gibbs (1877) wrote that Clallam settlement occurred on both the east and west sides of the Dungeness River, along with at least one settlement further upstream. The Dungeness River was used by the Clallam Tribe for fishing and transporting of cedar logs for building canoes, house posts and cedar planks for long houses. Gunther (1927) documented that weirs consisting of young firs were driven into the riverbed to trap some species of fish, but many other species were caught with lines and nets. Fishing and hunting camps were also seen along various locations on the river.

In the 1790s, Manuel Quimper and George Vancouver were the first white explorers to discover the Dungeness River. A map labeled “Bahia de Quimper” exists that shows soundings and documentation of anchoring at the Dungeness Bay. In the 1850s, the first white settlers began establishing themselves in the valley.

The first irrigation canal was completed on May 1, 1896 by the Sequim Prairie Ditch Company (Dungeness Community Web Site: www.dungeness.com/index.htm). It was 2 mi (3.2 km) long and capable of irrigating 3000 acres (12 km^2) of land. Also in the 1890s, a fish hatchery was built near RM 10.5 at Canyon Creek to sustain salmon populations for harvesting. Today there are more than 97 mi (156 km) of irrigation ditches which could irrigate up to 23,000 acres (93 km^2) and the fish hatchery is still in operation. Based on recent irrigation reports, around 6,000 acres (24.3 km^2) are actually irrigated each year: 5,000 acres (20.2 km^2) of farmland and 1,000 acres (4.0 km^2) of lawns and gardens (Cynthia Nelson, written communication, 2002). Most of the water for irrigation use is diverted directly from the river from May through September. Irrigation diversions are located on the west bank of the river at RM 11.2 and RM 7.2, and on the east bank at RM 10.7, 8.9, 8.5, and 6.9 (Northwest Hydraulic Consultants, 1987). Withdrawal from ground-water wells for domestic use occurs year-round.

Irrigation has increased ground-water recharge and has created an artificially high water table (Thomas et al., 1999). However, since the late 1970s, the population of the Dungeness River valley has increased 250 percent (Drost, 1960, 1983; Thomas et al., 1999). Whereas agriculture needs dominated water use before the late 1970s, residential needs are now primary (Thomas et al., 1999). Therefore, withdrawals directly from the river for irrigation have been decreasing and withdrawals from ground-water wells have been increasing.

2.5.2 Bridges and Roads

The Dungeness River is presently crossed by five bridges in the lower 10.5 mi (see Figures 3A and 3B). From upstream to downstream, these bridges are:

1. Highway 101 Bridge at RM 6.4 , span of 590 ft (180 m) (Figure E1: Appendix E)
2. Chicago, Milwaukee, St. Paul & Pacific Railroad Bridge (Railroad Bridge) at RM 5.7, has been a footpath since 1992 and is also known as the Howe Truss Bridge, span of 1005 ft (306 m) (Photo 16 – Photographic Overview)
3. Burlingame Bridge on Old Olympic Highway, at RM 4, span of 430 ft (131 m), rebuilt in 1998-99 (previous span of 130 ft [40 m]) (Photos 18A and B – Photographic Overview)
4. Woodcock Bridge, also known as the Ward Bridge or Ward Road Bridge, at RM 3.3, span of 405 ft (123 m) (Photo 19 – Photographic Overview)
5. Schoolhouse Bridge near the Old Dungeness Schoolhouse at RM 0.7 along School Road or Marine Drive, span of 200 ft (61 m) (Photo 25 – Photographic Overview)

At least three more bridges existed in the past across the main Dungeness River as indicated by remnants that are still visible, historical accounts, or photographs. These bridges were located at RM 5.5, about 0.1 mi (.16 km) downstream from the Railroad Bridge (known as the Canfield Bridge); at RM 9.5, about 1 mi (1.6 km) downstream of the Fish Hatchery (known as the Duncan Road Bridge); and at RM 13.3, about 3 mi (4.8 km) upstream of the Fish Hatchery (known as the Clink Bridge). The Gray Wolf River is presently crossed by one bridge at RM 15.8 on Forest Service Road 2880, just upstream of the junction with the main fork of the Dungeness River. Although the construction date of the bridges is not known, the bridge at or very near the present location is shown on a 1935 map (Metzger, 1935). A detailed history of bridges on the Dungeness is listed in Appendix A (Table A4).

2.5.3 Levees and Bank Protection

Levees (sometimes referred to as dikes) and bank protection have been constructed along several areas of the lower 10.5 river miles since at least the early 1900's. Levees are defined in this report as a structure, typically built of native material, that is higher in elevation than the natural ground surface to provide protection to a given area from flooding. Levees are often lined with rock to provide additional protection from floods. A 1935 map of the Dungeness River shows wooden bulkhead structures in many of the same areas where levees exist today (Metzger, 1935). The major levees from upstream to downstream are as follows:

1. Levee Kinkade Levee, RM 9.6 to 9.9 on east bank, a private levee along the west side of Kinkade Island, bank protection efforts at this location began in the 1940's and the present levee was built in 1971 after a large flood
2. Haller Dike, RM 8.57 to 8.87 on west bank, originally a private levee but replaced and setback by the County in 1997 (see Figure 3A)
3. Dungeness Meadows Levee, RM 7.5 to 8.1 on east bank, private levee at Dungeness Meadows Neighborhood built in 1960s (Photo 23 – Photographic Overview)
4. Army Corps of Engineers Levee (ACOE Levee), RM 2.6 to near the mouth on east bank, originally a smaller, private levee that was lower in elevation and not continuous, rebuilt and significantly enlarged by the ACOE in 1961 (Photos 24 to 26 – Photographic Overview)
5. Olympic Game Farm Levee (also known as Beebe's Levee), RM 2.1 to 1.0 on west bank, private levee originally built in early 1900's and later expanded (see Figure 3A)
6. River's End Levee, RM 0.8 to near the mouth along west bank, a private levee constructed to protect private residences (Photo 26 – Photographic Overview).

In addition to levees, several reaches of river have riprap or other forms of bank protection to prevent erosion. River bank protection alone (no levee) is defined in this report as material placed along a river bank to protect the bank from erosion, but none of the material is placed higher than the elevation of the river bank. Recently during the winter of 2001-2002, the most extensive bank erosion has occurred along Kinkade Creek and on the east bank downstream of the Highway 101 Bridge. The majority of levees also have riprap on them, and often private landowners on the other side have responded by hardening the opposite bank with riprap to prevent erosion. In some areas such as downstream of the Railroad Bridge on the west bank, logs and/or log jams have been used to protect the bank while also providing fish habitat.

3.0 PREVIOUS INVESTIGATIONS

This study was designed to build upon previous and ongoing studies within the Dungeness watershed. Listed below are brief summaries of Dungeness River reports that provided information related to this study.

3.1 Dungeness Area Watershed Analysis (1995)

The Dungeness Area Watershed Analysis Cooperative Team (1995) compiled the watershed analysis for the U.S. Forest Service, as was mandated by the President's Northwest Forest Management Plan. The analysis compiled existing data for the watershed of the Dungeness River and its primary tributary, the Gray Wolf River. Also included in the analysis were MacDonald, Siebert, and Johnson Creeks, as these streams collect irrigation return flows originally diverted from the Dungeness and discharge them into either the Strait of Juan de Fuca or Sequim Bay.

The watershed analysis focused on five key components of the watershed: (1) fish and fish habitat, (2) water quality and quantity, (3) wildlife, (4) vegetation, and (5) riparian areas. Available information from literature, maps, personal communications, and aerial photography were summarized, trends in the data were analyzed, and opportunities for watershed restoration activities were identified for each component. No new data were collected for the watershed analysis. This analysis served as an excellent reference for our study. The broad scope of the analysis precludes presentation of a detailed summary here. Of particular interest was the discussion of the fire history of the watershed and evidence for stand-clearing wild fires on approximate 200-year intervals in 1308, 1508, and 1701.

3.2 Hydraulic & Sedimentation Investigations

3.2.1 Dungeness River Bridge Study (Northwest Hydraulic Consultants, 1987)

Northwest Hydraulic Consultants was retained by Clallam County to address the adequacy and safety of the five bridges on the Dungeness River. In addition, their report addresses some overall concerns about river bank erosion and flooding along the County Roads on the Dungeness River. Channel changes and debris accumulation were all documented as causes of river bank erosion on the Dungeness, particularly from the fish hatchery downstream to Woodcock Bridge. This report documented that the most severe bank erosion on the Dungeness River at the time of the study (1987) was along Hatchery Road (RM 10), and on private land between the Railroad and Burlingame Bridges (RM 5). A prediction of the tidal effects of Dungeness Bay was noted as extending upstream to RM 0.9, just upstream of the Schoolhouse Bridge.

The strongest recommendation given by the report to help manage the river was removal of gravel in sufficient quantities and at the right locations. Bedload measurements were not taken for the Northwest Hydraulics study, but an estimate based on sediment transport relationships predicted an annual sediment load at the Highway 101 Bridge of 80,000 yds^3 (61,170 m^3) and 40,000 yds^3 (30,580 m^3) at the Woodcock Bridge (+/- 50 percent as noted in the report). The report recommended gravel mining a trench at various gravel bar locations at RM 7 and RM 5.5 (downstream of the Railroad Bridge). The total annual removal at each site would be geared towards 25,000 yds^3 (19,120 m^3). The report predicted that the low flow channel would migrate to the trench each year, and then subsequently be filled in during the next high flow.

The report recommended placing bank protection at Hatchery Road near RM 10 because of severe bank erosion posing a safety risk to the road. The report also recommended extending the Dungeness Meadows Levee downstream at RM 7.8 to prevent capture of the main channel in a side channel that conveyed at least half the river flow after a 1986 flood. This levee was extended by the County following the results of this study. Another risk addressed was the possible escapement of the Dungeness River into Cassalery Creek at RM 6.8. At this location, the river was noted as being currently blocked from Cassalery Creek by an embankment at an irrigation diversion. The report also recommended that spur dikes be used to prevent further bank erosion at Ward Road. The Burlingame Bridge was noted as being in danger from overtopping during a 100-yr flood because of the short span and low deck clearance. It was recommended that the bridge span be increased to at least 300 ft (91 m) and the bridge deck be raised at least 3 ft (0.9 m). The Burlingame Bridge was replaced in the winter of 1998-99 and the span increased to 430 ft. Finally, the report recommended a management group be formed to address the management of the Dungeness River watershed.

3.2.2 Dungeness River Assessment Study (Orsborn and Ralph, 1994)

A comprehensive assessment study of the lower Dungeness River was undertaken by Orsborn and Ralph at the request of the Jamestown S'Klallam Tribe and the Quilcene Ranger District. The goal of this study was to provide data and technical information for river management decisions. The study involved three phases including a literature and data review (phase I), physical channel analysis, hydrology and hydraulics (phase II), and a fisheries habitat survey (phase III). The report focused on several reaches of the lower Dungeness River and provided interpretation of changes in the river channel at all five bridge crossings. Of particular assistance to the Reclamation study was the interpretation of channel changes from a 1913/14 map compared to 1994 aerial photography and bed material data collected in the lower 10.8 miles. Data collection and analysis related to the channel morphology assessment included the following comparisons, analyses and assessments:

<u>River planform comparison:</u>

- A comparison of 1994 aerial photographs with a 1914 land use map and historical aerial photographs (1966, 1981, 1988, 1993, and 1994) was performed for a reach of the Dungeness River from 1600 ft downstream of the Railroad Bridge to 5000 ft (1524 m) upstream of the Highway 101 bridge. Orsborn and Ralph hypothesize in their report that a change in activities in the upstream watershed has caused a period of channel adjustment between 1966 and 1994. One possible cause identified was two landslides in the upstream watershed (Silver and Gold Creek watersheds). Another possible cause identified was an increase in Forest Service roads from 1949 (8 total road miles) to 1983 (77 total road miles). Orsborn and Ralph observed from aerial photographs that a lot of channel change had occurred downstream and upstream of the Highway 101 and Railroad Bridges. They concluded that the bridges act as hydraulic controls and were the cause of these changes. The amount of change was dependent on the frequency of high flows and the amount of sediment transported into the reach.

Stream temperature analysis:

- Water and air temperature monitors were installed in the lower 10.8 RM. Thermistor data from locations downstream of RM 15.7 were combined with USGS gage data to develop long-term average predictions of temperatures between June and October.

Habitat Assessment and Recommendations:

- Survey of habitat units and characteristics for a total of 53 RM including mainstem Dungeness and Gray Wolf Rivers and Gold Creek tributary. In particular, the physical aspects and suitability of spawning habitat was evaluated to try and identify limiting factors on chinook and pink salmon stocks. Conclusions from this analysis were that salmon redds are unsuccessful in many areas because of the scour process in the redds, the limited amount of pool tailout habitat (glides), and the lack of appropriate water depth and velocity due to reduced flows and shallow, wide channels.

- An extensive list of recommendations and considerations for habitat improvement projects were also provided with reference to two previous habitat restoration plans developed by KCM (1990) and Northwest Hydraulic Consultants (1987). Some examples include placement of boulders in long, shallow riffles to create roughness elements, increasing low flows, and setback of levees and improvement of passage through bridges.

Bridge Analyses:

- Water surface profiles were developed from USGS quadrangle maps. Cross-section surveys were performed in October 1994 at all five bridges on the lower Dungeness River. The analysis of this data concluded that the Dungeness River channel locations and pattern shown in the 1913/14 map is nearly identical to the channel on the 1994 aerial photograph at the locations of the Schoolhouse Bridge, Woodcock Bridge, and Olympic Highway Bridge. However, just downstream of the Railroad Bridge the 1914 map shows a large island that had been cleared of vegetation. Orsborn and Ralph's observations noted that the vegetation had since regrown and then been largely removed by river flow. At the Highway 101 Bridge, they note the channel in the 1914 map was a single channel, but was changed to a multiple channel pattern by the 1994 photographs. Recommendations were made to improve flow and debris passage at all bridges except Schoolhouse Bridge.

Sediment:

- Scour monitors were installed near known pink and chinook redds. Coarse bed material was sampled in riffles. Forty pebble counts of the pavement surface in riffles were measured from RM 10.8 to 0.9. The results indicated that the mean particle size in riffles decreases in the downstream direction from a D_{50} of 109 mm at the upstream end (RM 10.8) to a D_{50} of 51 mm near RM 2 (as shown in Figure 7-4: Orsborn, 1994). A scour chain analysis was also conducted that observed gravel transport during a small flood peaking at 2,100 cfs (59 cms) on December 10, 1993. Sediment aggradation at the USGS gaging station was also evaluated based on changes in the stage-discharge relationship.

River Flow:

- Orsborn and Ralph also analyzed floods on the Dungeness River to try and identify causes of increased flooding between 1969 and 1972. Possible causes for increased flooding were an increase in road building in the upper watershed from 1965 to 1983.

3.2.3 Kinkade Island Dike Removal Study (West Consultants, July 2000)

Kinkade Island is located on the Dungeness River approximately 10 mi upstream from the mouth. The island is bounded by the Dungeness River on the west side, and Kinkade Creek on the east, which is a side channel of the Dungeness River that is less than a mile in length. The long term project goal of the County and the City of Sequim is to reduce the flood hazard that currently exists on Kinkade Island through purchase of the seven homes constructed on the island. This would also increase side channel access for fish habitat usage.

A small dike was built at an unknown date along the west side of the island (east side of the main stem of the Dungeness River). An engineering analysis recommended that the project be scaled back from the original goal of complete removal of the Kinkade Island Dike (West Consultants, 2000). During two-year and higher magnitude floods, the middle portion of the dike was overtopped, and water entered the flood plain behind the dike. This periodic overtopping created a side channel that was spring-fed year-round at the lower end and remained dry except in flood events in the upper portion. Removal of about 55 feet of the dike at the upstream end was recommended to allow water from the Dungeness River to flow through the side channel for most of the year and create viable fish habitat. The consultants' report also recommended that the inlet to the side channel (on the east side of the dike) be armored with large woody debris and boulders to prevent the mainstem river from being captured in the side channel.

The Kinkade Island Dike Removal Project was completed in September of 2000 (Freudenthal, 2000). Monitoring of the site by the County during several small floods has indicated that when the Dungeness River flow exceeds about 320 cfs (9 cms) that water will enter the side channel. Therefore, the side channel will have flow for approximately 10 months out of the year (Freudenthal, 2000). The county is conducting additional monitoring of the site including measuring cross-sections and pebble counts from the river, the new side channel, and Kinkade Creek over the next five years. On January 7, 2002 the flood of record (7,610 cfs) occurred on the Dungeness River. It is known that several houses on Kinkade Island were damaged during the flood. However, details of the channel change in both the main Dungeness River and Kinkade Creek were not known at the time of this report writing.

3.3 Dungeness Bay Investigations

3.3.1 Dungeness Bay Geomorpholgy Study (Schwartz et al, 1987)

Schwartz et al. studied the geomorphology of Dungeness Spit to evaluate net shore-drift, spit progradation (growth), and lagoon processes operating along the spit and in Dungeness Bay. Their work built upon earlier studies by Bortleson et al. (1980) and Downing (1983) which had examined physical changes of the spit over time. Their work included surveying and mapping of spit segments and beach profiles, sediment sampling of the beach and lagoon deposits, measurement of surface salinity within Dungeness Bay, and measurement of spring flood and ebb tides.

Their study showed that the dominant shore-drift along the Strait of Juan de Fuca was from west to east along Dungeness Spit (see Figures 1 and 3). Bottom sampling in Dungeness Bay showed that the channel between Graveyard and Cline spits was scoured and had a gravel bottom. Gravel was also observed in the 1978 breach through Cline Spit. Schwartz et al. attributed the gravel to occur as lag deposits due to the strong tidal currents operating in these channels. The spits which form Dungeness Bay were largely sand derived from erosion of mainland bluffs, shore-drift along the Strait of Juan de Fuca, and washover at narrow sections of Dungeness Spit. Mud composed of silt and clay was mapped in the center of both the east and west lagoons where quiet water conditions allowed settling of the fine-grained material.

Using a comparison of historic maps of Dungeness Spit from dating 1855, 1926, and 1979 in conjunction with field surveys conducted in 1985, Schwartz et al. measured an eastward growth of the spit of about 1900 ft (575 m) over a period of record of 130 years. This elongation of Dungeness Spit was confined to that portion of the spit east of the junction with Graveyard Spit, as both Graveyard Spit and the west end of Dungeness Spit have remained relatively unchanged since the 1855 land survey. The study found an average elongation rate of 14.4 ft/yr (4.4 m/yr) for the spit which agreed closely with 14.8 ft/yr (4.5 m/yr) calculated by Bortleson et al. (1980). The volumetric increase in Dungeness Spit was estimated at about 65,305,000 yd^3 (1,850,000 m^3) from 1855 to 1985.

3.3.2 Dungeness Bay Bathymetry, Circulation and Fecal Coliform Study (Rensel and Smayda, 2001)

Increased fecal coliform concentrations in Dungeness Bay have resulted in a closure of 519 acres (210 ha) of the bay in the vicinity of Graveyard Spit. In response to this closure, a study by Rensel and Smayda was contracted by the Tribe to address water circulation and fecal coliform sources and losses within the marine environment of Dungeness Bay (Rensel and Smayda, 2001). The summary listed below focuses on the water circulation study results.

Data was collected for this study in order to produce a new bathymetric map (channel bottom topography) of inner Dungeness Bay (defined as the portion located west of Graveyard Spit). The spits were measured to be not higher than 16 ft (5m) above sea level and generally composed of sand and accumulation of drift logs on the surface. Water was documented as overtopping and breaching only the southern 2.8 mi (4.5 km) of Dungeness Spit due to storm surge from the west. As a result, the inside (south) portion of this section has scalloped-shaped, coarser sediment composition. The new map was compared to historical maps of the bay to determine that between 1908 and 1956, the Dungeness Spit has grown in length at a rate of 14.8 ft/yr (4.5 m/yr) (matches Schwartz et al., 1987 study), and at a rate of 9.8 ft/yr (3.0 m/yr) from 1956 to 2000. The study also determined that there was a major relocation of the mouth of the Dungeness River sometime between 1856 and 1908. The report speculates that there has been some filling in of the Bay at the river mouth area because of the shallow water depths that exist at areas in the east side of the bay that were formerly deeper on historic maps. The inner bay and Graveyard Spit are noted to have not changed significantly during the past 50 years, with the exception of Cline Spit which has been breached twice over the last 150 years.

The study also determined that the water transport through the inner bay shellfish closure area is rapid and is exchanged with the outside bay water about once per average tidal cycle. The inner bay not closed to shellfish (far west side) circulates within this area, but does not dynamically exchange water with the outside bay and Strait of Juan de Fuca. The study determined that during tidal floods, the majority of water passes through Cline Spit Pass, a break in the spit created over a decade ago when Cline Spit was breached. A water budget was done to determine that about half of the river water (about 188 million ft^3 or 5 million m^3) enters the inner bay in a given year and slightly more than 4 billion ft^3 (113 million m^3) of marine water enters and exits the bay each year.

Related to the Dungeness River flows, it was determined that only during a storm tide does the Dungeness River plume enter the inner bay shellfish closure area (to the west of Graveyard Spit). However, during the low (ebb) tide, the river flow was documented to exit into the Strait of Juan de Fuca in a variety of flow paths through the side and middle of the outer bay (to the north and east of the mouth of the river). In between tides, the river water was documented as flowing into the inner bay half of the time and forming a pool at the southern tip of Graveyard Spit the remaining time. The water residence time in the inner bay averages about 40 hours.

A 1 km area to the west of Cline Spit (southeast portion of inner bay) was documented as having a counterclockwise circulation pattern, while the northeast portion of the inner bay was noted to move south, often onto the Graveyard Spit. The Dungeness River flow was documented as being dynamic, meandering throughout the outer bay at various locations at various times. The report summarized that the water in the bay is comprised of 14.8 percent freshwater (Dungeness River, irrigation return, Railway Creek, stormwater, and direct precipitation) and 85.2 percent seawater (Strait of Juan de Fuca).

3.4 Landslide Investigations

Landslides in the upstream watershed of the Dungeness River and their contribution of sediment to the river system are a major concern due to the potentially adverse impacts of this sediment to anadromous fish habitat. The U.S. Forest Service manages much of the upstream watershed and maintains an internal file on landslide activity within the Olympic National Forest at the forest headquarters in Olympia, Washington. However, published geologic information on landslides within the Dungeness basin is generally lacking and a basin-wide evaluation of landslide occurrence and the role of landslides as contributors of sediment to the river system has not been performed. Summaries of two of the more prominent landslide reports from the Forest Service records are provided below.

3.4.1 Landslide Assessment (Kohler, 1989)

The U.S. Forest Service conducted a preliminary assessment of erosion, slope movement, and sedimentation processes within the Dungeness-Gray Wolf river basin for the U.S. Fish and Wildlife Service and the Dungeness Management Team for use in making resource management decisions (Kohler, 1989). Kohler expanded the extent of the assessment from the Olympic National Forest to also include Olympic National Park, as many of the first order streams in the basin were located within the park boundary. Using geologic data (Forest Service's Geologic Resource and Conditions Database) in combination with interpretation of 1:12,000 scale aerial photographs (1962, 1968, 1973, and 1982) and field reconnaissance of the watershed, Kohler mapped and classified landslides and related slope movement features in the drainage basin. Kohler also evaluated stream channel disturbance over time by measuring tree canopy openings across the river channel using 328-ft (100-m) segments for the main stem of the Dungeness and its tributary streams. Areas indexed as having high channel disturbance were evaluated for potential slope movement.

Kohler's analysis identified numerous rock slope failures in the Dungeness watershed, including rock fall, rock topple, rock glide, and rock avalanches. The shape of the failures appeared to be controlled by structural features within the rock outcrops, such as bedding planes, joints, and faults, and he noted that hundreds of these features were present in areas of the National Park unaffected by human activity. Soil mass movements were generally associated with glacial, glaciolacustrine, and alluvial fan deposits along the main stem of the Dungeness and the larger tributary streams, including the Gray Wolf River and Gold Creek. In many of these areas, younger alluvial fans deposited on the older glacial materials contributed to the failures by conducting water to the underlying, fine-grained glacial and lacustrine sediments, saturating the sediments and causing them to lose strength. Stream erosion along the toe and subsequent oversteepening of the unstable slopes were primary causes of slope failures in and adjacent to the riparian zone. Kohler concluded that sedimentation in the Dungeness basin was largely a result of natural processes, including the physical properties of the parent bedrock materials, widespread slope failure processes in the watershed, and the tectonic uplift of the Olympic Peninsula. Kohler further cited evidence of deposition of large volumes of gravel and boulders in the river system prior to 1950 and the onset of logging on national forest lands. Kohler considered logging and associated road building to be contributory factors which may have accelerated these natural processes, but discounted them as major elements in sedimentation due to the small area of the forest affected by logging activities.

3.4.2 Landslide Evaluation (Golder and Associates, 1993)

Golder Associates (1993) performed an evaluation of a series of 12 or more, nearly continuous landslides along a one-mile reach of Gold Creek to assist the U.S. Forest Service in assessing the sediment contribution from the slides to both Gold Creek and to the overall sediment load in the Dungeness River. Golder discussed options for management of the sediment and developed relative cost estimates for each alternative. The Golder investigation included a literature review for landslides in the Gold Creek area in 1969, 1972, 1980, and 1990/1991 and performed an aerial photograph analysis using a series of photographs dating as far back as 1939. Their field investigations of the 1990/1991 landslides addressed the site geomorphology, the surface water and ground-water hydrology of the slide areas, the condition of existing gabion structures installed in the channel in 1977/1978, and the stability of slopes in the slide areas.

Golder Associates mapped bedrock outcrops along the channel floor of Gold Creek which were resistant to erosion. They reported that the hard bedrock outcrops forced Gold Creek to migrate laterally and erode the adjacent side slopes during high runoff events. Fine-grained lacustrine sediments were deposited on top of the bedrock and were interbedded with and overlain by more permeable outwash and till deposits left by the Cordilleran ice sheet. Recessional outwash composed of permeable sand and gravel mantled the ground surface in the area, resulting in infiltration of precipitation into this material rather than surface runoff during storms. A series of three perched seepage areas were mapped in the slide mass where downward percolating water was forced to move laterally along contacts with underlying geologic materials of lower permeability, such as the lacustrine and glaciolacustrine sediments. Golder Associates concluded that slope failures typically occurred during storms when infiltration elevated local ground-water levels and saturated the soil materials near the base of the slope, leading to increased pore pressures in the materials and decreased shear strength. High discharge from the higher elevations in the Gold Creek drainage resulted in lateral erosion and oversteepening of channel side slopes. Golder Associates concluded that the landslides occurred a result of these two factors acting in combination on the channel slopes. Failure of debris dams within the Gold Creek channel may have contributed to bank erosion and the slope failures. Slope stability analyses by Golder indicated that factors of safety remained low after initial slope failure, suggesting that failures would continue to occur in these landslide areas. Their aerial photography analysis indicated that the 1990/1991 landslides were localized portions of an older, larger slide mass observed in the 1939 aerial photography which had been remobilized during the storm.

The volume of the 1990/1991 landslide mass was estimated at about 2552 yd^3 (1951 m^3) and Golder Associates calculated a rate of movement for the slide mass at about 375 yd^3 (287 m^3) per year. Factoring in the other landslides present within this reach of Gold Creek and those observed in the aerial photo interpretation dating back to 1939, Golder Associates estimated that the annualized average rate of sediment being delivered to Gold Creek ranged from 700 to 1400 yd^3 (535 to 1070 m^3) per year. They qualified this calculation and noted that sediment was delivered to Gold Creek in pulses rather than on a more uniform basis because the rate of landsliding was controlled by the rate of undercutting at the toe of the slide and by ground-water levels in the slope. When applying these rates to the Dungeness basin as a whole, Golder Associates identified four main sources of sediment in the system: areas covered by glaciers, areas covered by bare rock, undisturbed forest areas (including logged areas more than 10 years old), and clear cut areas less than 10 years old. Using published sedimentation rates from other studies in the Olympic and Cascades mountains, sediment yields were then calculated for both the Gold Creek sub-watershed and the Dungeness basin as a whole. These calculations showed that Gold Creek comprised about 5 percent of the Dungeness watershed, but contained about 22 percent of the clear cut area (up to 1990). The sediment yield from Gold Creek accounted for about 2.6 percent of the total sediment generated within the Dungeness basin. In the Gold Creek watershed, erosion from undisturbed forest areas, including landslides, accounted for about 58 percent of the total sediment yield with the remaining 42 percent coming from disturbed or clear cut areas.

3.5 Historical Land and Water Use Investigations (Eckert, 1998)

In her investigation of land and property history in the lower Dungeness River drainage basin, Eckert (1998) used aerial photographs taken in various years between 1956 and 1990 and several old maps beginning with one dating from 1858-59 to determine the changes in patterns of land cover and property boundaries over time. All of the information in her study was put into a GIS (geographic information system) data base in order to compare changes in patterns of land ownership with changes in land cover. Eckert (1998) also investigated the history of irrigation in the lower Dungeness River drainage, because the irrigation systems controlled the types of land uses by redistributing both surface and subsurface water.

Using the GIS data base in which she compiled all the available information, including topography, geology, soils, and available water, Eckert (1998) produced a series of maps that shows the changes in land use that she identified. From these, she interpreted the changing land-use patterns, the reasons why the patterns existed, and the possible causes of the changes. In making these interpretations, she considered water rights (including irrigation patterns), natural and human-induced fires, and other social, political, and economic issues.

The general change in land use that Eckert (1998) noted during the last 150 years has been from forest (before Euro-American settlement) to farms and, most recently, to rural residences. Property size has changed from large farms to small residential lots. In converting natural land to farms in the first half of the 1900's, settlers cleared much of the vegetation in the lower basin.

3.6 Archeology Investigations (Morgan, 1999)

The Dungeness River valley and surrounding area, especially along the coast, has been the site of human occupation for at least the last 10,000 years (Morgan, 1999). Three prehistoric sites in the Dungeness River area have received detailed study. In addition, several villages or encampments were reported by the first Europeans in the area beginning in the 1790s: three along the Dungeness spit, five near the mouth of the Dungeness River, one along the Dungeness River about 3.5 miles upstream from the mouth, three along the coast between Cassalery Creek and Gieren Creek (Jamestown and Kulakala Point), and three around Washington Harbor at Sequim Bay (Morgan, 1999). Morgan (1999) also includes information about the geologic history, paleoclimate, vegetation, and fauna for the region. The sites that provide evidence on the historic path of the Dungeness River are listed below.

At the request of the Washington Department of Transportation (WDOT), Archaeological and Historical Services (AHS) conducted investigations in 1996 and 1997 at two sites along the proposed 5-mile-long Sequim Bypass Project on State Highway 101. After surveying the bypass area between the east bank of the Dungeness River and Palo Alto Road for cultural resources, AHS identified two sites for detailed investigations. These investigations included surveys of the area, 24 test pits (excavated by hand shovels), and 35 trenches (excavated by backhoes and hand shovels).

One site (45CA426), at the Fasola Farm at the east end of the project area, is situated on a low terrace of Bell Creek. AHS interpreted this terrace as cut into deposits of the last glaciation when the Dungeness River flowed in the present Bell Creek drainage before 6,840 yr BP (Morgan, 1999). The older occupation of this site was located on the terrace surface during the early and middle Holocene (8,000 to 4,000 yr BP), which was after the channel was abandoned by the Dungeness River. The younger occupation at the Fasola Site was during the late Holocene on an alluvial fan that was deposited on the terrace beginning before 4,960 yr BP.

The other site (45CA433) is located on a high terrace on the east bank of the Dungeness River at the Hyer/Sherk Farm. The terrace is about 45 ft (14 m) above the present flood plain of the Dungeness River and is composed of older gravel that was deposited by the Dungeness River.

The conclusions from these investigations are that the Dungeness River flowed in the present location of the Bell Creek drainage at some time before 6,840 years ago and that the Dungeness River was 45 feet higher than its present elevation a few thousand years ago.

4.0 DATA COLLECTION AND PROCESSING

Data collection for this study has been a cooperative effort involving several individuals from Reclamation, the Tribe, Clallam County, USGS, and the National Park Service (NPS). Data collection activities (described in detail below) included:

- Conduct a field and aerial reconnaissance (Reclamation)
- Measure river flow (USGS)
- Establish a survey control network and 61 benchmarked cross sections (Reclamation)
- Rectify 1998 and 2000 aerial photographs and develop topographic map (Reclamation)
- Collect historical information
- Measure river bed-material samples
- Install scour chains and measure bed-material samples (sediment in vicinity of spawning areas)
- Measure total sediment load passing the Highway 101 Bridge (USGS)
- Describe soil profiles and radiocarbon dating of alluvial terraces
- Installation of three cameras and video of daily time-lapse pictures (Reclamation and NPS)

River cross sections, aerial photographs, and topographic maps were used to develop a model of existing hydraulics and sediment transport capacity. Previous cross sections and historic aerial photographs and maps was used to evaluate the amount of change in channel morphology over time. Sediment sampling was used to identify the sizes of sediment present in the river channel and the availability of spawning material. Sediment load measurements were used to assess the transport capability of the river. Information about alluvial terrace deposits and their possible ages was used to create a geologic map of the river corridor. This map was used to identify areas of natural river migration and flooding bounded by geologic controls versus existing boundaries imposed by man-made structures. Time-lapse photography was used to evaluate the interaction between gravel bar formation and woody debris transport during high flows.

4.1 Field and Aerial Reconnaissance

Several field reconnaissance trips were conducted to field check conclusions and investigate questions that arose during the analysis phase of the study. An aerial reconnaissance was also conducted on September 10, 1998 by helicopter to investigate the upper watershed because the majority of the upstream river is inaccessible by roads. The flight covered from the mouth of the Dungeness River at the Straight of Juan de Fuca, upstream into the headwaters in the Olympic Mountains. A flight path was also flown along the Gray Wolf River from the confluence with the Dungeness upstream to its headwaters. A set of photographs from the aerial reconnaissance depicting some of the lower and upper Dungeness River is included in the photographic log at the beginning of this report.

4.2 River Flows

The precipitation source for the Olympic Peninsula, including the Dungeness River basin, is from prevailing southwesterly and westerly Pacific moisture. Major storms that result in heavy precipitation and large-magnitude flooding in the Dungeness River basin usually occur

in winter and are primarily warm frontal systems. In general, intense winter rainfall on snow at low altitudes causes most of the flooding in western Washington (England, 1999, Appendix G).
Discharge on the Dungeness River is continuously recorded by the USGS at a gage site about 1 mi upstream from the confluence with Canyon Creek (USGS Gage 12048000, RM 11.8, drainage area of 156 mi^2). The period of record includes June 1923 to September 1930, and from June 1937 to present (Figure 5). In addition to this gage, two additional sites were used to estimate discharge from 1897 to 1901, but are not directly equivalent to the current gage.

Prior to the winter of 2001-2002, the largest recorded flood on the Dungeness River occurred at one of the former gage sites on December 20, 1900 with an instantaneous peak of 7,540 cfs. This peak value was used as the flood of record for modeling purposes. During the final writing of this report, the new flood of record of 7,610 cfs was recorded at the existing USGS gage on January 7, 2002. Therefore, at the present gage, the annual instantaneous peak discharges have ranged from 740 cfs (1925) to 7,610 cfs as shown in Figure 5. The ten highest recorded peaks at the existing gage are listed in table 1 (7,540 cfs occurred at previous gage site). Additional discharge and water temperature measurements have also been collected by the USGS and the Washington Department of Ecology since September 1, 1999 on the right bank 10 ft downstream of the Schoolhouse Bridge (Gage 12049000, RM 0.8, drainage area of 197 mi^2).

Table 1. Largest annual peak discharges for Dungeness River (Gage 12048000)

Date	Water Year	Discharge (cfs)
1/7/2002	2002	7,610
11/24/1990	1991	7,120
11/27/1949	1950	6,820
11/3/1955	1956	6,750
1/18/1986	1986	6,560
2/11/1924	1924	6,340
3/19/1997	1997	5,990
1/15/1961	1961	5,900
11/15/1983	1984	5,510
12/28/1937	1938	5,380

4.3 Cross Section Surveys

Many previous surveys of the lower Dungeness River had not been well documented. In 1996, the Washington Department of Fish and Wildlife tried to replicate previous surveys, but because the previous surveys did not use permanent monuments, replication was difficult. In 1997, Reclamation expanded the 1996 survey to a network of 60 cross sections (XSs) using a control network established by Clallam County and Washington State (Photo 12 – Photographic Overview). This network was established in Washington State Plane Coordinates (1983 North American Datum, Washington North Zone and 1988 National American Vertical Datum) and has permanent benchmarks so that repeat survey work is possible. Documentation of the control network and cross section monuments are provided in

Appendix C. Aerial photographs taken in March 30, 2000 are presented at the end of this report that show the locations of each cross section.

The cross sections were established across the active, unvegetated channel in 1997 from near the location of the fish hatchery at RM 10.4 (XS 60), downstream to the mouth of the Dungeness River at RM 0.03 (XS 1). Where possible, cross sections were extended to include the high point on either bank (extent of existing flood plain). Longitudinal cross section spacing was approximately 1000 ft, with sections spaced closer together in areas where significant changes in planform or geometry were evident.

In May 1998, additional coverage was added to include bridge surveys and a few water surface profiles. In October 1998, an additional cross section was added between XS 31 and XS 32 (labeled XS 31A), and two additional cross sections were added in the west side channel at the Railroad Bridge (XS 34A and XS 35A). In certain areas such as near the Railroad Bridge, dense vegetation limited the amount of survey work possible outside the active channel, but a few representative sections were extended in October 1998. In October 1999, about one-third of the cross sections were re-surveyed where the most significant channel change was thought to have occurred. In October 2000, several cross sections in the vicinity of the Railroad Bridge were re-surveyed to quantify observed channel change from high flows. Also, several new cross sections were established (in the active channel only) where scour chains have been placed by the Tribe to measure the thickness and particle size of the riverbed mobilized by floods. (Jamestown S'Klallam Tribe, 1999).

Tables C-1 and C-2 in Appendix C include a detailed documentation of the cross sections surveyed. A complete set of cross section plots are contained in Appendix F that show comparison survey data where available. Plots are shown looking in the downstream direction so that station “0" is on the west (left) bank and the highest station is located at the east (right) bank. Locations of the cross sections were tied to river miles upstream from the mouth (RM).

4.4 Photogrammetry and Development of Topographic Maps

The majority of cross section data surveyed along the lower Dungeness River includes only the active, unvegetated channel and portions of the wooded flood plain. To supplement data from the cross section network and provide a photo mosaic base for illustration and analysis, aerial photographs were taken on April 29, 1998 at a scale of 1:6000. This initial set of photographs was used to generate a 2-foot contour map from RM 4.0 downstream to the mouth and extend cross sections in the lower 2.7 mi (ACOE Levee reach). An additional 2-foot contour map was produced by Clallam County for the short reach from a set of April 6, 1999 aerial photography by Clallam County from just upstream of Schoolhouse Bridge (RM 0.8) downstream to the mouth.

A new set of photographs were flown on March 30, 2000 at a scale of 1:6000. Prominent features of these photographs were surveyed using GPS instruments and the NGS control monument (see Appendix C). The new photographs and survey data were used to generate a photo mosaic, color rendering, and 2-foot topographic map from the mouth upstream to near the fish hatchery (about RM 8.6). The upstream 2 mi (3.2 km) could not be contoured due to the dense vegetation in this area that prevents using photogrammetry to determine ground elevations. This 2000 data set was used to generate all of the existing maps and photo images presented in this report. The horizontal coordinate system utilized the latitude and longitude (WGS). However, the cross section survey control network was based on work performed referenced at the NGS monument, and the vertical coordinate system utilized the NAVD 88 Washington North State Plane coordinates of this monument. The coordinate systems of the photograph mosaic and cross sections are supposed to be identical. The exact cause of the difference was never found.

4.5 Collection of Historical Information

Several historical aerial photographs and maps were collected as documented in tables A1 and A2 in Appendix A. Historical aerial photographs from 1942-43, 1965, 1994, and 1996 were compared to the new 1998 and 2000 sets to evaluate geomorphic changes along the study reach. Each of the historical photographs were matched to the ortho-rectified 2000 photographs using common features in the photographs. The 1942-43 photographs were more difficult to accurately match than the more recent photographs because many features had changed since that time period, the quality of the older photographs was not as good, and the older photographs were at a higher altitude. The primary historical map utilized was a topographic map developed from survey data collected in 1935 along the lower 2.7 miles (4.3 km) of river channel. A 1913/14 map was also utilized (Avery), but detailed comparative analysis was accomplished in Orsborn and Ralph's study in 1994. Aerial photographs from 1957 were recently found and were visually looked at for comparison to other photo years.

The lower 10.5-mile Dungeness River is included on U.S. Geological Survey, 1:24,000-scale topographic quadrangles (Carlsborg, Dungeness, and Sequim). Maps that show the geology of the drainage basin include Tabor and Cady (1978), which includes the entire Olympic Peninsula; Othberg and Palmer (1979a, 1979b, 1979c), Schasse and Logan (1998), and Schasse and Wegmann (2000), which cover individual 1:24,000-scale quadrangles.

4.6 River-Bed Material Samples

This investigation included an examination of the alluvium in the active channel and alluvial deposits of the Dungeness River and focused on two primary objectives. The first objective was to identify any spatial trends in sediment size along the lower 10.5 mi (17 km) of the river. The second objective was to assess the availability of spawning gravels along the river channel needed by different species of anadromous fish.

There are several methodologies available to characterize alluvial deposits. Previous work by Orsborn and Ralph (1994) used pebble counts to assess the grain size of riverbed materials in riffles. This analysis gave a good assessment of pavement material present in riffles along the Dungeness River. To determine sizes of sediment present in the riverbed, shallow test pits were excavated to examine the grain size of the deposits and to evaluate the development of the surface pavement or armor layer which can restrict anadromous fish access to spawning gravels. The samples were collected from exposed, unvegetated bar deposits adjacent to the low-flow channel(s) of the Dungeness River during minimal flow periods in the late summer and early fall (Photo 11 – Photographic Overview). These locations permitted relatively rapid sampling and sieve processing of the bar materials in the field. Individual sample sites were selected by visually examining the riverbed materials at the site and then locating adjacent bar materials that appeared to be representative of the riverbed. At sample sites where a wide variation of riverbed materials was observed, two samples were collected representing materials at the coarse- and fine-grained end members of the riverbed gradation distribution. Samples were not collected from the wetted riverbed due to a number of considerations, including potential disturbance of migrating anadromous fish and their redds, increased handling and processing time required for wet samples, and adverse impacts to sample quality due to winnowing of fine sand, silt, and clay by the river current during sample collection. The measured particle size data is presented in Appendix B along with a detailed description of the field sampling methodology in Appendix D.

Subsequent to the initial field sampling conducted in 1998, the sampling procedure was modified to incorporate laboratory testing of the material finer than 8 mm to better evaluate the concentrations of fine-grained particles present in the alluvium. Feedback from Habitat Biologist Byron Rot of the Jamestown S'Klallam Tribe indicated that two additional particle size fractions within this fine-grained group could have adverse impacts on fish habitat, if present in sufficient quantities: 0.85 and 0.063 mm.

Fourteen samples were measured at eight different locations on the lower 10.5 mi (17 km) of the Dungeness River in 1998 (see Figures 3A and 3B; Table D.1, Appendix D). At five of these localities (DRsed-1, DRsed-3, DRsed-4, DRsed-5, and DRsed-19), samples from both a coarse-grained and fine-grained bars were measured. For all but three samples, the pavement and underlying material were measured separately. For the other three sites, a pavement was not present or was very poorly formed (DRsed-1A, DRsed-4A, and DRsed-4B). At two locations, gravel bars were found to be unusually high above the low-water channel: one between the ACOE and the Olympic Game Farm levees (DRsed-3B) and the other adjacent to Dungeness Meadows Levee (DRsed-13). A sample was measured at each of these locations to estimate the maximum sediment size in these elevated bars and to compare them to those of other bars in the same area and at different locations along the river.

4.7 Scour Chain Bed-Material Measurements

Bed-material sampling was conducted in 2000 in support of the Jamestown S'Klallam Tribe's investigation of riverbed scour and its impact to anadromous fish spawning habitat in the Dungeness River. Sampling was conducted from the East Crossing Campground near RM 17.7 downstream to the ACOE and Olympic Game Farm Levee reach at RM 1.5. Five of the nineteen 2000 samples sites were measured at locations in the upper watershed including the East Crossing Campground (DRsed-101 and -102), the Gray Wolf River confluence (DRsed-103 and -104), and the USGS gaging station (Drsed-105). Sixteen of these samples were located on mid-channel and point bar deposits in and adjacent to the low-flow channel while two samples were obtained in side channels (DRsed-102 and -103) and one sample was located on a debris fan at the mouth of Canyon Creek (DRsed-106B). Six of the sixteen samples taken from bar deposits (DRsed-104, -108, -109, -110, -114, and -118) had sufficiently developed surface pavement to warrant separate sampling of the pavement and underlying bed material. Measured sediment size data and results of that investigation were discussed in a separate report by Piety and Link (2000), attached to this document. (See Appendix N).

The sampling philosophy used in the 2000 field work varied from the earlier work conducted in 1998. The 2000 work sampled riverbed materials on or adjacent to scour chain transects previously installed in the Dungeness River by Tribal staff. The scour chain transects focused on reaches of the river suitable as spawning habitat whereas the 1998 investigation generally focused on sampling of gravel bars representative of the alluvial materials present in and adjacent to the low-flow river channel. The areas sampled in the 2000 scour chain study often concentrated on more fine-grained portions of the riverbed and included two samples in side channels. One additional sample was collected from the debris fan at the confluence of Canyon Creek and the main Dungeness River to help evaluate the input of fine sediment from debris flows and other types of landslides.

4.8 Sediment Load Measurements at Highway 101 Bridge and Schoolhouse Bridge Gage Sites

Sediment load and instantaneous discharge measurements were made by the USGS on the Dungeness River at the Highway 101 bridge during 5 floods (all greater than 1,200 cfs) during December 30, 1998 to May 25, 1999, and on June 15, 2000 (USGS, 1999). Sediment load measurements included both bedload and suspended load measurements using standard techniques (Edwards and Glysson,1999). A plot of the particle size distribution of measured bedload is included (See Figure 6); and the data in Appendix E are presented. Additional suspended sediment load and discharge measurements were also made by USGS at the Highway 101 Bridge and at a new gage site at the Schoolhouse Bridge during December 1, 1999 to September 30, 2000. Unfortunately this time period did not have any significant high flows and therefore would not provide any new information at flows not already recorded. All measured data are documented in USGS Water Resource Publications (Kimbrough, et al., 1999 and 2000).

4.9 Stratigraphy, Soil Profile Descriptions, and Radiocarbon Samples

To help understand the geologic history of the Dungeness River corridor and define the boundaries of the active and historical floodplains, sediment exposed in banks adjacent to the active channel or in pits excavated by hand or backhoe were examined (Photo 13 – Photographic Overview). Observations were made at numerous sites along the river, and 12 sites were selected to do more detailed descriptions and sampling. At five of these sites, the characteristics of the sedimentary units and the relationships between the units were described (Appendix Q). At seven sites, the soil development was described (Appendix I). In addition, charcoal samples were collected, where available, from one or more of the sedimentary units at each of the twelve sites. If no charcoal was visible or if it was too small to sample separately, bulk sediment samples from which charcoal could be extracted were collected. Out of the nearly 50 charcoal samples collected in 1998 and 2000, 27 were submitted to Paleo Research Laboratories and Beta Analytic, Inc. for macrofloral and radiocarbon analyses (Appendices J and K).

4.10 Time-lapse Photography

Three video cameras were placed along the Dungeness River to monitor day to day changes in the physical channel due to varying river flow. Of particular interest was the relationship between gravel bar development and woody debris (Photos 14A and B – Photographic

Overview). Each camera was placed in a fixed position and set to take a picture automatically. For practical purposes, only one picture was taken per day at noon to get the best lighting and so that the film only had to be changed once per month. The monitoring period for Camera 1 was from November, 1998 to February, 1999 and was extended to April, 1999 for Cameras 2 and 3.

Camera 1 was located at RM 5.6, just downstream of the Railroad bridge, at the downstream tip of the wooded island located left of the main channel, set to look downstream. Camera 2 was located at RM 5.7, just upstream of the Railroad bridge, at the head of the west side channel and along the west bank set, to look upstream. Camera 3 was located at RM 8.5, near cross section 50, along the east bank looking upstream. Camera locations are shown in Figures 3A and 3B.

Hourly discharge data for the Dungeness River were obtained for the monitoring periods from the USGS stream gage site near Sequim, Washington (12048000). Based on the gage data, several winter storms were captured on film during the monitoring. The peak flows are as shown in Table 2.

Table 2. Occurrence of floods during the time-lapse photography.

1,900 cfs	(Nov. 20, 1998, 9:00 p.m.)
2,070 cfs	(Nov. 25, 1998, 3:00 a.m.)
4,300 cfs	(Dec. 13, 1998, 8:00 a.m.)
1,120 cfs	(Dec. 28, 1998, 1:00 a.m.)
2,200 cfs	(Dec. 29, 1998, 4:30 p.m.)
1,730 cfs	(Jan. 14, 1999, 4:00 p.m.)
3,340 cfs	(Jan. 29, 1999, 3:00 p.m.)
3,150 cfs	(Feb. 24, 1999, noon)

The Dungeness River in view of Cameras 1 and 3 had significant changes in gravel bars and large woody debris during the monitoring period. However, the portion of the channel in view of Camera 2 showed little change.

Time-lapse videos were made for Cameras 1 and 3 and are included on a CD in Appendix P.

5.0 ANALYTICAL METHODOLOGY

Defining the existing geomorphic, hydraulic, and sedimentation conditions are important components for understanding the complex physical processes of the lower Dungeness River. A Reclamation study team comprising backgrounds of hydraulics, sedimentology, geology, geomorphology, hydrology, and photogrammetry was formed to work with various individuals from the Tribe, DRMT, Clallam County, and other cooperating agencies. The following sections describe the various analytical components of this study and the methodologies used to accomplish them.

5.1 Hydrology

A hydrologic analysis was completed which summarizes flood frequency, flow duration and stream flow trends for the Dungeness River (England, 1999, See Appendix G). This analysis was based on USGS stream gaging station data from the Dungeness River gage site near Sequim, Washington (12048000). The discharge data for this stream gage are rated as good (± 5 percent) by the USGS.

Flood frequency estimates were made for the annual instantaneous peak discharge (Table 3) using a log-Pearson Type III (LP-III) distribution. The data define a range of annual exceedance probabilities for the 2-year (50 percent probability of occurring) to the 100-year flood (1 percent probability of occurring). Peak discharge probability estimates indicate the 100-year flood model estimate is 8,960 cfs with a 95 percent probability (England, 1999). The recent flood of record of 7,610 cfs fits within the range of model estimates for the 100-year flood provided in England (1999) .

Table 3. Peak flood frequency estimates based on USGS stream gage (12048000) (Appendix G: England, 1999)

Return Period (years)	Annual Exceedance Probability (percent)	Peak Discharge (cfs)
2	50	2,990
5	20	4,690
10	10	5,780
25	4	7,120
50	2	8,060
100	1	8,960

5.1.1 Mean Daily Flow Duration

A mean-daily flow duration curve was developed for the period of record that defines discharge as a function of the percentage of time that the discharge is equaled or exceeded (Figure 3 in Appendix G: England, 1999). The flow duration curve for the entire year indicated that mean daily flows are typically less than 480 cfs 75 percent of the time. The seasonal flow duration curve indicated that mean daily flows for the April to July snowmelt season are nearly always greater than other selected seasons. However, peak flows are greater during the late fall and winter. These percentages are for the USGS gage located upstream of the irrigation diversions.

The mean-daily flow duration curve was used to determine the probability of occurrence of the recommended instream flows developed for the lower Dungeness River downstream of the irrigation diversions (Hiss, 1993) The recommended flow of 575 cfs for November to March has been equaled or exceeded 13.6 percent of the time (England, 1999). The recommended flow of 475 cfs for April to July has been exceeded 48.6 percent of the time. The August to October recommended flow of 180 cfs has occurred on a daily basis (100 percent of the time). Mean daily flow duration statistics by month are listed in the attached hydrology report (England, 1999).

5.1.2 Analysis of Mean Daily Streamflow Trends Over Period of Record

Mean daily seasonal, and annual streamflow were analyzed for significant trends in increases or decreases of flow over the period of record to determine if there was a correlation during periods of significant logging activities in the watershed (England, 1999). It would be expected that logged areas would result in a localized increase in rainfall runoff due to removal of the tree canopy that would normally intercept rain and dissipate runoff. However, no statistically significant trends were found for the Dungeness River mean daily flow records (1924-1930, 1938-1998) that would indicate any long-term increase or decrease in mean daily flow values during periods of logging (England, 1999). This is likely due to the fact that the total area of logging is small relative to the entire watershed area.

5.2 Hydraulic Model

The U.S. Army Corps of Engineers (HEC - RAS computer model Hydraulic Engineering Center - River Analysis System, version 3.0, Brunner, 2001) was applied to the lower 10.5 mi of the Dungeness River to predict hydraulic properties (water surface elevation, depth, mean velocity, and channel capacity). Cross-section data from the 1997-2000 surveys were used to describe the channel geometry (see section 4.2). Significant features along the lower Dungeness River that were modeled include levees, bridges, wooded flood plain inundation, and areas with bank modifications.

The HEC-RAS model performs water surface profile and other hydraulic calculations for one-dimensional steady flow. The model predicts river stage and other hydraulic properties at each cross section along the river for any specified discharge. The model was limited to the subcritical and critical flow regimes. Although supercritical flow may occur over a short distance in a riffle or rapid, it does not occur as an average condition across the river or between cross sections. Subcritical flow is the most common condition in natural channels (where the flow velocity is less than the speed of a gravity wave). Critical flow occurs where there is a transition between subcritical and supercritical flow and would typically occur at the top of a riffle or rapid.

Water discharges for the model were chosen based on the hydrologic analysis report (England, 1999) to represent a range of possible flow conditions from the 2-year flood to the flood of record (see section 5.1). Extremely low flows are not a focus as they are not responsible for significant changes in channel planform. In addition, low flows are difficult to model in the Dungeness River system because of split flow conditions (i.e. multiple flow paths) in the active channel and side channels.

Several types of energy loss coefficients are utilized in the HEC-RAS model. The primary one is friction losses associated with channel bed roughness (flow resistance) which is selected using the Manning's *n* value. Manning's *n* values are determined based on the surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of the channel, stage and discharge, seasonal change, temperature, and suspended load and bedload. For the Dungeness River, roughness values can change locally due to gravel bar aggradation, woody debris deposition, and vegetation cover and type. Manning's n values were varied throughout each cross section to account for these factors. Values were determined from aerial photographs, field observations, and several computation procedures. Several methods of computing roughness were evaluated to determine roughness values applicable for the Dungeness River hydraulic model. Measured D_{50} of the bed-material data was used in the analysis. The logarithmic method (n varied with depth to D_{50} ratio) showed the most consistency in computed roughness values compared to visual methods of estimating roughness from the field and descriptive data published by USGS (Barnes, 1967). Typical roughness values used in the model range from 0.035 to 0.04 in the main channel and 0.03 to .055 in the flood plain.

Modeled water surface elevations for the 2-year flood and the flood of record at each cross section are contained in Appendix H. Hydraulic output at each cross section location are presented in Section 8.1.1. Additional hydraulic modeling was performed to evaluate potential effects of setting back or removing the levees in the lower 2.7 river mile reach (Appendix M), and for potential effects of widening Schoolhouse Bridge (RM 0.8) (Appendix L). The full version of the reports are attached to this document and provide detailed model output in their respective appendices.

Results from the hydraulic model were field checked shortly after a flood of approximately 4,300 cfs, on December 13, 1998. Just downstream of the Schoolhouse Bridge at XS 3, the computed water surface elevation (stage) at a flow of 4,300 cfs showed the River's End Levee (west bank) would be overtopped. Field observations and conversations with local landowners verified that the levee was indeed overtopped and breached during the flood. In the vicinity of the Railroad Bridge, the computed water stage at 4,300 cfs indicated the east river bank would be overtopped. Field observations of debris piled against trees in the right flood plain verified that this flow did indeed reach a high enough stage to overtop the banks and flow through side channels in the wooded flood plain.

Water velocity, wetted width, and stage measurements were made at the Highway 101 Bridge gage site during high flows as part of the bedload sampling effort by USGS. This data offers a great opportunity to check measured stage and average velocity with computed values from the hydraulic model at this location (Figures 7 and 8). A comparison plot was generated of measured versus computed stage for a range of discharges (Figure 7). Around flows of 1,500 cfs, the measured stage varies by almost 2 ft due to a change in channel geometry. The computed stages from the model do plot within the range of the measured stages, and in general match well at the two high flows measured. The range in measured velocities is likely due a change in channel geometry that occurred at this gage. Figure 9 shows cross section plots measured at the gage site (upstream side of Highway 101 Bridge) and the hydrograph during the measurement period. As the plot shows, the left side of the river channel (looking downstream) was scoured during a flood of at least 3,500 cfs (mean daily flow) between the November 20 and December 30, 1998 measurements. As a result, a larger channel capacity was created which would tend to lower water stage. Since the change on the left side, the plot shows the channel remained stable even during a larger flood that occurred on January 29, 1999.

At the same site, a comparison of the measured average water velocity versus computed average water velocity was done (Figure 8). Overall, the computed velocity curve fits very well with the measured data. At low flows, a range of velocities were measured and the computed velocities fit the upper limit of this range. At the largest flow measured, the computed mean velocity is only 0.5 ft/s greater than the measured mean velocity. This is considered acceptable for the scope of this study.

5.3 Sediment Analysis

5.3.1 Sediment Rating Curves

Bedload is defined as the transport of sediment particles that frequently maintain contact with the channel bed (Julien, 1995). Generally, bedload consists of sand, gravel, and cobble particles (> .125 mm in size) that roll and slide in a thin layer near the channel bed. Suspended load typically consists of sand, silt, and clay sized particles (< 2 mm in size) transported through the river system in suspension above the channel bed layer. The bedload and suspended load data were used to develop a correlation between water discharge and sediment load using the following relationship documented in literature (Strand and Pemberton, 1982):

Sediment Load and Discharge Power Equation 1

$$Q_s \text{ or } Q_b = aQ_w^b$$

Where:
Q_s = suspended sediment transport (tons/day)
Q_b = bedload transport (tons/day)
Q_w = water discharge (cfs)
a = coefficient
b = exponent

The finer fraction of the suspended load that is not present in the bed material is called wash load. While wash load can have a significant impact on fisheries, it has little impact on the morphological features of the channel. Therefore, bedload transport was the focus of this study but the measured suspended load and discharge relationship are presented (Figure 10). The largest flow recorded during a suspended sediment load measurement was 3,700 cfs at the Highway 101 gage (slightly more than the 5-year return flow) and 1,850 cfs at the Schoolhouse gage (less than the 2-year return flow). The rate at which suspended sediment load increases with discharge is not always a constant and can vary by location. Further, at the Schoolhouse gage where much lower flows were also measured the suspended sediment data show a dramatic increase in slope at flows above 700 cfs. Therefore, the data from the Schoolhouse Bridge gage were treated separately from the data at the Highway 101 gage and two power equations were developed for the Schoolhouse Bridge data to account for the change in slope. This indicates suspended sediment load increases much more rapidly with discharge at flows greater than 700 cfs.

Suspended Sediment Load Power Equations

Equation 2 (Schoolhouse)	Equation 3 (Schoolhouse)	Equation 4 (Highway 101)
$Q_{s<700\ cfs} = 1x10^{-4}Q_w^{.1.7802}$	$Q_{s>700\ cfs} = 1x10^{-13}Q_w^{5.0485}$	$Q_{s>700\ cfs} = 7x10^{-8}Q_w^{3.22}$
$R^2 = 0.72$	$R^2 = 0.90$	$R^2 = 0.86$

The measured bedload data and power equation are shown in Figure 11. The largest flow recorded during a bedload measurement at the Highway 101 gage was 4,500 cfs (slightly less than the 5-year return flow). The bedload measurements were all made at flows greater than 1,000 cfs.

Bedload Power Equation 5

$Q_b = 7x10^{-7}Q_w^{2.7779}$

$R^2 = 0.925$

5.3.2 Effective Discharge

The discharge which transports the most sediment over time is called the "effective discharge" and is an indicator of the channel forming flow. The effective discharge is defined as the flow that moves the most sediment over time and forms the morphological characteristics of the channel (Wolman and Miller, 1960). The effective discharge is often associated with the flow that fills the main channel and just begins to overtop the river banks. The frequency of the effective discharge is unique for every river, but typically occurs every 1 to 2 years. Although extremely high flows also transport a large amount of sediment and can be responsible for channel changes, these flows are rare and do not account for the majority of sediment movement and channel changes on a long-term basis.

Effective discharge can be computed by taking the product of the frequency of a given discharge (flow duration) and the sediment transport rate associated with that particular flow (Strand and Pemberton, 1982). Because flow rates vary by season, flow frequency curves were divided into three time periods to determine the appropriate effective discharge. The bedload equation (No. 5) developed from measured bedload data at the Highway 101 Bridge was used to compute the effective discharge.

The area under the effective discharge curve represents the amount of sediment mobilized by a particular season. The time period from November to March has the largest area underneath the curve. Therefore, this period when winter floods occur is responsible for the majority of sediment transport on the Dungeness River. The time period from November to March resulted in an effective discharge of approximately 2,900 cfs as shown in Figure 12, which is nearly equivalent (within gaging accuracy) to the 2-year peak discharge of 2,990 (see Table 3).

The annual peak discharges for the Dungeness River are shown in Figure 13 for the period of record. Values in red indicate a water year where a flow, equal to or greater than the effective discharge, occurred at least once. The plot indicates that an annual peak equal to or greater than the effective discharge has been recorded at least once a year for about 60 percent of the water years during the period of record (1923 to 1930 and 1937 to the present).

5.3.3 Sediment Transport Capacity

Sediment transport capacity is a measure of a river's ability to move certain grain sizes at a given flow. Sediment transport capacity helps identify areas of potential deposition or erosion based on sediment sizes present in the riverbed and river hydraulics. During low flow periods on the Dungeness River, sediment transport capacity is small and the water in the river channel often looks calm and clear. This is because a river needs a certain amount of energy to get a sediment particle sitting on the channel bed into motion. For a typical cross section along the river, water depth and velocity increase rapidly with increasing discharge. Therefore, as the discharge and water velocities increase, so does the river's ability to get the sediment particles into motion. Eventually, the water stage reaches the height of the river banks and flow begins to spill out onto the flood plain. When this occurs, the wetted width increases much more rapidly than stage, velocities remain relatively constant in the main channel, and sediment transport capacity also remains relatively constant. Besides water velocities, sediment transport capacity is also dependent on the steepness of the river, referred to as the channel gradient or slope. The steeper the slope, the more energy the river has and the greater the river's ability to transport sediment. Unit stream power is one method of looking at a river's ability to move sediment at a given location. Unit stream power is determined by taking the average computed water velocity multiplied by the computed energy slope at each cross section location.

The ability of a stream to move sediment is not only dependent on velocity and slope, but also on the size of sediment present in the channel bed. Yang (1973) noted that for equilibrium sediment transport, the total bed-material load must be directly related to unit stream power (velocity-slope product). Yang developed a predictive sediment transport equation based on the concept that there is a critical unit stream power required to move a particle of sediment. The equation was developed using laboratory data for sand-sized materials. However, there is very few sediment transport equations developed for larger sized particles such as gravel and cobble. Equations developed for sand-sized material can be used if a successful calibration to measured sediment load data can be accomplished. Yang (1984) also developed a similar predictive equation for gravel up to 10 mm, but this equation has some inconsistencies for gravel bed rivers with large grain size mixtures. The following bedload equation was developed for the Dungeness River based on the Yang 1973 equation (Yang, 1996) and is plotted with the measured bedload data in Figure 11:

Calibrated Dungeness River Bedload Equation Using Yang 1973:

$$\log C_{ts} = a[\ 5.435 - 0.2861*\log(?\ d/?) - 0.457*\log\ (U_*/?\ )]$$
$$+\ b[(1.799 - 0.409*\log(?\ d/?) - 0.314\log\ (U_*/?\ ))*\log((VS/?\ )-(V_{cr}S/?\ ))]$$

Where equation variables are defined as:
C_{ts} = total sediment concentration or bed-material load (in ppm by weight)
? = fall velocity of sediment (ft/s) in still water
d = median particle diameter (ft)
? = kinematic viscosity (ft^2/s)
U_* = shear velocity (ft/s)
VS = Product of Velocity and Slope or Unit Stream Power (ft/s)

The coefficients a and b were calibrated so that the predictive equation agreed well with the measured data (See Figure 11). This equation was used to evaluate sediment transport capacity by river mile using output data from the hydraulic model at the effective discharge and median particle diameter measured in the vicinity of the Highway 101 Bridge of 50 mm (presented in report section 7).

5.3.4 Bed-Material Particle Size Analysis

Bed material samples were collected from gravel bars exposed along the low-flow channel. These samples were analyzed using standard manual, graphical, and statistical techniques. Particle size measurements were sieved in the field and each size was weighed. The weights retained on each sieve were input into spread sheets and converted to percent passing each respective sieve size. These data were compiled onto standard particle size distribution curves as plots of particle diameter (in mm) versus percent passing (or percent finer grained than) the respective sieve sizes. These plots are included in Appendix D of this report. Statistically important particle diameters were then calculated from the size distribution plot for each sample. These diameters included:

- D_{16} (i.e., 84 percent of the sample was finer than the D_{16} diameter)
- D_{35} (i.e., 65 percent of the sample was finer than the D_{35} diameter)
- D_{50} (i.e., 50 percent of the sample was finer than the D_{50} diameter)
- D_{65} (i.e., 35 percent of the sample was finer than the D_{65} diameter)
- D_{84} (i.e., 16 percent of the sample was finer than the D_{84} diameter)
- D_{90} (i.e., 10 percent of the sample was finer than the D_{90} diameter)

For instance, if the D_{50} of a gravel bar sample was 50 mm, then 50 percent of the sediment in the sample was smaller than 50 mm and the remaining 50 percent was larger than 50 mm. Line graphs and bar charts were also prepared to illustrate the change in sediment particle size from the upstream end of the study reach (RM 10.5) to the downstream end at the mouth of the Dungeness River (presented in Section 7. 1.3).

Sampling of the riverbed sediment present in the gravel bars along the Dungeness River identified two distinct materials: (1) a surface pavement (or armor) layer composed chiefly of gravel and cobbles with occasional boulders and (2) an underlying layer of typical riverbed sediment composed of sand, gravel, and cobbles with boulders and minor amounts of silt.

These two distinct layers have been differentiated in both the field sampling data and in analyses of the field data. The pavement layer is a lag deposit resulting from the erosive action of flowing river water which winnows out the fine-grained gravel sand, silt, and clay particles and leaves behind the larger particles which it lacks the energy to move. Pavement is common along the bars of the Dungeness River, but has not formed at all sample locations, as will be discussed further in Section 8.1.2. The pavement forms a protective layer which prevents further erosion of the underlying, finer-grained sediment until the sediment transport capacity becomes great enough to begin transport of the larger pavement layer particles. The underlying layer of sediment underneath the pavement layer represents the bulk of the sediment transported by the river and generally has not been substantially modified by erosion effects from moving water.

Bed material analysis also included a review of previous sediment sampling conducted on the Dungeness River by Orsborn and Ralph (1994). Orsborn and Ralph (1994) used the Wolman pebble count method to determine the sizes of sediment present in riffles in contrast to the test pit sampling performed for this study that identified the sizes of sediment present in gravel bars (see Section 4.5). A comparison of the two data sets was included in our study to evaluate the two methodologies and to build upon the earlier data set (see Section 8.1.3).

Kondolf and Wolman (1993) summarized previously published studies and presented particle size data of the sizes of spawning gravels relative to specific species of salmonid fish. Particle size data (D_{50}) measured in the gravel bar samples for both pavement and underlying layers were compared to the sizes of spawning gravels required for each species of salmonid fish. This analysis presents the suitability of the alluvium in the Dungeness River for use as spawning gravels by each specific species of salmonid fish (presented in Section 8.1.3).

5.4 Geomorphic Map

A geomorphic map of the lower 10.5 miles of the Dungeness River corridor was constructed using ortho-photographs developed from the 1:6,000-scale (1 inch = 500 feet) aerial photographs flown on March 30, 2000, output from the hydraulic model, stratigraphic descriptions, soil profiles, and radiocarbon dates (Section 4.8; Appendices I, J, and Q), and GIS[1] software. The map included several geomorphic units such as terraces, gravel bars (unvegetated and vegetated), delineation of side and overflow channels, and delineation of the existing and historic active channel and floodplain boundaries. Woody debris and man-made features were also mapped.

Geomorphic units were mapped on the aerial photographs using photogrammetry software that allows the photographs to be viewed in three-dimensions (stereoscopically) on a computer screen. This capability assisted in the delineation of features such as side channels that would otherwise be difficult to see. Because the photographs have been rectified using the locations and elevations of points that were surveyed on the ground (Section 4.3), the geomorphic units are correct in three dimensions relative to the ground and other plotted features, such as bridges, levees, and cross section locations (Section 4.2). The resulting map can also be displayed on historical aerial photographs that have been matched to the 2000

[1]GIS software utilized was Integraph's Image Analyst and Microstation

ortho-photographs to determine channel changes over time (Section 4.4). This capability also allows accurate measurement of channel changes such as lateral change in river banks due to erosion, which was accomplished in the vicinity of the Railroad Bridge (see Section 7.3.3).

On the digital version of the aerial photographs and in the field, surficial deposits along the river corridor were differentiated mainly on the basis of their surface characteristics and vegetation type and cover. Surface elevation, topographic position, underlying deposits, soil development, and radiocarbon dates also were used to differentiate units. In addition to surfaces or terraces adjacent to the river, the presently active main channel, side channels, and overflow channels were mapped, where visible. Because some side channels and overflow channels flow through tree-covered portions of the flood plain, they were sometimes difficult to see. Continuous, sinuous breaks in the tree canopy were interpreted as possible overflow channels or as possible continuations of side and overflow channels that are readily visible in less vegetated areas.

Using the location of the channels as a guide, the presently active flood plain (orange line) and possible prehistoric flood plain (yellow line) were delineated on the 2000 aerial photographs (Appendix O, Figures 26, 27, 28, 30, and 31 in main report). Areas within the presently active flood plain boundary include the active channel and areas likely to be inundated by high flows. The prehistoric flood plain represents the natural flood plain prior to human modifications to the river corridor such as levees. The geologic flood plain defines the present valley of the lower Dungeness River and dates back to the end of the late Pleistocene ice age, about 12,000 years ago (Porter and Swanson, 1998). The geologic flood plain (purple line) is much larger than the existing or prehistoric (natural) flood plain. The climate has significantly changed since the late Pleistocene, especially in the last 4,000 years which have shown a progressive trend toward drier conditions. This trend has resulted in rivers and flood plains throughout the western United States that are generally smaller in comparison to their geologic flood plains. Selected geomorphic units outside of the immediate flood plain were also included on the geomorphic map.

5.4.1 Man-made Features and Disturbances

In addition to the channels, surfaces, and flood plain boundaries, man-made features and disturbances (e.g., levees, riprap on banks, bridge embankments) were delineated, where visible. As with the natural features, human activities are most apparent in less vegetated areas of the flood plain. Those concealed under the tree canopy could not be mapped directly from the aerial photographs. Some of these were added on the basis of field observations. Areas where the boundary of the present flood plain is defined by man-made features rather than natural topography were also delineated (Appendix O).

5.4.2 Woody Debris Analysis

The excellent resolution of the 2000 ortho-photographs and the GIS software allows both enlargement and stereographic viewing of the images. Consequently, woody debris deposited in the unvegetated active channel can be easily mapped (Appendix O). Even relatively small pieces of wood are readily visible and have been delineated along the study reach. In areas where debris is prevalent, the debris has been grouped because of the scale of the map; however, individual piles of debris are readily distinguishable, and debris of different ages within a single pile can be discerned by color, position of wood, deposition of sediment, and amount of vegetation.

5.4.3 Geomorphic Mapping on Historical Aerial Photographs

Two sets of older aerial photographs (1942/43 and 1965) were matched to the 2000 ortho-photographs for the study reach, with the exception of the upstream portion of Reach 5 (RM 9 to 10), where the 1942/43 photographs were not available (Sections 4.3 and 4.4; Appendix O). Because the older photographs lack vertical control points, they can be compared to the 2000 ortho-photographs in plan view only. Using GIS software, geomorphic maps of the Dungeness River corridor were made based on the 1942/43 photographs, the oldest set acquired, and in 1965, soon after several of the largest man-made features were built along the flood plain. These maps have less detail than the map derived from the 2000 photographs, partly because of the absence of stereographic capabilities and partly because of the poorer resolution of the photographs, especially the 1942/43 set which were fairly high in elevation.

Woody debris was delineated on the 1965 photographs. The quality and high elevation of the photographs taken in 1942/43 did not allow for detailed mapping of woody debris, although some large logs are visible. In addition, extensive logging of the flood plain was noted on a 1913/14 map of the Dungeness River and can be seen in several locations on the 1942/43 photographs. The presence of logging would make interpretation of woody debris in the 1942/43 channel difficult.

Two additional sets of aerial photographs were matched to the 2000 ortho-photographs for a section of the Dungeness River near the Railroad Bridge (RM 5.5) (Appendix O). This section was prioritized for evaluation of channel change because it has been a very dynamic section of river. On these two sets of aerial photographs, taken in 1994 and 1996, the active channel, including the low-flow channel and gravel bars, were delineated for the area covered. In some areas, side channels, overflow channels, and low terraces were also mapped.

6.0 UPPER WATERSHED

This study focused on morphology and physical processes in the lower 10.5 mi of the river system. Activities within the upper watershed were limited to reconnaissance-level examination of the Dungeness River and its major tributaries. The focus of our work in the upper watershed was to identify sources of sediment and the processes that deliver the sediment to the river and its tributary streams. Due to constraints of time and budget, the scope of our work in the upper watershed was limited to review of existing technical literature describing the area and to field observation of geomorphic features and natural processes. Data collection in the upper watershed was limited to sediment sampling conducted in support of the Jamestown S'Klallam Tribe's ongoing study of riverbed scour impacts to spawning habitat (see Piety and Link, 2000, attached) and will not be discussed further in this chapter.

The importance of the upper watershed for our study lies in its linkage to the lower Dungeness River as the primary source of runoff (occurring from both rainfall and snowmelt) and of sediment carried in the river system. Our evaluation of physical processes operating in the upper watershed is based on a review of technical literature describing the area and reconnaissance by ground and air of areas within the watershed:

The upper watershed is located in very steep terrain and large portions of the Dungeness River are not accessible from the ground. Our ground reconnaissance accessed as much of the river system as was possible using available Forest Service and logging roads supplemented by existing trails and occasional cross-country bushwhacking, when required. The following discussion summarizes our observations on the morphology and inferred physical processes active in the upper watershed and the supply of sediment delivered to the Dungeness River. These observations are subsequently presented as a conceptual model of the upper watershed, based on a series of working hypotheses developed from our field observations. Additional detailed study of the upper watershed is needed to test the validity of our working hypotheses and conceptual model, as will be discussed in the final section of this chapter.

6.1 Sources of Sediment

Our reconnaissance of the upper watershed identified four general sources of sediment supplied to the Dungeness River. A fifth sediment source has been added as a result of our literature review of available technical reports on the watershed. For the purpose of our study, it is the coarse sediment (i.e., sand, gravel, cobbles, and boulders) carried by the river that is most significant in effecting the pattern of the river channel and the rate of channel migration in the lower Dungeness River. Fine sediment (i.e., silt and clay) is carried rapidly through the system as wash load and appears to have little effect on the river channel geomorphology. The fine sediment can, however, have significant affect on anadromous fish species due to increased turbidity levels during storm events, etc., which do not relate directly to river channel plan form. The sediment sources identified in our reconnaissance are:

- steep alpine slopes above timberline
- forested slopes
- logged slopes

- river terraces and bar deposits
- active glaciers

6.1.1 Steep Alpine Slopes above Timberline

During our helicopter reconnaissance (Photographs 4 and 5 – Photographic Overview), widespread sediment deposits were observed above the timberline in the upper portions of the Gray Wolf River drainage and to a lesser extent in the upper watershed of the main stem of the Dungeness. These deposits generally occur as aprons of coalescing talus cones forming along the base of the rugged mountain peaks. These sediment cones are often steep and unstable, as evidenced by small surface slides and rock avalanches. Kohler (1989) reported mapping hundreds of rock slope failures in the high alpine reaches of the watershed, including rock fall, rock topple, rock glide, and rock avalanches, in his preliminary assessment of erosion, slope movement, and sedimentation processes of the Dungeness watershed. He noted that the failures appeared to be controlled by structural features within the bedrock outcrops, such as bedding planes, joints, and faults. Freeze-thaw effects at these high altitudes contribute significantly to mechanical weathering of rock outcrops and associated sediment piles. Sediment deposits occurring at these high-elevations are likely buried by snow during the winter flood season and are subsequently transported downstream through a series of channels during the spring snowmelt. Numerous steep avalanche chutes and bedrock ravines were observed in our helicopter reconnaissance that can convey sediments from the steep alpine deposits through the adjacent forested slopes directly to the river channel downstream. Although significant volumes of material are stored in the steep alpine slopes, the amount of sediment available for transport and the processes by which the sediment is delivered to the river and its tributaries are poorly understood at present and need further study. The coarse sediment may tend to remain in storage in the alpine slopes and is not readily transferred to the river system until localized events, such as landslides, rock falls, or avalanches can move the material directly into the stream channels.

Golder Associates (1993) also considered bare rock slopes at high elevations to be a potential source of sediment in their qualitative assessment of sediment yield within the Dungeness watershed. They estimated that these slopes comprised about 15 percent of the basin’s surface area. They cited a lack of published sediment yield data for bare alpine slopes that could be applied to the Dungeness watershed and assigned a yield of 2,623 tons per year to this sediment source.

6.1.2 Forested Slopes

Another source of the sediment delivered to the Dungeness River is the forested slopes which dominate the upper watershed (Photo 3 – Photographic Overview). Golder Associates (1993) estimated that undisturbed forested slopes and well-established second growth forests greater than 10 years old comprised nearly 81 percent of the watershed area. Runoff of rainfall and snowmelt within the forested slopes cause surface erosion of sediment which is then transported downslope into the Dungeness River and its tributary streams. Rainfall runoff primarily occurs at low to moderate elevations during the winter flood season with snow accumulating at the higher elevations. Runoff due to snowmelt occurs later in the year in response to warming temperatures in the spring and early summer. Landslides are part of the natural processes in the upper watershed and also contribute to the sediment load in the Dungeness River, but are generally few in number and extent. The effects of landslides are discussed in a separate section which follows. Citing published sediment yields from the Oregon Cascades and within the Olympic Peninsula, Golder Associates estimated the sediment yield from undisturbed forest at 28,000 tons per year for the Dungeness watershed.

The amount of sediment produced from the forested slopes has not been constant, but has varied over geologic time. Due to rain shadow effects of the Olympic Mountains, which restrict the amount of precipitation compared to that in other basins on the peninsula, the watershed is subject to large, intense, stand-replacing wildfires that have repeatedly swept across the upper basin over the past several hundred years. Old-growth forests surviving these intense fires have been generally restricted to higher elevations within the watershed and along riparian corridors. Present data (Dungeness Area Watershed Cooperative Team, 1995) indicate that the large, stand-replacing fires occur on approximate 200-year intervals with the last series of fires taking place in A.D. 1308, 1508, and 1701 within the Dungeness watershed. In addition, a large, man-caused fire occurred in 1890-1891 which started near the Sequim Prairie and burned much of the timber in the lower reaches of the upper watershed. Other man-caused fires were reported in the watershed in 1860, 1880, 1896, 1902, 1917, and 1925 (Dungeness Area Watershed Cooperative Team, 1995), but these fires tended to be more localized in extent (Dave Peters, personal communication, 1999) and would not have had the same effect on the river system as the larger, stand-replacing fires. The 200-year time interval between the stand-replacing fires is generally long enough to permit the regrowth of a replacement forest stand and allows for accumulation of both ground and ladder fuels within the forest. These repeated stand-replacing wildfires probably increased runoff from burned forest lands, resulting in higher sediment loads in the Dungeness River. The sediment load in the river also probably increased due to increased surface erosion in the burned areas and higher incidents of landslides in the steep terrain present in the upper watershed.

The response of the lower river to the effects of increased sediment load in the Dungeness River would have been an increased rate of riverbed aggradation leading to more frequent channel changes, as the river moved down progressively flatter gradients to the mouth of the river at the Strait of Juan de Fuca. Regrowth of the replacement forest stand over time would have led to decreased sediment loads in the Dungeness River, as the river returned to normal conditions. Continuing decline in sediment loads could have led to incision of the aggraded river channel through the previously deposited post-fire sediments and to the formation of river terraces along the incising stream channel. This sediment cycle would continue about 200 years later with the next stand-replacing wildfire, resulting in a repeating sequence of fire, channel aggradation, forest regrowth, and channel incision. Under this scenario, sediment loads supplied to the Dungeness would occur as a base level of sediment supply with episodic pulses of higher sediment loads, as the forest repeatedly burned off and then replacement stands gradually grew back.

6.1.3 Logged Slopes

Dungeness River sediment is also derived from logged slopes in the upper watershed. Logging has occurred largely within the watershed of the main stem Dungeness and its eastern tributary streams, such as Gold, Silver, and Copper creeks. The Gray Wolf River lies largely within the Buckhorn Wilderness and Olympic National Park and logging activities have been concentrated in the lower reaches near the confluence with the Dungeness or are old enough that regrowth of the forest is well underway. Logged areas tend to absorb less precipitation than do forested slopes, resulting in increased rates of runoff following logging operations (MacDonald, et al., 1991). The logged areas tend to increase the volume and peak discharge of rainfall runoff and also increase the peak of snowmelt runoff (MacDonald, et al., 1991). The increase in volume and discharge of runoff events may lead to increased sediment production, as the streams can access larger volumes of sediment and larger sediment particle sizes under these conditions. The stability of slopes in logged areas can also be adversely effected as the root systems of the logged forest decay over time, leading to a loss of slope stability as the root structure supporting the soil is removed from steep slopes (Logan, et al., 1991). This loss of supporting root structure can lead to increased levels of landslide activity following logging operations, depending on local soil conditions, slope angle, the frequency and intensity of precipitation events, the rate of forest regrowth, and other factors. Effects from landslides are discussed further in the following section of this report.

Logging roads can also increase sediment production. Road surfaces tend to rapidly shed runoff rather than absorb moisture into the road base, and unpaved surfaces are susceptible to erosion. Additionally, runoff tends to be concentrated at culvert crossings and forced into undersized drainages, leading to erosion of adjacent channel slopes. Failures of natural slopes and road embankments may result where slopes have been oversteepened by erosion, such as occurred at numerous locations within the watershed during the 1998-1999 winter season (Photo 15 – Photographic Overview).

The impacts from logging and road building are difficult to quantify. The increased sediment loads from these activities may not be large relative to the natural sediment supply, but detailed study of the watershed is lacking to provide any quantitative analysis. Golder Associates (1993) considered logged forest slopes to be one source of the sediment derived from the upper watershed. They estimated that clear-cut areas and forest regrowth less than 10 years old composed less than 4 percent of the surface area of the Dungeness watershed. Most of this logging had been concentrated in the eastern portion of the watershed near Gold and Silver creeks. Golder Associates estimated that the sediment yield from recent clear-cut areas within the Dungeness watershed is about 4,985 tons per year, based on published data from the Oregon Cascades and elsewhere within the Olympic Peninsula. Our limited reconnaissance of the upper watershed did not provide any additional data with which we could evaluate the estimate by Golder Associates.

6.1.4 River Terraces and Bar Deposits

The Dungeness River is also able to access sediment through erosion of older alluvial deposits within and adjacent to the existing channel, including gravel bars, river banks, and older river terraces (Photo 10 – Photographic Overview). Sediment is temporarily stored as bars in various reaches of the river channel throughout the upstream watershed and these bars can be accessed as sources of sediment during periods of high runoff. Many of the bar deposits within the upper watershed appear to be related to bedrock constrictions in the river channel profile and likely result from a loss of transport capacity due to backwater and eddy effects upstream of the constrictions. The bar sediment likely moves downstream through the constrictions in response to high river flows during large floods. Remobilization of the channel deposits is likely a significant source of sediment for the Dungeness River, but additional study is required to evaluate the volume of material produced by this process.

The Dungeness River has downcut its channel at various times over at least the last 500 years. We observed at least three terraces above the present channel of the main stem Dungeness at the East Crossing Campground. We consistently noted at least two terraces bordering both the Dungeness and the Gray Wolf Rivers at many locations in the upper watershed. Cursory examination of recently-cut tree stumps on many of the higher terraces along the Dungeness River frequently indicated tree ring ages in excess of 250 years. Erosion of these older terrace deposits during periods of incision and lateral channel migration could locally access significant volumes of material, although we did not observe this process in the field. Golder Associates (1993) did not consider erosion of older alluvial deposits in their qualitative analysis of sediment yield in the upper watershed. We suspect that significant volumes of alluvium could be accessed by the river under the right set of circumstances, but additional detailed study of the watershed processes would be required to evaluate the contribution of sediment from the older alluvial deposits.

6.1.5 Active Glaciers

Golder Associates (1993) considered active glaciers present within the upper watershed to be a significant source of sediment for the Dungeness River. We did not initially consider active glaciers as a sediment source for the Dungeness due to the very limited extent of glaciers within the watershed, but have included this sediment source here for completeness, based on the Golder Associates analysis. Six alpine glaciers were reported within the Dungeness watershed by the Dungeness Area Watershed Analysis Cooperative Team (1995):

- Deception and Surprise glaciers on Royal Creek
- High Moraine, Needles and Walkinshaw glaciers on the Gray Wolf River
- Cameron Glacier on Cameron Creek

Golder Associates estimated that active glaciers accounted for less than 1 percent of the surface area of the Dungeness watershed. They used sediment yield data reported for the Emmons and Nisqually glaciers on Mt. Rainier to estimate a yield of 20,000 tons per year for the Dungeness River. This source accounted for about 36 percent of the watershed's sediment yield in the Golder Associates analysis and only sediment derived from undisturbed forests exceed this yield in their analysis. Based on field observations made during our reconnaissance of the upper watershed, we suspect that the role of glaciers as a sediment source for the Dungeness River is probably overestimated in the Golder Associates analysis. The cirque basins and moraines present in the upper watershed would tend to trap coarse sediment generated by the glaciers and prevent it from moving downslope to the river. The glaciers present in the upper watershed of the Dungeness are significantly smaller both in volume and extent than those present on Mt. Rainier and probably produce significantly smaller volumes of sediment, although we have collected no data to verify this observation. Further, glacier-fed rivers, such as the White River at Mt. Rainier and the Hoh River, which drains Mt. Olympus to the west of our study area, typically have significant levels of background turbidity due to high concentrations of glacially derived rock flour which is transported in the rivers as suspended load. The background level of turbidity on the Dungeness River is significantly lower than that on either the White or Hoh rivers and the Dungeness is relatively clear much of the year, except during and after storm events which tend to elevate turbidity levels. These observations suggest that glaciers play a significantly smaller role in the supply of sediment to the Dungeness River than estimated by Golder Associates. Further study of the upper watershed processes is needed to better quantify the sediment yield from the glaciers.

6.2 Landslide Activity

The upstream watershed of the Dungeness River was examined on a reconnaissance level to evaluate the role of landslides and other mass wasting processes as sources of sediment for the Dungeness River and its tributary streams (Photos 6A and B – Photographic Overview). This evaluation included:

- field observations made at the Gold Creek landslide in 1997
- a reconnaissance of the main Dungeness watershed by vehicle and of the lower 4.4 mi of the Gray Wolf River on foot in 1998
- a helicopter reconnaissance of the entire watershed in 1998
- a preliminary geologic interpretation of 1990 high-altitude aerial photographs in 1998
- examination of several U.S. Forest Service road failures in 1999
- field observations made at the Silver Creek landslide in 2000

A more detailed analysis of upper watershed processes, including sediment sources and transport, has been proposed by the U.S. Geological Survey (USGS, 1998). This analysis would also address the contribution of landslides and related features in greater detail.

We identified two primary source materials in which there are landslides in the upper watershed: (1) glacial deposits from the Cordilleran ice sheet and associated glaciolacustrine sediments and (2) a variably deformed sequence of marine basaltic lava flows and sedimentary rocks composed largely of sandstone, siltstone, slate, and argillite (Cady and others, 1972; Tabor and Cady, 1978). Each of these source materials and the landslides associated with them are discussed in the following paragraphs.

A continental ice sheet advanced southwards out of British Columbia beginning about 18,000 years ago (Easterbrook, 1986). This ice sheet moved south into the Puget Sound until it intercepted the Olympic Mountains and split into two distinct lobes: one moving south into the lower Puget Sound and the other moving west along the Strait of Juan de Fuca. The Juan de Fuca lobe continued west until reaching the continental shelf on the western coast of Washington State and British Columbia. The ice sheet had reached its maximum extent by about 17,000 years ago (Porter and Swanson, 1998). The Juan de Fuca lobe advanced southwards up into the Dungeness watershed to an approximate elevation of 3200 ft on both the main stem Dungeness and the Gray Wolf rivers (Cady et al., 1972). The glacial ice dammed the river system and formed a series of lakes along the ice margin. Relatively thick sequences of fine sand, silt and clay were deposited in these glacial lakes and larger gravel, cobbles and boulders were rafted into the lakes by icebergs and were later dropped into the lake sediments as the icebergs melted. Retreat of the Juan de Fuca lobe from its terminal position on the west coast had begun by 15,000 years ago (Heusser, 1973) and the Dungeness area was probably free of ice by 12,000 years ago, based on the radiocarbon date of a peat layer at the Manis mastodon site south of Sequim (Petersen et al., 1982). Erosion by the Dungeness River following retreat of the ice sheet eroded much of the glacial and lacustrine sediments, but extensive glacial deposits remain in the lower main stem of the Dungeness, the Gray Wolf and the Gold Creek drainages (Cady et al., 1972; Tabor et al., 1972; and Tabor and Cady, 1978). Erosional remnants of the fine-grained lacustrine sediment are nested along the slopes throughout the upper watershed and are particularly prominent near Silver and Copper creeks and on the Gray Wolf River.

A strong correlation appears to exist between the landslides and the glacial and lacustrine sediment in the Dungeness watershed described above. The landslides in the glacial and lacustrine deposits typically occur where steep slopes have been undercut and oversteepened by migrating river channels. These predominantly fine-grained glacial sediments are inherently unstable in steep slopes and landsliding has probably been an important natural process within the upper watershed since the retreat of the glacier. Large, inactive landslides were noted within these glacial deposits and several smaller, active slides masses were observed nested within the inactive landslides at both Gold Creek and on the Gray Wolf River. Golder Associates (1993) investigated the 1990 reactivation of the 1968 Gold Creek landslides and attributed the cause of the failures to a resistant layer of bedrock in the bottom of the channel which limited downcutting by the stream and forced lateral migration of the stream bed. Lateral erosion of the stream banks resulted in oversteepened slopes. A series of three perched water tables was noted within the glacial sediments which caused saturation of the glacial sediments and resulted in a loss of in-place strength, leading to slope instability. Landslides and debris flows were also observed within the isolated erosional remnants of lacustrine sediments at several locations on the main stem of the Dungeness River and along Silver and Copper creeks. This sediment currently rests at high angles and landsliding has been initiated where the slopes have been undercut by stream erosion or logging roads. The 1972 Silver Creek landslide occurred within these sediments and temporarily dammed the main stem of the Dungeness River (Freudenthal, personal communication, 2000).

Logging and construction of access roads are contributing factors to slope failures. The effects of logging and logging roads on runoff have been discussed in the previous section on logged alpine slopes. In addition, logging activities have tended to concentrate on areas underlain by the glacial and lacustrine sediments due to the generally flatter topography associated with these materials and the relative ease of road building compared to bedrock slopes. Above normal precipitation and heavy spring runoff triggered a number of landslides within the upper watershed during the spring of 1999. Our examination of accessible landslides on the main stem of the Dungeness River between the East Crossing Campground and the confluence with the Gray Wolf River showed that Cordilleran ice sheet glacial sediments were involved at each failure, although we were able to visit only a small number of the landslides. The majority of the failures we examined were located at culvert crossings. A significant factor in the failures was the concentration of runoff from several adjacent drainages into undersized channels by culverts crossing under the road surface. Runoff exceeded the natural flow levels of the drainages and substantial erosion of the channel slopes ensued, leading to numerous slope and road embankment failures. Some of the culverts also appeared to be undersized in comparison to the actual flows that developed during the runoff season.

Much of the upper Dungeness watershed consists of bedrock outcrops that have limited soil and/or colluvium development. These bedrock slopes are generally not prone to landsliding even in steep terrain. Kohler (1989) reported numerous other types of mass wasting features such as rock fall, rock topple and rock glide present in the high alpine slopes above the timberline. These failures appeared to be related to structural features present within the bedrock units, including bedding planes, joints and faults. Kohler noted that rock avalanche chutes occur below areas of rock slope failures and commonly terminate in alluvial fans on the valley floors. We observed scattered minor shallow, surface debris flows on very steep bedrock slopes where thin soil horizons, colluvium and regolith have been undercut by stream channels. These features are relatively shallow and typically involve small volumes of sediment. Scars left by these debris flows are susceptible to chronic long-term surface erosion by runoff, as these detachment surfaces are often too steep to permit rapid regrowth of vegetation after the failure event.

Our reconnaissance of the upper watershed indicates that landslides are present along the Dungeness River and its tributary streams, but that these slides are generally limited in extent and relatively few in number. Our evaluation suggests that landslides are not a major source of coarse sediment for the river system, as they occur predominantly in fine-grained glacial and lacustrine deposits. Although the introduction of fine sediment can increase the river's turbidity, generally only the supply rate of coarse sediment can affect the channel's planform. Therefore, coarse sediment sources from landslides in the watershed are not significant relative to the total coarse sediment load naturally entering the river system. Fine sediment (i.e., fine sand, silt and clay) is present only in very small concentrations in the channel alluvium and bar deposits of the lower river, as shown in our sediment sampling investigation, and are probably carried rapidly through the system as suspended load. These fine-grained sediments would likely have little effect on the geometry, alignment and channel stability of the Dungeness River in our study area in the lower 10.5 mi of the river. However, the fine-grained sediments can have significant impacts to salmonid species present in the Dungeness due to chronic increased turbidity levels which could affect the viability of spawning gravels and the survival of juvenile fish.

6.3 Conceptual Model

A conceptual model was developed for the Dungeness River based on our reconnaissance of the upper watershed. This model summarizes the observations presented in the preceding discussions and can serve as a framework for continuing future investigation of the watershed. As with any model, additional data collection will be required to test the validity of the hypotheses presented in the model. Future study can add data to the conceptual model over time and could eventually lead to the development of a predictive model. Further, the conceptual model can help to direct the focus of future research and investigations.

Based on our limited evaluation of the upper watershed and its processes, sources of coarse sediment (sand, gravel and cobbles) entering the Dungeness River system are the steep, alpine slopes above timberline, the remobilization of channel deposits and erosion of river banks and terraces, the slopes affected by surface-runoff erosion, and landslides. Sediment that is supplied from the upstream watershed can be classified by its location within the watershed:

1. **Steep alpine slopes above timberline.** Large and numerous sediment deposits (talus) were observed above timberline in the upper portions of the Grey Wolf River drainage and to a lesser extent in the Dungeness River drainage. These deposits were generally conical in shape, steep and unstable as evidenced by small surface slides. These high-elevation deposits are likely covered by snow during the winter flood season and transported downstream through a network of channels during the spring snowmelt. Numerous chutes exist through the steep forested slopes that can convey sediments directly to the river channel below.

2. **Forested slopes.** Sediment is eroded from the forested slopes by surface erosion during runoff. During the winter flood season, rainfall runoff primarily occurs at low to moderate elevations. Landslides are part of the natural processes in the upper watershed, but are relatively few in number and extent within the forested slopes. The rate of sediment supply from the forested slopes has likely varied over time due to the effects of large, intense, stand-replacement wildfires have swept across the watershed on approximate 200-year intervals. These fires result is a repeating cycle of fire, episodic sediment pulses, and channel aggradation followed by channel incision as the forest grows back and the sediment load decreases.

3. **Logged slopes.** Logging and road building have occurred in approximately 12 percent of the drainage area (Cynthia Barton, USGS District Chief, written communication, December 16, 1998). Logging would be expected to decrease rainfall interception, and therefore increase rainfall runoff (MacDonald, et al.,1991). However, no increase in runoff during periods of logging was detected by analysis of USGS stream-gaging records (England, 1999). Some landslides have been documented in logged areas (Golder and Associates, 1993), but the landslide volumes are estimated to be small relative to the annual sediment loads transported by the Dungeness River. The largest impact from logging on the watershed stems from road building which causes local erosion along the hillsides. Fine sediments contributed from logging road failures potentially affect fish habitat by increasing turbidity and depositing fine gravel, sand, and silt in wooded side channels where velocities are slower.

4. **River terraces and bar deposits.** Within the upper watershed, the Dungeness River has been downcutting over the last 500 years or so. Channel incision and lateral erosion has resulted in formation of river terraces and up to three terraces have been observed along the Dungeness in the upper watershed. Sediment is stored within gravel bars that tend to form upstream of river channel constrictions as a result of backwater and eddy effects. Transport of the material through the constrictions occurs during large floods. Remobilization of channel deposits and erosion of river banks and terraces probably represent a significant source of the sediment present in the Dungeness River.

5. **Active glaciers**. Glaciers can supply significant volumes of sediment to river systems, as has been documented for Mt. Rainier. However, only six active glaciers are present

in the Dungeness watershed and the areal extent of these glaciers comprises less than one percent of the total surface area of the entire watershed (Golder Associates, 1993). The sediment yield from the glaciers is likely small, but further investigation of the upper watershed processes is needed to confirm this hypothesis.

6.4 Conclusions and Recommendations

Our evaluation of the natural processes acting in the upper watershed of the Dungeness River is based on a review of existing literature and a reconnaissance-level examination of the more accessible portions of the watershed. We have identified five potential sources of coarse sediment in the Dungeness River drainage basin. These sources are the steep alpine slopes above timberline, the channel deposits and terraces (banks) that can be remobilized by the river, the forested and logged slopes that are eroded by rainfall runoff and snowmelt landslides, and glaciers. The rate at which sediment is contributed by glaciers is likely too slow to produce significant volumes of sediment to the Dungeness River.

Any evaluation of the upper watershed processes suffers from a lack of data. There is a definite need for a detailed analysis of the natural processes at work in the upper watershed to determine sediment input into the Dungeness River. This analysis should address those processes contributing to the river's sediment load and develop a sediment budget for the river system. Any analysis of the upper watershed should address the linkage of the natural processes and sediment load to the lower 10.5 mi of the river evaluated in our study. This linkage would enable an assessment of the natural processes and human-caused impacts active throughout the entire reach of the Dungeness River from its headwaters in the Olympic Mountains to its mouth at the Strait of Juan de Fuca. The detailed analysis of upper watershed processes, including sediment sources and transport, proposed by the U.S. Geological Survey would address this critical data gap of the Dungeness River processes. Efforts to acquire funding for the U.S. Geological Survey's study should continue.

7.0 LOWER DUNGENESS RIVER REACH ANALYSIS: RESULTS AND DISCUSSION

This section provides the results and discussion for the hydraulics, sediment, and geomorphic analyses completed for the lower Dungeness River study. Section 7.1 discusses how the lower Dungeness River was subdivided into five reaches for analysis and comparison purposes. Section 7.2 discusses overall trends for the 10.5 mi study reach, and Section 7.3 provides a more detailed analysis with issues specific to each of the five reaches.

7.1 Lower Dungeness River Reach Subdivisions

The Dungeness River has distinct physical characteristics that vary throughout the lower 10.5 mi. The surficial geomorphic map developed for this study was used to characterize the lower Dungeness River corridor, which was then subdivided into five reaches based on differences in physical characteristics (Table 4, see Figures 3A and 3B for reach boundaries on map).

Table 4. Reach subdivisions in lower 10.5 mi.

Reach	River Miles	Major Landmarks
1	RM 0 to 2.6	ACOE and Olympic Game Farm Levees, and Schoolhouse Bridge
2	RM 2.6 to 4.6	Burlingame and Woodcock Bridges
3	RM 4.6 to 7.0	Highway 101 and Railroad Bridges
4	RM 7.0 to 9.0	Dungeness Meadows Subdivision and Levee
5	RM 9.0 to 10.5	Kinkade Island and Fish Hatchery

The reach boundaries are based on a combination of several characteristics that were qualitatively assessed on the geomorphic map, in the field, and on aerial photographs. These characteristics include:

(1) Active channel pattern

(2) Number, location, and pattern of side and overflow channels

(3) Definition of banks that define the flood plain and the estimated ages of the surfaces above these banks

(4) Sizes of sediment transported through the reach and the sizes that are being stored in gravel bars

(5) Estimated gradient of the river

(6) Widths of the active channel and present flood plain

(7) Number, location, and pattern of unvegetated bars (those that are frequently modified by flows)

(8) Number, location, and pattern of vegetated bars and low terraces (those that are infrequently modified by flows) and an estimate of the number of vegetated bars of different ages

(9) Amount, location, and pattern of large woody debris

(10) Type, location, and extent of man-made features and activities

Because of the qualitative nature of the defining characteristics and because of the transitional nature of the changes in the characteristics, the boundaries between the reaches are approximate, and often are gradational. In addition, because it is difficult to see the ground in areas of dense trees and other vegetation, the characteristics in the wooded flood plain are more poorly defined than in the active channel. For example, side and overflow channels along with woody debris in those channels that flow through densely forested portions of the flood plain are difficult to map from the aerial photographs.

7.2 Active Channel and Flood Plain Characteristics

7.2.1 Sinuosity

In addition to cross section and profile data, the planform of the channel is an important component in evaluating natural processes over time and how those processes may have been altered. Sinuosity is a measure of the curvature of a river, computed by the ratio of river length to valley length. For the purpose of characterizing the channel in relation to the bankfull discharge, sinuosity was measured for the entire active channel. The low flow channel(s) sinuosity could also be evaluated for future studies and would be useful for characterization of fish habitat parameters. For the measured active channel sinuosity, a sinuosity of 2 would be high, indicating the river length is twice as much as the valley length. A sinuosity of 1 means the river channel is straight relative to the valley. The valley slope and alignment is defined by its geologic boundaries.

A historical comparison between 1942/43, 1965, and 2000 of active channel sinuosity by reach is provided in Figure 14 (data presented in Table O-2, Appendix O). Reach 5 does not have historical sinuosities presented because the historical aerial photographs were not matched to the 2000 aerial photographs (see Section 4.4). Overall, the lower Dungeness River has low sinuosity ratios ranging between 1.3 at the upstream end to near 1 at the downstream end of the study reach. The sinuosity is greatest in the upstream portions of the lower Dungeness River because the valley slope is steep and the river must meander to reduce the channel slope to a stable condition. The sinuosity generally decreases in the downstream direction because as the valley slope flattens in the downstream direction, the river maintains sediment transport capacity by maintaining a straighter channel and, therefore, a steep slope. The river tends to adjust its sinuosity so that the longitudinal slope is relatively constant.

The active channel sinuosity has changed most significantly in Reach 4, where the Dungeness Meadows Levee has cut off historical active channel and flood plain (RM 7 to 9). The river is now forced to run straight where historically meandering channels existed resulting in a higher sinuosity ratio. Reach 1 has also been impacted by levees on either side of the river. However, the levees were constructed along the existing curvature of the river. Therefore, while the levees have had other significant impacts on this reach that will be discussed later, the sinuosity has not changed since 1942/43 because the planform was essentially locked in place.

For each cross section, a comparison of the existing flood plain boundaries relative to natural flood plain boundaries was defined based on the geomorphic and hydraulic analyses (Figure 15). The flood plain is defined as the area adjacent to the river channel that becomes inundated by water due to overtopping of the river banks during a high flow. The flood plain boundary is defined as the extent of the flooding on either side of the river. Existing flood plain boundaries may be different than natural boundaries as a result of man-made structures physically blocking access to the flood plain, such as levees and bridges. The specific reasons for deviations between natural and existing flood plain boundaries will be discussed in more detail in the reach analysis (Section 7.3). It is important to note that based on the magnitude of flood plain widths in Figure 15, there is not one constant flood plain width that occurs naturally in the lower 10.5 mi. Instead, the flood plain naturally varies as a result of changing topography and geologic controls on the river corridor.

Measurements were made by reach to quantify the magnitude of human impacts along the active channel banks of the lower Dungeness River (Figure 16; data in Table O-6, Appendix O). Reach 1 was subdivided to show the human impacts both upstream and downstream of Schoolhouse Bridge. Human impacts considered were levees, bridges, roads, and bank protection. By far the most impacted reach is Reach 1 (RM 0 to 2.7) where levees have been placed on both sides of the river. Reach 4 has also been heavily impacted by levees on both sides of the river and bank protection. Reaches 2 and 3 have been less impacted but do contain bridge embankments and roads. Reach 5 has a small amount of levees and bank protection along the river banks.

7.2.2 River Hydraulics

River hydraulics are presented as computed by the hydraulic model for the 2-year flood (2,990 cfs), which is nearly equivalent to the effective discharge at the Highway 101 Bridge (USGS gage site). The effective discharge is the flow that does the most work in the channel over time and shapes its morphological characteristics (Wolman and Miller, 1960). A plot of the modeled water surface elevations shows a fairly steep profile from RM 10.5 to 5.4 with an average water surface elevation slope of 1.2 percent (Figure 17). Between RM 4.5 and RM 3.5, there is a transition zone where the average slope is still fairly steep, but flattens slightly to 0.9 percent. The river slope is the flattest near the Strait of Juan de Fuca, where the average slope is 0.05 percent and a large delta exists. In many areas along the lower Dungeness River, multiple low flow channels are present and as a result, a variety of water surface elevations can exist. As the model results show, at the 2-year flood and higher, the water surface is fairly uniform. This is because the active channel fills in with water from the left bank to the right bank, and the low flow channels combine to form one large active channel. The model output also shows that at the 2-year flood, backwater effects exist at some of the bridges, but due to the steep slope of the Dungeness River these effects do not extend very far upstream.

Initial draft results from the USGS groundwater study for seepage runs, in-stream mini-piezometers, and off-stream well transects indicate that the river generally loses water to the groundwater in Reaches 3, 4 and 5 (F. William Simonds, verbal communication). In Reach 2 where the transition in slope occurs, there are interspersed losing and gaining reaches. In the portion of Reach 1 from the upstream end of the levees to Schoolhouse Bridge, the river generally loses water to groundwater except for in the vicinity of Schoolhouse Bridge itself.

Hydraulic results of water velocity, maximum and mean depths, and width-depth ratio by river mile for the 2-year flood in the active channel are plotted by reach in Figures 18, 19 and 20, respectively. Each of the five bridges are denoted in the plots by square symbols. At a 2-year flood, velocities range from 2 to10 ft/s, except for at the mouth of the river where velocities are typically low due to backwater effects from Dungeness Bay (Figure 18). Reach 1 has by far the most variation in velocity, fluctuating between 4 and 10 ft/s, excluding the cross section at the mouth. Velocities in this reach fluctuate largely because of the variation in the amount of channel constrictions caused by the levees. For example, at cross sections 2, 5, 7, 11, and 13 the levees combined with natural geologic controls on the river constrict the width of the active river channel to between 90 and 135 ft (see cross section plots in Appendix H). This causes velocities to be higher than other areas in Reach 1 that are not as constricted and have larger wetted widths. Upstream of these sections, velocities are lower due to a backwater effect caused by the constrictions. This backwater effect has resulted in deposition along the channel bed which will be discussed further in Section 7.3.5. At cross section 15SC (cross section at a scour chain location), the velocity is high due to a natural high bank on either side of the river that confines the 2-year flood.

Mean depths do not fluctuate much throughout the lower 10.5 mi, averaging around 2.5 ft, but maximum depths vary quite a bit (Figure 19). Maximum depths during a 2-year flood range from 2.5 ft in Reach 4, a wide section, to 13.5 ft in a more constricted area at RM 2.1. The largest maximum depths occur in Reach 1, where as discussed above, levees constrict the channel, and river stage increases much more rapidly than wetted width with an increase in flow. The width-depth ratio can sometimes be used as an indicator of sediment transport capacity (Figure 20). A high width-depth ratio represents a cross section with large widths and shallow depths, thus low sediment transport capacity. A low width-depth ratio represents a cross section with narrow widths and large depths which result in high velocities and high sediment transport capacity. Reach 1 (ACOE and Olympic Game Farm Levees) by far has the lowest width-depth ratios with the exception of at the mouth and one area where the ACOE Levee is setback far enough away from the channel that a flood plain exists. Reach 3 has the highest width-depth ratios at two cross sections that have wide active channels.

Water travel time is defined as the average amount of time it takes a particle of water to move along the river channel. Wash load (silt and clay) is transported at near the same velocity as water and can be assumed to have approximately the same travel time during a flood. Bedload, however, is transported at slower rates and the travel time for a given particle varies depending not only on the magnitude of flow but also on the size of the particle and its location within the active channel. Computed water travel times decrease with an increase in flow and velocity. On the lower Dungeness River, computed water travel times from the fish hatchery downstream to the mouth are less than 2 hours during the flood of record, about 2.5 hours during a more typical 2-year flood, and up to 4 hours during low flow periods.

7.2.3 Sediment

Sediment transport capacity is a measure of a river's ability to move sediment downstream. The capacity varies throughout a river depending on local hydraulics, size of sediment in the channel, magnitude of flow in the river, and local morphological impacts that form and shape the channel. For instance, at a constricted, narrow section the river stage increases rapidly with discharge and velocities also increase. This results in higher sediment transport capacity, particularly if the slope of the river is also steep. At wider sections of river, multiple channels may exist and water depths are typically shallower and wetted width increases much more rapidly with discharge than stage. At these sections, velocities and slopes tend to be less and sediment transport capacity is lower. If the upstream sediment supply is greater than the local sediment transport capacity, then sediment will tend to deposit in the channel. If the upstream sediment supply is less than the local sediment transport capacity, then sediment will be eroded from the channel, often leaving a coarse layer of cobbles on the bed. Based on bedload data measured at the Highway 101 Bridge, a relationship for sediment load and discharge was developed (see Section 5.3). While there is no true average year for a river, the average annual sediment supply can be computed from this relationship to give a feel for the order of magnitude of sediment load being transported each year. The majority of this sediment is transported during high flows in the winter or during spring snowmelt. Based on this relationship and the mean-daily discharge data for the period of record, the average annual sediment supply of the Dungeness River is estimated to be 10,300 yds^3/yr.

One indicator of sediment transport capacity is unit stream power, a product of the water velocity and slope at any cross section. Model output at a 2-year flood was used to compute unit stream power at each cross section relative to the Highway 101 Bridge where bedload was measured by USGS (Figure 21). The Highway 101 Bridge is a constricted area that, based on the measured bedload, is capable of moving particles over 100 mm (cobble) in size at slightly greater than the 2-year flood (see Figure 6). If the river has approximately the same capacity to move sediment as at the Highway 101 Bridge then the relative unit steam power is computed as 1. If the value is less than 1, the river has less capacity, and it has more capacity if the value is greater than 1. A 3-point moving average of the data shows that there is a general decrease in unit stream power in the reach downstream from the Railroad Bridge (RM 5.5) to the mouth. This results from the overall flattening of the channel slope in the downstream direction. However, at each cross section the unit stream power fluctuates from the average because of local changes in velocity from section to section.

A more detailed approach to sediment transport capacity can be accomplished using the calibrated sediment transport equation developed for the Dungeness River (discussed in Section 5.3.2). This method incorporates not only velocity and slope, but also accounts for water depth, viscosity, and the fall velocity for the median size of sediment in the Dungeness River channel. For this analysis, the median size of bed material present in the river channel at the Highway 101 Bridge (at bedload measuring site) was 50 mm, based on measured gravel bar samples in this area. Data is presented in Figure 22 with values relative to the sediment transport capacity at the Highway 101 Bridge. Similar to unit stream power, if the relative transport capacity is equal to 1, the section has the same sediment transport capacity as at the Highway 101 Bridge. If the value is less than 1, the river has less capacity and if it is greater than 1 it has more capacity.

The sediment transport capacity remains high in Reaches 5 and 4, with the exception of cross section 57 where the localized slope is flat and the flow is reduced due to a flow split slightly upstream (Kinkade Creek). In reaches 1, 2, and 3 areas of high sediment transport capacity are intermixed with areas of low transport capacity all the way downstream to the mouth. This is due to both natural and human-induced constrictions throughout the lower river. As mentioned previously, these constrictions cause higher water stage and velocity and result in localized high transport capacity. However, in other areas of the river the active channel width is significantly wider, such as at cross section 31 (RM 5.1903), downstream of the Railroad Bridge. Overall, a trend line shows that sediment transport capacity does decrease in the downstream direction as a result of the flattening of the river channel slope. Evaluation of sizes of sediment present in gravel bars also showed that while gravel and cobble-sized material was present in most of the lower Dungeness River, the median sizes of sediment do decrease in the downstream direction and only sand and gravel-sized sediments are present at the mouth.

7.2.4 Evaluation of River Alluvium as Spawning Gravel

Sediment size data were collected from exposed gravel bars along the Dungeness River to aid in the analysis of river channel processes and sediment transport. This data can also be used to qualitatively evaluate the suitability of the river channel sediments to serve as spawning gravels for the five anadromous fish species that inhabit the Dungeness River: (1) chinook salmon, (2) coho salmon, (3) pink salmon, (4) chum salmon, and (5) steelhead trout (Haring, 1999). Salmonids typically utilize gravel beds for spawning with sediment sizes ranging from 8 to 100 mm in diameter (Schuett-Hames, 1999), but the size of sediment selected for spawning within this range varies from species to species. Kondolf and Wolman (1993) compiled published sediment size data for salmonid redds (egg nests) which had been sampled for a large number of rivers in the western United States. They then analyzed the data in terms of sediment sizes preferred by species. Specific data for salmonid redds on the Dungeness River are not available and are inferred to be similar to those reported by Kondolf and Wolman for the purposes of this analysis.

In order to qualitatively assess if sediment of the proper size for spawning is present along the lower Dungeness River, the D_{50} of the underlying bed material measured in gravel bars was compared to the sediment sizes measured for fish redds of the five species on other rivers in the western United States (Kondolf and Wolman, 1993). The D_{50} for the Dungeness River bar samples are compared to both the mean D_{50} (Figure 23, both 1998 and 2000 data) and maximum D_{50} of 1998 data (Figure 24), and 2000 data (Figure 25) for the redds of each of the five Dungeness salmonid species reported. It is inferred that in sample sites where the measured D_{50} of Dungeness River bed material is finer grained than the D_{50} diameters reported by Kondolf and Wolman, the sediment is suitable as spawning gravel for the purpose of this qualitative analysis. The possible detrimental effects from the fine-grained fraction of the sediment, which can adversely impact the productivity of salmon redds, were not considered. The 2000 sediment sampling (Piety and Link, 2000; Appendix N) included testing for the minus 0.85 and 0.0625 mm material which can be used to evaluate the effects of fine-grained sediment in future studies.

Lastly, data for the pavement layers which have formed on the surface of the gravel bars were also included in the comparison plots. These layers are typically only about one-particle-diameter thick, and are usually formed of cobble-sized sediments. The primary impact of the surface pavement would be to limit access to the underlying bed material, where the pavement is sufficiently large enough to prevent excavation of the river bottom by spawning salmonids. While the pavement data are provided, the primary focus in the qualitative analysis presented here is the underlying bed material.

A few comments are necessary before presenting the results of the qualitative evaluation. Two sets of gravel bar samples were collected on the Dungeness River. The1998 sediment sampling was designed to determine the sizes of sediment present in the Dungeness River channel throughout the lower 10.5 miles. The sample sites were chosen on gravel bars exposed along the channel of the Dungeness River, primarily due to ease of sample handling and processing dry materials versus wet samples obtained from the submerged riverbed (data presented in Appendix D). Spawning salmonids would not select bar deposits for their redds as the bars are exposed above the water surface and often contain pavement layers of coarse sediment, but would instead search out suitable bed materials submerged within the active river channel. However, sampling sites on the bars were selected to be representative of the riverbed materials for a given reach, based on visual comparison with the adjacent river channel sediment. The sediment present in the Dungeness channel can be highly variable even over short distances. The inference regarding sediment similarity of gravel bars versus sediment present in the wetted channel may not hold true at all sample locations. Field observations during this study noted localized areas of more fine-grained sediment which could be more suitable habitat for spawning, but these areas tend to form a minority of the sediment present in the river, and are often localized or present in side channels. Thus, the 1998 data may tend to concentrate on more coarse-grained materials which are more typical of the sediment found in the Dungeness River, but not necessarily suitable habitat for salmonid redds. Sediment sampling conducted in 2000 is more directly applied to the evaluation of spawning gravel, as sample sites were selected adjacent to scour chains installed by the Jamestown S'Klallam Tribe in potential spawning areas (see Piety and Link, 2000, Appendix N). Results from the 1998 and 2000 sampling program have been incorporated together for this analysis, but could be separated as part of a more detailed evaluation in future study.

The following discussion of alluvium suitability is subdivided by the five salmonid species. The discussion includes a brief summary of the reaches of river and primary tributary streams used by each of the five species as reported in the salmon and steelhead habitat limiting factors report by Haring (1999). The individual discussions are presented in order of relative sediment size selected for spawning gravel from most coarse-grained to most fine-grained, based on the work of Kondolf and Wolman (1993). The results are summarized in Table 5.

Chinook Salmon. The chinook salmon present in the Dungeness River consist of a spring/summer run which was listed as a threatened endangered species (Puget Sound chinook) by the U.S. National Marine Fisheries Service in March 1999. Haring (1999) indicates that chinook are found on the Dungeness River as far upstream as an impassable falls at RM 18.7 just upstream from the confluence with Gold Creek. The chinook run also extends up the Gray Wolf River to about RM 2.5 with a potential upstream limit at RM 6.1 as found in a recent 2001 Washington Department of Fish and Wildlife spawning survey (Haring, 1999).

Of the five anadromous fish species that are present in the Dungeness River, the chinook salmon select the most coarse-grained sediment for spawning gravel. A total of 33 gravel bars was sampled in 2000 within the reported range of the chinook salmon spawning. A comparison of the measured D_{50} of bed material with the reported mean D_{50} for chinook salmon found eighteen sites suitable for chinook salmon spawning, sixteen on the Dungeness River and two on the Gray Wolf River. Theses samples are shown in green on Table 5. A comparison of the measured bed material D_{50} with the reported maximum D_{50} for chinook salmon added thirteen additional sites that could be suitable as spawning gravel on the Dungeness River (samples shown in yellow on Table 5). Overall, for areas of the chinook salmon on the Dungeness River, about 55 percent of the sampled Dungeness River gravel bars had an average sediment size that was finer grained than the mean D_{50} for chinook spawning gravels while about 94 percent of the sample sites were finer grained when compared to the maximum D_{50} for chinook spawning gravels. Two sample sites were too coarse grained to serve as spawning gravel for any of the five anadromous fish species present in the Dungeness River, one near the Dungeness Meadows Levee in Reach 4 and one just downstream from the confluence with Canyon Creek in the upper watershed (shown in red on Table 5).

Chum Salmon. Haring (1999) lists two runs of chum salmon on the Dungeness River. The summer chum run extends upriver as far as RM 10.8 at the Dungeness Fish Hatchery, but most of the spawning reportedly occurs downstream of Woodcock Bridge at RM 3.3. The fall chum covers a slightly larger portion of the river, extending upstream to RM 11.8. Chum have not been reported on either the Gray Wolf River or on Gold Creek.

A total of 26 gravel bars was sampled within the reported range of the summer chum salmon on the Dungeness River. Of these sample sites, many were suitable for use as spawning gravel by chum salmon. A comparison of the measured D_{50} in the gravel bars with the reported mean D_{50} for chum salmon spawning gravels (Kondolf and Wolman, 1993) found twelve sites on the Dungeness River suitable as spawning gravel (i.e., measured D_{50} bed material that is finer grained than the mean D_{50}; shown in green on Table 5). A comparison of the measured D_{50} bed material with the reported maximum D_{50} for chum salmon spawning gravels added an additional 12 sites which could provide suitable spawning gravels on the Dungeness River (shown in yellow on Table 5). Overall, for areas of the summer chum salmon on the Dungeness River, about 46 percent of the sampled Dungeness River gravel bars had an average sediment size that was finer grained than the mean D_{50} for summer chum spawning gravels while about 92 percent of the sample sites were finer grained when compared to the maximum D_{50} for summer chum spawning gravels.

The fall chum run on the Dungeness River reportedly has a slightly larger extent on the river than does the summer chum (Haring, 1999). Consequently, a total of 29 gravel bars was sampled within the reported range of the fall chum salmon, three more sites than the summer chum to account for spawning areas in the upper watershed. A comparison of the measured Dungeness bed material D_{50} with the reported mean D_{50} for chum salmon spawning gravels (Kondolf and Wolman, 1993) found 14 sites which could provide suitable spawning gravels (i.e., bed material D_{50} that is finer grained than the mean D_{50}) on the Dungeness River (shown in green on Table 5). A comparison of the Dungeness bed material D_{50} with the reported maximum D_{50} for chum salmon added an additional 13 sites that could be suitable as spawning gravel for the chum on the Dungeness River (shown in yellow on Table 5). Overall, for areas of the fall chum salmon on the Dungeness River, about 48 percent of the sampled

Dungeness River gravel bars had an average sediment size that was finer grained than the mean D_{50} for chum spawning gravels while about 93 percent of the sample sites were finer grained when compared to the maximum D_{50} for chum spawning gravels. This result is nearly identical to the result found for summer chum salmon.

Steelhead Trout. The Dungeness River supports two runs of steelhead trout (Haring, 1999). Both the summer and winter steelhead have been observed as far upstream as the impassable falls at RM 18.7 on the main stem Dungeness. The summer steelhead distribution on the Gray Wolf River extends to at least the three forks area at RM 9.6, and may reach into tributaries upstream from that location. The extent of the winter run on the Gray Wolf is believed to be similar to that of the summer steelhead. Winter steelhead have also been observed on Gold Creek upstream to the slide area at RM 0.1, but may have historically extended as far upstream as RM 1.5 (estimated pre-slide extent).

A total of 33 gravel bars was sampled within the reported range of the steelhead trout on the Dungeness River. Of these sites, many were too coarse grained to be used as spawning gravels by the steelhead. A comparison of the measured Dungeness bed material D_{50} with the reported mean D_{50} found 15 sites suitable as spawning gravel for steelhead trout (Kondolf and Wolman, 1993). Thirteen of these sites are on the Dungeness River; two are on the Gray Wolf River (shown in green on Table 5). Analysis using the maximum D_{50} added six more sample sites with measured D_{50} diameters that could be suitable as spawning gravel for steelhead redds (i.e., bed material D_{50} that is finer grained than the maximum D_{50}) on the Dungeness River (shown in yellow on Table 5). About 45 percent of the sampled Dungeness River gravel bars were finer grained than the mean D_{50} for steelhead trout redds while about 64 percent of the sample sites were finer grained when compared to the maximum D_{50} for steelhead.

Coho Salmon. Haring (1999) reports that coho salmon have been documented as far upstream on the Dungeness River as the impassable falls at RM 18.7. Coho are present in the Gray Wolf River up to the cascades at RM 8.6 about one mile downstream of the three forks area. Gold Creek supports a run up to the slide area at RM 0.1, but Haring reports a pre-slide extent as far upstream as RM 1.5.

A total of 33 gravel bars were sampled within the reported range of the coho salmon on the Dungeness River. Of these sites, many were too coarse grained to be used as spawning gravels by the coho. A comparison of the measured Dungeness D_{50} with the reported mean D_{50} for coho salmon (Kondolf and Wolman, 1993) found 10 sites finer than the mean D_{50} which could be suitable as spawning gravel (i.e., bed material D_{50} that is finer grained than the mean D_{50}). Nine sites are on the Dungeness River and one is on the Gray Wolf River (shown in green on Table 5). Analysis using the maximum D_{50} for coho salmon added 9 additional sites with sediment that could be suitable as spawning gravel (i.e., bed material D_{50} that is finer grained than the maximum D_{50}). Eight sites are on the Dungeness River and one is on the Gray Wolf River (shown in yellow on Table 5). From this analysis, only 30 percent of the sampled Dungeness River gravel bars were finer grained than the mean D_{50} for coho salmon redds, and 58 percent of the sampled gravel bars were finer grained when compared to the maximum D_{50}.

Pink Salmon. Two distinct pink salmon runs are supported on the Dungeness River (Haring, 1999). The upper Dungeness pink salmon spawn on the main stem of the Dungeness between approximate RM 9.7 and the impassable falls at RM 18.7. The lower Dungeness pink salmon use the Dungeness downstream from the Highway 101 bridge at RM 6.5. Haring (1999) reports that the upper Dungeness pink salmon also spawn in the lower reach of the Gray Wolf River to the cascades at RM 8.6, although others have suggested an uppermost extent as far as the three forks area at RM 9.6 (Haring, 1999). The upper Dungeness run also extends up to RM 0.3 on Gold Creek. Prior to the Gold Creek landslide, Haring shows an upstream extent of RM 1.5 for Gold Creek.

Of the five anadromous species that spawn in the Dungeness River, the Pink salmon use the finest sediment sizes. A total of 18 gravel bars were sampled within the reported range of the lower Dungeness pink salmon. A comparison the D_{50} of the bed material sampled on the bars along the Dungeness River and the mean D_{50} for the pink salmon redds (Kondolf and Woman, 1993) suggests that all the bars that were sampled are too coarse for use by pink salmon, except for two locations (i.e., about 11 percent of the sampled sites): the finer bar near the mouth of the Dungeness River in Reach 1 (Sample DRsed-1A) and the finer bar at RM 3 (Sample DRsed-4B) in Reach 2. A comparison of the measured Dungeness D_{50} with the maximum D_{50} reported for pink salmon redds added one additional sample site that was suitable for spawning: the finer-grained gravel bar at RM 2.1 (DRsed-117) in Reach 1.

The area of the upper Dungeness pink salmon is generally upstream of the study reach and only 9 gravel bars were sampled, mostly during the 2000 field investigation in support of the riverbed scour study by the Jamestown S'Klallam Tribe. All but one of the nine sample sites were too coarse grained for pink salmon, based on both the mean and maximum D_{50} diameter for the underlying bed material. The single suitable site sampled was a finer-grained bar at RM 11.6 in the upper watershed near the USGS gaging station (DRsed-105). This qualitative analysis indicates that the available spawning material in gravel bars is about the same for both the lower and upper Dungeness pink salmon populations at about 11 percent of the total sample sites when comparing to the mean D_{50} for pink salmon redds. Use of the maximum D_{50} also shows similar numbers for both pink populations: 16 percent for the lower Dungeness pink salmon and 11 percent for the upper Dungeness pinks.

Table 5. — Evaluation of River Bed Material as Suitable Fish Spawning Gravel[1]

Salmon Species		Chinook	Chum		Steelhead	Coho	Pink	
		Spring/ summer	Summer	Fall	Summer/ winter		Upper	Lower
Habitat range (RM)	Dungeness River	0 to 18.7	0 to 10.8	0 to 11.8	0 to 18.7	0 to 18.7	9.7 to 18.7	0 to 6.5
	Gray Wolf River	0 to 2.5	Not present	Not present	0 to 9.6	0 to 8.6	0 to 8.6 or 9.6	Not present
[2]Mean spawning bed (mm)		36.5	28.1		25.5	20.2	9	
[2]Maximum spawning bed (mm)		78	62		42	35	11	
Number of samples in species range		33	26	29	33	33	9	18
Sample								
Location (RM)	**Locality number[3]**							
Reach 1								
0	DRsed-1A	<Mean	<Mean	<Mean	<Mean	<Mean		<Mean
0	DRsed-1B	<Mean	<Mean	<Mean	<Mean	<Max		>Max
1.5	DRsed-119	<Max	<Max	<Max	<Max	>Max		>Max
1.55	DRsed-3A	<Mean	<Mean	<Mean	<Mean	<Mean		>Max
1.55	DRsed-3B	<Mean	<Mean	<Mean	<Mean	<Max		>Max
1.9	DRsed-118	<Max	<Max	<Max	>Max	>Max		>Max
2.1	DRsed-117	<Mean	<Mean	<Mean	<Mean	<Mean		<Max
2.4	DRsed-116	<Mean	<Mean	<Mean	<Max	<Max		>Max

Table 5. — Evaluation of River Bed Material as Suitable Fish Spawning Gravel[1] (Continued)								
Salmon Species		**Chinook**	**Chum**		**Steelhead**	**Coho**	**Pink**	
		Spring/ summer	**Summer**	**Fall**	**Summer/ winter**		**Upper**	**Lower**
Reach 2								
2.8	DRsed-115	<Max	<Max	<Max	>Max	>Max		>Max
3	DRsed-114	<Max	<Max	<Max	>Max	>Max		>Max
3	DRsed-4A	<Mean	<Mean	<Mean	<Mean	<Mean		>Max
3	DRsed-4B	<Mean	<Mean	<Mean	<Mean	<Mean		<Mean
3.33	DRsed-5A	<Max	<Max	<Max	<Max	>Max		>Max
3.33	DRsed-5B	<Mean	<Mean	<Mean	<Mean	<Max		>Max
Reach 3								
5.0	DRsed-112	<Max	<Max	<Max	>Max	>Max		>Max
5.33	DRsed-8	<Max	<Max	<Max	>Max	>Max		>Max
5.4	DRsed-111	<Max	<Max	<Max	>Max	>Max		>Max
5.5	DRsed-110	<Max	<Max	<Max	>Max	>Max		>Max
Reach 4								
7.5	DRsed-13	<Max	<Max	<Max	>Max	>Max		
7.55	DRsed-14	>Max	>Max	>Max	>Max	>Max		
7.7	DRsed-109	<Max	<Max	<Max	>Max	>Max		

Table 5. — Evaluation of River Bed Material as Suitable Fish Spawning Gravel[1] (Continued)

Salmon Species		Chinook	Chum		Steelhead	Coho	Pink	
		Spring/ summer	Summer	Fall	Summer/ winter		Upper	Lower
7.8	DRsed-108	<Mean	<Mean	<Mean	<Mean	<Mean		
Reach 5								
9.0	DRsed-19A	<Max	<Max	<Max	<Max	>Max		
9.05	DRsed-19B	<Mean	<Mean	<Mean	<Mean	<Mean		
10.05	DRsed-21	<Mean	<Mean	<Mean	<Mean	<Max	>Max	
Upstream watershed								
10.8	DRsed-107	>Max	>Max	>Max	>Max	>Max	>Max	
10.9	DRsed-106A	<Mean		<Mean	<Max	<Max	>Max	
10.9	DRsed-106B	<Mean		<Max	<Max	<Max	>Max	
11.6	DRsed-105	<Mean		<Mean	<Mean	<Mean	<Mean	
17.7	DRsed-101	<Max			>Max	>Max	>Max	
17.7	DRsed-102	<Mean			<Mean	<Mean	>Max	
Gray Wolf River								
0.9	DRsed-104	<Mean			<Mean	<Max	>Max	
1.0	DRsed-103	<Mean			<Mean	<Mean	>Max	

Table 5. — Evaluation of River Bed Material as Suitable Fish Spawning Gravel[1] (Continued)							
	Chinook	**Chum**		**Steelhead**		**Pink**	
Salmon Species	**Spring/ summer**	**Summer**	**Fall**	**Summer/ winter**	**Coho**	**Upper**	**Lower**
Percent of samples finer than mean	55	46	48	45	30	11	11
Percent of samples finer than maximum	94	92	93	64	58	11	16

Notes for Table 5:

[1]The samples are subdivided into three categories. The ones shown in green and labeled "<Mean" are those for which the D_{50} of the sampled bed material is less than the mean D_{50} for the sediment samples that have been used by the species in other rivers in the region as reported by Kondolf and Wolman (1993). These sites on the Dungeness River and Gray Wolf River are probably the best suited for spawning for each species.

The samples shown in yellow and labeled "<Max" are those for which the D_{50} of the sampled bed material is less than the maximum D_{50} for the sediment samples that have been used by the species in other rivers in the region as reported by Kondolf and Wolman (1993). These sites on the Dungeness River and Gray Wolf River could have sediment suitable for spawning but may be less favorable than the sites shown as <Mean.

The samples shown in red and labeled ">Max" are those for which the D_{50} of the sampled bed material is larger than the maximum D_{50} for the sediment samples that have been used by the species in other rivers in the region as reported by Kondolf and Wolman (1993). These sites on the Dungeness River and Gray Wolf River may be marginal for spawning.

The samples shown by the diagonal lines are not within the range for that species in the Dungeness River and Gray Wolf River as reported by Haring (1999).

[2]The mean and the maximum values for the spawning bed are from Kondolf and Wolman (1993), who sampled sediment from redds on other rivers in the region.

[3]The samples numbered 1 through 21 were collected in 1998. The samples numbered 101 through 119 were collected in 2000.

7.2.5 Large Woody Debris

The distribution of woody debris in each reach of the lower Dungeness River was mapped on the 2000 aerial photographs and is summarized in Appendix O (Table O-4 and shown on Figures O-3, O-8, O-17, O-24, and O-31). This analysis does not differentiate large piles of debris (log jams) from single logs. Out of the five reaches in the lower Dungeness River, Reach 3 appears to contain the largest amount of woody debris and Reach 1 appears to contain the least. Woody debris is common in Reach 4 as a whole, but is sparse in the section adjacent to the upstream end of the Dungeness Meadows Levee. In most reaches, woody debris is concentrated in areas where there are multiple channels and the river is sinuous, rather than in areas where the channel is constricted and the river runs straight.

Woody debris was also mapped on the 1965 aerial photographs for Reaches 4 through 1 (RM 9 to 0) as shown in Figures O-9, O-18, O-25, and O-32 (Appendix O). In general, less woody debris is visible in 1965 than in 2000. The reduction in woody debris could be due to several factors including prior flow history and mechanical clearing of woody debris from the channel. In addition, the lack of stereoscopic viewing and the quality of the photographs may contribute to the apparent lack of woody debris visible on the 1965 aerial photographs.

Photography from two of the three time-lapse cameras placed along the Dungeness River during the 1998-99 winter flood season was used to look at the dynamics of gravel bar development and woody debris deposition as a result of high flows. During low flows, no major reworking of the channel was evident from the photographs. During small floods, large gravel bars were not affected because they were not typically inundated. The smaller gravel bars were reworked, but the impact on the woody debris and channel geometry was insignificant. The majority of woody debris and gravel bar dynamics occurred during two floods: the December 13, 1998, flood of 4,300 cfs and the January 29, 1999, flood of 3,340 cfs. During these floods, the river became increasingly dynamic wetting the entire width of the unvegetated channel (including the gravel bars). In addition to wetting the active channel, flood flows were observed to spill over into the vegetated flood plain inundating side channels that are normally only groundwater fed. During subsequent smaller floods, several pieces of woody debris that had deposited on small bars caused an acceleration of deposition on the bars. In one case, the gravel bar enlarged enough to cause the flow to split where it had run as one single channel previous to the monitoring showing the dynamic nature of the river.

7.3 Reach Analysis of the Lower Dungeness River

For each of the five reaches, an analysis was done to evaluate trends in hydraulics, sediment processes, woody debris deposition, the natural boundaries on the river channel and flood plain, and the impacts of man-made modifications on both the present flood plain and active channel. For two reaches where human influence has been particularly great, Reach 4 (RM 7 to 9) and Reach 1 (RM 0 to 2.6), the characteristics for the natural river system were inferred on the basis of the geologic units that are preserved in the river corridor. The results from this analysis are provided in the following sections and the boundaries of the existing and prehistorical (natural) flood plains are shown by reach on 2000 aerial photographs in Figures 26 (Reach 5), 27 (Reach 4), 28 (Reach 3), 30 (Reach 2), and 31 (Reach 1). A description of these boundaries is provided in section 5.4.

7.3.1 Reach 5 (RM 10.5 to RM 9)

Reach Boundaries

The upstream boundary of Reach 5 is at RM 10.5 near the fish hatchery, the upstream extent of the study reach (Figure 3B). The downstream boundary of Reach 5 is at RM9, where the river exits the foothills of the Olympic Mountains and the flood plain markedly widens. Because the river in Reach 5 flows within the foothills, the banks of this reach are generally well defined by rock on the east bank and high deposits of glacial sediments on the west bank (Figure 26).

Main Features of the Reach

The most significant feature in Reach 5 is Kinkade Island. This island is tree-covered and lies in the present flood plain. It is preserved between the main channel and the largest side channel in the study reach, Kinkade Creek. Kinkade Creek was not mapped on the USGS Quadrangle Map based on 1956 photography, but it does clearly show up in 1957 aerial photographs (Clallam County, 2000) and on 1965 and 1984 aerial photographs. In these earlier aerial photographs, the entrance to the channel is upstream and east of its present location (Figure O-2, Locality R5b, Table O-8). During a recent resurvey of the cross sections at Kinkade Island (May 2002) it was noted that three entrances to Kinkade Creek now exist and woody debris has naturally accumulated at each of these entrances. Each of these entrances is located on the outside of the bend on the right (east) side of the channel. Multiple other smaller side channels also pass through Kinkade Island either from the river to Kinkade Creek or vice versa. The majority of these side channels have woody debris at their entrances also which limits the amount of flow and sediment entering the channel. On the basis of its size relative to the main channel, it was estimated that approximately one-third of the total flow passed through Kinkade Creek prior to this last winter. Following the occurrence of the flood of record in January 2002, it is estimated that 50 percent of the total flow now enters Kinkade Creek through one of three channel entrances.

Channel and Flood Plain Morphology

At low flows, Reach 5 has both complex channel and bar patterns (multiple channels) and areas of less complexity (single channel). At high flows, the active channel is slightly meandering with one relatively tight meander bend at the downstream end of the fish hatchery (upstream end of Kinkade Island) (Table O-1; Figure O-2; Appendix O). The active channel is slightly meandering, with a sinuosity of 1.31. Short sections of the channel at meander bends have multiple depositional features, which are point and longitudinal bars mostly with some mid-channel bars. Longer, straighter sections that have primarily a single, low-flow channel have point bars only. The active channel in Reach 5 gradually widens in a downstream direction. Vegetated bars or low terraces are preserved as longitudinal and point bars. On the basis of differences in vegetation type and density, vegetated bars of two different ages are suspected.

Woody Debris

Large woody debris in Reach 5 is concentrated along the outside of meander bends and is nearly absent along the straighter sections (Figure O-3, Table O-4, Appendix O). Large log jams exist at the two upstream meander bends in the reach, at the head of Kinkade Creek (Figure O-3, Locality R5c, Appendix O), at the entrances to the numerous side channels on

Kinkade Island, and at the southwest corner of Kinkade Island (Figure O-3, Locality R5d, Appendix O).

Bed Material

A bed-material sample at RM 10, near the fish hatchery, was collected on a large bar on the west side of the low-water channel (Sample DRsed-21, Figure 3B; Appendix D). The pavement on this bar is well formed, especially on the upstream end of the bar. Fine-grained sediment has collected around some of the cobbles in the pavement. Samples of the coarser and finer portions of the bar were not collected because the size of the pavement seemed to be fairly uniform. Thus, the single sample appears to be representative of the grain sizes in the entire bar, at least at the surface. At RM 9.5, both a finer (Sample DRsed-19B) and coarser bar (Sample DRsed-19A) on the west side of the low-water channel were sampled due to a variation in sediment size in the bar (Figure 3B; Appendix D).

Reach Hydraulics & Sediment Transport

For a 2-year flood, computed average water velocities range from 5.8 to 9.3 ft/s in Reach 5 and show a decrease after the flow split with Kinkade Creek at RM 10.2 (cross sections 57 and 58, Figure 18). At cross section 56 when the flow from Kinkade Creek re-enters the main channel the water velocities increase. Mean depths averaged around 2.5 ft and maximum depths are roughly 1.5 to 3 times mean depth (Figure 19). Width to mean depth ratios range from 30 to 150, with the narrowest sections located at Kinkade Island (Figure 20). Sediment transport capacity is high throughout the majority of Reach 5, but does show a decrease downstream of the flow split with Kinkade Creek (Figure 22). Due to the woody debris located at the entrances of Kinkade Creek, a portion of the main channel flow is diverted into this side channel but the majority of coarse sediment remains in the main channel. This reduction in water but not sediment reduces the sediment transport capacity in the main channel.

Man-made Features

Man-made features in Reach 5 include a 0.4-mile-long (0.6-km-long) levee on the east bank across from the fish hatchery, a levee along the west (left) side of Kinkade Island, a bridge across Kinkade Creek, and riprap or logs along short sections of both the east and west banks of the main channel (e.g., along Fish Hatchery Road) and along at least one section of Kinkade Creek (Figure O-5, Table O-7, Appendix O). Piles of rock can be seen upstream of the fish hatchery on the west side of the river, but these piles are not continuous and, therefore, do not function as a levee but more as spot bank protection. The river runs straight and appears to be steep along the bank where the piles of rock are placed. There is also a diversion for irrigation water (Highland Ditch) in this reach on the east bank just upstream of Kinkade Island. In the main channel, only 20 percent of the right bank and only 12 percent of the left bank are lined by levees in Reach 5 and another 5 percent of each bank have been influenced by other man-made modifications (Table O-6, Figure O-5, Appendix O). An analysis was done by cross section to compare the widths of the natural, or prehistorical, flood plain and the present flood plain (Figure 26, Table O-5, Appendix O). In Reach 5, the present flood plain boundary almost everywhere coincides with the prehistorical flood plain boundary, indicating that man-made modifications have not cut off the flood plain. The exception is a small loss of flood plain width at cross sections 54 and 55 (RM 9.3 and 9.54) just downstream of Kinkade Island, where the banks have been modified to protect homes at the edge of the bank (Figure O-5).

Riprap has been added periodically to the left bank along Fish Hatchery Road (Locality R5e, Figure O-2, Appendix O) in an attempt to slow severe bank erosion that forced the County to relocate the road farther to the west. Near RM 9.1, erosion of the right bank has undercut the foundation of a house near the entrance to a side channel (Figure O-5, Appendix O). This house was located along the outside of a meander bend where natural erosion of the banks is likely to occur.

<u>Reach 5 Discussion and Conclusions</u>
The major feature in Reach 5 is Kinkade Island and Kinkade Creek.

- The majority of Reach 5 is heavily vegetated and an extensive wooded floodplain is present. The present flood plain boundaries are primarily as they were prehistorically. Levees along portions of the present flood plain boundaries do raise the bank height and cut off the flood plain locally (Table O-7, Appendix O). However, the relatively short extent of these man-made modifications means that they offer limited flood protection and have relatively little impact on the present flood plain and fluvial processes.

- Following a study by West Consultants (2000), the County removed approximately
- 55 feet of the levee to allow water into a 700 foot long side channel located on the west side of Kinkade Island. The goal of the removal was to allow water from the Dungeness River to flow through this channel for most of the year, creating a stable, large side-channel in an off-channel area with minimal disturbance to the mature riparian/floodplain vegetation which exists on the site. According to the County, similar pre-existing channels have been shown to be both a limiting and preferred habitat type for rearing of the Spring Chinook in the Dungeness River. To reduce the risk of flooding, large woody debris was placed at the inlet to the side channel. The County has scheduled continued monitoring of the project site for the next five years including cross-sections and pebble counts from the river, the new side channel, and Kinkade Creek (Freudenthal, 2000).

- Channel processes include erosion along the outside of meander bends and deposition of sediment on the inside of bends. Large woody debris also accumulates on the outside of meander bends and at the entrances to side channels. These ongoing natural processes have resulted in migration of the meander at the entrance of Kinkade Creek in a downstream direction. Migration of the next meander bend downstream has resulted in the channel being nearly perpendicular to the valley slope. Erosion along the outside of meander bends has resulted in erosion of the bank along Fish Hatchery Road, and undercutting of houses from the right bank.

- Approximately half of the river flow now enters Kinkade Creek through several side channel entrances, but mostly through the upstream most entrance. Because a portion of the flow passes into Kinkade Creek but all of the coarse sediment remains in the main channel, the ability for the main channel to transport this coarse sediment is reduced. Further, the main channel just downstream of the entrance to Kinkade Creek has migrated to the point that it is perpendicular to the valley. Eventually, the river will try to cut off the main channel in order to find an easier path to move sediment and flow downstream. The most obvious location for channel change is into Kinkade

Creek because it is already a well-developed channel. Any substantial flood has the potential to remove the log jam at the entrance to Kinkade Creek, allowing the main channel to be captured. Continued downstream migration of the meander at the head of Kinkade Creek may enhance the removal of the log jam. The existing main channel would then become a side channel and slowly revegetate over time. Several other smaller side channels flow through Kinkade Island, making future channel changes at any one of these sites another possibility.

- If the main channel is captured by the Kinkade Creek side channel, then bank erosion along Kinkade Creek is likely. This expected bank erosion could cause failure of the vehicle bridge leading to the island. Island residents are presently subject to flooding and may loose potential evacuation routes during a major channel change. In fact, during the recent flood of record on January 7, 2002, of 7,610 cfs, the downstream bridge did wash out and severe flooding and bank erosion occurred on Kinkade Island and Kinkade Creek. It is likely that the Kinkade Island area will continue to be subject to flooding (Figure 26).

7.3.2 Reach 4 (RM 9 to RM 7)

<u>Reach Boundaries</u>
The downstream boundary of Reach 4 is not clearly distinct, however, the boundary is placed at RM 7 because the pattern of the low-water main channel, side channels and bars becomes more complex downstream of this point. The downstream 0.4 miles of the reach, between the downstream end of the Dungeness Meadows Levee at RM 7.4 and the reach boundary at RM 7, This segment can be considered a transitional zone between Reach 4 and Reach 3, it has characteristics of both the simpler pattern of the channel and bars along the levee and the more complex pattern downstream of RM 7. This segment was included in Reach 4 because the present characteristics of the short section may represent the characteristics of the channel before the levee was built.

<u>Main Features of the Reach</u>
The main feature in Reach 4 is the Dungeness Meadows Levee, which is a 2,500-foot-long (760-m-long) structure along the east bank (Figure O-11, Appendix O). An additional levee on the west bank (Haller Dike) is located from RM 8.57 to 8.87 and is a prominent feature at the upstream end of the reach.

Several side channels, which surround wooded portions of the flood plain, also are characteristic of this reach (Figure O-7, Appendix O). The entrance to one side channel is blocked by the downstream end of the Dungeness Levee on the east side (RM 7.4) and this side channel extends into Reach 3. Historically, several shorter side channels were present on the east side of the river just upstream in what is now the Dungeness Meadows subdivision. Another fairly large side channel on the west side is apparent on the 1942/43 aerial photographs and may now be cut off by the downstream end of the Haller Dike.

<u>Channel and Flood Plain Morphology</u>
At high flows, the active channel in Reach 4 has broad meander bends upstream and downstream of Dungeness Meadows Levee and a long, straight section adjacent to the levee.

The active channel appears to have had a more sinuous pattern with shorter and tighter bends before the levee was built (Figures O-6 and O-12, Appendix O). The existing sinuosity through Reach 4 is only 1.04, but historically the sinuosity was higher (1.2), similar to the present sinuosity in Reach 3 (Figure 14). At low flows, water is conveyed in multiple, branching channels that are separated by unvegetated bars; however, the channel configuration is less complex than it is downstream in Reach 3. Upstream of Haller Dike in the transition area between Reach 5 and 4, the river is actively eroding the east bank on the outside of the river bend.

A spring-fed tributary and side channel, referred to as Spring Creek, cuts across a low, vegetated terrace on the east side of the river near the downstream end of the Dungeness Meadows Levee (Figures O-6 and O-7, Localities R4f and R4i, Appendix O). Spring Creek continues at least another 0.1 mi (0.2 km) downstream and connects with the Dawley side channel, the next major downstream side channel (Figure 3B). Other channels are visible on the right in the Dungeness Meadows subdivision and these were likely side channels before the development (Figures O-7 and O-12, Locality R4e, Appendix O). Presently, houses are built along the banks of this channel. This channel is separated from the main channel by a vegetated terrace. Presently, the upstream end of this channel is cut off by the Dungeness Meadows Levee and access by fish can only occur from the downstream end in Reach 3. Water in the channel originates from groundwater flow.

Unvegetated bars are common in Reach 4 and can be classified as longitudinal, point, and mid-channel bars (Table O-1, Appendix O). Adjacent to the Dungeness Meadows Levee, the bars appeared to be elevated relative to bars in other areas of the river. Vegetated bars are primarily present as longitudinal and point bars. Vegetated mid-channel bars are present only at the upstream and downstream ends of the Dungeness Meadows Levee. Vegetated bars of two different ages may be present in parts of Reach 4, but appear to be of a single age adjacent to Dungeness Meadows Levee. The pattern of the unvegetated and vegetated bars is less complex than it is downstream in Reach 3.

The bank on the east side of the prehistoric flood plain and the one on the west side downstream of about RM 7 are mostly well defined by high terraces that are estimated to be Pleistocene in age (Figure 27). The bank on the west side upstream of about RM 7 is poorly defined by irregular and intermittent risers of low terraces that are probably Holocene in age. These surfaces often include channels, some of which appear to have been side channels in 1942/43.

Woody Debris

Woody debris is common in Reach 4, but is not as prevalent as it is in Reach 3 (Figure O-8, Table O-4, Appendix O). Woody debris is concentrated at the broad meanders upstream and downstream of the Dungeness Meadows Levee. Very few piles of large woody debris are preserved upstream of about RM 8 (upstream of the Dungeness Meadows Levee) than compared to the reach downstream of this point. The majority of woody debris preserved along the straight section adjacent to the levee is located on high, elevated bars that do not appear to be accessed by the river except during large floods.

Bed Material
Near RM 7.5, finer and coarser portions of a gravel bar adjacent to the downstream end of the Dungeness Meadows Levee were sampled. On the finer portion (Sample DRsed-13, Figure 3B), the pavement is chiefly cobbles, mostly subrounded to well-rounded, with weakly imbricated stones. The underlying material is loose. The coarser portion of the bar (Sample DRsed-14, Figure 3B), about 0.05 mi (0.08 km) upstream, is a weakly developed pavement and some sand could be seen between stones. However, the pavement is better developed about 100 ft (30 m) downstream of the sample site. The underlying material is loose. The coarser portion of the bar is fairly elevated above the present low-water channel and is about 4 ft (1.5 m) higher than the finer portion of the bar.

Reach Hydraulics & Sediment Transport
For a 2-year flood, velocities range from 5.3 to 9.4 ft/s in Reach 4 and remain particularly high in the constricted levee reaches upstream of RM 7.5 (Figure 18). Mean depths average around 2.1 ft and maximum depths are roughly 1.5 to 4 times mean depth (Figure 19). Width to mean depth ratios are significantly lower in the upstream half of Reach 4 than the downstream half (Figure 20). Sediment transport capacity is high throughout Reach 4, which is shown in the field by the coarse bars discussed in the bed-material section (Figure 22).

Man-made Features and Their Impacts
The Dungeness Meadows Levee, built in the 1960s to protect houses in the Dungeness Meadows subdivision from flooding, is the major man-made feature in Reach 4 and it is the second largest levee in the lower 10.5 miles of the Dungeness River corridor. In 1968, this levee was nearly overtopped and had to be repaired by the ACOE (Northwest Hydraulic Consultants, 1987). A downstream extension was added to the original Dungeness Meadows Levee in 1992 (DRRWG, 1997). Along the west bank, a relatively new levee, referred to as the Haller dike, has been added in the section between RM 8.57 to 8.87, just downstream of the reach boundary at RM 9 (Figure O-11, Appendix O). Analysis of aerial photographs taken in 1942/43 and 1965 shows that both these levees cut off both the active channel and the flood plain (Figures O-10 and O-12, Appendix O).

The downstream extension that was added to the Dungeness Meadows Levee cuts off the entrance to the long side channel on the right (Figures O-7, O-11, and O-12, Appendix O). Haller Dike cuts off the downstream end of a side channel visible on the 1942/43 photographs, as well as the upstream entrance to another side channel located on the left at approximately RM 8.5 (Figures O-7 and O-11, Appendix O).

During extensive gravel mining and removal of woody debris along the west bank between 1992 through 1996, about 200,000 yds^3 of sediment were removed from the channel between RM 7 and RM 8, adjacent to the Dungeness Meadows Levee. A previous report noted that this resulted in a lowering of the channel bed by 8 ft (2.5 m), which caused repeated damage to the downstream extension of the Dungeness Meadows Levee (DRRWG, 1997).

Across from Dungeness Meadows Levee, the west bank can be overtopped due to the higher flood stage that results from the Dungeness Meadows Levee. Flooding and bank erosion was observed in a May 2002 survey that was the result of the January 2002 flood. Property owners on the west side have built short, low levees to provide protection from lower magnitude, frequent flooding in topographically low areas where water could easily get out.

Development and clearing of the riparian vegetation on either side of the river and in the flood plain have been extensive in Reach 4. Much of this was done in order to build houses in the Dungeness Meadows subdivision or on the west side of the river. This reach also has a diversion for irrigation water on the west bank, where riprap has been added to the bank on both sides of the diversion structure.

In total, 32 percent of the east bank and 31 percent of the left bank of the present flood plain are lined by levees in Reach 4 (Figure 27; Table O-6, Appendix O). An additional 6 percent of the west bank is modified indirectly by the Dungeness Meadows Levee, because the levee raises the elevation of the present flood plain boundary extending it farther to the west (Figure 27).

Several changes in the characteristics of the Dungeness River along Reach 4 have occurred between about RM 7.4 and RM 8.4 adjacent to the Dungeness Meadows Levee since 1942/43 (Figure O-7, Appendix O). The channel pattern adjacent to the levee is less complex with a more single channel pattern than in portions of the reach without the levee. The meanders are less defined so that the channel is straighter as a result of the levee. Flow to Spring Creek on the east side of the river and to additional smaller channels through what is now the Dungeness Meadows subdivision have been cut off by the levee. An analysis was done by cross section to compare the widths of the natural, or prehistoric, flood plain and present flood plain (Figure 27; Table O-5, Appendix O). In Reach 4, a major portion of the prehistorical flood plain has been eliminated by man-made levees, so that the present flood plain along Dungeness Meadows Levee is only 70 to 75 percent of the natural flood plain (Table O-5, Figures O-10 and O-12, Appendix O).

<u>Reach 4 Discussion and Conclusions</u>
The major consideration in Reach 4 is the effect of the construction of the Dungeness Meadows Levee and subdivision in the active channel and flood plain along the east side. Additional considerations are the influence of both the Haller Dike on the west side at the upstream end of the reach and the short, low-elevation levees along the west side across from the Dungeness Meadows Levee.

- A complex channel and bar pattern, similar to that in Reach 3, was present in Reach 4 before the levees were built, as shown in the 1942/43 photographs. This complex system of multiple channels would have provided a variety of habitat for fish and wildlife. The multiple channels that were present prehistorically would have limited sediment transport capacity in any one channel because the in flow, was spread among many channels. Sediment probably often filled in the main channel, causing the low flow channel to change to another location, often an existing side channel. In this way, the locations of the active main channel and side channels changed over time. This process probably continued in episodes with the river migrating throughout the natural flood plain boundaries.

- Because the Dungeness Meadows Levee and the houses of the Dungeness Meadows subdivision have been built on surfaces that historically appear to have contained side channels and active bars, as well as overflow channels, it is difficult to estimate the number and complexity of channels that were on these surfaces before construction of the levee and subdivision started. However, it is apparent from a comparison of older aerial photographs that this levee, especially its downstream end, cuts off a significant portion of the active channel, flood plain, and side channels, and has significantly altered stream processes.

- As a result of all of the levees on the east and west banks, stage now increases much more rapidly than wetted width during high flows. The levees cut off access to side channels that would otherwise convey some of the flow and provide habitat to fish. The increased stage during high flows results in higher velocities and higher sediment transport capacity in the upstream portions of Reach 4.

- Because the river is confined by the levees to a narrow corridor that is relatively straight, sediment has deposited in the form of elevated bars along the confined sections. These bars are the only locations where woody debris has been deposited, because other areas of the channel have high-velocity flows that flush the wood downstream. This wood is generally located out of the low flow channel and does not provide any stable pools in the main channel (Figure O-8, Appendix O). In addition, the sediment on the gravel bars is fairly coarse, and armors the bars, and traps sands and gravels underneath.

- Bank stabilization on the west bank does not impact the boundaries of the active channel like the levees do, but the Haller Dike, especially, and some of the short, private levees do cut off flood plain and, thus, restrict flood flows and deposition of fine sediment.

- Rock in the east bank upstream of RM 8 prevents natural river migration and recruitment of woody debris.

- Taylor Cutoff Road along the west bank coincides with a short section of the active channel, but because the road is on a relatively high terrace, it seems to have had little effect on the position of the present flood plain boundary or on fluvial processes within the active channel.

7.3.3 Reach 3 (RM 7 to RM 4.6)

<u>Reach Boundaries</u>
The downstream boundary of Reach 3 at RM 4.6 is moderately distinct (Figure 3A). A boundary was identified at this location because it is the downstream end of the section where low-water channel and bars form a more complex pattern than downstream. Also, this is the upstream end of a section in which both banks of the prehistoric and present flood plains are fairly well defined (Figure 28). In addition, the number and complexity of side and overflow channels decrease downstream of RM 4.6. In Reach 3, these channels are present on the both sides of the main channel (Figure O-16, Appendix O).

<u>Main Features of the Reach</u>
The most significant features of Reach 3 are the changes in the planform and location of the active channel and flood plain boundaries between the 1942/43, 1965, 1994, 1996, and 2000 aerial photography. A significant portion of the west bank in the vicinity of the Railroad Bridge has eroded since 1942/43. Except for the Highway 101 and the Railroad Bridges, man-made features are few and consist of some bank protection and woody debris placed

within the active channel boundaries. A 1913/14 map documented that the wooded floodplain and riparian zone was logged and cleared of woody debris in many areas of this reach. The 1942/43 aerial photographs also show these areas as being cleared of vegetation, most significantly in the active channel downstream of the Railroad Bridge.

Channel and Flood Plain Morphology

The active channel in Reach 3 is relatively wide, nearly twice as wide as portions of Reach 2 immediately downstream (Table O-5, Appendix O). At high flows, the active channel is slightly meandering with the tightest bends near the Railroad Bridge (Figure O-13, Table O-1, Appendix O). At low flows, the channel has multiple (often three) branches that form complex patterns around unvegetated bars (Table O-1, Appendix O). Although the numerous low flow channels have high sinuosity, the main active channel has a sinuosity of only 1.2 and has not changed significantly since 1942/43 (Figure 14; Table O-2, Appendix O).

Both unvegetated and vegetated bars are prevalent and both types of bars are found in a complex pattern of longitudinal, point, and mid-channel bars (Table O-1, Appendix O). Unvegetated transverse bars also are common in the active channel. Based on the type and density of vegetation, the vegetated bars appear to be of at least three different ages.

Aerial photographs taken in 1942/43, 1965, 1994, 1996, and 2000 were examined (Figure O-14 and O-15, Appendix O) and a time-lapse video was produced (on CD in appendix P). The aerial photographs indicate that the river channel has changed position across the prehistoric flood plain, especially in the section near Railroad Bridge. Areas that are now primary side channels were once active channels and vice versa.

Side and overflow channels are common and have multiple branches at a single locality (Table O-1, Figure O-16, Appendix O). In many cases the overflow channels are lower in elevation than the main low-flow channel, as shown in cross section 36 (plot in Appendix F), just upstream of the Railroad Bridge. Comparative cross section plots show the dynamic nature of this reach and the channel bed. In places, overflow channels that are significantly lower than the active channel have a small amount of flow due to groundwater connections. Most of the overflow channels contain water during higher flows.

An analysis was done by cross section to compare the widths of the natural, or prehistoric, flood plain and the present flood plain (Figure 28; Table O-5, Appendix O). In Reach 3, the river still has access to all of the natural flood plain, except near the two bridges. The Highway 101 Bridge is located at a natural geologic constriction that is created by terraces that are probably Pleistocene in age, making the impact of this bridge on river processes minimal. Highway 101 Bridge reduces the width of the prehistoric flood plain by only 10 percent
(Table O-5, Appendix O). The Railroad Bridge itself does not constrict the active channel, but the embankment on the east side does cut off access to side channels and the flood plain that were active in 1942/43 (Figure 28). The Railroad Bridge and its embankment reduces the width of the natural flood plain by about 20 percent (Table O-5, Appendix O).

The banks of the prehistoric and present flood plains are fairly well defined along most of both banks in Reach 3. However, just upstream of RM 4.6 and near Railroad Bridge, the east bank is poorly defined by a broad rise of a low terrace.

Woody Debris

Woody debris is abundant along Reach 3, especially along the insides of meander bends and at the entrances to side channels (Figure O-17, Table O-4, Appendix O). Large piles of interconnected logs are common. These are preserved both in the center of the main channel, on gravel bars in the main channel, and along side and overflow channels. Woody debris has been anchored by the Jamestown S'Klallam Tribe along the east bank upstream of the Railroad Bridge in order to protect an interpretive center and amphitheater. Woody debris also has been placed along the west bank on the Severson's property (Figures O-17 and O-20, Locality R3h) downstream of Railroad Bridge in order to slow bank erosion (Figure 29). In addition, large jams were placed by the Tribe at the entrance to a side channel on the west side upstream of the bridge (Figure O-17, Locality R3f) to prevent a potential channel change into the side channel.

Bed Material

The upstream end of a gravel bar in the middle of the low-water channel was sampled at RM 5.3 (Sample DRsed-8, Figure 3A). The cobble-sized pavement at this site is moderately developed and is about one particle diameter thick. Cobbles in the pavement are not imbricated. The material under the pavement is heterogeneous and loose.

Reach Hydraulics & Sediment Transport

For a 2-year flood, average velocities range from only 1.5 to a maximum of 9.5 ft/s (Figure 18). The lowest velocity area is just upstream of the Highway 101 Bridge due to the wide channel width and backwater effect caused by the constriction at the bridge opening. Mean depths average around 2.2 ft, and maximum depths are roughly 1.7 to 4.4 times mean depth (Figure 19). The areas just upstream of the two bridges both have large maximum depths from 7 to 8 feet. Two areas around RM 5.3 and 6.3 have extremely high width to mean depth ratios (Figure 20). Sediment transport capacity fluctuates quite a bit in the upstream portion of Reach 3, and remains relatively high in the downstream half of the reach with the exception of one wide section at RM 5.190 (Figure 22). A field reconnaissance was done in this reach shortly after a 4,300 cfs flow. Evidence was found on the flood plain of debris and fine sediment deposition indicating that this flow overtopped the natural banks and had water flowing in the overflow channels.

Man-made Features and Their Impacts

Man-made features along the river banks are more subtle in Reach 3 than upstream in Reach 4. The Railroad Bridge at RM 5.7 and the Highway 101 Bridge at RM 6.4 together account for 62 percent of the total human impact on the west bank and 80 percent on the east bank in Reach 3. However, the total human impact is only about 10 percent of the total length of each bank in the lower 10.5 miles (Table O-6, Figure O-20, Appendix O). The vegetated island located on the west side at Railroad Bridge is not a product of the bridge or bridge construction, but rather a natural feature that is at least several thousand years old (Appendix Q). Short stretches of the banks (about 8 percent of the total length of the left bank and about 3 percent of the right bank) are protected with logs or riprap, but, except for two sections along the west bank on the Severson's property (about RM 5), the protected sections are near the two bridges (Figure O-20, Appendix O). Reach 3 also has less development in the river corridor than the other reaches and this may explain the less extensive bank protection.

While the river banks have not been heavily affected by human activities, up until the early 1980's it was a common practice to remove any accumulation of large woody debris in the channel in this area (Byron Rot, written communication, 2002). This was accomplished by using heavy equipment, pushing the woody debris onto gravel bars, and then burning the wood. It is not known how much wood was removed or how often.

Measurement of Bank Erosion in Vicinity of the Railroad Bridge

In a disturbed reach, bank erosion can be a significant contributor to the sediment load of a river. Bank erosion was measured in the vicinity of the Railroad Bridge by using a comparison of the bank line from historical aerial photographs and an estimate of bank height from field measurements (Figure 29). The majority of bank erosion measured occurred along the west bank of the river. The maximum amount of lateral erosion between 1942/43 and 2000 was 740 ft downstream of the bridge and 660 ft upstream of the bridge. To get a value comparable to the average annual sediment load of the river, the total volume of bank eroded was divided by the number of years between photographs (Table O3: Appendix O). This indicates the sediment eroded from the bank in Reach 3 contributed on average from 8,000 to 12,000 yds^3/yr between 1942 and 2000. This amount is similar to the average annual sediment supply estimated at 10,300 yds^3/yr. A portion of the bank materials are fine sediments that would be quickly suspended and easily transported downstream following erosion. However, a significant portion of these bank materials do contain river alluvium that would contribute coarse sediment to the natural sediment load of the river. This large amount of sediment that has been contributed over the years to the natural sediment supply could result in localized channel aggradation. Recently, log jam structures have been placed along the west bank downstream of the Railroad Bridge to stop bank erosion and appear to be working. Upstream of the Railroad Bridge a meander cut off has occurred in the low flow channel and bank erosion along the west bank has been slowed. These observations indicate that the amount of future bank erosion in this section may be reduced.

Reach 3 Discussion and Conclusions

The major consideration in Reach 3 is the relative instability of the planform and location of the active channel and the channel bed.

- Reach 3 is very dynamic and historically has moved back and forth within the boundaries of the active flood plain. Historical and prehistoric locations of the main channel can still be seen on surfaces in the river corridor. These old channels are lined with gravel- and cobble-sized sediments in some locations and finer sediments in other areas where flooding occurs. As the main low-flow channel meanders and eventually fills with sediment, the channel typically changes location to an existing side channel and begins the migration and deposition process again.

- Although the majority of channel changes in the active floodplain boundaries are natural, on the west bank downstream of the Railroad Bridge on the Severson's property, a large amount of terrace has eroded since 1942/43 (Figure 29; Table O-3, Appendix O). This terrace was dated as being several thousand years old. While a small amount of erosion and channel migration is natural, the accelerated rate of erosion between 1942 and 2000 is likely due to the historic clearing of the vegetation (e.g., logging) in the flood plain.

- The construction from the Railroad Bridge embankment has prevented the downstream migration of channel meander bends. Consequently, the channel meander bends migrated laterally upstream of the bridge and resulted in wide channel widths.

- In 1961 after a large flood, a new embankment for the Railroad Bridge was constructed on the east side. This embankment has restricted flows and sediment from entering the east flood plain. While this embankment has locally affected the flood plain boundaries, it is unlikely that this embankment had any impact in the downstream bank erosion along the west side. Historical aerial photograph comparison shows that the alignment of the low-flow channel has remained consistent through the bridge from 1942/43 (prior to the embankment) to 2000.

- Large piles of woody debris are present in the main channel, along with several piles in side and overflow channels (Figure O-17, Appendix O). A time-lapsed camera (# 1) was positioned to look downstream of the Railroad Bridge. This camera showed some very interesting interaction between gravel bar formation and woody debris deposits. The video and interpretation can be viewed from a CD attached in Appendix P. Analysis of pictures taken by this camera show that as woody debris deposits on a gravel bar, the sediment deposition on the bar accelerates. This deposition of sediment and woody debris increases the complexity of the main channel and results in a variety of depositional features and multiple low flow channel paths.

- A second camera (# 2) was aimed upstream at a low flow channel on the west side just upstream of the Railroad Bridge. This low flow channel had gradually migrated over time to the point that it was perpendicular to the valley slope and parallel to Railroad Bridge. This channel filled with sediment and the main low flow channel changed to the east side of the active channel upstream of the bridge.

- The Highway 101 Bridge does not significantly cut off the prehistoric flood plain because the bridge is at a natural constriction created by terraces. However, just downstream of the bridge a large portion of the east floodplain has been cleared of trees and vegetation. Similar to the area downstream of the Railroad Bridge on the west side, clearing the riparian zone has made this area susceptible to an accelerated rate of erosion. During the recent flood of record that occurred on January 7, 2002, up to 75 ft of this bank was eroded (Ross, 2002).

7.3.4 Reach 2 (RM 4.6 to 2.6)

Reach Boundaries
The downstream boundary of Reach 2 at RM 2.6 is relatively distinct, because the river corridor downstream of this point in Reach 1 is impacted by levees on both sides of the river where as in Reach 2, no major levees exist (Figure 3A).

Main Features in the Reach
The main feature that affects channel processes in Reach 2 is a flattening of slope, which would tend to reduce water velocities and sediment transport capacity. The width of the present flood plain varies because of the configuration of the terraces that define the flood plain boundaries. Narrower areas may have high velocities and transport more sediment, but

these areas also create small backwater areas upstream that would have low velocities and sediment transport capacity. Man-made features in this reach are limited to Ward Road and two bridges. The new Burlingame Bridge no longer constricts the width of the active channel.

Woodcock Bridge in combination with Ward Road, which is immediately downstream of the bridge on the west side, reduce the natural flood plain width, eliminating some side channels and riparian habitat.

Channel and Flood Plain Morphology

The active channel, which is fairly well defined by banks 6 to 9 ft (2 to 3 m) high, is at least twice as wide as it is between the two levees downstream (200 to 300 ft in Reach 2 versus 100 to 130 ft in Reach 1; Table O-5, Appendix O). At high flows, the active channel is slightly meandering (Table O-1, Figure O-22, Appendix O). At low flows, the channel consists of one or, at most, two branches. Side channels are located adjacent to and nearly parallel with the main channel along much of the reach (Table O-1, Figure O-23, Appendix O). A few short, single, or branching overflow channels were identified.

Unvegetated gravel bars are preserved as longitudinal, point, and mid-channel bars (Table O-1, Appendix O). Vegetated, or older, bars are preserved almost solely as longitudinal and point bars. Vegetated mid-channel bars were noted only near the Burlingame Bridge. Of the vegetated bars that are present, differences in vegetation type and density suggest that bars of two different ages are preserved.

A comparison of the active channel in Reach 2 in 1942/43 and 2000 shows the channel planform has changed only a small amount since 1942/43 (Figure O-28, Appendix O). In addition, Reach 2 is one of the few areas on the lower Dungeness River where significant clearing of the riparian zone was not evident from the historic aerial photographs. A comparison of the active channel over time suggests that channel sinuosity is essentially the same today (value of 1.14) as it was in either 1942/43 (value of 1.09) or in1965 (value of 1.1) (Table O-2, Appendix O). This reach is the location of the transition in slope as shown in Figure 17. It would be expected that sediment transport capacity would decrease in this reach and deposition would be likely. This deposition would tend to initiate channel change. However, the natural floodplain boundaries for Reach 2 are relatively narrow. Further, computation of sediment transport capacity shows that while there are some cross sections in Reach 2 that have a low sediment transport capacity, other cross sections are fairly constricted and have high sediment transport capacity. These areas of high sediment transport capacity likely prevent significant deposition that would result in significant channel change.

Woody Debris

Woody debris is present, especially along the outside of meander bends upstream of Woodcock Bridge (Figure O-24, Table O-4, Appendix O). Overall, woody debris does not seem to be as common in Reach 2 as it is in the upstream Reach 3 (Figure O-24, Table O-4, Appendix O).

Bed Material

Near RM 3, samples were measured on coarser (Sample DRsed-4A) and finer (Sample DRsed- 4B) portions of a bar on the west side of the low-water channel at Mary Lukes Wheeler (Clallam County) Park (Figure 3A). Neither the coarser or finer portions had much pavement development, and so a single sample was measured at each site. The surfaces were generally composed of loose sediment.

Just upstream of RM 3, at the downstream side of the Woodcock Bridge, samples were measured on coarser and intermediate portions of a gravel bar on the west side of the low-water channel (Figure 3A). (This sample is called intermediate because portions of the bar are finer than the portion of the bar that was sampled.) The cobble-sized pavement on the coarser portion of the bar (Sample DRsed-5A) is fairly well packed and is about one particle diameter thick. The material underlying the pavement is also well packed. The pavement on the intermediate portion of the bar (Sample DRsed-5B), which is in a dry channel, is loose. Similarly, the underlying material is loose. The packing of the pavement, along with the presence of woody debris, suggests that the coarser portion of the bar has been more stable than the intermediate portion.

Reach Hydraulics & Sediment Transport

This reach is a transitional reach for the lower 10.5 mi because of the flattening in slope that occurs. The transition area for the slope change is mainly between RM 4.5 and 3.5. For a 2-year flood, average velocities range from 3.4 to 8.9 ft/s in Reach 2 and on average are slightly lower than in the upstream reaches (Figure 18). Mean depths average around 2.6 ft and maximum depths are roughly 1.2 to 4 times mean depth (Figure 19). The width to mean depth ratios are all less than 100 with the exception of just upstream of the Woodcock and Burlingame Bridges (Figure 20). The unit stream power computation shows a clear decreasing trend in sediment transport capacity from the upstream end of this reach to the mouth (Figure 21). While overall sediment transport capacity does begin to decrease in this reach as a result of the significant reduction in slope, several areas of high sediment transport capacity do exist (Figure 22).

Man-made Features and Their Impacts

Reach 2 seems to have been slightly more modified by humans than Reach 3, but much less modified than Reach 1 immediately downstream. The man-made features in Reach 2 are the Burlingame Bridge, Ward Road, and the Woodcock Bridge (Table O-7, Figure O-27, Appendix O). The Burlingame Bridge was rebuilt in 1998-99 to increase the opening from 130 to 430 feet. This new opening allows for access to the flood plain and side channels which were previously inaccessible. In addition, the west bank has been protected with riprap along Ward Road just downstream of Woodcock Bridge (Figure O-27, Appendix O). The upstream side of the Woodcock Bridge embankment and the east river bank have also been covered with riprap to protect the bridge abutment. In total, 17 percent of the east bank has been affected by humans with the largest impact resulting from the two bridge embankments (Table O-6, Figure O-27, Appendix O). Forty percent of the west bank has been affected, mostly along Ward Road and Olympic Highway Bridge (Table O-6, Figure O-27, Appendix O). Of the historical flood plain, all of it is accessible in Reach 2 except in the vicinity of the two bridges and along Ward Road, where the natural flood plain has been reduced by as much as 25 percent (Figure 30; Table O-5, Appendix O).

The earliest documentation of bank protection in Reach 2 are bulkheads shown on a 1935 topographic map of the lower Dungeness River channel. Bulkheads, or post-and-plank shear walls, were present along portions of the banks until 1950 (Beebe, unpublished). Several bulkheads were located along Ward Road on the west bank, one on the east bank just upstream of the upstream end of the ACOE Levee (Figure O-27, Locality R2e, Appendix O), and one on the west bank at the present Mary Lukes Wheeler Park (Clallam County Roads Department) where the river bends to the east (Beebe, unpublished). In 1997, a post- and shear- bulkhead was found with four feet of gravel above it when a gravel trap was excavated on the Dungeness River (Beebe, unpublished).

Gravel has been extracted periodically from the riverbed. For example, a gravel trap was excavated in 1996 upstream from the Woodcock Bridge and in 1997 adjacent to the Moore's property (Figure O-22, Locality R2e, Appendix O). Although these excavations leave large holes in the bed initially, the holes are filled quickly with sediment during subsequent high flows.

<u>Reach 2 Discussion and Conclusions</u>
Overall Reach 2 has had limited impact from man-made features relative to the other four reaches in the Lower Dungeness River. The recent replacement of the old Burlingame Bridge eliminated the impact from this bridge. The Woodcock Bridge and Ward Road along the west bank downstream have the largest impact in this reach.

- Reach 2 has access to the majority of the natural flood plain, which allows natural channel changes to occur. The exception is at the location of the Woodcock Bridge which constricts the main channel and in combination with the downstream Ward Road cuts off access to the west floodplain. This reach has no evidence of historic clearing of the riparian zone from the 1942/43 or 1965 aerial photographs. The 1913/14 map does show areas in the active channel that are vegetated today as being gravel bar so there is some potential that the channel was logged prior to the 1913/14 map. However, this stability in the riparian zone since at least 1942/43 has likely provided channel stability in this reach and limited the amount of accelerated bank erosion that has occurred in other areas where the riparian zone has been removed.

- The most significant characteristic in this reach is the flattening of slope which causes slower velocities and reduced sediment transport capacity. The transitional zone for this flattening of slope is from RM 3.5 to 4.5. However, several areas of high sediment transport capacity also exist due to natural geologic controls that constrict the flood plain boundaries.

- The old Burlingame Bridge caused a constriction in the river channel which likely helped increase sediment transport capacity through the bridge, but caused a backwater effect and depositional zone upstream. The new Burlingame Bridge eliminated this constriction by increasing the opening to 430 ft from130 ft prior. Recent field observations in 2001 noted a lot of woody debris and depositional bars in the vicinity of the bridge (Photos 18A and B – Photographic Overview).

- The Woodcock Bridge embankment and Ward Road, together, now cause the biggest man-made impacts in Reach 2. These infrastructures cut off a portion of the flood plain on the west side and decrease riparian vegetation, but in general have much less impact than levees in Reach 4 or Reach 1.

7.3.5 Reach 1 (RM 2.6 to RM 0)

The following reach analysis builds upon two previous analyses completed by Reclamation for the Tribe (Appendices L and M). These other analyses investigated the following:

1) Levee setback alternatives for the ACOE and Olympic Game Farm Levees upstream of Schoolhouse Bridge in Reach 1 (RM 0.8 to 2.7)
2) Modification options for the Schoolhouse Bridge and levee setback or removal options for the ACOE and River's End Levees downstream of Schoolhouse Bridge in Reach 1 (RM 0.8 to mouth)

Conclusions from these reports are included below, and further details can be found by referring to the original reports included in Appendices L and M.

Reach Boundaries
The boundaries for Reach 1 are defined by the upstream end of the ACOE Levee on the east bank and the mouth of the river at Dungeness Bay in the Strait of Juan de Fuca (Figure 3A).

Main Features in the Reach
Reach 1 by far has experienced the greatest human impacts both today and historically, largely because of the extensive levee network. On the east bank, the ACOE Levee extends from
RM 2.6 (upstream end of Reach 1) all the way downstream to near the mouth (Figure O-34, Appendix O). At RM 0.8, the Schoolhouse Bridge crosses the river channel. On the west bank, the Olympic Game Farm Levee extends from RM 2.6 to RM 1.6. From RM 1.6 to RM 0.8, the west side of the prehistoric and present flood plain is bounded by a high glacial exposure (Figure 31). Downstream of the Schoolhouse Bridge on the west side, a private levee is present and is known as River's End Levee (Figure O-34, Appendix O). This levee extends downstream to near the mouth but is much lower in elevation than the ACOE Levee on the east side of the river. All of the levees were built to protect property and infrastructure from flooding.

Channel and Flood Plain Morphology
At high flows, the active channel is slightly meandering with very broad meander bends, except where the river flows along a remnant of Pleistocene deposits between Matriotti Creek and Schoolhouse Bridge (Figure O-29, Locality R1e, Table O-1, Appendix O). At low flows, the channel is mostly a single branch due to the constriction caused by the levees (Table O-1, Appendix O). Some short side channels, as well as a few overflow channels, are present on the east side of the present flood plain (Table O-1, Figures O-29 and O-30, Appendix O). Similar side and overflow channels were present on the west side of the natural flood plain.

Unvegetated bars in the active channel are primarily longitudinal bars that are preserved along the relatively straight sections of the channel (Figure O-29, Table O-1, Appendix O) . A few of the unvegetated bars are point bars that are preserved at meander bends. Mid-channel bars were not observed. Only a few vegetated bars are present in Reach 1; they are longitudinal bars (Figure O-29, Table O-1, Appendix O).

The natural flood plain widens in this reach and often exceeds 1500 ft (458 m) (Figure 31; Table O-5, Appendix O). The boundaries of the natural flood plain are mostly undefined topographically, but were defined from the approximate limit of the 1949 flood (Figure 31). The exceptions are the remnants of Pleistocene deposits that create well-defined banks on the west side between Matriotti Creek and Schoolhouse Bridge (Figure 31; between Localities R1e to R1g, Appendix O) and on the east near Schoolhouse Bridge. At Schoolhouse Bridge, the Dungeness River is pinned between the Pleistocene deposits, possibly as a result of isostatic rebound following the retreat of the continental ice sheet 12,000 to 13,000 years ago.

The present flood plain is bounded almost entirely by levees, except for the portions that are defined by the remnants of the Pleistocene deposits. Sixty percent of the east (right) boundary of the present flood plain is defined by levees and 37 percent of the west (left) bank is defined by levees (Table O-6, Figures O-33 and O-34, Appendix O). These levees reduce the width of the natural flood plain by 80 percent (Figure 31; Table O-5, Appendix O).

Fluvial and Tidal Processes Near the Mouth

Historically, the Dungeness River downstream of Schoolhouse Bridge flowed in multiple channels simultaneously creating a delta. The main channel likely filled with sediment rapidly as the slope dramatically flattens in this section. As one channel filled, the main channel would change to another location depositing material across the span of the lower 0.8 miles. Because the banks of the natural main channel or channels were low and poorly defined, water would have spilled onto adjacent flood plains during high flows.

It is hypothesized that the surface of the delta is probably quite young, and that the sediments composing the delta have been aggrading northward into Dungeness Bay since at least the late 1700s and probably much longer. The downstream most 0.8 mi (1.3 km) of Reach 1 (downstream of Schoolhouse Bridge) is hypothesized to be affected by tides and storm surges, so that the fluvial processes and tidal processes interact. The highest tides usually occur in December and June (Clark et al., 1995). The major floods occur along this section when high tides combine with high flows on the Dungeness River. Monitoring of the stage and flow at Schoolhouse Bridge is ongoing by the USGS and the Washington Department of Ecology. Personal observations and recorded data collected by the gage operators indicate that the tidal influence does not extend to the Schoolhouse Bridge. Hydraulic model computations using the maximum recorded tide stage in combination with the flood of record also indicate that the tidal influence does not likely extend upstream past Schoolhouse Bridge.

Woody Debris

Natural woody debris in the channel is nearly absent from Reach 1 except at meander bends, along Dungeness Bay, and at the mouth of the river (Table O-4, Figure O-31, Appendix O). The area that contains the most debris is the relatively tight meander along the remnant of the Pleistocene deposit (Figure O-31, Locality R1e, Appendix O). Along straighter sections of the reach, small pieces of wood are stranded on elevated longitudinal bars (Table O-4, Figure O-31, Appendix O). In recent years, several logs have been cabled to the west bank along the Olympic Game Farm Levee.

Bed Material

Near RM 1.5, between the ACOE and Olympic Game Farm levees, measurements were made on coarser and finer portions of a bar on the east side of the low-water channel (Figure 3A;

Appendix D). The top of the coarser bar (Sample DRsed-3B) is about 6 ft (2 m) above the low-water surface and is elevated. This portion of the bar is heavily armored; the gravel in the armor is weakly imbricated. A pavement also is present on the finer portion of the bar (Sample DRsed-3A). This pavement consists primarily of coarse pebbles and fine cobbles and is about one particle diameter thick. The underlying material is heterogeneous and loose.

At the mouth of the river, measurements were made on both a coarser bar (Sample DRsed-1B) and a finer bar (Sample DRsed-1A) (Figure 3A; Appendix D). The pavement on the finer bar is only very weakly developed and was not sampled separately. The finer bar is loose and sandy. The pavement on the coarser bar is only slightly better developed than it is on the finer bar, but was sampled separately. The pavement on the coarser bar is discontinuous and covers about 60 percent of the surface. The pavement rocks are not imbricated. Coatings of salt about 0.08 to 0.1 inch (2 to 3 mm) thick have formed at the ground surface on the pavement stones on the coarser bar. The underlying material on the coarser bar is loose and sandy.

Reach Hydraulics & Sediment Transport

Several hydraulic and sediment transport analyses were conducted in Reach 1 to evaluate:

1) Existing Conditions
2) 1935 Channel Conditions
3) Potential Levee Setback Options Upstream of Schoolhouse Bridge (see section 9)
4) Potential Schoolhouse Bridge and Downstream Levee Modifications (see section 9)
5) Tidal Influence

The cross section at the mouth of the Dungeness River is very wide and is heavily influenced by Dungeness Bay. The hydraulic results presented in this section do not include the cross section at the mouth. For existing conditions, Reach 1 has average velocities during a 2-year flood ranging from 4.1 to 10.2 ft/s and on average has more areas of high velocity than upstream reaches (Figure 18). Higher velocities result in a coarser channel bed than would naturally exist and tend to flush away fish eggs. Mean and maximum depths are also on average higher in Reach 1 than upstream reaches. Mean depth averages about 3.3 ft and maximum depths are roughly 1.3 to 3.9 times mean depth, with a range of 4.3 to 13.4 ft (Figure 19). Width to depth ratios are much smaller in Reach 1 than upstream reaches, with the exception of the area around RM 1.3 (cross section 9 near high bluff) and at the mouth (Figure 20).

The unit stream power computation shows a clearly decreasing trend in sediment transport capacity in this reach as a result of the flattening in slope (Figure 21), More detailed calculations using the calibrated sediment transport equation show a fluctuation throughout the reach (Figure 22). While overall sediment transport capacity does decrease in this reach as a result of the flattening in slope, several areas of high sediment transport capacity exist where levees have constricted the river channel. A detailed comparison of the existing channel bed relative to the 1935 channel bed was done to evaluate potential areas of change (Figure 32; copy in Appendix M). From RM 2.7 downstream to RM 2.3, the existing active channel can still contain the flood of record, even though a minor amount of aggradation has occurred. From RM 2.3 to RM 1.7, the ACOE and Olympic Game Farm Levees cut off flood plain and the active channel in some locations. The levees collectively constrict the river channel to much smaller widths than were present in 1935. The most constricted areas result in a backwater area upstream and several feet of riverbed aggradation have occurred. As a result, at some locations, such as at cross section 8 at RM 1.26, the river channel is now higher than the surrounding flood plain and channel capacity has been reduced (Figure 33).

Very little tidal data has been recorded in Dungeness Bay. Tide data that was available estimated a maximum tide elevation of 10.5 ft (3.2 m). Although not likely to occur often, the high tide would have the maximum influence on upstream river hydraulics when there is also a flood in the river at the same time. The hydraulic model was used to estimate the upstream influence from a high tide combined with a high flow in the river. The river slope is still fairly steep in this reach even though it is flatter than upstream. The thalweg at Schoolhouse Bridge is at the same elevation as the maximum tide. As a result, the tidal influence only extends to slightly downstream of Schoolhouse Bridge.

<u>Man-made Features and Their Impacts</u>

Although the entire lower 10.5 mi (17 km) of the Dungeness River corridor has been altered by humans, Reach 1, along with Reach 4, has been the most substantially modified by levees. Schoolhouse Bridge is an additional man-made feature that was constructed in the late 1870s, although it has been modified and rebuilt since that time.

The 2.6 -mile-long (4.2 km) ACOE Levee along the east side of the Dungeness River was completed in 1963. According to a local landowner, the levee was originally planned to follow the alignment of Towne Road upstream of the Dungeness Schoolhouse (Beebe, unpublished). However, after concern from citizens who lived between the east bank of the river and Towne Road that they would be unprotected from floods, the ACOE agreed to locate the levee along or close to the riverbank.

Prior to the ACOE Levee, several old post and plank bulkheads had already been built in several areas on the sharpest corners of the lower river to keep flood flows in the river channel (Dickinson, 1985; 1935 County Map). The longest bank protection had been placed at the Town of Dungeness (Figure 3A) and was 2000 ft (610 m) in length (Beebe, written communication). This bulkhead, in the same location as the ACOE Levee, was originally built at a much lower elevation in the 1950s by private landowners.

On the west bank upstream of Schoolhouse Bridge, a farm levee formerly called Seamands' Dike existed at the location of the present Olympic Game Farm Levee (L. Beebe, 1998, oral communication). The farm levee was likely low in elevation and constructed in the early 1900s to protect the property from flooding (Beebe, 1998, oral communication; Dickinson, 1985). However, local landowners have recalled that between the levee and Ward Road, wide-spread flooding still occurred. Washington State Fisheries also built a levee on the west bank downstream of the Seamands' Dike at an island just above the point of the high clay bank [remnant of Pleistocene deposits at Locality R1e, Figure O-29, Appendix O] (Beebe, unpublished). The purpose of this levee was to protect the clay bank, which was being eroded by the Dungeness River. This levee was later connected to the Seamands' Dike. Following the construction of the ACOE levee on the opposite side, flood stage was increased due to the cutting off of the east flood plain. The elevation of the west dike was subsequently raised and is now referred to as the Olympic Game Farm Levee (Beebe, written communication). Large woody debris has often been cabled to this levee to provide additional stability and protection during floods.

Downstream of Schoolhouse Bridge, the River's End Levee on the west bank is lower in elevation than the ACOE Levee on the opposite east bank. In 1998, Rivers End Levee was breached by a 2-year flood and the river flowed into an old 1855 channel depositing fine grained- and gravel-sized sediments (Figure 31; Locality R1h, Appendix O). During the flood of record on January 7, 2002 (7,610 cfs) the levee was again breached.

Downstream from Schoolhouse Bridge, levees are present on 60 percent of the east (right) bank and 37 percent of west (left) bank (Table O-6, Figure O-34, Appendix O). Upstream of Schoolhouse Bridge, levees are present on 97 percent of the right (east) bank and 65 percent of the left (west) bank with the remainder of the left bank being controlled by a high natural bluff (geologic control). This results in virtually all of the river bank being either naturally or levee controlled upstream of Schoolhouse Bridge. The majority of the river downstream of Schoolhouse Bridge is controlled by levees until just before the river's mouth. Throughout Reach 1, 33 to 86 percent of the natural flood plain has been cut off by the levees (Figure 31; Table O-5, Appendix O).

The levees have essentially locked in the channel pattern that was present in 1963 when the ACOE Levee was constructed. The sinuosity in Reach 1 between Schoolhouse Bridge and the upstream end of the levees has remained relatively the same from the 1942/43 time period to 2000 at a low value of 1.04 (Table O-2, Appendix O). Between Schoolhouse Bridge and the natural cliff on the west side, there is a short reach where the river path is controlled by the natural features in the valley and the sinuosity will also remain low. However, upstream from the cliff to the end of the levees and Reach 1, the sinuosity would be much higher if the levees on either side of the bank did not constrict the river and cut off flood plain.

The combination of the ACOE, Olympic Game Farm, and River's End Levees, together, have markedly changed the characteristics of the banks along the Dungeness River. Because the present levees have modified this reach so dramatically, natural processes were inferred from the deposits and surficial features that are preserved along the present channel and on the surfaces adjacent to it (Tables O-1, O-2, O-4, and O-7, Appendix O). Prior to the levees, a main channel, somewhat similar to that in the upstream reaches, must have existed in this reach and transported gravel and sand to Dungeness Bay. It is possible that more than one channel existed simultaneously. Upstream of Schoolhouse Bridge, a large portion of high flows historically ponded on the adjacent flood plains or entered Meadowbrook Creek, located on the east side of the river (Figure 3A). Water that entered Meadowbrook Creek traveled directly into Dungeness Bay and never returned to the main Dungeness River. Water ponded on the flood plain further reduced the amount of water flowing in the main channel downstream during high flows. This meant that the main channel downstream of Schoolhouse Bridge needed less capacity to contain river flows, even during floods. Today, levees restrict access to the flood plain and Meadowbrook Creek so that all flow must remain in the main channel and pass through Schoolhouse Bridge.

Other human impacts that have occurred frequently in Reach 1 are gravel mining and removal of woody debris from the main channel. Private landowners document that, they assisted the county from mining gravel in the lower river channel and removed woody debris from the late

1940s until 1954 (Beebe, unpublished). The mined gravel was used to build up private levees on either side of the river to protect private land from flooding. One landowner notes that since the 1950s gravel mining has been continued along his Olympic Game Farm into the late 1990s (Beebe, oral communication, 1998). The most extensive gravel mining documented was in 1991 and 1992 when 21 gravel traps were dug in bars on the inside of meander bends (Beebe, unpublished). Gravel traps were dug in the channel in this reach adjacent to the Olympic Game Farm to prevent aggradation of the channel which would result in increased risk of flooding. According to observations, gravel always was redeposited on the mined gravel bars, although the traps did succeed in temporarily lowering the bed (Beebe, unpublished). A statement by another local landowner noted that the riverbed has aggraded in the reach of the Olympic Game Farm Levee as documented by the height of the banks relative to the elevation of the riverbed (Dickinson, 1985). Northwest Hydraulics (1987) noted that in the 1982-84 time period a debris dam formed adjacent to the Olympic Game Farm property and resulted in flooding. Today, woody debris is infrequent in Reach 1, particularly in comparison to upstream reaches and aggradation of the riverbed continues to be a concern (Figure O-31: Appendix O).

<u>Reach 1 Discussion and Conclusions</u>
The most important features in this reach are the levees, which line nearly the entire active channel. These levees have affected fluvial processes in a number of ways. Some of these changes are listed below.

- Local landowners have reported river sediments (gravel and coarse sand) beneath surfaces adjacent to the west side of the river (Beebe, oral communication, 1998). It is not unlikely that gravel should be preserved in the existing flood plain because sediment this big could not be transported by over bank flows. The presence of the gravel indicates the locations of old channels that were later filled in and buried by finer, overbank, sediment. At this time, it is not known the extent of the gravel in the flood plain or the ages of any of the former channels.

- A single, well-defined main channel with high banks that are created by the man-made levees now exists along the entire length of Reach 1. Even at very high flows, water does not spill out of these artificial banks onto the surrounding surfaces. The only exception is downstream of Schoolhouse Bridge on the west side where flows greater than the 2-year flood have been documented to overtop and breach the River's End Levee. A small amount of wooded flood plain can be accessed by the river in a few areas where the ACOE Levee has been slightly setback from the main channel.

- Historically, the main channel capacity did not have the capacity to contain all of the water during a flood and a significant portion of the flow exited the main river. Flow either entered Meadowbrook Creek or overtopped the banks of the active channel and ponded on the adjacent flood plains. Today, all of the flow is forced to remain in the main channel all the way to the mouth at Dungeness Bay. Because no overflow of water occurs now, all the fine-grained sediment (silt and clay) that was previously deposited on flood plain surfaces is transported downstream to the bay.

- Levees constrict the river, which results in higher stage, higher velocity, and greater transport capacity for both sediment and wood. As a result, Reach 1 has some constricted areas where the river channel has remained at a relatively constant elevation before and after the levees were built. This is because stage, velocity, and sediment transport capacity increase rapidly with river flow. Where the levees constrict the river, backwater areas exist upstream where the levees are setback some distance from the active channel. In these areas, river velocities actually are slower and sediment transport capacity decreases. As a result, comparison of the existing channel bed to the one that existed before the levees were built show several feet of channel bed aggradation.

- Because the flood stage in the main channel is now higher than it was before the levees were built, gravel has accumulated into bars that are higher in elevation than they would be naturally. The tops of these bars are elevated with respect to all but extreme floods. Consequently, the gravel in these bars is moved only in the highest flows and is not as mobile as that in bars along the natural main channel. This means that there are probably thicker deposits of gravel adjacent to the main channel than before the levees were built. The high bars are preserved at the edges of the main channel. Because the main channel is a single channel with no side channels, there are no mid-channel bars along this reach. Before the levees were built, side channels may have existed and mid-channel bars may have been present. The width may be so constricted at this time that the gravel, which is transported as bedload, cannot entirely pass through the reach and aggradation of the channel is accelerated.

- The levees constrict the width of the channel which would limit the number of side channels in two ways. First, the present width does not allow side channels to form. Second, the constricted width limits meandering and channel migration which are the processes by which productive side channels develop.

- Before the levees were built, multiple channel branches existed downstream of Schoolhouse Bridge. The lowermost 0.27 mi (0.4 km) of the Dungeness River is now confined on the east by the ACOE Levee and by the River’s End Levee on the west. River’s End Levee is much lower in elevation than the ACOE Levee. This portion of the river regularly overflows the River’s End Levee into one or more of the former channels that extend to the west of the present main channel. Many old levees and excavations are visible on the tidal flat north of the high bluff of Pleistocene sediment. Several generations of levees are present, where one levee broke and was later fixed or modified or where one levee was replace by a later one. This attests to the transitory nature of the channels and indicates that humans have a long history of trying to control this portion of the river.

- Very little woody debris is present in the main channel. Before the levees were built, it is likely that woody debris was much more common and created a complex system with multiple channels and wooded side channel areas. Landowners document that wood was historically cleared out of the channel to prevent debris dams from forming and increasing flooding.

- All of the bars that are preserved along the sides of the main channel are unvegetated. Vegetated bars that might be older are nearly nonexistent. The lack of vegetation seems to indicate that the gravel bars are mobilized and reworked frequently enough that vegetation cannot become established.

8.0 CONCLUSIONS

The natural physical processes of the Dungeness River have been impacted by several human activities. The magnitude of the impact varies by the type of human activity and by the reach of the river. Five reaches were identified in the lower 10.5 miles of river based on natural geologic features and geomorphic characteristics (described in Section 7.1). Several options exist to help restore some of the natural physical processes in each of these reaches. Each of these restoration options have several management implications which need to be understood before actions are taken. This chapter describes the conclusions regarding natural processes, the impacts by human activities, and management implications of restoration options.

8.1 Natural Physical Processes

The Dungeness River has always been a complex and dynamic system that naturally migrated across the flood plain throughout the lower 10.5 miles. The majority of sediment transport and subsequent channel change occurs during flood flows, which typically take place during winter. The river is relatively wide, shallow, and has a relatively straight alignment with active channel sinuosity ranging between 1 and 1.3. However, the river planform does have some meandering or sinuous characteristics. River bank erosion naturally tends to occur along the outside of meander bends while sand, gravel, and cobbles are deposited along the inside of meander bends. Riparian vegetation and the resulting woody debris tend to limit the rates of bank erosion, but ultimately the river bends can and do migrate across the flood plain and downstream over time. If the meander bends migrate too far and become elongated, then meander cut off channels will form during floods and the low flow channel will become straighter. After this change, the channel meandering and migration processes begin again.

In reaches with particularly wide flood plains (e.g., reach 3), the bed of the active river channel is at a higher elevation than some of the side and overflow channels in the wooded flood plain. Also, the main river channel transports most of the coarse sediment (coarse sand, gravel, and cobbles) along and near the riverbed and relatively little is transported near the water surface. During a flood, sediment and woody debris loads in the main channel increase, but a portion of the flood flow is conveyed through the side and overflow channels. Large woody debris often collects at the entrance to side channels. The woody debris limits the amount of water and substantially reduces the concentrations of coarse sediment entering these channels. This leaves the main river channel with less water to transport its load of coarse sediment and large woody debris. Therefore, coarse sediments tend to deposit along the main river channel (aggradation) because less water is available to continue the transport of coarse sediments in the main channel. Also, large woody debris tends to become stable in the main channel. As the main channel continues to aggrade, more and more river flow will enter the side and overflow channels, particularly when they are at a lower elevation. This process will ultimately result in a shift in channel position during a flood when the majority of river flow is diverted into a side or overflow channel.

The river slope naturally decreases in the downstream direction, especially in reach 2 between RM 3.5 and 4.5. This decrease in a river slope reduces the river’s energy or hydraulic capacity to keep the coarse sediment moving. Consequently, cobbles and large gravels deposit along the main river channel and the channel is forced to shift laterally, often spilling into side channels. However, the rate at which cobbles and gravels are supplied from upstream is relatively slow so the rate of deposition along the riverbed is also slow.

Riparian vegetation and woody debris are important components of the river in that they maintain scour pools, side channels, and diverse habitats utilized by fish and other species. During the summer-low flow period, the deeper depths associated with scour pools provide lower velocities and cooler water temperatures. During floods in the winter or spring snowmelt periods, scour pools and side channels provide refuge areas where fish can escape turbulent, high velocity and high turbidity areas of the river.

8.2 Impacts from Human Activities

All of the natural processes described in the previous section continue today, but they have been impacted, to varying degrees, by human activities. The following human activities have had the most significant impact on river plan from (morphology) and physical processes:

- Construction of levees
- Clearing of riparian vegetation
- Construction of highway and railroad bridges
- Construction of riverbank protection structures
- Gravel extraction
- Water diversions

The five reaches of the lower Dungeness River have been impacted to varying degrees (see Table O-6). Reaches 1 and 4 have been impacted the most while reaches 2 and 3 have been impacted the least. The magnitude of impact also varies by the type and longevity of human activity.

8.2.1 Construction of Levees

The construction of levees has had the greatest impact on the river because of the number of processes affected and the length of the river impacted. The levees cut off the river’s access to all or a portion of the flood plain, side channels, and, in some cases, access to the active river channel. By cutting off flood plains the levees force more water to stay in the main channel, especially during flood flows. Consequently, the water velocity, depth, and the capacity to transport sediment and large woody debris all increase with increases in river flow. These increases result in a coarser gravel or cobble size along the deeper portions of the riverbed and limits the amount of stable woody debris. Also, gravel bars tend to deposit at greater heights because the water surface elevations and depths are greater during floods than they would be without the levees. Because the side channels and flood plain are cut off, all of the fine sediments (silt and clay) present in the river remain in the main channel and are easily transported to the mouth. If the levees were not present, a large portion of these fine sediments would leave the main channel and be deposited onto the flood plain surface as flows spill out and overtop the river banks.

When the levees are at or close to the edge of the active river channel, they effectively lock the channel into one place and prevent natural migration of the river channel. When the levee alignment causes local constrictions in the river channel or flood plains, then flood velocities are high at the constriction and a backwater pool forms upstream. Cobbles, gravel, and sand then deposit in the backwater pool. For example, the river has aggraded as much as 10 feet as a result of local levee constrictions in reach 1. Eventually, the channel bed in these backwater areas reaches an equilibrium level as the water depth becomes shallow and the velocities increase.

Because levees affect multiple natural processes, they cause the greatest impact on the physical system. The levees cause the main river channel to have coarser sediments on the bed, elevated gravel bars, less woody debris, and fewer stable pools. The levees also cut off side channels and result in higher velocities and depths in the main channel during floods. All of these effects alter fish habitat conditions including water depth, velocity, sediment substrate, and vegetative cover.

8.2.2 Clearing of Riparian Vegetation

The clearing of riparian vegetation along the river channel causes the banks to become more susceptible to erosion. The root structure from trees reinforces and adds roughness to the river banks. When the banks do erode, the trees fall in the channel at the toe of the bank and help protect it from additional erosion by slowing river velocities along the bank. However, when the riparian vegetation is cleared, the river banks have less strength and roughness. When bank erosion does occur, there are no trees to add roughness at the toe of the bank and slow the rate of erosion. For example, downstream from the Railroad Bridge, large areas of trees were cleared from the flood plain and terraces prior to mapping in 1913 and again prior to the aerial photography of 1942-43 (Photo 29 – Photographic Overview). Some of the most severe bank erosion on the lower Dungeness River occurred in this area between 1942 and 1994.

8.2.3 Construction of Highway and Railroad Bridges.

Bridges have impacted natural river processes by locally constricting the flood plains and the active river channel. These local constrictions cut off access to side channels and flood plain overflow channels. Bridge constrictions can also interfere with the natural channel migration of meander bends. However, most of the present bridges along the Dungeness River were built at natural geologic constrictions in the flood plain. Although, some of the bridges constrict a portion of the flood plain, they do not, in general, constrict the active river channel. Therefore, the impact of bridges on natural processes tends to be local, extending only a few thousand feet upstream and downstream from the bridge. One local effect from a bridge constriction is to accelerate flow under the bridge and cause a backwater to form upstream. Coarse sediment and woody debris then deposit in this backwater and the channel bed aggrades. Presently, the embankments of the Woodcock Bridge impose the greatest constriction on the natural channel and flood plain. Bridge piers can also locally cause the flow to be parallel to the bridge pier.

8.2.4 Construction of riverbank protection structures

A variety of structures has been placed along the river in various locations to control or prevent the erosion of river banks, levees, and dikes. Riprap is the most common material used in these erosion control structures, but wooden bulkheads and large woody debris have also been used. When levees or dikes need erosion protection from river flow, it is typically because the levee or dike is too close to the active river channel. In these cases, the levee or dike is preventing the natural migration of the active river channel and forcing the slope and velocity to increase. This also prevents the recruitment of large woody debris. Examples include the Dungeness Meadows Levee, Olympic Game Farm Levee, and portions of the ACOE Levee (Photos 23 and 24 – Photographic Overview).

When natural river banks need to be protected from erosion (especially when they are hundreds or thousands of years old), human impact is generally the cause of the erosion. Such human impact may include levees, dikes, or bridges that force too much river flow toward the eroding bank. In addition, the clearing of riparian vegetation makes the banks more susceptible to erosion. The bank protection structures do not normally constrict the natural river channel. The protection is typically placed after the natural bank has already experienced some erosion which results in a wider channel. When the bank protection structures do not cut off access to the flood plain or side channels, the structures have much less potential to impact natural processes. When the structures incorporate large woody debris, they can also provide fish habitats (cover and scour holes) along the bank. Rock riprap structures can provide scour holes along the bank, but do not typically provide vegetative cover or diversity of habitat for fish. Bank protection structures do impact natural processes when they protect levees, dikes, and bridges, or otherwise cut off the flow access to side channels and flood plains. However, bank protection placed on natural river banks experiencing erosion as a result of a human impact can be viewed as mitigation for the human impact and not, by itself, a direct impact on natural processes.

8.2.5 Gravel Extraction

Gravel has been extracted or mined from the Dungeness River channel at various locations in an attempt to control aggradation. In theory, gravel extraction could be used to control aggradation if the extraction rate can be matched to the aggradation rate. However, gravel extraction can cause problems for the channel and for fish habitat. For example, gravel excavation can also cause the channel to migrate laterally to the trap during a flood. If too much gravel is extracted at one time (especially at too great a depth), then headcut erosion can migrate upstream from the gravel pit and destabilize the upstream channel. The material excavated from smaller gravel traps can be filled during a single winter flood. Gravel traps can also attract spawning fish whose offspring will become suffocated the following winter when the trap becomes filled with new sediment.

There are problems with using gravel extraction as a long-term strategy to control aggradation. However, gravel extraction would be needed on a one-time basis at various locations in Reach 1 if the either the ACOE or the Olympic Game Farm Levees are setback. In this case, the gravel extraction would be mitigation for local aggradation caused by levee constrictions and to prevent the channel from flowing over the east flood plain after a levee setback.

8.2.6 Water Diversions

The diversion of river water for irrigation or municipal uses reduces the river flow, depth, velocity, and wetted channel width. When river flows are high, the amount of water diverted may be relatively small. Further, the majority of high flows occur during the winter months when significant quantities of water is not diverted for agricultural purposes. However, during the low-flow summer period, the amount of water diverted could be a much larger portion of the total river flow. The reduction of river flow in summer, and the resulting decreases in water velocity, depth, and wetted width, would also lead to increases in water temperature and potentially allows fine sediments to temporarily deposit along the riverbed. Although these effects would directly impact fish habitats (especially during summer), they would not affect the channel geometry, alignment, or vegetation characteristics. This is because the amount of coarse sediment transported during low-flow periods is naturally very low.

8.3 River Restoration Options

A variety of management actions that could be considered to restore the Dungeness River are discussed below. Each action will require that decision makers assess the existing river channel conditions, the future consequences if no action is implemented, and the costs and benefits of implementing a particular restoration action.

8.3.1 Levee Setback or Removal Options

Setting back or removing the levees restores a chain of natural processes. Where possible, levee setback or removal may be one of the most powerful management tools available to restoring fish habitat. The natural processes or linkages include allowing room for natural channel migration or meandering to occur, restored access to side channels and the flood plain which would reduce velocities and water depths in the main river channel. The lower depths and velocities will allow gravel-sized sediments to accumulate over coarser bed material increasing potential spawning areas. The lower depths and velocities will also allow for more recruitment of large woody debris. This will, in turn, increase the number of local scour holes which can become pools during periods of low flow. High elevation bars and, in some places, the aggraded channel bed would have to be removed or lowered in order to prevent channel avulsions into areas the river would not naturally flow. Encouraging the growth of riparian vegetation to create a buffer zone along the river to prevent unnatural bank erosion and restore riparian habitat. Specific management considerations for restoration options related to the major levees along the Dungeness River are described in the following sections.

Levees From RM 0.0 to 2.7 — The existing levees in Reach 1 have significantly altered natural physical processes and impacted habitat for fish. However, housing and infrastructure in the flood plain of reach 1 are relatively sparse and it may be locally acceptable to setback and even remove portions of the levees that exist on both sides of the river. A potential restoration option for RM 2.7 to the mouth could include a series of levee setback and removal actions that would be implemented in phases. The reach downstream of Schoolhouse Bridge could be one restoration area and the reach upstream from Schoolhouse Bridge a second area.

<u>Levees Downstream from Schoolhouse Bridge: RM 0.0 to 0.8</u> **—** Downstream from the Schoolhouse Bridge, the U.S. Army Corp of Engineers (ACOE) Levee on the right (east) side is much higher and is more stable than the River's End Levee that exists on the left (west) side. The ACOE Levee protects the community of Dungeness from virtually all river floods, while the River's End Levee only protects local residents from flows up to the 2-year flood. The ACOE Levee extends about 300 feet farther downstream than necessary to protect the

community of Dungeness. Residents living behind the River's End Levee are subject to river flooding on a frequent basis because the levee is often breached.

If it is desired to restore natural river processes downstream from Schoolhouse Bridge, the River's End residents and buildings would need to be relocated. The next step would be to remove the entire River's End Levee (west side) and remove the downstream-most 300 ft of the ACOE Levee (east side). This series of levee removals would reduce water surface elevations under Schoolhouse Bridge during floods and allow the Dungeness River to migrate laterally across the delta as it enters Dungeness Bay. The community of Dungeness would still be protected from river floods by the remaining ACOE Levee. With this option, additional bank protection may be required along the road leading to the Three Crabs Restaurant (location shown on Figure 3A).

<u>Levees Upstream from Schoolhouse Bridge: RM 0.8 to 2.6</u> **—** Upstream from the Schoolhouse Bridge, the Olympic Game Farm Levee on the left (west) side matches and sometimes exceeds the height of the ACOE Levee on the right (east) side. The ACOE Levee is only adjacent to the active river channel at a few locations and does leave narrow portions of the flood plain connected to the river. The flood plain protected by this levee contains both homes and farm pasture land. The Olympic Game Farm Levee is adjacent to the river for its entire length. The flood plain protected by this levee contains a portion of the Olympic Game Farm. The combination of the two levees have caused several constricted areas that have affected natural physical processes.

If it is desired to restore natural river processes upstream from Schoolhouse Bridge, the ACOE Levee could be setback to Towne Road and the Olympic Game Farm Levee setback to Ward Road by raising the elevation of the road surfaces (see Figure 3A for locations). Setting back both the levees to Towne and Ward Roads would roughly approximate the boundaries of the 1949 flood, thus restoring the natural floodplain processes. The exception would be that the new east levee would still block the flood overflow channel leading to Meadowbrook Creek. Flood flows entering the overflow channel would pond up against the new levee. Some of this ponded water would again enter the Dungeness River and the remainder would either seep into the ground or evaporate. A small opening or drain in the new levee could be considered to allow a limited amount of flow to enter Meadowbrook Creek and slowly drain any flood flow ponded against the levee.

Setting back both of these levees would restore a large portion of the natural river processes and fish habitat, but first the existing river channel would have to be restored to the pre-levee topography. The local aggradation caused by the levees at RM 1.3 and other locations would have to be mechanically removed to prevent the river from changing course and flowing over the flood plain soils. The 1935 contour map and the levee construction drawings provide the best source of information on the pre-levee channel topography.

Setting back the Olympic Game Farm Levee to Ward Road would still provide protection to the majority of the Olympic Game Farm and existing buildings. Setting back the ACOE Levee to Towne Road would require relocation of homes and structures presently protected. Another option that could be considered is leaving portions of the levee in place to protect individual homes while setting back the remainder of the levee. Setting back the ACOE Levee to Towne Road would reduce the total length of the levee required because the boundary of the 1949 flood did not extend to Towne Road in the upstream portion of Reach 1.

If only the ACOE Levee were setback, then the entire left (west) flood plain would still be cut off by the Olympic Game Farm Levee and the setback levee on the east side would have to be extended farther upstream.

Dungeness Meadow Levee: RM 7.5 to 8.1 — The Dungeness Meadows Levee was built in the 1960s to protect the homes of the Dungeness Meadows Neighborhood that were built within the flood plain. Some of the homes built in the flood plain were also built very close to the edge of the main river channel and along a large side channel. The levee protecting these homes cuts off portions of the1942/43 main channel and a side channel leading to the downstream end of the neighborhood. This side channel still conveys water through a groundwater connection from the main river channel. The side-channel flows rejoin the main river channel farther downstream. The side channel still provides habitat for upstream migrating fish, but the fish can only enter the side channel from the downstream end.

The Dungeness Meadows Levee also cuts off significant portions of the flood plain. Consequently, there are increases in water depth, velocity, and the capacity to transport sediment and woody debris in the main river channel. In response to these increases, small rock levees and bank protection have been built on the left (west) bank to protect private property and the Taylor Cutoff Road. However, a recent 2002 survey documented that bank erosion and flooding on the west bank across from Dungeness Meadows Levee is still occurring. The river is unnaturally constricted between the Dungeness Meadows Levee on the right and a high, near vertical bank on the left. This constriction will lead to additional erosion of the left bank during large floods.

Unless the homes built in the flood plain are relocated, the Dungeness Meadows Levee is needed to protect the neighborhood from floods. The fish habitat along the levee has been impacted because of the increased particle size on the bed, the increased water depth and velocity during floods, the absence of cover from riparian vegetation, and the blocked access to side channels. One restoration option would be to allow fish passage from the upstream end of the side channel throughout the year. This could be accomplished by setting back the downstream end of the levee to continue to provide protection to residents but allow a connection between the river and the side channel. Another potential option is to construct an opening in the levee to allow fish access from the upstream end of the flood plain side channel. It may be possible to design a small opening in the levee that would allow water flow and fish passage, but limit the main channel from taking over the side channel. The opening design could be wider at the bottom and narrower at the top to limit the amount of water entering the side channel to safe channel capacity during floods. A log jam might also be designed at the levee opening to decrease velocities for fish and further limit the flow into the side channel during floods. Additional study would be required to determine the feasibility, cost, and benefit of either option.

A potential restoration option for fish habitat would be to create stable pools in the main channel that would facilitate upstream fish passage during low flow periods. Engineered log jams could be added to the main channel for this purpose and to also prevent further erosion of the west bank opposite Dungeness Meadows Levee. However, the design would have to ensure that water surface elevations of the main channel would not significantly increase during floods.

Haller Dike: RM 8.6 to 8.9 — The Haller dike was originally constructed by the land developer to protect a few homes that were built in the flood plain. After flood damage to the dike in 1996, the dike was rebuilt and setback a limited amount by Clallam County in 1997. The dike no longer has a direct impact on the main channel, but it does cut off the entire left (west) flood plain from the river. However, this flood plain is relatively high so that the impacts from this dike (higher depth and velocity in the main channel) are minimal compared to the impacts from other downstream levees.

Kinkade Island Levee (RM 9.6 to 9.9) and Kinkade Creek — Kinkade Island exists between the main channel of the Dungeness River on the west and a prominent side channel, known as Kinkade Creek, on the east. Kinkade Creek has grown since the 1960s to become a well-established side channel (Photos 21 and 22 – Photographic Overview). Kinkade Island is part of the flood plain and includes 7 homes, a levee, and two vehicle bridges that cross Kinkade Creek. A 1,100-foot long levee was built along the west edge of the island to protect residents from frequent flooding.

A recent study by West Consultants (2000), under contract from Clallam County, described plans for removing the 1,100-foot long levee. Based on the study findings, a 55-foot long portion of the levee was removed by the County to allow fish access to a productive side channel (J. Freudenthal, Clallam County, WA, written communication, 2000). Continued fish monitoring in the side channel has been scheduled by the County to determine the increase in use and provide a flood risk assessment. The County and the City of Sequim have stated that the long-term objective for Kinkade Island is to reduce the flood hazard through the purchase of the approximately 7 homes on the island (Freudenthal, County Memorandum, 2000). If these residents are relocated, the remaining portion of the levee could be removed to restore full access to the flood plain and side channels.

The Kinkade Island Levee is known to overtop at frequent floods and the residents of Kinkade Island are currently still at risk from flooding. In addition, at least half of the main river flow now enters Kinkade Creek. Two of the upstream entrances to Kinkade Creek are presently controlled by natural log jams and the other entrances are also accumulating woody debris. The entrances are located on the outside of a meander bend in the Dungeness River (about 600 ft downstream from the fish hatchery). With erosion along the outside of this meander bend and deposition along the inside of the bend, the river bend has been migrating down the valley over the last several decades. Downstream from this meander bend, the river flows nearly perpendicular to the valley slope before intersecting glacial deposits on the left (west) side. There is a decrease in river slope when the main channel crosses the valley and coarse sediments have the potential to deposit in the main river channel. Both the down-valley migration of the meander bend and the potential for sediment deposition in the channel crossing the valley may one day cause the main Dungeness River channel to be entirely captured by Kinkade Creek. Such a change in channel position would most likely occur during a flood by either removing the log jam at the entrance to the side channel or eroding a new channel around the log jam. If Kinkade Creek were to capture the main channel of the Dungeness River, both banks of the present creek channel would be subject to erosion. Bank erosion of the present channel has already caused failure of the downstream vehicle bridge during the January 2002 flood. Additional erosion and flooding pose a serious danger to the remaining bridge and residents. If flooding occurred at night, the bridge could potentially wash out before residents of the island could evacuate. Therefore, the log jam and the position of the Dungeness River at the entrance to Kinkade Creek should be carefully monitored and an emergency evacuation plan should be prepared for the residents of Kinkade Island. A potential option that could be considered is the addition of large woody debris to the entrances to Kinkade Creek that would slow the rate of channel migration and limit the amount of flow.

8.3.2 Integration of Large Woody Debris

Large woody debris could be placed in the Dungeness River to help restore many natural processes. Engineered log jams or wood revetments could be constructed to stop erosion of old river banks while at the same time provide scour pool and cover habitat for fish. In this case, the engineered log jams would simulate the natural roughness and cover of trees falling into the river channel from naturally eroding banks. The spacing and size of the log jams is an important design feature. If the spacing is too large or the log jams too small, they may be ineffective in protecting the bank. If the log jam is too large, it may cause unexpected problems downstream. If the objective of the log jams are constructed to create scour pool habitat for fish, they must be constructed in the low flow channel. A system of engineered log jams may be needed to accommodate lateral migration of the low-flow channel over time. Engineered log jams also could be constructed to better align flows under bridges and even prevent woody debris from being captured on bridge piers. Engineered log jams could be effective along eroding river banks where riparian vegetation has been cleared and along banks where riprap prevents or limits the interaction between river flows and riparian vegetation.

Engineered log jams need to be carefully planned to avoid potential problems. Geomorphic analysis is needed to anticipate the potential future alignments of the river to ensure that the log jam is functional in the future and that the jam does not cause future bank erosion by deflecting flows into the bank. Structural and hydraulic analysis of fluid forces and strength of the log jam is needed to ensure that the log jam does not float away or come apart during a flood. Hydraulic analyses are needed to ensure that the log jams would not significantly increase water surface elevations during floods.

Engineered log jams may be the most effective in locations where levees are being removed or setback (reach 1), in locations where mitigation is required for existing riprap bank protection (reaches 4 and 5), and in locations where there is active erosion of natural river banks
(reach 3). Recently, woody debris has been placed in side channels to improve fish habitat. One example is in Dawley's side channel in the east flood plain just upstream of Highway 101 Bridge (see Figure 3A for location; Rot, 2001).

8.3.3 Modification of Bridges

As stated in section 9.2.3, the impact of bridges on natural processes tends to be local, extending only a few thousand ft upstream and downstream from the bridge. In general, the bridges were built at natural geologic constrictions in the flood plain and the impact on natural processes varies from bridge to bridge.

Schoolhouse Bridge. — Removal of the downstream River's End Levee and lengthening the span of Schoolhouse Bridge have been discussed as potential restoration alternatives to reduce water surface elevations under the bridge to more natural levels. Presently, the west terrace just upstream of Schoolhouse Bridge is inundated at the 5-year flood and culverts have been placed to prevent overtopping of the road. The higher water surface elevations that now occur are mainly due to the levees downstream and upstream of Schoolhouse Bridge. The downstream levees cut off hundreds of feet of flood plain and constrict the channel which causes a backwater effect under the bridge and an elevated flood stage. The upstream levees also cut off the flood plain and access to Meadowbrook Creek which result in the entire flood peak passing under Schoolhouse Bridge. Prior to construction of the upstream levees, flows greater than the 2-year would be stored on the flood plain or transferred to Meadowbrook Creek.

The bridge itself does not significantly constrict the river beyond natural conditions because it is located on glacial knobs which naturally constrict the flow and are very resistant to erosion (Photo 25 – Photographic Overview). Consistent with the local geology, construction drawings of the bridge show that no embankment was built on the east side, but rather resistant glacial material was excavated in an attempt to widen the channel. A narrow road embankment was built on the west side. In addition to the bridge constriction, the natural geologic controls form a stable bend in the river at the bridge that would exist even if the bridge was not in place. As flow accelerates around the bend, the high velocities and secondary currents along the outside of the bend maintain the thalweg along the east (right) bank. This thalweg has remained on the outside of the bend and at about the same elevation since at least 1963 (just prior to the construction of the bridge). The secondary currents deposit sediment along the inside of the bend forming a gravel bar.

If the bridge were widened to the west and the west road embankment were excavated back down to the pre-bridge topography, the gravel bar would still persist and the wetted channel width would not change for flows up to the 2-year flood. Model results predict that the natural river bank, under a widened bridge, would begin to be overtopped at the 2-year flood. The flood of record would overtop the bank and extend the wetted width an additional 200 feet beyond the existing bridge embankment. However, the average depth over the bank would be small (less than 1.5 feet). Thus any proposal for bridge extension should be limited to 200 feet. There would be no increase in wetted widths for flows less than the 2-year flood peak.

Three restoration alternatives for reducing water surface elevations under the bridge were evaluated: lengthening the bridge span only, removal of River’s End Levee only, and a combination of both. The ability of these alternatives to reduce water surface elevations under the bridge were compared (Table 6). While the hydraulic model may only be able to predict flood stage within a foot of the actual flood stage, a comparison of model results for various alternatives is accurate to with a few tenths of a foot.

Alternative 1 – Model results for flood stage show that if the downstream and upstream levees were left in place but the bridge span were lengthened, the flood stage would only reduce by 0.1 feet during flows greater than the 2-year flood peak.

Alternative 2 – If the bridge was left in place but the River’s End Levee was removed the flood stage would reduce by 0.7 feet during the 2-year flood peak, 1.4 feet during the 5-year flood peak, and 2 feet during the flood peak of record. Therefore, removing the River’s End Levee would restore several hundred feet of flood plain and reduce the backwater effect and flood stage under the bridge more than lengthening the bridge itself. Removal of the downstream ACOE Levee would have a similar effect, but this alternative is not being considered.

<u>Alternative 3</u> – Bridge extension combined with River's End Levee removal would additionally decrease flood levels (beyond only removing the levee) underneath the bridge 0.2 feet at the flood of record.

Based on these conclusions, it would be more effective to first remove the River's End Levee, and then monitor future hydraulic conditions at the bridge before making any decisions to lengthen the bridge span. Setting back all or portions of the upstream levees would further reduce the unnaturally high flood peaks passing under the bridge.

Table 6. Relative water surface elevation comparison for flood peaks at Schoolhouse Bridge for three restoration alternatives (rounded to the nearest tenth of a foot). Reduction in flood stage for each alternative are shown in parenthesis.

Restoration Alternative	Water Surface Elevations (feet)		
	2-year Flood	5-year Flood	Flood of Record
Existing Conditions	*19.2*	*20.9*	*22.6*
Lengthening Bridge Span Only	19.1 (-0.1)	20.8 (-0.1)	22.6 (-0.0)
Removing River's End Levee Only	18.5 (-0.7)	19.5 (-1.4)	20.6 (-2.0)
Lengthening Bridge Span and Removing the River's End Levee	18.5 (-0.7)	19.4 (-1.5)	20.4 (-2.2)

The model results presented in table 6 assume a maximum tide elevation in Dungeness Bay of 10.5 feet. Model results for the estimated maximum tide were compared to the typical high tide of 9.1 feet and the water surface elevation did not change at Schoolhouse Bridge. This is because the bottom of the river channel under Schoolhouse Bridge is at the elevation of the maximum tide (10.5 feet). While either the maximum or typical high tides would have a large backwater effect, based on current measurements the tidal influence would be downstream of Schoolhouse Bridge by about a tenth of a mile.

Woodcock Bridge. — Woodcock Bridge and the approach embankments of Ward Road constrict the river channel and cut off the flood plain by a maximum of 400 feet on the east (right) side and 400 feet on the west (left) side. Of the five bridges that span the Dungeness River, the Woodcock Bridge constricts the natural channel and flood plain more than any other bridge. The impacts of this constriction are to locally block flood flow access to the downstream flood plain on both sides of the river and cause several hydraulic and sediment impacts to the river channel immediately upstream from the bridge. These upstream impacts include increased water surface elevations, channel aggradation, increased lateral migration of the river channel, and bank erosion. These impacts to natural processes could be reduced or eliminated by lengthening the span of Woodcock Bridge. The length that the bridge span should be increased is a decision dependent on both economic and management criteria. Useful information to such a policy decision would include data from a site specific study on how cost and river hydraulic conditions (water surface elevation, depth, and velocity) would change as the bridge span is increased.

Burlingame Bridge on Old Olympic Highway. — The Burlingame Bridge was replaced during the period 1998-1999 to increase the span over the river channel from 130 to 430 feet. Although the new bridge span is much longer, the lowest part of the span is only about 6 feet higher than the riverbed (Photo 18 – Photographic Overview). Computer modeling of river hydraulics indicates that the flood of record can pass under the new bridge. However, the bridge span may not be high enough to pass woody debris during large floods. The assumption for the bridge design was that the old bridge constriction caused backwater and aggradation in the upstream river channel and that the aggraded sediments would erode once the bridge constriction was eliminated by lengthening the bridge span. However, the bridge is located in a reach where the longitudinal river slope is decreasing in the downstream direction. This natural decrease in the river slope may result in aggradation of the riverbed rather than erosion of the channel upstream from the bridge. The narrower active channel in this reach may limit the amount of aggradation. Therefore, monitoring of riverbed and water surface elevations over time is recommended for a distance of at least 1,000 ft upstream and downstream from the bridge. Monitoring results can be used to detect if the future hydraulic capacity under the bridge is decreasing over time.

Railroad Bridge. — The Railroad Bridge has the longest span of all Dungeness River bridges. The bridge crosses the left (west) flood plain on a series of wooden trestles, then crosses the main river channel over a steel truss. The original bridge continued to cross the right (east) flood plain on another series of wooden trestles, but this portion of the bridge was destroyed during a 1961 flood. The damaged portion of the bridge was replaced with an earth embankment which now crosses the right flood plain.

The Railroad Bridge was built at a natural constriction in the flood plain. The left flood plain contains a prominent side channel with a high river island between this side channel and the main channel. This island is a few thousand years old, so the island is a natural constriction in the flood plain and not a product of the bridge. The wooden trestles of the bridge that cross the left flood plain do not prevent flood waters from entering the flood plain. A log jam was constructed at the entrance to the side channel, upstream from the bridge, to prevent the side channel from capturing the main river channel.

The earth embankment interrupts flood flows passing through the right flood plain. This embankment on the right and the high island on the left force the main river channel to pass under the bridge in a fixed location. The fixed location of the main channel prevents the downstream translation of river meander bends. As a river bend forms upstream from the bridge, bank erosion occurs along the outside of the bend and sediment deposition occurs along the inside of the bend. The river bend migrates laterally over time, but the river channel still has to pass under the bridge in the same location. This creates an elongated flow path which will eventually be cut off by a straight channel and the process repeats. The most recent channel change was in 2000 which caused sediment erosion upstream from the bridge and deposition downstream.

The investigators of this study hypothesized that the earth embankment, crossing the right flood plain, directed river flows toward the left bank and caused extensive bank erosion downstream from the bridge. However, inspection of historical aerial photographs reveals that the downstream alignment of the main river channel, as it passes under the main bridge span, has not changed since at least 1942. This downstream alignment has remained relatively stable, even though the alignment of the upstream channel has changed continually since 1942. Also, there is evidence of bank erosion in the 1942 aerial photograph. Although, the embankment does interrupt flows through the right flood plain, construction of the embankment, after the 1961 flood, is not likely responsible for the substantial bank erosion that has occurred downstream.

Highway 101 Bridge. — Built at a natural geologic constriction, the Highway 101 Bridge does not pose a significant constriction to the main river channel or flood plains. The bridge does cut off a small portion of flood plain on each side of the river, but impacts to natural processes are small. However, downstream of the bridge on the east side, vegetation has been cleared from the terrace and the bank is susceptible to accelerated erosion. In fact, the recent flood of record (7,610 cfs on January 7, 2002) caused up to 75 ft of bank to erode (Ross, 2002).

8.3.4 Bank Protection

If property owners are protecting an old river bank from erosion (older than a few hundred years), then the bank protection could be considered as mitigation for previous human impacts to the river channel. In this situation, the bank protection does not significantly impact the natural processes so long as the protection doesn’t cut off the hydraulic connection with the flood plain or side channels. When the bank protection incorporates large woody debris, cover and scour hole habitat can be provided for fish.

When recently-formed river banks, levees, or dikes are protected from erosion, then natural channel migration cannot occur. If the bank protection extends into the historical river channel, then the channel becomes constricted and the opposite bank can erode or the channel can degrade and bed sediments will become coarser.

8.3.5 Estuary Management

Perhaps the best way of restoring natural river-related processes to Dungeness Bay would be the setback or removal of levees in Reach 1. Setting back the ACOE and the Olympic Game Farm levees would restore access to the flood plains of Reach 1 upstream from the Schoolhouse bridge. Removing the River’s End Levee and downstream-most 300 ft of the ACOE Levee would restore access to the west flood plain (downstream from Schoolhouse Bridge) and allow the Dungeness River greater freedom to laterally migrate across the delta as it enters Dungeness Bay. The restored access to the flood plain would allow a portion of the fine sediments (clay, silt, and fine sands) to deposit on the flood plain rather than in Dungeness Bay. These fine sediment can be associated with pollutants from agricultural and urban runoff (Rensel, et al, 2001). Greater lateral migration of the Dungeness River channel might help to distribute sediments over a greater area of the outer Dungeness Bay (east of Graveyard Spit).

If the levees are not setback or removed, then all of the fine sediments being transported by the Dungeness River (and any associated pollutants) will continue to enter Dungeness Bay. Because the river will continue to enter the bay at a relatively fixed location, the fine sediments will continue to deposit in the same areas of the Bay.

9.0 POTENTIAL RESTORATION PLANS

This study builds upon previous studies and helps identify natural river processes, human impacts on those processes, and potential management options for restoration of the lower Dungeness River. Several site-specific implementation plans are now needed before restoration activities can begin. These plans would have to be developed in close coordination with resource managers who will provide policy guidance. The development of these plans would likely require several iterations of technical analyses and policy guidance.

9.1 Levee Setback and Removal

Policy decisions would have to be made regarding levee setback and removal plans. For example, should the River's End Levee be removed and the residents and buildings be relocated? Should the ACOE and Olympic Game Farm Levees be set back? Should a portion of the Dungeness Meadows Levee be modified or setback to allow a surface water connection with the side channel that is presently cut off? Technical analyses and cost estimates would have to be prepared, along with policy guidance, before any restoration plan could be finalized. The restoration plans would have to address the questions listed below:

- What is the cost of levee removal?
- If the levee is set back, where would the new levee be relocated? What level of flood protection should the new levee provide, to what height should the levee be constructed, and how much would the levee setback cost? What are the expected benefits to fish?
- What volume of gravel needs to be excavated from the river bed so that the river would continue to flow in the same location (avoid a channel avulsion into the flood plain) after the existing levee is removed? Where would this gravel volume be disposed of? Is there a market value for the excavated river gravel?
- Do side channels need to be constructed to provide additional fish habitat? If so, where should these side channels be located, are they sustainable, and how much would they cost? What flows are needed in the side channels?
- How should riparian vegetation be restored after the levee setback or removal and how much would this cost?
- What should be done with any buildings or structures that are protected by levees now, but wouldn't be protected in the future? For example, should these buildings and structures be removed from the flood plain and possibly relocated elsewhere and at what cost? Would there be any hazardous materials to dispose of? If so, how much would the disposal cost be?
- Does the property no longer protected by a levee have to be purchased and at what cost? Can a flood easement be purchased instead of the entire property and at what cost?

- Is it feasible to modify or setback a portion of the Dungeness Meadows Levee to provide a surface water connection between the main channel and the cut off side channel without causing a significant risk of flooding to the Dungeness Meadows subdivision?

9.2 Kinkade Island Restoration

Policy decisions would have to be made regarding any restoration plans for Kinkade Island. For example, should the property be purchased and residents relocated? Should the existing buildings, levees, and other structures be removed? Technical analyses and cost estimates would have to be prepared, along with policy guidance, before any restoration plan could be finalized. The restoration plans would have to address the questions listed below:

- What are the expected future flood damages (in dollars) if nothing is done?
- How much would it cost to purchase the property of Kinkade Island?
- How much would it cost to remove the existing buildings and structures? Would there be any hazardous materials to dispose of? If so, how much would the disposal cost?
- Would there be a benefit to removing the riprap along Kinkade Creek? If so, how much would that cost?

9.3 Bank Protection

Active bank erosion is occurring along the Dungeness River at several locations:

- near RM 9.3 along the outside of the river bend (right bank),
- between RM 7.5 and 8.0 along the left bank in the straight reach opposite the Dungeness Meadows Levee,
- between RM 6.1 and 6.4 along the outside of the river bend (right bank) downstream from the Highway 101 Bridge.

The existing landowners would likely want to protect these banks from continued erosion, but would like to minimize the cost. Without some assistance, the affected landowners may not necessarily choose bank protection alternatives that also provide fish habitat. Technical assistance could be provided to help landowners design bank protection plans that both prevent bank erosion and provide useful fish habitat. Some example bank protection concepts that would also provide useful habitat are listed below:

- Log revetments or engineered log jams could be constructed to increase the strength and roughness of the bank and provide cover for fish in areas where riprap is already in place or areas where the bank is actively eroding. The planting of trees and willows along the bank would provide additional strength to the bank and vegetative cover for fish.

- Submerged rock weirs could be constructed to deflect high flow velocities away from the bank and create stable scour holes for fish. The planting of trees and willows would increase the strength and roughness of the bank and provide cover for fish.

- Riprap could be placed along the bank in an irregular alignment to create additional roughness. A riprap design could also incorporate the planting of willows and trees and engineered log jams.

The bank protection plans would have to address the questions listed below:

- What is the present cause of bank erosion and how might this cause change over time? Is the bank erosion occurring at a natural rate or accelerated by human impact?

- What are the expected future damages (in dollars) from bank erosion if nothing is done?

- What type of bank protection design is best suited to stop continued bank erosion and provide useful fish habitat? What are the expected benefits to fish?

- Would new bank protection measures cause any bank erosion impacts to other areas of the river?

- How much would new bank protection measures cost?

9.4 Bridge Modification

Since the new Burlingame Bridge no longer constricts the main channel or cuts off flood plain, the Woodcock Bridge now constricts the natural channel and flood plain more than any other bridge on the Dungeness River. The present constriction of the Woodcock Bridge has resulted in bank erosion and channel widening upstream of the bridge along with sediment deposition in the backwater upstream of the bridge. The bridge in combination with Ward Road also cuts off a portion of the flood plain and side channels downstream of the bridge. There are similar effects at the Railroad Bridge east embankment, but these effects are limited to the east flood plain.

The impacts at Woodcock Bridge could be reduced or eliminated if the bridge span across the river was lengthened and Ward Road was set back. The impacts at the Railroad Bridge could be eliminated if the east embankment was removed. Policy guidance is needed to determine if the potential benefits (relative to costs) from modifying either bridge are greater than the benefits from other types of restoration plans. A bridge modification plan would have to address the questions listed below:

- How much would it cost to lengthen the bridge span?

- What would be the benefits to fish habitat from lengthening the bridge span?

The Burlingame Bridge was replaced with a much longer bridge span, but the bridge only has about 6 ft of clearance over the riverbed. Will the average elevation of the riverbed increase, decrease, or remain about the same over time? Continued monitoring of the cross-section network established for this study would help determine if the average channel bed elevations are changing or time.

9.5 Other Fish Habitat Restoration

In addition to levee setbacks, bank protection structures that provide fish habitat, and bridge modifications, other fish habitat restoration goals should be considered. For example, the reach of the Dungeness Meadows Levee is straight and steep with high velocities and large cobbles. These conditions may be difficult for the upstream passage of fish. If correctly designed, engineered log jams or weirs could be placed to provide local areas of slow velocity without increasing the flood stage to help improve fish passage.

9.6 Upper Watershed Restoration

Restoration plans for the upper watershed would most likely focus on the existing logging roads, drainage crossings, and landslides. The excavation required for logging roads over steepens the hillside and make it more susceptible to surface erosion and landslides. When the logging roads were constructed across natural drainage channels, culverts were typically placed in the road embankments to convey rainfall and snowmelt runoff. Ditches were also constructed along these roads that delivered more water to the culverts, often by capturing runoff from several adjacent drainages and concentrating them into a single channel. During periods of intense rainfall, the runoff may exceed the flow capacity of the culvert, or the culvert may become plugged with debris. When this happens, the runoff overtops the road surface causing rapid erosion on the downstream side of the road embankment and can result in the failure of the entire road. The erosion associated with logging roads will lead to a general increase in turbidity which would impact fish.

The technical questions related to restoration plans for the upper watershed are listed below:

- Is the runoff turbidity from portions of the drainage area with logging activities greater than the runoff turbidity from portions of the drainage with no logging activities? If so, now does the greater turbidity impact fish?

- Where have hillsides become unstable because of logging road excavations?

- What are the discharge capacities of the logging road culverts and what are the probabilities that these capacities will be exceeded? If necessary, what is the cost increasing the culvert capacity? What is the cost of closing the road and removing the culvert and road embankment?

- What is the cost of stabilizing existing landslide areas?

An improved understanding is needed of the physical processes that affect the quantity, grain size, and timing of sediment supplied by the upper watershed to the lower river. Some of the processes that affect the sediment yield of the watershed include runoff, slope, vegetation, surface erosion, forest fires, landslides, logging, and road building. Any future investigation of the upper watershed should determine which watershed characteristics are most important in influencing the sediment erosion, storage, and the transport to the lower river. A comprehensive investigation of all landslides in the upper watershed is needed to evaluate their role in the supply of sediment to the river and impacts to salmonid habitat in the river system. The U.S. Geological Survey has proposed a detailed analysis of upper watershed processes, including sediment sources and transport, that would address this gap in our knowledge of the Dungeness River processes.

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11.0 GLOSSARY

active channel – The unvegetated channel that conveys the river's bed-material load.

active flood plain – The zone of active channel, side channels, overflow channels and intervening surfaces that receive some flow at annual intervals. It is synonymous with present flood plain.

aggradation – Deposition of sediment along the channel bed.

alluvium – Sediment deposited by flowing water.

bank-full channel – The channel that holds the bank-full flow or discharge.

bank-full flow – The flow that fills the active channel to the incipient point of overtopping the banks. It is the flow that causes the majority of channel changes and sediment transport over a long period of time. It is usually determined from field observations. It often is called the effective discharge and channel-forming discharge.

bar – Ridge-shaped accumulations of bed load (sand and gravel) that are deposited along or adjacent to a river as flow velocity decreases. If the sediment is reworked frequently, the deposits will remain free of vegetation. If the surface of the bar becomes higher than the largest flows, vegetation stabilizes the surface making further movement of the sediment in the bar difficult.

bed material – Sediment (usually coarse sands, gravels, cobbles, and boulders) that is preserved along the channel bottom and in adjacent bars.

bed load – The coarse sediment (boulders to coarse sand) that is transported intermittently along the bed of the river channel by creeping, rolling, sliding, or bouncing along the bed. It is the sediment that is too heavy to be transported in suspension (suspended load).

bulkhead – A wall-like structure that is designed to prevent flooding and erosion of a river channel bank. It could be made with a variety of materials, such as wood, rock, or concrete.

channel deposits – Coarse sediment (boulders to coarse sand) that is deposited in the channel as flow subsides. It may include some fine sediment that gets stranded as the flow velocity decreases.

coarse sediment – Boulders to coarse sand; sizes that are usually transported as bedload and are too large to be deposited outside of the channel on the flood plain by overbank flow. It is the sediment found in a channel deposit.

control point – A station that provides horizontal or vertical position data, or both, that can be identified on aerial photographs and used to ortho-rectify the photographs or to correlate data.

D_{50}– The median particle-size diameter for a sediment sample, such that 50 percent of the sample is larger than this value.

dike – An artificial embankment that is built along a river to protect an area from flooding. It can be constructed with a variety of materials, but is often composed of earth or rock. Also referred to as a levee.

discharge – The volume of water in a river that flows through a given cross section of the river channel per unit time. It is usually measured in cubic feet per second (ft^3/s).

effective discharge – The discharge that transports the most sediment over a given time interval. It is the discharge that is the most effective in shaping and maintaining the form of the channel. It is directly calculated, rather than determined by field observations as is bank-full discharge. It often compares closely with the bank-full discharge.

elevated bar – A gravel bar that has been deposited, at least in part, when the stage is higher than it would be expected during natural conditions. For example, a levee that raises the elevation of the natural bank along a river allows higher stage for a given discharge.

fine sediment – Fine sand, silt, and clay; sizes that can be transported as suspended sediment and are often deposited outside of the channel on the flood plain by overbank flow.

first order stream – The smallest and highest tributary in a watershed.

flood-flow channel – A channel, often adjacent to the active channel, that carries water only during high (flood) flows. It can be dry for much of a year, but receives flow frequently enough that it is generally unvegetated. It is synonymous with overflow channel.

geologic flood plain – The zone interpreted on the basis of geomorphic and geologic data as being the active flood plain a few thousand years ago. The boundaries of this flood plain are usually large-scale geologic features, such as remnants of glacial deposits or rock, that have been (and probably will be) relatively stable parts of the landscape.

Holocene – The time interval since the Pleistocene, between about 10,000 years ago and the present. It is the period since the last world-wide ice age.

hydraulics – The physical laws governing water movement and their application to engineering problems.

large woody debris – Logs, branches, and other large pieces of trees that are transported by the river during high flows and are often deposited on gravel bars as flow velocity decreases. Because the debris acts as an obstruction to flow, additional woody debris and sediment often accumulate around in-place woody debris. Large, complex piles of logs can result. Used interchangeably with woody debris.

levee – An artificial embankment that is built along a river to protect an area from flooding or confine water to a channel. It can be constructed with a variety of materials, but is often composed of earth or rock. Often called a dike.

loess – A deposit of wind-blown silt.

longitudinal bar – An elongated gravel bar that extends along and roughly parallel to a relatively straight section of river channel. It grows in a downstream direction, with its steep side toward the channel bank and with a narrow trough between the bar and the bank.

low-flow channel – The channel that carries water during times of low flow. It tends to follow the deepest part of the channel and can be very sinuous and branching. The exact location and configuration of the low-flow channel depend on the discharge.

mid-channel bar – A ridge-shaped or somewhat circular-shaped gravel bar that is preserved between branches of a low-flow channel.

morphology – The study of river channel geometry and planform, and how it changes over time.

ortho-rectified photograph – An aerial photograph that has been corrected for the geometries and tilt angles of the camera when the image was taken and for topographic relief using a digital elevation model, flight information, and surveyed control points on the ground.

overbank deposits – Fine sediment (fine sand, silt, and clay) that is deposited outside of the channel on the flood plain by overbank flow.

overflow channel – A channel, often adjacent to the active channel, that carries water only during high flows (floods) . It can be dry for much of a year, but receives flow frequently enough that it is generally unvegetated. It is synonymous with flood- flow channel.

planform – Characteristics of the river channel that can be determined in a two-dimensional view of the ground surface, aerial photograph, or map.

Pleistocene – The time interval between 1.6 million years ago and 10,000 years ago, which includes most of the last world-wide ice age.

point bar – A sand or gravel bar that is deposited at the inside of a meander bend as a result of secondary currents that transfer sediment from the inside of the bend to the outside of the bend. It is usually found where the meander is eroding the outside of the bend, so that the bar grows as sediment continues to be added to the inside of the bend.

prehistoric or natural flood plain – The zone that we interpret on the basis of geomorphic and geologic data as being the active flood plain before intervention by human activities. The boundaries of this flood plain are natural topographic features, such as terrace risers, that may be easily eroded. It is the active flood plain a few hundred years ago.

present flood plain – The zone of active channel, side channels, overflow channels and intervening surfaces that receive some flow at regular intervals. It is synonymous with the active flood plain. In our study, this zone is often bounded by man-made features, such as levees or bridge embankments, that replace natural boundaries to the flood plain.

Quaternary – The time interval between 1.6 million years ago and the present. It includes both the Pleistocene and the Holocene.

riparian – The area in or along the edge of the river channel. It often refers to habitat or vegetation and could include islands.

riprap – Large angular rocks that are placed along a river bank to prevent or slow erosion. Placement of the rock can be designed or haphazard.

river mile (RM) – The distance in miles measured along the centerline of the river channel upstream from the mouth.

scour – Local erosion of sediment from the channel bed caused by high velocity.

side channel – A channel that nearly always carries flow and is located in the active flood plain, but it does not carry the majority of flow. Along the Dungeness River, some side channels carry water year around, but are fed from groundwater much of the time. It is synonymous with secondary channel.

sinuosity – The ratio between the length of the channel, as measured along the centerline of the channel, to the length of the valley for the equivalent section. The higher the sinuosity value, the more curving the channel pattern.

stage – The height of the water surface above the channel bed; referenced either by depth or to a vertical datum.

suspended-sediment load – The fine sediment (fine sand, silt, and clay) that is transported in suspension above the channel bed. It is the sediment that is light enough to be transported in suspension much of the time, in contrast to the bed load that is primarily moved along the bed.

terrace – A relatively flat surface that is bounded on one side by a relatively steep slope (the terrace riser, scarp, or escarpment) formed when the river cut into the flood plain that it had previously deposited. It often parallels the river channel, but is high enough above the channel that it rarely, if ever, is covered by water and sediment. The deposits underlying the terraces are alluvial, either channel or overbank deposits, or both. Because a terrace represents a former flood plain, it can be used to interpret the history of the river.

terrace riser – vertically or steeply sloping surface of one of a series of natural steplike landforms, as those of a glacial stairway or of successive stream terraces (e.g. the near vertical slope that defines the edge of the nearly horizontal terrace surface)

transport capacity – The river's ability to move sediment. It depends upon channel gradient, discharge, size of the available sediment, and channel form (e.g., width, depth, roughness).

transverse bar – A gravel bar that extends roughly perpendicular across the direction of flow. It is often associated with split, branching flow and can create steps in the channel bed.

Wolman pebble count – A standard technique to determine the composition of the sediment composing the riverbed. Sediment sizes are noted by randomly selecting surface particles at regularly spaced intervals along a transect across the river channel.

12.0 ABBREVIATIONS

ACOE – U.S. Army Corps of Engineers

BP – years before present

ºC – degrees centigrade

cal yr – calibrated year (for radiocarbon dates)

cm – centimeters

DRMT – Dungeness River Management Team

DRRWG – Dungeness River Restoration Work Group

ºF – degrees Fahrenheit

FEMA – Federal Emergency Management Agency

ft – feet

cfs – cubic feet per second

GIS – geographic information system

GPS – global positioning system

ha – hectare

in – inch

km^2 – square kilometers

m – meter

cms – cubic meters per second

mi – mile

mm – millimeter

mi^2 – square mile

NAVD88 – 1988 National American Vertical Datum; vertical coordinate system referenced to Washington State Plane Coordinates

NGS – National Geodetic Survey

NPS – National Park Service

Reclamation – Bureau of Reclamation

RM – River mile

Tribe – Jamestown S'Klallam Tribe

USGS – U.S. Geological Survey

WGS84 – 1984 horizontal coordinate system referenced to latitude and longitude

XS – cross section

yd^3 – cubic yards

ACKNOWLEDGMENTS

We have thoroughly enjoyed not only working on this study, but working with all of the people who have shared their own experiences and thoughts about the Dungeness River over the last five years. There has been insight from individuals who work with and live by the river and numerous pieces of historical information and analyses provided. We thank all of the following individuals and organizations for their assistance in helping us complete this study over the past five years. We hope they enjoy this report and will find it useful in some part of their interaction with the Dungeness River.

Bill Shelmerdine (U.S. Forest Service, Olympia, Washington) let us examine their aerial photographs of the upper Dungeness River basin, including a partial set of photographs taken in 1939.

Brian Cluer (National Park Service, Fort Collins, Colorado) provided time-lapse cameras and associated gear and helped us install them at three sites along the Dungeness River.

Byron Rot (Biologist for Jamestown S'Klallam Tribe) and Linda Newberry have been active participants working with our study team. Byron has provided a lot of insight concerning what elements are needed to restore fish habitat along the Dungeness River. Byron and Linda have given helpful recommendations that geared the tasks for this study to provide needed information for future management decisions concerning restoration activities. We were sorry to see Linda move on but hope she is happy in her new surroundings!

Connie Manson (Washington Department of Natural Resources Library, Olympia, Washington) has been, and still is, helpful in locating all of their references on the Dungeness River valley and providing us with copies of some of them.

Cory Stolsig and his crew (Bureau of Reclamation, Ephrata Field Office) surveyed 60 cross sections along the lower Dungeness River between the mouth and the fish hatchery. Some of these locations had dense vegetation and required a great deal of effort to survey.

Dan Levish (Geophysics, Paleohydrology, and Seismotectonics Group, Bureau of Reclamation, Technical Service Center, Denver, Colorado) joined our initial reviews of the study area in 1997 and 1998 and provided many good comments and suggestions. He also attended a field review and provided a technical review of the study.

Dave Nelson (Bureau of Reclamation, Portland, Oregon) has supported this study not only by providing the necessary finances to complete the work, but also by sharing his interest, time and ideas.

Dave Peter (Ecologist, U.S. Forest Service, Olympia, Washington) shared his information about the fire history of the northeastern Olympic Peninsula.

Dick Rogers (State Fish Hatchery, Dungeness River valley) provided us information about the fish, about additional contacts for more detail about fish habitat and habits, and gave us access to the fish hatchery land for geologic mapping and for sediment sampling (Locality DRsed-21).

Dungeness River Management Team (all of the members and attendees) has provided a wonderful forum for us throughout the study to provide information and ideas to those who care most about the restoration of the Dungeness River. This group has been a great asset to the Dungeness River and we hope their work will continue and be able to utilize the information provided in this report.

Gus Ilika (Dungeness Meadows, Sequim, Washington) provided accounts of the Dungeness River at Dungeness Meadows during high flows in 1978 and 1990. He also provided information about gravel mining along this section of the river.

Jack Orsborn has provided a wealth of information from his own analyses completed on the lower Dungeness River and has provided useful suggestions throughout our study.

Jamestown S'Klallam Tribe has provided numerous resources from their own library and many times has provided facilities and staff to assist us with presentations to the Dungeness River Management Team.

Jim O'Connor (U.S. Geological Survey, Portland, Oregeon) and Tom Zembrzuski and Myrtle Jones (U.S. Geological Survey, Tacoma, Washington) discussed the project with us as they prepared their proposal for work in the upper basin. These discussions provided ideas for our study and resulted in shared information, especially regarding the availability and location of historical maps and older aerial photographs.

Joel Freudenthal (Habitat Specialist, formerly with Clallam County, Port Angeles, Washington) provided information about the Dungeness River valley and has been especially interested in and supportive of our study.

Joy Werlink (Research Center, Washington State Historical Society, Tacoma, Washington) researched their collections for historical maps of Clallam County and for historical photographs of the Dungeness River valley.

Kathryn Puseman and Laura Ruggiero (Paleo Research Laboratories, Denver, Colorado) cleaned the charcoal samples from the surrounding sediment, examined each charcoal sample, and identified the species of each, so that the samples could be submitted for radiocarbon analyses.

Landowners along the Dungeness River generously gave us permission to dig soil pits or measure sediment samples. These owners include:

Al Moore who provided insight on past floods and river activities
"Doc" Severson (Bremerton, Washington) and Mike Hagen (land manager)
Jeff and Debbie Brown (Sequim, Washington)
Mrs. Jack Sallee (Sequim, Washington)

Dennis Dehmalo (Sequim, Washington) who also provided us with information about the changes in the river near his property.
Art Lang and his wife (Dungeness Meadows)

Les Soule (Civil Engineer, Army Corps of Engineers, Seattle, Washington) looked for their copies of aerial photographs taken in 1939 of the coast in the Dungeness area.

Librarians in the Map Library, Special Collections, and Manuscripts and Archives at the University of Washington helped us locate information on the Dungeness River in their collections, including the Jervis F. Russell collection and the Gordon Williams collection, and provided us with copies of some of this material.

Lloyd and Kathryn Beebe (Olympic Game Farm, Sequim, Washington) spent several hours with us and gave us detailed information about the Dungeness River near their Game Farm through observations made during their 70 years (since 1930) in the valley. They also regaled us with great stories about life in the valley and their past. They also allowed us access to their land to complete our work, including sediment samples DRsed-3A and DRsed-3B and cross-section surveys.

Matt Hines (Dungeness Farms, Sequim, Washington) allowed us access to the lower mile of the Dungeness River and generously took his time to show us this portion of the river more than once. He also allowed us to sample sediment near the mouth at DRsed-1A and DRsed-1B and provided information about land ownership along the lower river.

Matt Jones (Seismotectonics and Geophysics Group, Bureau of Reclamation, Technical Service Center, Denver, Colorado) used GIS to create an orthophoto of the 1:6,000-scale, color aerial photographs taken in 2000.   The resulting mosaic is being used as a base for the geomorphic map of the river corridor.

Mike Reed (formerly of the Jamestown S'Klallam Tribe, Sequim, Washington) generously provided his knowledge about the river basin, including its fish, plants, history, and land ownership. He gave us our initial view of the river, allowed us access to the tribal library, and was always available for discussion of our work. He supplied many helpful comments and suggestions along the way. He also changed the film in the cameras that were placed at three locations along the river.

Mike Donald (Fisheries Biologist, formerly with U.S. Forest Service, Quilcene Ranger District, Quilcene, Washington) gave us access to Forest Service files to look through their aerial photographs of the Dungeness River basin.

Numerous landowners along the lower Dungeness River gave us permission to their land and the adjacent portions of the river in order to survey the cross sections and the locations of topographic and man-made features that were used to rectify the aerial photographs.

Staff at the Port Angeles Library allowed us access to their collections of photographs and maps, including the Bert Kellogg Collection, in their Archives Room.

Staff at the Photographic Archives in the Museum of the Clallam County Historical Society (Port Angeles, Washington) was very helpful in supplying us with their collection of old photographs and maps, including ones by Charles Metsker (1925/1935) and Kroll's Atlas of Clallam County (1917).

Clallam County Road Department, Port Angeles, Washington gave us copies of old maps showing portions of the Dungeness River near the bridges, survey data at the new Burlingame Bridge and let us look through their files for information on bridge designs, history, and geology.

The Sequim Historical Museum contains excellent information about the history of the Dungeness River valley. The staff at the museum, especially Margaret DeWitt who is head of the museum, arranged for us to look at their collections of old photographs, including those by Joe McKissick.

The late Dallas Childers (Retired, U.S. Geological Survey) and Tom Zembrzuski (U.S. Geological Survey, Tacoma, Washington) established and carried out the sediment-load sampling program. Johanna Higgins has followed through with this work and has added on the gage at the Schoolhouse Bridge.

The late Harriet Fish (Historical writer, Carlsborg, Washington) shared her extensive knowledge about various aspects of the Dungeness River valley, including its history, irrigation practices, bridges, roads, logging practices, and floods. In addition, she generously provided us with copies of newspaper articles, maps, photographs, and letters that she had collected over the years.

Victor Huang took the time to provide his hydraulic modeling expertise through a technical review of the study.

Engineering Geology Group A, (Bureau of Reclamation, Technical Service Center, Denver, Colorado) digitized a 1939 map of the lower about 4 miles of the Dungeness River from a Clallam County Road Department map.

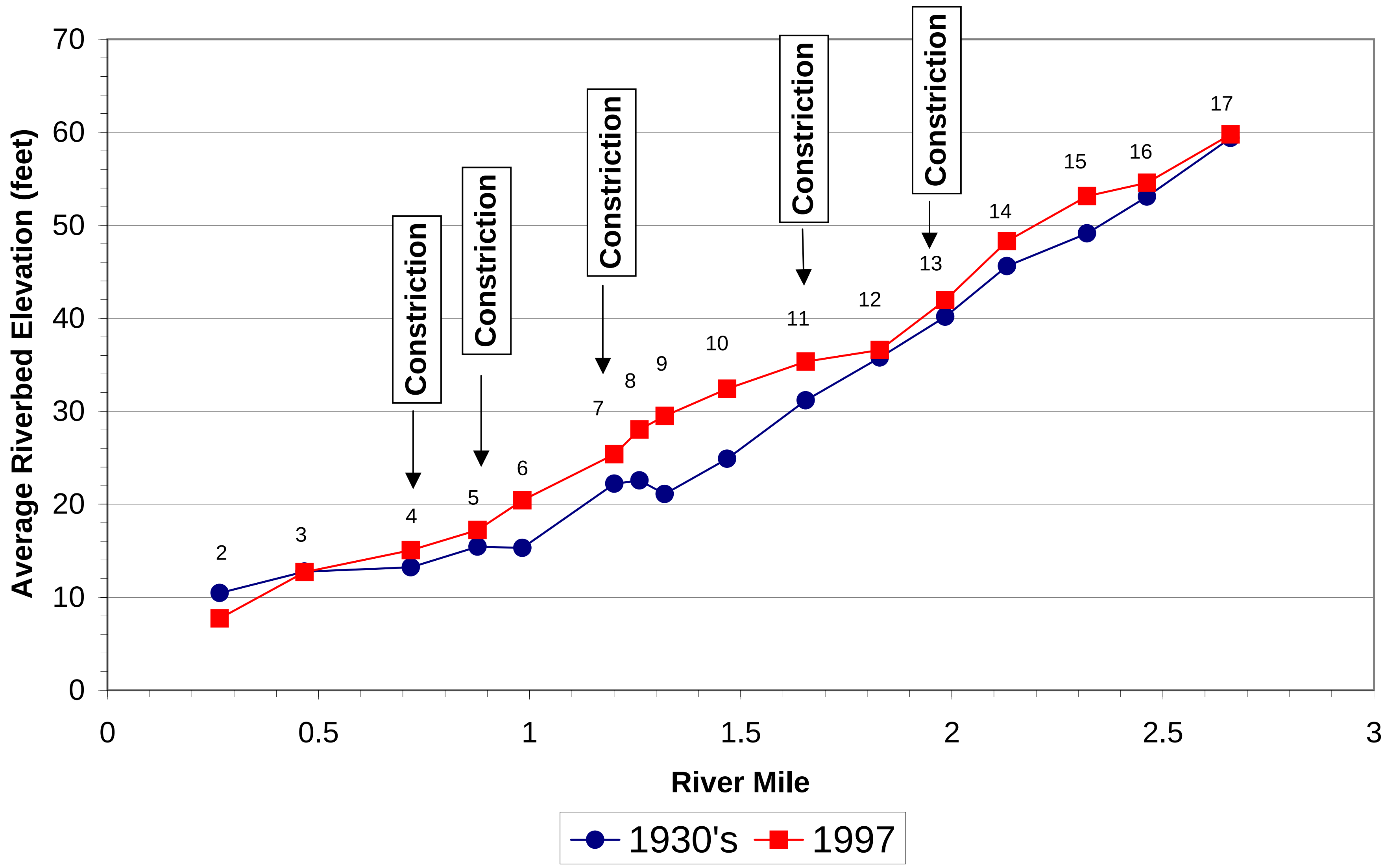
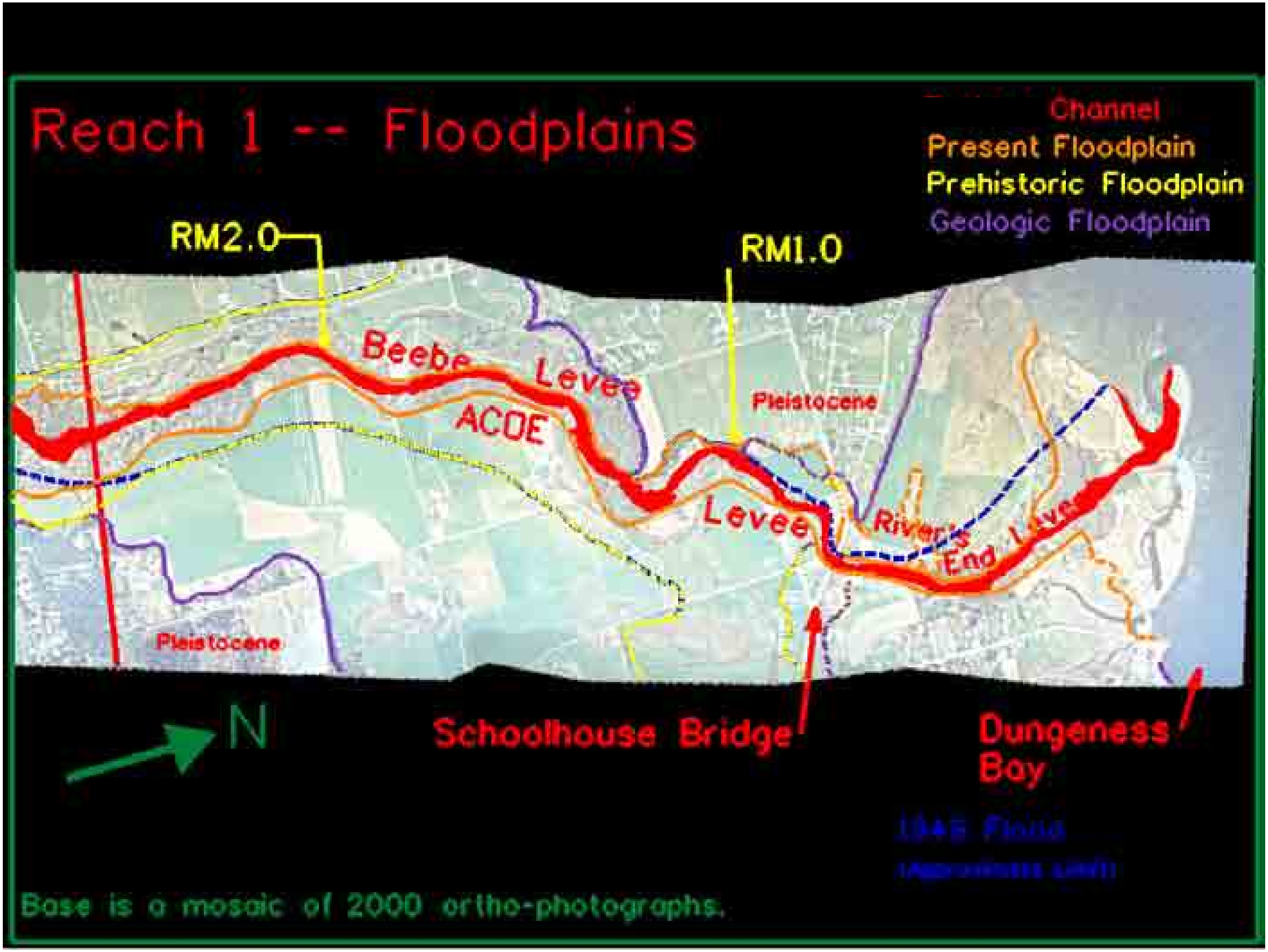


Figure 32: Comparison of Existing and Historic (1935) Channel Bed in Reach 1.


Reach 1 -- Floodplains
Channel
Present Floodplain
Prehistoric Floodplain
Geologic Floodplain
RM2.0
RM1.0
Beebe Levee
ACOE
Pleistocene
Levee
River's End Levee
Pleistocene
N
Schoolhouse Bridge
Dungeness Bay
Base is a mosaic of 2000 ortho-photographs.

Reach 2 Floodplains

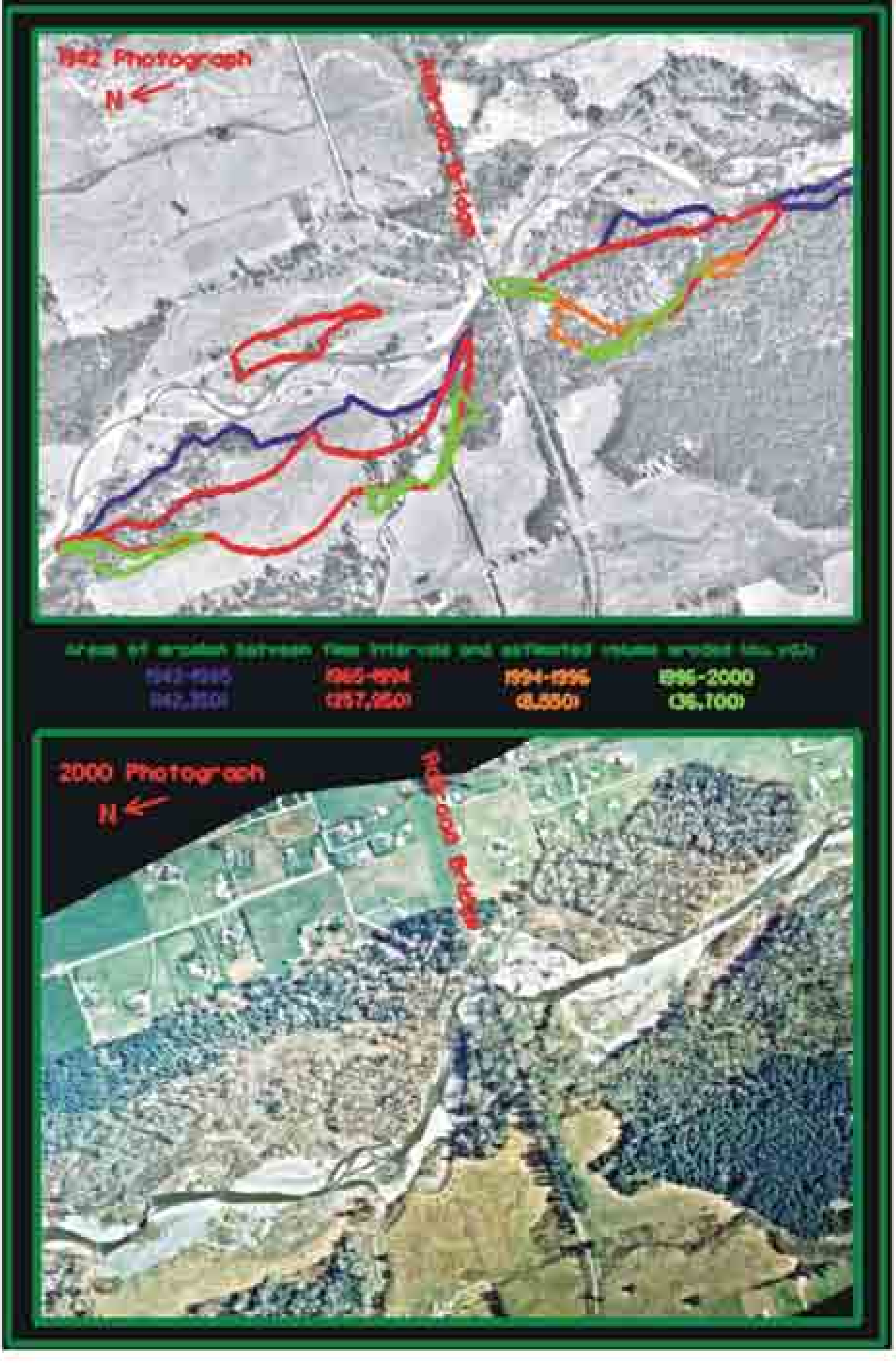
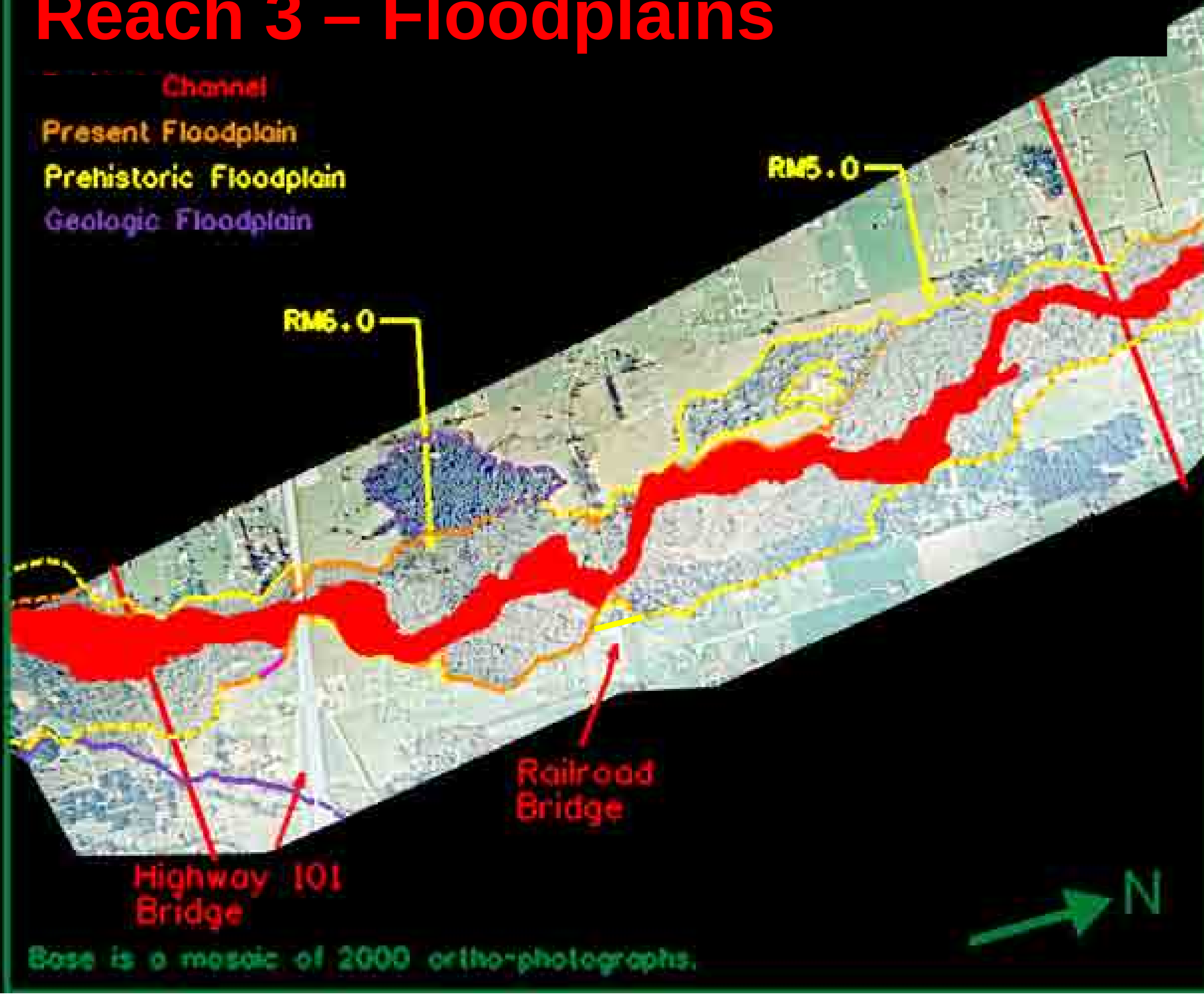
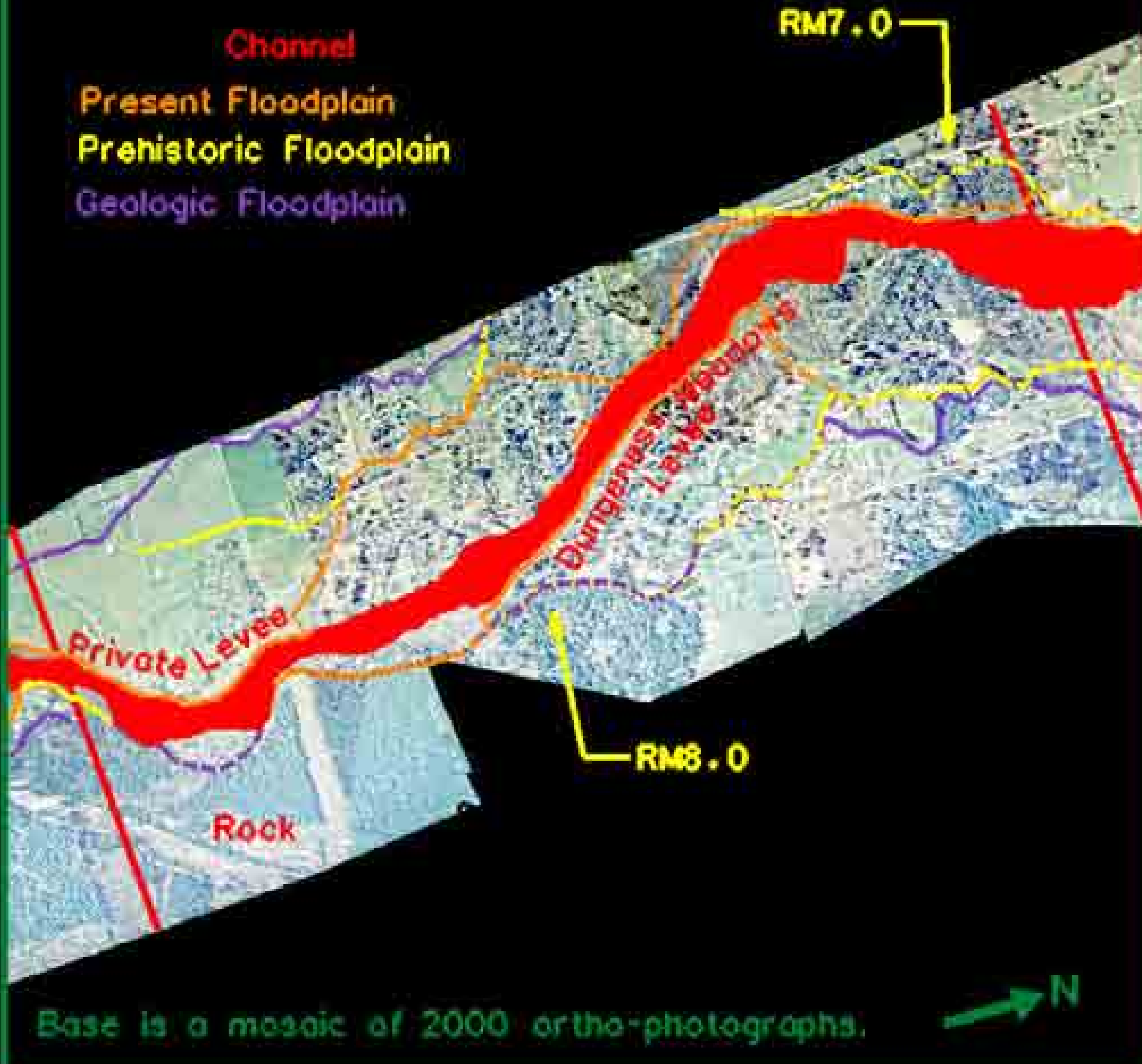


Figure 26. Bank erosion in the section of Reach 3 near Railroad Bridge. Eroded portions of the bank are for the time intervals between aerial photographs as shown.

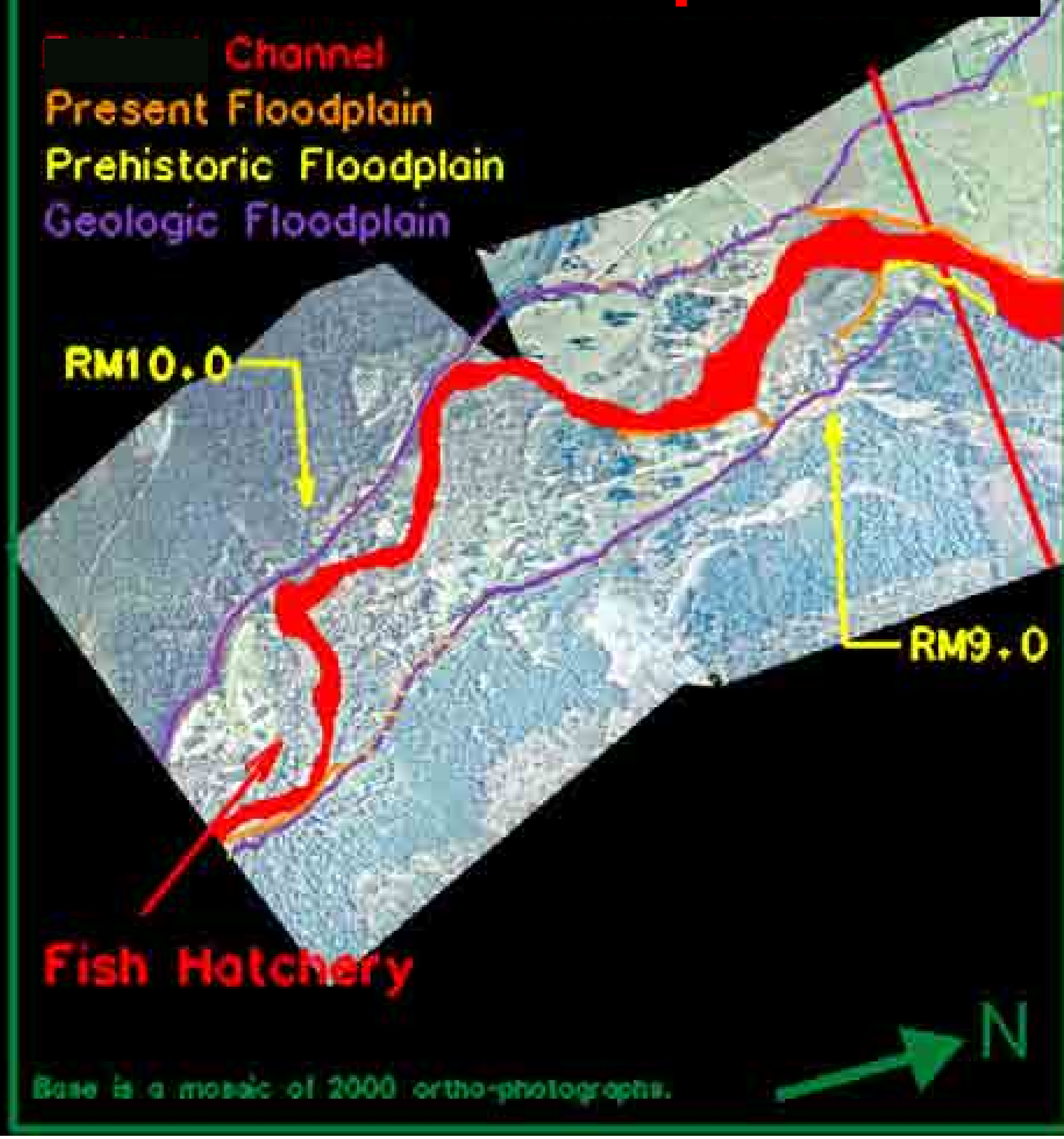
Reach 3 – Floodplains



Reach 4 – Floodplains



Reach 5 - Floodplains



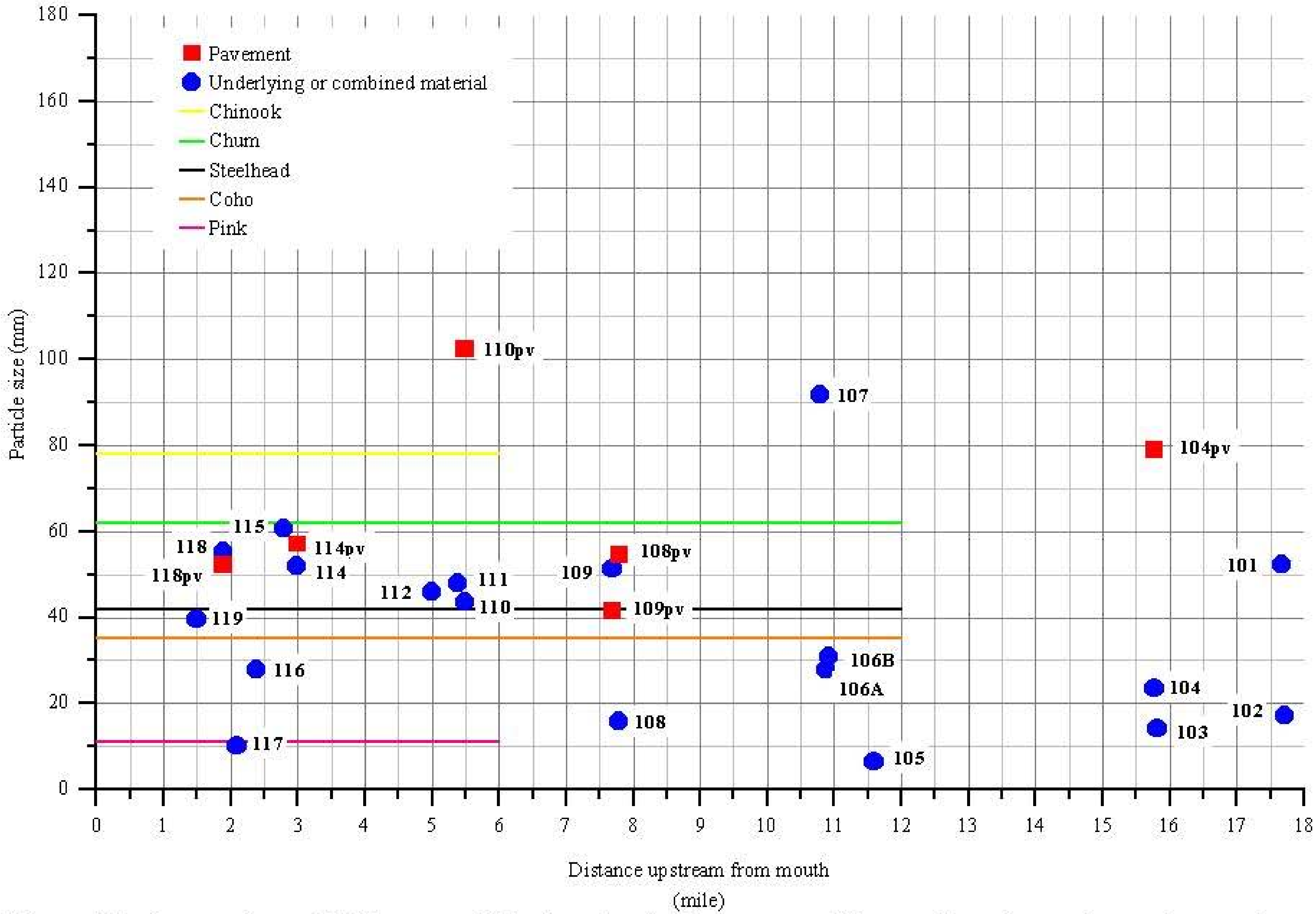


Figure 25. Comparison of D50max particle diameter for Dungeness River sediment samples and spawning redds for selected anadromous fish species.

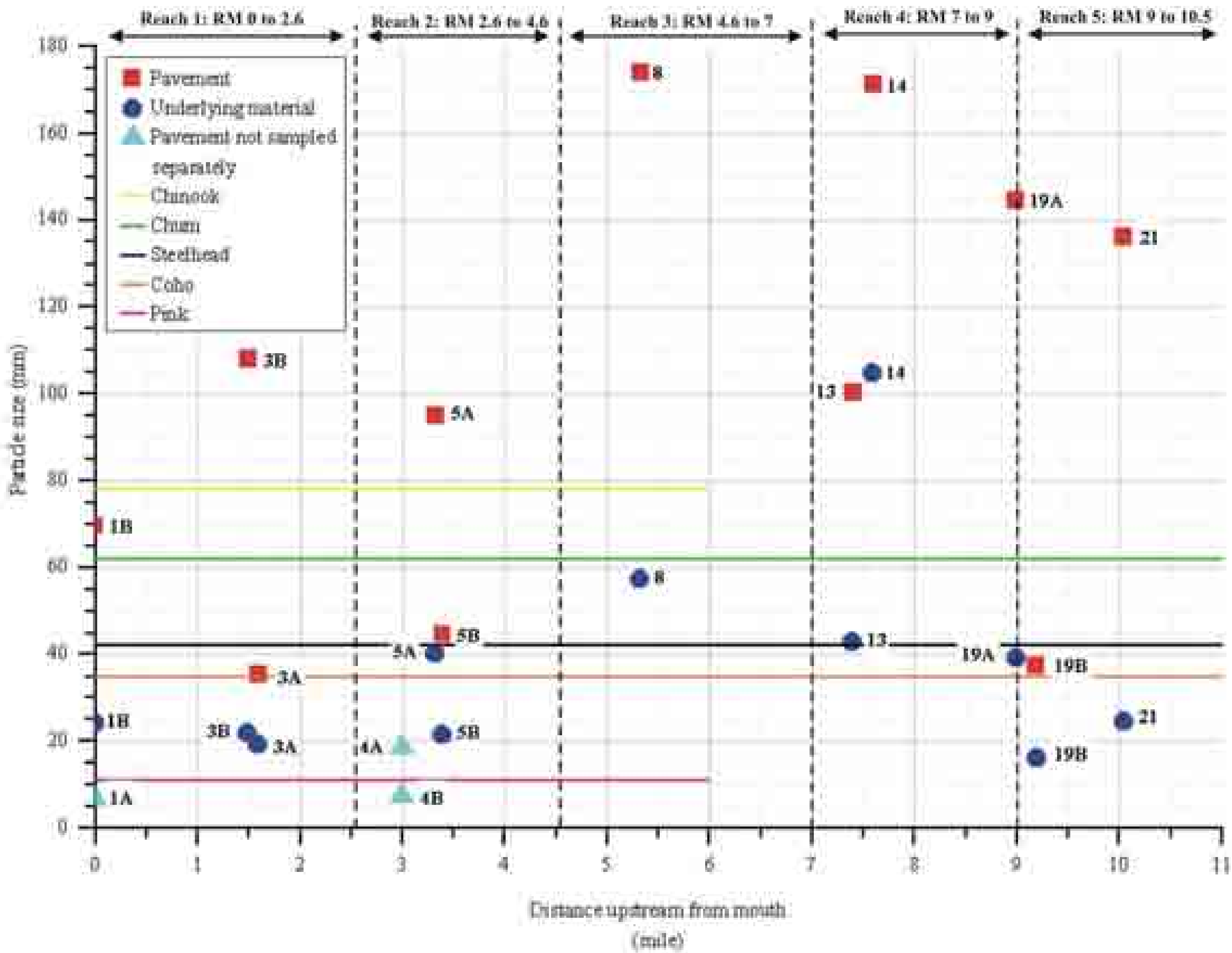


Figure 24. D50 for pavements and underlying materials on bars along the lower Dungeness River compared to the maximum D50 for fish redds on other rivers. Data for the redds have been compiled by Kondolf and Wolman (1993). Data for the bars along the Dungeness River are shown in Table 7 and Appendix D.

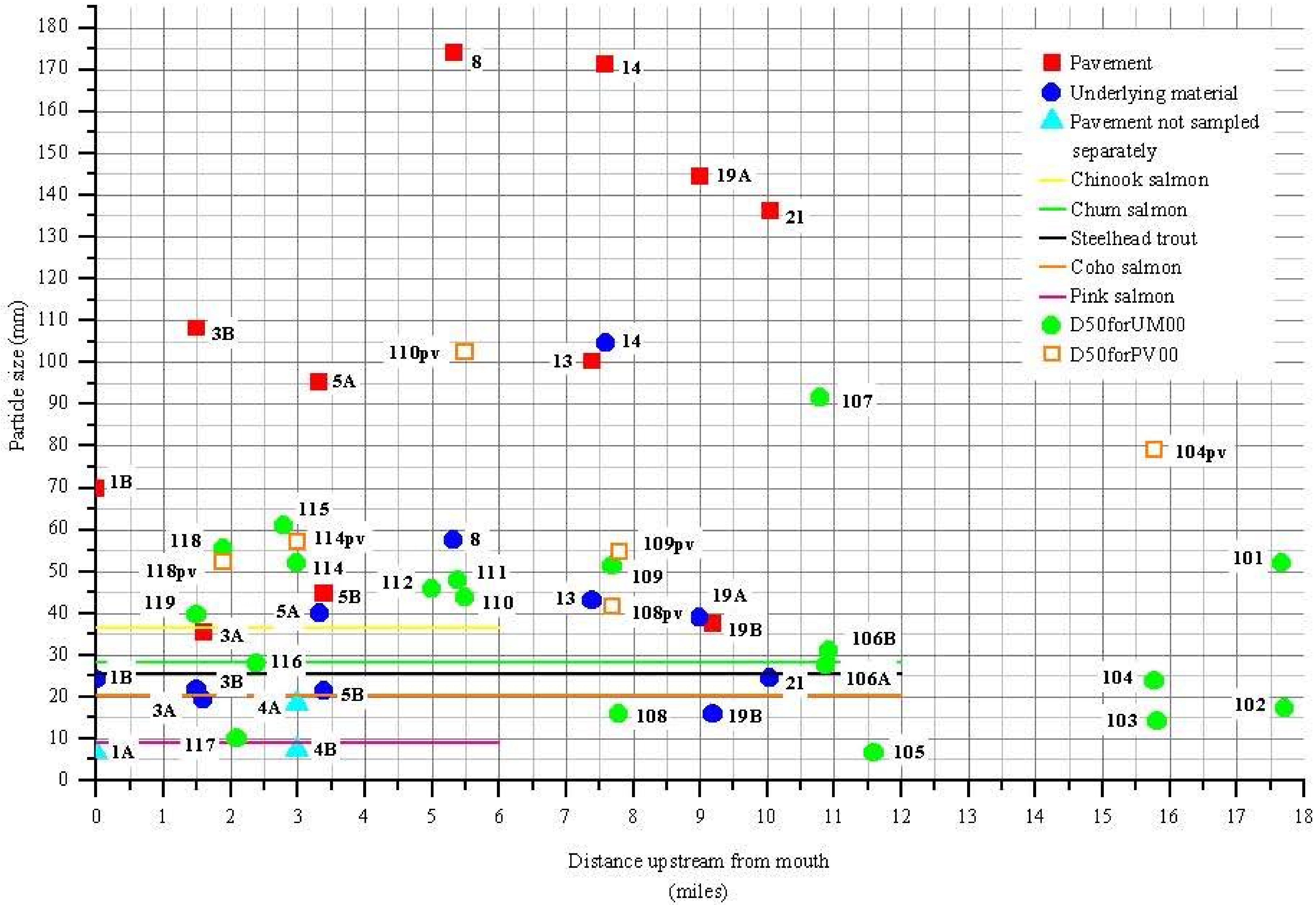


Figure 23. Comparison of D50mean particle diameter for Dungeness River sediment samples and spawning redds for selected anadromous fish species.

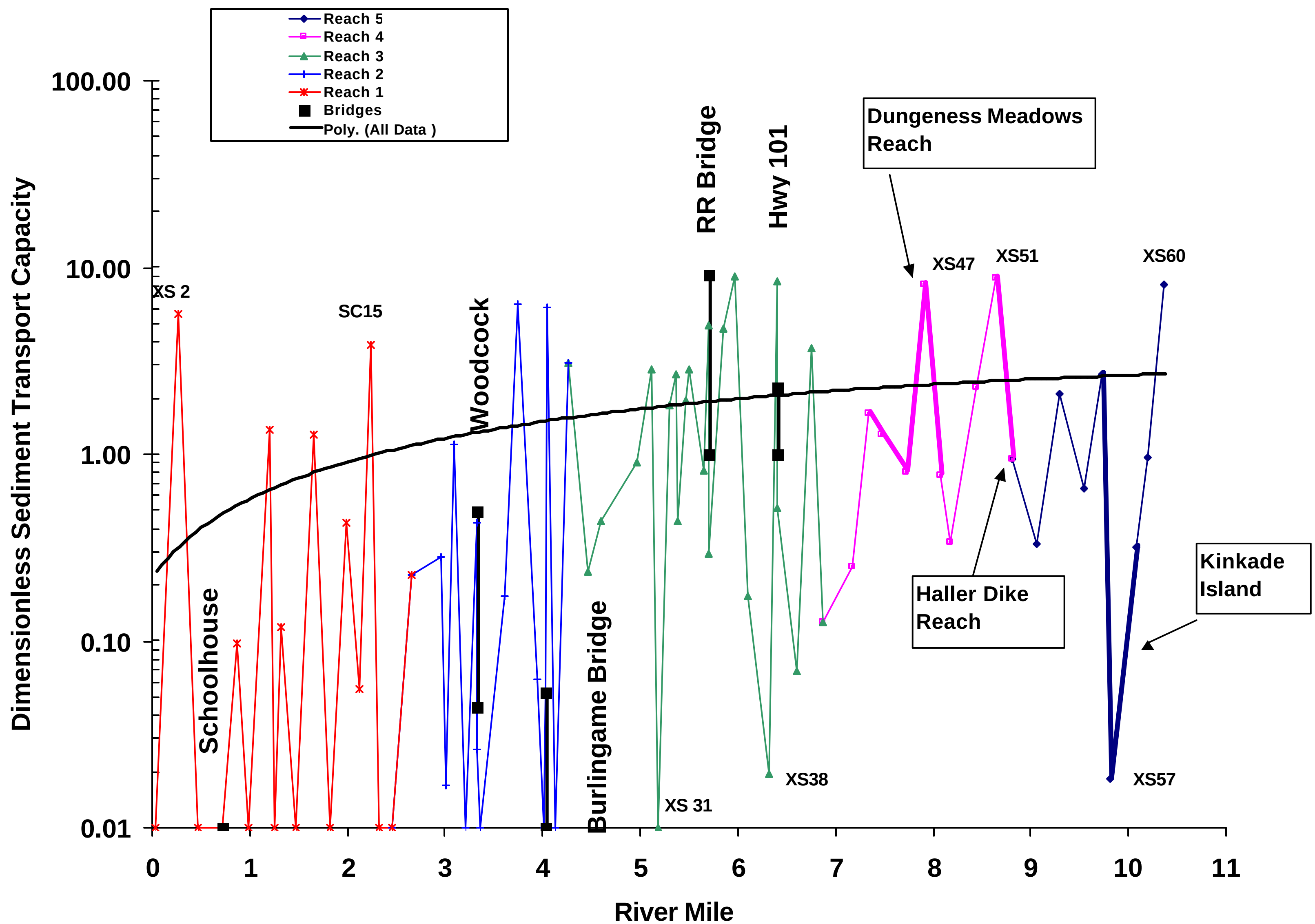


Figure 22: Sediment Transport Capacity by River Mile for the Lower Dungeness River.

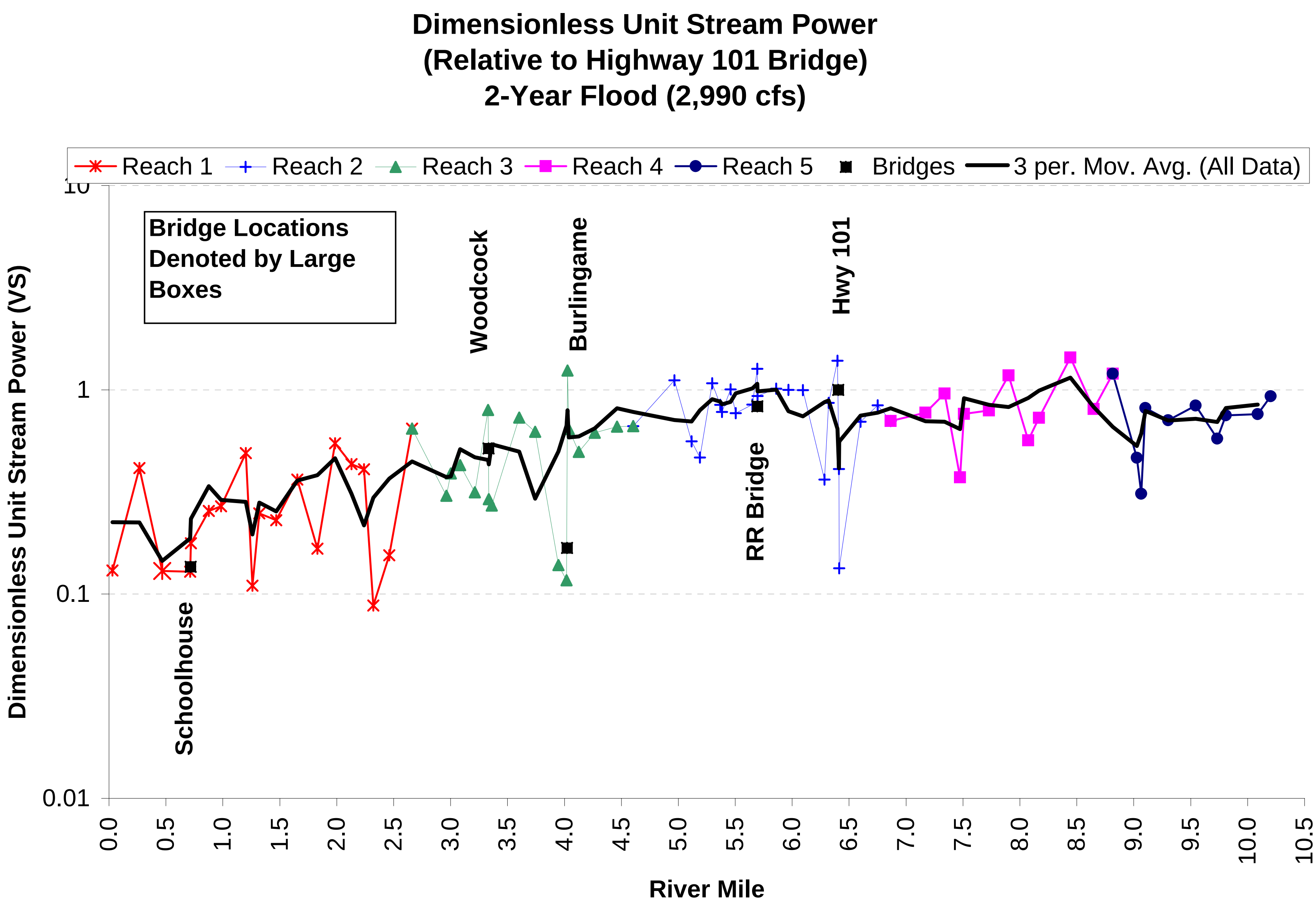


Figure 21: Unit Stream Power by River Mile at a 2-year flood.

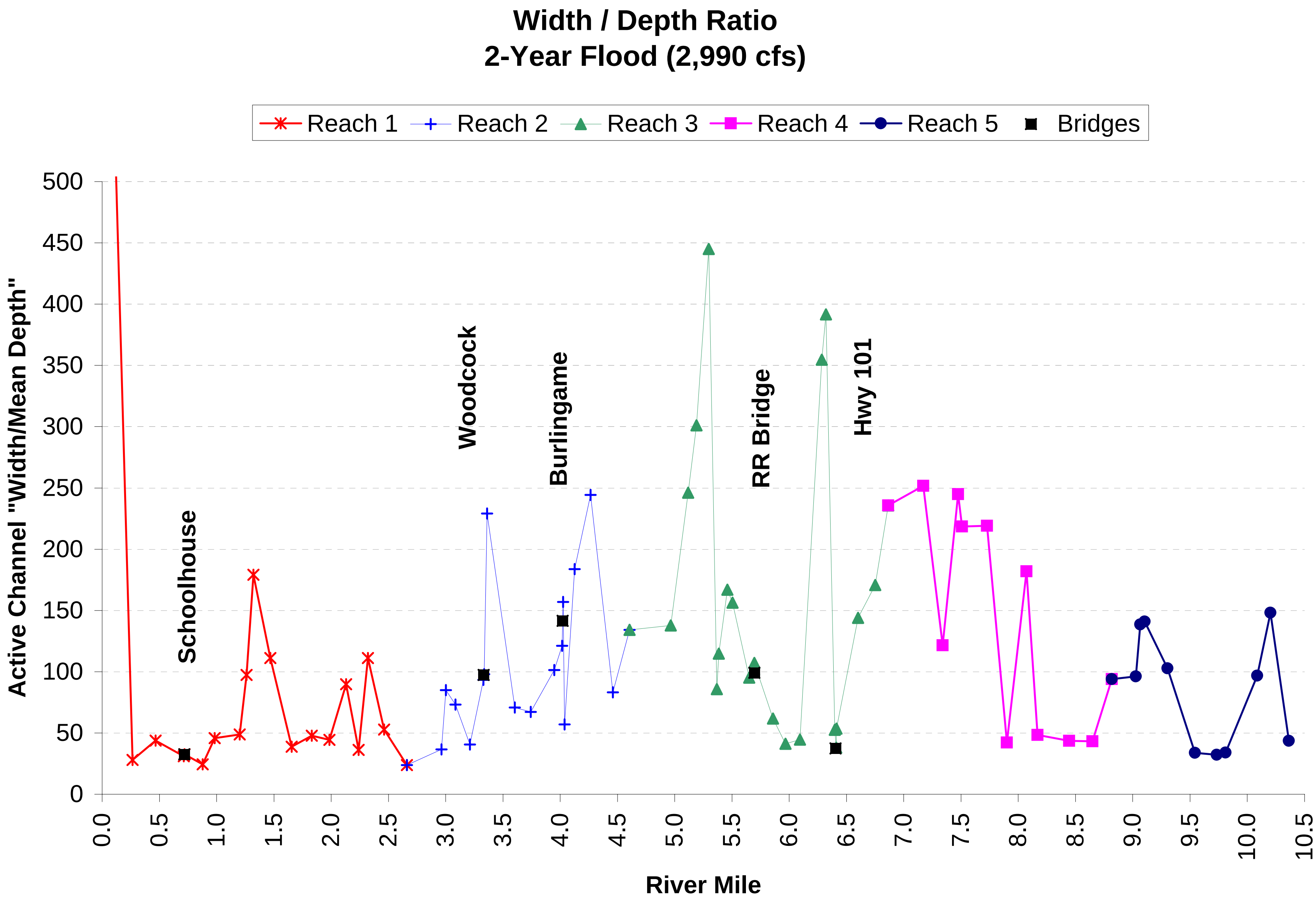


Figure 20: Model Output By River Mile for Width to Mean Depth Ratio at a 2-year flood.

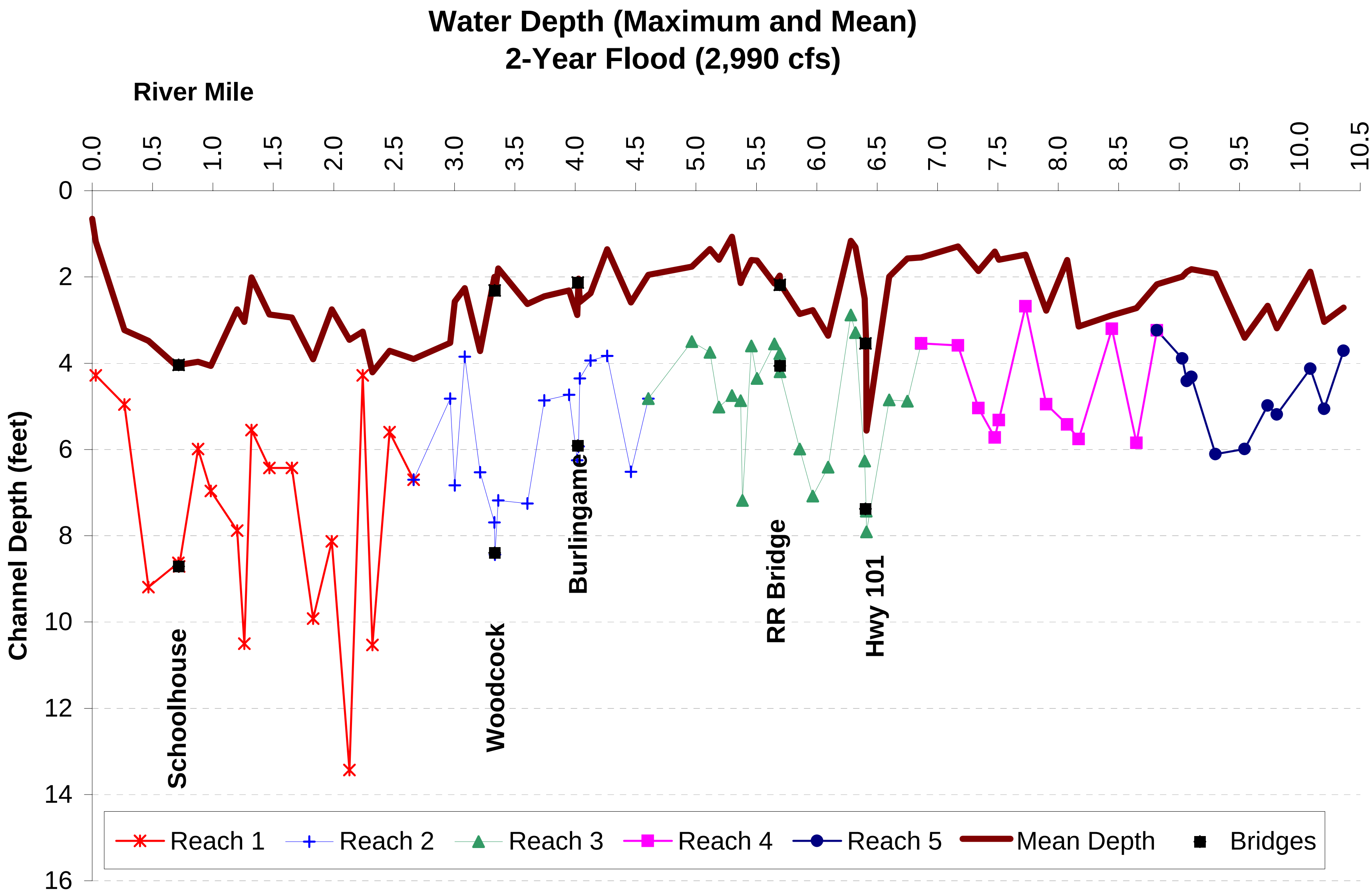


Figure 19: Model Output By River Mile for Mean and Maximum Depths at a 2-year flood.

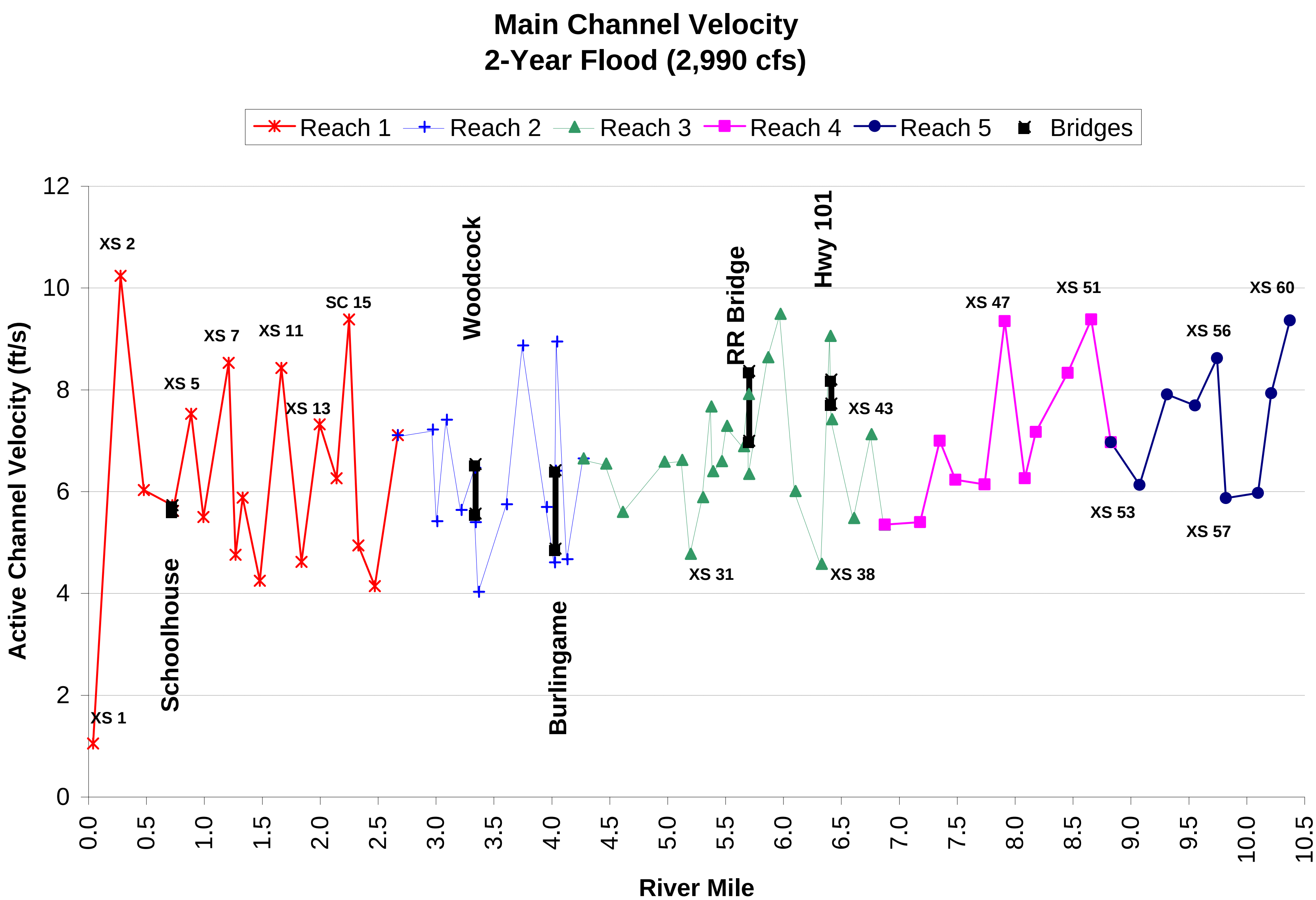


Figure 18: Model Output By River Mile for Main Channel Velocity at a 2-year flood.

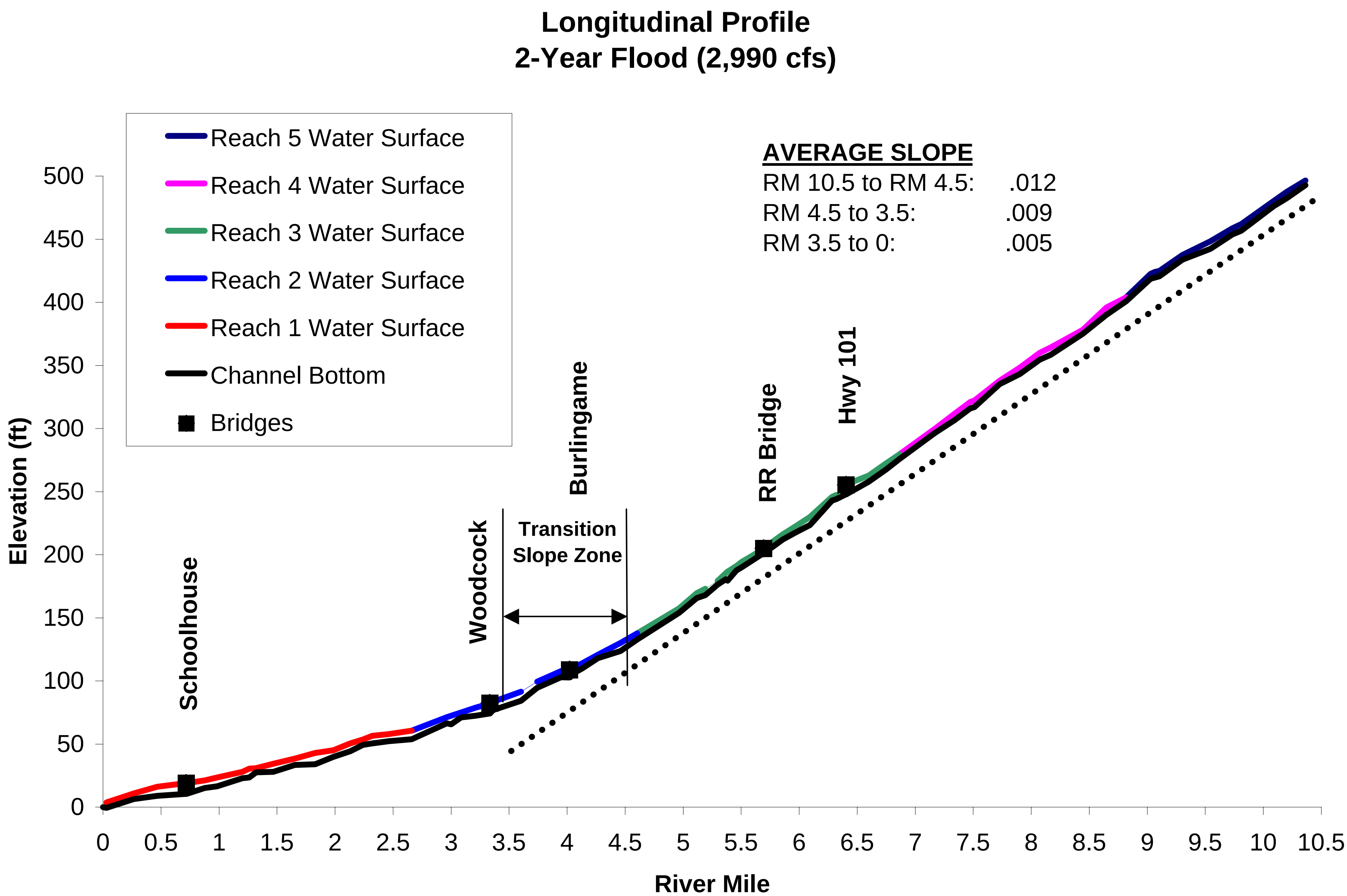


Figure 17: Model Output By River Mile for Water Surface Elevation at a 2-year flood.

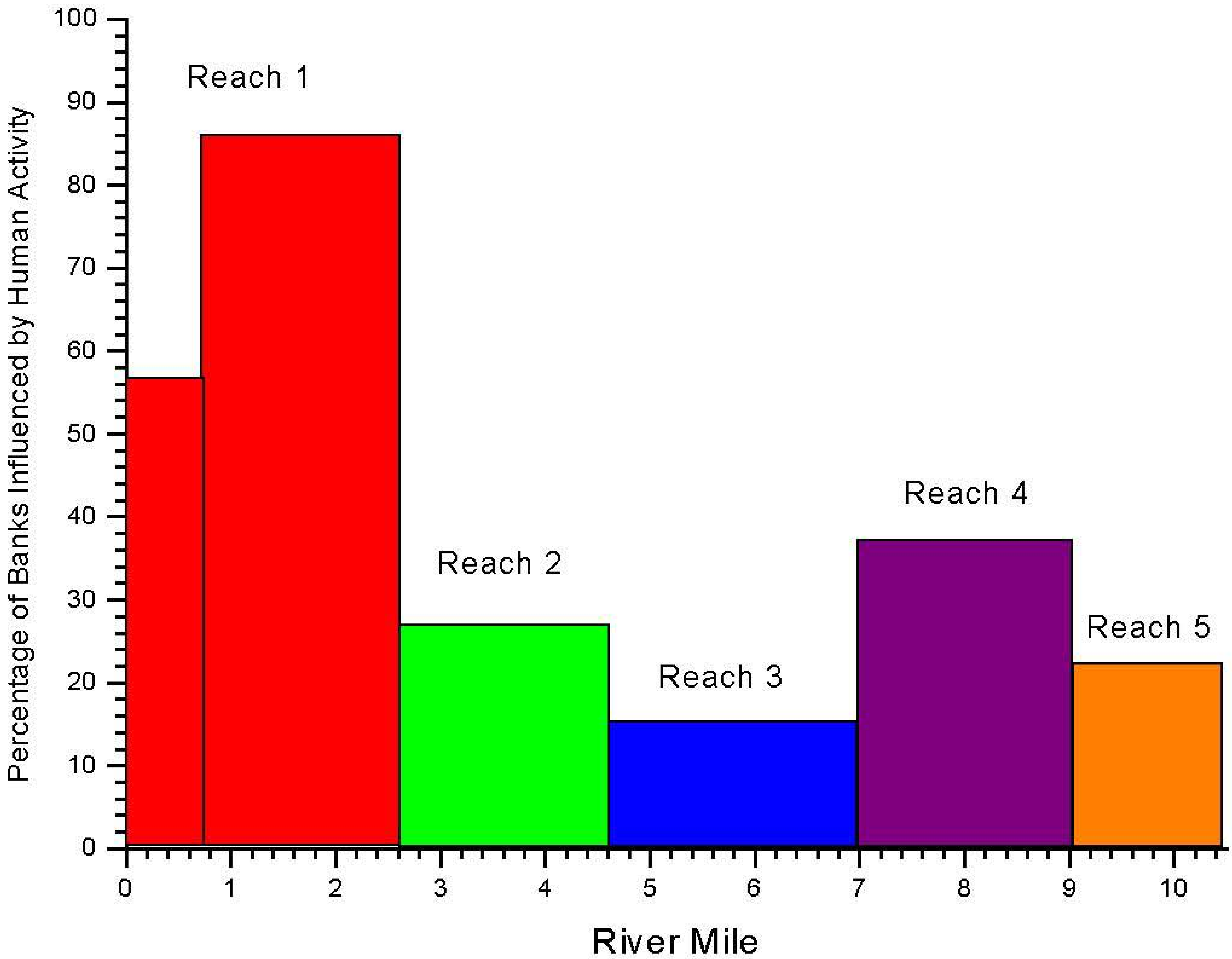


Figure 16. Percentage of the banks that have been influenced by human activities along the present floodplain.

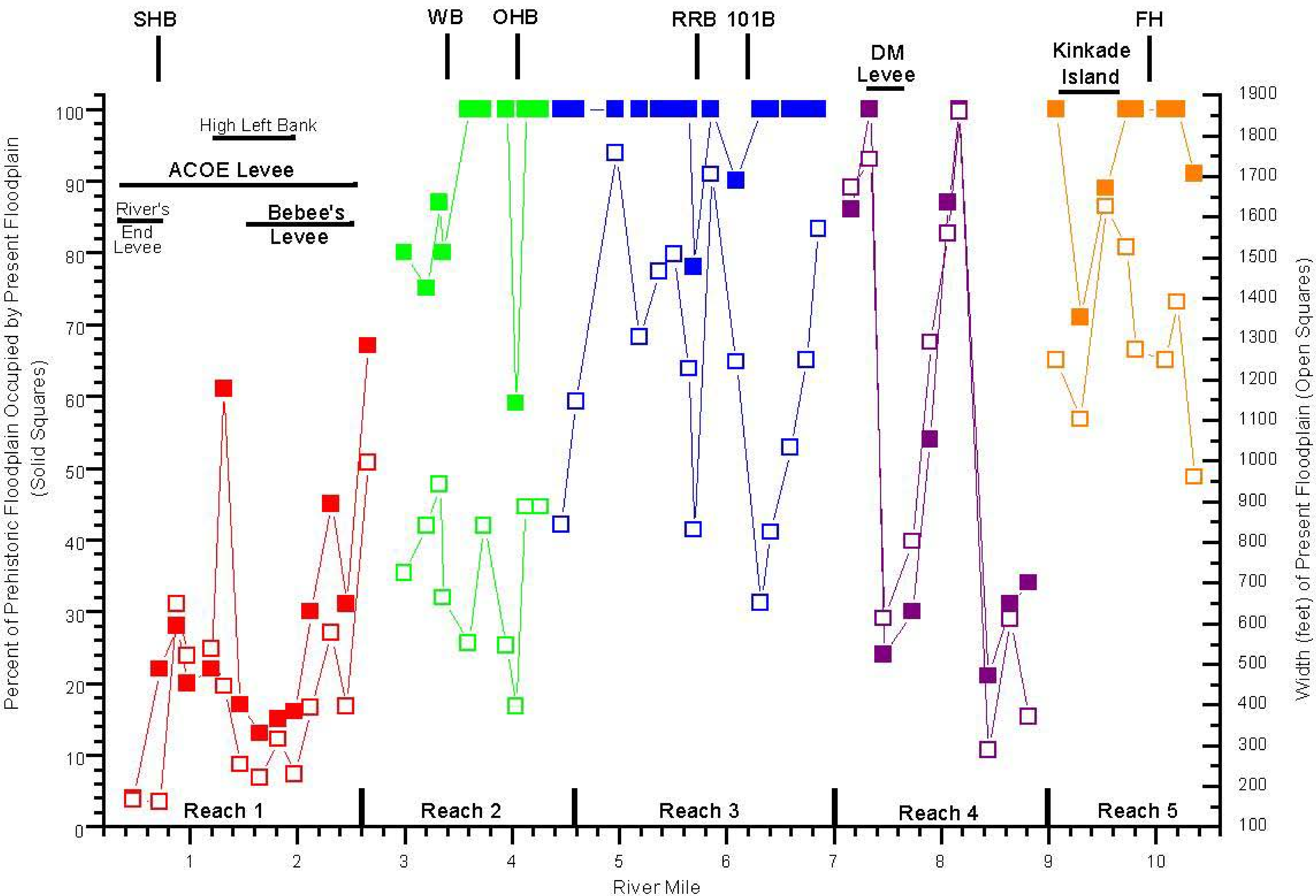


Figure 15. Percent of prehistoric floodplain that is occupied by the present floodplain and width of the present floodplain. Abbreviations are as follows: DM, Dungeness Meadows; FH, Fish Hatchery; OHB, Olympic Highway Bridge; RRB, Railroad Bridge; SHB, Schoolhouse Bridge; WB, Woodcock or Burlingame Bridge; and 101B, Highway 101 Bridge.

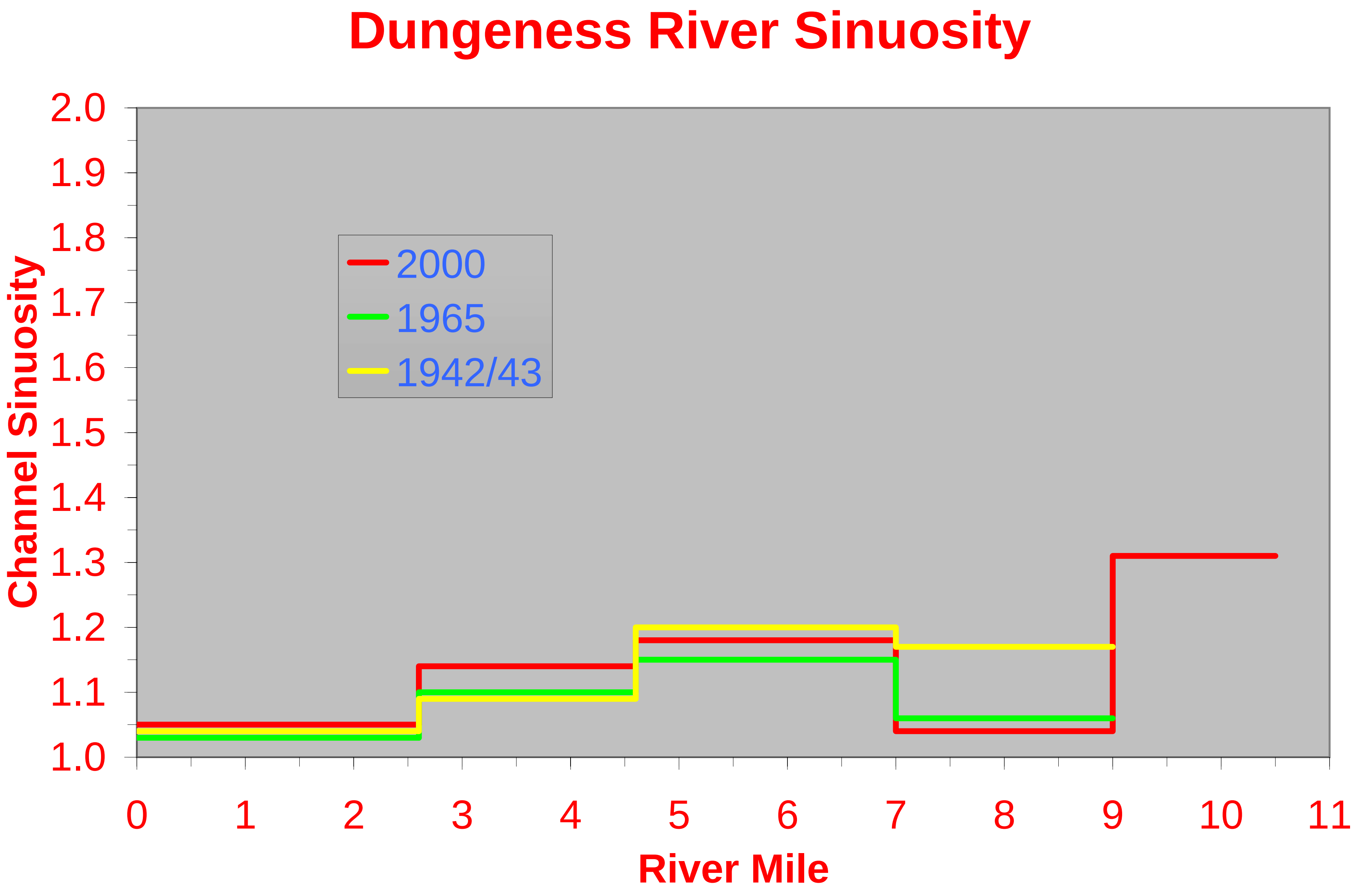


Figure 14: Existing and Historical Sinuosity of the Lower Dungeness River.

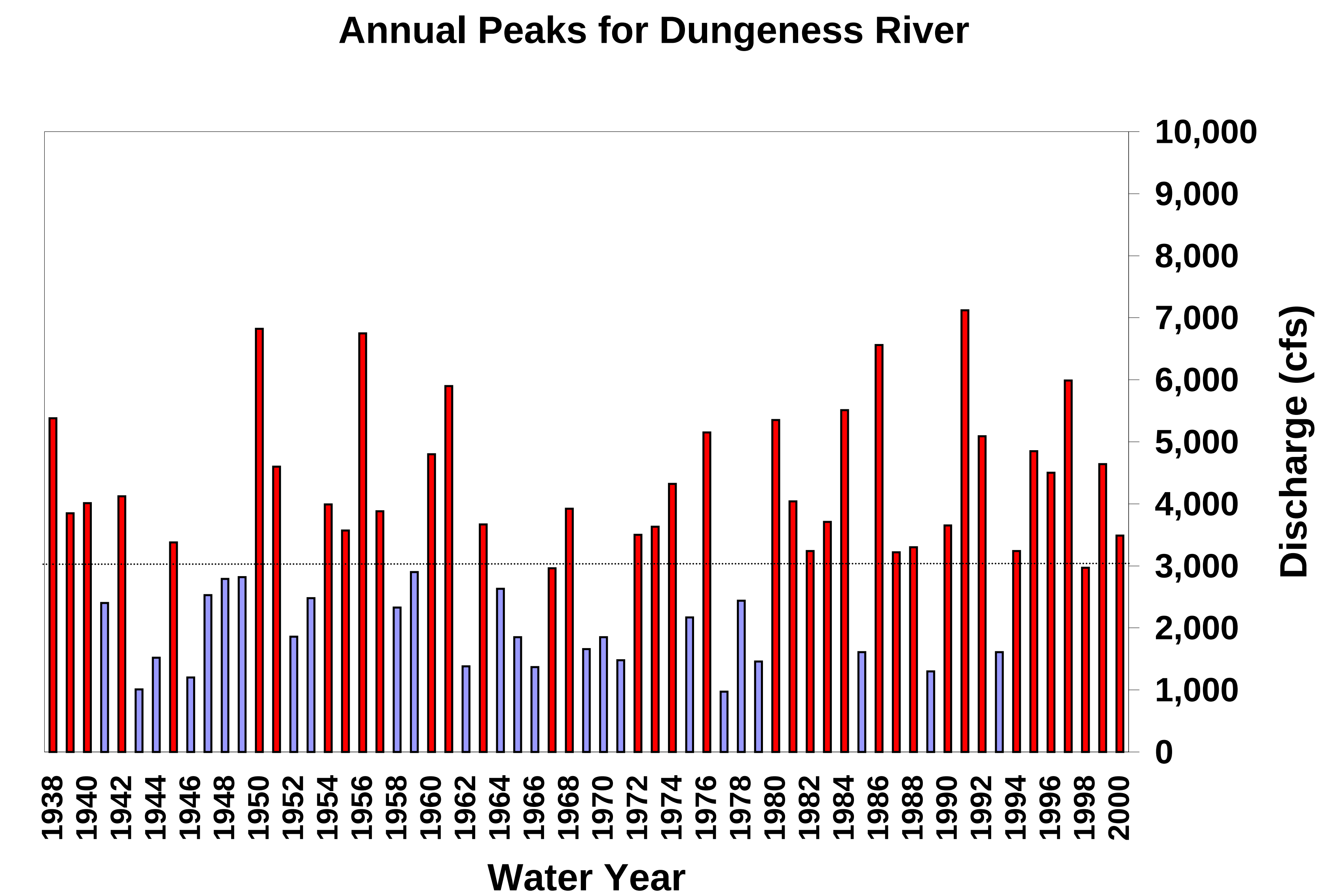


Figure 13: Annual Peak Flows for Dungeness River (USGS Gage 12048000)

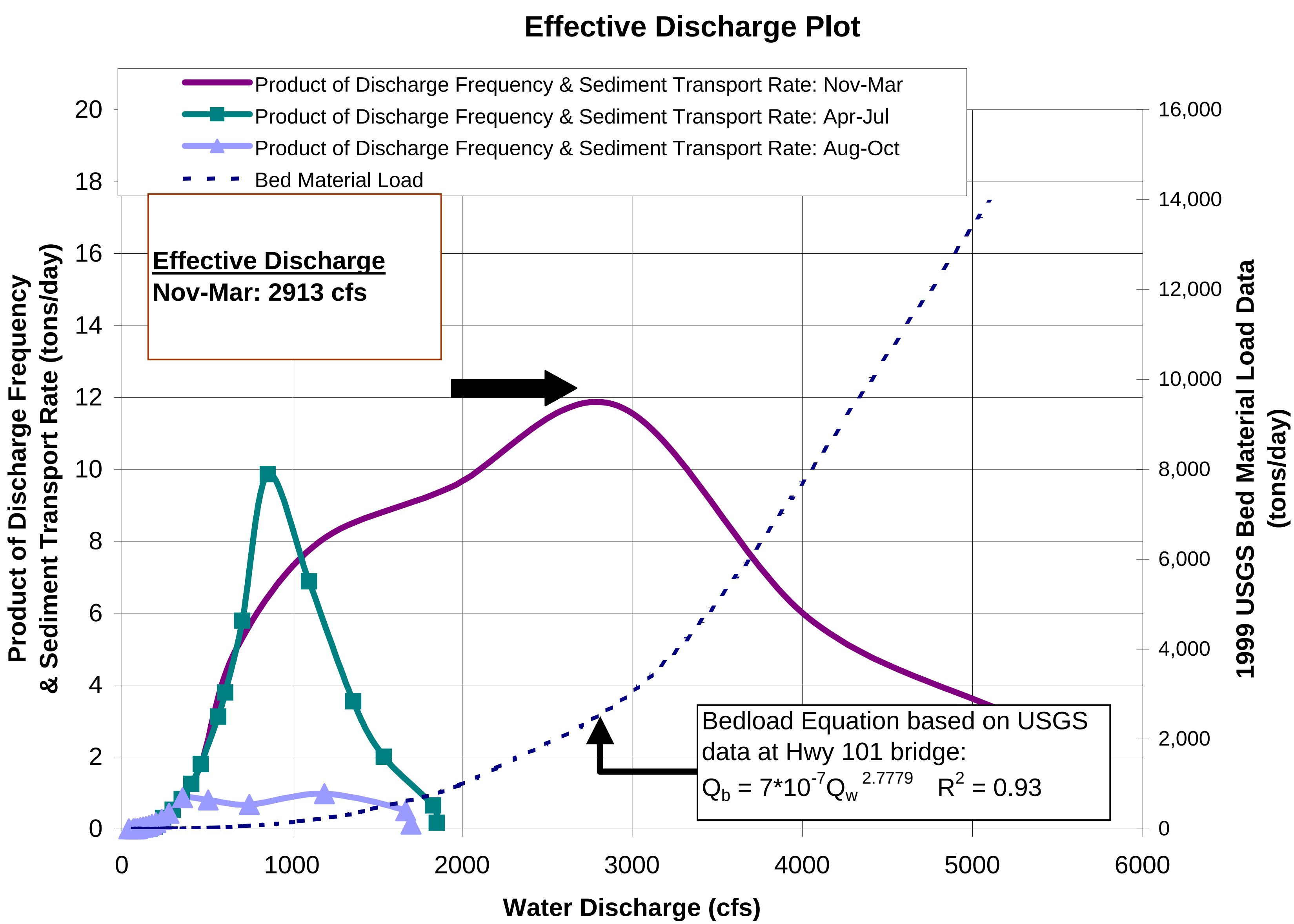


Figure 12: Effective Discharge for the Dungeness River.

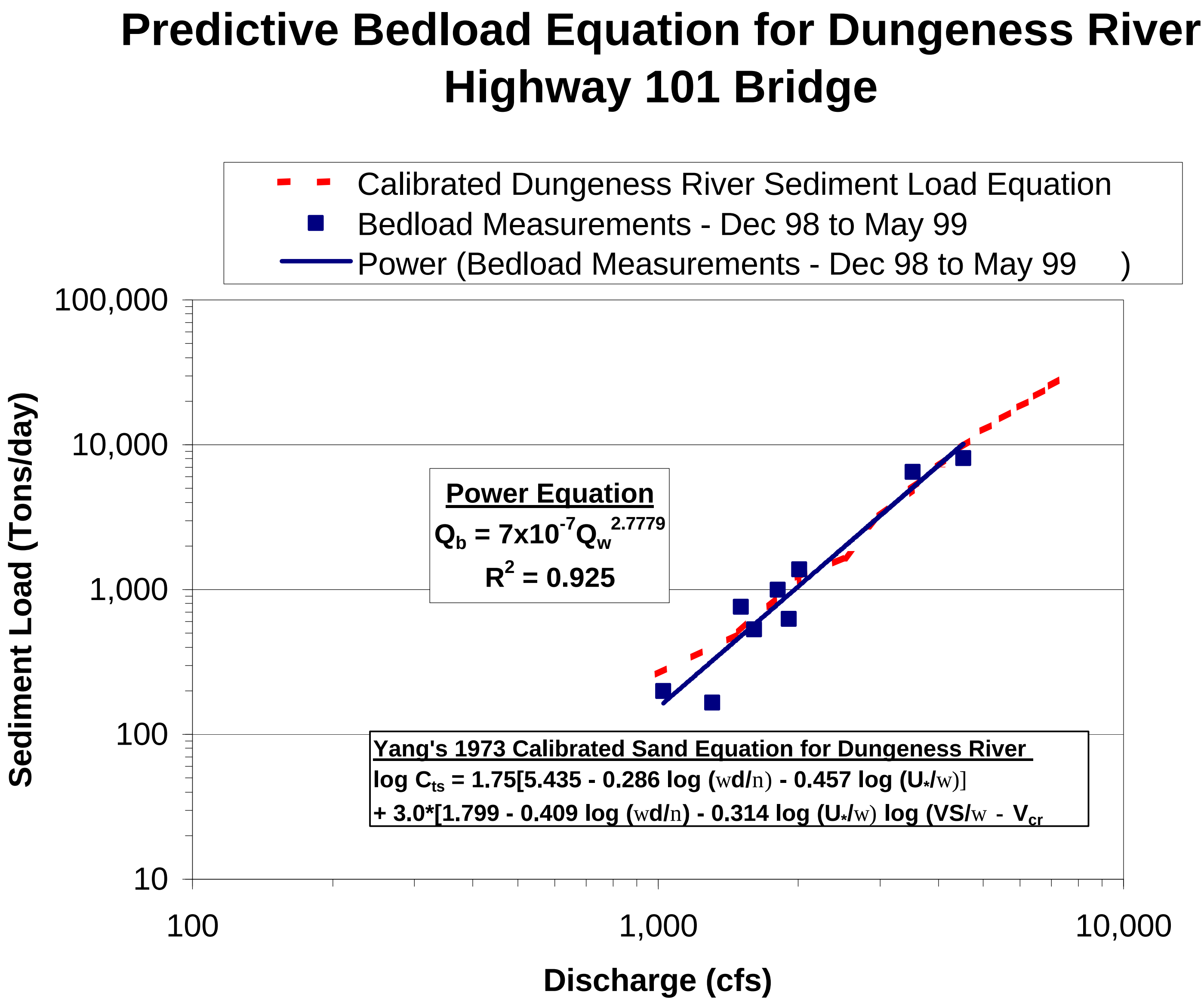


Figure 11: Measured Bedload Data and Predictive Equations for Dungeness River.

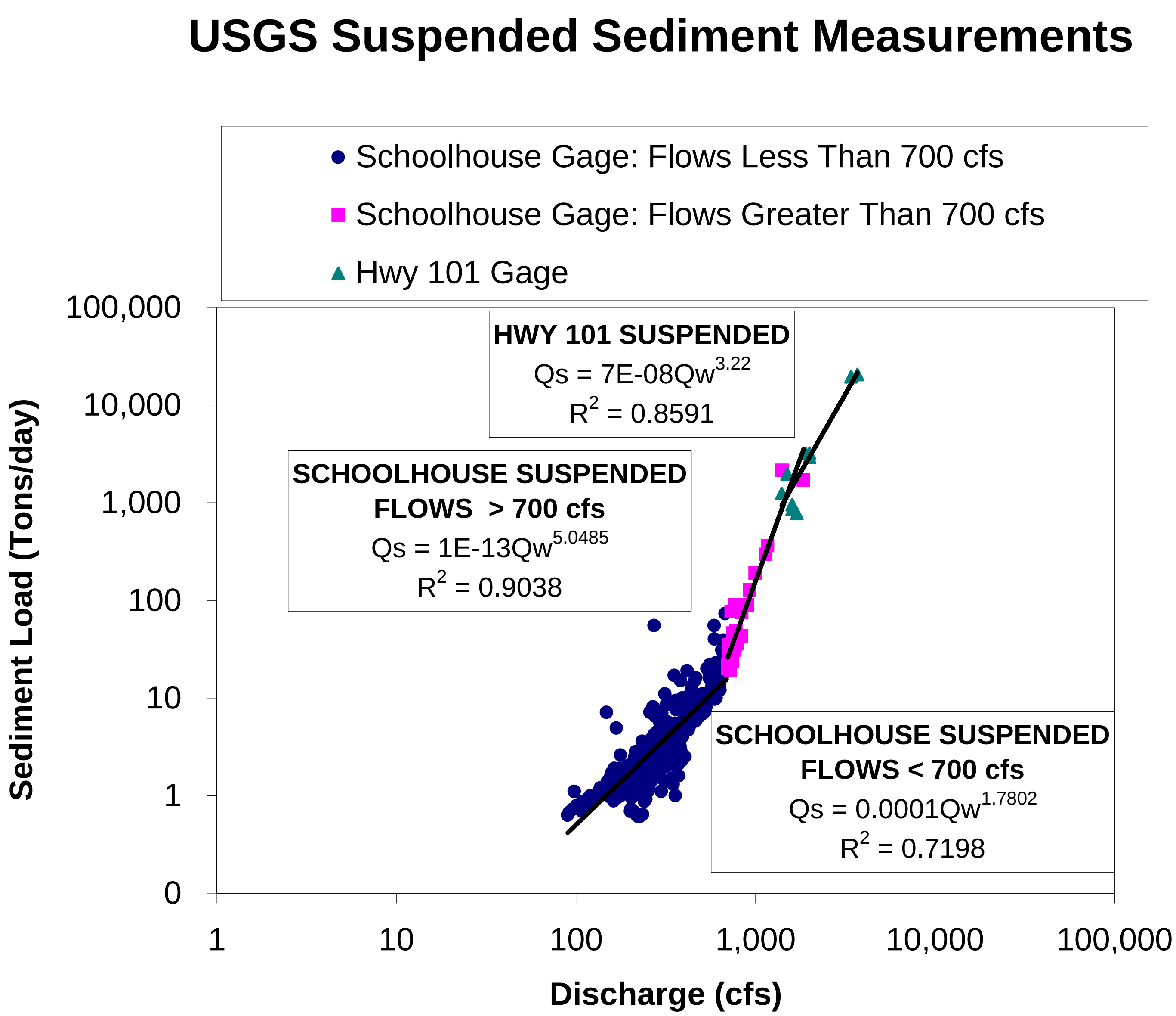


Figure 10: Suspended Sediment Measured Data and Predictive Equations at USGS Gage Sites.

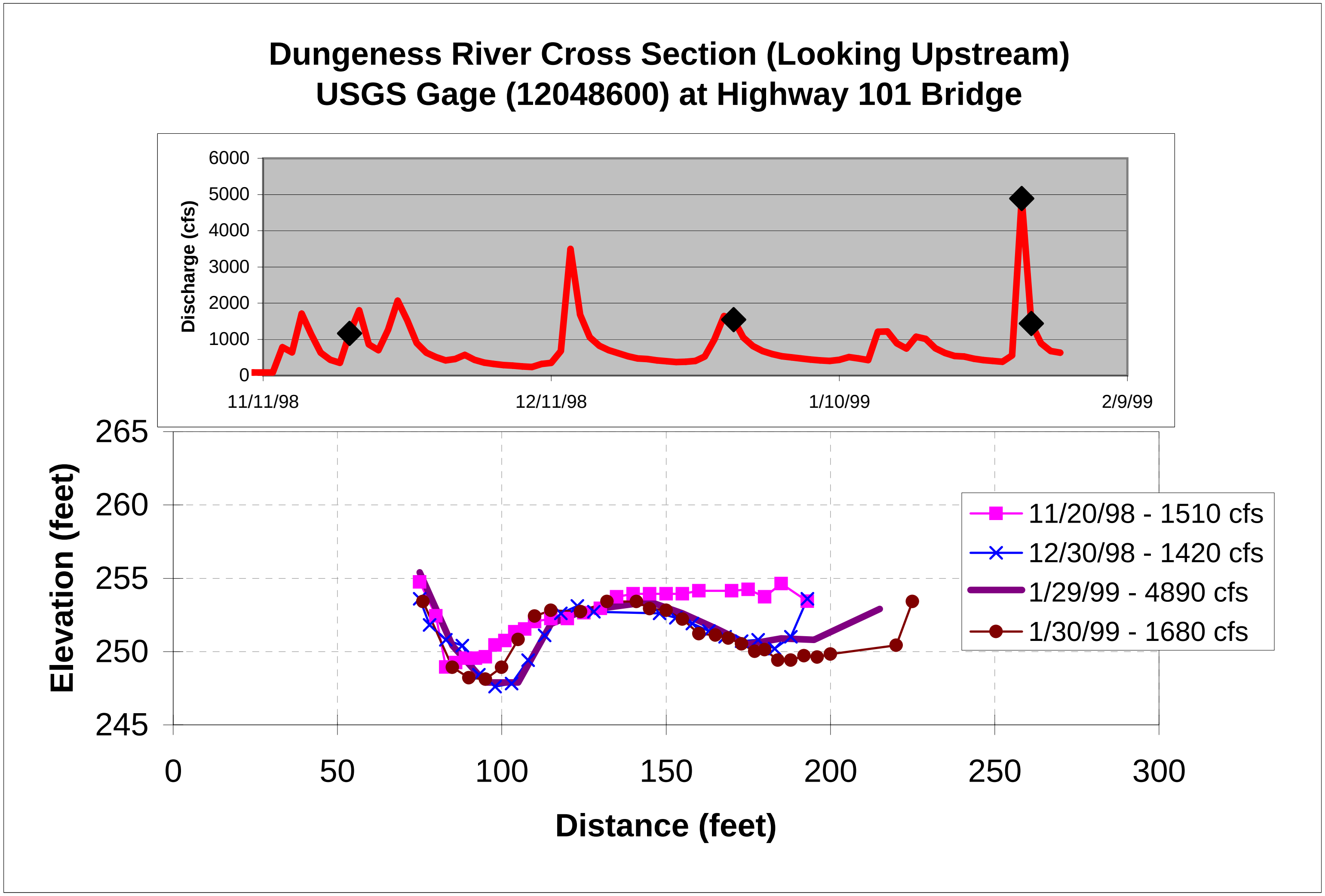


Figure 9: Comparison of cross section data at Highway 101 Gage (12048600).

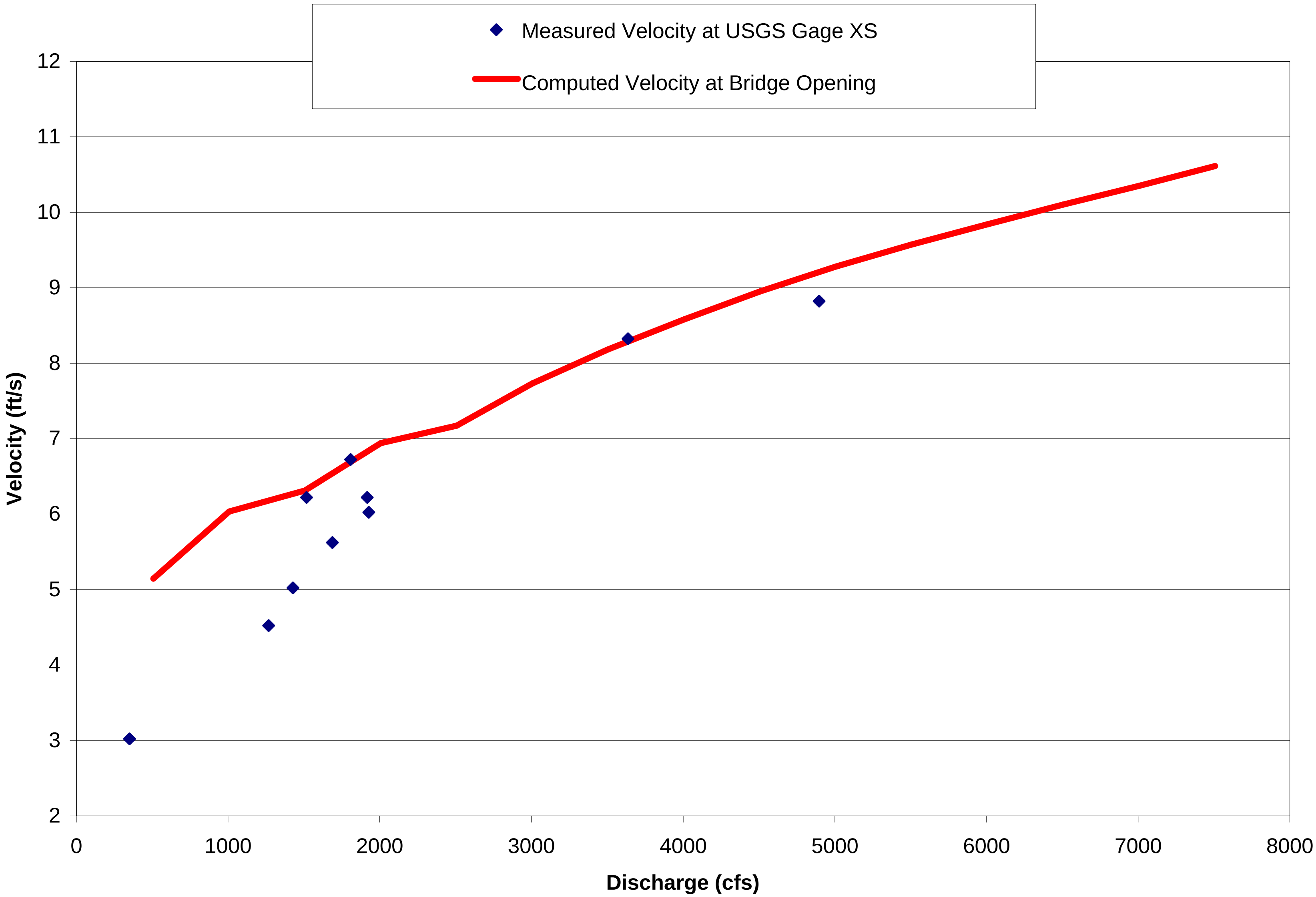


Figure 8: Comparison of comupted versus measured velocity at Highway 101 Gage (12048600).

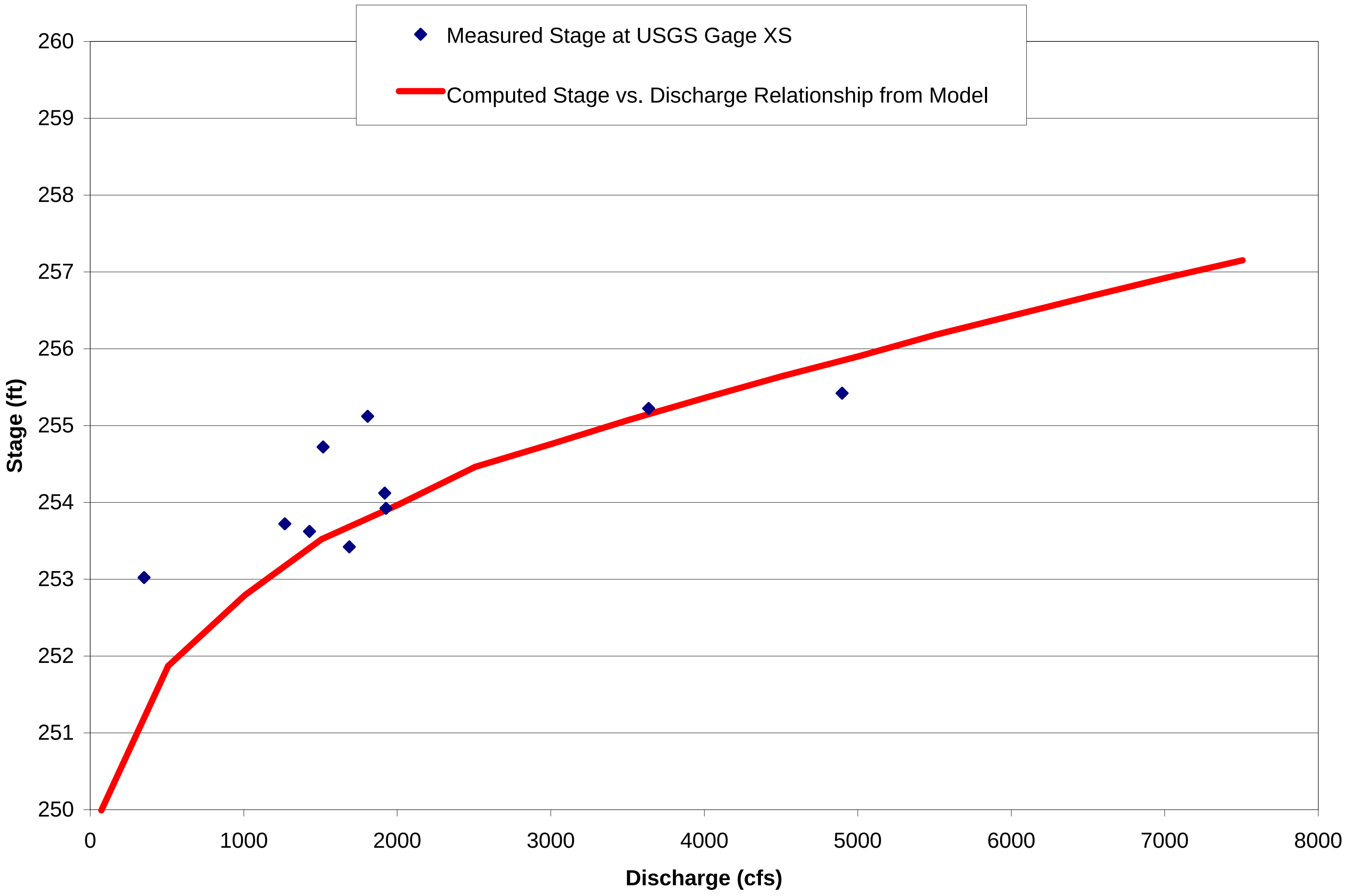


Figure 7: Comparison of comupted versus measured stage at Highway 101 Gage (12048600).

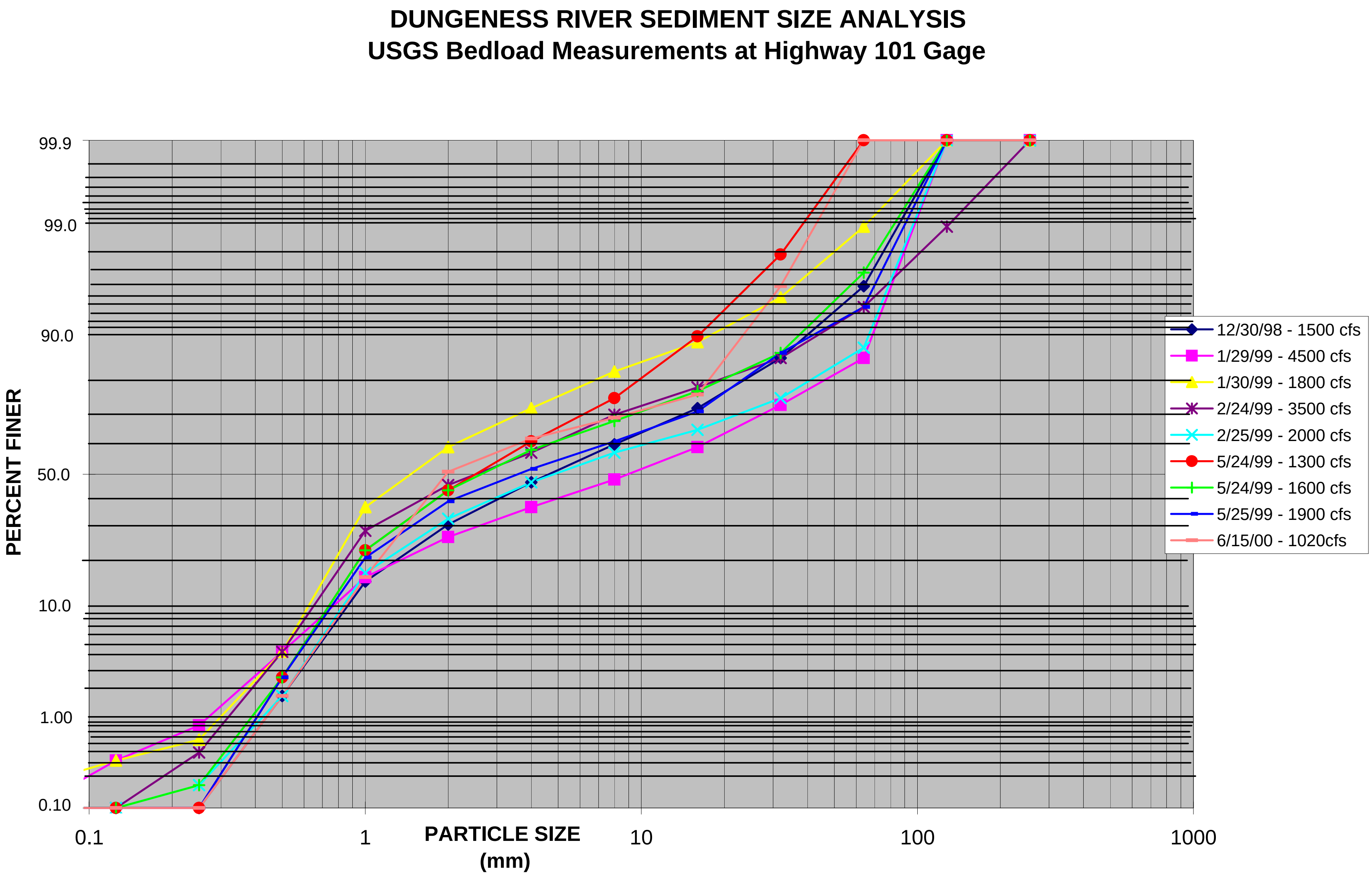


Figure 6: Particle Size Distribution of USGS Bedload Measurements at Highway 101 Gage Site (12048600)

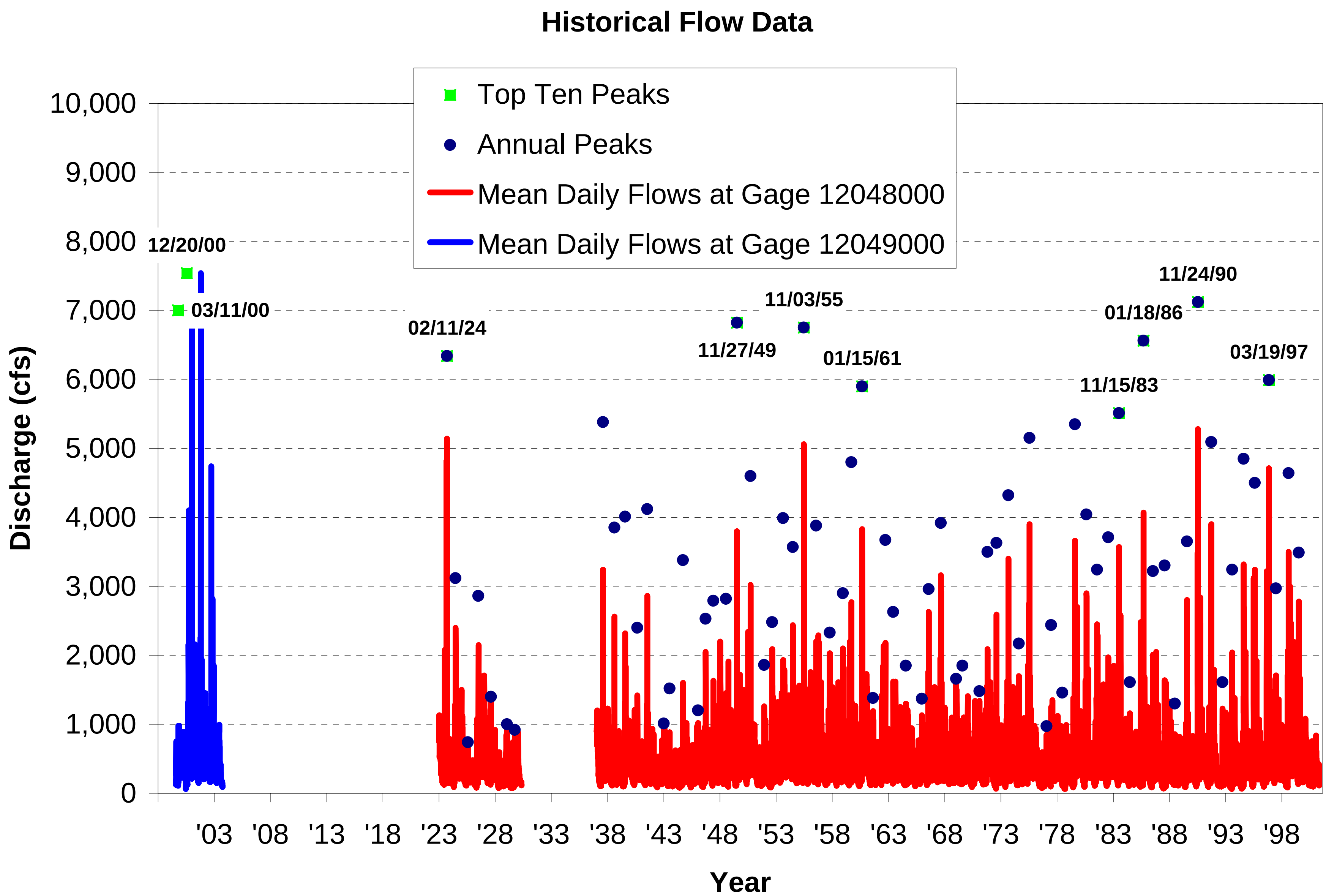
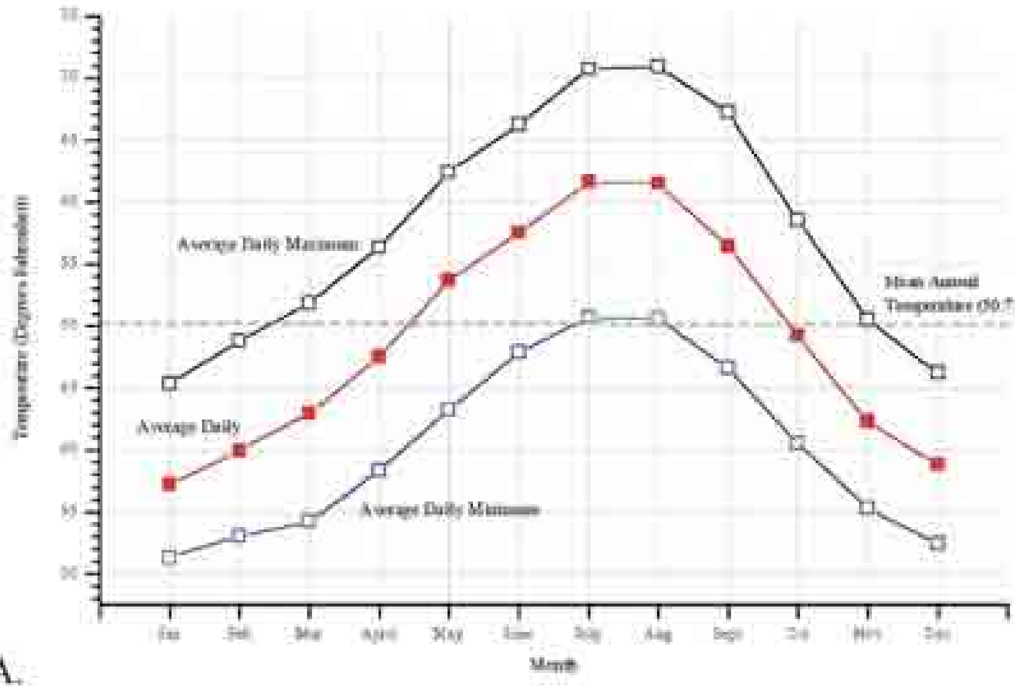
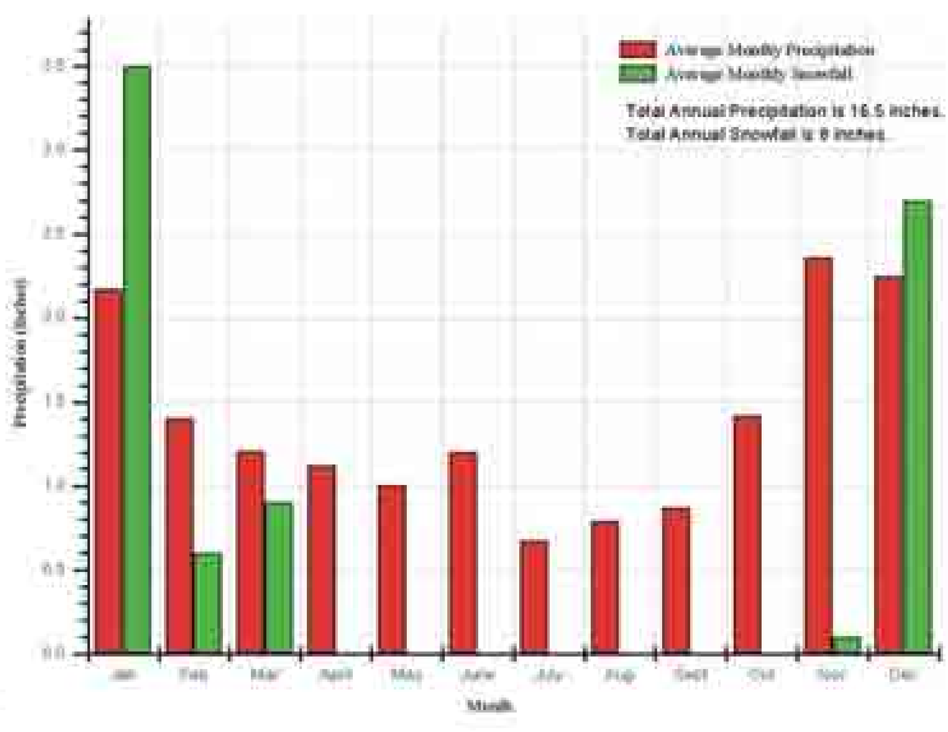


Figure 5: Historical flow data for Dungeness River.



A.



B.

Figure 4. Temperature (A) and precipitation (B) data for Sequim.

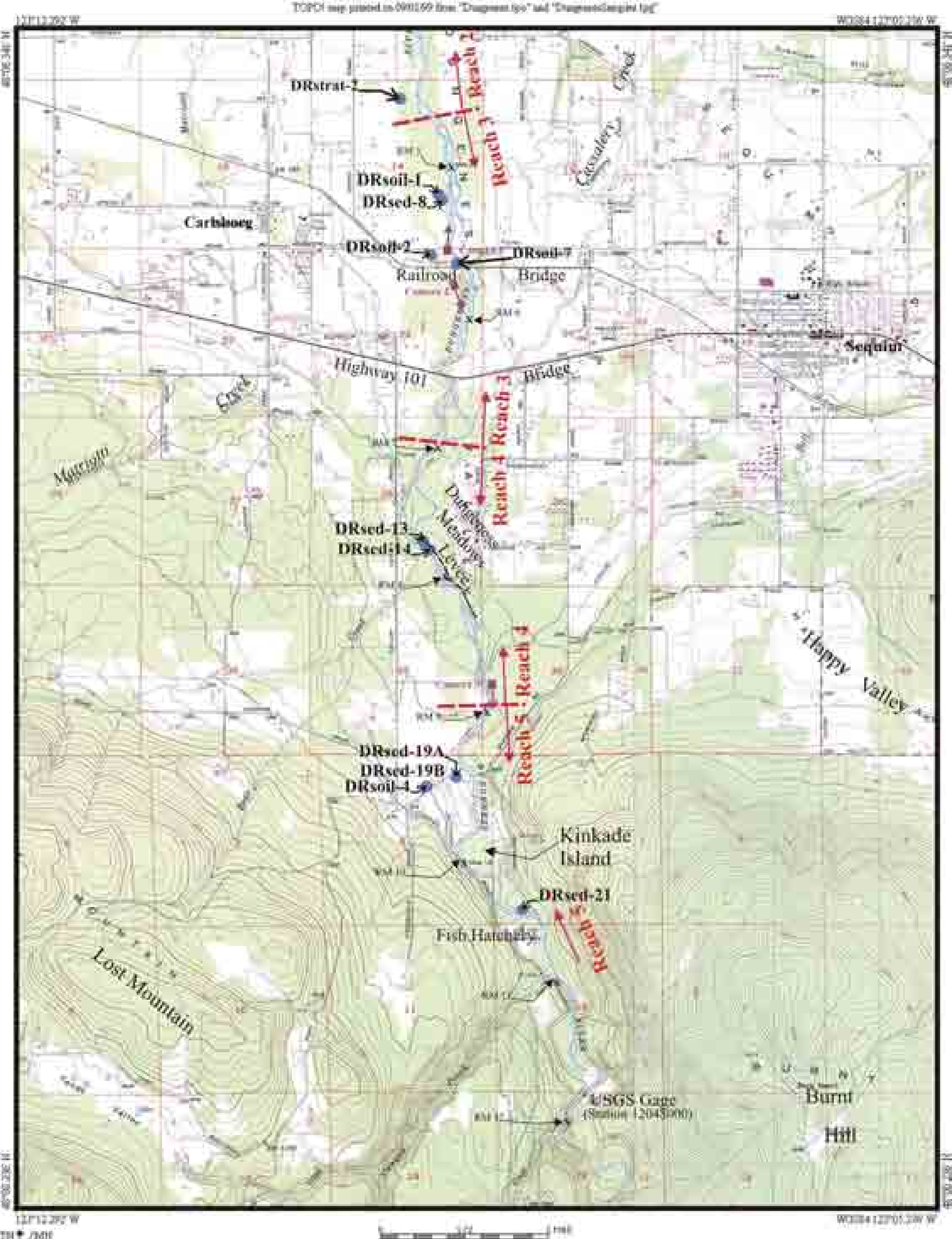


Figure 3B. Location map showing sample localities of the south half of the lower Dungeness River corridor. Overlaps with Figure 3A.

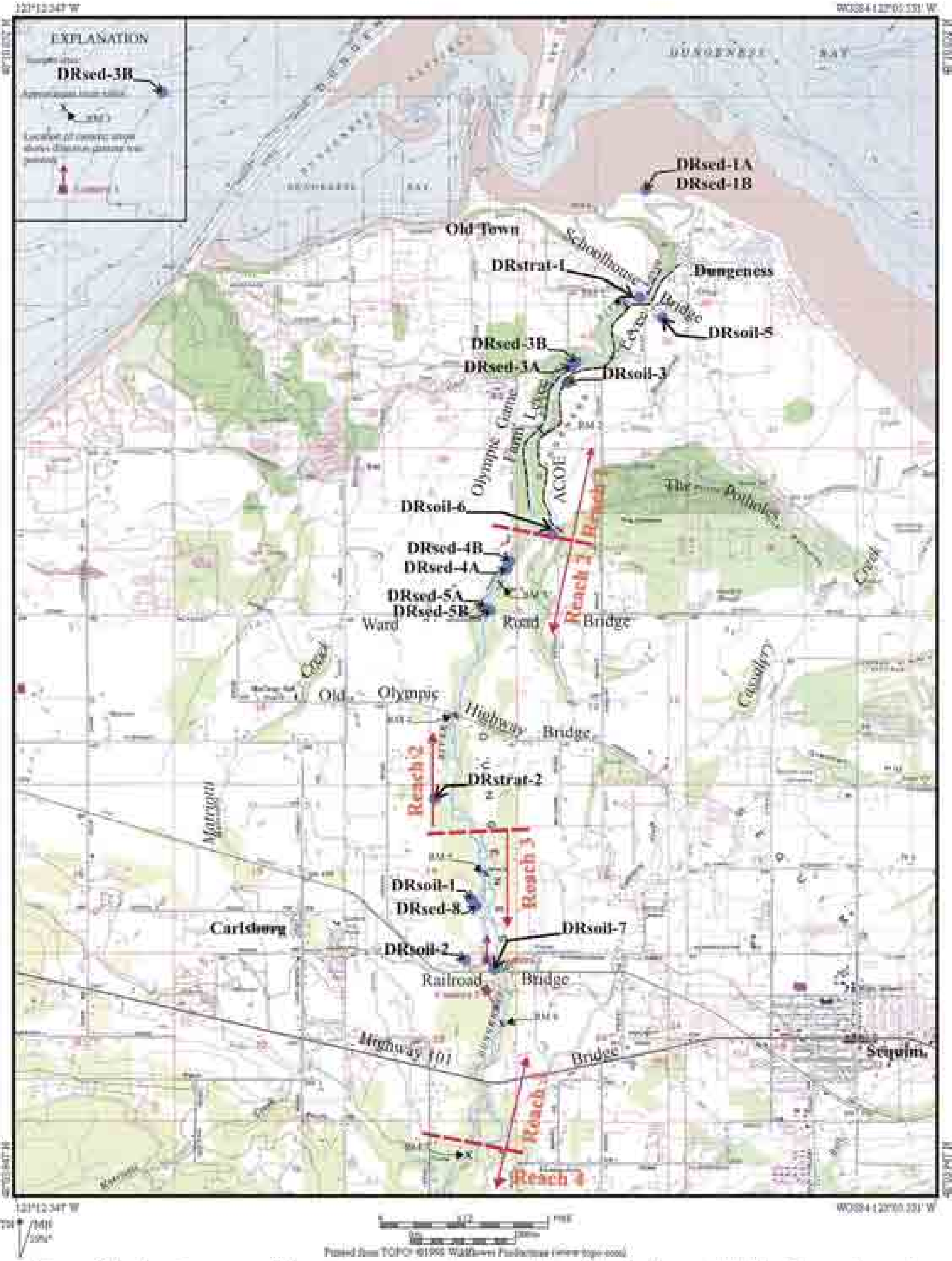


Figure 3A. Location map of the study area showing sample localities in the north half of the study reach.

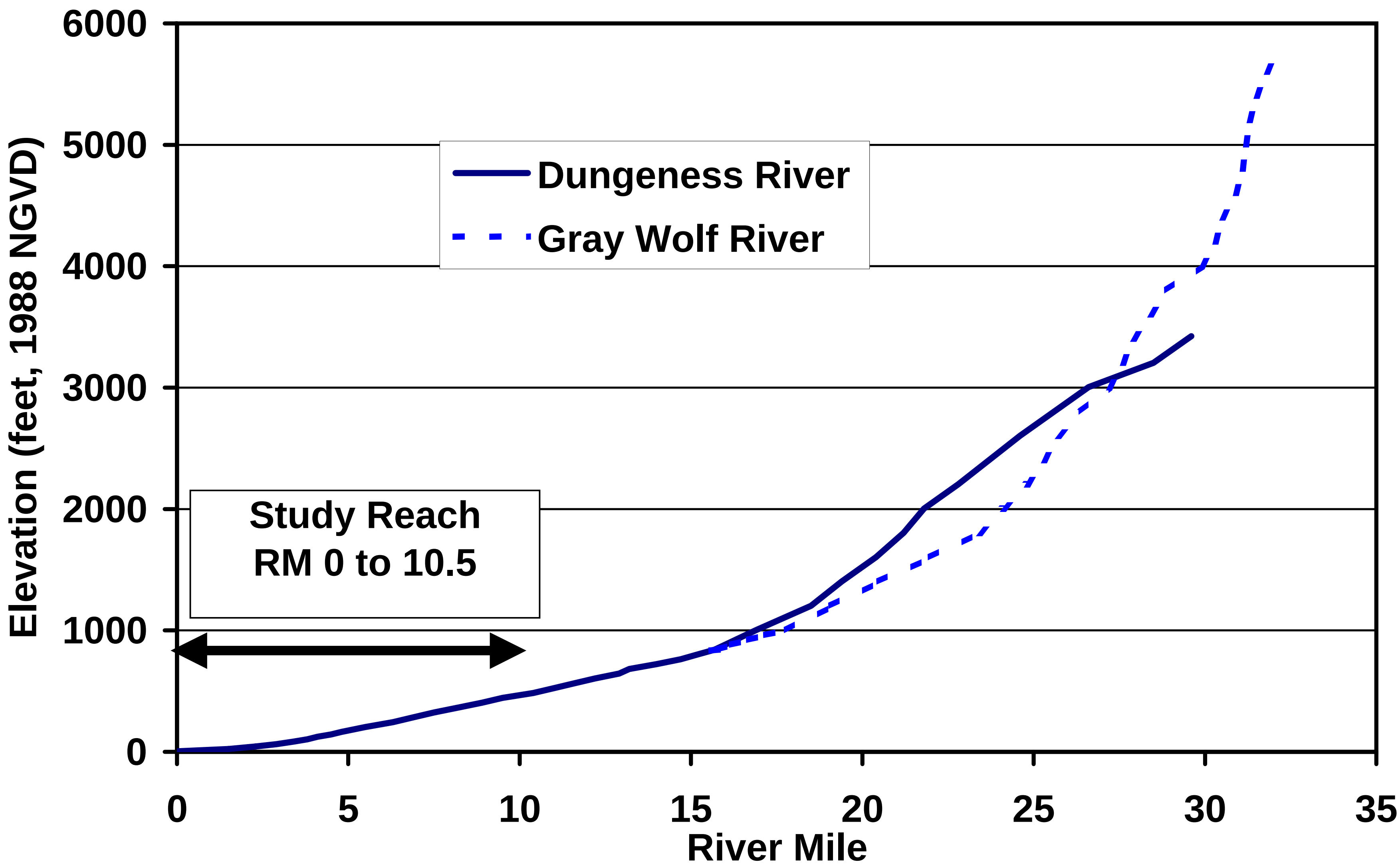


Figure 2: Longitudinal Profile of Dungeness and Gray Wolf Rivers

Figure 1. Location of the Dungeness River drainage basin on the northeastern Olympic Peninsula in northwestern Washington. The drainage basin is outlined in black. MC indicates Meadowbrook Creek.

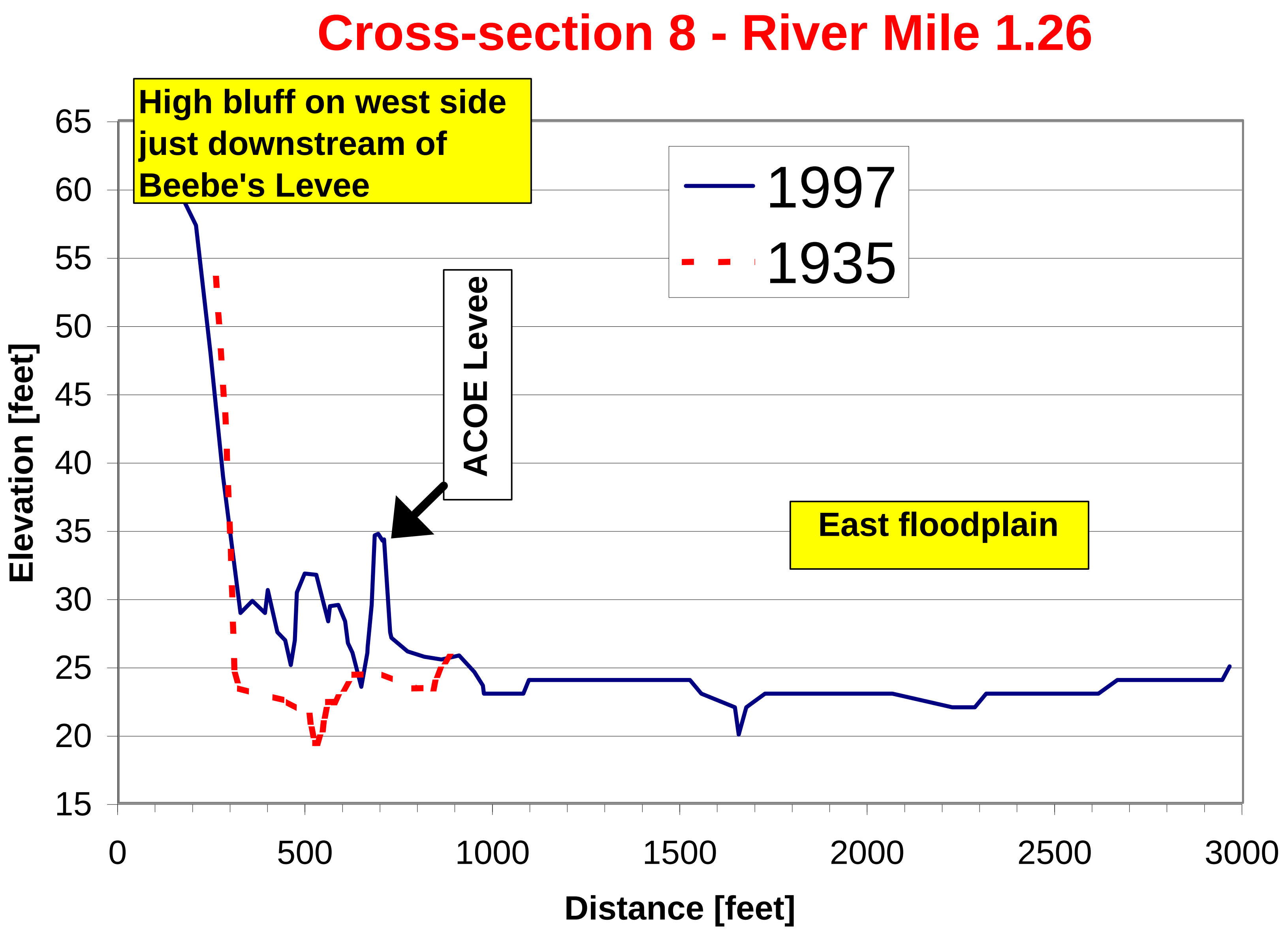


Figure 33: Existing versus 1935 cross section at RM 1.26 in Reach 1.

APPENDIX A.
SUMMARY OF HISTORICAL INFORMATION

Historical information for the Dungeness River basin is important in understanding the conditions that are now present along the lower river corridor. Humans have been in the Dungeness area for thousands of years. Records of conditions of the river corridor and human activities along it are available for nearly 200 years (since the early 1800s) for at least part of the lower river corridor. These records yield information about the former locations of channels of the Dungeness River and its tributaries and about the natural and cultivated vegetation. These two features, in particular, have changed at fast enough rates to be recorded in the historical records. Other geologic features, such as terraces, would be unchanged during this time frame. The historical records also yield information about human activities along the river corridor. Human activities that potentially affect the river system are related to water use and land use along the river corridor. These activities include irrigation, ground-water use, building of structures within the corridor (e.g., roads, bridges, buildings), logging, farming, burning of land, gravel removal, adding bank protection (e.g., riprap, levees), modifications of the channels (e.g., changing locations, adding or removing woody debris). Some of these activities, including logging and farming, may be important to river conditions and processes even if they were primarily done outside of the Dungeness River corridor.

For these reasons, we have tried to locate and obtain copies of old aerial photographs, maps, and historical photographs. We also have searched county files for information about bridges and roads. In addition, we have attempted to locate and read historical accounts of life and activities and to interview long-time residents of the Dungeness River valley to learn what we can about the natural conditions and human activities along the river corridor. The following sections summarize our work in locating and obtaining historical information and briefly review this historical information.

A variety of sources was consulted for information about the Dungeness River basin. We started with sources in the valley, such as the Sequim Museum and Sequim Library, but also searched regional sources, such as the libraries at the University of Washington in Seattle. In addition, we tried to find information from Federal government agencies, such as the National Archives and Records and the U.S. Forest Service. In conjunction with searching these sources for old maps, aerial photographs, and historical photographs, we also interviewed long-time residents of the Dungeness River valley. All this information has been compiled and integrated into our geomorphic map of the river corridor and into our interpretation of river processes, where possible.

A.1. Literature

Published and unpublished reports of the history of the Dungeness River valley have been useful in learning about events that have shaped the valley and the conditions at various times in the past. Some of the more informative references and maps are Lawson (1855), Dodwell and Rixon (1902), Avery (1914), Kroll (1917), Metzger (1935), Russell (1971), Keeting (1976), Bortleson, and others (1980), Fish (1993), Clark and others (1995), and Beebe (undated).

A.2. Museums, Libraries, Archives, and Other Government Agencies

Local, regional, and national repositories for historical information provided old aerial photographs, old maps, historical photographs, and other information about the Dungeness River valley. The following museums, libraries, government agencies, and archives were either visited or sent inquiries in order to obtain any information that they have about the Dungeness area. The main types of information located at each site are shown in parentheses.

<u>Museums</u>

- Sequim Historical Museum, Sequim, Washington (Historical photographs by Joe McKissick, other historical photographs)
- Museum of the Clallam County Historical Society, Port Angeles, Washington (Historical maps, including Avery (1914), Kroll (1917), and Metzger (1935), and historical photographs)
- Washington State Historical Society, Research Center, Tacoma, Washington (Maps from 1910 (Clallam County) and 1943; historical photographs, including those in the Curtis collection)

<u>Libraries</u>

- Sequim Library, Sequim, Washington (Historical accounts and references)
- Port Angeles Library, Port Angeles, Washington, especially their Archives Room (Historical photographs including those in the Bert Kellogg Collection, and historical accounts and references)
- Map Library, University of Washington, Seattle (Maps from 1859, 1902, 1926, 1937/1938, 1945, and 1946; aerial photographs from 1942 (orthophoto quads), 1962, 1981, and 1988)
- Special Collections, University of Washington, Seattle (Historical photographs, including those in the Jervis F. Russell and Gordon Williams collections)
- Washington Department of Natural Resources Library, Olympia, Washington (Mosaic of aerial photographs taken in 1942; Map (soils) from 1912)

<u>Archives</u>

- Manuscripts and Archives, University of Washington, Seattle, Washington (Tried to locate an account of life along the Dungeness River by Allen Weir, possibly given as a speech or presentation in1892 to the State Historical Society)
- Washington State Archives, Olympia, Washington (Aerial photograph from 1936; Map from 1947)
- National Oceanic and Atmospheric Administration (NOAA) Archives, Rockville, Maryland (Lawson, J.L. (1855), Coast survey)
- National Archives and Records, College Park, Maryland (1942/1943 aerial photographs)

<u>Other Government Agencies</u>

- Clallam County Road Department, Port Angeles, Washington (Information on and maps of bridge construction and reconstruction in their files, Clallam County Commissioners Journal (1859-1884), Dames and Moore (1975), historical photographs of bridges)

U.S. Forest Service, Quilcene Ranger District Office, Quilcene, Washington (Aerial photographs, particularly of the upper Dungeness River basin)

U.S. Forest Service, Olympia, Washington (Aerial photographs, particularly some of the upper Dungeness River basin that were taken in 1939, unpublished information of the history of forest fires in the basin)

Aerial photographs, historical maps, and historical photographs that we have located, some of which we have copies, are shown in Tables A-1, A-2, and A-3. In addition to the 2000 set of aerial photographs, the sets from 1942/1943 and 1965 have been scanned for use in the Integraph system. The older photographs have been registered using points that are visible on the 2000 photographs and that have surveyed locations. The map from the Clallam County Road Department that was surveyed in about 1935 for the Dungeness River from the mouth to about RM 4.5 has been digitized.

A.3. Interviews

Interviews were conducted with long-time residents Lloyd and Kathryn Beebe and the late Harriet Fish. Notes were taken at each interview and each interview was recorded. The interview with the Beebes was conducted at their house on the bluff overlooking the Olympic Game Farm on September 14, 1998. The interview with Harriet Fish was conducted at her house near Carlsborg on September 15, 1998.

The Beebes arrived in the Dungeness River valley in the 1930s and have lived on the west bank of the Dungeness River at the Olympic Game Farm between about RM 1.5 and RM 2.5 since that time. During their nearly 70 years in the valley, Lloyd Beebe has been a careful observer of the river and has been involved in activities that have affected the section of the river along their property (e.g., construction of a dike to protect the west bank, instream gravel extraction and gravel traps, additions of anchored woody debris, and digging of a new side channel, which he refers to as Beebe Creek, that crosses the Olympic Game Farm and enters Matriotti Creek. He summarized many of his activities and observations in an unpublished report, which he generously shared with us. In addition, Lloyd and Kathryn Beebe provided accounts of floods on the Dungeness River, information on the locations of channels, roads, and bridges (including information about those that no longer exist), and observations on many activities along the river corridor, including dike building, logging, and management of woody debris.

Harriet Fish was not only a long-time resident of the Dungeness River valley but also was an historical writer who published several articles and books about various aspects of the history of the area (e.g., Fish, 1993). Over the years she talked with many people who have lived in the valley and recorded their remembrances. She had searched the files of the libraries and museums in the region for historical maps and information. She also had collected newspaper articles on the main events that have occurred along the river. She also received letters that contained historical information that others had located. She used some of these in her writings. During our interview, she provided information on bridges and roads along the Dungeness River, logging, buildings, irrigation practices, and other topics. She also noted additional references and historical accounts that might be of interest.

A couple of other people that we met during our field work provided information about the Dungeness River corridor in informal discussions. Gus Ilika, a resident of the Dungeness Meadows subdivision, provided us with accounts of the Dungeness River adjacent to Dungeness Meadows during high flows in 1978 and 1990. He also had information about instream gravel extraction along this section of the river. Dennis Dehmalo, a resident of Sequim who owned property near RM 9 on the west bank of the Dungeness River, told us about bank erosion, woody debris, and channel changes at and near his property.

A.4. References

Avery, D.F., 1914, Land survey of Clallam county. [includes lower 12 miles of Dungeness River]

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Lawson, J.L., 1855, New Dungeness – Strait of Juan de Fuca: U.S. Coast Survey, Field sheet T-539, scale 1:10,000.

Lichatowich, Jim, 1993, Oral history of Dungeness River salmon – Part 1. Interview with Dick Goin [unpub.]: Sequim, Washington, Alder Fork Consulting, Report prepared for the Jamestown S'Klallam Tribe, 12 p.

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Table A-1. Aerial photographs for the Dungeness River basin

Year	Scale	Type	Coverage	Project	Source	Availability
1936					ACOE	
1939	1:30,000	B&W; Stereo	Entire basin	GS-J	USGS; Wallace Aerial Surveys, Spokane	Prints at USGS office, Tacoma, and at USFS office, Olympia (Coverage of Olympia National Forest only; No photos downstream of about Canyon Creek; Bill Shelmerdine (360-956-2282); copies USFS, Quilcene, Mike Donald (360-765-2231); may be Washington State Library, Olympia (360-753-5592)
1939			Along coast		ACOE	
1942	***1:20,000***	***B&W***	***Part of Lower Dungeness River valley (6 photographs); Have dia-positives***	***RG 373, CAN#ON 10466***	***NARA***	***NARA, College Park, Maryland (301-713-7030)***
1943	***1:30,000***	***B&W***	***Part of Lower Dungeness River valley (4 photographs); Have dia-positives***	***RG 373, CAN#ON 7574***	***NARA***	***NARA, College Park, Maryland (301-713-7030)***
1944	1:20,000	B&W; Orthophoto quads	Mouth to south of confluence with Gray Wolf		ACOE; First edition, AMS-1	ACOE (Flown under contract for USGS); UW Map Library; USFS, Quilcene, Mike Donald (360-765-2231) has 2 photographs (16-17 & 16-18; upper basin)
1951		B&W	Enlargement of Louwella area (2 photographs)	D, N, W, 3-109 & 3-111	USFS	USFS, Quilcene, Mike Donald (360-765-2231)
1951		B&W?	Olympia National Forest portions of the Carlborg, Sequim, and Tyler Peak quads		USFS	USGS, ESIC, Denver (Paula, 303-202-4166)
1956	1:30,000	B&W?	Dungeness quad	550	US Army	USGS, ESIC, Denver (Paula, 303-202-4166)
1962	1:12,000	B&W; Stereo	Upper half of basin; south of north side of Burnt Hill	EJK	USFS	Mosaic index & photos, USFS, Quilcene (their oldest full set); USFS, Salt Lake City; UW Map Library
1963	1:20,000	B&W; Stereo	Lower half of basin; north of USFS boundary	DYE	USFS	USFS, Salt Lake City
1965	***1:12,000***	***B&W; Stereo***	***NE 1/4 of Clallam County and E 1/4 of Jefferson County; lower part of basin at least***	***OLY65***	***WDNR***	***WDNR, Olympia (360-902-1234)***
1966	***1:24,000***	***B&W; Stereo***	***River corridor adjacent to roads; Have 3 photographs near Hwy 101 and RR bridges***	***(3-101-24-205 & 206; 3-101-25-207)***	***WDOT***	***WDOT, Tumwater (360-709-5550)***

Table A-1. Aerial photographs for the Dungeness River basin

Year	Scale	Type	Coverage	Project	Source	Availability
1966	1:60,000	B&W; Stereo	Downstream of 48º (about north side of Burnt Hill)	WFPA66	WDNR	WDNR, Olympia (360-902-1234)
1968	1:15,840	B&W; Stereo	Upper half of basin; south of north side of Burnt Hill	ETI	USFS	USFS, Salt Lake City (801-975-3503)
1968	1:36,000	B&W	Portion of basin within Olympic National Park		ONP	Olympic National Park, Port Angeles
1969		Color; Stereo	Most of upper basin	EROS	USGS	
1970	1:24,000	B&W	Mouth to ~RM 1.0		ACOE	ACOE, Seattle (206-764-3552); their oldest complete set
1971	1:12,000	B&W; Stereo	Downstream of 48º (about north side of Burnt Hill)	OLY71	WDNR	WDNR, Olympia (360-902-1234)
1971	1:63,360	B&W; Stereo	E 1/4 of Jefferson County; part of upper basin	NWH71	WDNR	WDNR, Olympia (360-902-1234)
1971			River corridor adjacent to roads		WDOT	WDOT, Tumwater (360-709-5550)
1972	1:12,000	B&W; Stereo	E 1/4 of Jefferson County; part of upper basin	JK72	WDNR	WDNR, Olympia (360-902-1234)
1972	1:70,000	B&W		53031	USDA	USFS, Quilcene, Mike Donald (360-765-2231)
1973	1:24,000?	Color; Stereo	Olympia National Forest portion of basin	53009	USFS	USFS, Quilcene, Mike Donald (360-765-2231); UW Library
1974	1:24,000	Color; Stereo	Part of N and E coasts; may include mouth	MLM74	WDNR	WDNR, Olympia (360-902-1234)
1974	1:63,360	B&W; Stereo	E 1/4 of Jefferson County; upper basin	NWH74	WDNR	WDNR, Olympia (360-902-1234)
1975	1:24,000	Color; Stereo	Entire basin	OLC75	WDNR	WDNR, Olympia (360-902-1234)
1975	1 in = 1500 ft	B&W?	All but upper quarter of basin; Clallam County		Walker & Assoc.	Walker & Assoc., Seattle (206-244-2300)
1976	1:24,000	Color; Stereo	Olympia National Forest portion of basin		ONP	ONP, Port Angeles
1976	1:24,000	Color; Stereo	E 1/4 of Jefferson County; upper basin?	NWC76	WDNR	WDNR, Olympia (360-902-1234)
1977	1:12,000	B&W; Stereo	Downstream of 48º (about north side of Burnt Hill)	OL77	WDNR	WDNR, Olympia (360-902-1234)
1978			River corridor adjacent to roads		WDOT	WDOT, Tumwater (360-709-5550)
1979	1:12,000	B&W; Stereo	NE 1/4 of Jefferson County; upper basin?	OBD79	WDNR	WDNR, Olympia (360-902-1234)
1979	(high alt.)	Color; Stereo	Olympia National Forest portion of basin	616090	USFS	USFS, Quilcene, Mike Donald (360-765-2231)

Table A-1. Aerial photographs for the Dungeness River basin

Year	Scale	Type	Coverage	Project	Source	Availability
1980	1:63,360	B&W	Downstream of 48º (about north side of Burnt Hill)	OLH80	WDNR	WDNR, Olympia (360-902-1234)
1981	1:12,000	B&W	Downstream of 48º (about north side of Burnt Hill)	OL81	WDNR	WDNR, Olympia (360-902-1234)
1981*	1:40,000 (1:12,000 enlarge.)	B&W; Orthophotos	Clallam County; basin except for upper quarter; Olympic National Park	OSI81	WDNR	WDNR, Olympia (360-902-1234); enlargements (OSI81-82) at UW Map Library
1981	1:24,000	B&W; Orthophotos	Tyler Peak quad.			UW Map Library
1981			River corridor adjacent to roads		WDOT	WDOT, Tumwater (360-709-5550)
1982	1:24,000	Color; Stereo	Olympia National Forest portion of basin	616090A	USFS	USFS, Quilcene, Mike Donald (360-765-2231)
1984	1:63,360	B&W; Stereo	E 1/4 of Jefferson County; upper basin?	OS84	WDNR	WDNR, Olympia (360-902-1234)
1985	1:12,000	B&W; Stereo	Clallam County; basin except for upper quarter	OL85	WDNR	WDNR, Olympia (360-902-1234)
1985	1 in = 1500 ft	B&W?	All but upper quarter of basin; Clallam County		Walker & Assoc.	Walker & Assoc., Seattle (206-244-2300)
1987		Color IR	Upper basin?	HAP80		
1988	1:40,000 (1:12,000 enlarge.)	B&W; Orthophotos	Clallam County; basin except for upper quarter	OLH88	WDNR	WDNR, Olympia (360-902-1234); enlargements at UW Map Library (NE1/4, T.29N. R.4W. (Fish Hatchery))
1988			River corridor adjacent to roads		WDOT	WDOT, Tumwater (360-709-5550)
1990	1:12,000	B&W; Stereo	Clallam County; basin except for upper quarter	OL90	WDNR	WDNR, Olympia (360-902-1234)
1990	***1 in = 2000 ft (1:24,000)***	***Color; Stereo***	***All but upper quarter of basin; Clallam County***	***CLAM90***	***Walker & Assoc.***	***Walker & Assoc., Seattle (206-244-2300)***
1990	1:24,000?	Color; Stereo	Olympia National Forest portion of basin	616092	USFS	USFS, Quilcene, Mike Donald (360-765-2231)
1990 (a few 1991)	***1:40,000***	***B&W; Stereo***	***Entire basin; have upper basin only***	***NAPP***	***USGS***	***USGS, ESIC, Denver (Paula, 303-202-4166)***
1992	1:12,000	Color; Stereo	Upper half of basin; south of north side of Burnt Hill	616094A	USFS	USFS, Salt Lake City (801-975-3503)
1992			River corridor adjacent to roads		WDOT	WDOT, Tumwater (360-709-5550)

Table A-1. Aerial photographs for the Dungeness River basin

Year	Scale	Type	Coverage	Project	Source	Availability
1993	1:12,000	Color; Stereo	Upper half of basin; south of north side of Burnt Hill	616094B	USFS	USFS, Salt Lake City (801-975-3503)
1993			River corridor adjacent to roads		WDOT	WDOT, Tumwater (360-709-5550)
1994	1:12,000	Color; Stereo	Upper half of basin; south of north side of Burnt Hill	616093	USFS	USFS, Salt Lake City (801-975-3503)
1994	1:24,000	B&W Digital Orthophotos	Olympia National Forest and Olympic National Park portions of basin		USFS and ONP	USFS, Olympia
1994	1:31,200		River corridor adjacent to roads	0504-0-0505-7	WDOT	WDOT, Tumwater (360-709-5550)
1994	1 in = 500 ft	Color	River corridor from mouth to about 1/4 mi into the upland		Sound Aerial Surveys	Sound Aerial Surveys, Seattle (206-763-1603) for Jamestown S'Klallam Tribe (Mike Reed, 360-681-4615)
1995	1:24,000?	Color	No index available	616092A	USFS	USFS, Quilcene, Mike Donald (360-765-2231)
1995	1 in = 500 ft	Color	River corridor from mouth to about 1/4 mi into the upland		Sound Aerial Surveys	Sound Aerial Surveys, Seattle (206-763-1603) for Jamestown S'Klallam Tribe (Mike Reed, 360-681-4615)
1996	1:12,000	Color	Olympia National Forest portion of basin	616092A	USFS	USFS, Quilcene, Mike Donald (360-765-2231); or USFS, Salt Lake City (801-975-3503)
1996	1:24,000	Color	Mouth to ~RM 1.0		ACOE	ACOE, Seattle (206-764-3552); their newest set
1996	1 in = 500 ft (1:6,000)	Color; Stereo	River corridor from mouth to about 1/4 mi into the upland		Sound Aerial Surveys	Sound Aerial Surveys, Seattle (206-763-1603) for Jamestown S'Klallam Tribe (Byron Rot, 360-681-4615)
1997	1 in = 500 ft (1:6,000)	Color; Stereo	River corridor from mouth to about 1/4 mi into the upland; have color copies (xerox) only	97-09376	Sound Aerial Surveys	Sound Aerial Surveys, Seattle (206-763-1603) for Jamestown S'Klallam Tribe (Byron Rot, 360-681-4615)
1998	***1 in = 500 ft (1:6,000)***	***Color; Stereo***	***River corridor from mouth to about 1/4 mi into the upland; extends upstream to Gold Creek***	***98-0194***	***Sound Aerial Surveys***	***Sound Aerial Surveys, Seattle (206-763-1603) for Jamestown S'Klallam Tribe (Byron Rot, 360-681-4615)***
1999	***1 in = 500 ft (1:6,000)***	***Color; Stereo***	***River corridor from mouth to upstream of USGS gage***	***99-0423***	***Sound Aerial Surveys***	***Sound Aerial Surveys, Seattle (206-763-1603) for Jamestown S'Klallam Tribe (Byron Rot, 360-681-4615)***
2000	***1 in = 500 ft (1:6,000)***	***Color; Stereo***	***River corridor from mouth to upstream of USGS gage***		***Sound Aerial Surveys***	***Sound Aerial Surveys, Seattle (206-763-1603) for Jamestown S'Klallam Tribe (Byron Rot, 360-681-4615)***

Entries shown in bold italic font are the photographs that we have

*Orthophoto quads are prepared from 1:40,000-scale, black-and-white aerial photographs taken in 1981 and 1982. Quads (1:24,000-scale) available are Dungeness, Maiden Peak, Morse Creek, Mt. Deception, Mt. Townsend, Mt. Zion, Sequim, Tyler Peak, and Wellesley Peak.

Table A-2. Historical maps for the Dungeness River area

Year	Title	Author or Agency	Type	Scale (Contour interval)	Coverage	Features Shown	Source
1852	Reconnaissance of the coast of Oregon from Port Townsend (Admiralty Island) to the Columbia River Sheet No. 1 (Register No. 333)	U. S. Coast Survey; Hydrographic party under direction of James Alden	Bathymetric	1:214,240 (No contours)	North and south coasts along the Strait of Juan de Fuca; Cape Flattery to Seattle area; 47º30'-48º40'; 122o25'-124o50'	Depths along coast from soundings	NOAA archives, Rockville, Maryland
1855	Map of New Dungeness, Strait of Juan de Fuca, Washington Territory (Register No. 539)	U. S. Coast Survey	Topographic; surficial conditions	1:10,000 (Not given)	Mouth of Dungeness River to about RM1; Dungeness spit; 48º08'-48º11'; 123º06'-123º11'	Indian village near mouth of Dungeness River; vegetation and deposits (no explanation)	NOAA archives, Rockville, Maryland
1859	Land Survey, Territory of Washington	Surveyor General's Office, Olympia; Survey by John Trutch in February 1859	Public Land Survey by Township and Range; from field notes of survey	1 in = 40 chains; 1 in = 0.5 mi (2,640 ft); 1:31,680	Mouth to Dungeness RM9.5; T.30N., R.3W.; T.30N., R.4W.; T.31N., R.3W.; T.31N., R.4W.	Drainages, roads, surficial conditions (for part of area); land use; land ownership	University of Washington Library (Microfiche Room), Seattle
1870	Part of New Dungeness, Strait of Juan de Fuca, Washington Territory, Section XI (Register No. 1168)	U. S. Coast Survey	Topographic; surficial conditions	1:10,000 (Not given)	Dungeness River (shown as "New Dungeness River") along coast eastward to about Jamestown; Mouth to about RM0.75; 48º08'-48º09' 123º05'-123º08'	Vegetation and deposits (no explanation); drainages, roads	NOAA archives, Rockville, Maryland
1870	Protection ID. To New Dungeness, Strait of Juan de Fuca, Washington , Section XI (Register No. 1169)	U. S. Coast Survey	Topographic; surficial conditions	1:10,000 (Not given)	Along coast east of Dungeness River; from about Jamestown eastward to Washington Harbor; 48º04'-48º08'; 122º57'-123º06'	Vegetation and deposits (no explanation); drainages, roads	NOAA archives, Rockville, Maryland

Table A-2. Historical maps for the Dungeness River area

Year	Title	Author or Agency	Type	Scale (Contour interval)	Coverage	Features Shown	Source
1907-1908	South Shore, Strait of Juan de Fuca, Morse Creek to Dungeness (Register No. 2859)	Coast and Geodetic Survey, Dept. of Commerce and Labor; survey by C.G. Quillian, W.B. Dunning, and W.C. Dibrell	Topographic (Plane table survey completed between Nov. 1907 and Jan. 1908); surficial conditions for part	1:20,000 (No contours)	Morse Creek (west of Dungeness) to Dungeness; Mouth to RM0.7 (Schoolhouse Bridge); 48º06'-48º11'; 123º06'-123º22'	Elevations (in feet) along bluff along coast west of Dungeness Bay; Dungeness River channel, town of Dungeness, dock; notes on vegetation and surficial deposits	NOAA archives, Rockville, Maryland
1893 (Approved 2/4/93; surveyed 11-12/1891)	Land survey, Washington	Surveyor General's Office, Olympia; Surveyed by George A. Kline in Nov. and Dec., 1891	Public land survey by Township and Range; from field notes of survey	Scale not given; (No contours)	T.29N., R.3W.; Dungeness and Gray Wolf Rivers in sections 19 and 30; Dungeness River between about RM13 and RM16.5; Gray Wolf River between RM0 and RM0.5	Drainages, roads, land ownership; some vegetation	University of Washington Library (Microfiche Room), Seattle
1894 (Approved 8/10/94; surveyed 10/1893)	Land survey, Washington	Surveyor General's Office, Olympia; Surveyed by Henry L. Fitch in Oct. 1893	Public land survey by Township and Range; from field notes of survey	1 in = 40 chains; 1 in = 0.5 mi (2,640 ft); 1:31,680	T.29N., R.4W., Dungeness River in sections 1, 2, 12, 13, 24; river between RM9.5 and RM13.5	Drainages, roads, land ownership, land use in some areas	University of Washington Library (Microfiche Room), Seattle
1913-1914	Topograph sketch; Clallam County Assessor's survey	D.F. Avery	Assessor's survey (completed between Dec. 1913 and Apr. 1914) by Township and Range	1 in = 0.08 mi (406 ft); approximatel y 1:5,000	D.F. Avery; Clallam County Assessor's Map; have T.29N., R.4.W., sec. 1, 2, 12, 13; T.30N., R.4W., sec. 1, 2, 11, 12, 13, 14, 23, 26, 35, 36, NW1/4, sec. 24, SW1/4, sec. 24; T.31N., R.4W., sec. 25, 36; 48º01'-48º08'; 123º06'-123º08'	Land conditions, soils, surface deposits, roads, present and old channels of the Dungeness River, land ownership; Mouth to about RM12.5	Jamestown S'Klallam Tribe; John Orsborn scanned portions at the five bridges into digitized format (figs. 3.1-3.5, Orsborn and Ralph, 1994)

Table A-2. Historical maps for the Dungeness River area

Year	Title	Author or Agency	Type	Scale (Contour interval)	Coverage	Features Shown	Source
1917	Atlas of Clallam County, Washington Sheets 3, 5, 6, and 7	Kroll Map Company, Seattle, Washington	Land ownership	1 in = 0.5 mi (1:31,680)	By township, range, and sections; Mouth to about RM16.5 (above confluence with the Gray Wolf); river to T.29N., R.3.W., sec. 30	Drainages, land ownership, roads, railroad	Clallam County Historical Museum, Port Angeles
1925 (Revised 1935)		Charles F. Metzker	Land ownership	1 in = 0.5 mi (1:31,680)	Mouth to about RM18 on the Dungeness River and to about RM3 on the Gray Wolf River; T.29N., R.4W.; T30N., R.4W.; T.31N., R.3W.; T.31N., R.4W.	Land ownership, land conditions, roads, drainages, present and old channels of Dungeness River	Clallam County Historical Museum, Port Angeles
1926	Reconnaissance survey of Dungeness River, Washington	Survey by E.E. Jones	Topographic (survey completed in June and July, 1926)	1 in = 1 mi 1:63,360 (contour interval = 50 ft)	Mouth to about RM22 (upstream of Copper Canyon) on the Dungeness River; to about RM5 (Slab Camp Creek) on the Gray Wolf River	Topography (scanned to be digitized)	University of Washington, Map Library, Seattle
1926	South shore of Strait of Juan de Fuca, Washington New Dungeness to east side of Port Angeles (Register No. 4193)	U. S. Coast and Geodetic Survey; survey by C.I. Aslakson in May and June, 1926	Land conditions	1:20,000 (No contours)	Dungeness area west to about Port Angeles; Mouth to RM0.7 (Schoolhouse Bridge); 48º06'-48º11'; 123º06'-123º24'	Channels of Dungeness River (shown as “New Dungeness River”) including those in “New Dungeness” Bay; vegetation and land use (no explanation)	NOAA archives, Rockville, Maryland

Table A-2. Historical maps for the Dungeness River area

Year	Title	Author or Agency	Type	Scale (Contour interval)	Coverage	Features Shown	Source
1926	South shore of Strait of Juan de Fuca, Washington Mouth of Washington Harbor to New Dungeness (Register No. 4194)	U.S. Coast and Geodetic Survey; survey by C.I. Aslakson in May and June, 1926	Land conditions	1:10,000 (No contours)	Coastal area east of Dungeness River, except for an eastern channel near the mouth; 48º05'-48º10'; 123º03'-123º08'	Eastern channels of Dungeness River, town of New Dungeness, drainage entering bay north of Jamestown, roads; vegetation and land use (no explanation)	NOAA archives, Rockville, Maryland
1926	Reconnaissance survey of Dungeness River	U.S. Geological Survey		~1:20,000	Mouth to Dungeness RM22 and Gray Wolf RM5		University of Washington, Map Library, Seattle (blueprint)
1930s	Flood Damage Assessment	Clallam County Road Department	Topographic; Flood Damage Assessment; digitized format	1" = 200' (contour interval = 1 ft)	Mouth to about RM4.5	Channel of Dungeness River and stream east of main channel near mouth, bridges, roads, bulkheads, levees; Old Olympic Highway Bridge is shown as Burlingame Bridge; Woodcock Bridge is shown as Lawrence Bridge	Steve Hauff, Clallam County Road Dept., Port Angeles; 360-417-2319
1941	Georgia Strait and Strait of Juan de Fuca, United States – West Coast, Washington, Plate No. 3945, Edition 11, 9/6/41 (Chart No. 6300)	U.S. Coast and Geodetic Survey (survey completed in September 1941)	Topographic on land and bathymetric in ocean	Scale not given (contour interval = 200 ft)	North coastof Olympic Penisula between Ozette Lake and Cape Flattery (west) to Seattle area (east); coast of Georgia Strait in British Columbia; includes Dungeness Bay and surrounding coast; 48º06'-49º20'; 122º16'-125º04'	Topography on land; depths (in fathoms) by soundings at mean lower water for ocean	NOAA archives, Rockville, Maryland

Table A-2. Historical maps for the Dungeness River area

Year	Title	Author or Agency	Type	Scale (Contour interval)	Coverage	Features Shown	Source
1945 (Surveyed in 1945, printed in 1947)	Plan and profile of Dungeness River,Washington	U.S. Geological Survey and State of Washington, Dept. of Conservation and Development (Topography by H.L. Pumphrey)	Topographic and profile of 7-mile-long section of Dungeness River and 3.5-mile-long section of the Gray Wolf River	1:24,000	Dungeness River between RM11.5 (USGS gage) and RM19 (Gold Creek); Gray Wolf River between mouth and about RM3.5 (upstream of Two-mile Camp)	Clink footbride, bridge (unnamed) across the Gray Wolf River about 1 mi upstream of confluence with Dungeness River	University of Washington, Map Library, Seattle
1945	Admirality Inlet and Puget Sound to Seattle, United States – West Coast, Washington Plate No. 3743, Edition No. 11, 3/3/45 (Register No. 6450)	U.S. Coast and Geodetic Survey; survey completed March 1945	Topographic on land and bathymetric in ocean	1:80,000 (contour interval = 100 ft)	East of the Dungeness River; 47º35'-48º20'; 122º06'-123º00'	Topography on land; depths (in fathoms) by soundings at mean lower water for ocean	NOAA archives, Rockville, Maryland
1963	Topographic map near Dungeness Bridge site (Revised 5/1/63)	Clallam County Road Department	Topographic	1 in = 10 ft (contour interval = 1 ft)	Dungeness River and adjacent banks near Dungeness Bridge (Schoolhouse Bridge)	Channel of Dungeness River, Dungeness (Schoolhouse) Bridge, ACOE levee, old log bulkheads	Steve Hauff, Clallam County Road Dept., Port Angeles; 360-417-2319
1963/1964	Site plan of Dungeness Bridge, Clallam County Region 8, Road 92 (2/5/63, revised 5/2/64)	Clallam County Road Department Project No. APW WASH 92G, sheet 1 of 5	Plan and profile of proposed new bridge and adjacent road	1 in = 100 ft (No contours)	Dungeness River at Dungeness Bridge (Schoolhouse Bridge); T.31N., R.4W., sec. 36	Channel near Dungeness River (Schoolhouse) Bridge, road east of river to be changed to position north of the Dungeness Schoolhouse (old and new alignments); cross section of road, bridge, and Dungeness River channel for new alignment	Steve Hauff, Clallam County Road Dept., Port Angeles; 360-417-2319

Table A-2. Historical maps for the Dungeness River area

Year	Title	Author or Agency	Type	Scale (Contour interval)	Coverage	Features Shown	Source
1964	Dungeness River Bridge layout, Clallam County (Dated 1/29/64)	Clallam County Road Department Project No. APW WASH 92G, sheet 2 of 5	Topography of banks at bridge sites on plan map; cross section at alignment of proposed new bridge showing depths and units exposed in drill holes	1 in = 20 ft (Contour interval = 1 ft)	Dungeness River at Dungeness Bridge (Schoolhouse Bridge); T.31N., R.4W., sec. 36	Cross section of new bridge and topography (present and proposed change) across Dungeness River channel at alignment of new bridge; geologic units in drill holes at east (77.0 ft deep) and west (71.5 ft deep) sides of the old alignment of the bridge	Steve Hauff, Clallam County Road Dept., Port Angeles; 360-417-2319

Table A-3. Historical photographs obtained as part of our study

Topic and area	Date	Negative or photograph number	Photographer and (or) collection	Source
Aerial view looking northwest from Silberhorn Road east of the Dungeness River; shows river just downstream of Highway 101to Olympic Highway Bridge, including the Railroad Bridge section (Reaches 3 and 2); shows river between about RM 6 and RM 4; Severson's property is visible; Dungeness River has nearly bank-full flow	July 29, 1935	371	Gordon Williams collection; Collection No. 252	Special Collections Division, University of Washington Libraries, FM-25, Seattle, WA 98195
Aerial view looking northwest across the floodplain east of the Dungeness River and north (downstream) of the Highway 101 Bridge; Sequim in foreground; Dungeness Bay and mouth of river in background; river downstream from about RM 5 (Reaches 3, 2, and 1)	July 29, 1935	372	Gordon Williams collection; Collection No. 252	Special Collections Division, University of Washington Libraries, FM-25, Seattle, WA 98195
Dungeness River and covered bridge; gravel bar and cows standing in river; appears to be in the area of Schoolhouse Bridge; caption noted that this was the only bridge out of 7 left after "The Flood"; noted that land surrounding the bridge was level and flood waters spread out	1909?	77-17-17	Joe McKissick; J.R. Williamson collection	Sequim Historical Museum Sequim, Washington
Dungeness River and bridge construction	No date	77.11.1-24	Joe McKissick; J.R. Williamson collection (M006)	Sequim Historical Museum Sequim, Washington
Dungeness River and bridge; construction of Milwaukee Railroad Bridge	1915	77.11.1-23	Joe McKissick; J.R. Williamson collection (M001)	Sequim Historical Museum Sequim, Washington
Dungeness River and bridge; horses and cart on gravel bar; low flow; bridge along Olympic Highway?	No date	97.31.32	Joe McKissick; J.R. Williamson collection	Sequim Historical Museum Sequim, Washington
Dungeness River and bridge; appears to be same locality as above but bridge is different and flow is higher	No date	77.11.1-16	Joe McKissick; J.R. Williamson collection (M005)	Sequim Historical Museum Sequim, Washington
Dungeness bridge; foot bridge? with people; bridge spans rock outcrops; near Fish Hatchery; Clink Bridge?	No date	79-108-1.18	Joe McKissick; J.R. Williamson collection (M001)	Sequim Historical Museum Sequim, Washington
Dungeness River near the Fish Hatchery with fish traps in water; gravel bars	No date	95.45.154	Joe McKissick; J.R. Williamson collection	Sequim Historical Museum Sequim, Washington

Table A-4. Historical events in the Dungeness area

1792: April 30: George Vancouver "discovered" Dungeness spit and called it New Dungeness because of it resembled the harbor at Dungeness, England (Sequim Museum)
1851: First white settlers at New Dungeness; area was still part of the Oregon Territory (until 1953) (Sequim Museum); settlers included B.I. Madison, J.C. Brown, John Donnell, Elisha McAlmond, John Thornton (320 acres), George Gerrish (Russell, 1971, p. 106; Keeting, 1976, p. 1)
1852: More settlers moved to New Dungeness (Keeting, 1976, p. 1), including Elliot Henry Cline, who became a prominent Dungeness pioneer (Russell, 1971, p. 109)
-- Fall: About 1,000 Indians lived on the flats in front of Dungeness in houses (some 100 ft long)
1853: Spring: John W. Donnell took an Indian trail to Sequim Prairie and built a cabin on 320 acres northwest of what became the town of Sequim (Sequim Museum)
-- Heavy forest separated the coastal area near New Dungeness from the uninhabited Sequim Prairie (Sequim Museum)
-- The summer droughts were disastrous but other settlers followed (Sequim Museum), including William King, an early homesteader (Russell, 1971, p. 109)
-- Spring: First cargo ship, the *John Adams*, entered the harbor at New Dungeness (Russell, 1971, p. 108; Keeting, 1976)
1854: Clallam County founded (Sequim Museum); area was split from Jefferson County (Keeting, 1976, p. 1)
-- John Bell first homesteaded at the Sequim townsite (Russell, 1971, p. 97)
1858: John Weir arrived and built the first wagon in the Dungeness valley (Russell, 1971, p. 109)
1859: New Dungeness was the largest settlement in Clallam County (Russell, 1971, p. 113)
-- George Henry Lotzgesell arrived from Germany; built a log cabin by a creek now known as Matriotti Creek (Keeting, 1976, p. 7)
-- First tax was levied to build schools (Russell, 1971, p. 114)
1860: First county election was held (Keeting, 1976, p. 4)
1861: The first school opened in a vacated lot on the Abernathy farm (now known as the James Dick farm) (Russell, 1971, p. 114)
1862: McAlmond home was built in an area where 500 Indians had camped at one time (Keeting, 1976, p. 3)
-- Dungeness was voted the first county seat (Russell, 1971, p. 108)
-- First real schoolhouse of sawed timbers was built on the J. Thornton farm (where now is Colonel Morrison's home on Thornton Lane); this was the school for 35 years (until 1897) (Russell, 1971, p. 114)
1865: New Dungeness had two dozen log and clapboard buildings (Sequim Museum)
-- Townsite of New Dungeness was platted by Elliot Henry Cline (Keeting, 1976, p. 1)
-- Elliot and Margaret Cline deeded two lots in New Dungeness to the county for a courthouse and jail (Sequim Museum)
1865-1866: First county courthouse and jail were built (Keeting, 1976, p. 4)
1866: John W. Donnell was the first white settler in Clallam County to receive a government patent (3/6/1866) to his homestead claim (Russell, 1971, p. 107; Keeting, 1976, p. 2)
1869-1939: Joe McKissick was a photographer who recorded life in Dungeness
1887: New Dungeness was the principal town in the area until this year, when Puget Sound Cooperative colony came to Port Angeles (Sequim Museum; Keeting, 1976, p. 5)
1888: Main crops and products were potatoes, wheat, oats, peas, hay apples, hogs, veal, beef cattle; Dungeness was the principal crop-producing center in the region (Keeting, 1976, p. 8)
1890: Port Angeles became the county seat, which was moved (forcefully) from New Dungeness (Sequim Museum)
-- Inner bay at New Dungeness was filling with silt and ships were getting stuck at low tide (Sequim Museum)
-- Fall: Began building a new dock that was paid for by C.F. Seal; the first dock was on Cline Spit near the bluff and ships came into the harbor between Cline's Spit and Deadman's Spit (Keeting, 1976, p. 9)
-- Dungeness was developing and increasing in population (Russell, 1971, p. 115)
1891: Spring: A 1,430-foot-long dock was finished at the end of Groveland Avenue (Russell, 1971, p. 112; Keeting, 1976, p. 9); the dock had to be this long (3/4 mile) in order to reach deep water (Sequim Museum

Table A-4. Historical events in the Dungeness area (cont.)

-- Entire town of New Dungeness was moved eastward to the foot of the dock and was called Dungeness (New Dungeness became Old Dungeness or Old Town) (Sequim Museum); a double row of pilings is what is now left of this dock (Sequim Museum)
1892: The first business building, a small grocery, was built in Dungeness (Sequim Museum)
1893: February 27: Dungeness School opened in a new schoolhouse (Russell, 1971, p. 115)
-- Dungeness offered 300 lots of the townsite to the railroad in the hope that the railroad would go through Dungeness (Russell, 1971, p. 113); the railroad was built eventually through Sequim in 1915 instead
1894: William Long operated a mill in Long Prairie (now Carlsborg); material from the mill was used to build many of the houses in Sequim (Sequim Museum)
1895: Fish hatchery built at RM10.5 (Sequim Museum)
1896: The first irrigation ditch was completed (see History of Irrigation); growth of the Sequim area expanded rapidly after this (Russell, 1971, p. 97)
1890s: The wharf at Port Williams was the only port of entry to Sequim (Sequim Museum)
1902: Products out of Dungeness included eggs, butter, hogs, potatoes, apples, crabs, turkeys, cream, hides, wool, pelts; much of the produce went to the logging camps (Keeting, 1976, p. 12)
-- William Long's mill was moved to west of Priest Road near the Dungeness River (Sequim Museum)
1903: Joseph L. Keeler arrived at Sequim; he did much to found the early town (Russell, 1971, p. 97)
1907: Original plat for the town of Sequim was filed; the town consisted of one long block along the east side of Sequim Avenue (then the main street between Washington and Fir) (Russell, 1971, p. 99)
– William Long's mill burned (Sequim Museum)
1908: Hotel Sinclair was built in Sequim (Sequim Museum; Russell, 1971, p. 97)
1911-1912: The Clallam County directory shows the population of Dungeness as 250 (Keeting, 1976, p. 12)
1913: October 20: Town of Sequim was incorporated (Russell, 1971, p. 99)
-- First mayor was Jilson White (Russell, 1971, p. 99)
1913-1914: The first cemetery in Sequim, at what is now Pioneer Park on Washington Street, was moved to the ridge north of town because a high water table was causing problems at the first cemetery (Sequim View Cemetery) (Sequim Museum)
1914: April: First telephone franchise in Sequim (Keeting, 1971, p. 100)
October: First electric power franchise in Sequim (Keeting, 1971, p. 100)
1914-1915: Fire destroyed buildings on the west side of Dungeness main street from the hotel south (Sequim Museum)
1915: Railroad went through Sequim (not Dungeness); this ended Dungeness as a shipping center (Sequim Museum; Russell, 1971, p. 113)
-- June: Railroad had reached the Dungeness River (Keeting, 1976, p. 88)
-- July: Construction camp was moved to Sequim (Keeting, 1976, p. 88)
-- September 3: First passenger train trip from Port Townsend to Sequim (Keeting, 1976, p. 89)
1922: Port Williams was abandoned as the railroad and main highways were in other localities (Sequim Museum)
-- Sequim purchased Keeler's water system (Russell, 1971, p. 100)
1926: The main intersection in Sequim was Washington Street and Sequim Avenue (Sequim Museum)
1929: Hotel in Dungeness burned (Sequim Musem); the hotel had been one of the first buildings in Dungeness (Sequim Museum)
-- Sequim enlarged its water system by building a reservoir and pipeline to the Dungeness River; this replaced the springs that were the previous water source (Russell, 1971, p. 100)
1930: Carlsborg Railroad depot was no longer used after the mill was inactive for several years (Keeting, 1976, p. 89)
1931: April 1: Last passenger train run was made (Keeting, 1976, p. 89)
1937: C.F. Seal's Trading Company in Dungeness burned (Sequim Museum)
1938: Olympic National Park established (logging on land before this time) (Sequim Museum)
1948: Sequim added a second main water supply line from the reservoir into town (Russell, 1971, p. 101)
1953: A new, larger reservoir was built along with a new intake pipeline from the reservoir back to the headgate in the Dungeness River (Russell, 1971, p. 101)

Table A-4. Historical events in the Dungeness area (cont.)

1954: Dungeness-Sequim Cooperative Creamery was liquidated (Keeting, *in* Russell, 1971, p. 120); the Sequim-Dungeness valley was the oldest dairying center in Washington; it was started by Hall and Alonzo Davis with Jersey and Guernsey cows predominantly (Keeting, *in* Russell, 1971, p. 117)

1956: Sequim had grown to 1,400 people and 640 acres; had began with 300 people and 400 acres (Russell, 1971, p. 101)

1967: September 25: Sequim Railroad depot closed (Keeting, 1976, p. 89)

Table A-5. History of bridges along the Dungeness River
(present bridges shown in bold; those no longer present shown in italics)

RM UNKNOWN: Likely same location as Schoolhouse Bridge

Mar 1872	A bridge across the Dungeness River was completed (Russell, 1971, p. 69); Dungeness Bridge was built in the 1870s (Russell, 1971, p. 70)

RM 0.7: Bridge(s) near the Old Dungeness Schoolhouse (Schoolhouse Bridge; School Road or Marine Drive; lat 48º0.8.6' long123º08.0'; bridge no. 4753-BR-1)

14 Nov 1864	Bound over $500 to build bridge over Dungeness River at Territorial Road crossing (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
2 Nov 1868	Notice of public benefit to open county road from Dungeness River Bridge to Sequim Prairie (Clallam County Commissioners Journal, Vol. 1, 1859-1884; Fish, 1998, personal communication).
7 Feb 1870	Call for bids to construct a bridge across the Dungeness River (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
3 May 1870	Clallam County set aside $950 for the Dungeness River Bridge (Fish, 1998, personal communication).
1 Aug 1870	Dungeness River Bridge opened (Fish, 1998, personal communication).
10 Aug 1870	Bridge over Dungeness River completed and contractor ordered paid (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
1873	Bids made to construct a cover over the Dungeness River Bridge (Fish, 1998 personal communication).
5 May 1873	Bids for a contract to cover the Dungeness River Bridge (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
4 Nov 1878	Payment for repairs to both causeways at the Dungeness River Bridge (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
1880	Bridge needed repairs (Fish, 1998, personal communication).
3 Jan 1881	Paid for repairs to Dungeness River Bridge; George E Shammett and Michael Gaffney to be builders (Clallam County Commissioners Journal, Vol. 1, 1859-1884; Fish, 1998, personal communication).
29 Aug 1881	Bid to replace old Dungeness River Bridge; contractor directed to salvage all usable parts from existing bridge (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
7 Nov 1881	Inspected and accepted new Dungeness River Bridge (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
3 Dec 1910	Completed Dungeness River and Burlingame bridges (Clallam County Commissioners Journal, Vol. 1, 1859-1884).
1914	One bridge that crosses river diagonally in approximately the same location as the present bridge (T.31N., R.4W, section 36; Clallam County Assessor's Map, 1914)

Table A-5. History of bridges along the Dungeness River (cont.)

1917 One bridge shown on an east-west road (School Road on 1979 topographic map), trend of river here shown as north-south, this bridge would have been northwest of present bridge near the schoolhouse (T.31N., R.4W, section 36; Kroll, 1917, sheet 7)

1935 Two bridges are shown near the Dungeness Schoolhouse, one is on an east-west road (not shown on 1979 topographic map) and the other (downstream of the east-west bridge) on a north-south road (Towne Road on 1979 topographic map); neither bridge appears to be in the location of the present bridge near the Dungeness Schoolhouse, both bridges are upstream of present bridge near the schoolhouse (T.31N., R.4W, section 36; Metzger, 1935)

1964 Bridge replaced (Clallam Road Department files); photographs when river was built show river bed.

RM3.3: Bridge at Woodcock Road (Woodcock Bridge; also known as Ward Bridge; bridge no. 95000-BR-1)

11 Jan 1899 Inspection of Ward Bridge; location uncertain (Clallam County Commissioners Journal, Vol. 1, 1859-1884).

1914 No Woodcock Road, and so no bridge at this location; Ward Road is shown (T.30N., R.4W., section 2/11 boundary; Division of Forestry, 1914)

1917 No Woodcock Road, and so no bridge at this location; Ward Road is shown (T.30N., R.4W., section 2/11 boundary; Kroll, 1917, sheet 6, east half)

1932 Bridge is built. The three piers constructed at this time are still present, even though the bridge has been raised and extended laterally (in 1977; Clallam Road Department files)

1935 Woodcock Road is shown up to the river on both sides, but no bridge is shown at this location (ford) (T.30N., R.4W., section 2/11 boundary; Metzger, 1935)

1936 Report to replace Ward Bridge received; replacement date of bridge not listed (Clallam County Commissioners Journal, Vol. 1, 1859-1884).

July 1977 New bridge, which included new abutments, superstructure, and new caps on the old piers, was constructed (Clallam Road Department files); 2/10/77 article in the Daily New, Port Angeles, noted that the bridge was closed for construction; bids for the project were opened 12/76.

RM 4: Bridge at (Old) Olympic Highway (also known as the Burlingame Bridge; lat48º06.9' long123º09.4'; bridge no. 9412-BR-3)

6 Feb 1895 Repairs to Burlingame Bridge over Dungeness River (Clallam County Commissioners Journal, Vol. 1, 1859-1884).

3 Dec 1910 Completed Dungeness River and Burlingame bridges (Clallam County Commissioners Journal, Vol. 1, 1859-1884).

1911 Bridge built at this locality; possibly same event as previous entry (Clallam County Road Department files).

Table A-5. History of bridges along the Dungeness River (cont.)

1914	Bridge (or ford?) at this location (T.30N., R.4W., section 11; Clallam County Assessor's Map, 1914).
1917	Bridge at this location (T.30N., R.4W., section 11; Kroll, 1917, sheet 6, east half).
Dec 1921	Approaches to bridge were washed out.
1922	Bridge rebuilt beginning in January; new pile approach of 19 bents (Clallam County Road Department files).
1935	Bridge at this location (T.30N., R.4W., section 11; Metzger, 1935). First "modern" bridge. Trestle bridge before this. Trestle bridge was torn out and a "short" bridge was made after filling in the west side about 450-480 ft (Clallam County Road Department files).
1955	Present bridge built (Clallam County Road Department files).
19 Jan 1961	Newspaper article, Bridge closed because of soil erosion at the approaches; "The last flood washed out the approaches."
1992	Scour inspection report dated 3/31/92 by the Clallam County Department of Public Works stated that the bridge is highly susceptible to scour and that the substructure dates back at least to the early 1900s. The third substructure was present in 1992. The span length was 140 ft; the recommended length is between 180 and 270 ft.
1999	Bridge is being replaced.

RM 5.5: Bridge about 0.1 mi (1.6 km) downstream of the Railroad Bridge (concrete pier on east bank remains); Hendrickson Road east of the river and Runnion Road west of the river. This may be the Canfield bridge referred to in records of Clallam County Department of Public Works.

1914	Bridge at this location (Clallam County Assessor's Map, 1914).
1917	Bridge at this location (T.30N., R.4W., section 14/23 boundary; Kroll, 1917, sheet 6, east half).
1935	Bridge at this location (T.30N., R.4W., section 14/23 boundary; Metzger, 1935)

RM 5.7: Railroad Bridge (now a footpath; also known as the Howe Truss Bridge (letter from Harriet Fish))

1914	Grading of road bed for the Railroad Bridge began in January (John F. Hook letter to H. Fish, citing Dietrich, Don, A Brief History of the Olympic Peninsula).
1914	Railroad Bridge (Seattle-Port Angeles and Lake Crescent Railroad), in same position as present railroad bridge (T.30N., R.4W., section 23; Clallam County Assessor's Map, 1914).
1915	Work continues on the Railroad Bridge; heavy timbers for upper part of bridge were hauled from Port Angeles once the tracks were laid (John F. Hook letter to H. Fish, citing Sequim Press, June 19, 1915).
1917	Railroad Bridge (S.P.A. & W. Railway), in same position as present railroad bridge (T.30N., R.4W., section 23; Kroll, 1917, sheet 6, east half).

1935	Railroad (C.M. & S.P. Railway) Bridge (T.30N., R.4W., section 14/23 boundary; Metzger, 1935).
Mid 1950s	Railroad Bridge substantially upgraded; posts with creosote replaced untreated posts (John F. Hook letter to H. Fish, citing R.L. Shanklin, Pond Oreille Railroad, Newport).
Dec 1958	Railroad Bridge is moved east about 10 ft to new piers; locomotive and two large Caterpillar tractors pulled via cables to tow bridge to new location; a system of skids and rollers helped; (John F. Hook letter to H. Fish, citing R.L. Shanklin, Pond Oreille Railroad, Newport, and a Milwaukee Road document, Authorization For Expenditure No. 84006).
19 Jan 1961	Newspaper article, Bridge was barely standing at 6 pm Sunday because piling washed away in highest flood waters in history of valley; repairs were to be done by Jan. 27.
Jan 1961	Flood removed several spans of the east trestle (a bent frame structure); repairs included new creosote-treated pilings and a protective dike on the east bank (John F. Hook letter to H. Fish, citing Port Angeles Evening News, Jan. 17, 1961; R.L. Shanklin, Pond Oreille Railroad, Newport; and a Milwaukee Road document, Authorization For Expenditure No. 84006).
1964	New creosote-treated pilings replaced the old cedar pilings on the west trestle (John F. Hook letter to H. Fish, citing R.L. Shanklin, Pond Oreille Railroad, Newport).
1980-1984	S&NC filed for bankrupcy in June 1984 and closed.
23 Mar 1985	A final train removed all remaining rail cars to Port Townsend (John F. Hook letter to H. Fish, citing Sequim Press, March 27, 1985).
1989-1990	Railroad is dismantled (John F. Hook letter to H. Fish).
1992	Railroad Bridge Park is established (John F. Hook letter to H. Fish).

RM 6.4: Bridge at Highway 101

1914	No highway at this location (T.30N., R.4W., section 23; Clallam County Assessor's Map, 1914).
1917	No highway at this location (T.30N., R.4W., section 23; Kroll, 1917, sheet, east half).
1935	Bridge at unnamed highway (now 101) (T.30N., R.4W., section 23; Metzger, 1935).

RM 9.5: Bridge at Duncan Road (1985 topographic map), about 1 mi downstream from the present Fish Hatchery, at point where valley of Dungeness River widens (Duncan Bridge; also known as the Old Taylor Bridge (J. Lichatowich, 1993, p. 8, Interview with Dick Goin)

1914	Bridge at this location (T.29N., R.4W., section 2, NE; Clallam county Assessor's Map, 1914).
1917	Bridge at this location (T.29N., R.4W., section 2, NE; Kroll, 1917, sheet 5).
1935	Bridge at this location (T.29N., R.4W., section 2, NE; Metzger, 1935).
1949	Bridge washed out (J. Lichatowich, 1993, p. 8, Interview with Dick Goin).

Table A-5. History of bridges along the Dungeness River (cont.)

RM13.3: (Old) Clink Bridge (timber abutments remain)

pre-1911	Foot bridge consisting of a log and a hand rail (Sequim Bicentennial History Book Committee, 1976; p. 51). The Clink family left the area after a large flood just before the turn of the century (Sequim Bicentennial History Book Committee, 1976; p. 47).
1911	First real bridge built at this location by Bill Schmith; bridge subsequently washed out and was rebuilt many times (Sequim Bicentennial History Book Committee, 1976; p. 51).
1914	Area not covered (Clallam County Assessor's Map, 1914).
1917	Not shown on Kroll map (1917).
1935	Not shown on Metzger map (1935).

RM 15.8: Bridge on FS Road 2880 just upstream of junction with the Gray Wolf River

1914	Area not covered (Clallam County Assessor's Map, 1914).
1917	Bridge not shown, but near edge of map (Kroll, 1917, sheet 3, west half).
1935	Bridge near or at same location as present bridge; Dungeness Forks Camp shown immediately east of the junction east of the road (present Dungeness Forks Campground is shown as Camp Colonel Shelter); on road from Louella Guard Station (T.29N, R.3W., section 31; Metzger, 1935).

GWRM 1: Bridge on FS Road 2870 across the Gray Wolf River

1914	Area not covered (Clallam County Assessor's Map, 1914).
1917	Bridge not shown but near edge of map (Kroll, 1917, sheet 3, west half).
1935	Bridge across the Gray Wolf River appears to be about 0.2 mi (0.3 km) downstream of the present bridge; road shown to continue to west (across area of recurrent landslides) (T.29N., R.3W., section 31; Metzger, 1935).

Appendix C: Documentation on Cross Section Network and 2000 Mapping NGS Control

Table C1. Color scheme of cross section locations plotted by date surveyed on 2000 aerial photographs.

Table C2. Location and date of cross sections surveyed on the Dungeness River in the lower 10.5 river miles.

Table C3. Location of cross sections surveyed at scour chain locations in lower 10.5 river miles in October 1999.

Table C4. Cross section monument information for Reclamation network in lower 10.5 mi.

APPENDIX C: RECLAMATION SURVEY DATA DOCUMENTATION

This appendix documents the following:

- Visual locations of all cross sections surveyed on 2000 aerial photography
- Locations of all cross sections surveyed by river mile from the mouth
- Dates of original and resurvey cross section data
- Benchmark information needed to resurvey cross sections at same alignment as used for this study
- Documentation of NGS monument used as a reference for photogrammetry work with 2000 aerial photographs

Cross section locations are plotted on 2000 aerial photography and listed by river mile in Table C.1 and Table C.2. Data is plotted on the aerial photography by date surveyed in color scheme as listed below:

Table C1. Color scheme of cross section locations plotted by date surveyed on 2000 aerial photographs (contained in main report volume after report figures).

COLOR	DATA SET
Red:	March 1996 Washington Department of Transportation Data
Turquoise:	September 1997 Data
Light Green:	May 1998 Data
Yellow:	October 1998 Data
Dark Green:	October 1999 Data
Light Blue:	October 1999 Scour Chain Cross Section Data
Brown:	October 2000 Data
Red Circles:	Cross Section Permanent Benchmarks

Table C2. Location and date of cross sections surveyed on the Dungeness River in the lower 10.5 river miles.

Cross Section Description		River Mile	Distance to downstream XS (feet)	River Channel Data Collected RS = right side extended into floodplain LS = left side extended into floodplain				
Reach	Number			Mar 96[1]	Sept 97	Oct 98	Oct 99	Oct 2000
Reach 1: RM 0 to 2.7	1 - mouth	0.0291	0		x			
	2	0.2663	1252		x			
	3	0.4668	1059		x	RS, LS		
	4 Schoolhouse Bridge	0.7164	1318		x			
	5	0.8772	849		x			
	6	0.9831	559	x	x	LS	x	
	7	1.2009	1150	x	x			
	8	1.2603	314		x			
	9	1.3201	316	x	x			
	10	1.4683	782	x	x	LS	x	
	11	1.6544	983		x		x	
	12	1.8297	926		x	RS, LS	x	
	13	1.9849	819		x		x	
	14	2.1307	770		x	x	x	
	15	2.3207	1003		x			
	16	2.4623	748		x		x	
	17	2.6607	1048		x		x	
Reach 2: RM 2.6 to 4.6	18	3.0014	1799		x		x	
	19	3.2123	1114		x			

	20	3.3299	621		x			
	Woodcock Bridge	3.3324						
	21	3.3615	167		x			
	22	3.6035	1278		x			
	23	3.7427	735		x			
	24	3.9480	1084		x			
	Old Olympic Highway	4.0219						
	25	4.0377	474		x			
	26	4.1265	469		x			
	27	4.2652	732		x	x, RS		
	28	4.4608	1033		x			
	29	4.6046	759	x	x			x
Reach 3: RM 4.6 to 7.0	30	4.9650	1903		x	LS		x
	31	5.1903	1190		x			x
	31A	5.2966	561			x		x
	32	5.3840	461		x		x	x
	33	5.5050	639		x		x	x
	34	5.6496	763		x			x
	35 RR Bridge	5.6944	237		x		x	x
	36	5.8588	868		x	RS, LS		x
	37	6.0936	1240		x			x
	38	6.3211	1201		x	LS		x
	Highway 101 Bridge	6.4038						

	39	6.4118	479		x			
	40	6.6001	994		x			
	41	6.7504	794		x	x		
	42	6.8646	603		x			
Reach 4: RM 7 to 9	43	7.1700	1612		x	x		
	44	7.3391	893	x	x			
	45	7.4741	713		x			
	46	7.7276	1338	x	x			
	47	7.9007	914		x	RS, LS	x	
	48	8.0730	910	x	x			
	49	8.1687	505		x	x		
	50	8.4444	1456		x			
	51	8.6475	1073		x		x	
	52	8.8170	895		x			
Reach 5: RM 9 to 10.5	53	9.0652	1310		x	LS	x	
	54	9.3026	1253		x	x		
	55	9.5436	1272		x	RS	x	
	56	9.7338	1004		x		x	
	57	9.8095	400		x	x	x	
	58	10.0878	1469		x	RS		
	59	10.2024	605		x	x, RS		
	60	10.3627	846		x	x		

[1]Data collected and provided by Washington Department of Fish and Game.

Table C3. Location of cross sections surveyed at scour chain locations in lower 10.5 river miles in October 1999. (Only active channel was surveyed – no floodplain topography included in these sections)

Cross Section Description	River Mile	Upstream Cross Section Number	Downstream Cross Section Number
SC20	1.5771	11	10
SC10	1.6423	11	10
SC12	1.9394	13	12
SC13	1.9637	13	12
SC14	2.0565	14	13
SC15	2.2398	15	14
SC17	2.9635	18	17
SC9	3.0847	19	18
SC8	4.9392	30	29
SC7	5.0135	31	30
SC6	5.0816	31	30
SC5	5.1165	31	30
SC16	5.3688	32	31
SC4	5.4595	33	32
SC3	Side channel	34	33
SC2	Side channel	34	33
SC1	5.9663	37	36

CROSS SECTION BENCHMARK AND ALIGNMENT DATA

Documentation of the permanent Reclamation cross section network established in 1997 is listed below. This information provides the location and alignment of the sixty cross sections used in this study for resurvey purposes. In some cases, monuments had to be reset where bank erosion occurred during the study. The locations of these monuments have been updated in the table below.

(Permanent Monuments Established in Field)

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Table C4. Cross section monument information for Reclamation network in lower 10.5 mi.

X-SEC	OCCUPIED	B.S.	B.S. DIST.	ANGLE	F.S.	F.S. DIST.	F.S. NOT SET
1	1	6004	1,018.13	147E°50'25"	320	1,458.66	X
2	2	6004	740.7	151E°47'06"	278	346.17	X
3	3	6005	366.24	89E°07'33"	257	292.32	X
4	4	6002	1,745.81	124E°55'23"	239	284.06	X
5	5	6	586.24	96E°17'09"	222	215.16	X
6	6	5	586.24	289E°33'32"	206	278.57	X
7	7	8	243.75	92E°06'14"	190	305.37	X
8	8	11	1,852.48	18E°00'55"	165	378.67	X
9	9	10	807.81	71E°25'28"	2024	887.23	
10	10	9	807.81	268E°53'04"	2762	526.37	
11	11	12	754.86	106E°55'06"	886	222.93	X
12	12	11	754.86	251E°58'22"	909	336.87	X
13	13	14	536.00	108E°43'47"	929	246.28	X
14	14	13	536.00	239E°03'34"	2788	417.21	
15	15	14	866.67	273E°03'23"	487	609.31	X
16	16	6001	2,464.23	216E°12'01"	1014	431.01	X
17	17	6001	2,931.52	218E°45'18"	1049	761.07	X
18	18	19	986.60	258E°42'04"	1067	376.39	X
19	19	6009	1,049.73	259E°38'42"	1088	309.55	X
20	20	6006	227.87	183E°42'31"	1115	421.65	X
21	21	6009	197.17	143E°21'54"	1151	887.95	X
22	22	6009	1,198.98	128E°13'18"	1193	529.58	X

23	23	6015	1,290.56	250E°01'40"	1232	860.56	X
24	24	6015	615.06	202E°46'30"	1266	548.47	X
25	25	6017	154.03	354E°56'59"	342	522.49	X
26	26	6016	350.81	147E°04'45"	378	570.20	X
27	27	6022	317.67	153E°37'16"	2818	844.16	
28	28	6013	448.65	214E°27'46"	1301	575.45	X
29	29	6010	200.57	174E°51'57"	427	606.00	X
30	30	6018	697.05	188E°28'26"	2825	875.53	
31	31	32	1,223.01	260E°51'11"	447	544.54	X
32	32	6033	346.13	257E°40'12"	466	73685	X
33	33	6023	1,138.90	172E°00'44"	487	580.1	X
34	34	35	360.83	0E°10'31"	1403	249.01	X
35	35	6035	206.87	1E°44'35"	6034	402.19	
36	36	6035	876.73	77E°39'52"	1980	889.53	X
37	37	39	1,529.10	77E°30'59"	513	575.84	X
38	38	39	481.89	138E°40'00"	1931	889.85	X
39	39	6035	974.19	E°			
40	40	6025	1,050.70	175E°59'39"	2082	584.21	X
41	41	6026	328.21	251E°10'11"	2131	782.49	X
42	42	6027	309.68	141E°26'04"	651	935.44	X
43	43	44	838.29	269E°30'09"	1853	833.75	X
44	44	6029	1,785.99	97E°08'34"	679	669.08	X
45	45	44	981.19	113E°34'04"	721	448.72	X
46	46	45	1,334.71	269E°02'56"	743	411.21	X
47	47	48	944.72	84E°40'23"	315	657.24	X
48	48	46	1,829.66	276E°46'39"	767	444.24	X
49	49	6037	169.99	97E°10'07"	1900	681.11	X
50	50	6038	2,731.18	359E°36'22"	822	446.72	X
51	51	6040	2,864.08	208E°30'29"	1447	610.62	X
52	52	6040	2,319.81	266E°12'53"	1460	323.39	X
53	53	6041	497.42	213E°45'31"	1476	703.87	X
54	54	6062	535.30	88E°00'05"	1882	643.72	X
55	55	6043	439.19	297E°45'07"	1830	1,057.74	X
56	56	6044	234.32	240E°27'55"	1783	485.62	X
57	57	6061	490.24	93E°27'07"	1811	385.71	X
58	58	6048	472.98	255E°59'55"	1751	610.27	X
59	6060	58	795.55	78E°29'27"	1741	382.76	X
60	60	6049	444.35	176E°33'31"	1717	524.17	X

Survey Control Network Based on Clallam County and Washington State Control Network
Washington State Plane Coordinates
Horizontal Projection: NAD83
Vertical Projection: NGVD88

Table C5. Coordinates for Cross Section Benchmarks.

Cross Section	Survey Point Number	Easting (ft)	Northing (ft)	Elevation (ft)
1	1	1,080,944.52	428,811.47	5.73
2	2	1,080,709.53	427,637.90	18
3	283	1,080,774.00	426,543.00	23.11
4	4	1,080,095.20	425,395.80	33.36
5	5	1,079,441.60	425,266.80	30.93
6	287	1,079,041.70	424,838.20	32.41
7	7	1,078,948.70	424,150.40	33.37
8	8	1,078,985.40	423,909.40	34.16
9	9	1,078,853.50	423,407.70	37.2
10	10	1,078,051.60	423,309.80	38.54
11	11	1,077,422.90	422,914.50	44.59
12	1026	1,077,180.50	422,199.30	48.94
13	925	1,076,783.20	421,352.30	52.31
14	990	1,076,482.40	420,908.70	54.62
15	15	1,076,744.40	420,082.40	58.94
16	16	1,076,588.10	419,237.10	63.96
17	17	1,076,838.10	418,384.50	68.67
18	18	1,075,305.30	417,122.40	77.26
19	19	1,074,827.20	416,259.40	83.13
20	20	1,074,426.80	415,689.40	96.48
21	21	1,074,136.90	415,522.70	91.25
22	22	1,074,285.70	414,481.70	101.95
23	23	1,073,642.10	413,887.70	108.97
24	24	1,073,557.30	412,922.80	113.03
25	25	1,073,510.60	412,557.40	120.01
26	26	1,073,199.90	412,207.30	120.72
27	27	1,073,225.90	411,375.50	127.36
28	28	1,073,306.50	410,570.50	136.26
29	29	1,073,053.70	409,731.20	146.26
30	30	1,074,783.60	408,198.70	167.89
31	224	1,073,998.60	406,994.60	178.34
32	101	1,073,842.00	405,784.60	193.04
33	33	1,073,821.50	405,073.80	204.22
34	34	1,074,726.90	404,732.70	202.28
35	35	1,074,553.20	404,416.40	223.42
36	36	1,074,253.10	403,544.20	225.6
37	37	1,075,122.10	402,316.80	238.54
38	38	1,074,307.00	401,350.30	254.87
39	39	1,074,512.50	400,914.40	263.78
40	40	1,073,574.10	400,093.70	274.28
41	41	1,073,644.70	399,412.60	278.96
42	42	1,073,286.20	398,910.70	282.75

43	43	1,072,413.30	397,452.80	309.67
44	44	1,072,439.30	396,615.00	325.7
45	45	1,073,217.60	396,017.40	333.44
46	46	1,073,846.60	394,840.20	342.54
47	47	1,074,397.90	394,139.50	356.85
48	48	1,074,847.40	393,308.50	368.32
49	49	1,075,028.10	392,715.40	371.41
50	50	1,074,976.50	391,265.60	432.36
51	51	1,074,617.00	390,192.10	404.56
52	52	1,074,296.50	389,650.40	413.16
53	53	1,073,601.00	388,300.50	443.35
54	54	1,075,087.10	387,484.60	444.97
55	55	1,073,660.20	386,854.80	474.32
56	56	1,074,123.90	385,577.20	506.02
57	57	1,074,519.80	385,436.00	463.99
58	58	1,075,055.80	384,091.50	498.94
59				
60	60	1,076,315.90	383,518.90	502.76

BACKSIGHT POINTS FOR CROSS SECTIONS

Washington State Plane Coordinates
Horizontal Projection: NAD83
Vertical Projection: NGVD88

Cross Section	Survey Point Number	Easting (ft)	Northing (ft)	Elevation (ft)	Description
1	6004	1081431.30	427471.70	4.88	REBAR opp DUN AZ MK (near xs 2)
2	6004	1081431.30	427471.70	4.88	REBAR opp DUN AZ MK (near xs 2)
3	6005	1080618.60	426212.10	24.28	5/8" REBAR
4	6002	1079859.30	423666.00	25.45	5/8" REBAR
5	287	1079041.70	424838.20	32.41	XS 6 REBAR
6	5	1079441.60	425266.80	30.93	XS 5 REBAR
7	8	1078985.40	423909.40	34.16	XS 8 REBAR
8	11	1077422.90	422914.50	44.59	XS 11 REBAR
9	10	1078051.60	423309.80	38.54	XS 10 REBAR
10	9	1078853.50	423407.70	37.20	XS 9 REBAR
11	1026	1077180.50	422199.30	48.94	XS 12 REBAR
12	11	1077422.90	422914.50	44.59	XS 11 REBAR
13	990	1076482.40	420908.70	54.62	XS 14 REBAR
14	925	1076783.20	421352.30	52.31	XS 13 REBAR
15	990	1076482.40	420908.70	54.62	XS 14 REBAR
16	6001	1078485.70	420809.20	47.85	B.C. 36/1 T4W R31N
17	6001	1078485.70	420809.20	47.50	B.C. 36/1 T4W R31N
18	19	1074827.20	416259.40	83.13	XS 19 REBAR
19	6009	1073979.10	415640.80	88.79	5/8" REBAR
20	6006	1074199.20	415680.30	93.18	5/8" REBAR
21	6009	1073979.10	415640.80	88.79	5/8" REBAR
22	6009	1073979.10	415640.80	88.79	5/8" REBAR
23	6015	1072955.70	412794.80	114.55	5/8" REBAR
24	6015	1072955.70	412794.80	114.55	5/8" REBAR
25	6017	1073386.90	412649.30	118.74	LARGE NAIL 5' S OLY
26	6016	1072894.60	412380.00	116.68	REBAR & PLASTIC
27	6022	1072908.20	411380.90	128.10	PK & SHINER 272 GRA
28	6013	1072875.80	410444.90	136.79	PK NAIL #19 OLD SUR
30	6018	1075465.90	408341.50	164.19	LARGE NAIL
31	101	1073842.00	405784.60	193.04	XS 32 REBAR
32	6033	1073722.50	405459.70	196.95	5/8" REBAR
33	6023	1072682.60	405075.40	200.60	1/4 COR.14/23 T30N
34	35	1074553.20	404416.40	223.42	XS 35 SHINER
35	6035	1074346.40	404415.90	222.57	TACK
36	6035	1074346.40	404415.90	222.57	TACK
37	39	1074512.50	400914.40	267.77	XS 39 REBAR
38	39	1074512.50	400914.40	267.77	XS 39 REBAR
39	6035	1074346.40	404415.90	222.57	TACK
40	6025	1072526.00	400166.90	276.43	5/8" REBAR
41	6026	1073438.70	399157.10	278.54	PLASTIC ON REBAR
42	6027	1073111.00	399166.10	283.86	5/8" REBAR
43	44	1072439.30	396615.00	325.70	XS 44 REBAR
44	6029	1072442.50	398401.00	303.34	PK NAIL
45	44	1072439.30	396615.00	325.70	XS 44 REBAR
46	45	1073217.60	396017.40	333.44	XS 45 REBAR

47	48	1074847.40	393308.50	368.32	XS 48 REBAR
48	46	1073846.60	394840.20	342.54	XS 46 REBAR
49	6037	1075057.50	392882.80	368.38	LARGE NAIL
50	6038	1072246.50	391345.10	398.86	5/8" REBAR
51	6040	1072203.50	388650.20	458.94	5/8" REBAR
52	6040	1072203.50	388650.20	458.94	5/8" REBAR
53	6041	1073178.30	388038.30	455.52	5/8" REBAR
54	6062	1075087.00	386949.30	454.42	5/8" REBAR
55	6043	1073613.90	386418.10	488.55	LARGE NAIL
56	6044	1074230.10	385368.30	503.87	5/8" REBAR
57	6061	1074070.60	385632.40	505.38	LARGE NAIL IN OLD H
58	6048	1075191.70	383638.40	492.05	LARGE LAIL
59	58	1075055.80	384091.50	498.94	XS 58 REBAR
60	6049	1075903.10	383354.50	500.29	LARGE LAIL

FORESIGHT POINTS FOR CROSS SECTIONS

Washington State Plane Coordinates
Horizontal Projection: NAD83
Vertical Projection: NGVD88

Cross Section	Survey Point Number	Easting (ft)	Northing (ft)	Elevation (ft)	Description	Date of Survey
1	320	1079493.00	428667.20	4.14		Sep-97
2	278	1080375.50	427546.80	14.02		Sep-97
3	257	1080514.90	426665.40	7.65		Sep-97
4	239	1079886.40	425588.40	32.72		Sep-97
5	222	1079301.30	425429.90	23.80		Sep-97
6	206	1078913.30	425085.50	13.18		Sep-97
7	190	1078645.40	424115.50	28.68		Sep-97
8	165	1079003.20	423614.00	34.56	W-EDGE	Sep-97
9	2024	1078471.04	424208.28	74.91		Oct-98
10	2762	1077977.69	423830.99	32.16		Oct-98
11	886	1077241.70	423044.20	44.94		Sep-97
12	909	1076843.70	422203.50	48.06		Sep-97
13	929	1076634.50	421548.70	52.06		Sep-97
14	2788	1076065.82	420931.93	57.12		Oct-98
16	1014	1076145.90	419210.50	65.48		Sep-97
17	1049	1076110.40	418161.40	66.70		Sep-97
18	1067	1075663.90	417008.10	80.28		Sep-97
19	1088	1075051.60	416046.20	80.97		Sep-97
20	1115	1074848.40	415679.00	84.75		Sep-97
21	1151	1075024.90	415519.80	86.07		Sep-97
22	1193	1074771.70	414271.40	99.17		Sep-97
23	1232	1074483.40	413706.40	107.81		Sep-97
24	1266	1074096.10	412820.40	113.60		Sep-97
25	342	1073832.10	412375.80	114.68		Sep-97
26	378	1073769.10	412241.40	116.22		Sep-97
27	2818	1073988.37	411737.76	120.83		Oct-98
28	1301	1073853.10	410390.60	133.33		Sep-97
29	427	1073658.90	409762.60	140.94		Sep-97
30	2825	1073909.59	408147.45	162.31		Oct-98
31	447	1074561.20	407003.90	173.89		Sep-97
32	466	1074571.90	405683.70	190.82		Sep-97
33	487	1074396.10	405153.60	194.54		Sep-97
34	1403	1074606.40	404514.70	206.24		Sep-97
35	6034	1074151.20	404427.74	220.14	AL. TACK"W"END WOOD BRIDG	Oct-98
36	1980	1075137.36	403640.67	216.50		Oct-98
37	513	1074556.80	402426.80	239.32		Sep-97
38	1931	1073490.54	401704.11	250.05		Oct-98
39	39	1074512.50	400914.40	267.77	XS 39 REBAR	Sep-97
40	2082	1074157.59	400063.92	265.21		Oct-98
41	2131	1074379.78	399144.44	276.88	XS 41 Extension	Oct-98
42	651	1074180.80	398637.30	284.01		Sep-97
43	1853	1073246.38	397485.98	301.49		Oct-98
44	679	1073103.10	396530.60	317.18		Sep-97
45	721	1073610.40	396234.40	319.38		Sep-97
46	743	1073487.20	394640.40	341.86		Sep-97
48	767	1074451.40	393107.30	365.16		Sep-97
49	1900	1074346.64	392748.65	370.42		Oct-98
50	822	1074529.90	391275.50	389.89		Sep-97

51	1447	1075226.00	390235.40	402.25		Sep-97
52	1460	1074454.90	389368.50	408.65		Sep-97
53	1476	1074301.90	388276.80	426.65		Sep-97
54	1882	1074443.73	387462.18	442.22	B-RIPRAP	Oct-98
55	1830	1074539.20	386266.50	450.71		Oct-98
56	1783	1074391.98	385982.05	480.35		Oct-98
57	1811	1074695.18	385779.97	461.11		Oct-98
58	1751	1075580.59	384402.97	480.90		Oct-98
59	1741	1075719.85	384557.25	479.22		Oct-98
60	1717	1076790.33	383741.71	498.18		Oct-98

Documentation of Development of 2-foot Contour Map and Rendering Based on 2000 Aerial Photography

A 2-foot contour map and rendering was developed from the 2000 aerial photographs based on the NGS Survey Control Point "Carlsborg (1985)" and is projected in the following coordinate system:
Horizontal coordinate system: WGS 84 (latitude-longitude) referenced at this monument
Vertical coordinate system: NAVD 88 Washington North State Plane coordinates of this

A copy of the 2-foot contour map and rendering can be found at the Jamestown S'Klallam Tribal Center.

For more information on photogrammetry or mapping products, contact:
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Denver, CO 80225-0007
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NGS SURVEY CONTROL POINT- JOS 2

STATE/COUNTY- WA/CLALLAM
USGS QUAD - CARLSBORG (1985)

*CURRENT SURVEY CONTROL

* NAD 83(1991)-	48 04 53.13654(N)	123 11 00.58982(W)		ADJUSTED
* NAVD 88 -	72.8 (meters)	239.	(feet)	VERTCON

LAPLACE CORR-	-8.32 (seconds)	DEFLEC99
GEOID HEIGHT-	-20.83 (meters)	GEOID99

HORZ ORDER - THIRD

The horizontal coordinates were established by classical geodetic methods and adjusted by the National Geodetic Survey in December 1991.
No horizontal observational check was made to the station.

The NAVD 88 height was computed by applying the VERTCON shift value to the NGVD 29 height (displayed under SUPERSEDED SURVEY CONTROL.)
The Laplace correction was computed from DEFLEC99 derived deflections.
The geoid height was determined by GEOID99.

Table B-1. Sediment Sample: DRsed-1A

Locality No.: DRsed-1A Sampled by: RAL, TJR, JAK, and LAP Date: 9/14/98 Time: 1:45 pm
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 2-2
Quadrangle: Dungeness Closest Cross Section: 1 River Mile: 0
Section: South half, sec. 25 Township/Range: T. 31 N., R. 4 W. Elevation: -7 ft (-2 m)
Location: Near the mouth of the Dungeness River, on a fine-grained gravel bar
Latitude: 48º09'10"N. Longitude: 123º07'45"W. Error: +/-18 ft Waypoint No.: 29 Date: 9/14/98
Photographs Taken: LAP: 9-14; RAL:
Description of Pavement: Pavement is weakly developed; not sampled separately.
Description of Underlying Material: Loose and sandy. Sample is moist; some difficulty sieving the <2-mm material.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	49.1	49.1	30	30
2 to 8	38.1	87.2	23	53
8 to 16	30.9	118.1	19	72
16 to 32	35.9	154.0	22	94
32 to 63	10.8	164.8	7	101
63 to 90	0	--	--	--
90 to 128	0	--	--	--
128 to 180	0	--	--	--
>180	0	--	--	--

Table B-2. Sediment Sample: DRsed-1B

Locality No.: DRsed-1B   Sampled by: RAL, TJR, JAK, and LAP   Date: 9/14/98   Time: 3:15 pm
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 2-2
Quadrangle: Dungeness   Closest Cross Section: 1   River Mile: 0
Section: South half, sec. 25   Township/Range: T. 31 N., R. 4 W.   Elevation: 17 ft (5 m)
Location: Near the mouth of the Dungeness River, on a coarser gravel bar east of DRsed-1A
Latitude: 48º09'10"N.   Longitude: 123º07'45"W.   Error: +/-19 ft   Waypoint No.: 30   Date: 9/14/98
Photographs Taken: LAP: ; RAL:
Description of Pavement: Pavement is loose primarily. Formed in patches (discontinuous). About 60% of surface is pavement. No imbricated clasts. Rock hammer needed to dig out clasts. Salt coats (2-3 mm) on stones at ground surface.
Description of Underlying Material: Loose and sandy primarily. Some cobbles must be removed with rock hammer.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0	--	--	--
2 to 8	0	--	--	--
8 to 16	Trace	--	--	--
16 to 32	2.5	2.5	4	4
32 to 63	26.8	29.3	40	44
63 to 90	14.3	43.6	21	65
90 to 128	12.2	55.8	18	83
128 to 180	11.4	67.2	17	100
>180 (see back)	0	----	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	29.5	29.5	17	17
2 to 8	20.1	49.6	11	28
8 to 16	20.6	70.2	12	40
16 to 32	30.4	100.6	17	57
32 to 63	45.7	146.3	26	83
63 to 90	26.4	172.7	15	98
90 to 128	4.5	177.2	3	101
128 to 180	0	--	--	--
>180	0	--	--	--

Table B-3. Sediment Sample: DRsed-3A

Locality No.: DRsed-3A Sampled by: RAL and TJR Date: 9/13/98 Time: 2:30 pm
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 2-5
Quadrangle: Dungeness Closest Cross Section: 10 River Mile: 1.55
Section: West half, sec. 36 Township/Range: T. 31 N., R. 4 W. Elevation: 7 ft (2 m)
Location: Upstream end of gravel bar on right bank near active channel in section bounded by the Corps of Engineers dike and the Game Farm dike; representative of bed material
Latitude: 48º08'15"N. Longitude: 123º08'19"W. Error: +/- 23 ft Waypoint No.: 25 Date: 9/13/98
Photographs Taken: LAP: ; RAL: DR12-11 through DR12-21
Description of Pavement: Pavement is composed of coarse gravel and fine cobbles primarily. One particle in thickness.
Description of Underlying Material: Heterogeneous, loose, moist, and gray. Easy to excavate.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.5	0.5	1	1
2 to 8	1.6	2.1	2	3
8 to 16	6.1	8.2	8	11
16 to 32	22.7	30.9	31	42
32 to 63	34.4	65.3	47	89
63 to 90	7.6	72.9	10	99
90 to 128	0	--	--	--
128 to 180	0	--	--	--
>180 (see back)	0	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
[1]<2	43.3	43.3	26	26
[1]2 to 8				
8 to 16	27.7	71.0	17	43
16 to 32	43.6	114.6	26	69
32 to 63	42.7	157.3	26	95
63 to 90	7.7	165.0	5	100
90 to 128	2.1	167.1	1	101
128 to 180	0	--	--	--
>180	0	--	--	--

[1]Sizes were combined because the sample was moist and difficult to sieve.

Table B-4. Sediment Sample: DRsed-3B

Locality No.: DRsed-3B Sampled by: RAL, TJR, JAK, and LAP Date: 9/13/98 Time: 4:15 pm
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 2-5
Quadrangle: Dungeness Closest Cross Section: 10 River Mile: 1.5
Section: West half, sec. 36 Township/Range: T. 31 N., R. 4 W. Elevation: 22 ft (7 m)
Location On top of an inactive gravel bar about 2 m above the water surface in section bounded by the Corps of Engineers dike and the Game Farm dike
Latitude: 48º08'16"N. Longitude: 123º08'18"W. Error: +/- 23 ft Waypoint No.: 26 Date: 9/13/98
Photographs Taken: LAP: ; RAL: DR12-22 through DR12-
Description of Pavement: Pavement is heavily armored and weakly imbricated.
Description of Underlying Material:

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	Trace	--	--	--
2 to 8	0.2	0.2	0.1	0.1
8 to 16	0.4	0.6	0.2	0.3
16 to 32	6.8	7.4	3	3
32 to 63	37.6	45.0	14	17
63 to 90	45.9	90.9	17	34
90 to 128	81.4	172.3	31	65
128 to 180	90.8	263.1	35	100
>180 (see back)	0	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	38.7	38.7	19	19
2 to 8	27.8	66.5	14	33
8 to 16	20.7	87.2	10	43
16 to 32	31.5	118.7	16	59
32 to 63	38.4	157.1	19	78
63 to 90	22.0	179.1	11	89
90 to 128	19.9	199.0	10	99
128 to 180	0	--	--	--
>180	0	--	--	--

Table B-5. Sediment Sample: DRsed-4A

Locality No.: DRsed-4A Sampled by: RAL and LAP Date: 8/19/98 Time: 9 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 2-8
Quadrangle: Carlsborg Closest Cross Section: 18 River Mile: 3
Section: NE1/4, SE1/4, sec. 2 Township/Range: T. 30 N., R. 4 W. Elevation: 54 ft (16 m)
Location: Along Ward Road at Mary Lukes Wheeler Park (Clallam County Parks Department)
Latitude: 48º07'12"N. Longitude: 123º08'48"W. Error: ________ Waypoint No.: _____ Date: 8/31/99
Photographs Taken: LAP: 9, 10, 11, 12, 13; RAL: Roll 4: 16, 17, 18, 19, 20
Description of Pavement: Little pavement development; not sampled separately.
Description of Underlying Material: Maximum clast diameter identified by visual inspection is 100 mm.

Pavement: Not sampled separately

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	29.3	29.3	15	15
2 to 8	27.6	56.9	14	29
8 to 16	31.5	88.4	16	45
16 to 32	50.4	138.8	25	70
32 to 63	45.9	184.7	24	93
63 to 90	15.0	199.7	8	101
90 to 128	0	--	--	--
128 to 180	0	--	--	--
>180	0	--	--	--

Table B-6. Sediment Sample: DRsed-4B

Locality No.: DRsed-4B Sampled by: RAL and LAP Date: 8/19/98 Time: 11 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 2-8
Quadrangle: Carlsborg Closest Cross Section: 18 River Mile: 3
Section: NE1/4, SE1/4, sec. 2 Township/Range: T. 30 N., R. 4 W. Elevation: 55 ft (17 m)
Location: Along Ward Road at Mary Lukes Wheeler Park (Clallam County Parks Department)
Latitude: 48º07'14"N. Longitude: 123º08'48"W. Error: ______ Waypoint No.: ______ Date: 8/31/99
Photographs Taken: LAP: 14,15,16,17; RAL: Roll 4: 21-25, Roll 5: 1, 2
Description of Pavement: Little pavement development; not sampled separately.
Description of Underlying Material: ______

Pavement: Not sampled separately

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	38.6	38.6	24	24
2 to 8	44.3	82.9	28	52
8 to 16	29.0	111.9	18	70
16 to 32	28.5	140.4	18	88
32 to 63	16.8	157.2	11	99
63 to 90	1.5	158.7	1	100
90 to 128	--	--	--	--
128 to 180	--	--	--	--
>180	--	--	--	--

Table B-7. Sediment Sample: DRsed-5A

Locality No.: DRsed-5A Sampled by: RAL and LAP Date: 8/20/98 Time: 7:30 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 2-10
Quadrangle: Carlsborg Closest Cross Section: 20 River Mile: 3.33
Section: SE1/4, SE1/4/, sec. 2 Township/Range: T. 30 N., R. 4 W. Elevation: 55 ft (17 m)
Location: Downstream side of Woodcock Bridge; sample from coarser portion of gravel bar
Latitude: 48º06'59"N. Longitude: 123º08'58"W. Error: ________ Waypoint No.: _______ Date: ________
Photographs Taken: LAP: 19-23, 24, 1, 2, 3; RAL: Roll 5: 7-12, 13-14, 15-17, 18-19
Description of Pavement: Pavement is about one clast thick. Fairly well packed.
Description of Underlying Material: Well packed. A hammer or pick is required to loosen.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.3	0.3	0.1	0.1
2 to 8	0.3	0.6	0.1	0.2
8 to 16	1.6	2.2	0.7	1
16 to 32	13.9	16.1	6	7
32 to 63	56.1	72.2	24	31
63 to 90	38.2	110.4	16	47
90 to 128	45.5	155.9	19	66
128 to 180	82.0	237.9	34	100
>180 (see back)	0	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	28.7	28.7	12	12
2 to 8	23.8	52.5	10	22
8 to 16	20.5	73.0	9	31
16 to 32	30.8	103.8	13	44
32 to 63	42.7	146.5	18	62
63 to 90	41.5	188.0	18	80
90 to 128	44.3	232.3	19	99
128 to 180	0	--	--	--
>180	0	--	--	--

Table B-8. Sediment Sample: DRsed-5B

Locality No.: DRsed-5B Sampled by: RAL and LAP Date: 8/20/98 Time: 10:30 am
Aerial Photograph : 1998 (Project No. 98-0194) Color No. 2-10
Quadrangle: Carlsborg Closest Cross Section: 20 River Mile: 3.33
Section: SE1/4, SE1/4, sec. 2 Township/Range: T. 30 N., R. 4 W. Elevation: 62 ft (19 m)
Location: Downstream side of Woodcock Bridge; sample of intermediate portion of gravel bar
Latitude: 48º06'59"N. Longitude: 123º08'57"W. Error: ________ Waypoint No.: ______ Date: 8/31/99
Photographs Taken: LAP: 4-8, 9-10, 11-12; RAL: Roll 5: 20-25; Roll 6:
Description of Pavement: Pavement is loose.
Description of Underlying Material: Loose and easy to dig. Hole for sample is about 50 cm deep.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.2	0.2	0.1	0.1
2 to 8	1.0	1.2	0.7	1
8 to 16	7.2	8.4	5	6
16 to 32	28.8	37.2	20	26
32 to 63	69.9	107.1	49	75
63 to 90	23.4	130.5	17	92
90 to 128	11.5	142.0	8	100
128 to 180	0	--	--	--
>180 (see back)	0	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	36.7	36.7	16	16
2 to 8	22.0	58.7	9	25
8 to 16	35.2	93.9	15	40
16 to 32	55.5	149.4	24	64
32 to 63	62.5	211.9	27	91
63 to 90	18.4	230.3	8	99
90 to 128	2.8	233.1	1	100
128 to 180	0	--	--	--
>180	0	--	--	--

Table B-9. Sediment Sample: DRsed-8

Locality No.: DRsed-8 Sampled by: RAL, TJR, and JAK Date: 9/12/98 Time: 1:30 pm
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 3-5
Quadrangle: Carlsborg Closest Cross Section: 31A River Mile: 5.33
Section: NE1/4, SE1/4, sec. 14 Township/Range: T. 30 N., R. 4 W. Elevation: 173 ft (53 m)
Location: Upstream end of a gravel bar splitting the Dungeness River channel at Doc Severson's property downstream of the Railroad Bridge
Latitude: 48º05'28"N. Longitude: 123º09'02"W. Error: +/-21 ft Waypoint No.: 19 Date: 9/12/98
Photographs Taken: LAP: ; RAL: DR11-21 through DR12-7
Description of Pavement: Pavement is moderately armored, not imbricated, and about one particle thick.
Description of Underlying Material: Heterogeneous, loose, and dry to moist. Moisture increases with depth.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.4	0.4	0.1	0.1
2 to 8	0.6	1.0	0.1	0.2
8 to 16	1.7	2.7	0.4	0.6
16 to 32	8.5	11.2	2	3
32 to 63	34.6	45.8	8	11
63 to 90	44.8	90.6	11	22
90 to 128	44.5	135.1	11	33
128 to 180	80.4	215.5	19	52
>180 (see back)	203.7	419.2	49	101

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	23.2	23.2	10	10
2 to 8	25.5	48.7	10	20
8 to 16	16.5	65.2	7	27
16 to 32	25.7	90.9	11	38
32 to 63	34.4	125.3	14	52
63 to 90	31.6	156.9	13	65
90 to 128	40.9	197.8	17	82
128 to 180	45.8	243.6	19	101
>180	0	--	--	--

Table B-9 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
125 x 255 x 260	26.0		
195 x 270 x 280	52.8		
215 x 270 x 380	62.5		
190 x 310 x 310	62.4		
Total	203.7		

Summary for material larger than 180 mm in pavement

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
255	26.0	6	58
270	115.3	28	86
310	62.4	15	101

Table B-10. Sediment Sample: DRsed-13

Locality No.: DRsed-13 Sampled by: RAL and LAP Date: 9/9/98 Time: 11:30 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 3-11
Quadrangle: Carlsborg Closest Cross Section: 45 River Mile: 7.5
Section: SW1/4, SE1/4, sec. 26 Township/Range: T. 30 N., R. 4 W. Elevation: 328 ft (100 m)
Location: Gravel bar on east side of the Dungeness River at the lower end of the dike at Dungeness Meadows about 0.5 m above the water level
Latitude: 48º03'42"N. Longitude: 123º09'12"W. Error: +/-19 ft Waypoint No.: 2 Date: 9/10/98
Photographs Taken: LAP: 13-18 ; RAL: 6-16
Description of Pavement: Pavement is composed of chiefly cobbles, mostly subrounded to well rounded, of mixed lithology. A few boulders. Poorly imbricated. Scattered vegetation (dry weeds).
Description of Underlying Material: Loose. Slightly moist; sediment holds shape when clasts are removed.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.5	0.5	0.2	0.2
2 to 8	0.2	0.7	0.1	0.3
8 to 16	0.4	1.1	0.2	0.5
16 to 32	1.7	2.8	0.8	1.3
32 to 63	30.0	32.8	13	14
63 to 90	58.9	91.7	26	40
90 to 128	72.8	164.5	32	72
128 to 180	61.1	225.6	27	99
>180 (see back)	0	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	25.5	25.5	12	12
2 to 8	17.8	43.3	8	20
8 to 16	14.4	57.7	7	27
16 to 32	28.6	86.3	13	40
32 to 63	50.9	137.2	23	63
63 to 90	32.6	169.8	15	78
90 to 128	27.5	197.3	13	91
128 to 180	21.7	219.0	10	101
>180	0	--	--	--

Table B-11. Sediment Sample: DRsed-14

Locality No.: DRsed-14 Sampled by: RAL, TJR, JAK, and LAP Date: 9/9/98; 9/10/98 Time: 2:30 pm; 8:30 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 3-11
Quadrangle: Carlsborg Closest Cross Section: Half way between R-45 and R-46 River Mile: 7.55
Section: SW1/4, SE1/4, sec. 26 Township/Range: T. 30 N., R. 4 W. Elevation: 332 ft (101 m)
Location: Gravel bar at upstream end of Dungeness Meadows
Latitude: 48º03'39"N. Longitude: 123º09'08.56"W. Error: +/-19 ft Waypoint No.: 1 Date: 9/10/99
Photographs Taken: LAP: 19-24, 0 ; RAL: 17-
Description of Pavement: Pavement is weakly imbricated. About 100 ft downstream pavement has better imbrication. Some sand in depressions between clasts.
Description of Underlying Material: Loose, except for some large clasts.

Pavement: Pavement from 2-m square was sampled because of the large clasts.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.5	0.5	0.04	0.04
2 to 8	0.4	0.9	0.03	0.07
8 to 16	0.5	1.4	0.04	0.1
16 to 32	3.4	4.8	0.3	0.4
32 to 63	42.0	46.8	3	3
63 to 90	81.2	128.0	6	9
90 to 128	199.8	327.7	15	24
128 to 180	398.6	726.4	31	55
>180 (see back)	564.7	1,291.1	44	99

Underlying material: Underlying material was sampled from a 1-m square.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	33.4	33.4	7	7
2 to 8	24.8	58.2	6	13
8 to 16	15.7	73.9	3	16
16 to 32	24.0	97.9	5	21
32 to 63	48.7	146.6	11	32
63 to 90	66.2	212.8	15	47
90 to 128	31.9	244.7	7	54
128 to 180	36.6	281.3	8	62
>180	169.2	450.5	38	100

Table B-11. (Cont.)

For material larger than 180 mm

Pavement Diam (mm)	Pavement Wgt (lbs)	Underlying material Diam (mm)	Underlying material Wgt (lbs)
200	25.2	180	21.8
200	29.4	190	30.3
200	32.2	200	18.8
200	36.2	200	32.9
240	29.9	200	43.6
250	27.4	250	21.8
250	33.7	Total	169.2
260	32.1		
260	60.5		
270	27.9		
270	34.5		
270	36.7		
300	32.0		
330	57.0		
350	~70		
Total	564.7		

Summary for material larger than 180 mm in pavement

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
200	849.4	10	65
240	879.3	2	67
250	940.4	5	72
260	1,103.0	13	85
270	1,202.1	8	93
300	1,234.1	2	95
330	1,291.1	4	99

Summary for material larger than 180 mm in underlying material

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
180	303.1	5	67
190	333.4	7	74
200	428.7	21	95
250	450.5	5	100

Table B-12. Sediment Sample: DRsed-14

Locality No.: DRsed-14 Sampled by: RAL, TJR, JAK, and LAP Date: 9/9/98; 9/10/98 Time: 2:30 pm; 8:30 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 3-11
Quadrangle: Carlsborg Closest Cross Section: Half way between R-45 and R-46 River Mile: 7.55
Section: SW1/4, SE1/4, sec. 26 Township/Range: T. 30 N., R. 4 W. Elevation: 332 ft (101 m)
Location: Gravel bar at upstream end of Dungeness Meadows
Latitude: 48º03'39"N. Longitude: 123º09'08.56"W. Error: +/-19 ft Waypoint No.: 1 Date: 9/10/99
Photographs Taken: LAP: 19-24, 0 ; RAL: 17-
Description of Pavement: Pavement is weakly imbricated. About 100 ft downstream pavement has better imbrication. Some sand in depressions between clasts.
Description of Underlying Material: Loose, except for some large clasts.

Pavement: Pavement from 2-m square was sampled because of the large clasts.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.5	0.5	0.04	0.04
2 to 8	0.4	0.9	0.03	0.07
8 to 16	0.5	1.4	0.04	0.1
16 to 32	3.4	4.8	0.3	0.4
32 to 63	42.0	46.8	3	3
63 to 90	81.2	128.0	6	9
90 to 128	199.8	327.7	15	24
128 to 180	398.6	726.4	31	55
>180 (see back)	564.7	1,291.1	44	99

Underlying material: Underlying material was sampled from a 1-m square.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	33.4	33.4	7	7
2 to 8	24.8	58.2	6	13
8 to 16	15.7	73.9	3	16
16 to 32	24.0	97.9	5	21
32 to 63	48.7	146.6	11	32
63 to 90	66.2	212.8	15	47
90 to 128	31.9	244.7	7	54
128 to 180	36.6	281.3	8	62
>180	169.2	450.5	38	100

Table B-12. (Cont.)

For material larger than 180 mm

Pavement		Underlying material	
Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
200	25.2	180	21.8
200	29.4	190	30.3
200	32.2	200	18.8
200	36.2	200	32.9
240	29.9	200	43.6
250	27.4	250	21.8
250	33.7	Total	169.2
260	32.1		
260	60.5		
270	27.9		
270	34.5		
270	36.7		
300	32.0		
330	57.0		
350	~70		
Total	564.7		

Summary for material larger than 180 mm in pavement

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
200	849.4	10	65
240	879.3	2	67
250	940.4	5	72
260	1,103.0	13	85
270	1,202.1	8	93
300	1,234.1	2	95
330	1,291.1	4	99

Summary for material larger than 180 mm in underlying material

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
180	303.1	5	67
190	333.4	7	74
200	428.7	21	95
250	450.5	5	100

Table B-13. Sediment Sample: DRsed-19A

Locality No.: DRsed-19A Sampled by: RAL, TJR, and JAK Date: 9/16/98 Time: 2:30 pm
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 3-14
Quadrangle: Carlsborg Closest Cross Section: 53 River Mile: 9
Section: NE1/4, NE1/4, sec. 2 Township/Range: T. 29 N., R. 4 W. Elevation: 425 ft (130 m)
Location: Coarse-grained gravel bar near Duncan Road crossing
Latitude: 48º02'28.33"N. Longitude: 123º08'55.82"W. Error: +/-26 ft Waypoint No.: 35 Date: 9/16/98
Photographs Taken: LAP: ; RAL:
Description of Pavement:
Description of Underlying Material:

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.1	0.1	0.03	0.03
2 to 8	0.1	0.2	0.03	0.06
8 to 16	0.1	0.3	0.03	0.1
16 to 32	3.7	4.0	1	1
32 to 63	28.8	32.8	8	9
63 to 90	41.8	74.6	12	21
90 to 128	80.8	155.4	23	44
128 to 180	60.2	215.6	17	61
>180 (see back)	135.9	351.5	39	100

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
[1]<2 [1]2 to 8	60.1	60.1	24	24
8 to 16	23.9	84.0	10	34
16 to 32	27.9	111.9	11	45
32 to 63	43.1	155.0	17	62
63 to 90	12.6	167.6	5	67
90 to 128	25.2	192.8	10	77
128 to 180	0	(192.8)	--	(77)
>180	53.7	246.5	22	99

[1]Sizes were combined because the sample was moist and difficult to sieve.

Table B-13. (Cont.)

For material larger than 180 mm

Pavement		Underlying material	
Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
195	32.8	190	21.1
230	25.5	210	32.6
325	26.0	Total	53.7
360	51.6		
Total	135.9		

Summary for material larger than 180 mm in pavement

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
195	248.4	9	70
230	273.9	7	77
325	299.9	7	84
360	351.5	15	99

Summary for material larger than 180 mm in underlying material

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
190	213.9	9	86
210	246.5	13	99

Table B-14. Sediment Sample: DRsed-19B

Locality No.: DRsed-19B Sampled by: RAL, TJR, and JAK Date: 9/16/98; 9/17/98 Time: 8:40 am; 8:30 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 3-14
Quadrangle: Carlsborg Closest Cross Section: 53 River Mile: 9.05
Section: NE1/4, NE1/4, sec. 2 Township/Range: T. 29 N., R. 4 W. Elevation: 436 ft (133 m)
Location: Fine-grained gravel bar near Duncan Road crossing
Latitude: 48º02'28.65"N. Longitude: 123º08'56.35"W. Error +/-28 ft Waypoint No.: 36 Date: 9/16/98
Photographs Taken: LAP: ; RAL: 15-3, 15-4, 15-12 through 15-20
Description of Pavement:
Description of Underlying Material:

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	1.3	1.3	2	2
2 to 8	3.1	4.4	4	6
8 to 16	6.7	11.1	8	14
16 to 32	19.1	30.2	24	38
32 to 63	37.4	67.6	47	85
63 to 90	8.3	75.9	10	95
90 to 128	4.0	79.9	5	100
128 to 180	0	--	--	--
>180 (see back)	0	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	41.4	41.4	21	21
2 to 8	32.0	73.4	16	37
8 to 16	26.8	100.2	13	50
16 to 32	33.6	133.8	17	67
32 to 63	44.1	177.9	22	89
63 to 90	13.9	191.8	7	96
90 to 128	7.7	199.5	4	100
128 to 180	0	--	--	--
>180	0	--	--	--

Table B-15. Sediment Sample: DRsed-21

Locality No.: DRsed-21 Sampled by: RAL, TJR, JAK, and LAP Date: 9/15/98 Time: 8:30 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 4-3
Quadrangle: Carlsborg Closest Cross Section: 59 River Mile: 10.05
Section: SW1/4, SW1/4, sec. 1 Township/Range: T. 29 N., R. 4 W. Elevation: 465 ft (142 m)
Location: Gravel bar just downstream of the Fish Hatchery west side of the Dungeness River
Latitude: 48º01'47"N. Longitude: 123º08'26"W. Error: +/-23 ft Waypoint No.: 33 Date: 9/15/98
Photographs Taken: LAP: 17- ; RAL:
Description of Pavement: Pavement is well formed, especially on the upstream end of the bar. Larger clasts are difficult to remove. Uniform gravel size on entire bar (one unit). Some fine sediment in depressions.
Description of underlying material:

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.2	0.2	0.1	0.1
2 to 8	0.1	0.3	0	(0.1)
8 to 16	0.4	0.7	0.1	0.2
16 to 32	9.1	9.8	3	3
32 to 63	41.8	51.6	14	17
63 to 90	34.7	86.3	12	29
90 to 128	45.7	132.0	16	45
128 to 180	78.6	210.6	27	72
>180 (see back)	83.5	294.1	28	100

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	34.5	34.5	15	15
2 to 8	36.8	71.3	16	31
8 to 16	25.3	96.6	11	42
16 to 32	30.9	127.5	13	55
32 to 63	37.6	165.1	16	71
63 to 90	16.9	182.0	7	78
90 to 128	24.4	206.4	10	88
128 to 180	30.5	236.9	13	100
>180	0	--	--	--

Table B-15. (Cont.)

For material larger than 180 mm

Pavement		Underlying material	
Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
180	55.5		
200	28.0		
Total	83.5		

Summary for material larger than 180 mm in pavement

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)
180	266.1	19	91
200	294.1	10	101

Summary for material larger than 180 mm in underlying material

Interm. Diam (mm)	Cum. Wgt (lbs)	Percent	Cum. Percent (cont.)

APPENDIX D.
METHODS FOR MEASURING SEDIMENT IN BARS

Fourteen samples of sediment taken from gravel bars were measured at eight localities on the lower 10.5 mi (17 km) of the Dungeness River (see the location map in Figures 4A and 4B and the summary in Table D.1) in the 1998 field season. At five of these localities (DRsed-1, -3, -4, -5, and -19), samples of both coarse-grained and fine-grained bars were measured. The surface pavement and underlying bed material were measured separately at these sites, except at three localities (DRsed-1, -4A, and -4B) where the pavement was only weakly developed (see Table D.1); the pavement layer was not sampled separately at these locations.

The sediment was sampled, sieved, and weighed by size fraction in the field (see Figure D.1, photograph of the sampling setup). A one-meter square was selected from the surface of a given gravel bar on the basis of its appearance as representative of the material on the portion of the bar to be sampled. Areas that included particularly large rocks or areas of sand and silt were avoided, as these areas usually made up a small percentage of the surface of the bars. A two-meter square was used for a sample of the pavement at one site (DRsed-14) where the pavement rocks were particularly coarse and a larger sample area was considered necessary to obtain a sample that would be representative of the sizes of the pavement rocks. A brief description of the pavement, including gravel type, imbrication, and looseness, was made at each sample site. At most localities, the pavement layer is one particle diameter thick.

Once the sample area was selected, the pavement layer was removed with shovels and loaded into buckets (see Figure D.2, photograph of a bar pavement with the sample square selected). A pick was necessary to loosen the rocks where the pavement was tightly packed. All of the material was sieved through four screens (i.e., sieves with 32, 16, 8, and 2 mm openings) to separate material into representative fractions. Particles or rocks larger than 32 mm in diameter were manually passed through a pre-cut template or gravelometer to separate the larger material through openings sized at 63, 90, 128, and 180 mm (see Figure D.3, photograph of the gravelometer). The coarse particles were passed through the gravelometer by their shortest axis. Material of each size fraction was piled onto a tarp and photographed, including close oblique stereo pairs (see Figure D.4, photograph of a field sample segregated into size fractions on a tarp). The various particle sizes used in our investigation to classify the gravel bar material and their corresponding Wentworth scale size categories are tabulated on Table D.2 for reference.

Once the sample had been separated into fractions, each fraction was weighed to the nearest 0.1 lb using a scale suspended from a tripod (see Figure D.5, photograph of the scale used in the weighing procedure). For each rock with all three axes greater than 180 mm, its intermediate diameter was measured and the rock was weighed. These measurements were listed separately on the sample sheets. We targeted a representative weight of about 200 lbs for samples with significant concentrations of gravel or larger particles, but for some pavements, a sample this large was not possible using the one-meter-square sample area. Total weights of the sample sizes ranged between 70 to 1,300 lbs. Most samples weighed between 200 and 300 lbs. Each sample fraction was discarded after its weight was recorded.

The procedure was then repeated for the underlying bed material. The bed material exposed by removal of the overlying pavement was excavated from the one-meter square test pit with shovels or loosened with a pick first, if needed (see Figure D.6, photograph of bed material exposed after removal of pavement layer). The bed material was sampled down to a depth necessary to obtain a representative sample and the test pits generally did not exceed one foot in depth. The bed material was sieved or manually passed through a gravelometer to separate the material into size classes as previously described (see Figure D.7, photograph of bed material separated into fractions). No major changes in sediment size or type were encountered with depth at any of the sample sites. The sediment samples of the bed material were returned to the excavated test pit as each fraction was measured and recorded.

The measurements for both the surface pavement and the underlying bed material at each sample locality are in Appendix R, and are shown graphically as size distribution charts in Figures D.8 and D.9.

The sampling methodology outlined above for the 1998 field program was subsequently modified to incorporate feedback provided by habitat biologists Mike Reid and Byron Rot of the Jamestown S'Klallam Tribe. They recommended additional testing of the minus 2 mm fraction to determine the concentrations of fine sediment within the bar deposits that can prove detrimental to fish when present in significant concentrations. Of particular concern was the fraction of the sediment smaller than 0.0625 mm in diameter (i.e., the minus No. 230 sieve size). This fraction consists of medium silt- to fine clay-size particles in the Wentworth scale (Table D.2). Bulk samples of the minus 8 mm fraction were collected in the 2000 field season and sent to a contract soil testing laboratory (Materials Testing and Inspection, Inc.) in Boise, Idaho. The No. 230 sieve size was specifically added to the laboratory testing procedure to address fisheries concerns for that fraction of the sediment.

Additional sediment samples were collected in 2000 at nineteen localities along the Dungeness River in support of ongoing river bed scour investigations conducted by Habitat Biologist Byron Rot of the Jamestown S'Klallam Tribe using the modified procedure outlined above. Additional feedback provided by Mr. Rot during review of our draft sampling report indicated that the minus 0.85 mm fraction of sediment also had significant impacts on the biotic environment. We were unable to directly measure this fraction, as laboratory testing had already been completed and the samples had been discarded. We graphically estimated the concentration of the minus 0.85 mm fraction using particle size distribution graphs previously prepared for each sample (Piety and Link, 2000; attached as Appendix N). Our sample procedure has been modified to include laboratory determination of the minus 0.85 mm fraction in future sampling programs.

We reviewed the Timber Fish Wildlife (TFW) monitoring program method manual of salmonid spawning gravel composition (Schuett-Hames, 1999) published by the Northwest Indian Fisheries Commission to check for compatibility with our sampling procedure. The primary difference between the two methods was that the TFW uses wet sampling directly from the river bed while we dry sampled adjacent bar deposits to improve the speed of sample handling and field data processing. The sieve sizes used to analyze the sediment are generally compatible and our field dry sieves are identical to those recommended by TFW. Our contract laboratory used

Unified Soil Classification sieves which differ from those listed in the TFW method manual. We will evaluate laboratory implementation of the TFW sieve sizes for future studies.

References

Krumbein, W.C. and Sloss, L.L., 1963, Stratigraphy and Sedimentation [Second Edition]: San Francisco, W.H. Freeman and Co., p. 96.

Orsborn, J.F., and Ralph, S.C., 1994, An aquatic resource assessment of the Dungeness River system – Phase II. Physical channel analysis, hydrology, and hydraulics and Phase III. Fisheries habitat survey [unpub. report]: Report prepared for The Jamestown S'Klallam Tribe, Sequim, Washington, and The Quilcene Ranger Station, Olympic National Forest, Quilcene, Washington, variously paged.

Schuett-Hames, D., Conrad, R., Pleus, A., and McHenry, M., 1999, Timber Fish Wildlife Monitoring Program method manual for the salmonid spawning gravel composition survey: Report prepared for the Washington State Department of Natural Resources by the Northwest Indian Fisheries Commission under the Timber, Fish, and Wildlife Agreement, TFW-AM9-99-001, DNR #101, 51 p.

Table D.1. Sediment sampling localities along the Dungeness River

Locality number (Reach)	River mile[1)]	Cross section[2)]	Locality description	Notes
DRsed-1A (Reach 1)	0	1	Near mouth of Dungeness River; T.31N., R.4W., sec. 25, south half; 48º09'10"N., 123º07'45"W.; Elevation -7 ft (-2 m)	Sample of a fine-grained gravel bar; Pavement is weakly developed, not sampled separately; surface is loose and sandy.
DRsed-1B (Reach 1)	0	1	Near mouth of Dungeness River; T.31N., R.4W., sec. 25, south half; 48º09'10"N., 123º07'45"W.; Elevation 17 ft (5 m)	Sample of a coarse-grained gravel bar; pavement is loose primarily, formed in patches; about 60% of surface is pavement. Underlying material is loose and sandy primarily.
DRsed-3A (Reach 1)	1.55	10	Upstream end of gravel bar in reach bounded by the ACOE dike on the east and the Game Farm dike on the west; T.31N., R.4W., sec. 36, west half; 48º08'15"N., 123º08'19"W.; Elevation 7 ft (2 m)	Pavement composed of coarse gravel and fine cobbles one clast thick. Underlying material is heterogeneous, loose, and moist.
DRsed-3B (Reach 1)	1.5	10	Top of inactive gravel bar about 2 m above low-water surface in reach bounded by the ACOE dike on the east and the Game Farm dike on the west; T.31N., R.4W., sec. 36, west half; 48º08'16"N., 123º08'18"W.; Elevation 22 ft (7 m)	Pavement is heavily armored and clasts are weakly imbricated.
DRsed-4A (Reach 2)	3	18	Along Ward Road at Mary Lukes Wheeler Park; T.30N., R.4W., sec. 2, SE1/4, NE1/4; 48º07'12"N., 123º08'48"W.; Elevation 54 ft (16 m)	Little pavement development; pavement not sampled separately.
DRsed-4B (Reach 2)	3	18	Along Ward Road at Mary Lukes Wheeler Park; T.30N., R.4W., sec. 2, SE1/4, NE1/4; 48º07'14"N., 123º08'48"W.; Elevation 55 ft (17 m)	Little pavement development, not sampled separately.
DRsed-5A (Reach 2)	3.33	18	Downstream side of Woodcock Bridge; T.30N., R.4W., sec. 2, SE1/4, SE1/4; 48º06'59"N., 123º08'58"W.; Elevation 55 ft (17 m)	Sample is on coarser portion of bar. Pavement is fairly well packed and about 1 clast thick. Underlying material is well packed.

Table D.1. Sediment sampling localities along the Dungeness River (cont.)

Locality number (Reach)	River mile[1)]	Cross section[2)]	Locality description	Notes
DRsed-5B (Reach 2)	3.33	20	Downstream side of Woodcock Bridge; T.30N., R.4W., sec. 2, SE1/4, SE1/4; 48º06'59"N., 123º08'57"W.; Elevation 62 ft (19 m)	Sample is on intermediate portion of bar near DRsed-5A. Pavement and underlying material are both loose.
DRsed-8 (Reach 3)	5.33	31A	Upstream end of bar that splits the Dungeness River at Doc Severson's property downstream of the Railroad Bridge; T.30N., R.4W., sec. 14, SE1/4, NE1/4; 48º05'28"N., 123º09'02"W.; Elevation 173 ft (53 m)	Pavement one clast thick is moderately formed on bar; clasts are not imbricated. Underlying material is heterogeneous, loose, and dry to moist.
DRsed-13 (Reach 4)	7.5	45	Gravel bar on east side of Dungeness River at the lower end of the dike at Dungeness Meadows; T.30N., R.4W., sec. 26, SE1/4, SW1/4; 48º03'42"N., 124º09'12"W.; Elevation 328 ft (100 m)	Pavement is chiefly cobbles with a few boulders; clasts are poorly imbricated. Underlying material is loose and slightly moist.
DRsed-14 (Reach 4)	7.55	Between 45 and 46	Gravel bar upstream of the dike at Dungeness Meadows; T30N., R.4W., sec. 26, SE1/4, SW1/4; 48º03'39"N., 123º09'09"W.; Elevation 332 ft (101 m)	Pavement is weakly imbricated, but in other areas pavement is better developed; sand in depressions between clasts. Underlying material is loose, except for some large clasts.
DRsed-19A (Reach 4)	9	53	Near Duncan Road crossing; T29N., R.4W., sec. 2, NE1/4, NE1/4; 48º02'28"N., 123º08'56"W.; Elevation 425 ft (130 m)	Sample of coarse-grained bar.
DRsed-19B (Reach 4)	9.05	53	Near Duncan Road crossing; T29N., R.4W., sec. 2, NE1/4, NE1/4; 48º02'29"N., 123º08'56"W.; Elevation 436 ft (133 m)	Sample of fine-grained bar.
DRsed-21 (Reach 5)	10.05	59	Gravel bar just downstream of Fish Hatchery west of the Dungeness River; T.29N., R.4W., sec. 1, SW1/4, SW1/4; 48º01'47"N.; 123º08'26"W.; Elevation 465 ft (142 m)	Pavement is well formed, especially on upstream end of bar; fine sediment in depressions.

[1)]RM is along the Dungeness River and begin at the ocean
[2)]This is the closest cross section. Sample site is not necessarily exactly on the section.

Table D.2. Particle sizes for sediment sampling of Dungeness River gravel bars

Particle diameter (mm)	Wentworth scale particle size classification [1]
2048 - 4096 [2]	very large boulder
1024 - 2048 [2]	large boulder
512 - 1024 [2]	medium boulder
256 - 512 [2] (>180 [3])	small boulder [6]
128 - 256 (128 - 180 [3])	large cobble [6]
63 - 128	small cobble [6]
32 - 63	very coarse gravel [6]
16 - 32	coarse gravel [7]
8 - 16	medium gravel [7]
4 - 8 (4.75 - 8 [4]) [5]	fine gravel [7, 8]
2 - 4 (2.36 - 4.75 [4]) [5]	very fine gravel [7, 8]
1 - 2 (1.18 - 2.36 [4])	very coarse sand [7, 8]
0.5 - 1 (0.60 - 1.18 [4])	coarse sand [8]
0.25 - 0.5 (0.30 - 0.60 [4])	medium sand [8]
0.125 - 0.25 (0.15 - 0.30 [4])	fine sand [8]
0.0625 - 0.125 (0.075 - 0.15 [4])	very fine sand [8]
0.0313 - 0.0625 (0.037 - 0.075 [4])	coarse silt [8]
0.0156 - 0.0313 (0.019 - 0.037 [4])	medium silt [8]
0.0078 - 0.0156 (0.009 - 0.019 [4])	fine silt [8]
0.0039 - 0.0078 (0.005 - 0.009 [4])	very fine silt [8]
0.0020 - 0.0039 (0.002 - 0.005 [4])	coarse clay [8]
0.0001 - 0.0020 (0.001 - 0.002 [4])	medium clay [8]
0.00005 - 0.0001 (not tested in lab)	fine clay

Notes of Table D.2:

[1] Wentworth Scale classification was compiled from Krumbein and Sloss (1963) and Orsborn and Ralph (1994).
[2] This size fraction was not distinguished separately in our field sampling program.
[3] Modified sieve size used in our sampling program shown in parentheses; sizes larger than 180 mm were grouped into one fraction for the purpose of our study.
[4] Laboratory tests used sieves for Unified Soil Classification System rather than Wentworth Scale; USCS sieve sizes are shown in parentheses. Fractions 0.037 mm and smaller were measured with hydrometer.
[5] Fractions for 2 - 4 and 4 - 8 mm were combined into a single fraction during field dry sieving.
[6] Fraction measured with gravelometer.
[7] Fraction measured by dry sieving in the field; minus 2 mm material was combined into a single fraction in 1998 sampling.
[8] Fraction measured by laboratory testing (2000 field samples only).

Figure D.1. View of sampling setup at locality DRsed-113 near the downstream end of the Dungeness Meadows levee, seen in the background. Two sets of 5-gallon buckets and sieves were used to expedite sampling of the gravel bar.

Figure D.2. Surface of unvegetated gravel bar at Sample Locality DRsed-5B downstream from Woodcock Bridge. Our 1-meter square sample area was delineated by the flagging tape on the bar surface. The pavement was composed chiefly of gravel and cobbles and was about one particle diameter thick at this location. This pavement was excavated, sieved, and weighed before the underlying bed material was sampled.

Figure D.3. Gravelometer, or pre-cut template, used to sort particles larger than the 32-mm sieve. The smallest opening through which a particle passes determines its size group. Size groups measured with the gravelometer were 32 to 63 mm, 63 to 90 mm, 90 to 128 mm, 128 to 180 mm, and larger than 180 mm. Rocks larger than 180 mm were weighed individually and then totaled to obtain the weight for that fraction.

Figure D.4. Sediment from pavement material at Sample Locality DRsed-5B separated into the following size fractions (counterclockwise from bottom center): 90 to 128 mm, 63 to 90 mm, 32 to 63 mm, 16 to 32 mm, 8 to 16 mm, 2 to 8 mm, and finer than 2 mm. After the sediment was separated into fractions, each sample was weighed in order to determine the distribution of particle sizes within the pavement.

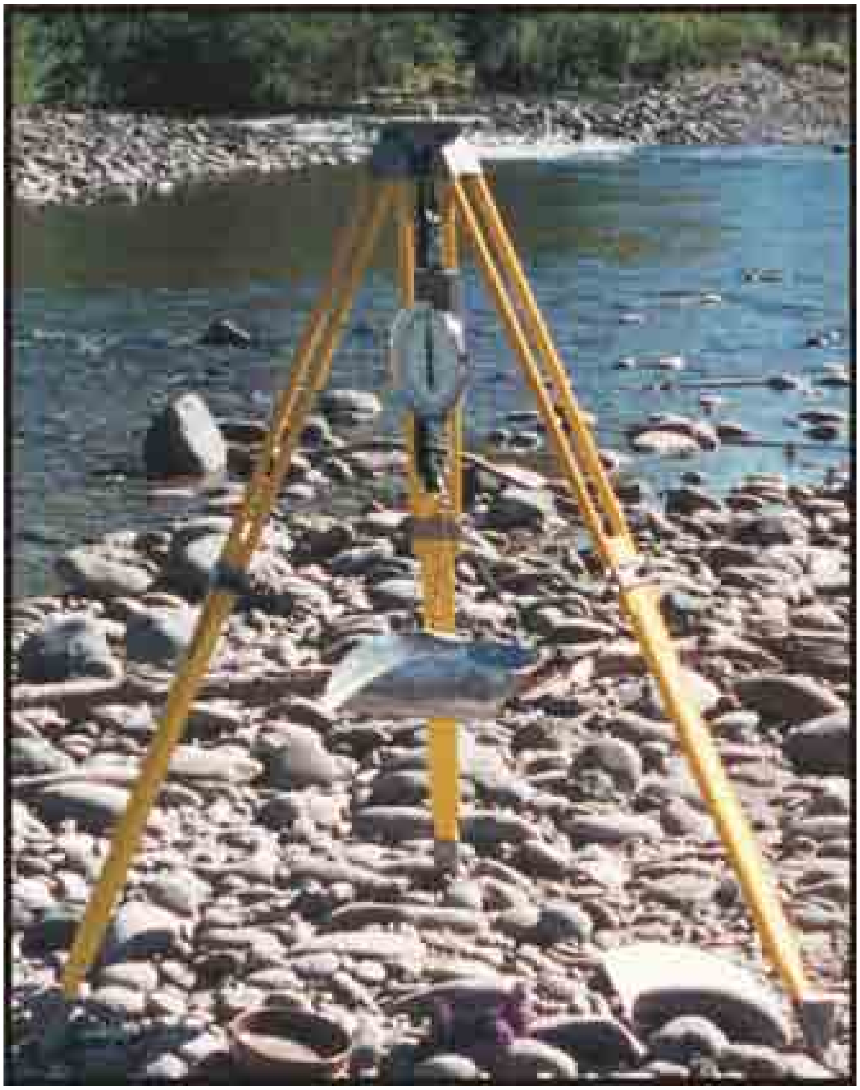


Figure D.5. View showing the scale suspended from a tripod which was used to weigh the sample in each size fraction. Samples too large for the pan were weighed in smaller portions and a cumulative weight was then calculated for the entire size fraction.

Figure D.6. Example of bed material exposed following excavation of the surface pavement layer at Sample Locality DRsed-5B. The thickness of the pavement was about one particle diameter at this location. The bed material beneath the pavement was markedly smaller than the pavement and is more representative of the material carried in the bed load of Dungeness River.

Figure D.7. Sediment from the bed material at Sample Locality DRsed-5B after separation into size fractions. Each fraction was individually weighed to determine the distribution of sizes within the sample. Compare the size fractions in this photo with those shown for the overlying pavement in Figure D.4.

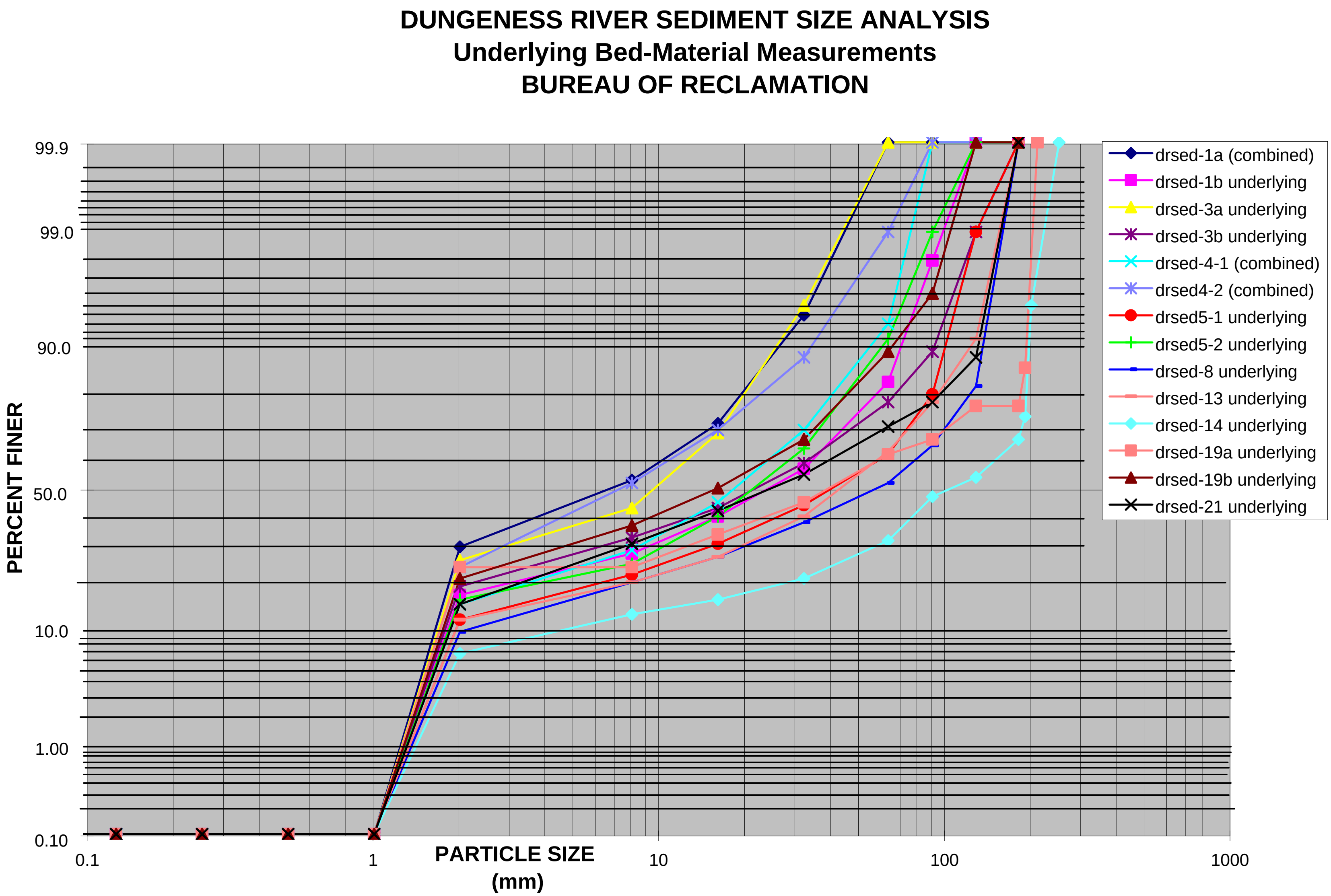


Figure D.8: Particle Size Distribution Graph for Underlying Bed-Material Samples.

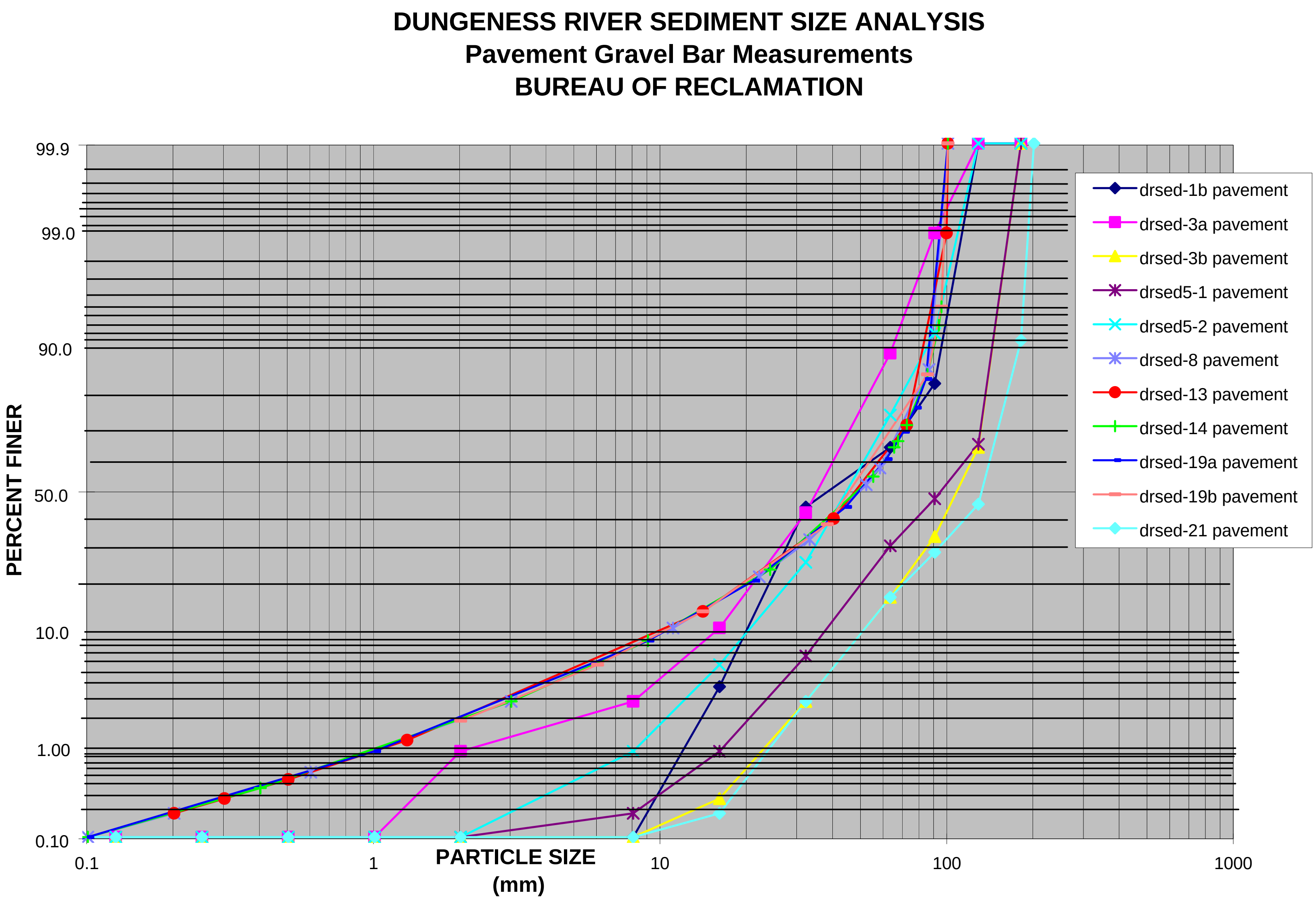


Figure D.9: Particle Size Distribution Graph for Pavement Gravel Bar Samples.

BEDLOAD DATA MEASURED BY UNITED STATES GEOLOGICAL SURVEY

GAGE SITE: **Hwy 101 Bridge Gage Site (12048000)**

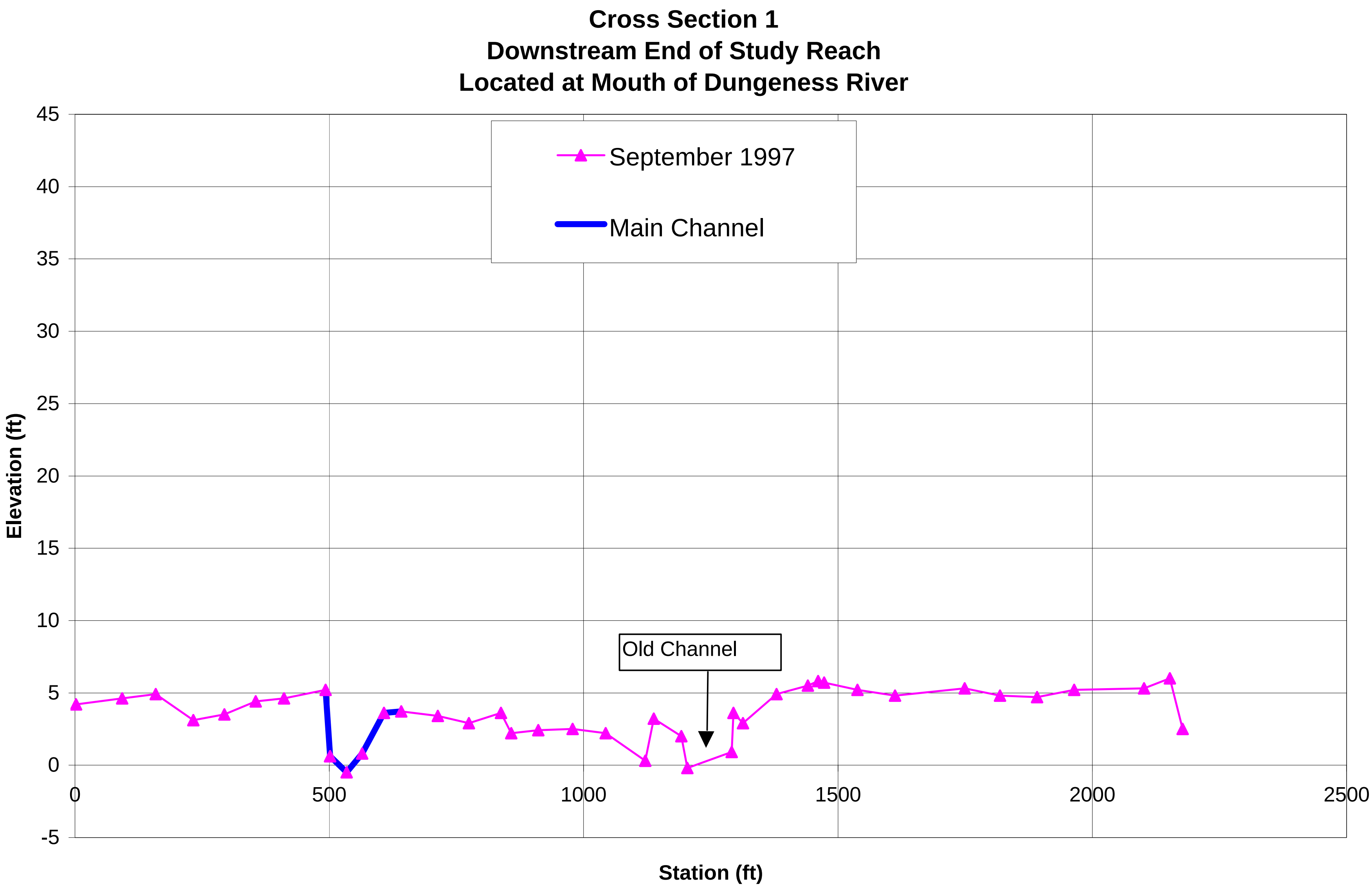
DATE	12/30/98		1/29/99		1/30/99		2/24/99		2/25/99	
FLOW (CFS)	1500		4500		1800		3500		2000	
INSTANTANEOUS BEDLOAD SEDIMENT (TONS PER DAY)	736		7820		968		6300		1340	
	Particle Diameter (mm)	**Percent Passing**	**Particle Diameter (mm)**	**Percent Passing**	**Particle Diameter (mm)**	**Percent Passing**	**Particle Diameter (mm)**	**Percent Passing**	**Particle Diameter (mm)**	**Percent Passing**
Smallest	0.062	0	0.062	0.1	0.062	0.2	0.062	0.1	0.062	0
	0.125	0	0.125	0.4	0.125	0.4	0.125	0.1	0.125	0.1
	0.25	0.1	0.25	1	0.25	0.7	0.25	0.5	0.25	0.2
	0.5	2	0.5	5	0.5	5	0.5	5	0.5	2
	1	16	1	17	1	38	1	30	1	18
	2	32	2	28	2	60	2	46	2	34
To	4	47	4	38	4	73	4	58	4	47
	8	61	8	48	8	83	8	71	8	58
	16	73	16	60	16	89	16	79	16	66
	32	86	32	74	32	95	32	86	32	76
	64	96	64	86	64	99	64	94	64	88
	128	100	128	100	128	100	128	99	128	100
Largest	256	100	256	100	256	100	256	100	256	100

BEDLOAD DATA MEASURED BY UNITED STATES GEOLOGICAL SURVEY

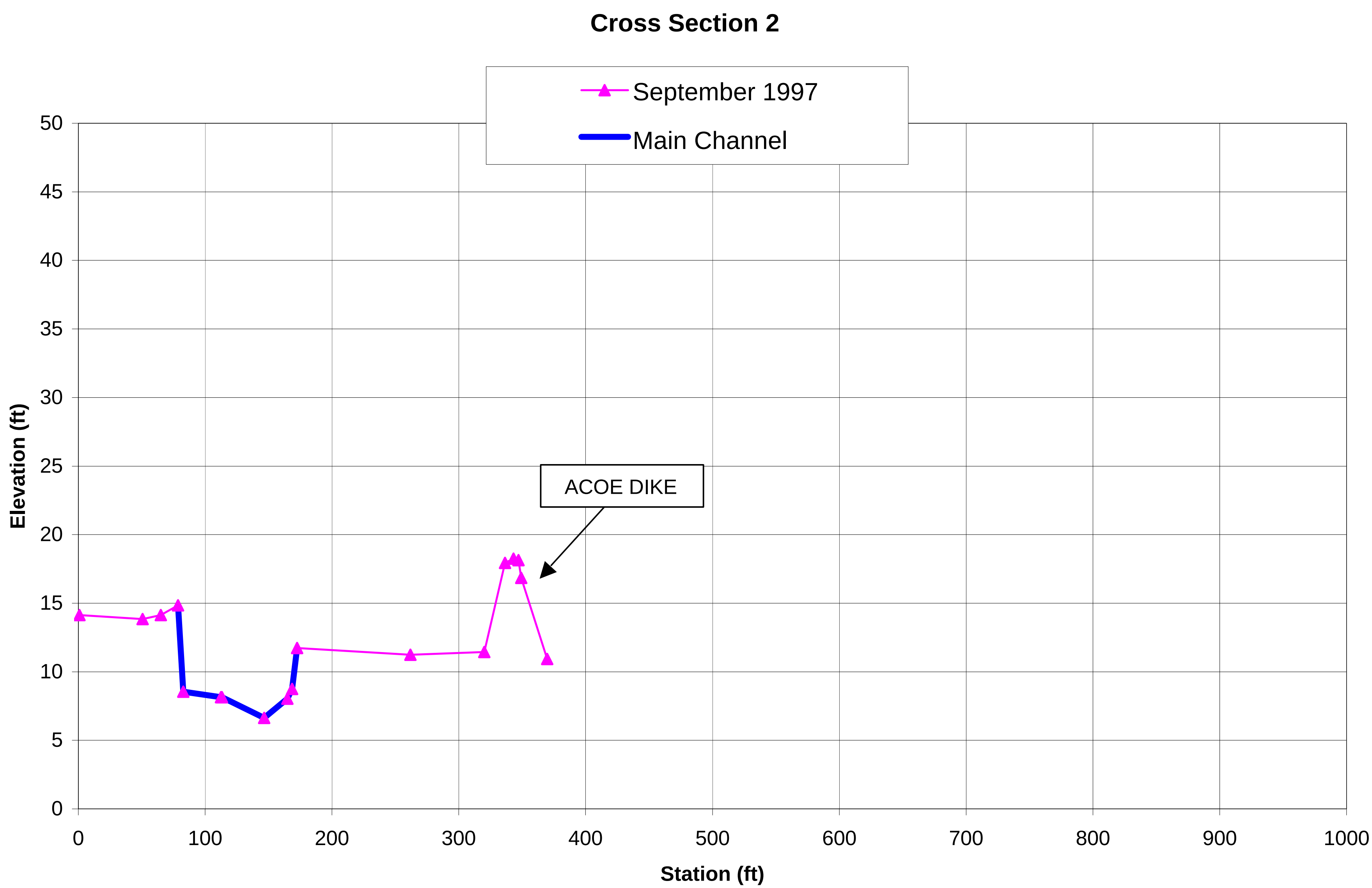
GAGE SITE: **Hwy 101 Bridge Gage Site (12048000)**

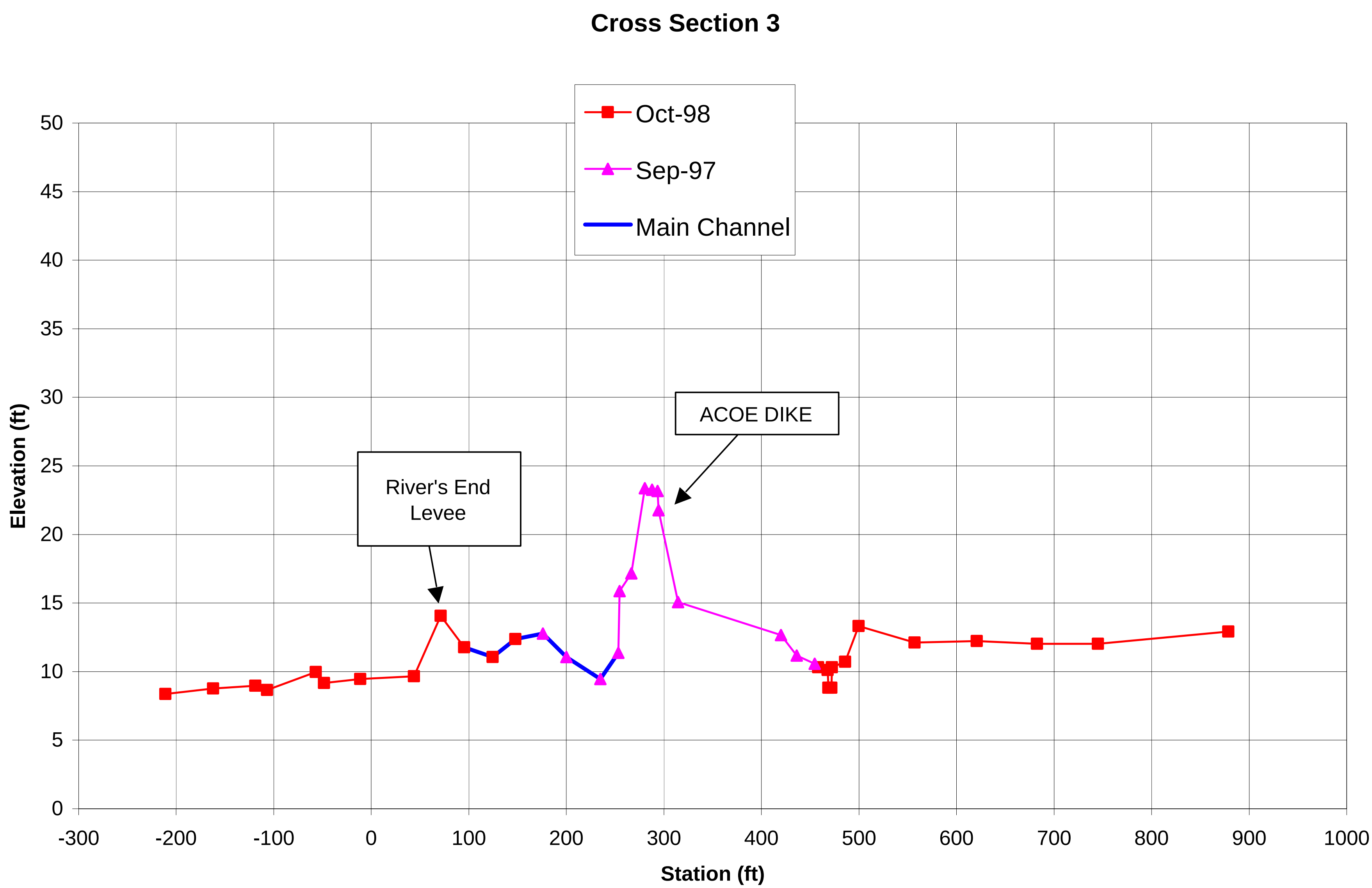
DATE	5/24/99		5/24/99		5/25/99		6/15/00	
FLOW (CFS)	1300		1600		1900		1020	
INSTANTANEOUS BEDLOAD SEDIMENT (TONS PER DAY)	160		515		606		192	
	Particle Diameter (mm)	**Percent Passing**	**Particle Diameter (mm)**	**Percent Passing**	**Particle Diameter (mm)**	**Percent Passing**	**Particle Diameter (mm)**	**Percent Passing**
Smallest	0.062	0	0.062	0	0.062	0	0.062	0
	0.125	0.1	0.125	0.1	0.125	0.1	0.125	0
	0.25	0.1	0.25	0.2	0.25	0.1	0.25	0
	0.5	3	0.5	3	0.5	3	0.5	2
	1	24	1	24	1	22	1	17
	2	44	2	44	2	40	2	51
To	4	62	4	59	4	52	4	63
	8	76	8	69	8	62	8	70
	16	90	16	78	16	72	16	77
	32	98	32	87	32	87	32	96
	64	100	64	97	64	94	64	100
	128	100	128	100	128	100	128	100
Largest	256	100	256	100	256	100	256	100

Figure E1. Looking downstream at USGS Gage Site on Highway 101 Bridge where sediment load measurements were done.

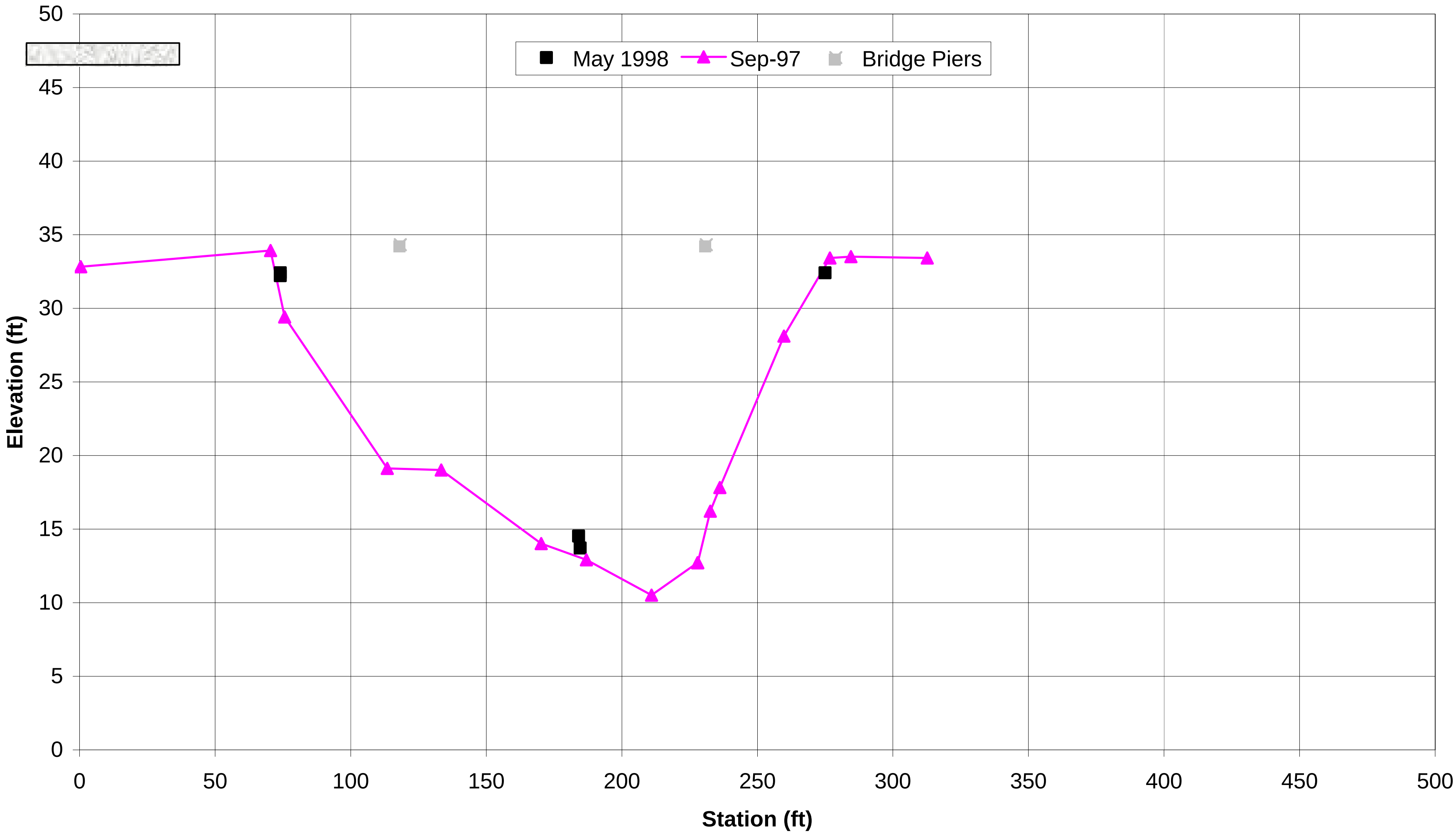


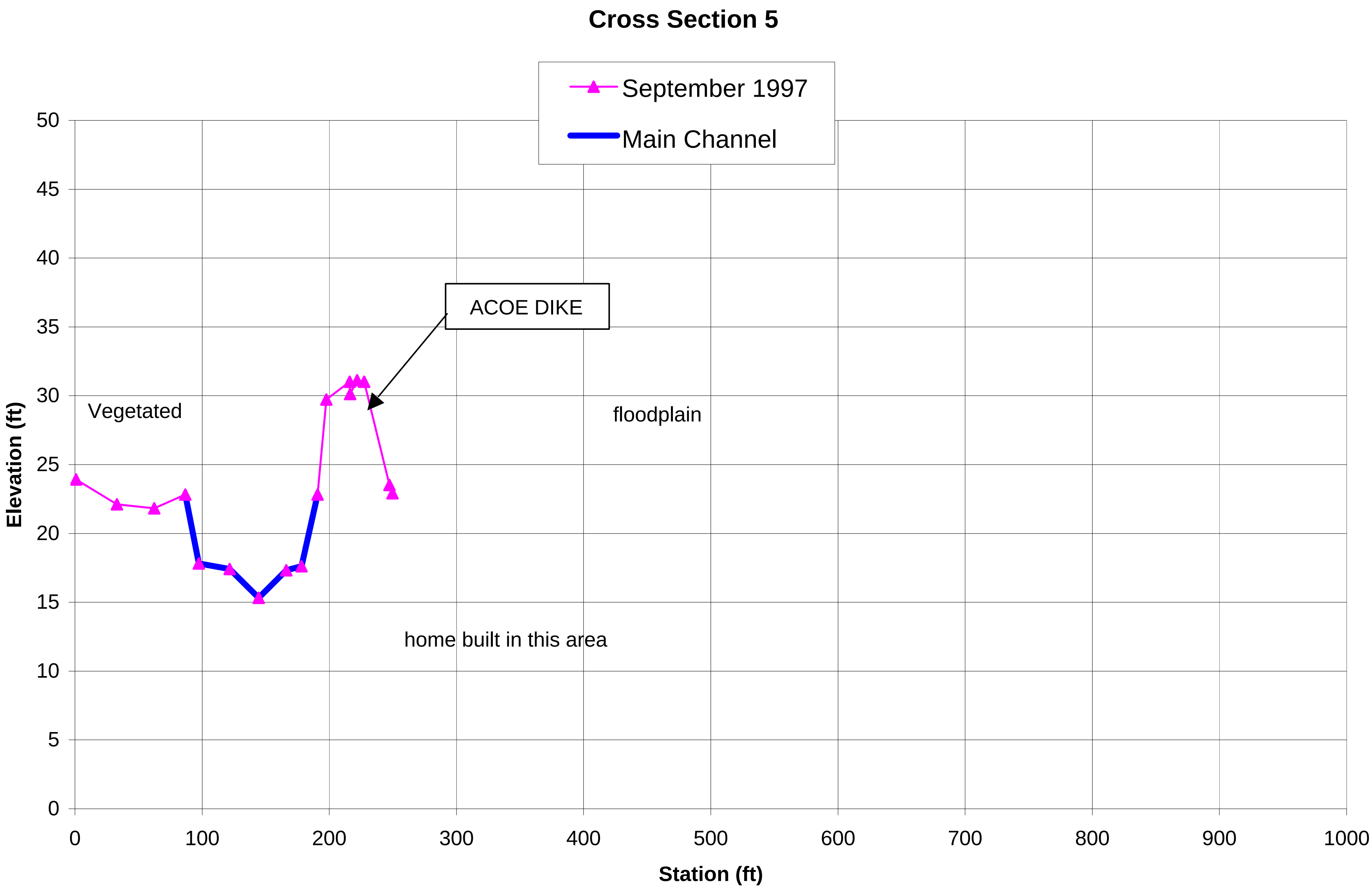
Cross Section 1
Downstream End of Study Reach
Located at Mouth of Dungeness River
September 1997
Main Channel
Old Channel
Elevation (ft)
Station (ft)
45
40
35
30
25
20
15
10
5
0
-5
0
500
1000
1500
2000
2500

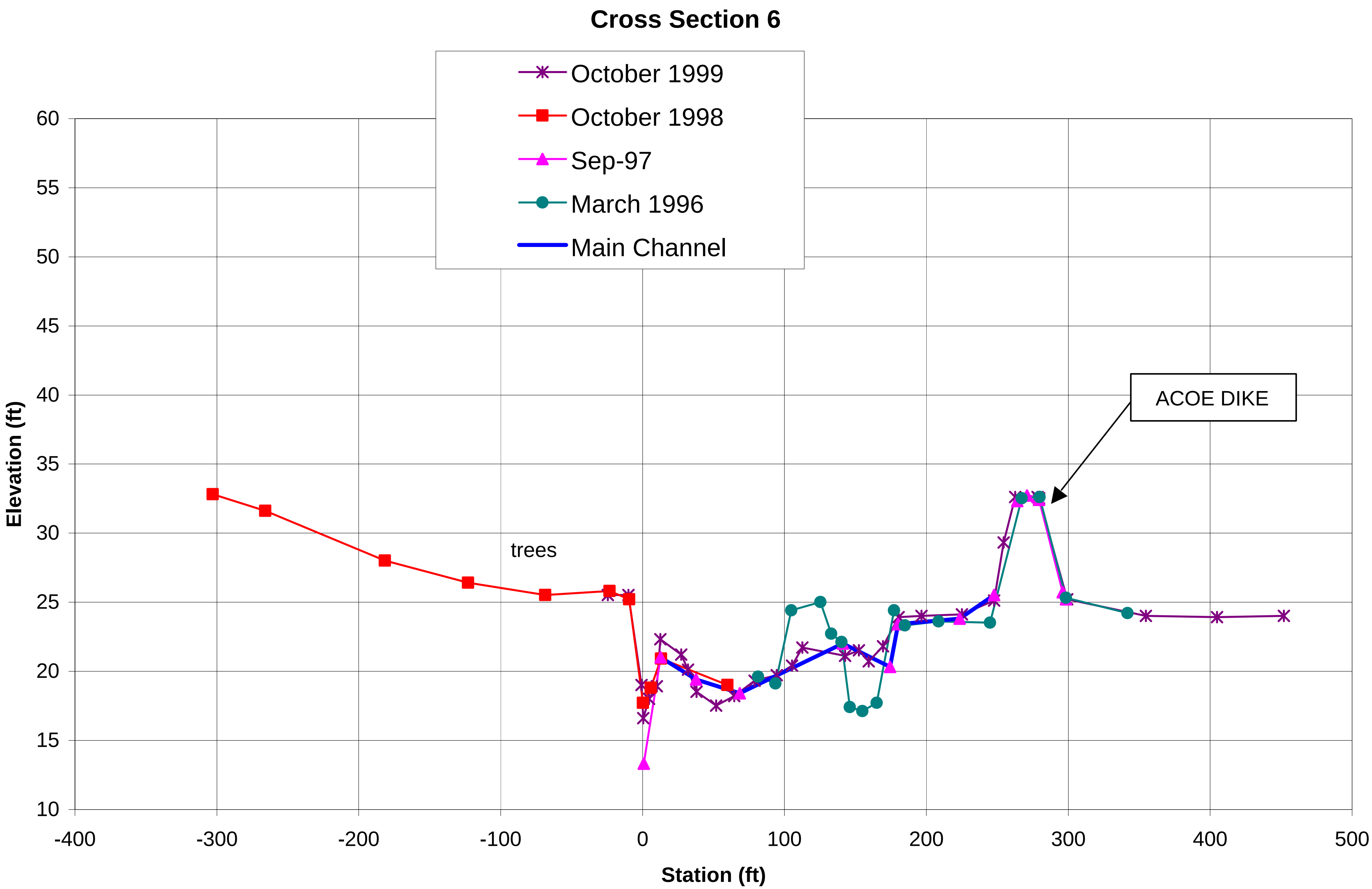

Cross Section 2
September 1997
Main Channel
ACOE DIKE
Elevation (ft)
Station (ft)
0
5
10
15
20
25
30
35
40
45
50
0
100
200
300
400
500
600
700
800
900
1000


Cross Section 3
Oct-98
Sep-97
Main Channel
River's End Levee
ACOE DIKE
Elevation (ft)
50
45
40
35
30
25
20
15
10
5
0
-300
-200
-100
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)

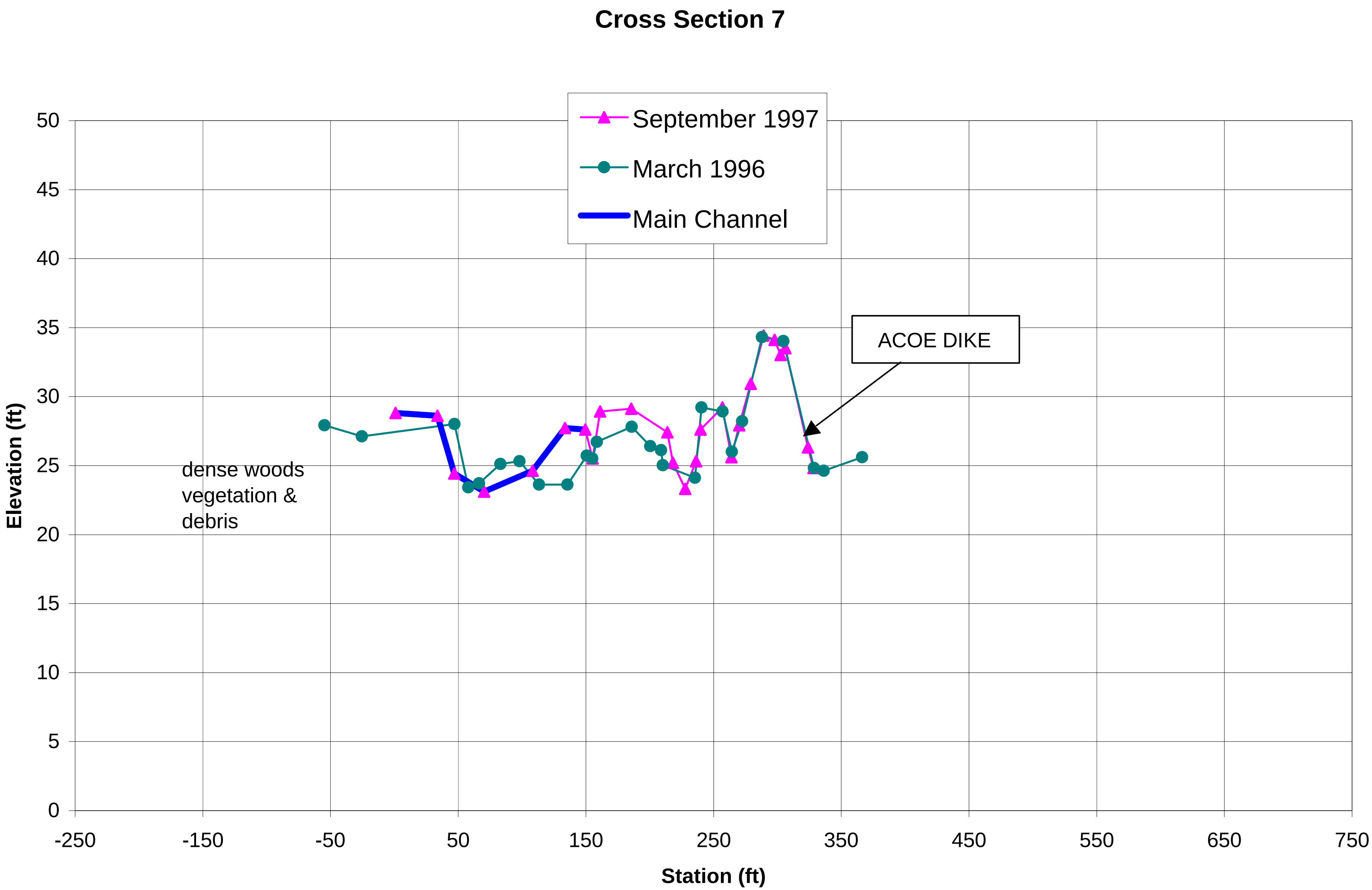
Cross Section 4
Just Downstream of Schoolhouse Bridge




Cross Section 5
September 1997
Main Channel
ACOE DIKE
Vegetated
floodplain
home built in this area
Elevation (ft)
Station (ft)
0
5
10
15
20
25
30
35
40
45
50
0
100
200
300
400
500
600
700
800
900
1000

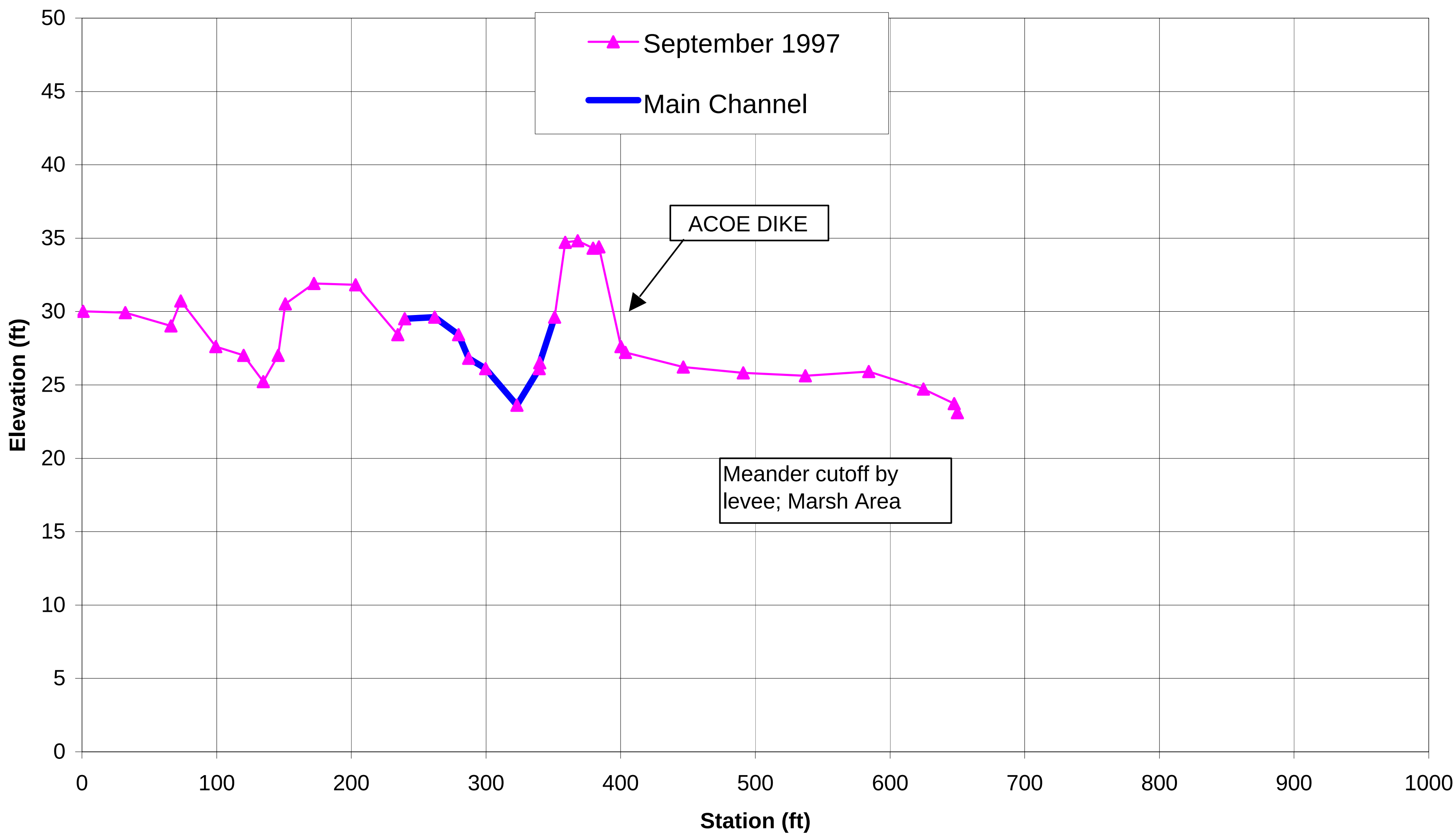


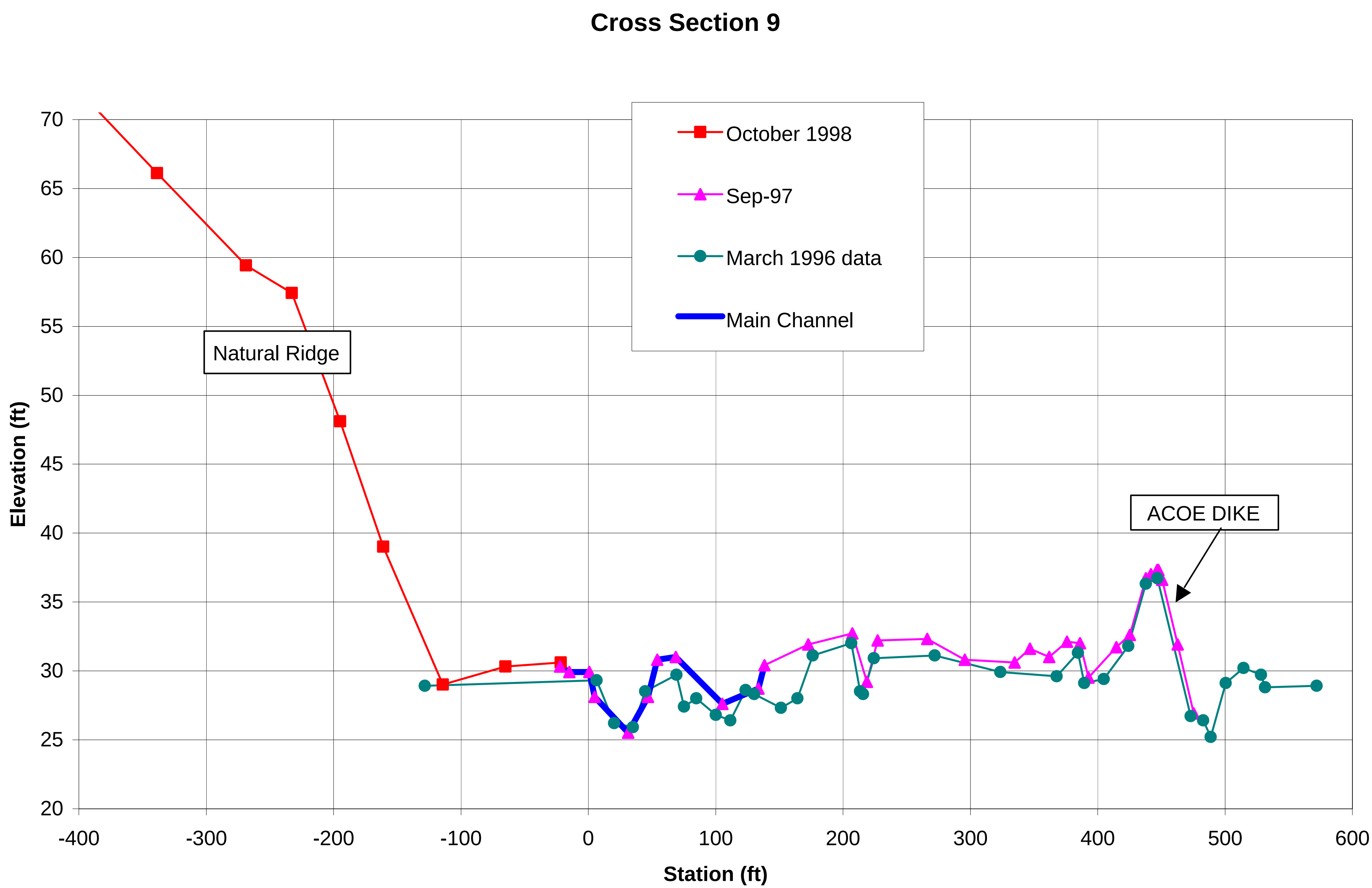
Cross Section 6
October 1999
October 1998
Sep-97
March 1996
Main Channel
ACOE DIKE
trees
Elevation (ft)
Station (ft)
60
55
50
45
40
35
30
25
20
15
10
-400
-300
-200
-100
0
100
200
300
400
500



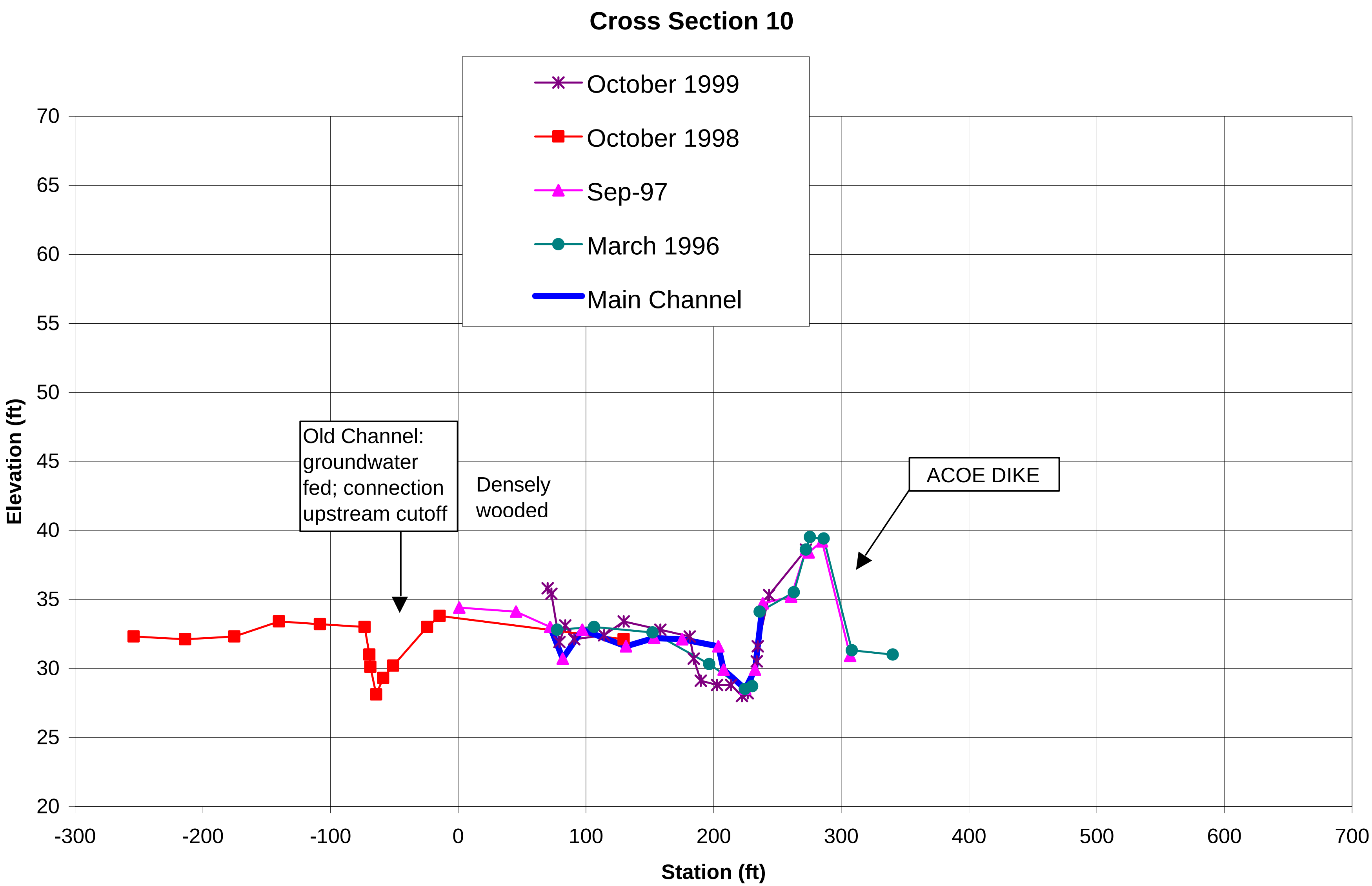
Cross Section 7
September 1997
March 1996
Main Channel
ACOE DIKE
dense woods
vegetation &
debris
Elevation (ft)
Station (ft)
50
45
40
35
30
25
20
15
10
5
0
-250
-150
-50
50
150
250
350
450
550
650
750

Cross Section 8

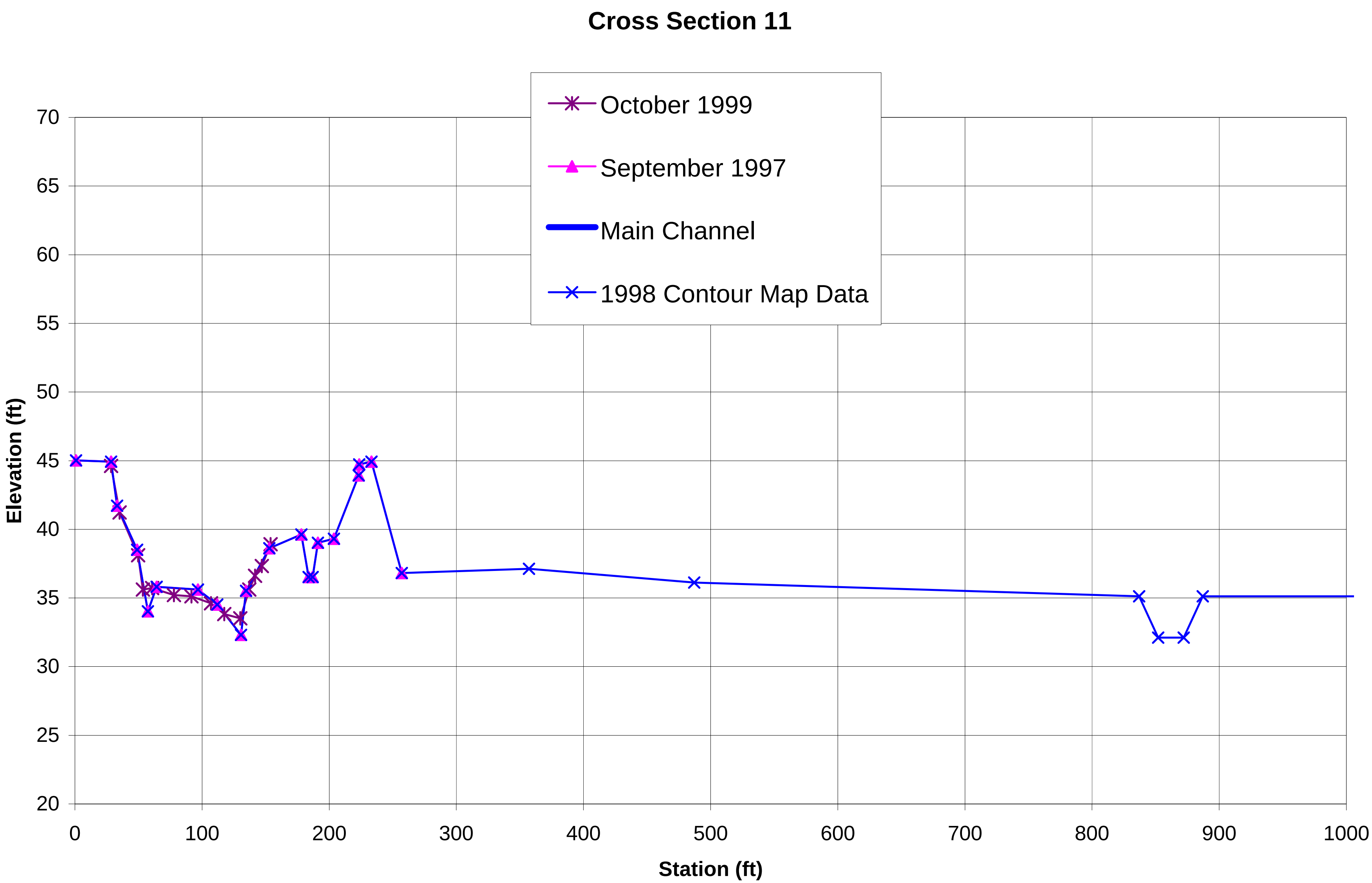




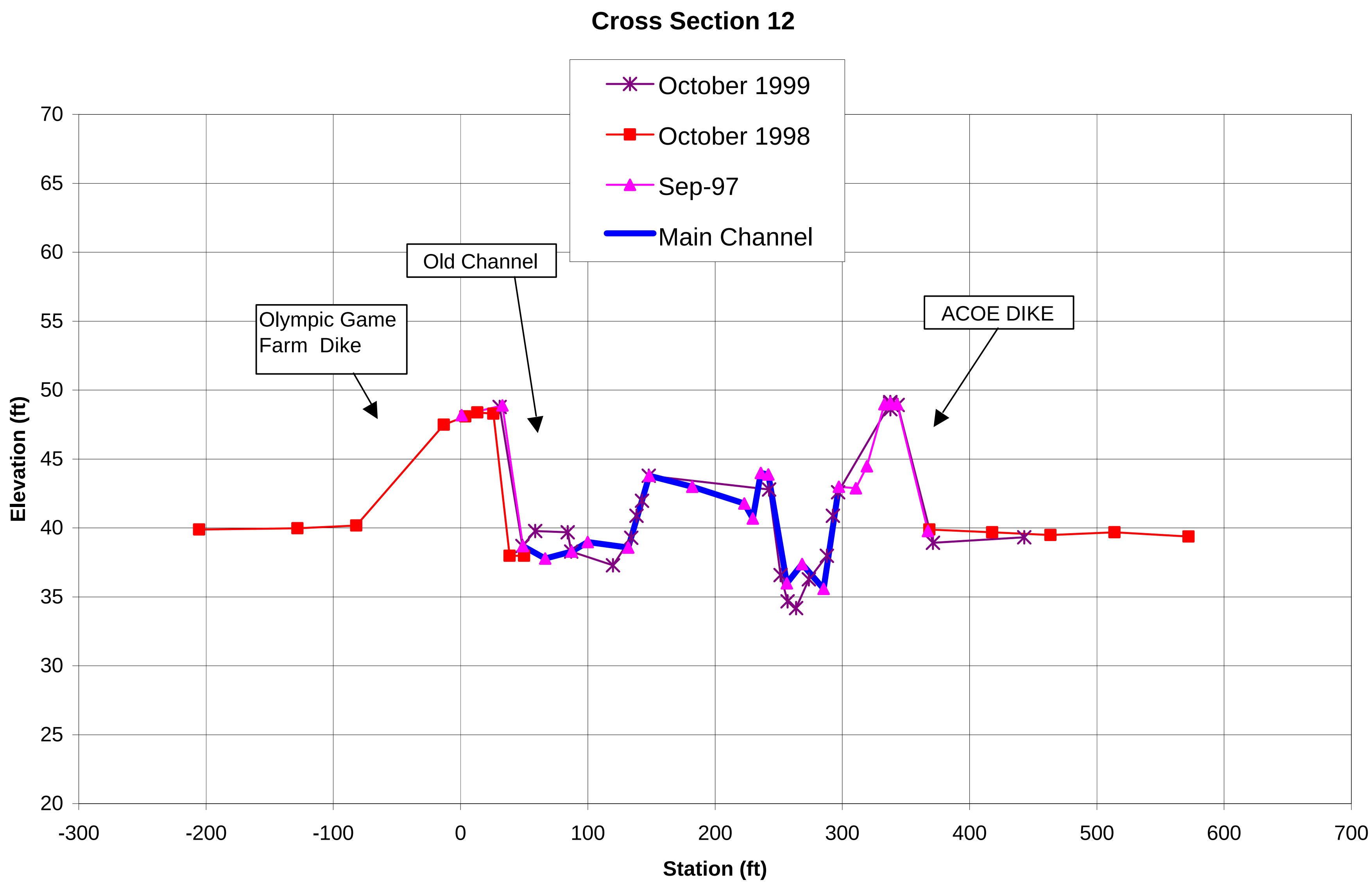
Cross Section 9
Elevation (ft)
Station (ft)
70
65
60
55
50
45
40
35
30
25
20
-400
-300
-200
-100
0
100
200
300
400
500
600
October 1998
Sep-97
March 1996 data
Main Channel
Natural Ridge
ACOE DIKE



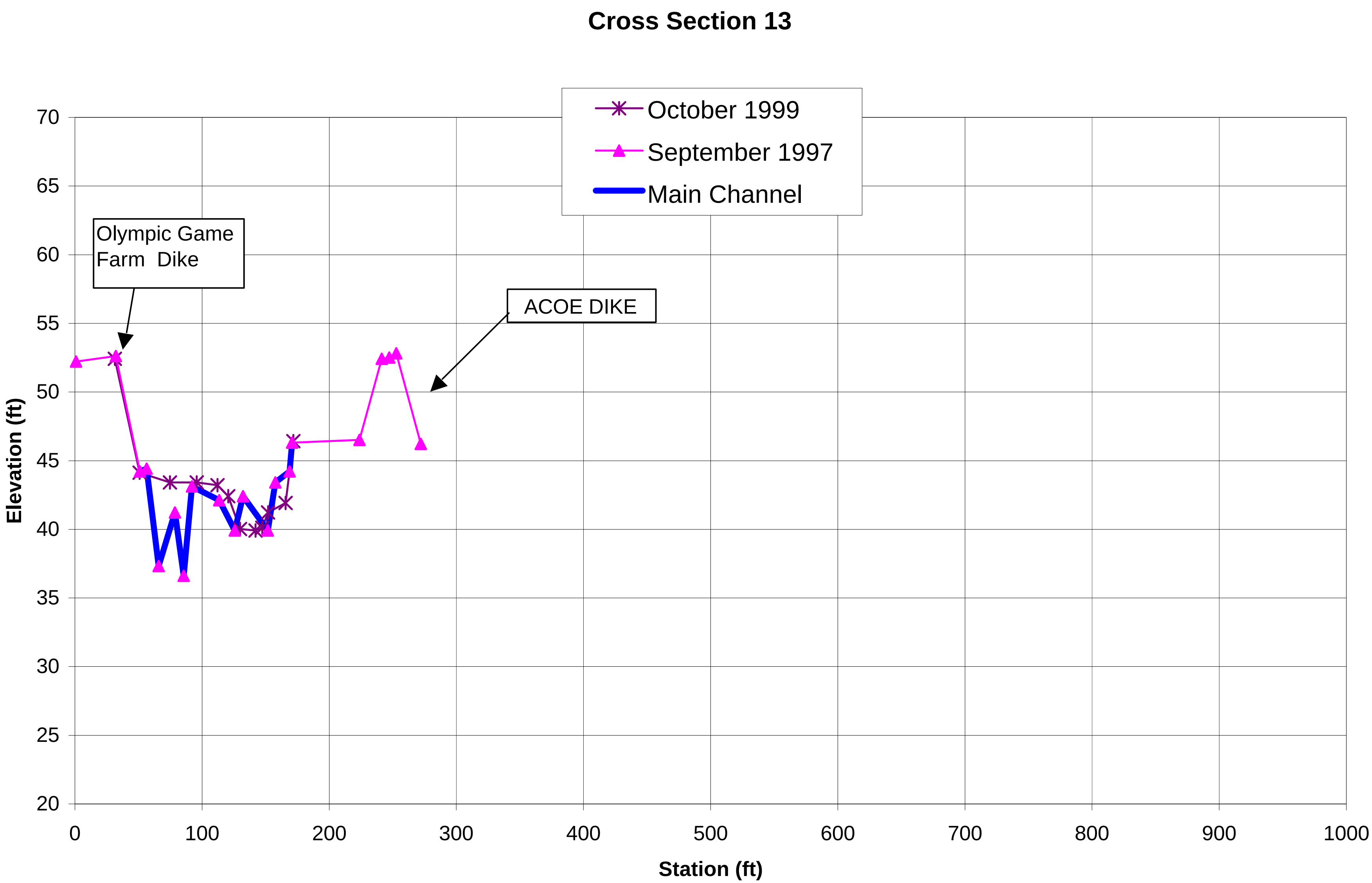
Cross Section 10
October 1999
October 1998
Sep-97
March 1996
Main Channel
Old Channel: groundwater fed; connection upstream cutoff
Densely wooded
ACOE DIKE
Elevation (ft)
Station (ft)
70
65
60
55
50
45
40
35
30
25
20
-300
-200
-100
0
100
200
300
400
500
600
700

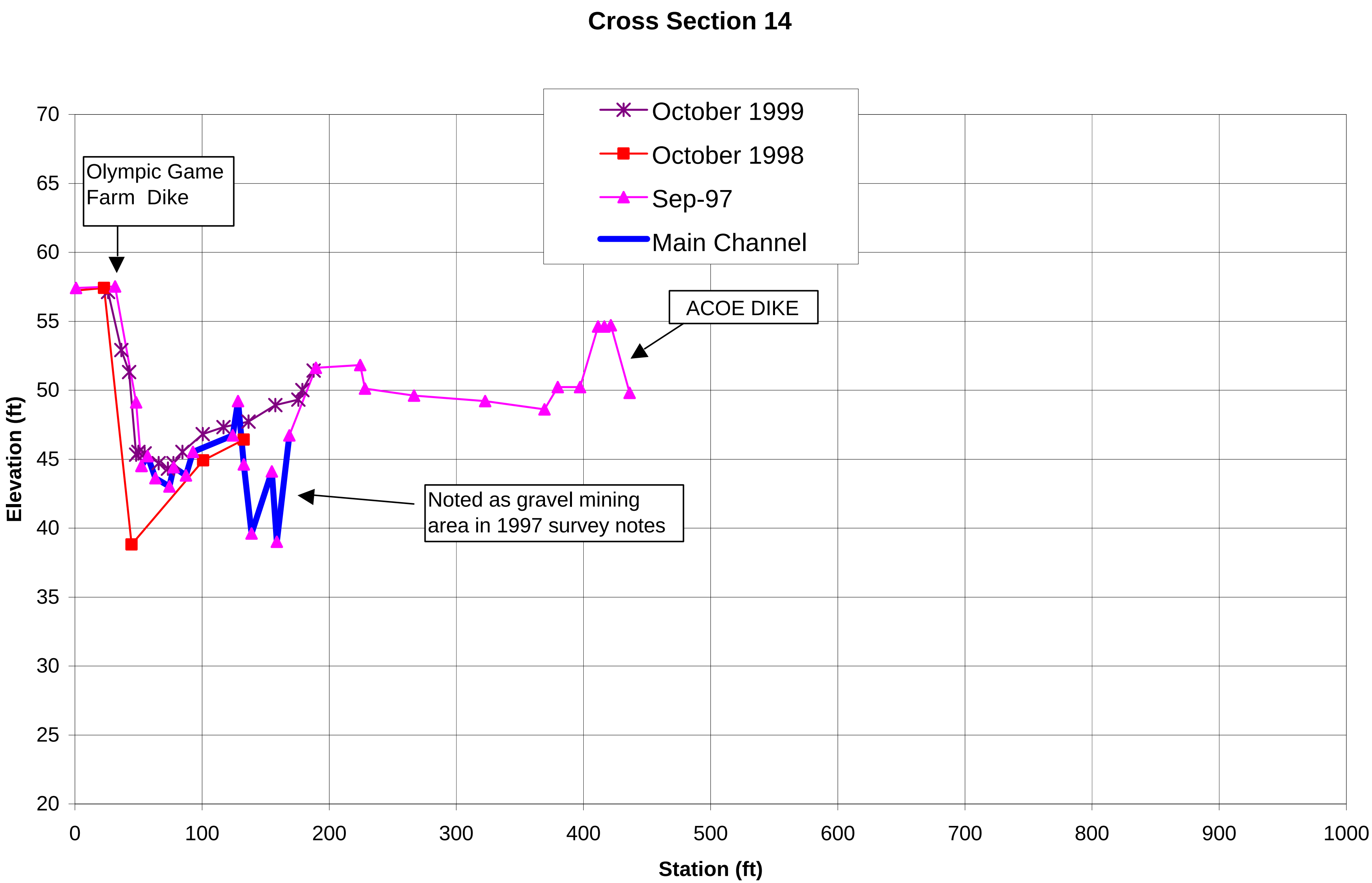


Cross Section 11
October 1999
September 1997
Main Channel
1998 Contour Map Data
Elevation (ft)
70
65
60
55
50
45
40
35
30
25
20
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)

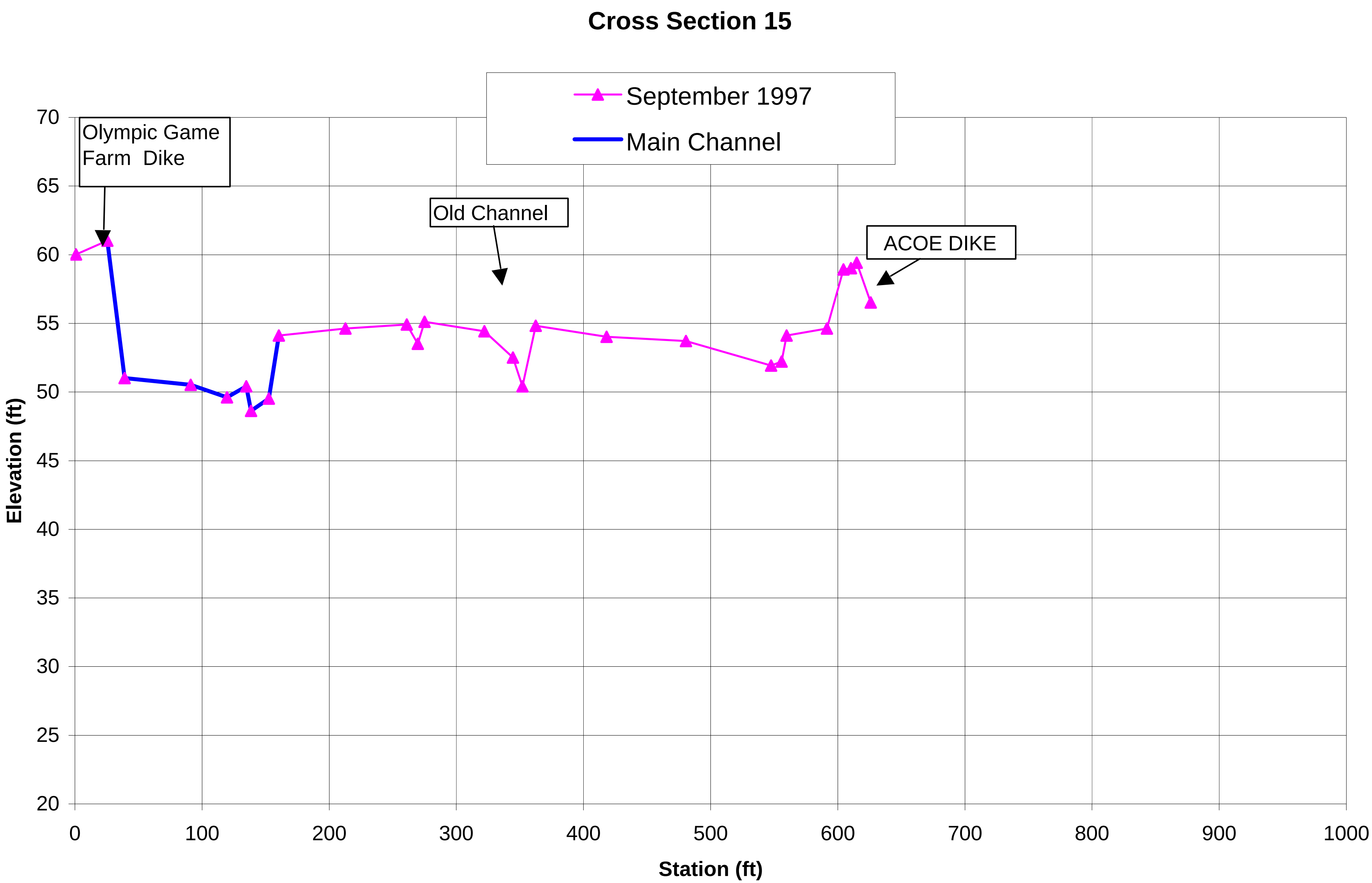


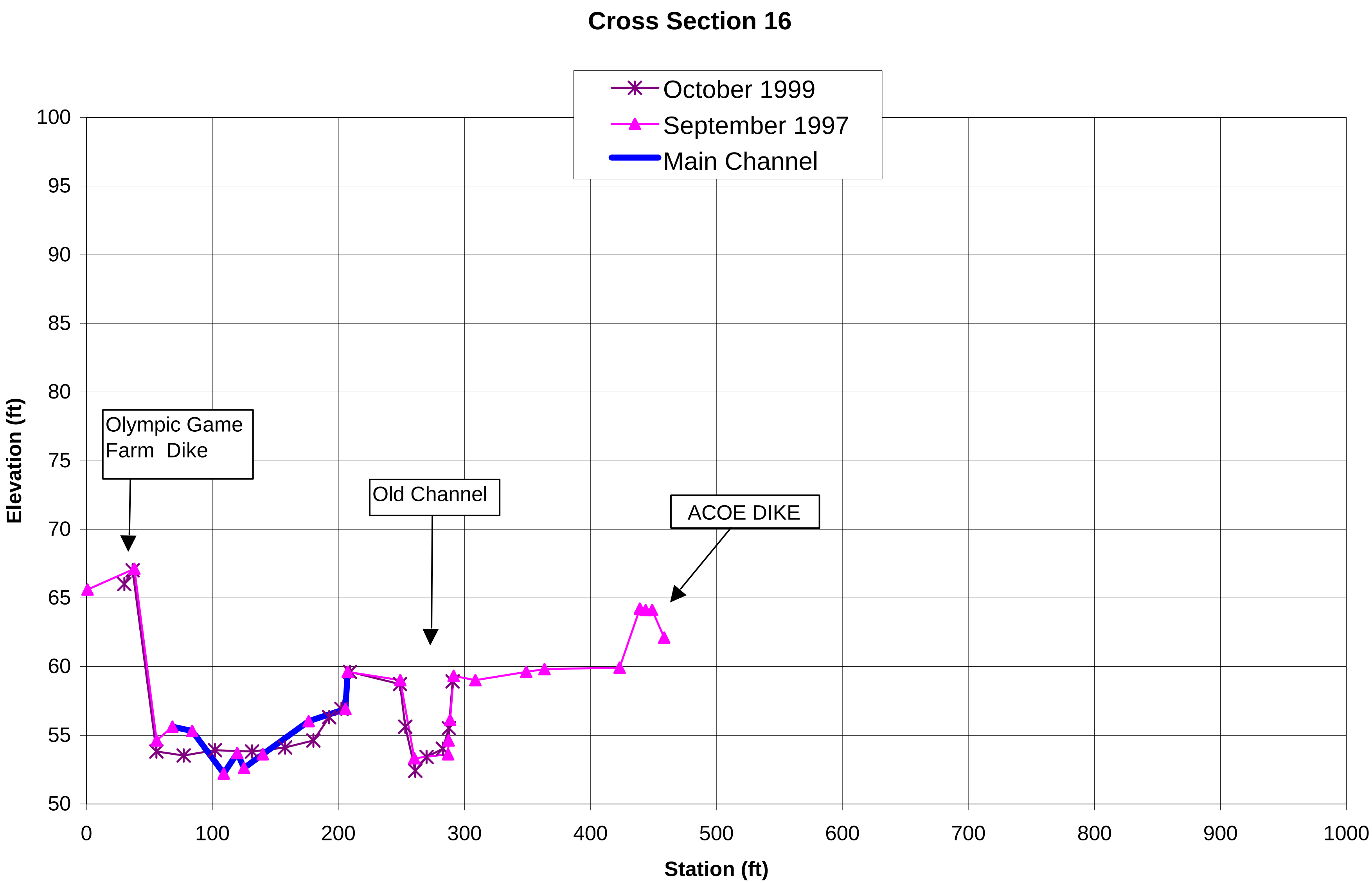
Cross Section 12
October 1999
October 1998
Sep-97
Main Channel
Old Channel
Olympic Game Farm Dike
ACOE DIKE
Elevation (ft)
Station (ft)
70
65
60
55
50
45
40
35
30
25
20
-300
-200
-100
0
100
200
300
400
500
600
700


Cross Section 13
October 1999
September 1997
Main Channel
Olympic Game Farm Dike
ACOE DIKE
Elevation (ft)
Station (ft)
70
65
60
55
50
45
40
35
30
25
20
0
100
200
300
400
500
600
700
800
900
1000

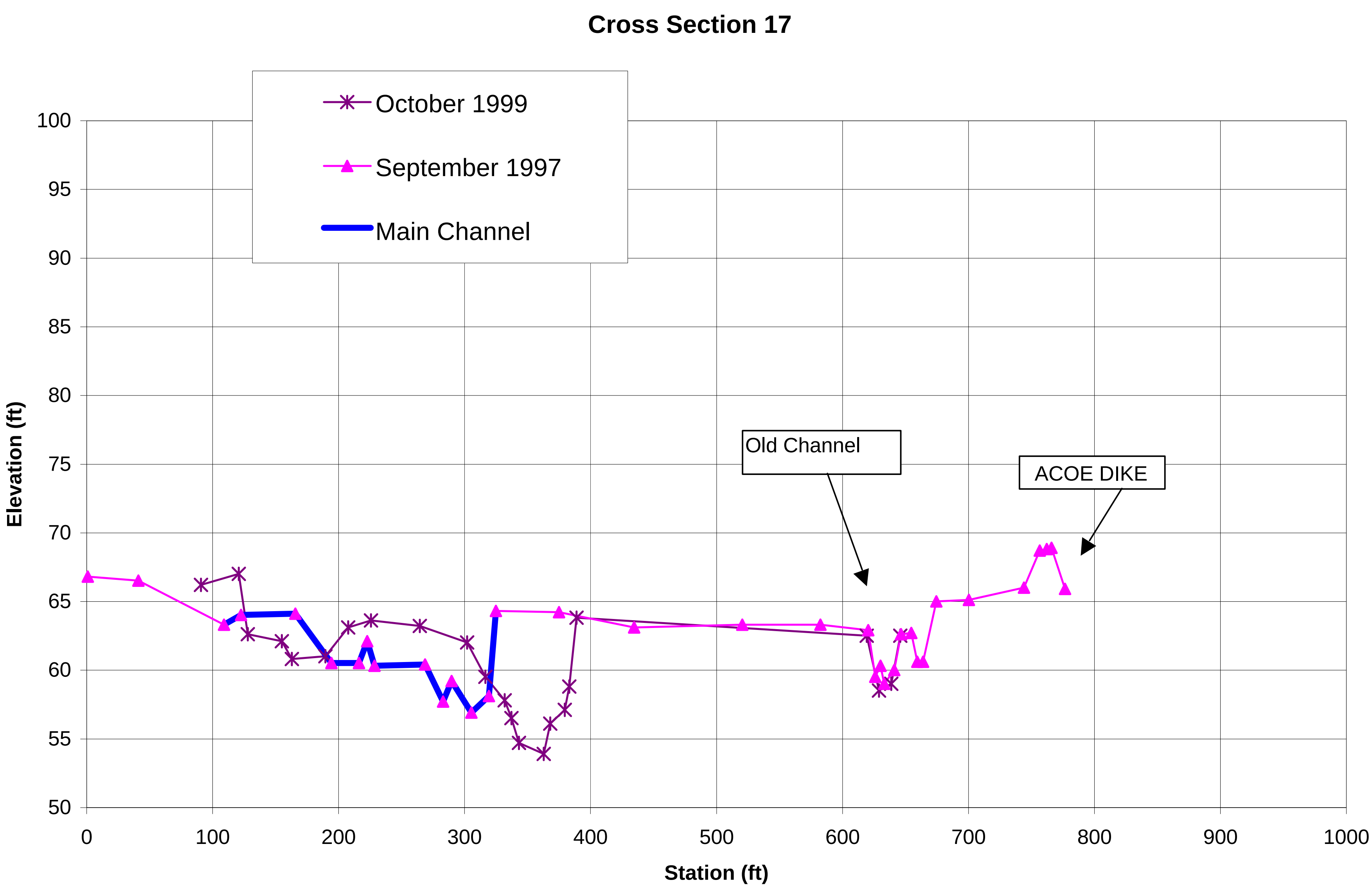


Cross Section 14
October 1999
October 1998
Sep-97
Main Channel
Olympic Game Farm Dike
ACOE DIKE
Noted as gravel mining area in 1997 survey notes
Elevation (ft)
Station (ft)
70
65
60
55
50
45
40
35
30
25
20
0
100
200
300
400
500
600
700
800
900
1000

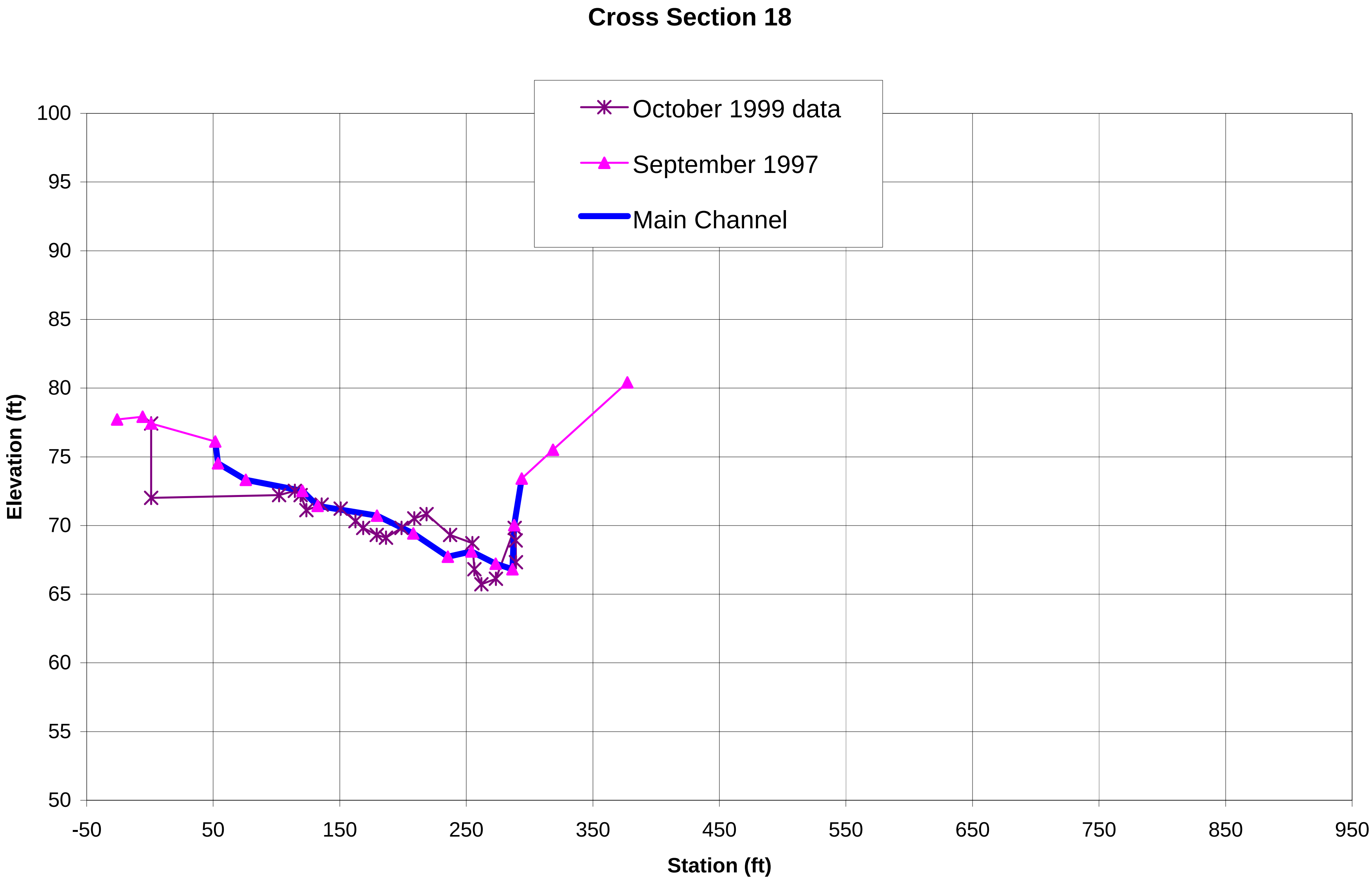

Cross Section 15
September 1997
Main Channel
Olympic Game Farm Dike
Old Channel
ACOE DIKE
Elevation (ft)
Station (ft)
70
65
60
55
50
45
40
35
30
25
20
0
100
200
300
400
500
600
700
800
900
1000

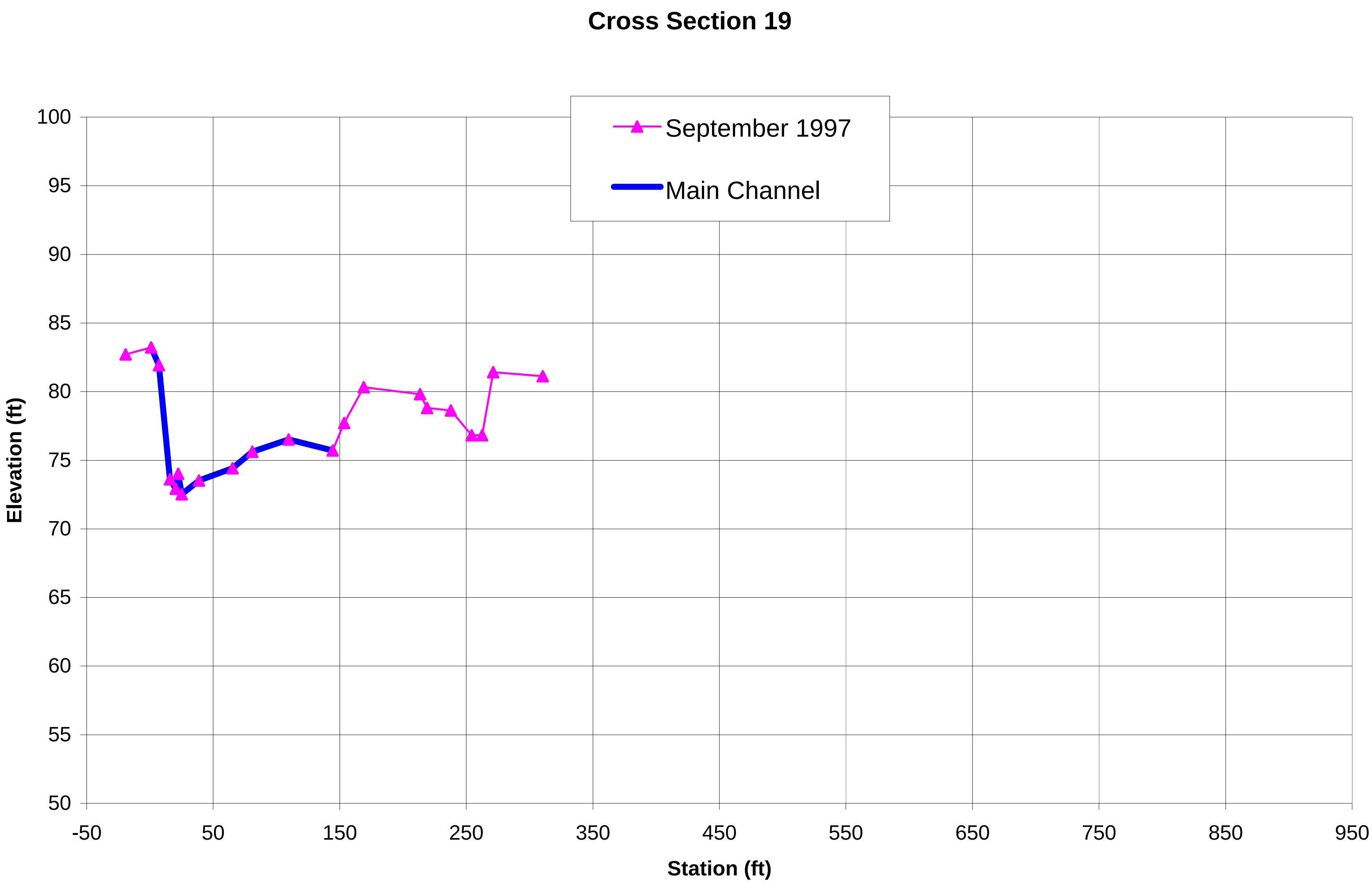


Cross Section 16
October 1999
September 1997
Main Channel
Olympic Game Farm Dike
Old Channel
ACOE DIKE
Elevation (ft)
Station (ft)
100
95
90
85
80
75
70
65
60
55
50
0
100
200
300
400
500
600
700
800
900
1000

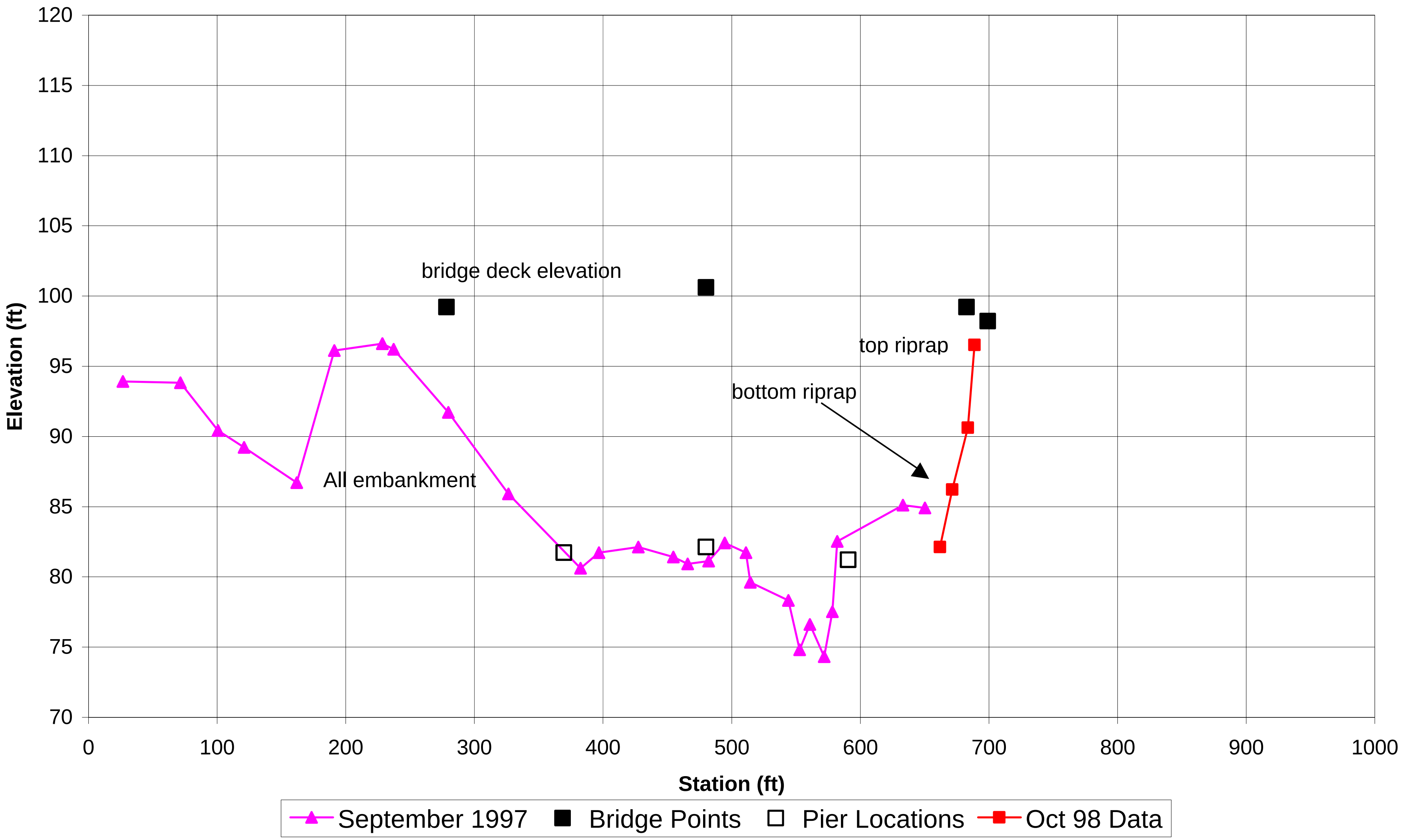


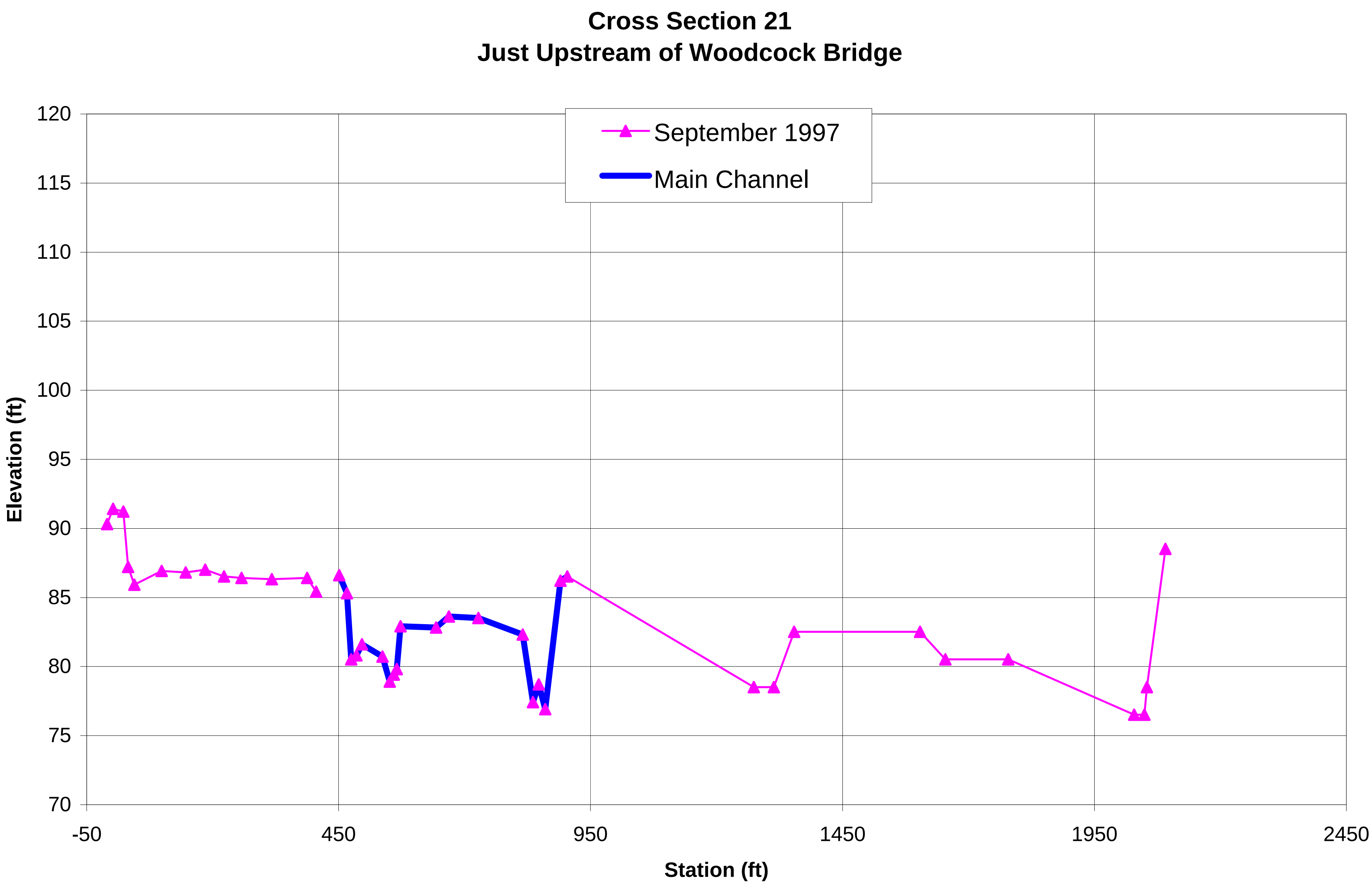
Cross Section 17
October 1999
September 1997
Main Channel
Old Channel
ACOE DIKE
Elevation (ft)
Station (ft)
100
95
90
85
80
75
70
65
60
55
50
0
100
200
300
400
500
600
700
800
900
1000


Cross Section 18
October 1999 data
September 1997
Main Channel
Elevation (ft)
100
95
90
85
80
75
70
65
60
55
50
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)


Cross Section 19
September 1997
Main Channel
100
95
90
85
80
75
70
65
60
55
50
Elevation (ft)
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)

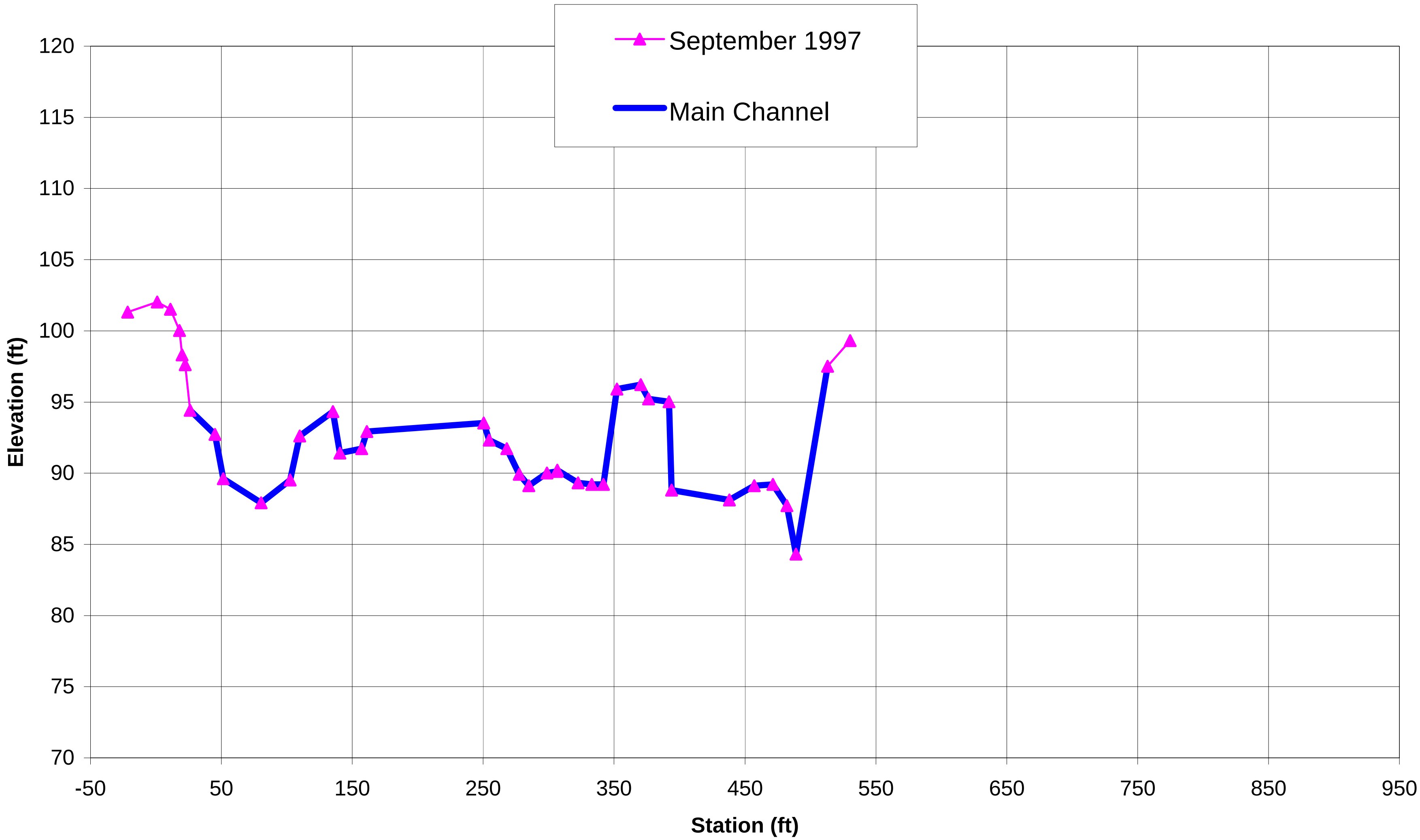
Cross Section 20 - Just Downstream of Woodcock Bridge

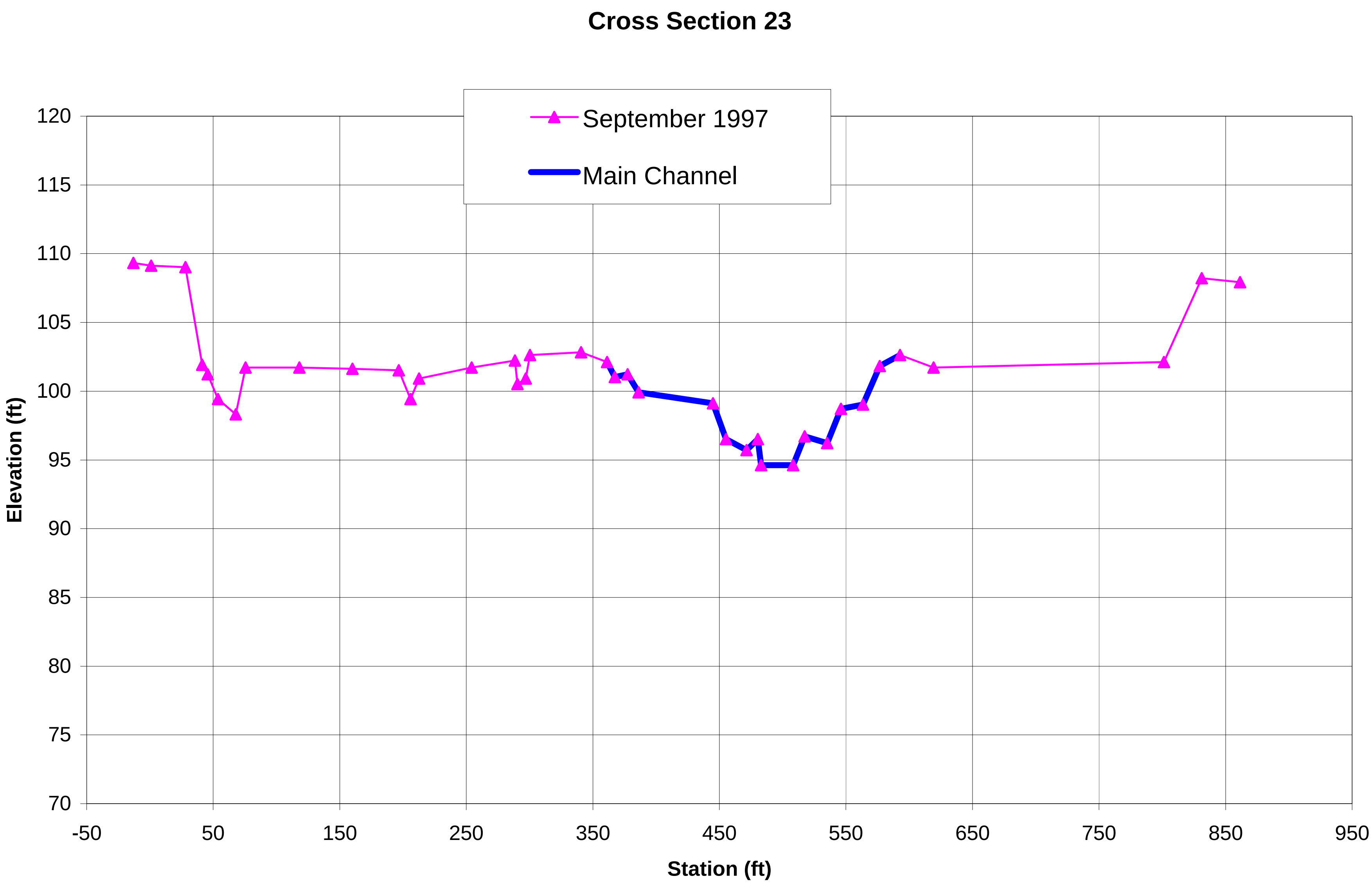


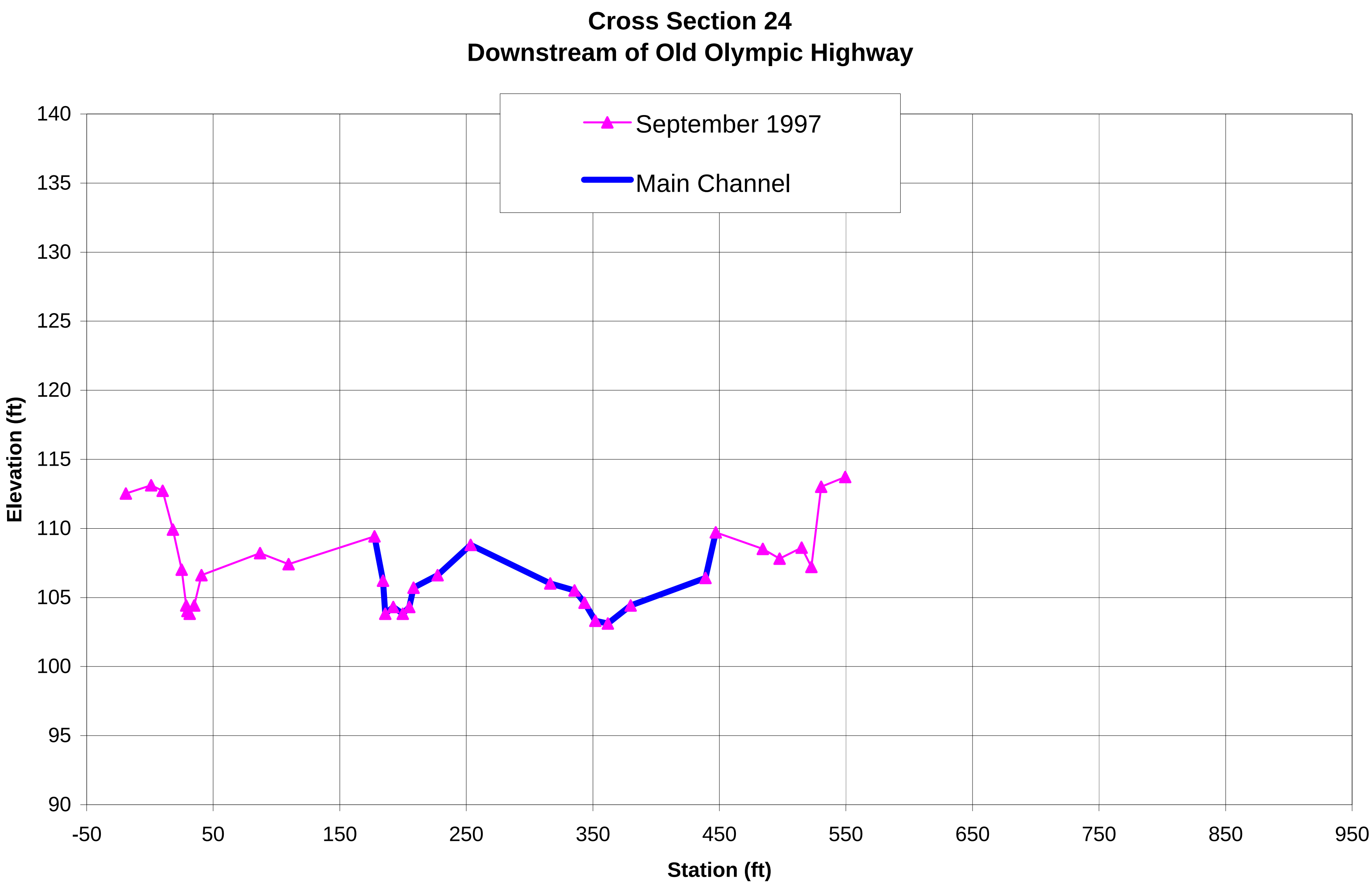


Cross Section 21
Just Upstream of Woodcock Bridge
September 1997
Main Channel
Elevation (ft)
Station (ft)
120
115
110
105
100
95
90
85
80
75
70
-50
450
950
1450
1950
2450

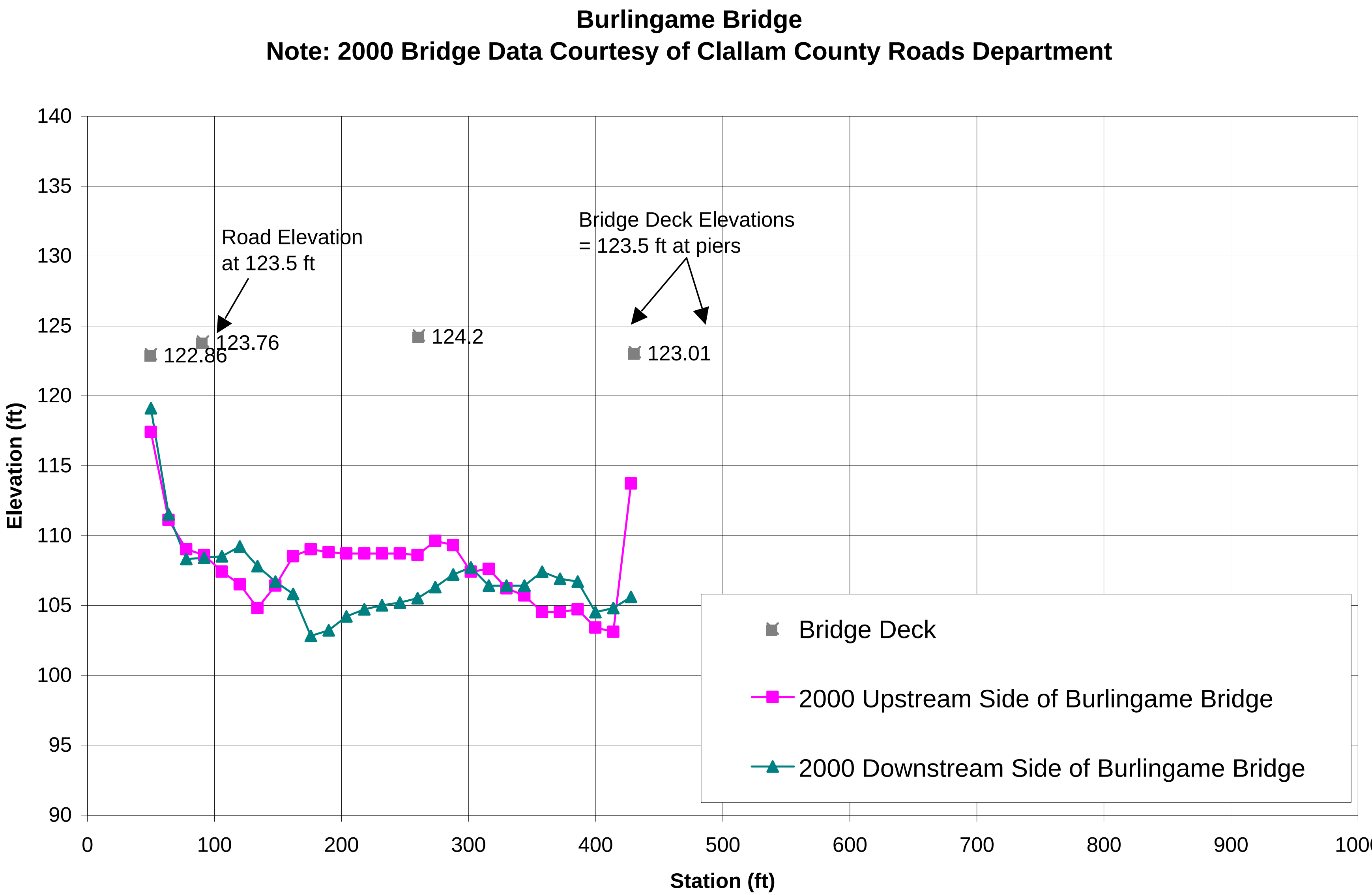
Cross Section 22




Cross Section 23
September 1997
Main Channel
Elevation (ft)
Station (ft)
120
115
110
105
100
95
90
85
80
75
70
-50
50
150
250
350
450
550
650
750
850
950

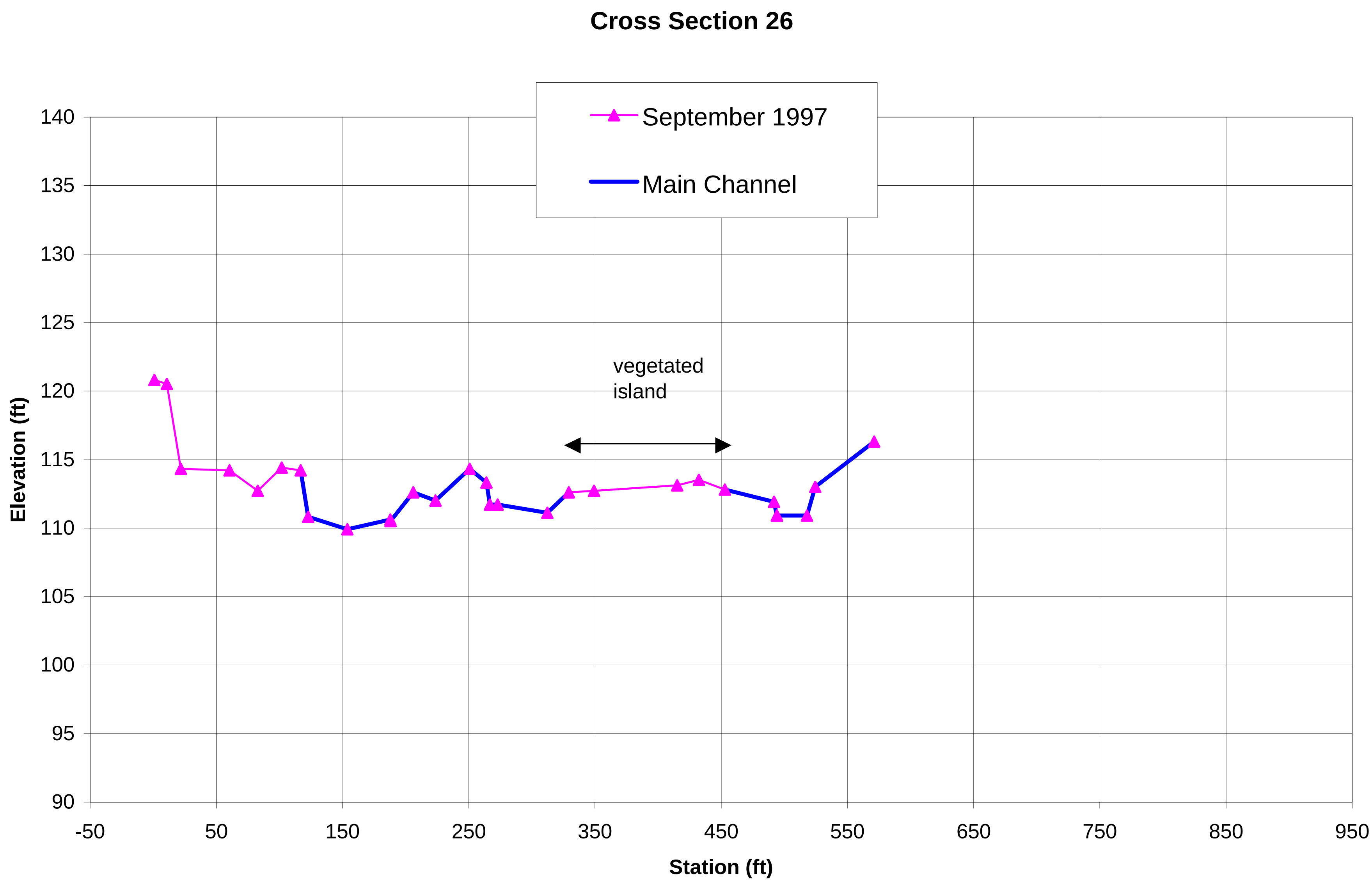


Cross Section 24
Downstream of Old Olympic Highway
September 1997
Main Channel
Elevation (ft)
140
135
130
125
120
115
110
105
100
95
90
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)

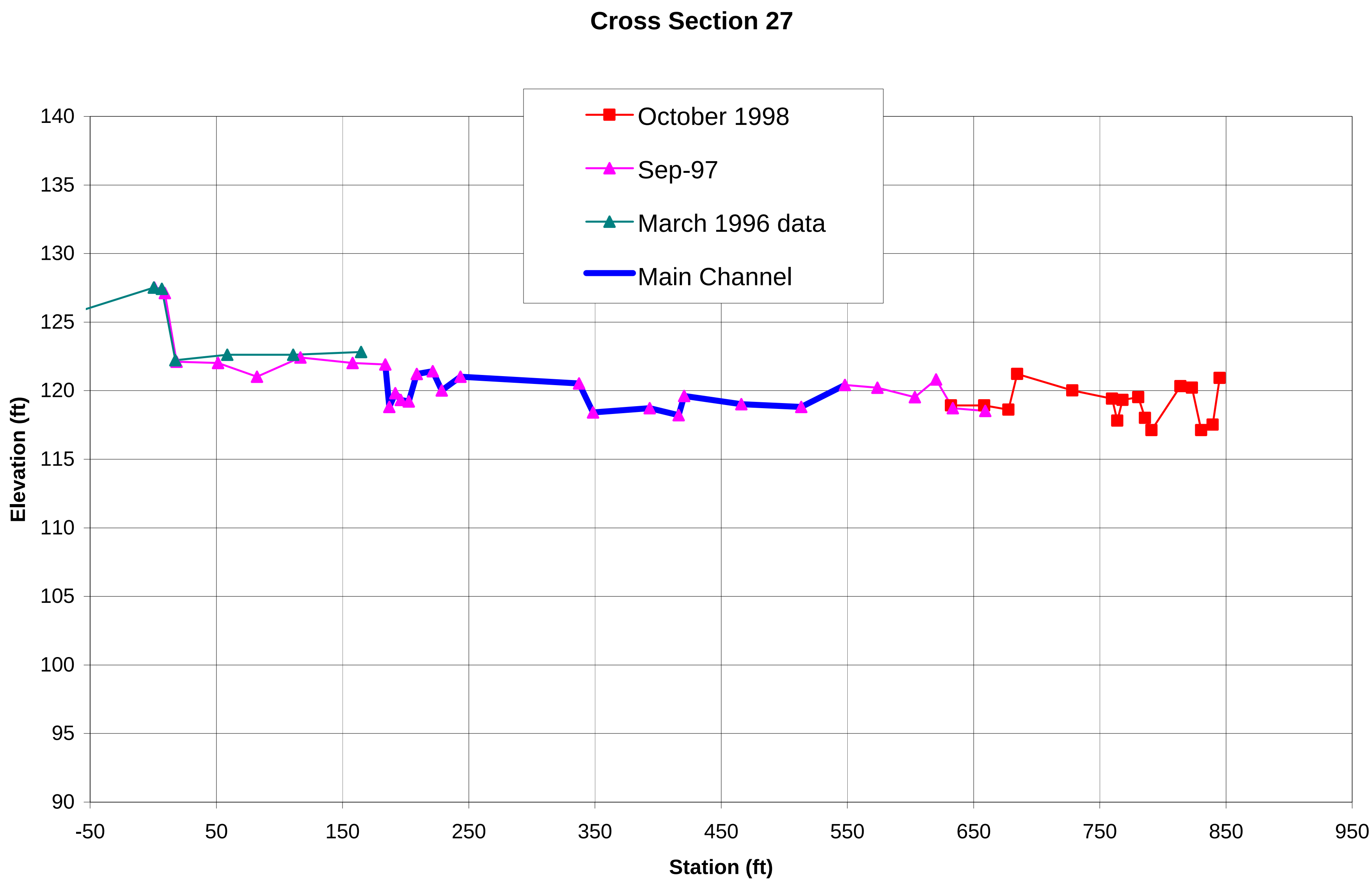


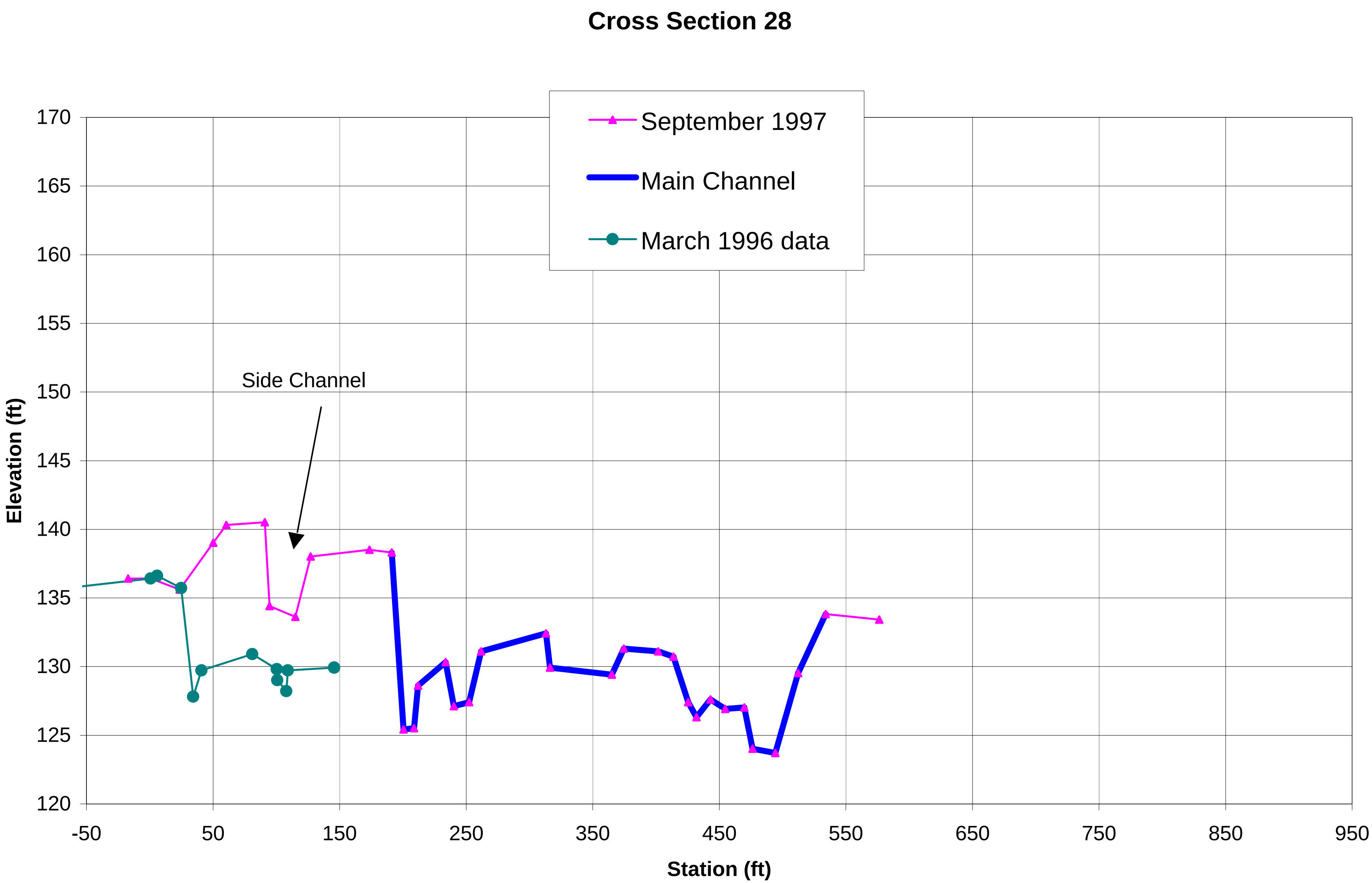
Burlingame Bridge
Note: 2000 Bridge Data Courtesy of Clallam County Roads Department
140
135
130
125
120
115
110
105
100
95
90
Elevation (ft)
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)
Road Elevation
at 123.5 ft
Bridge Deck Elevations
= 123.5 ft at piers
122.86
123.76
124.2
123.01
Bridge Deck
2000 Upstream Side of Burlingame Bridge
2000 Downstream Side of Burlingame Bridge

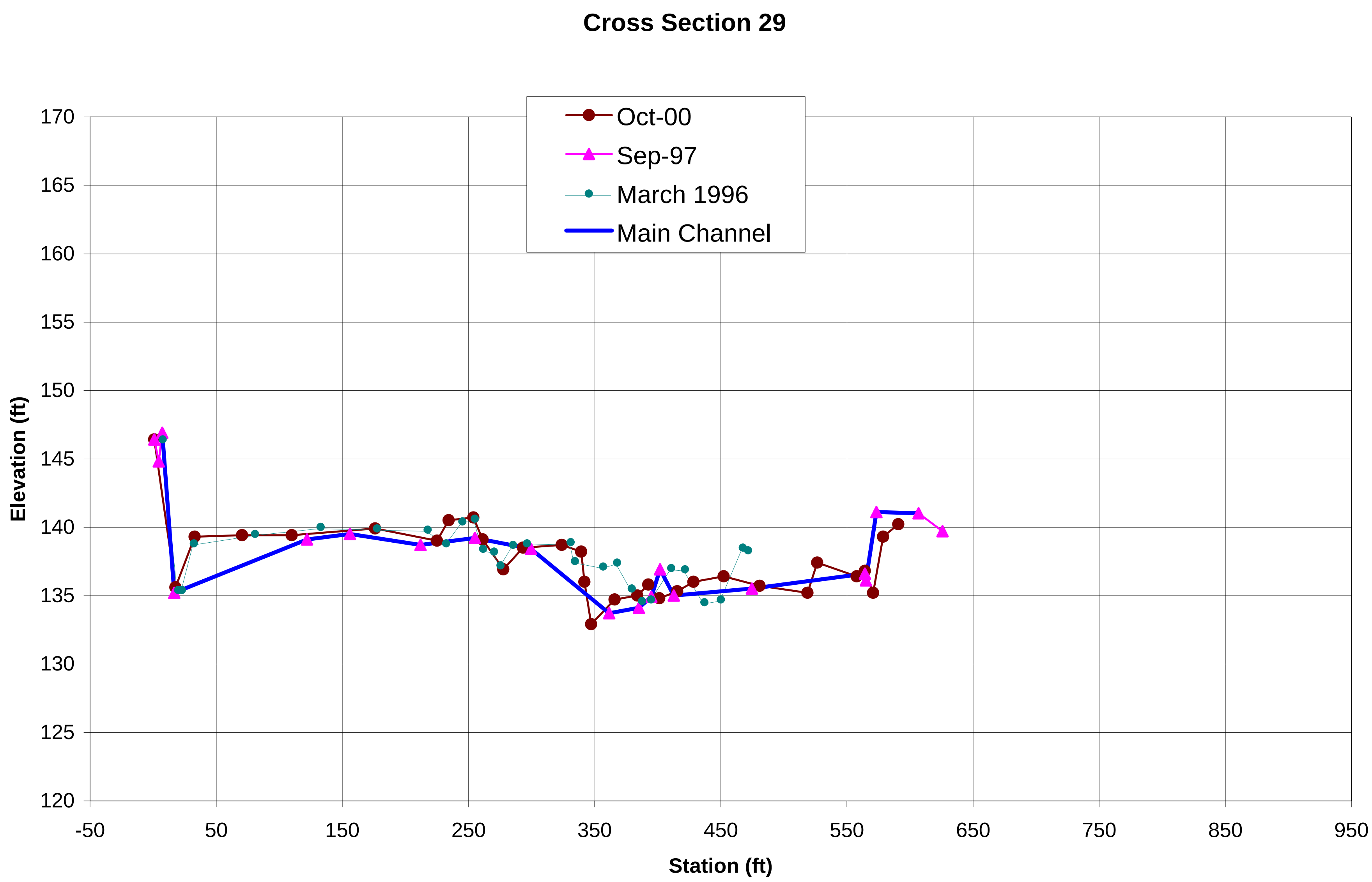
Cross Section 25
Just Upstream of Old Olympic Highway

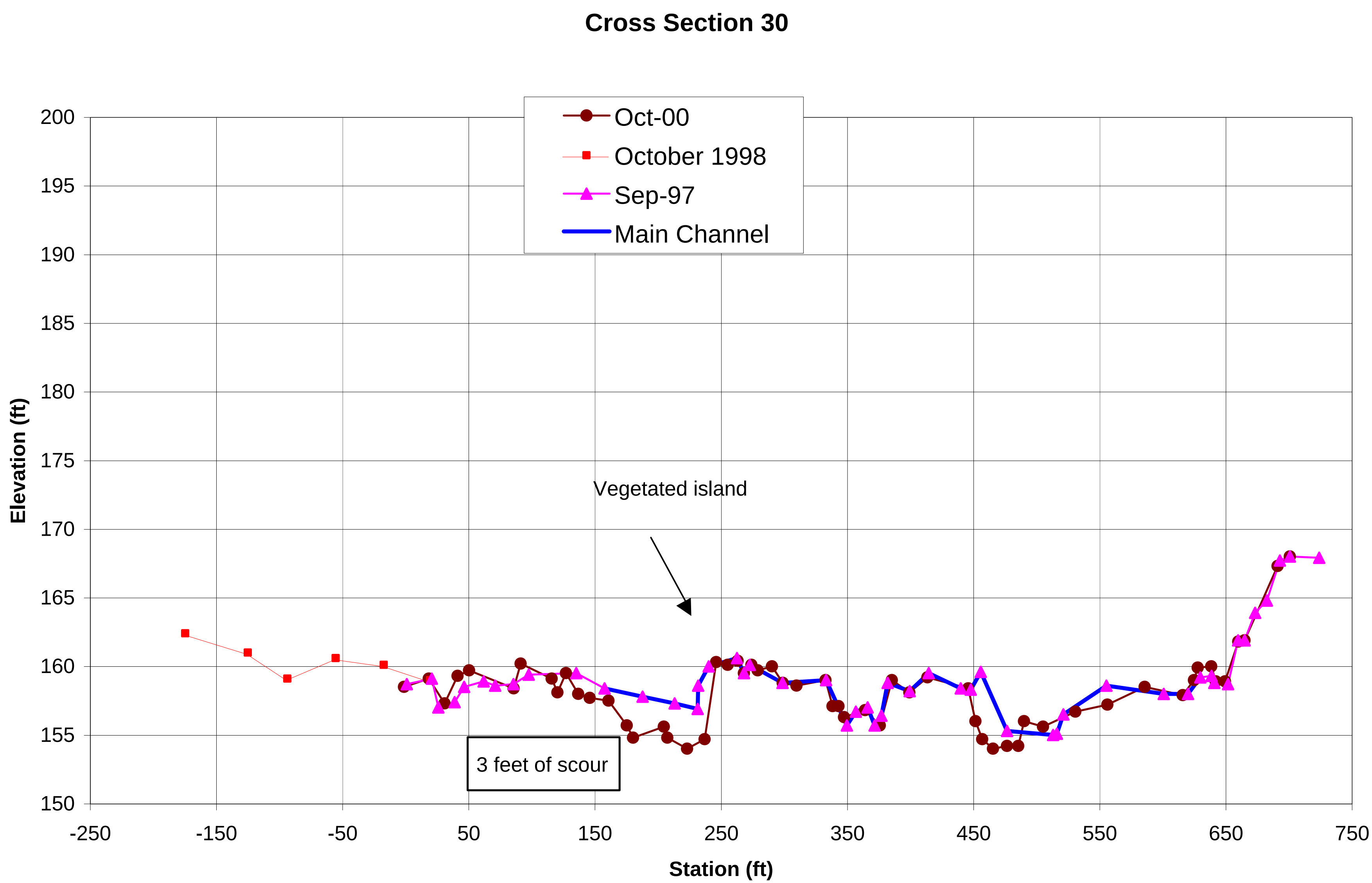


Cross Section 26
September 1997
Main Channel
vegetated
island
Elevation (ft)
Station (ft)
140
135
130
125
120
115
110
105
100
95
90
-50
50
150
250
350
450
550
650
750
850
950

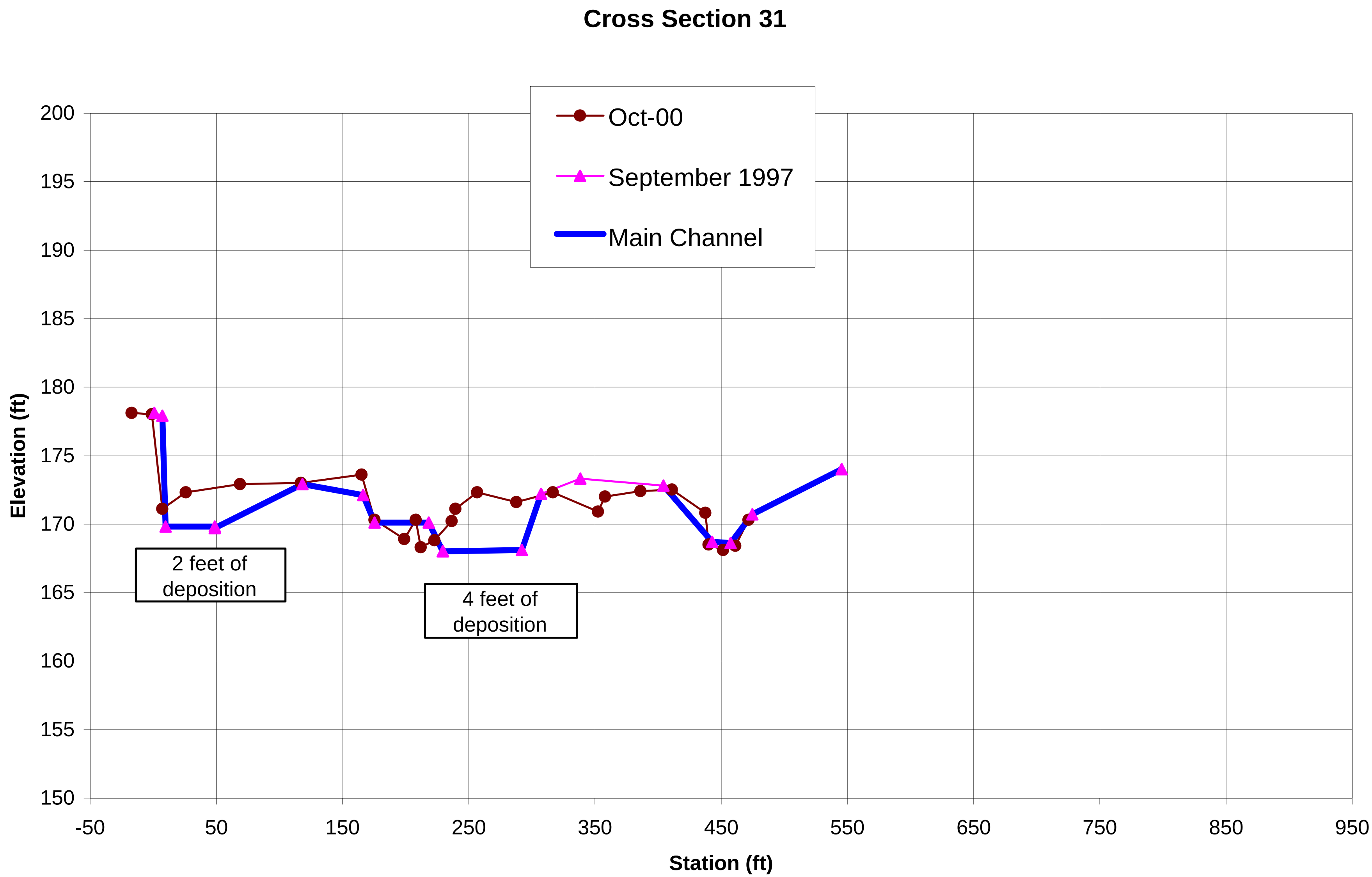

Cross Section 27
October 1998
Sep-97
March 1996 data
Main Channel
Elevation (ft)
Station (ft)
140
135
130
125
120
115
110
105
100
95
90
-50
50
150
250
350
450
550
650
750
850
950


Cross Section 28
September 1997
Main Channel
March 1996 data
Side Channel
Elevation (ft)
Station (ft)
170
165
160
155
150
145
140
135
130
125
120
-50
50
150
250
350
450
550
650
750
850
950

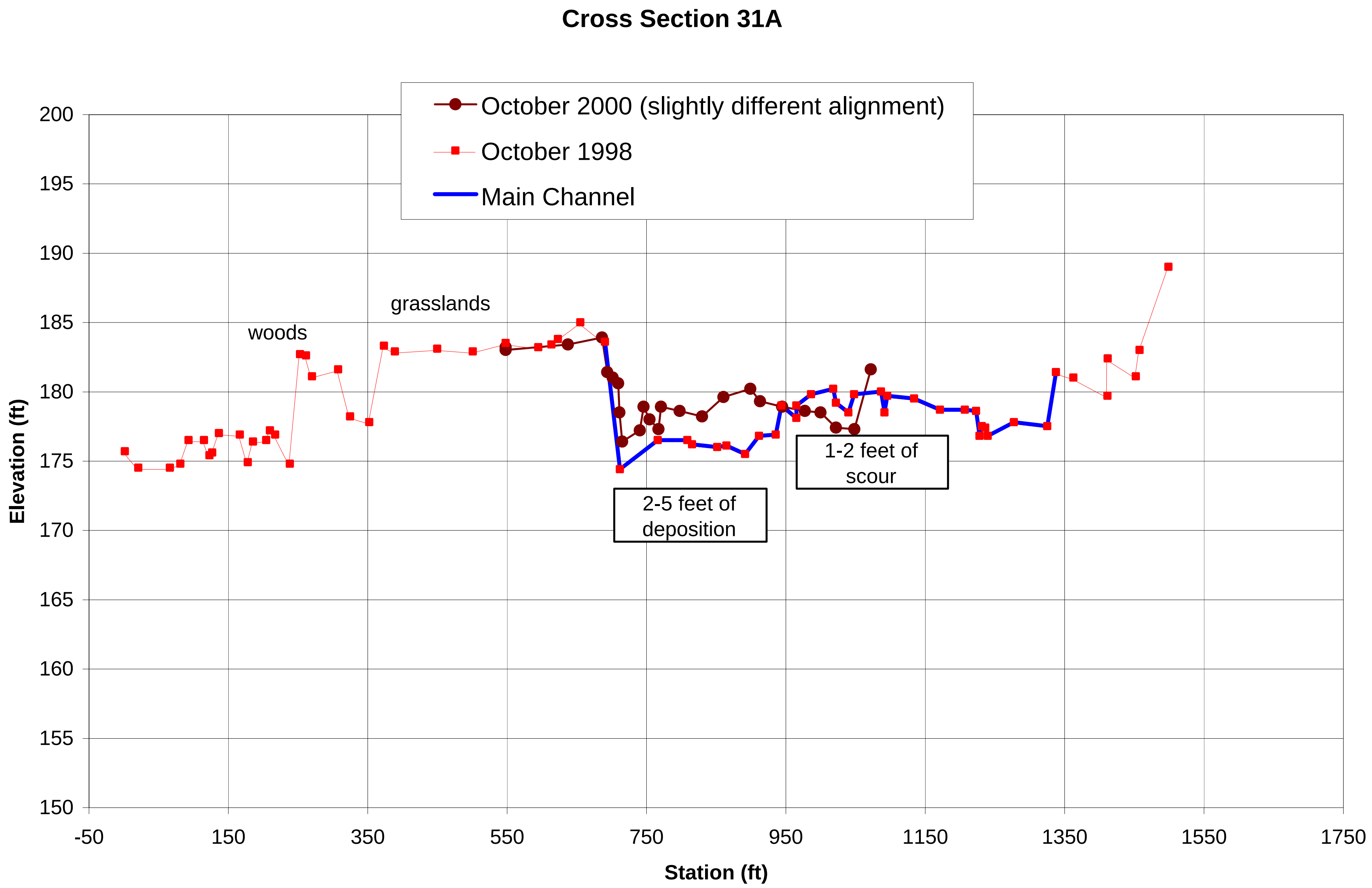

Cross Section 29
Oct-00
Sep-97
March 1996
Main Channel
Elevation (ft)
170
165
160
155
150
145
140
135
130
125
120
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)

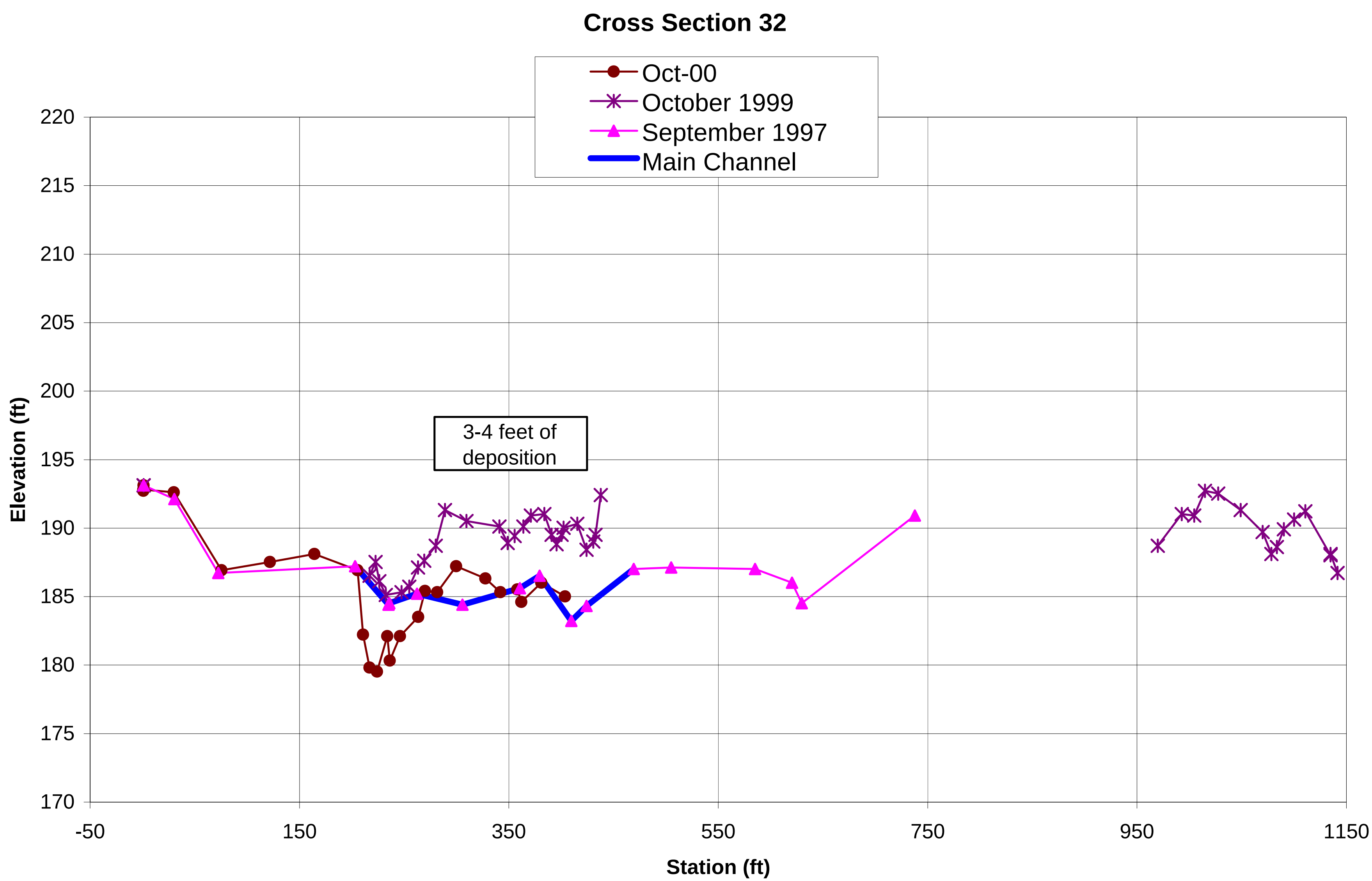


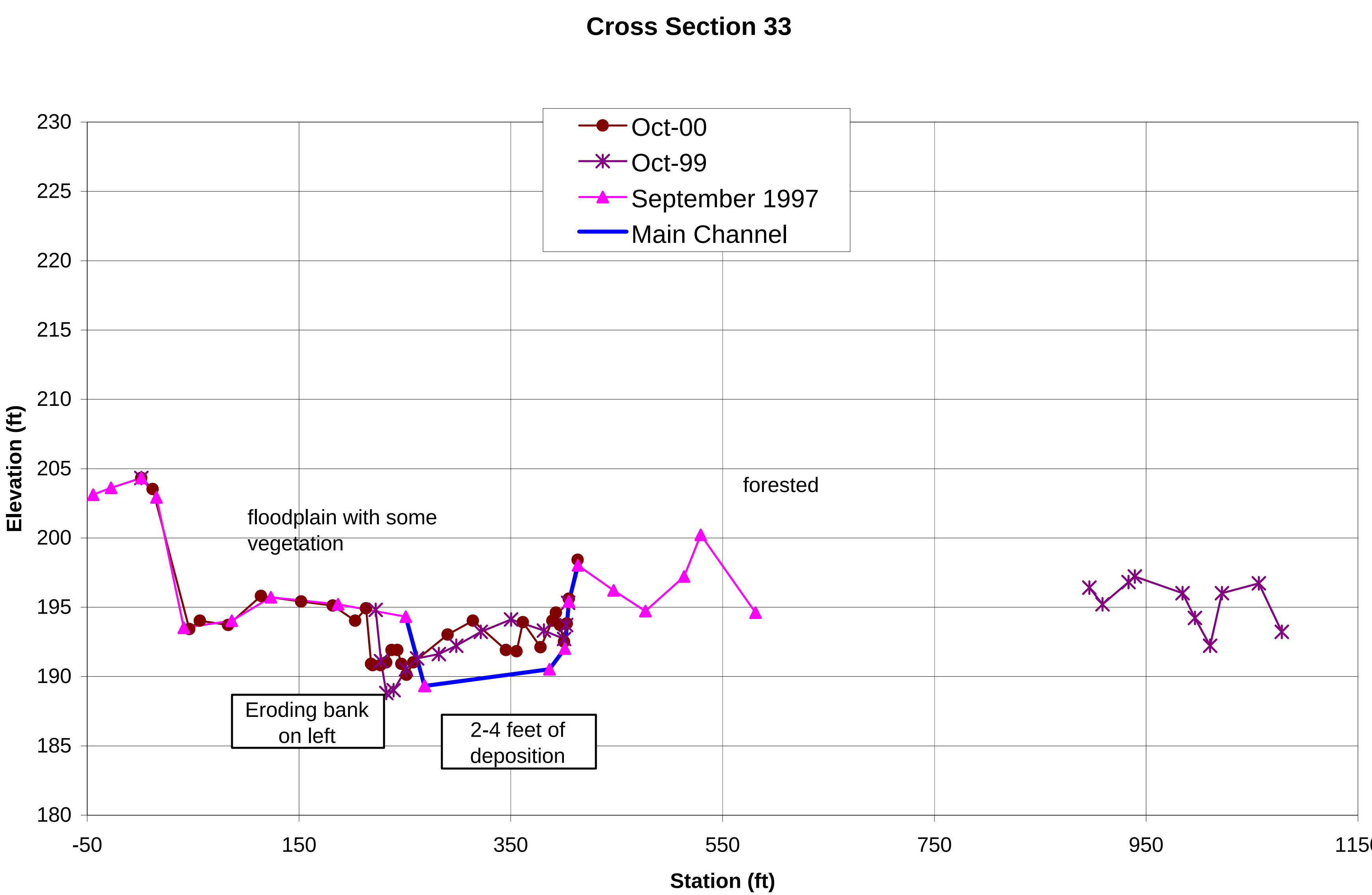
Cross Section 30
Oct-00
October 1998
Sep-97
Main Channel
Vegetated island
3 feet of scour
Elevation (ft)
Station (ft)
200
195
190
185
180
175
170
165
160
155
150
-250
-150
-50
50
150
250
350
450
550
650
750



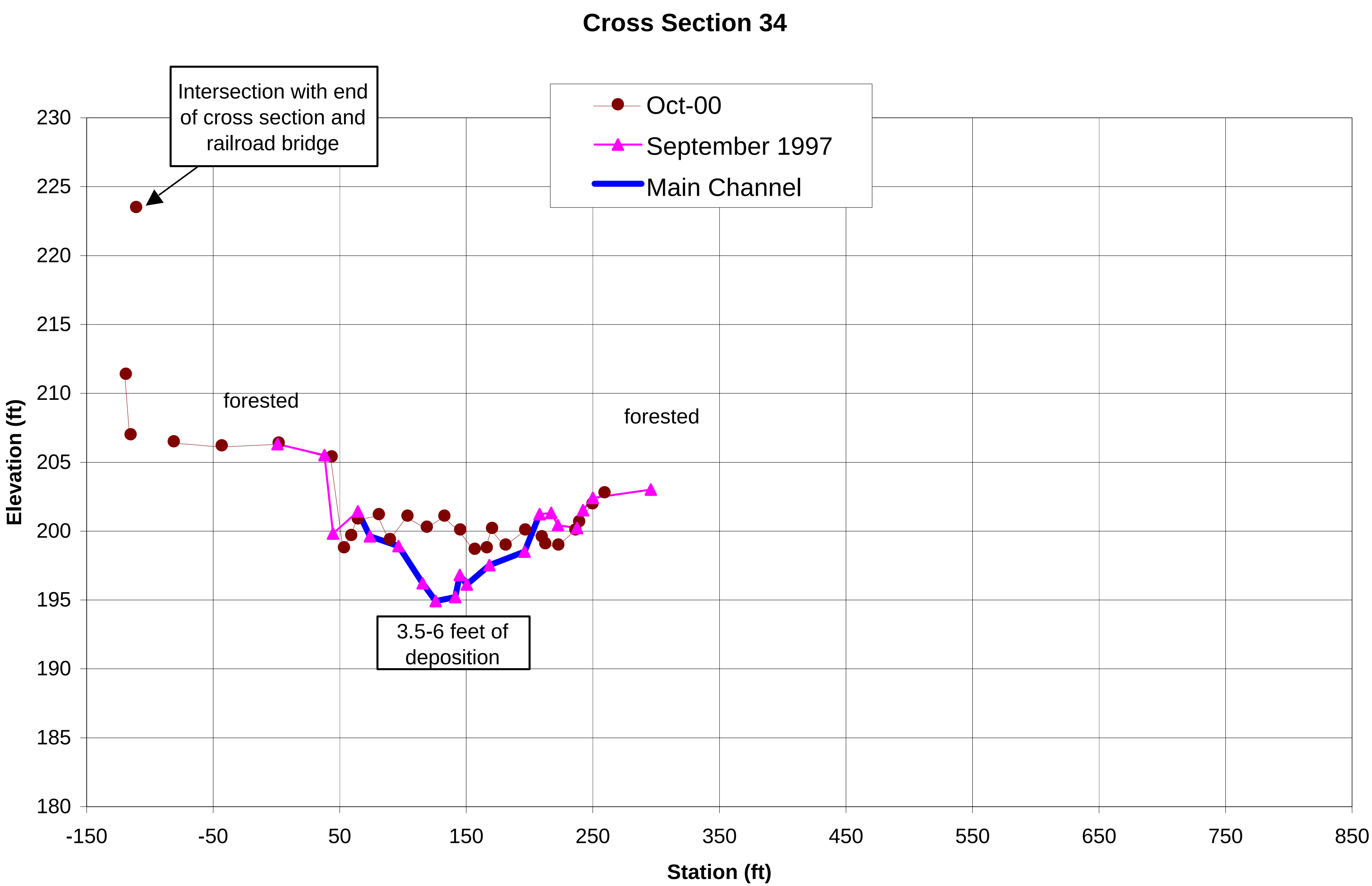
Cross Section 31
Oct-00
September 1997
Main Channel
200
195
190
185
180
175
170
165
160
155
150
Elevation (ft)
2 feet of deposition
4 feet of deposition
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)


Cross Section 31A
October 2000 (slightly different alignment)
October 1998
Main Channel
woods
grasslands
2-5 feet of deposition
1-2 feet of scour
Elevation (ft)
Station (ft)
200
195
190
185
180
175
170
165
160
155
150
-50
150
350
550
750
950
1150
1350
1550
1750

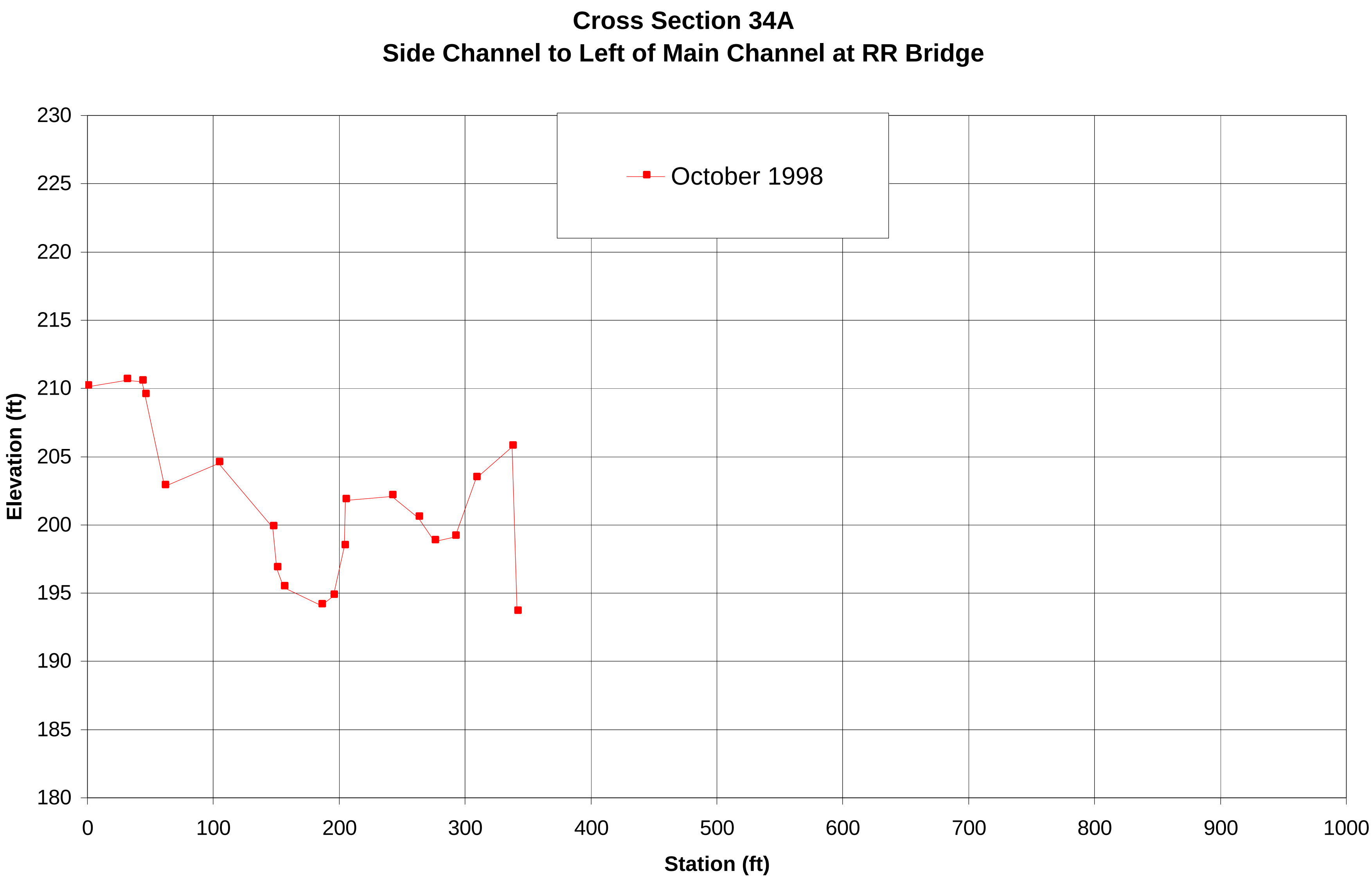

Cross Section 32
Oct-00
October 1999
September 1997
Main Channel
3-4 feet of deposition
Elevation (ft)
220
215
210
205
200
195
190
185
180
175
170
-50
150
350
550
750
950
1150
Station (ft)



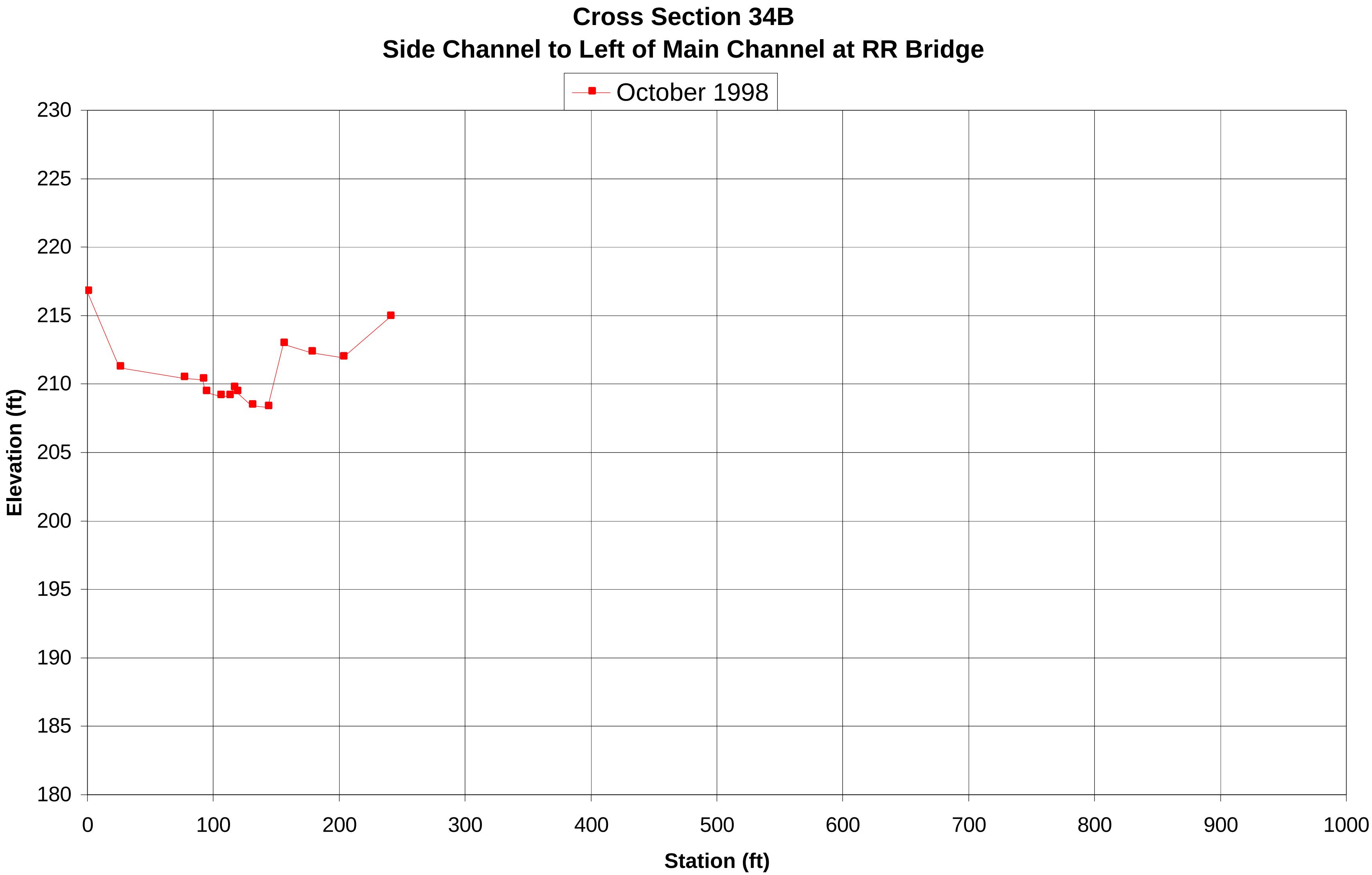
Cross Section 33
Oct-00
Oct-99
September 1997
Main Channel
floodplain with some vegetation
forested
Eroding bank on left
2-4 feet of deposition
Elevation (ft)
Station (ft)
230
225
220
215
210
205
200
195
190
185
180
-50
150
350
550
750
950
1150

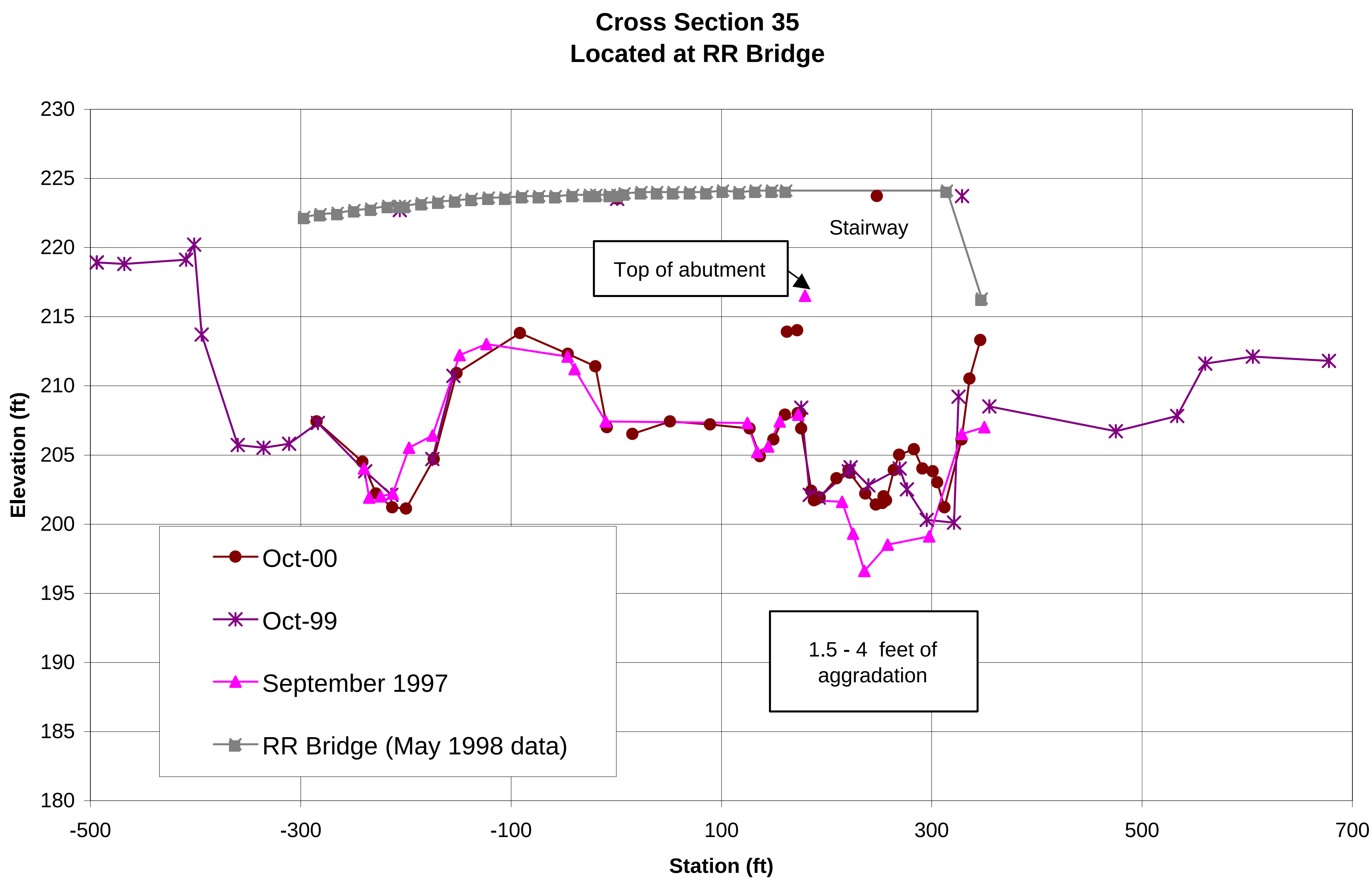


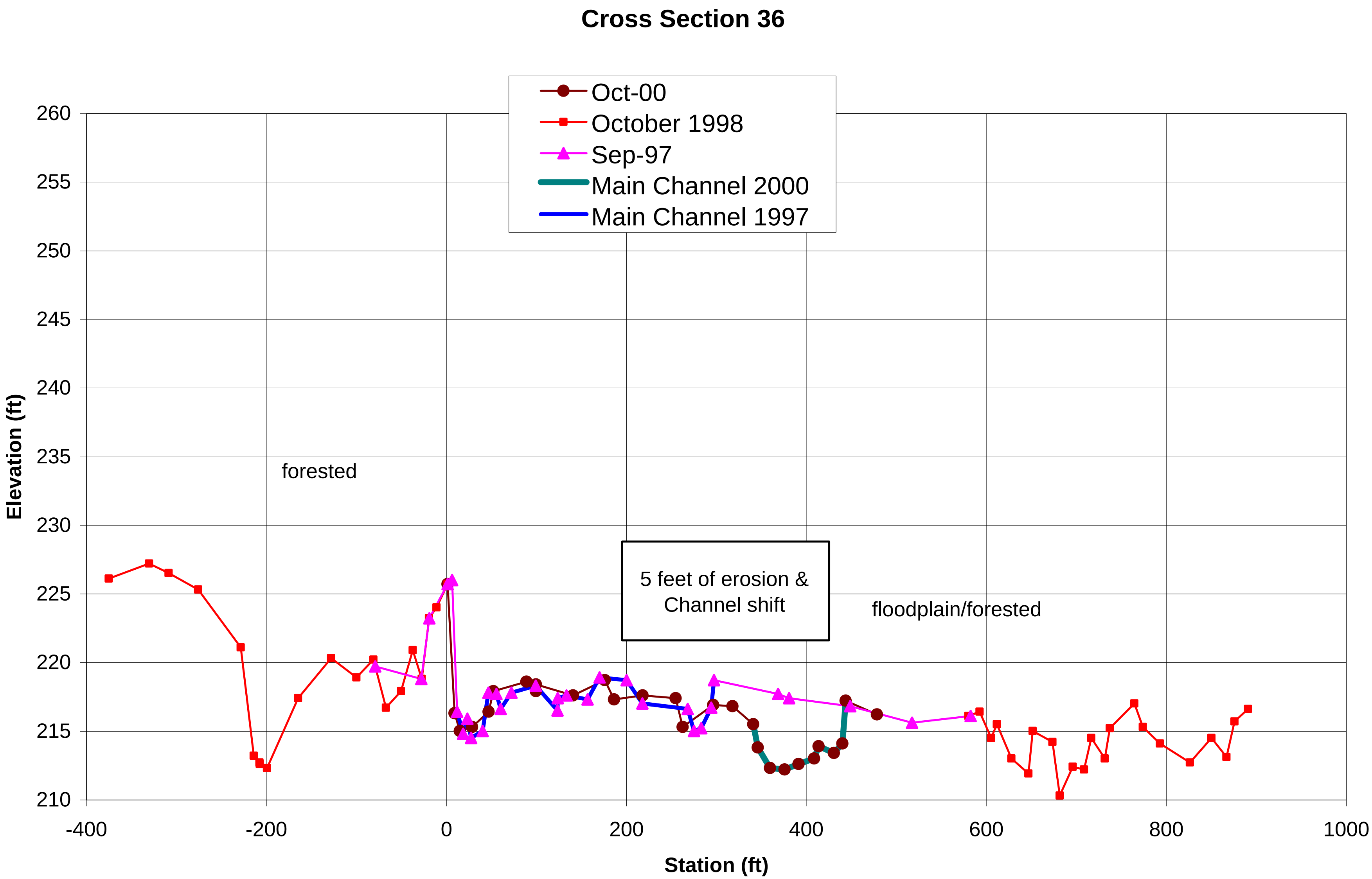
Cross Section 34
Intersection with end of cross section and railroad bridge
Oct-00
September 1997
Main Channel
230
225
220
215
210
205
200
195
190
185
180
forested
forested
3.5-6 feet of deposition
Elevation (ft)
-150
-50
50
150
250
350
450
550
650
750
850
Station (ft)



Cross Section 34A
Side Channel to Left of Main Channel at RR Bridge
Elevation (ft)
230
225
220
215
210
205
200
195
190
185
180
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)
October 1998

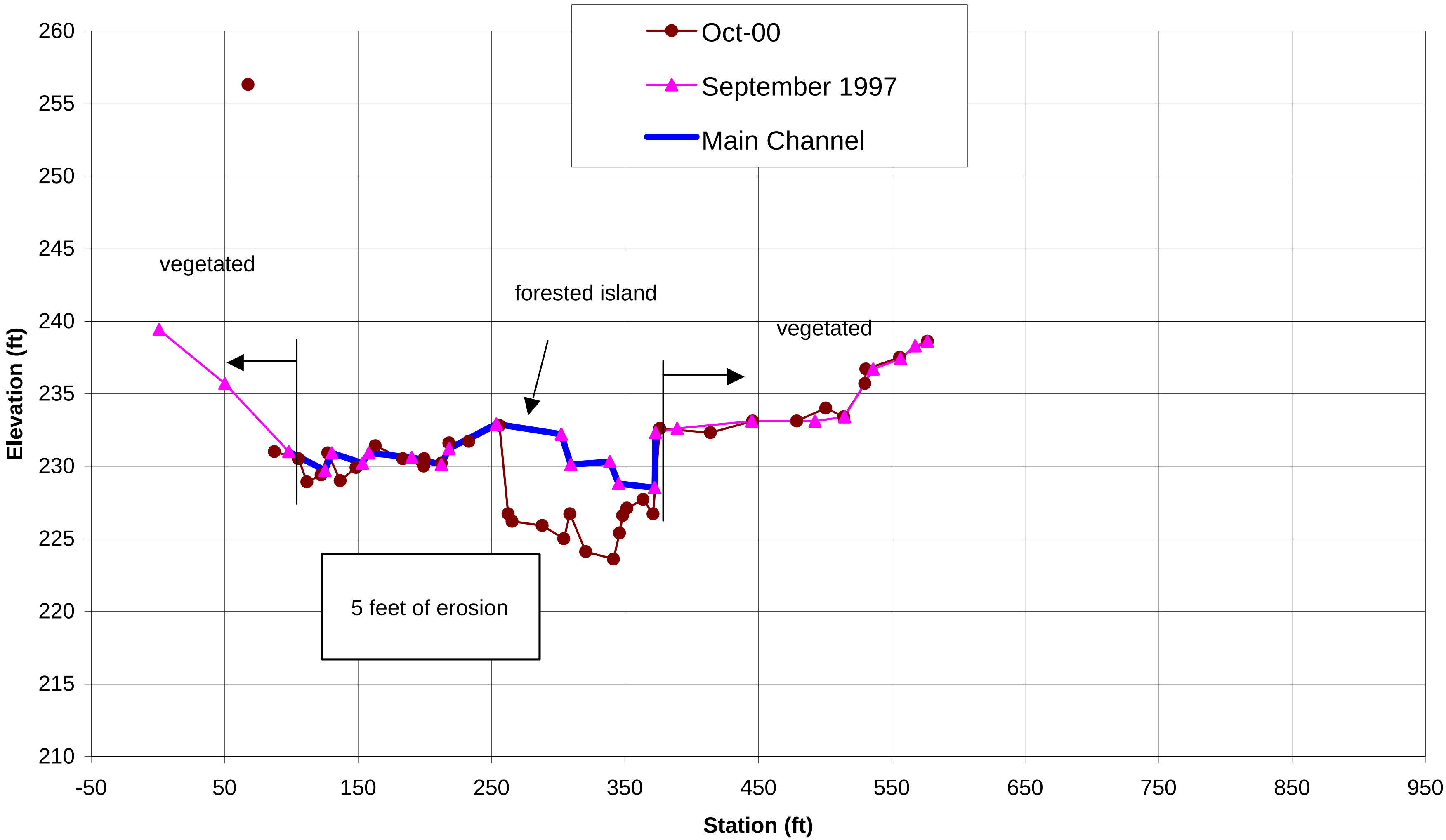

Cross Section 34B
Side Channel to Left of Main Channel at RR Bridge
October 1998
Elevation (ft)
230
225
220
215
210
205
200
195
190
185
180
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)

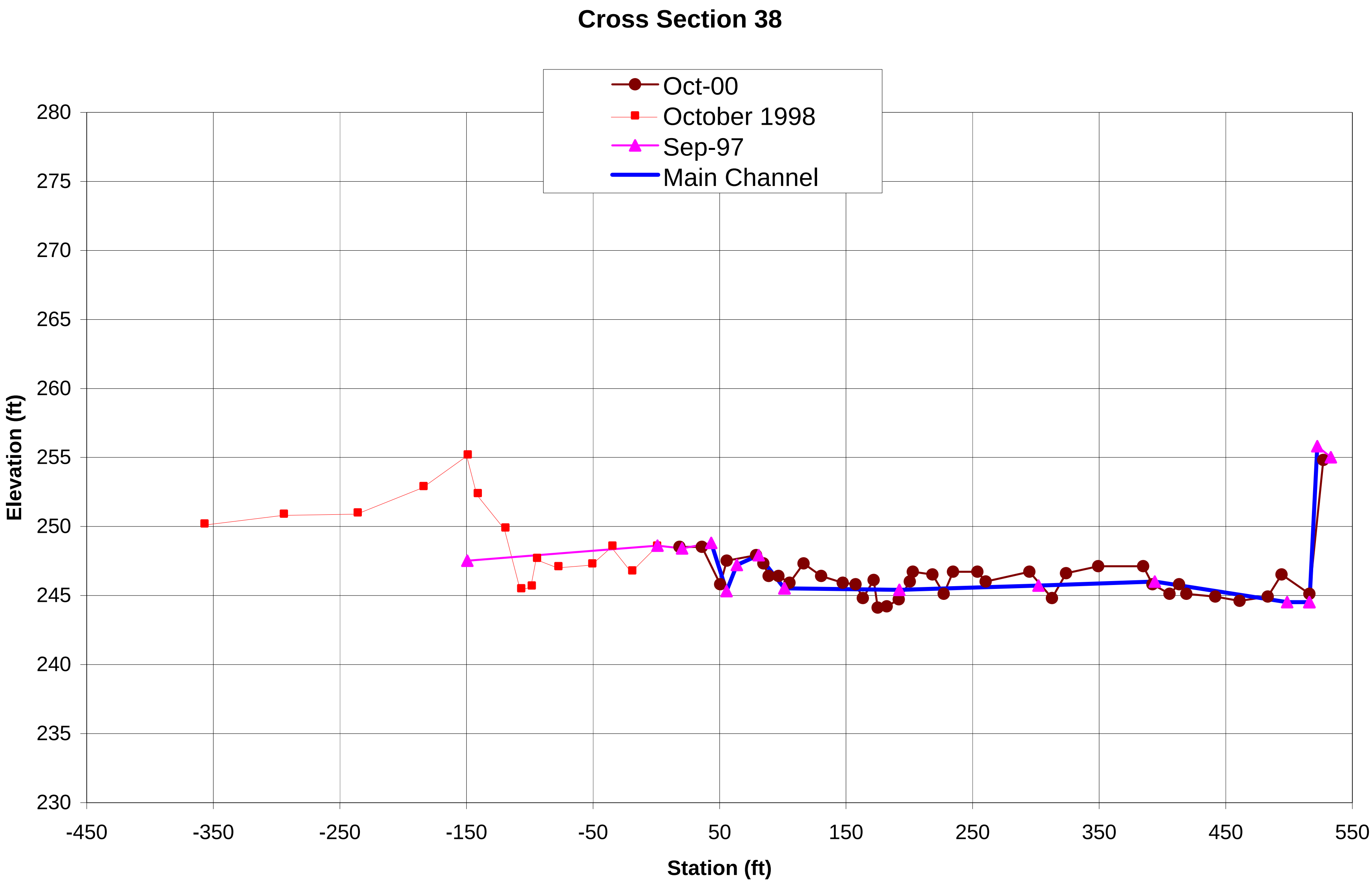

Cross Section 35
Located at RR Bridge
Elevation (ft)
Station (ft)
230
225
220
215
210
205
200
195
190
185
180
-500
-300
-100
100
300
500
700
Stairway
Top of abutment
1.5 - 4 feet of aggradation
Oct-00
Oct-99
September 1997
RR Bridge (May 1998 data)



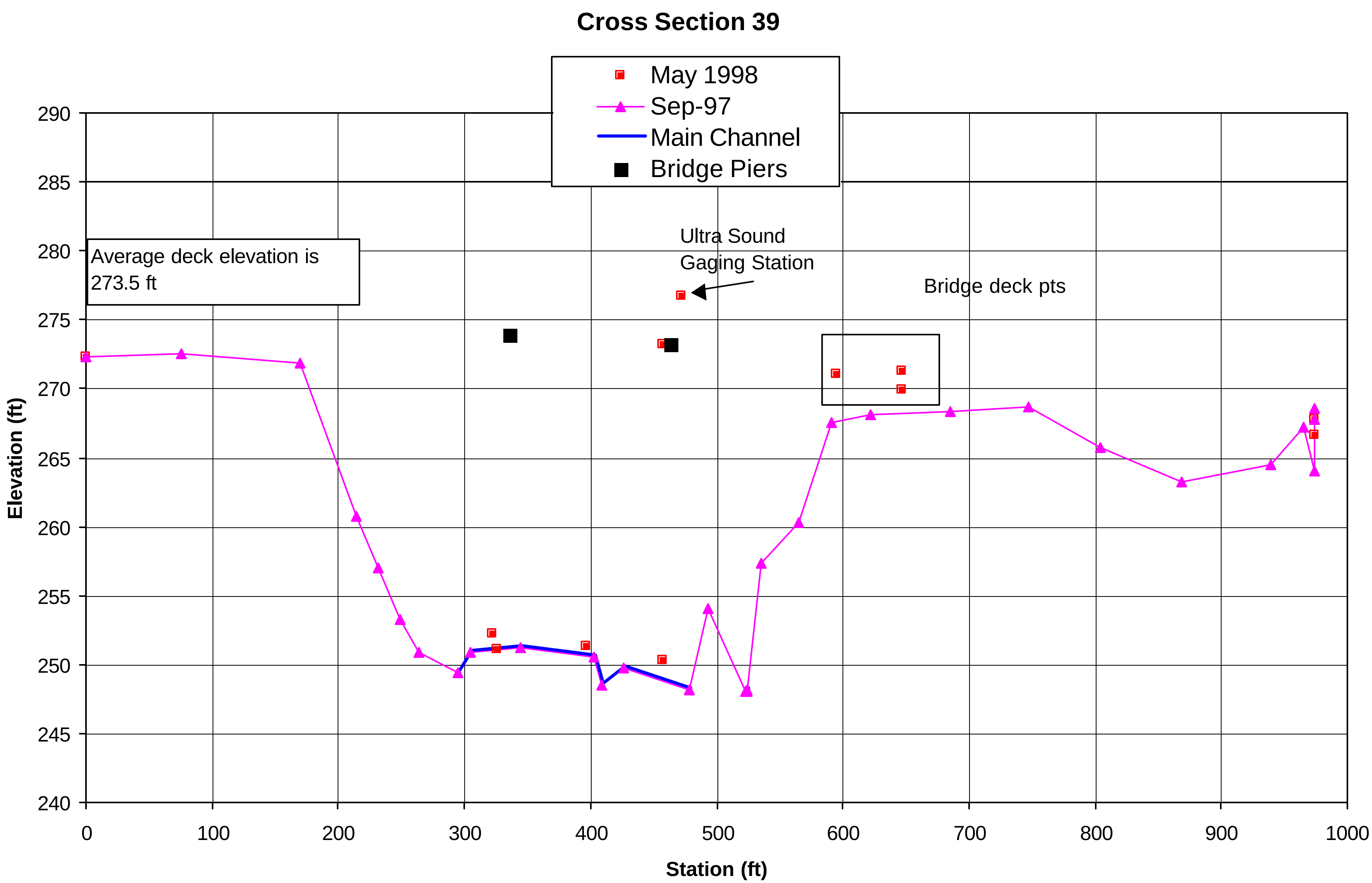
Cross Section 36
Oct-00
October 1998
Sep-97
Main Channel 2000
Main Channel 1997
Elevation (ft)
260
255
250
245
240
235
230
225
220
215
210
forested
5 feet of erosion & Channel shift
floodplain/forested
-400
-200
0
200
400
600
800
1000
Station (ft)

Cross Section 37

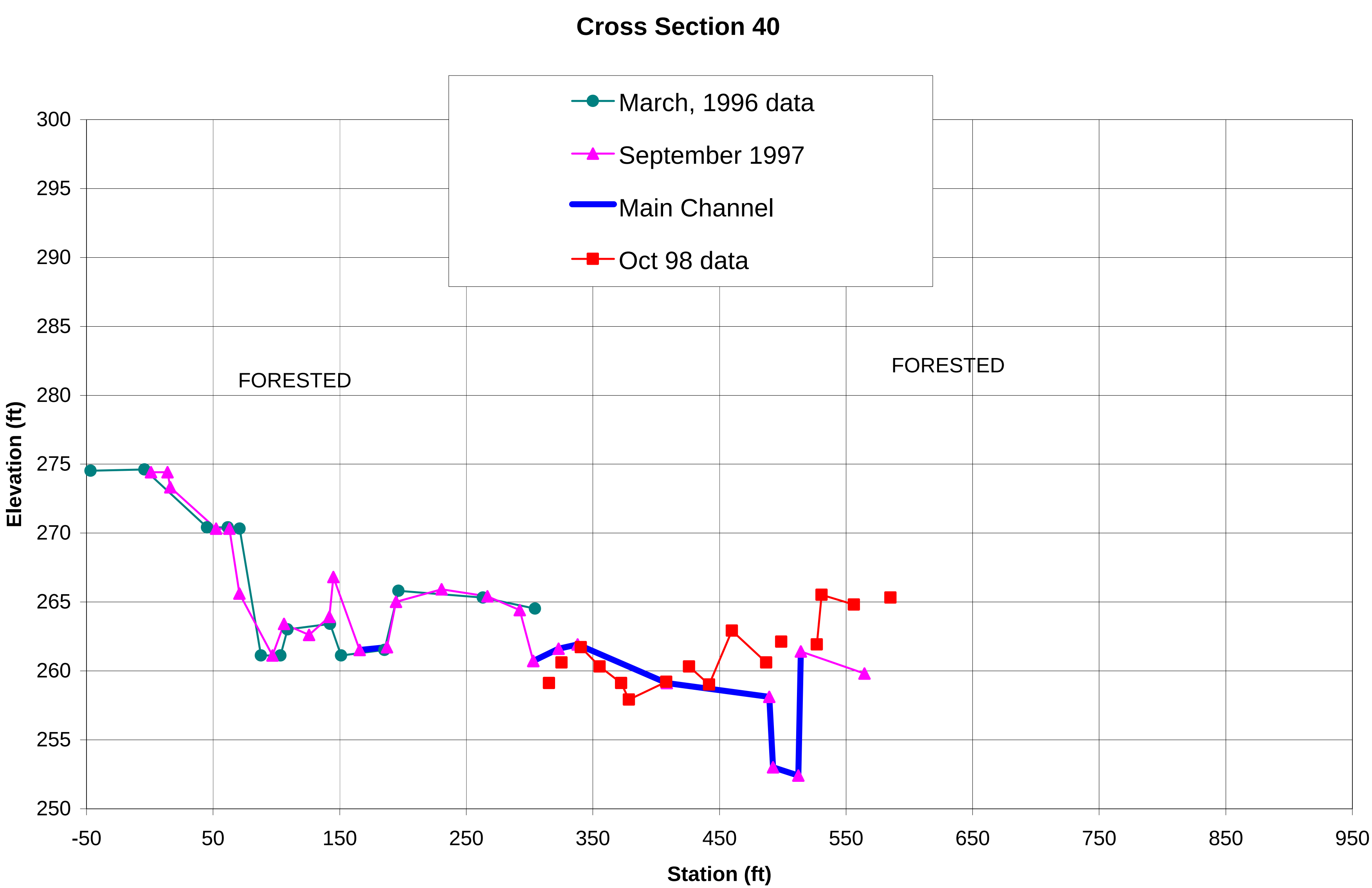




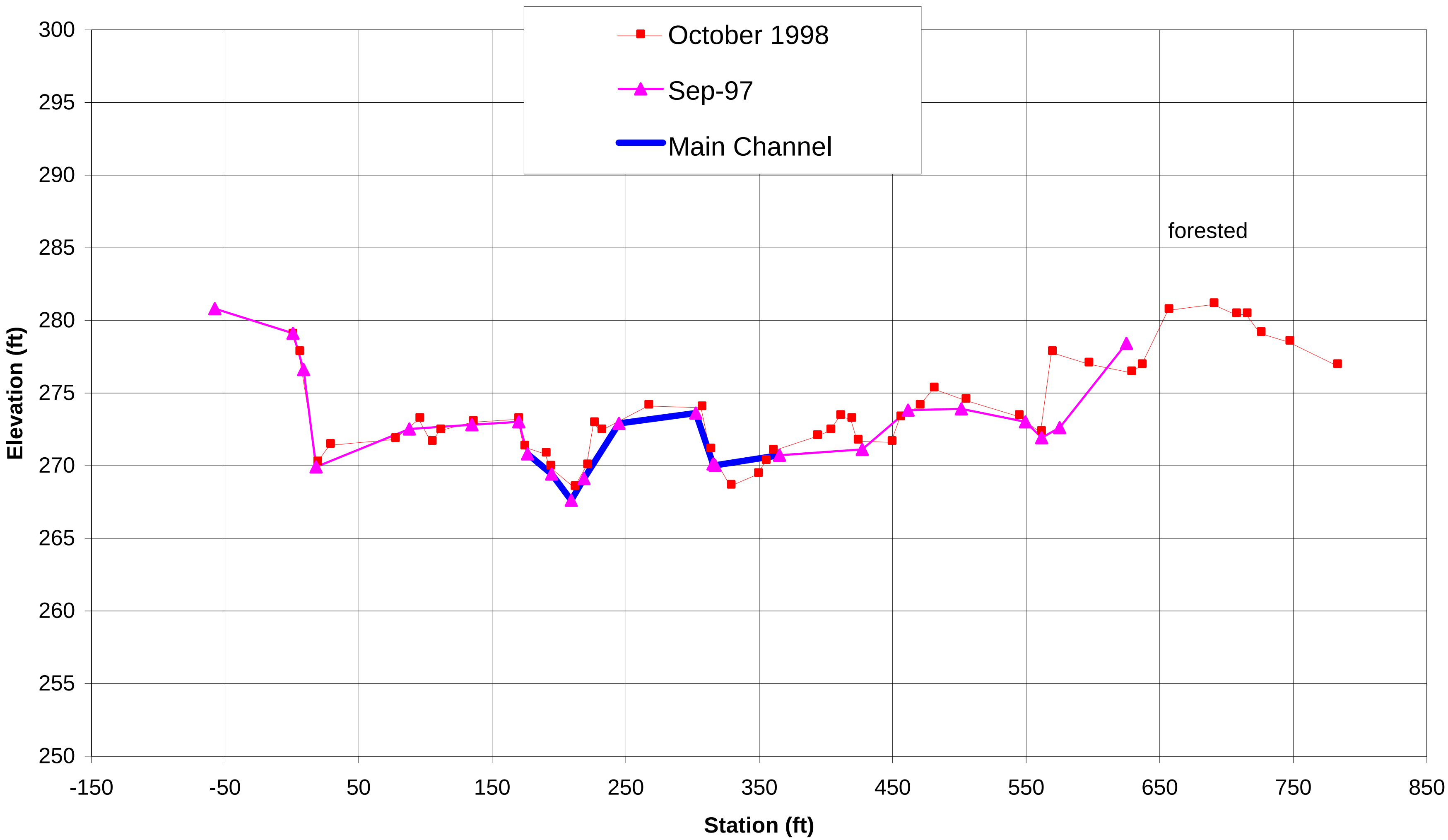
Cross Section 38
Oct-00
October 1998
Sep-97
Main Channel
280
275
270
265
260
255
250
245
240
235
230
Elevation (ft)
-450
-350
-250
-150
-50
50
150
250
350
450
550
Station (ft)

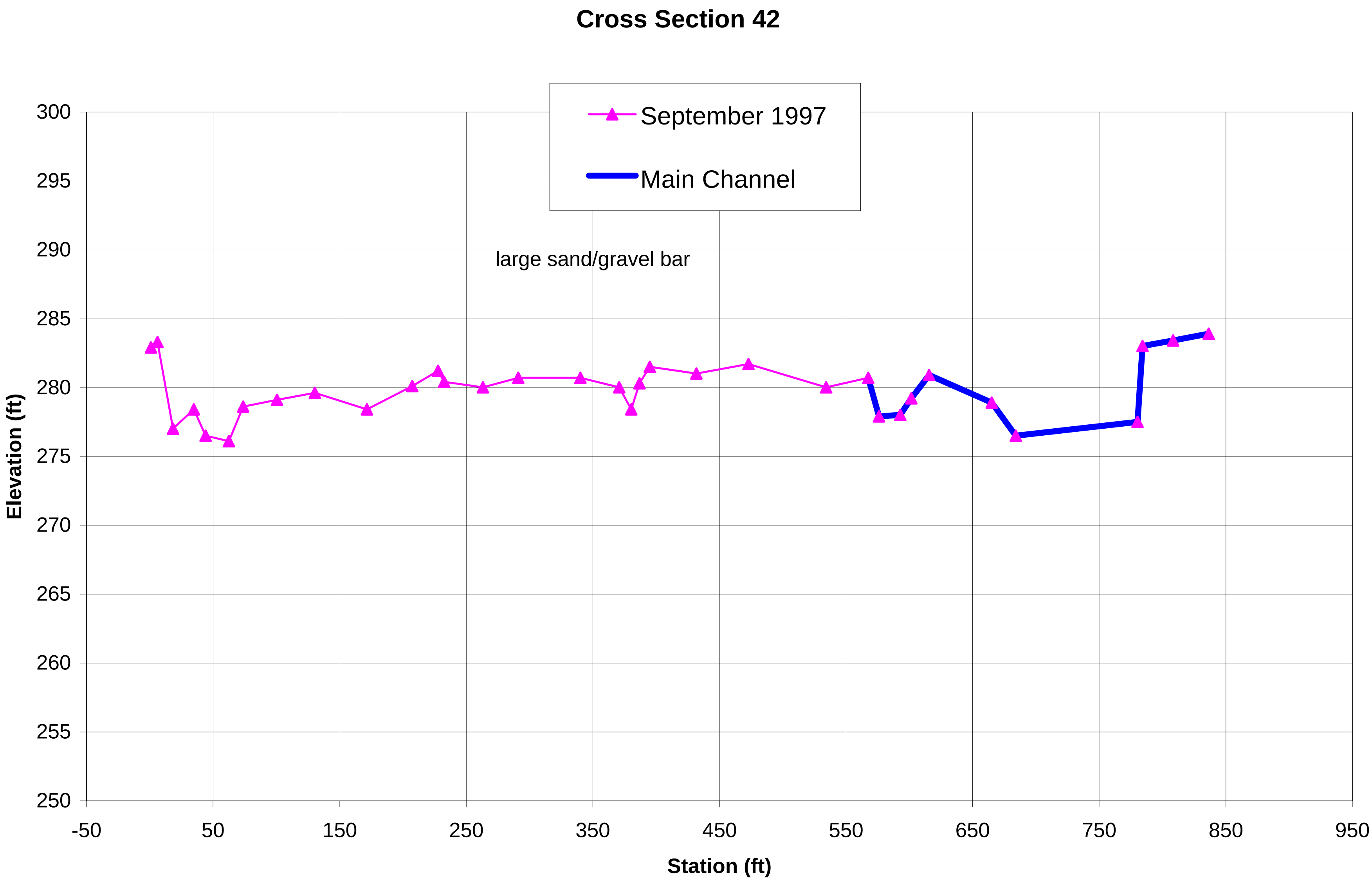


Cross Section 39
May 1998
Sep-97
Main Channel
Bridge Piers
Average deck elevation is
273.5 ft
Ultra Sound
Gaging Station
Bridge deck pts
Elevation (ft)
Station (ft)
290
285
280
275
270
265
260
255
250
245
240
0
100
200
300
400
500
600
700
800
900
1000

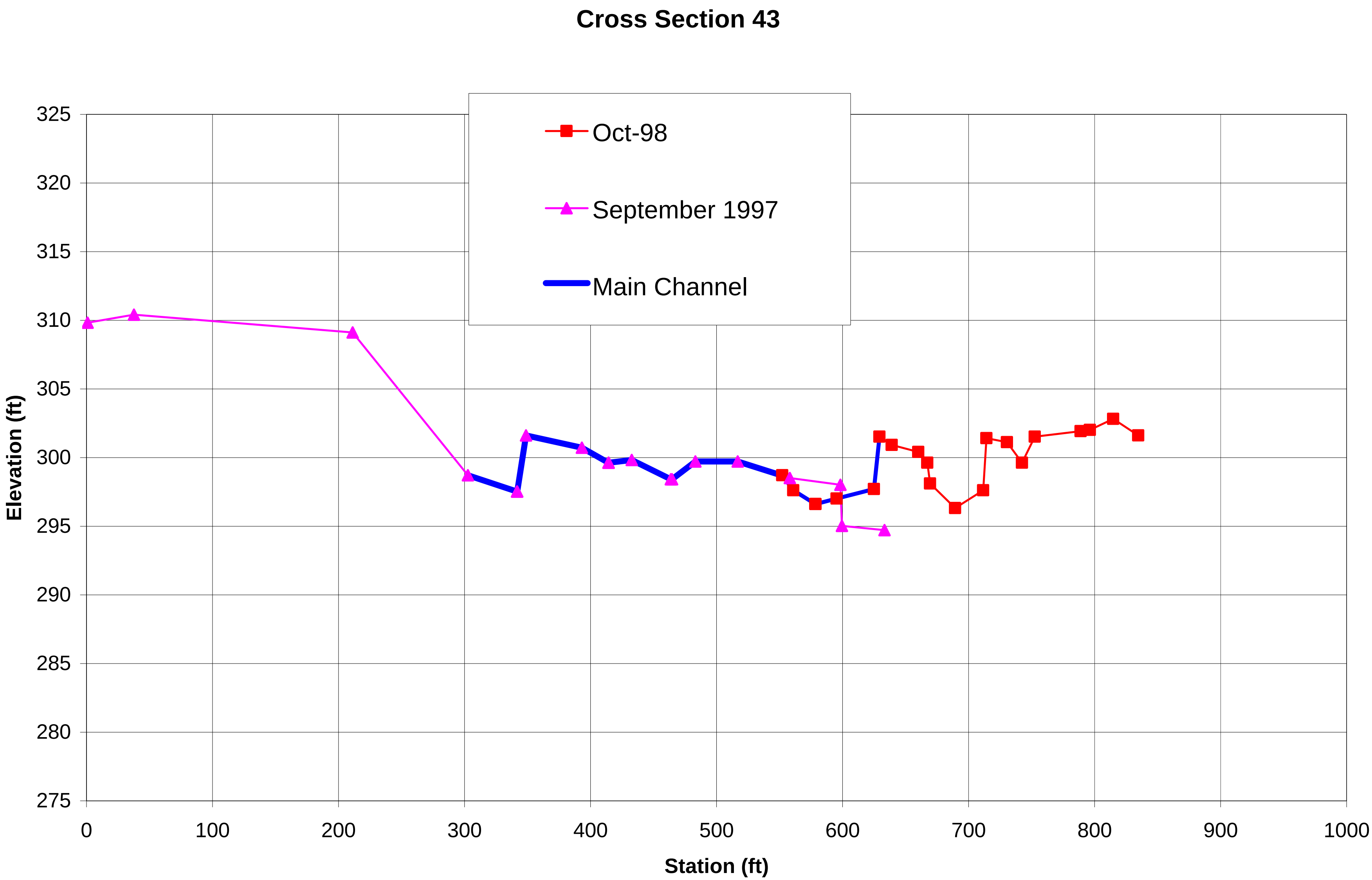

Cross Section 40
March, 1996 data
September 1997
Main Channel
Oct 98 data
FORESTED
FORESTED
Elevation (ft)
Station (ft)
300
295
290
285
280
275
270
265
260
255
250
-50
50
150
250
350
450
550
650
750
850
950

Cross Section 41

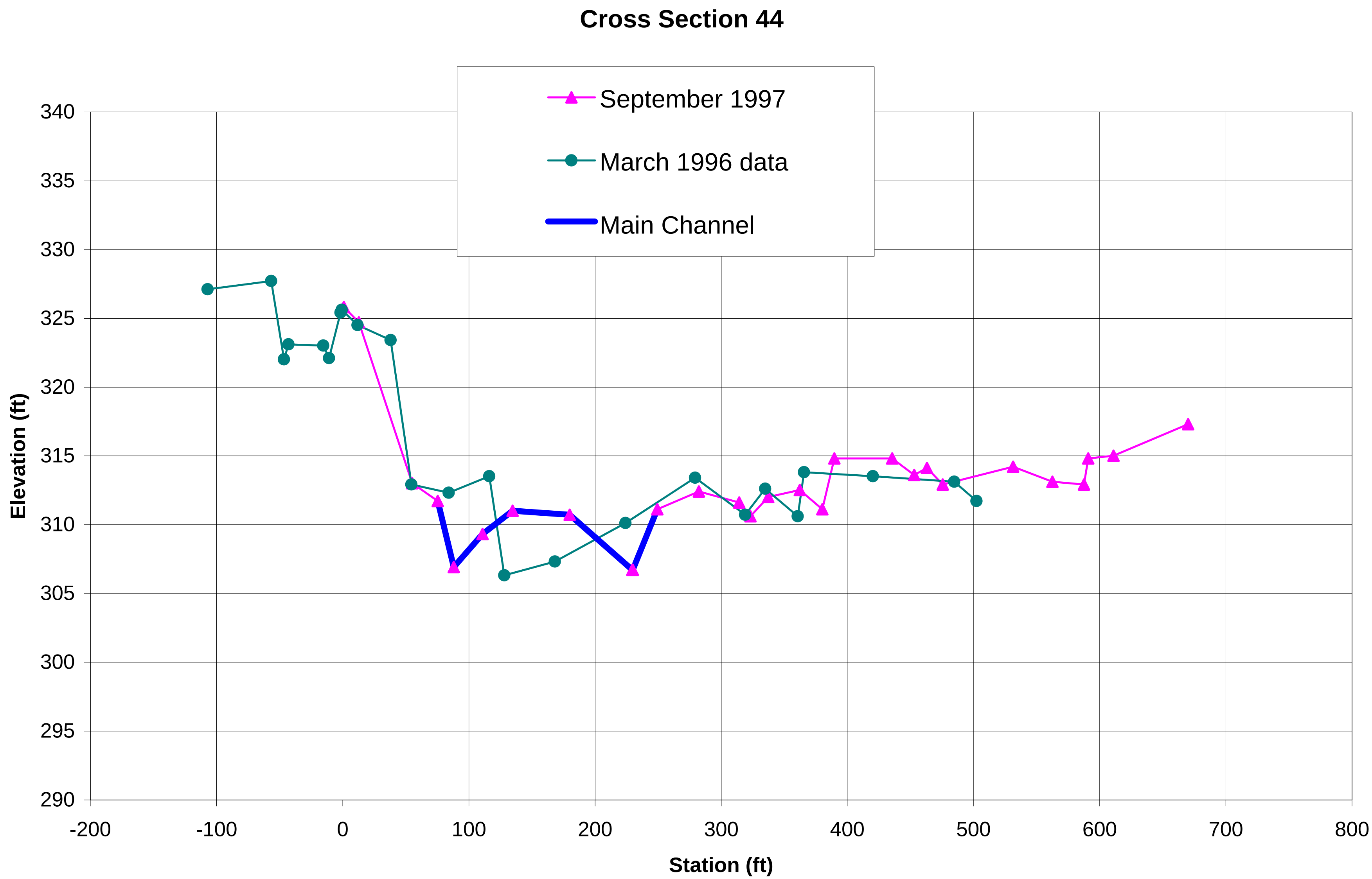




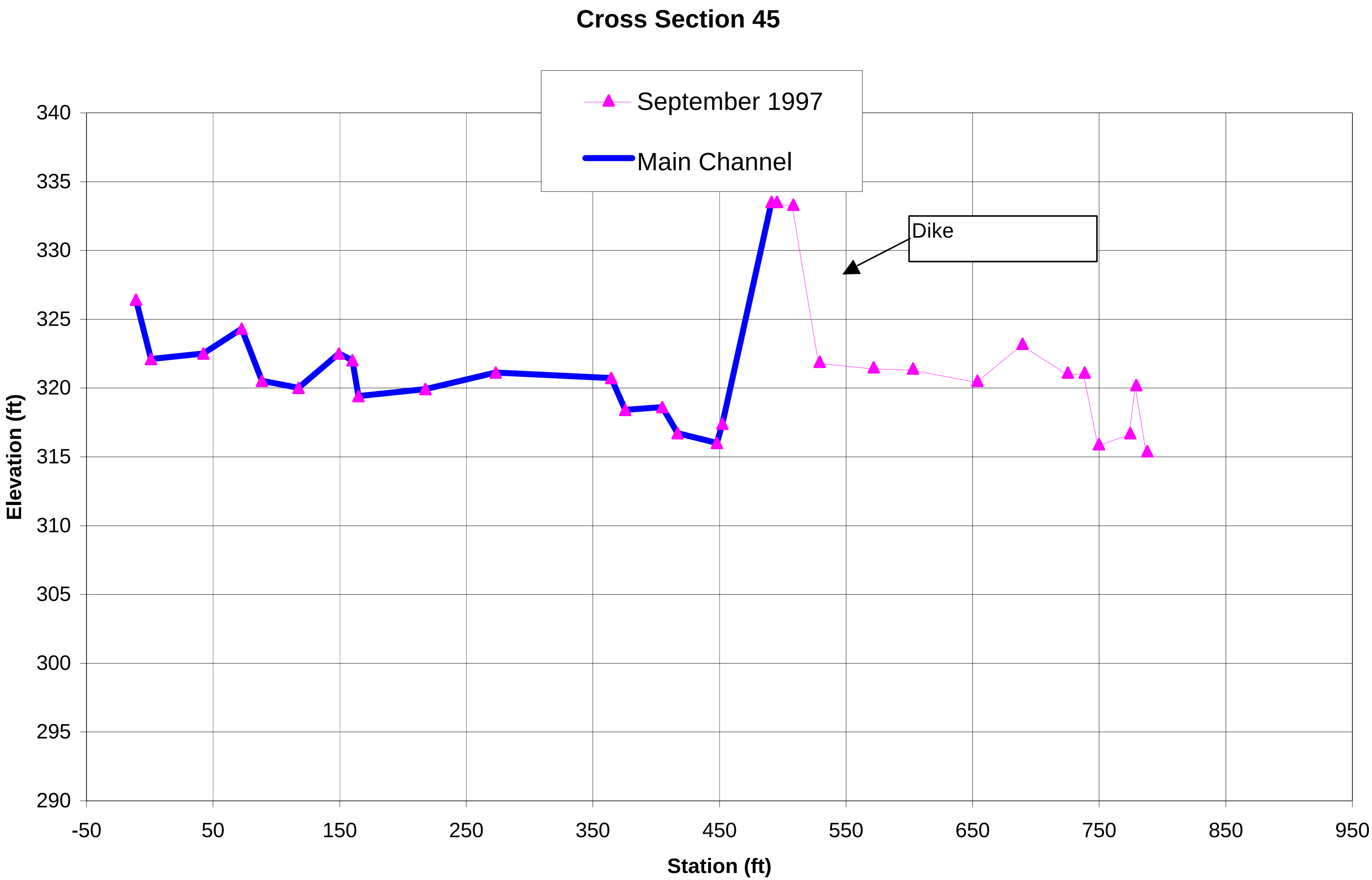
Cross Section 42
September 1997
Main Channel
large sand/gravel bar
Elevation (ft)
300
295
290
285
280
275
270
265
260
255
250
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)

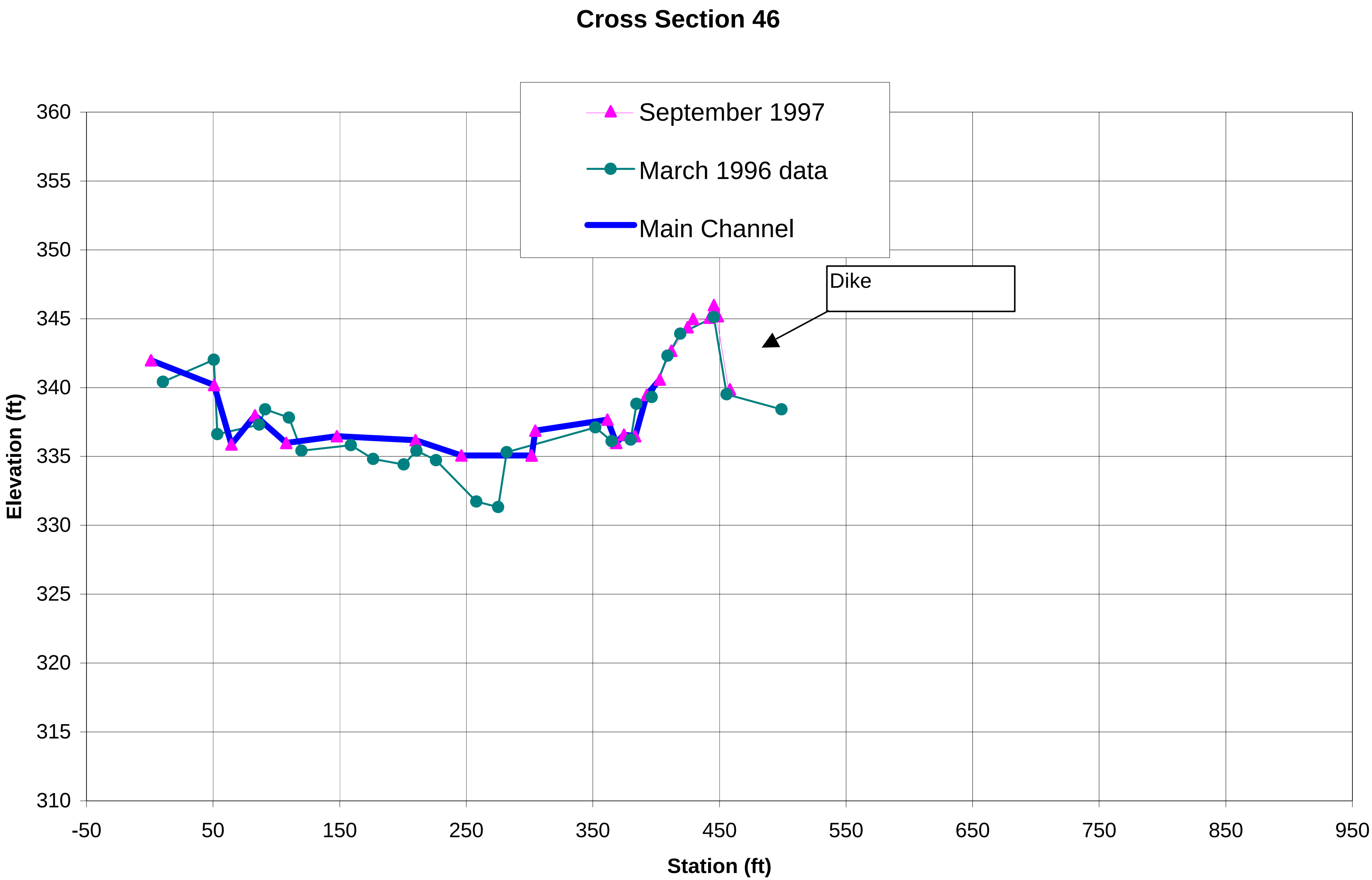


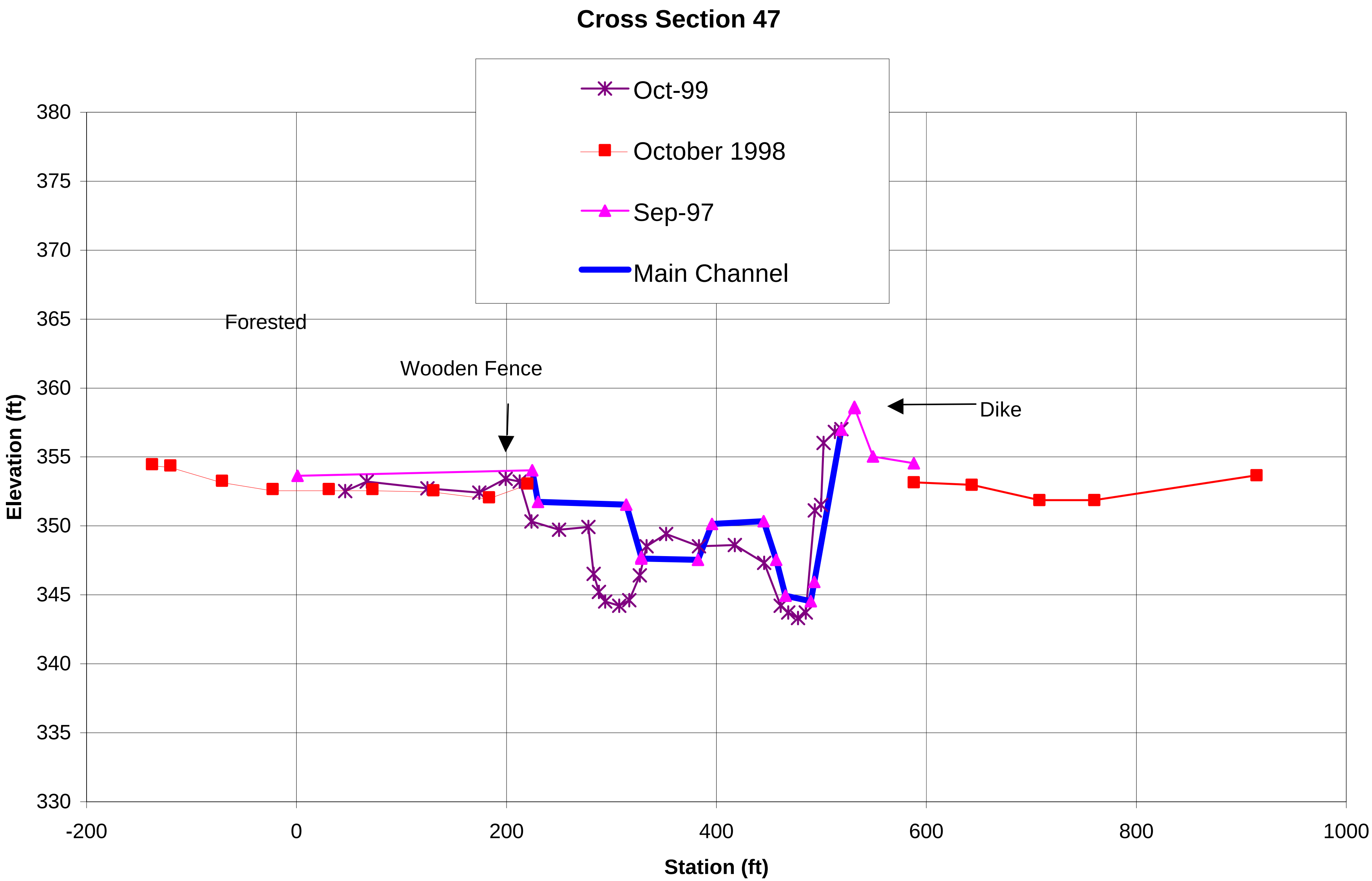
Cross Section 43
Oct-98
September 1997
Main Channel
325
320
315
310
305
300
295
290
285
280
275
Elevation (ft)
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)

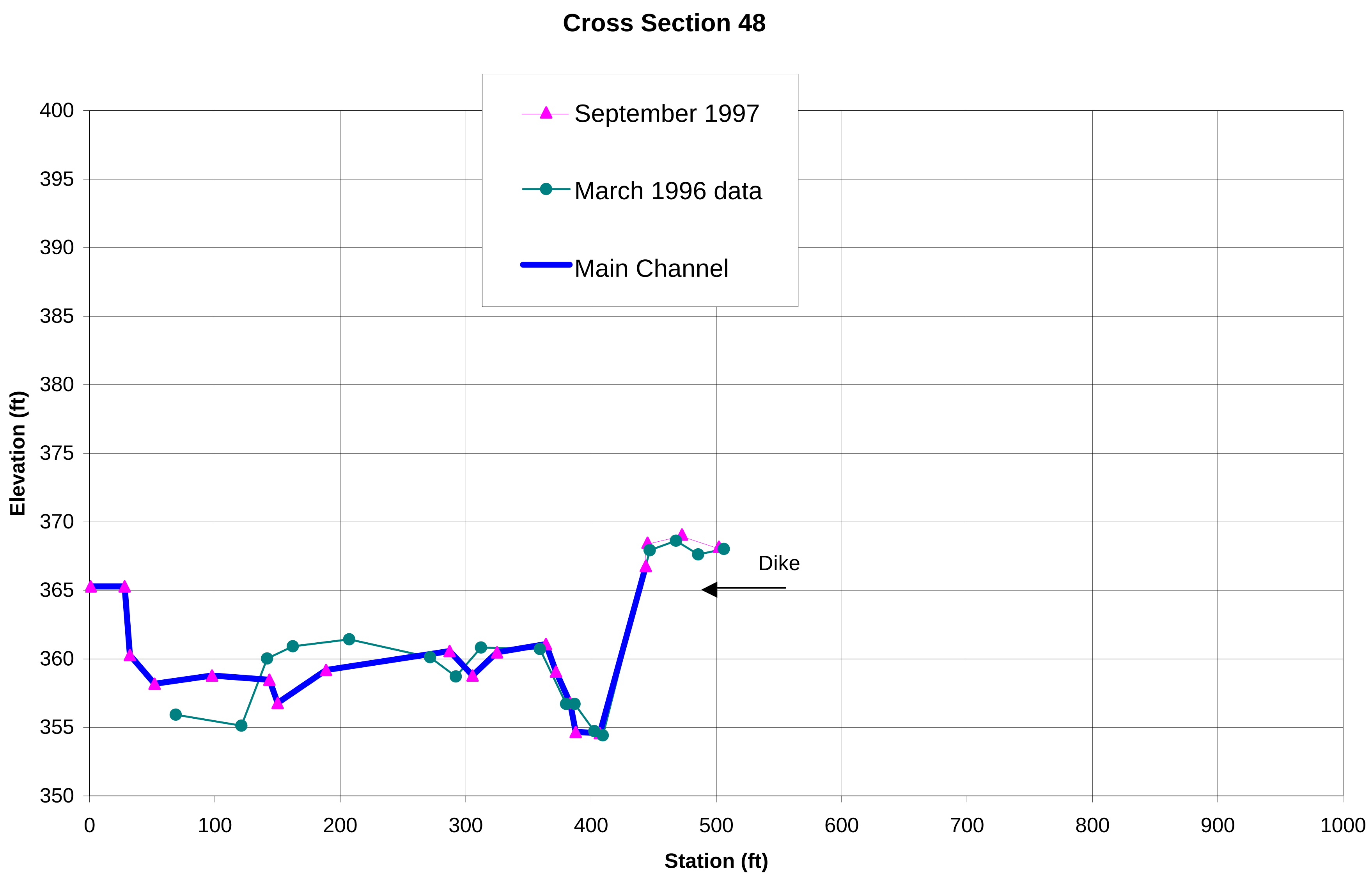


Cross Section 44
September 1997
March 1996 data
Main Channel
Elevation (ft)
340
335
330
325
320
315
310
305
300
295
290
-200
-100
0
100
200
300
400
500
600
700
800
Station (ft)

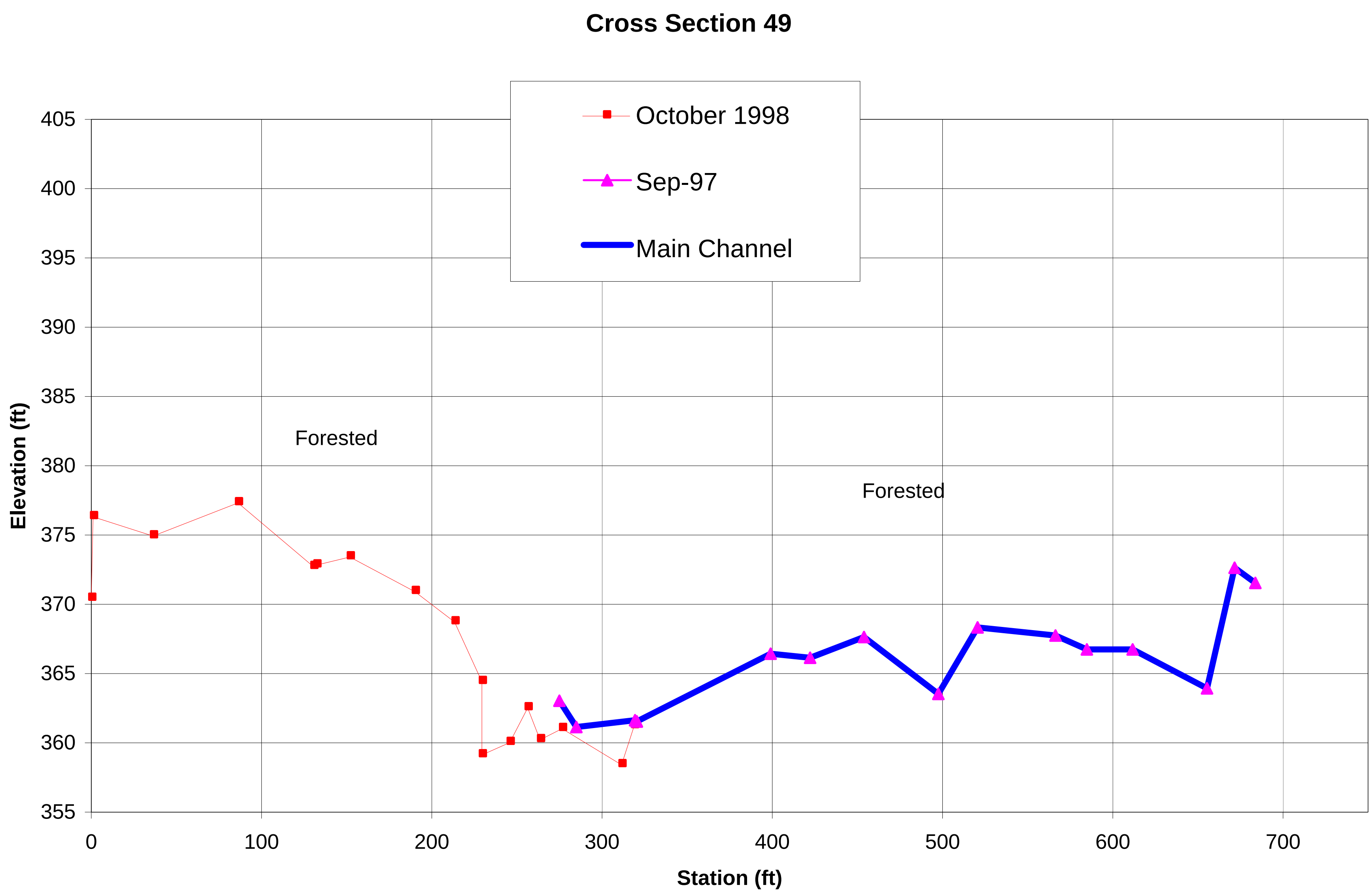

Cross Section 45
September 1997
Main Channel
Dike
Elevation (ft)
340
335
330
325
320
315
310
305
300
295
290
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)

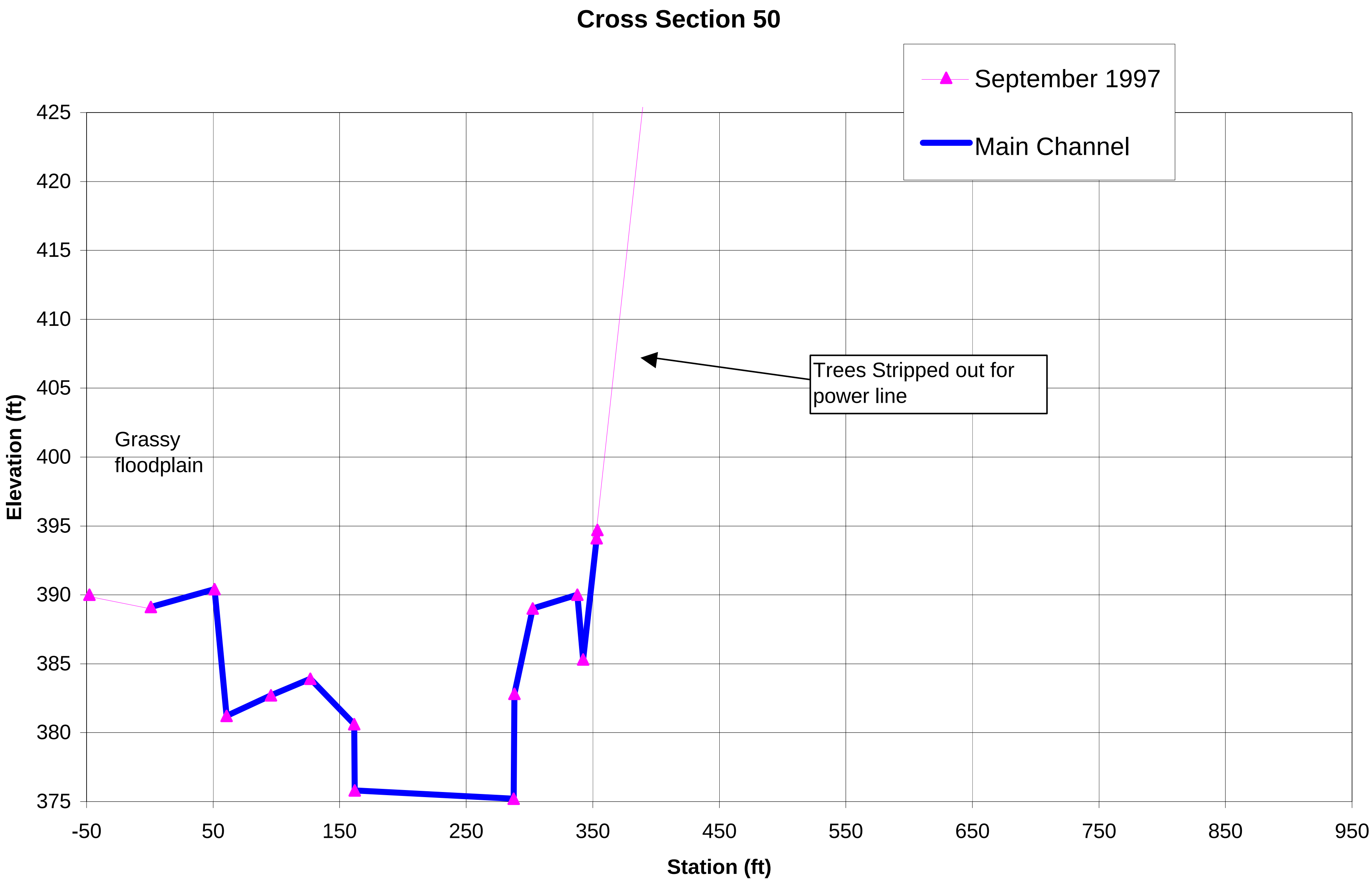

Cross Section 46
September 1997
March 1996 data
Main Channel
Dike
Elevation (ft)
360
355
350
345
340
335
330
325
320
315
310
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)


Cross Section 47
Oct-99
October 1998
Sep-97
Main Channel
Forested
Wooden Fence
Dike
Elevation (ft)
380
375
370
365
360
355
350
345
340
335
330
-200
0
200
400
600
800
1000
Station (ft)

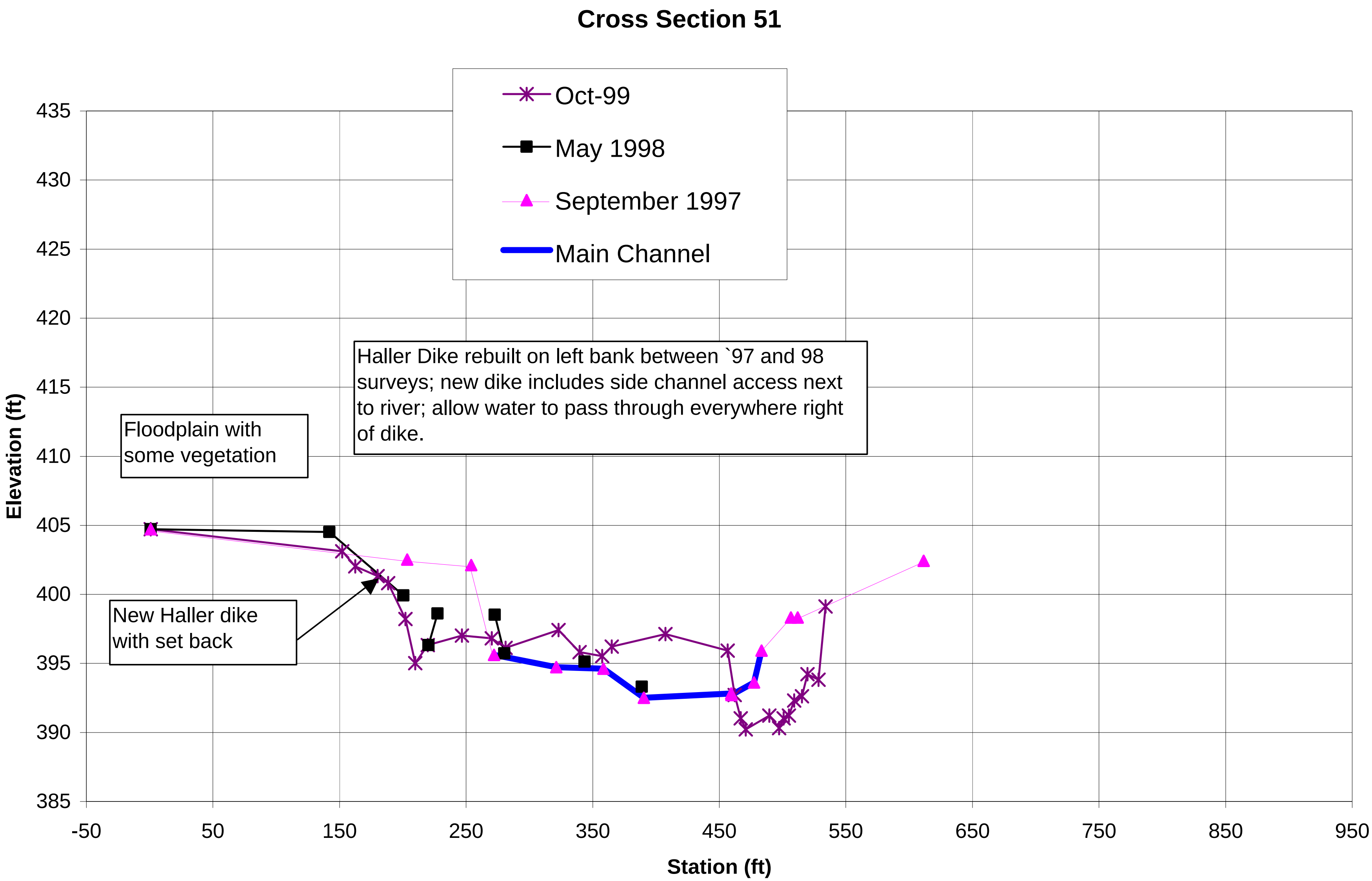


Cross Section 48
September 1997
March 1996 data
Main Channel
Dike
Elevation (ft)
Station (ft)
400
395
390
385
380
375
370
365
360
355
350
0
100
200
300
400
500
600
700
800
900
1000

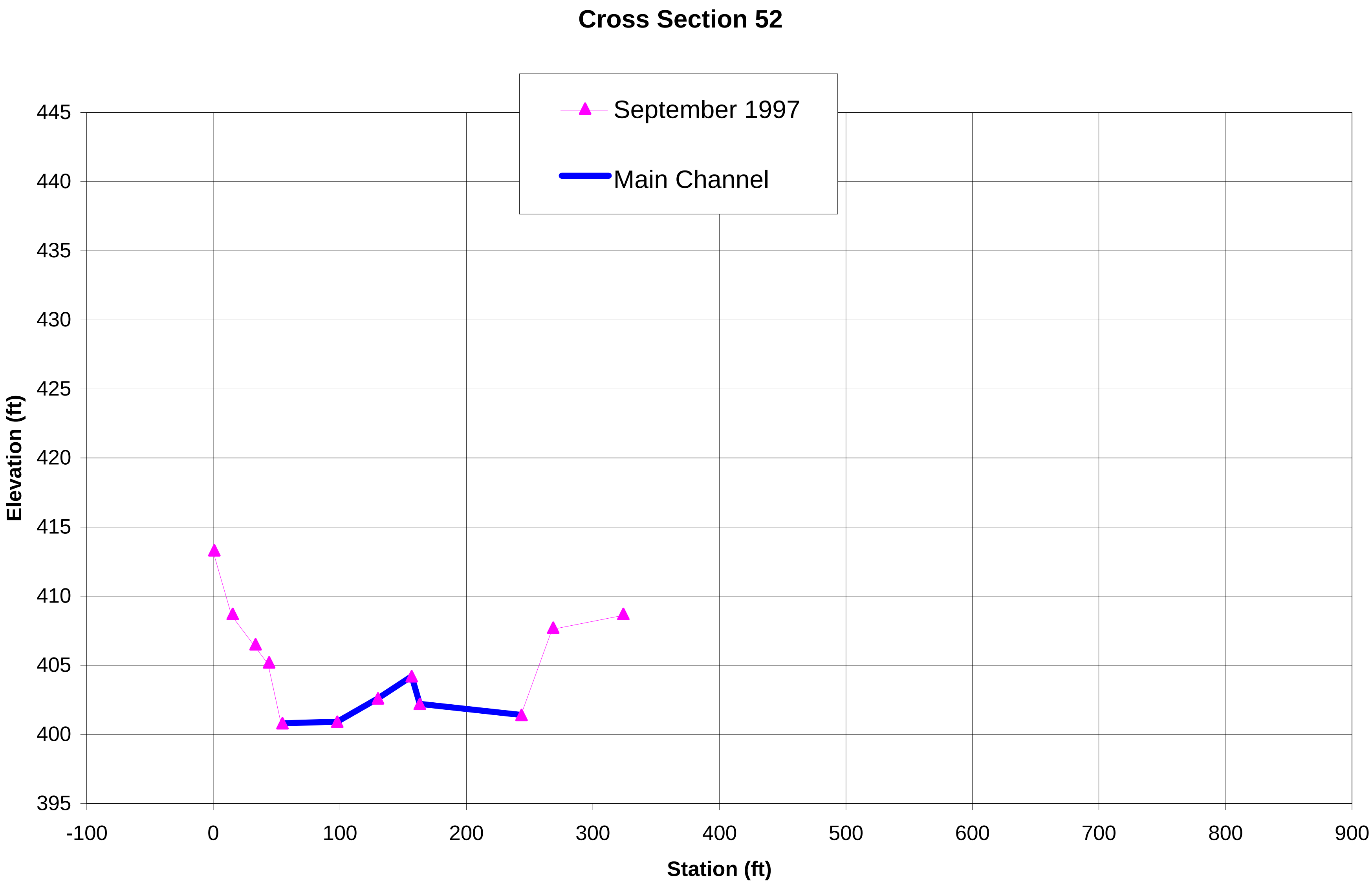

Cross Section 49
October 1998
Sep-97
Main Channel
Elevation (ft)
Station (ft)
Forested
Forested
405
400
395
390
385
380
375
370
365
360
355
0
100
200
300
400
500
600
700

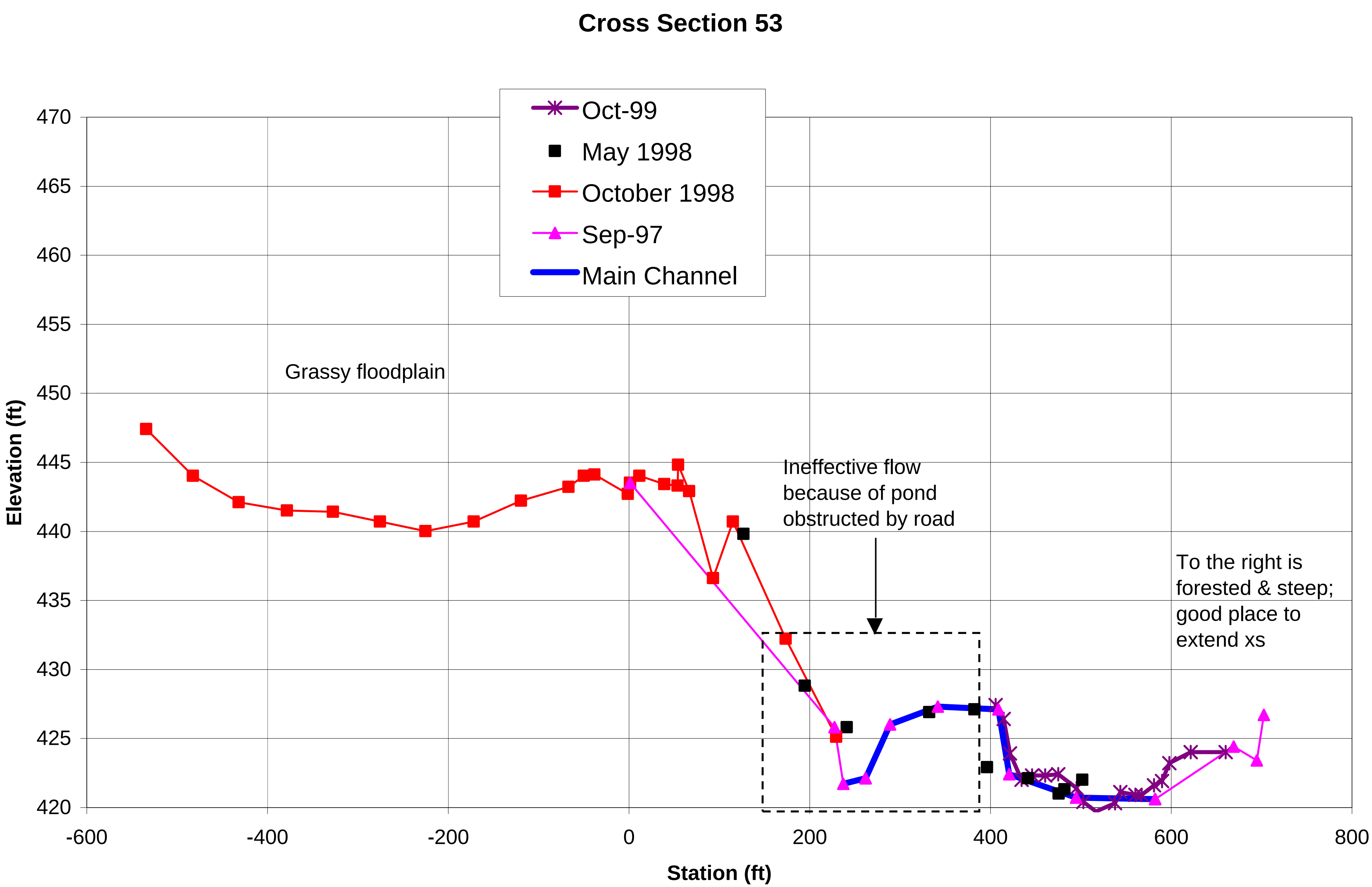


Cross Section 50
September 1997
Main Channel
Elevation (ft)
425
420
415
410
405
400
395
390
385
380
375
-50
50
150
250
350
450
550
650
750
850
950
Station (ft)
Grassy floodplain
Trees Stripped out for power line

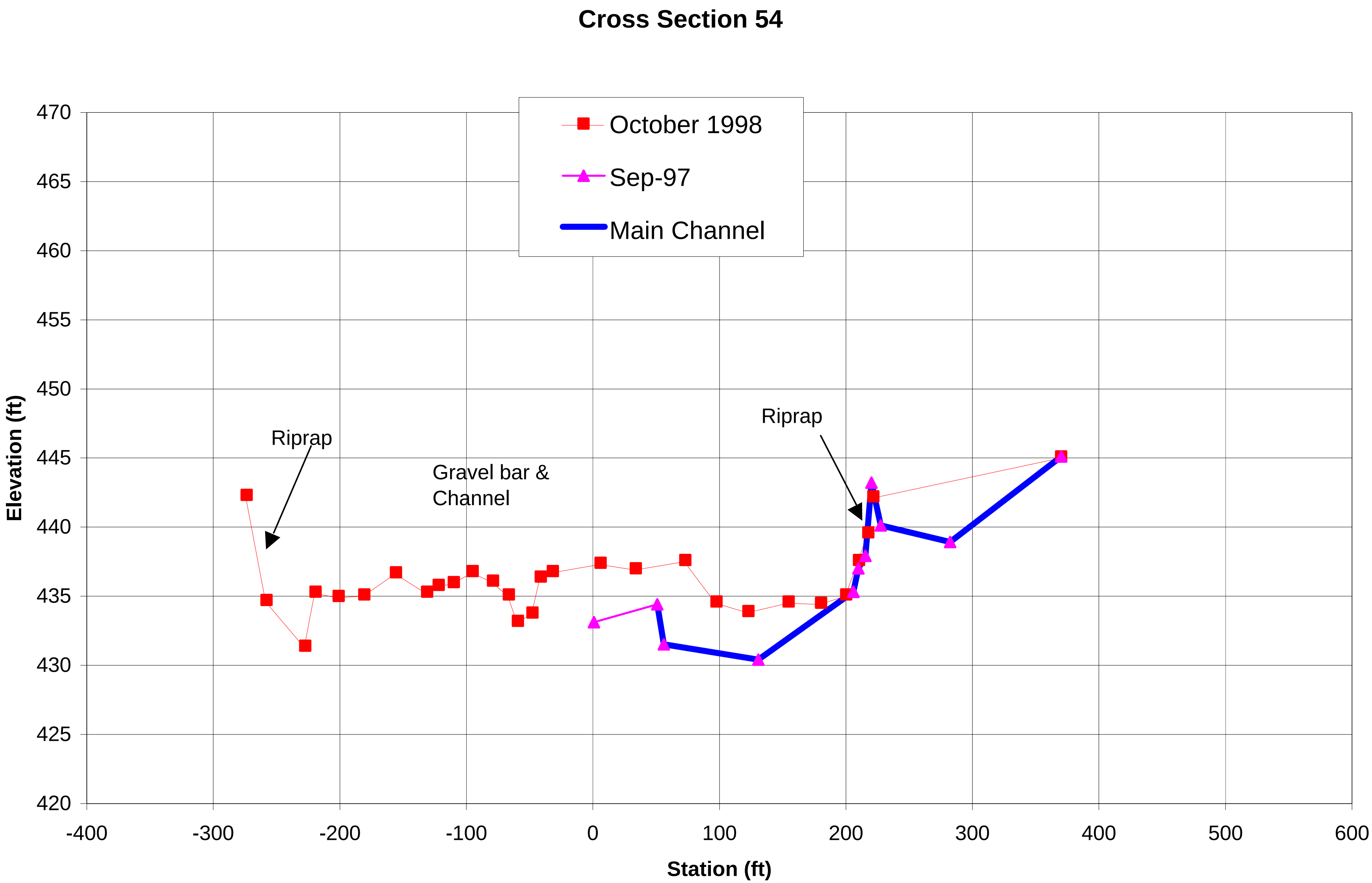


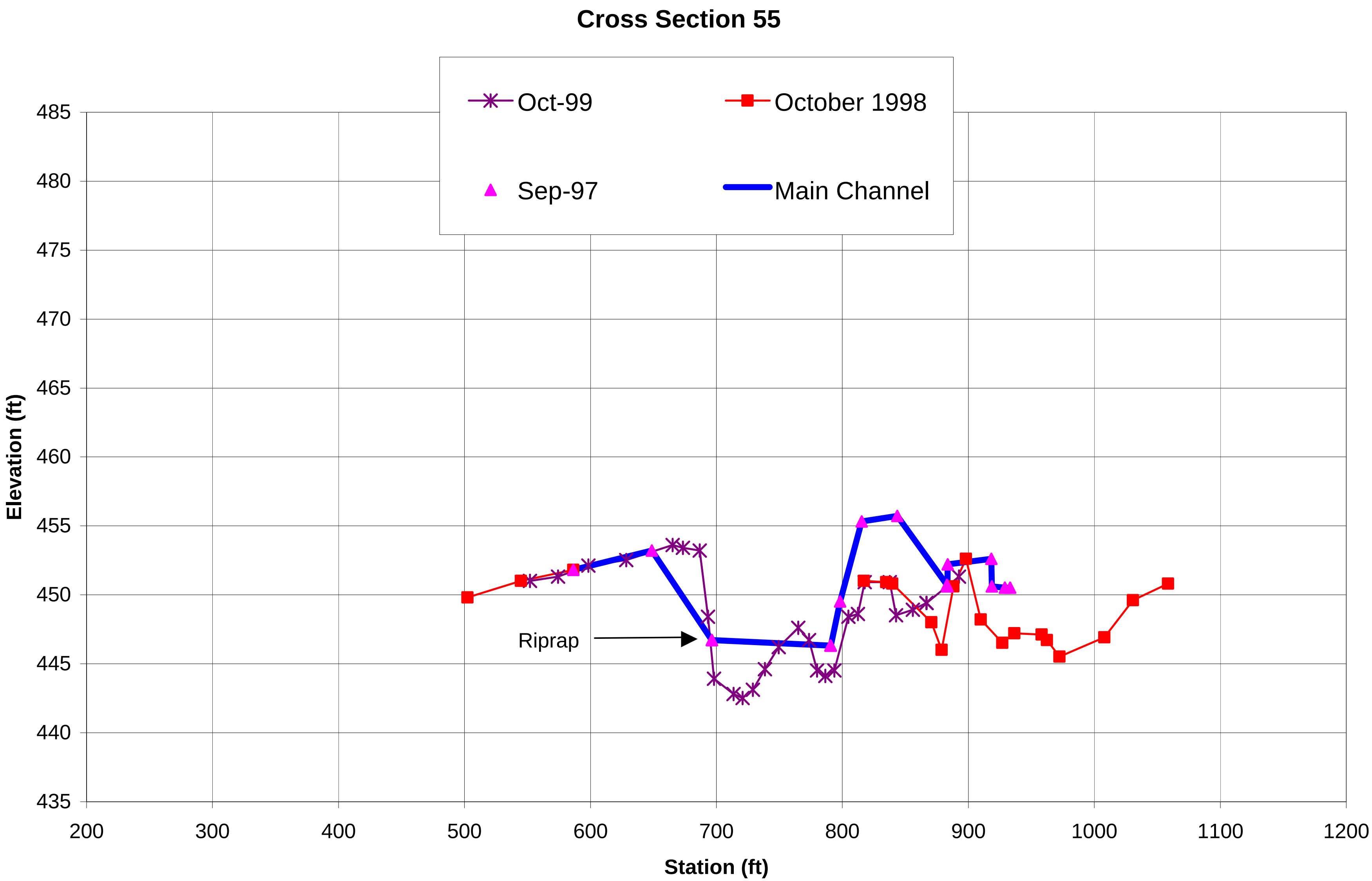
Cross Section 51
Oct-99
May 1998
September 1997
Main Channel
Haller Dike rebuilt on left bank between `97 and 98 surveys; new dike includes side channel access next to river; allow water to pass through everywhere right of dike.
Floodplain with some vegetation
New Haller dike with set back
Elevation (ft)
Station (ft)
435
430
425
420
415
410
405
400
395
390
385
-50
50
150
250
350
450
550
650
750
850
950


Cross Section 52
September 1997
Main Channel
445
440
435
430
425
420
415
410
405
400
395
Elevation (ft)
-100
0
100
200
300
400
500
600
700
800
900
Station (ft)

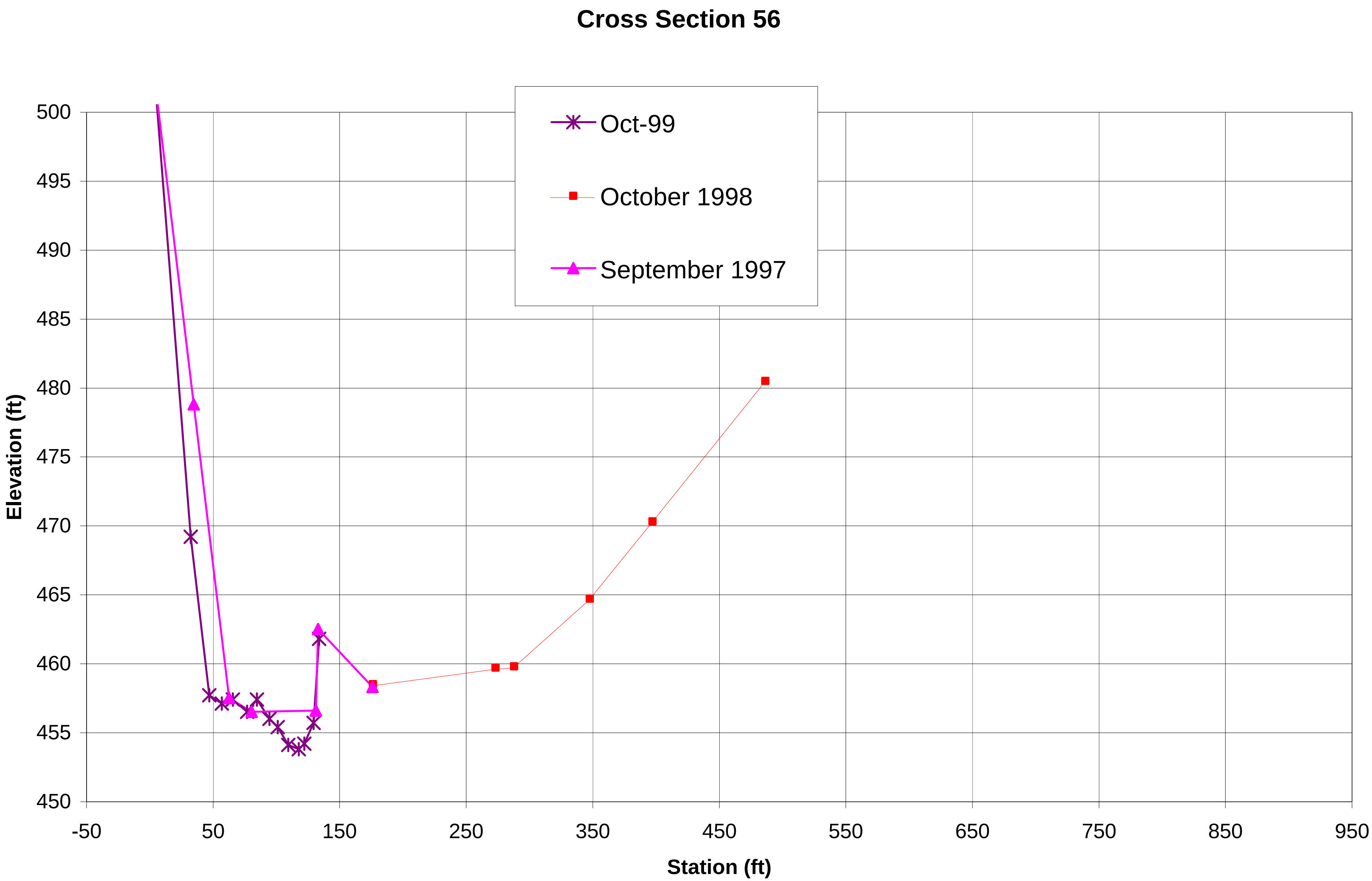


Cross Section 53
Oct-99
May 1998
October 1998
Sep-97
Main Channel
Grassy floodplain
Ineffective flow because of pond obstructed by road
To the right is forested & steep; good place to extend xs
Elevation (ft)
Station (ft)
470
465
460
455
450
445
440
435
430
425
420
-600
-400
-200
0
200
400
600
800


Cross Section 54
October 1998
Sep-97
Main Channel
Riprap
Gravel bar &
Channel
Riprap
Elevation (ft)
470
465
460
455
450
445
440
435
430
425
420
-400
-300
-200
-100
0
100
200
300
400
500
600
Station (ft)

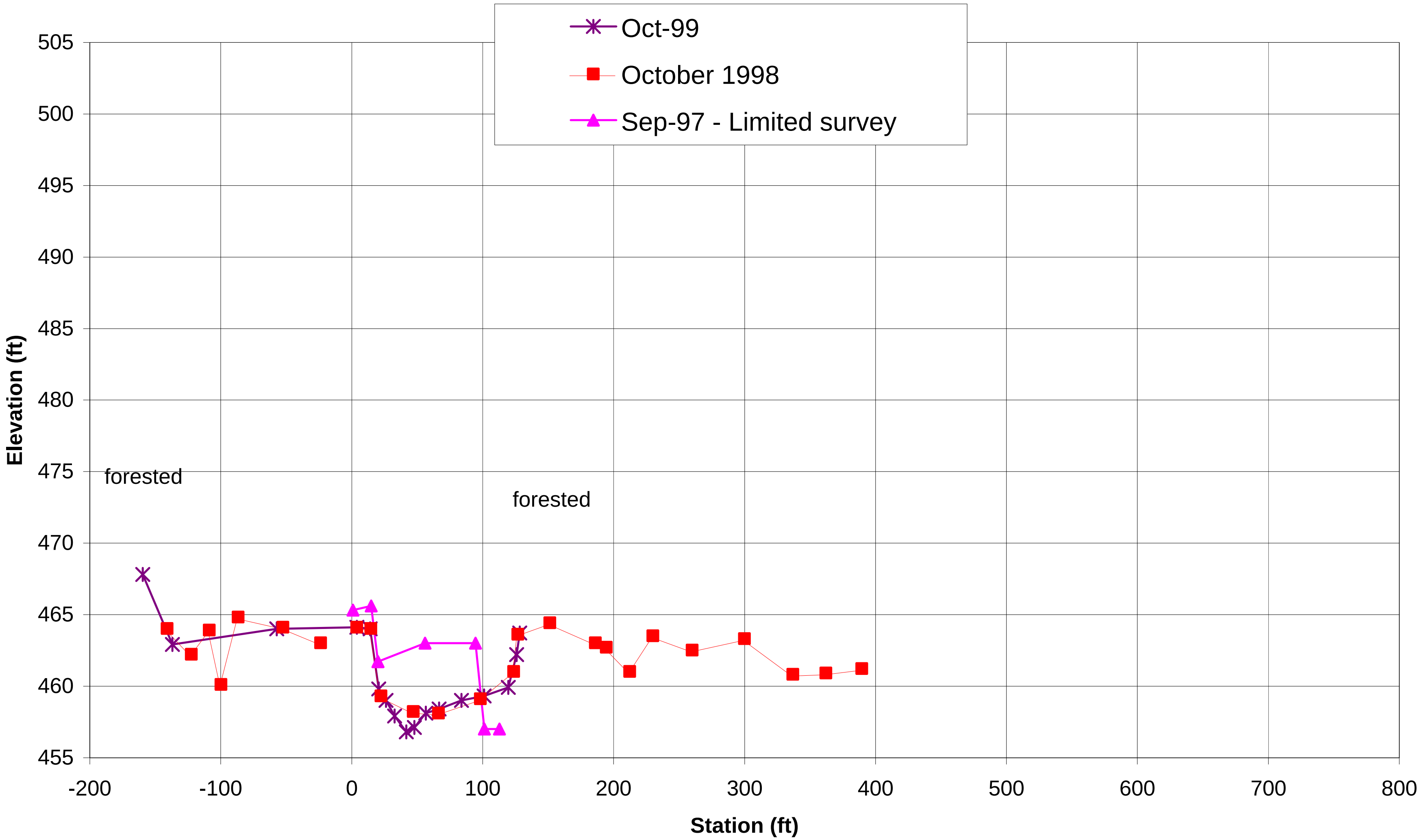


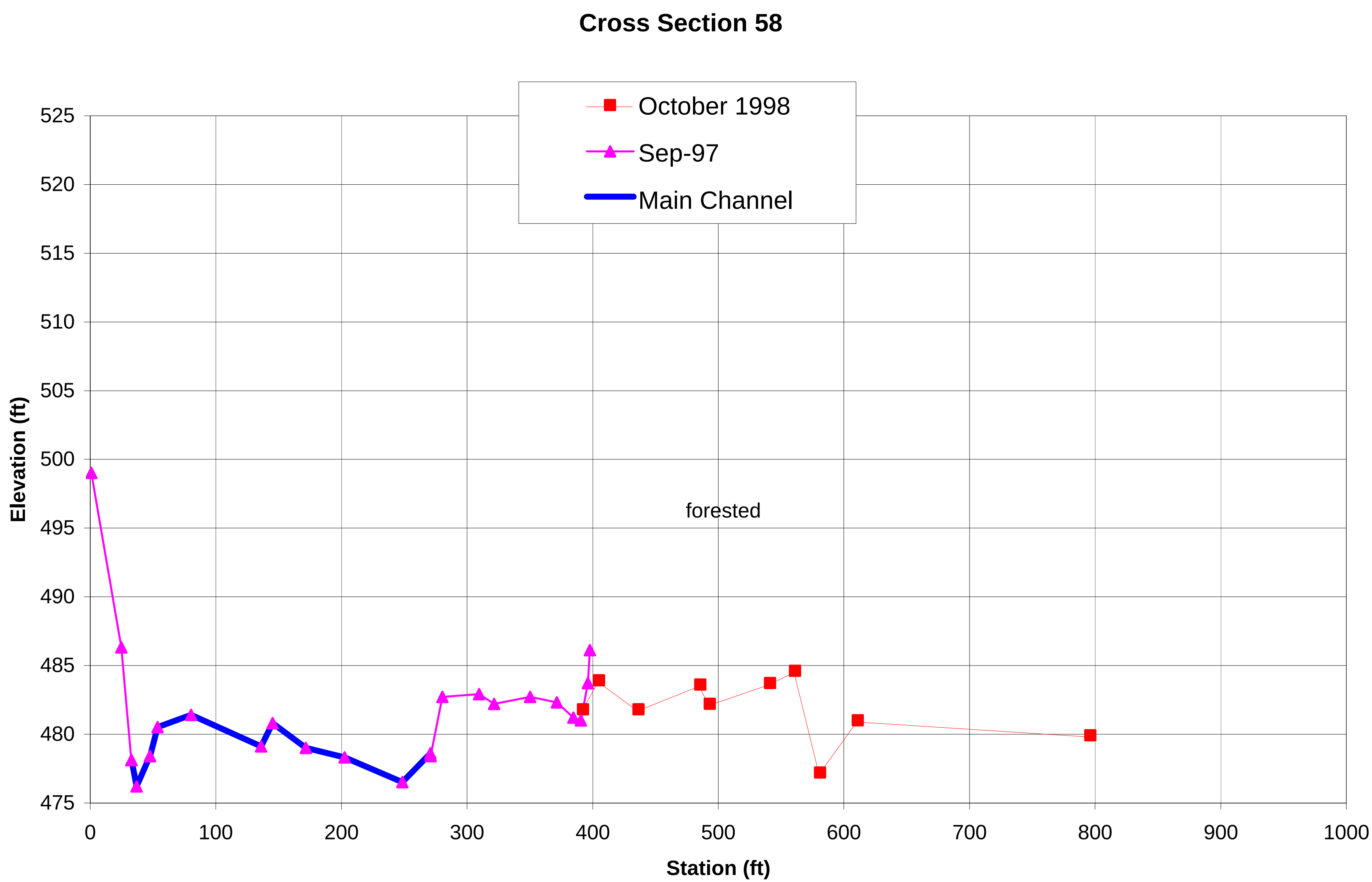
Cross Section 55
Oct-99
October 1998
Sep-97
Main Channel
Elevation (ft)
485
480
475
470
465
460
455
450
445
440
435
Riprap
200
300
400
500
600
700
800
900
1000
1100
1200
Station (ft)



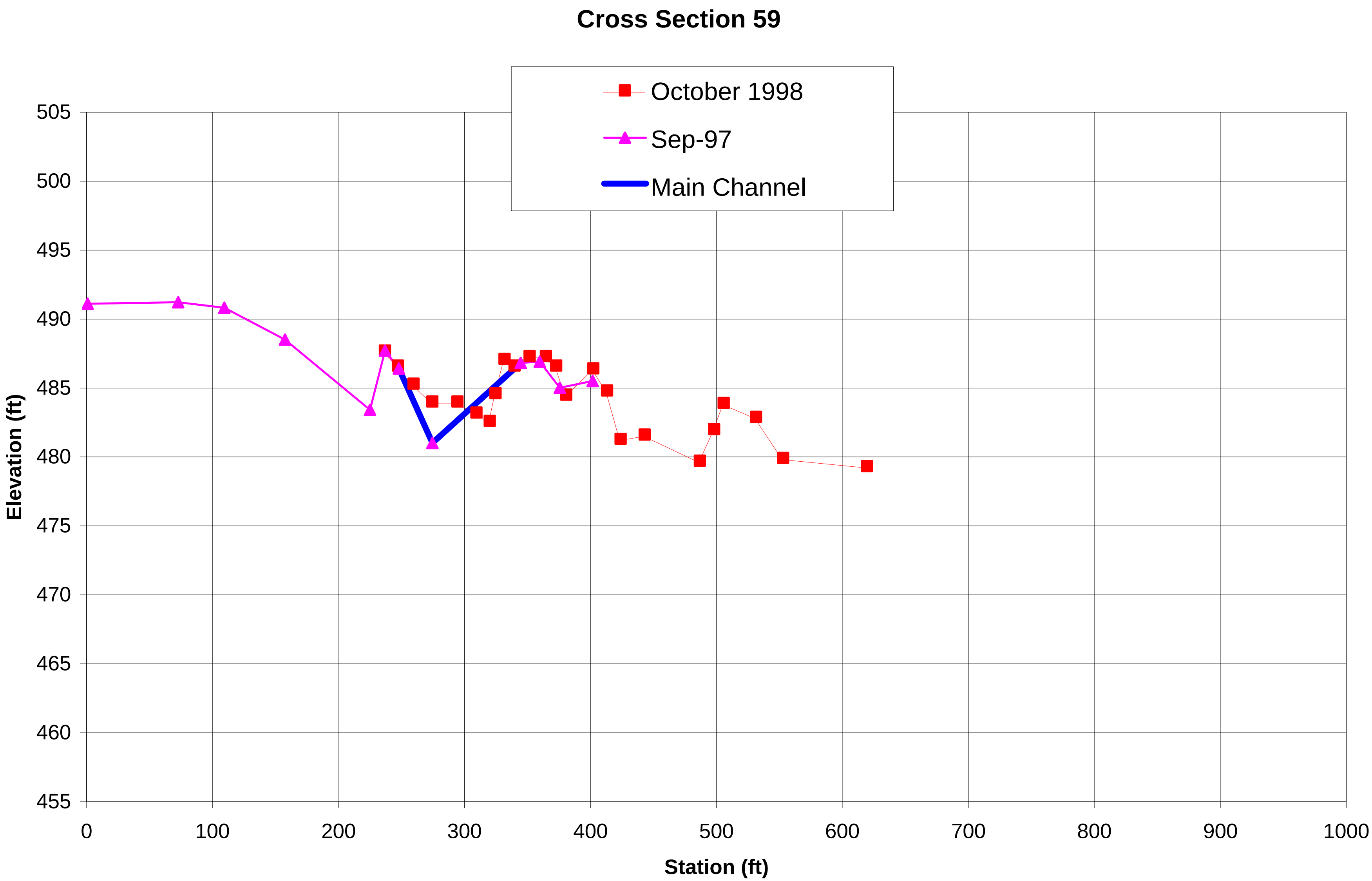
Cross Section 56
Oct-99
October 1998
September 1997
Elevation (ft)
Station (ft)
500
495
490
485
480
475
470
465
460
455
450
-50
50
150
250
350
450
550
650
750
850
950

Cross Section 57

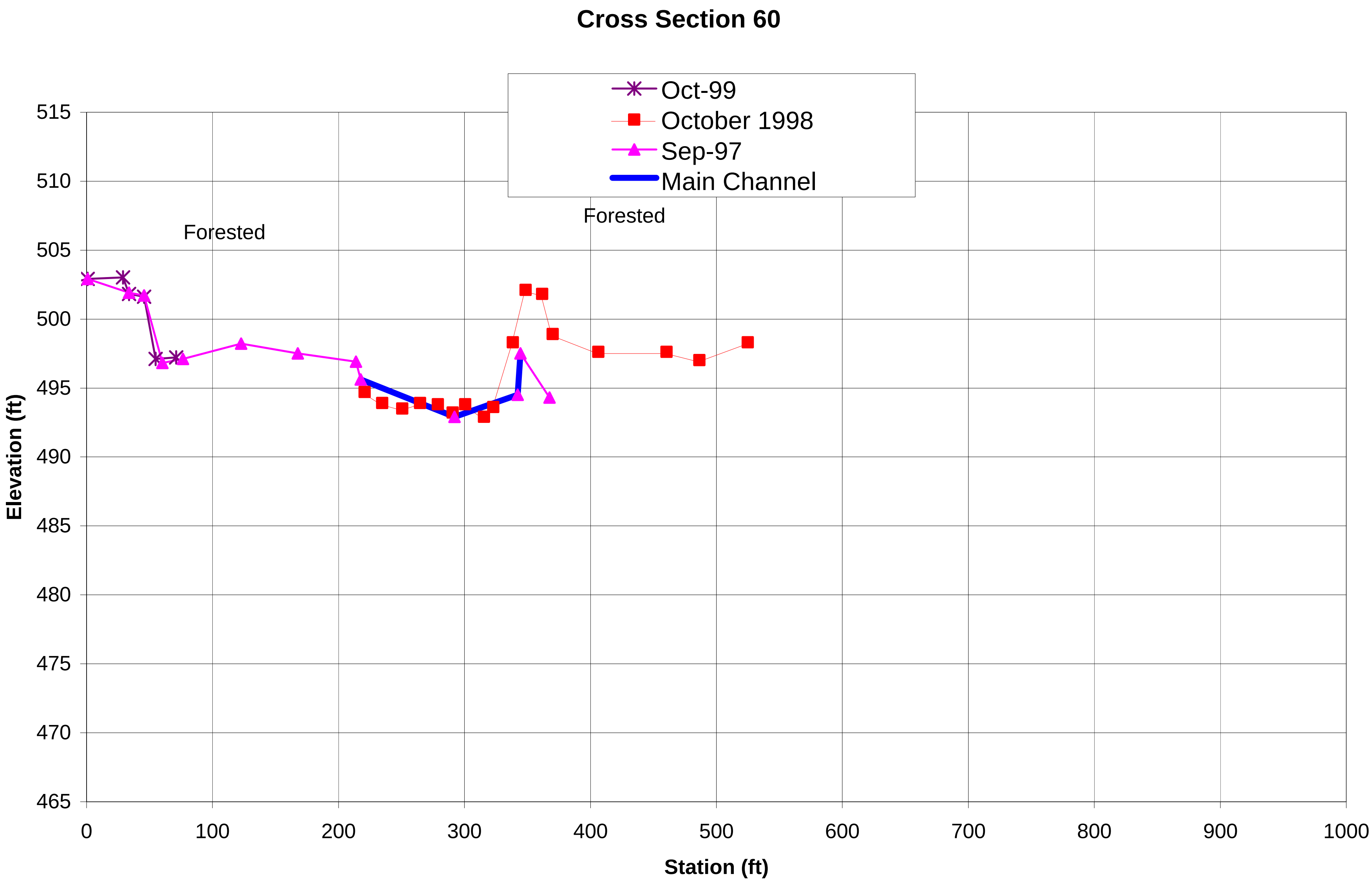




Cross Section 58
October 1998
Sep-97
Main Channel
525
520
515
510
505
500
495
490
485
480
475
Elevation (ft)
forested
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)



Cross Section 59
October 1998
Sep-97
Main Channel
505
500
495
490
485
480
475
470
465
460
455
Elevation (ft)
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)



Cross Section 60
Oct-99
October 1998
Sep-97
Main Channel
Forested
Forested
515
510
505
500
495
490
485
480
475
470
465
Elevation (ft)
0
100
200
300
400
500
600
700
800
900
1000
Station (ft)

September 14, 1999

MEMORANDUM

TO: Team Leader, Dungeness River Geomorphology Investigation
Attention: Timothy Randle, D-8540

FROM: John F. England, Jr., Hydraulic Engineer
Technical Service Center
Flood Hydrology Group

SUBJECT: Flood Frequency, Flow Duration and Trend Analyses
Dungeness River Geomorphology Investigation

The attached report summarizes flood frequency, flow duration and trend analyses for the Dungeness River near Sequim, Washington. These estimates were completed as part of Task 20 of the Dungeness River Geomorphology Investigation. The primary basis for the flood frequency and flow duration estimates, and streamflow trends, are U.S. Geological Survey peak discharge and mean daily flow records. The data and results presented in the report are appropriate for detailed hydraulic and geomorphic studies and analyses.

This report was peer reviewed by Kenneth L. Bullard. If you have any questions regarding the contents of the report, please contact John England at 303-445-2541.

cc: Jamestown S'Klallam Tribe (Newberry, Rot), LCA-6000 (Nelson), PN-3609 (Link), (w/attachment to each)

bc: D-8330 (Piety), D-8530 (England, Swain, File [2]), D-8540 (Keeley, Yang) (w/attachment to each)

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TECHNICAL SERVICE CENTER
Denver, Colorado

FLOOD FREQUENCY, FLOW DURATION AND TREND ANALYSES DUNGENESS RIVER GEOMORPHOLOGY INVESTIGATION

DUNGENESS RIVER, WASHINGTON

Prepared by

John F. England, Jr.
Hydraulic Engineer
Flood Hydrology Group

U.S. Department of the Interior
Bureau of Reclamation

SEPTEMBER 1999

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Flood Frequency, Flow Duration and Trend Analyses
Dungeness River Geomorphology Investigation
Dungeness River, Washington

PREPARED BY: ______________________ **DATE:** __________

John F. England, Jr., Hydraulic Engineer
Flood Hydrology Group

PEER REVIEWED BY: ______________________ **DATE:** __________

Kenneth L. Bullard, Hydraulic Engineer
Flood Hydrology Group

Flood Frequency, Flow Duration and Trend Analyses
Dungeness River Geomorphology Investigation
Dungeness River, Washington

This report summarizes flood frequency, flow duration and streamflow trends for the Dungeness River near Sequim, Washington. These estimates were completed as part of Task 20 of the Dungeness River Geomorphology Investigation. The primary basis for the flood frequency and flow duration estimates, and streamflow trends are U.S. Geological Survey peak discharge and mean daily flow records. The data and results presented herein are appropriate for detailed hydraulic and geomorphic studies and analyses.

INTRODUCTION AND OBJECTIVES

The Dungeness River is located in the northeast corner of the Olympic Peninsula. The river flows north from its headwaters in Olympic National Park to the Strait of Juan de Fuca; the river is approximately 32 miles long. Gray Wolf River is the main tributary to the Dungeness River; this left-bank tributary flows into the Dungeness River at about River Mile 15.8. The Dungeness River Geomorphology study area is located a few miles west of Sequim; the study reach is approximately 30 miles long. Elevations in the basin range from sea level at the Dungeness Spit (tidewater) to about 6,400 feet (Mt. Mystery) and 7,788 feet (Mt. Deception) at the headwaters of the Dungeness and Gray Wolf Rivers, respectively. Clark and Clark (1998) describe the basin physiography in detail.

There is one active U.S. Geological Survey streamflow gaging station in the Dungeness River basin: the Dungeness River near Sequim, Washington. Data from this gage are used to estimate flows on the Dungeness River. A list of basin, flood and climatic characteristics for this site is presented in Sumioka et al. (1998). A brief summary includes:

USGS Gaging Station No.:	12048000
Drainage Area:	156 mi^2
Latitude (decimal degrees):	48.014
Longitude (decimal degrees):	123.131
Mean Basin Elevation:	4,500 ft.
Mean Annual Precipitation:	62 in.
24-hour, 2-day Precipitation:	3.5 in.

There are three main objectives of this study: (1) estimate flood peak and volume frequencies; (2) estimate flow duration; and (3) assess streamflow trends for the Dungeness River. A secondary objective was to describe flood mechanisms on the Dungeness River.

STREAMFLOW DATA SOURCES AND DISCUSSION

The precipitation source for the Olympic Peninsula, including the Dungeness River basin, is from prevailing southwesterly and westerly Pacific moisture (Williams, 1991). Major storms that result in heavy precipitation and large-magnitude flooding in the Dungeness River basin usually occur in winter and are generally warm frontal systems. Intense winter rainfall on snow at low altitudes causes most of the flooding in western Washington (Williams, 1991). River basin drainage area and mean annual precipitation are the most significant characteristics for regional flood regression equations (Sumioka et al., 1998). However, topography is an important local factor to predict peak discharge magnitude and storm precipitation on the Olympic Peninsula. The Olympic Mountains act as a significant precipitation barrier to the Dungeness River basin. The Dungeness basin is located in a rain shadow; mean annual runoff (in inches) is about 44 percent of the Elwha River runoff.

Streamflow Data

Four data sources from the U.S. Geological Survey were used to characterize streamflow in the Dungeness River basin:

- Annual peak discharge estimates at gaging stations;
- Daily mean discharge estimates at gaging stations;
- Indirect discharge measurement estimates at gaging stations; and
- Qualitative information from USGS Water-Supply Papers and other reports.

The U.S. Geological Survey has published streamflow records from three gaging stations located in the Dungeness River basin upstream from Dungeness Spit; the sites are listed in Table 1. Currently, the only active gaging station in the Dungeness River basin is the Dungeness River near Sequim (Wiggins et al., 1998). Streamflow data from this station were used in flood volume frequency, flow duration and trend analyses. The peak discharge data from the three gages listed in Table 1 were combined to estimate peak discharge exceedance probabilities.

Table 1
U.S. Geological Survey Streamflow Gages Located in the Dungeness River Basin, Washington

USGS Gaging Station No.	Station Name	Drainage Area (mi^2)	Period of Record	Maximum Discharge and Date	Maximum Unit Discharge ($ft^3/s/mi^2$)
12048000	Dungeness River near Sequim	156	06/1923-09/1930, 06/1937-present	7,120 ft^3/s 11/24/1990	45.6
12048500	Dungeness River below Canyon Creek near Sequim	170	07/1897-07/1898	2,950 ft^3/s 11/18/1897	17.4
12049000	Dungeness River at Dungeness (Sequim)	197	07/1898-12/1901	7,540 ft^3/s 12/20/1900	38.3

The U.S. Geological Survey has been collecting streamflow data in Washington and the Olympic Peninsula since the late 1800s. Washington streamflow records prior to 1951 are summarized in Parker and Lee (1923), Grover and Parker (1940), and USGS (1955). Since that time, records have been summarized in Water-Supply Papers and are now listed in annual Water Resources Data reports (e.g., Wiggins et al., 1998). Peak and mean daily discharge estimates for the Dungeness River basin gages listed in Table 1 are obtained from these sources. The compilation reports by Parker and Lee (1923) and Grover and Parker (1940) indicate that there are major gaps in stream gaging on the Olympic Peninsula through about 1935. Records are particularly fragmentary on the Peninsula prior to 1900 and from 1900 to 1920.

Instantaneous, annual maximum streamflow is a strong indicator of flood potential and flood seasonality. The primary mechanism that causes large-magnitude instantaneous flood peaks in the Olympic Peninsula region is warm rains from winter storm frontal systems. Regional streamflow data indicate the flood potential is high in winter (early November through early March) and early summer (May to June). Peak discharge data from the Dungeness River indicates that the largest-magnitude floods occur in winter; however some annual peak discharges are from spring snowmelt. Based on 67 years of streamflow data on the Dungeness River near Sequim, winter floods are much more common than spring snowmelt (Figure 1).

Mean daily flow can also indicate flood seasonality and highlight rainfall-dominated floods from snowmelt floods. For example, winter storms caused repeated floods in 1991 that were absent in 1948; however there were higher snowmelt flows in the spring during 1948 (Figure 2). Overall, mean daily streamflow on the Dungeness River is bimodal (Figure 3). Winter floods produce larger peaks and maximum mean daily flows, but median flows are higher during late spring snowmelt runoff.

The largest observed flood on the Dungeness River, in terms of instantaneous peak discharge (about 7,540 ft^3/s), occurred on December 20, 1900. There was no readily available information that discussed this flood. Peak discharges nearly as large as December 1900 have occurred on the Dungeness River on March 11, 1900 (7,000 ft^3/s), November 26, 1949 (6,820 ft^3/s) and November 24, 1990 (7,120 ft^3/s). The 1949 flood indirect measurement defined the rating curve for these large floods (USGS, 1955). U.S. Geological Survey files indicate that there is some uncertainty in the 1949 peak discharge estimate, and conflict with published records that document the peak discharge as 6,820 ft^3/s (USGS, 1953 p. 39). A review of the 3-section slope-area (USGS, 1950) indicated that the computed peak discharge was 7,260 ft^3/s and was published as 7,120 ft^3/s. The 1990 peak was estimated from the rating curve extended to the 1949 flood (USGS, 1990).

Hubbard (1996) summarized the November 7-11 and 21-25, 1990 storms in western Washington. The November 24 flood on the Dungeness River was due to higher than normal precipitation in October and November, warm temperatures that melted snow, and intense rains (Hubbard, 1996). The November 1990 storms caused extreme floods, significant damage and two deaths; 18 counties (including Clallam) were declared disaster areas (NOAA, 1990). However, this flood is not unprecedented in the Dungeness River basin as floods of comparable magnitude have occurred in the past.

Historical Flood Information and Unobserved Flood Estimates

There is little readily available information that documents historical (pre-gaging station) flooding, or lack of flooding, in the Dungeness River basin. Bodhaine and Thomas (1964, p. 18) state that historical data are not available in Washington except for the Skagit River. Because little to no information on maximum stages and peak discharges was available in the basin or region prior to the commencement of streamflow gaging on the Dungeness River (July 1897), the peak discharge record for this report was not extended earlier than Water Year 1898.

Peak discharge estimates from the three gaging stations in Table 1 were combined to estimate a long record on the Dungeness River. A longer record provides more assurance for peak discharge probability model selection and reduced variance of estimated quantiles. Because storm systems that generate extreme floods on the Olympic Peninsula are significantly larger than individual drainage areas, it was assumed that flood-producing rainstorms would cover the lower Dungeness River watershed equally. No adjustments were made for drainage area differences between the sites, because: (1) an adjustment factor is within measurement error of large floods (10 percent); and (2) there were no overlapping peak discharge records to confirm a square-root (or other) drainage area adjustment. Peak discharge estimates for the three gaging stations on the Dungeness River (Table 1) were obtained from USGS (1955), for flows prior to 1951.

Censored data methods (e.g., Cohn et al., 1997; England, 1998) were used to “fill in” unobserved peak discharge estimates on the Dungeness River for water years 1902-1923 and 1931-1937. In this context, the term “censored data” means that some observations are missing or unknown. Instead of estimating a peak discharge for each of the 29 unobserved floods, data and information were analyzed to document that the unobserved (unmeasured) peak discharges were “less than” or did not exceed some level. Because the November 1990 flood was widespread, caused significant damage, and was noted, this flood and associated documentation was used as an analog for the unobserved floods on the Dungeness River.

Many streams on the Olympic Peninsula experience large floods on the same day, because the storm systems are large. Peak discharge records from three sites on the Olympic Peninsula were utilized to examine correlation with the Dungeness River for concurrent periods: the Elwha River at McDonald Bridge near Port Angeles (station no. 12045500); the Dosewallips River near Brinnon (station no. 12053000); and the Quinault River at Quinault Lake (station no. 12039500). The Dosewallips River (1938-1962) and Elwha River (1924-1930, 1938-1997) peak discharge records were compared with the Dungeness River to examine a possible peak discharge non-exceedance (censoring) level for 1930-1937 on the Dungeness River. Likewise, the Quinault River data were used to examine a censoring level for the unobserved Dungeness River peak flows from 1902-1923. Simple linear regression and correlation techniques were employed, as outlined in Helsel and Hirsch (1992). The Elwha River record was used to examine the peak discharge censoring level instead of the Dosewallips data, because three correlation metrics (Kendall's Tau, Spearman's rho and Pearson's r) (Helsel and Hirsch, 1992) were greater at a 0.01 significance level (Figure 4). Similarly, the Dungeness River peak discharge estimates were highly correlated with the Quinault River (Figure 5).

These data showed that annual peak discharges for the Quinault and Elwha Rivers typically occur on the same day as the Dungeness River, especially for the largest floods. The relatively strong correlation results also confirm that storm mechanisms are regional and widespread. Considering uncertainty in both regression estimates, a peak discharge censoring level was set equal to the December 1900 peak (7,540 ft^3/s). It is believed that if an extreme flood had occurred from 1902-1923 and/or 1931-1937, it would have been documented. While a large flood did occur on the Quinault River in November 1909, the regression results indicated it would not have been larger than the December 1900 flood on the Dungeness River.

Based on the information and analyses presented above, the flood observation period for the Dungeness River at this location is extended to 1898. It is assumed that unobserved floods in this time period (1902-1923, 1931-1937) were lower in magnitude than the December 1900 peak discharge (7,540 ft^3/s). A compiled historical peak discharge time series for estimated flows on the Dungeness River is presented as Figure 6. The data consist of 71 observed floods and 29 years of censored values below the December 1900 peak. Currently, there is insufficient flood data at this location and in the region (less than 110 years) to estimate extreme flood probabilities (1 in 200 to 1 in 10,000).

There is considerable uncertainty in combining mean daily discharge records from the three gages. Unlike peak discharge estimates, volume, median and low-flow records at the different gaging station sites could potentially be substantially different. No analyses were made as part of this report to determine if the mean daily flow records at the different sites were equivalent. For simplicity, the 68-year mean daily flow record on the Dungeness River near Sequim was used to estimate annual maximum one day and three-day mean volume frequencies, flow duration and examine for trends; streamflow data from the other two gages were not used for these estimates.

Paleoflood Data

Currently there are no paleoflood hydrology data available in the Dungeness River basin. Paleoflood data could be used to significantly extend the flood observation time base (hundreds to thousands of years) on the Dungeness River. One could estimate low probability (i.e., 1 in 1,000 to 1 in 10,000) peak discharges with these data.

HYDROLOGIC ANALYSES METHODS

Three analysis techniques were utilized for the Dungeness River geomorphology study: (1) frequency analysis of flood peak discharge and annual maximum volume estimates at a site; (2)

mean daily flow-duration estimates; and (3) mean daily flow trend analyses. In the context of the Dungeness River geomorphology study, peak and volume flood frequency estimates can be used for estimating stream bed shear stress and stream power (e.g., Costa and O'Connor, 1995). Flow-duration curves can be used to infer median river flow in a "typical" or "hypothetical" year, and determine instream flow requirements for habitat (e.g., Milhous et al., 1990).

Flood Frequency

Flood frequency estimates were made for three variables: annual instantaneous peak discharge estimates, annual maximum mean daily flows, and annual maximum 3-day mean flows. The data were assumed to follow a log-Pearson Type III (LP-III) distribution. The method of moments was used to estimate the LP-III parameters for peak discharge estimates using Expected Moments Algorithm (EMA) techniques (Cohn et al., 1997; England, 1998; England et al., 1998). The EMA procedure is an alternate method to USWRC (1982) for treating historical peak discharge information. Cohn et al. (1997) and England (1998) showed that the EMA estimator is an improvement over USWRC historical procedures. As discussed above, peak discharge data utilized to estimate flood frequency consist of 71 annual peaks and 29 years of censored flows less than the 1901 peak (Figure 6). One- and 3-day annual maximum mean daily flows for the 68 years of known observations were used to estimate flood volume frequency using USWRC (1982) procedures. The data are sufficient to define flood frequency relations to the 1 in 100 annual exceedance probability (100-year flood); the model and confidence intervals are tentatively extrapolated to 1 in 200.

Flow Duration

Mosley and McKerchar (1993, p. 8.27) provide a definition for flow duration: "A flow-duration curve (FDC) plots cumulative frequency of discharge, that is, discharge as a function of the percentage of time that the discharge is exceeded. It is not a probability curve, because discharge is correlated between successive time intervals, and discharge characteristics are dependent on the season of the year." Searcy (1959) and Vogel and Fennessey (1994) describe the theory and methods to construct flow-duration curves (FDCs). Flow-duration curve applications are presented and reviewed by Searcy (1959) and Vogel and Fennessey (1995). In addition to FDCs, box plots are used in this study to display percentiles of daily streamflow data. Box plots summarize the statistical characteristics of the data, such as central tendency, variability, symmetry (skewness) and extremes in a concise form (e.g., Helsel and Hirsch, 1992; Hirsch et al., 1993).

Two types of FDCs were constructed: period-of-record FDCs and a median annual FDC. The period-of-record FDC is constructed using flow data for all the years (entire period) that the gaging station is in operation. Thus, this FDC is dependent on the period used. In a strict sense, the flow-duration curve applies only to the period for which data were used to develop the curve (Searcy, 1959 p. 2). Vogel and Fennessey (1994) introduced the concept of an annual FDC. One constructs a FDC for each streamflow year i, $i = 1, ..., n$; then one may use the sample of n FDCs to estimate a mean or median curve and confidence intervals. If one considers n individual FDCs, each corresponding to one of the individual n years of record, then one may treat those n

annual FDCs in much the same way one treats a sequence of annual maximum (or minimum) streamflows (Vogel and Fennessey, 1994).

The 68 years of mean daily streamflow at the Dungeness River near Sequim gage were used to construct period-of-record FDCs and a median annual FDC. Period-of-record FDCs were estimated for: (1) the entire record (all days and seasons); (2) three separate seasons; and (3) each month. Seasonal mean daily FDCs were constructed for the November through March, April through July, and August through October seasons based on instream flow recommendations (Hiss, 1993).

Instead of using the bin method to construct the FDC empirical probability distribution function (as suggested by Searcy, 1959), the cumulative distribution function (CDF) of the FDC is estimated directly via techniques outlined in Vogel and Fennessey (1994). The period-of-record FDC is estimated using three steps:

1. separate out the s mean daily flows for each season and year i of the n years of record ($i = 1, ..., n$);

2. combine the s seasonal flows for each year i into a single series *(ns)* and rank the entire seasonal mean daily flow $q(j)$ series ($j = 1, ..., ns$), from largest to smallest magnitude; and

3. utilize a plotting position (equation 1) to estimate the percentage of time $p(j)$ a particular flow $q(j)$ was equaled or exceeded.

$$p(j) = \left(\frac{j}{ns+1}\right) 100 \qquad j = 1,...,ns \tag{1}$$

Note that $q(1)$ is the largest observation and $q(ns)$ is the smallest daily streamflow observation. Likewise, $p(1)$ and $p(ns)$ are the smallest and largest percent exceedances, respectively.

An median annual FDC is constructed using three steps:

1. the s (= 365) daily flows $q(k)$ for an individual year i are ranked from largest to smallest ($k = 1,..., s$);

2. a plotting position (equation 2) and a nonparametric smoothing function (equation 3) are used to estimate the exceedance probability $p(k)$ and quantile estimate $Q(k)$ for the s observations within year i;

$$p(k) = \frac{k}{s} \qquad k = 1,...,s \tag{2}$$

$$Q(k) = (1-\theta)q_{(k)} + \theta(q_{(k+1)}) \qquad k = 1,...,s \tag{3}$$

and $\theta = [(s+1)p(k) - k]$

From equations (2) and (3), one computes *n* individual FDCs, one for each of the *n* years of streamflow.

3. The *n* flow duration curve observations (one for each year) of *Q(k)*, for each exceedance probability *p(k)*, are treated as a random sample. The *n* observations of *Q(k)* for each *p(k)* are ranked from smallest to largest. The median *Q(k)* value for each *p(k)* is then determined (e.g., Helsel and Hirsch, 1992 p. 6) for each of the *s* observations in a typical year; this is the median annual FDC.

The 100(1 - α)% confidence interval [*Q(L)*, *Q(U)*] about the median value *Q(k)*, where *Q(L)* and *Q(U)* denote the lower and upper limits of that interval, is constructed using two steps:

1. A confidence level (α) is selected, e.g. α = 0.05 for 95% intervals. The *n* ranked observations *Q(k)* for each *p(k)*, computed in step (3) above, are used as the random sample about the true quantile *Q* for a particular exceedance probability *p(k)*. The lower and upper confidence interval for a particular *p(k)* are calculated using equations 4 and 5. Note that *i* is the integer component of [.], and that both *i* and θ are fixed values for this step.

$$Q(L) = (1-\theta)Q(i) + \theta Q(i+1)$$
$$i = [(n+1)\alpha/2]; \quad \theta = (n+1)\alpha/2 - i \tag{4}$$

$$Q(U) = (1-\theta)Q(i) + \theta Q(i+1)$$
$$i = [(n+1)(1-\alpha/2)]; \quad \theta = (n+1)(1-\alpha/2) - i \tag{5}$$

2. The *Q(L)*, *Q(U)* calculations are repeated for each of the *s* daily streamflow observations within a typical year.

In contrast to the period-of-record FDC, the median annual FDC represents the distribution of daily streamflow in a "typical" or median hypothetical year and its interpretation is not affected by the observation of abnormally wet or dry periods during the period of record (Vogel and Fennessey, 1994 p. 496). The median annual FDC is a more appropriate choice than the period-of-record FDC for examining hydrological extremes (< 10% and > 90%) of daily streamflow for a typical year. For a long streamflow record, the period-of-record and median annual FDCs converge for the 10- to 90-percent of time exceedance range. Vogel and Fennessey (1994) present further details to develop period-of-record FDCs, annual FDCs, and associated confidence intervals.

Streamflow Trends

Because there has been some logging and clear cutting activities in the Dungeness River basin, mean daily streamflow were analyzed for monotonic trends (increases or decreases) over time. Trend analyses were used to examine if there was a statistically significant increase (uptrend) or decrease (downtrend) in streamflow over time. Trends in streamflow were assessed using the nonparametric Mann-Kendall test (e.g., Helsel and Hirsch, 1992; Hirsch et al., 1993). This is a robust test that is appropriate when the variable of interest (streamflow) is skewed and has extremes. Lins and Slack (1999) used this test to examine streamflow trends in the United States. Likewise, Liebermann et al. (1989) used the Mann-Kendall test to examine streamflow and dissolved solids trends; Lettenmaier et al. (1994) used the test to examine trends in monthly average temperature, precipitation, streamflow and average of the daily temperature range. The trend analyses conducted here do not identify or differentiate the sources of any trends, such as logging, some other anthropogenic activity, or climate trends, if any trends are identified.

The study methodology used by Lins and Slack (1999) was used here. Two sets of analyses were performed: (1) trend tests for seven streamflow quantiles; and (2) examining interdecadal streamflow variability for four periods. The streamflow quantiles that were analyzed included the annual minimum daily mean (Q_0), the 90th (Q_{90}), 70th (Q_{70}), 50th (Q_{50}), 30th (Q_{30}), and 10th (Q_{10}) percentiles, and the annual maximum daily mean (Q_{100}) flows. Interdecadal streamflow trends were examined for 30, 40, 50, and 60-year periods, all ending in 1998, for the seven streamflow quantiles. Similar to Liebermann et al. (1989) and Lins and Slack (1999), a trend was deemed statistically significant if $p \leq 0.05$, where p is the probability of obtaining the computed test statistic, or one even less likely, when the null hypothesis is true (Helsel and Hirsch, 1992). The computer techniques that were used to estimate Kendall's tau, *p*-level, and median slope are documented in Lumb et al. (1990, 1993) and Flynn et al. (1995).

In addition to the daily flow records, the Dungeness River annual runoff was compared with the Elwha River runoff. Annual runoff, in inches, for each site was estimated by computed the mean annual (365-day) discharge, converting the discharge to a volume, and dividing by the drainage area at each site. Three series were analyzed for period of record and interdecadal trends: the Dungeness River annual runoff; the Elwha River annual runoff; and the ratio of the Elwha to Dungeness runoff.

RESULTS AND DISCUSSION

Peak Discharge

A peak discharge frequency curve was constructed for flows on the Dungeness River (Figure 7) based on the 71 years of peak discharge and 29 years of censored data presented above. The peak discharge LP-III model estimates may be used to estimate exceedance probabilities from 0.95 to 0.01 (1 in 100). The flood frequency results indicate that the two largest rainfloods have an exceedance probability less than about 1 in 50. The estimated frequency curve starts to depart from the trend of the data for exceedance probabilities less than 0.05 (20-year flood). Based on extrapolation of the peak discharge frequency relation, there is a 95 percent chance that flows with an annual exceedance probability of 1 in 200 are less than about 13,000 ft^3/s. Peak discharge flood frequency relations are summarized in Table 2. These estimates are nearly indistinguishable from peak discharge probability estimates presented in Sumioka et al. (1998). For the 100-year flood (exceedance probability 0.01), their weighted peak discharge estimate was 9,270 ft^3/s; 95 percent confidence intervals were 7,660 ft^3/s and 11,600 ft^3/s (Sumioka et al. 1998, p. 39).

Table 2
Peak Discharge Flood Frequency Estimates
Dungeness River near Sequim, Washington

Annual Exceedance Probability (percent)	Return Period (years)	Peak Discharge (ft^3/s)		
		5% Confidence Limit	Model Estimate	95% Confidence Limit
50	2	2640	2990	3380
20	5	4180	4690	5260
10	10	5110	5780	6550
4	25	6060	7120	8350
2	50	6610	8060	9820
1	100	7040	8960	11400

In addition to peak discharge, flood frequency estimates were made for 1-day and 3-day annual maximum mean discharge. The 1-day and 3-day frequency curves are contrasted with the peak discharge frequency curve on Figure 8. A regional coefficient of skew adjustment (USWRC, 1982) was not performed; no low outliers were detected. The curves reflect rainfall runoff-dominated floods; the curves have similar variance and are shifted by the mean. The upper ends of the three frequency curves and data (less than about 0.10 annual probability) are similar and reflect floods caused by rainfall. One- and 3-day mean discharge flood frequency relations are summarized in Table 3. Flood frequency calculation input and output files are attached as Appendix A.

Table 3 1-Day and 3-Day Annual Maximum Mean Flood Frequency Estimates Dungeness River near Sequim, Washington			
Annual Exceedance Probability (percent)	Return Period (years)	Discharge (ft^3/s)	
		1-Day Mean	3-Day Mean
50	2	2060	1590
20	5	3120	2320
10	10	3850	2810
4	25	4820	3430
2	50	5560	3900
1	100	6310	4360

Flow Duration

Two sets of flow-duration curves were made: period-of-record annual, seasonal and monthly FDCs; and a median annual FDC. The period-of-record annual FDC (Figure 9) shows that mean daily flows are less than about 480 ft^3/s 75 percent of the time. The median flow (50 percent) is 293 ft^3/s for the water year. Mean daily flows for the April-July season are nearly always greater than the two other selected seasons. In addition, daily flows during the August-October season are usually lower than flows in any other season for a given percentile (Figure 10). Specific FDC percentiles of daily mean discharge for the year and each of the three seasons are presented as box plots on Figure 10 and are summarized in Table 4. These mean daily flow FDCs are not directly comparable to the recommended monthly instream flows (Hiss, 1993), because the monthly flows are computed by averaging mean daily flows for each month and combining specified months. Nevertheless, these daily FDCs indicate that the recommended monthly instream flows (Hiss, 1993) would be exceeded 13.6 percent of the time for the November through March season (575 ft^3/s), and about 48.6 percent of the time for both the April through July (475 ft^3/s) and August through October (180 ft^3/s) seasons, on a daily basis. Mean daily flow-duration curves for each individual month, grouped by season, and percentiles are attached as Appendix B.

Instead of using a period-of-record curve that is sensitive to hydrological extremes, a median annual FDC was computed and is shown as Figure 11. The confidence intervals associated with the median annual FDC have a precise interpretation (Vogel and Fennessey, 1994 p. 498): for a particular quantile *Q*, the confidence intervals *Q(L)* and *Q(U)* represent the random interval within which one would expect the true annual median quantile *Q* to fall 100(1-α)% of the time. The median annual FDC is nearly indistinguishable from the period-of-record FDC between 5 and 95 percent exceedance. Thus, flows greater than about 1,300 ft^3/s and less than about 70 ft^3/s are not common for a "typical" or median year but can certainly be expected (well within 90 percent confidence intervals) for the period of record (Table 5).

Table 4
Mean Daily Flow Duration Statistics
Dungeness River near Sequim, Washington
Period of Record 06/01/1923-09/30/1930, 06/01/1937-09/30/1998

parameter	Annual	Season		
		November-March	April-July	August-October
number of samples	25081	10285	8418	6378
mean (ft^3/s)	380.7	370.2	518.5	215.5
standard deviation (ft^3/s)	304.9	357.9	257.1	138.3
minimum observation (ft^3/s)	65	65	98	66
99.99 percent exceedance (ft^3/s)	65	65	83	42
99.94 percent exceedance (ft^3/s)	68	66	122	68
99.7 percent exceedance (ft^3/s)	76	73	139	72
99 percent exceedance (ft^3/s)	88	84	164	83
96.75 percent exceedance (ft^3/s)	104	105	195	93
90 percent exceedance (ft^3/s)	133	137	244	109
80 percent exceedance (ft^3/s)	168	169	299	125
75 percent exceedance (ft^3/s)	186	184	326	134
70 percent exceedance (ft^3/s)	205	200	352	141
60 percent exceedance (ft^3/s)	245	233	408	159
50 percent exceedance (ft^3/s)	293	269	465	177
40 percent exceedance (ft^3/s)	351	316	567	201
30 percent exceedance (ft^3/s)	428	378	608	234
25 percent exceedance (ft^3/s)	480	417	651	254
20 percent exceedance (ft^3/s)	544	471	708	278
10 percent exceedance (ft^3/s)	724	672	858	357
3.25 percent exceedance (ft^3/s)	1040	1160	1100	507
1 percent exceedance (ft^3/s)	1471	1940	1360	750
0.3 percent exceedance (ft^3/s)	2200	2913	1540	1190
0.06 percent exceedance (ft^3/s)	3318	4041	1830	1669
0.01 percent exceedance (ft^3/s)	5100	5276	1852	1700
maximum observation (ft^3/s)	5280	5280	2200	2480

Table 5 **Approximate Median Daily Flow Duration Statistics for a Typical Year** **Dungeness River near Sequim, Washington**			
Percent Exceedance	**5 Percent Confidence (ft^3/s)**	**Median Curve (ft^3/s)**	**95 Percent Confidence (ft^3/s)**
10	326	695	1076
25	232	484	695
50	154	292	414
75	109	198	277
90	81	143	220

Trend Analyses

No statistically significant ($p \leq 0.05$) trends were found for the Dungeness River mean daily flow percentiles over the period of record analyzed (1924-1930, 1938-1998). Based on these trend analyses, it appears that there are no trends (increases or decreases) in mean daily streamflow for the Dungeness River period of record, for the percentiles investigated. However, there were statistically significant and consistent interdecadal downtrends for two low flow percentiles: the annual minimum, and the 90th percentile (Table 6). There is a consistent downtrend, for the last 40 to 60 years, for low streamflow percentiles. These trend results are consistent with the general pattern observed by Lins and Slack (1999) for the Pacific Northwest region. Trend analyses results and mean daily flow time series that were analyzed are attached as Appendix C.

Table 6 **Significant Interdecadal Trends** **Dungeness River near Sequim, WA**				
Decade	**Percentile**	**Kendall's Tau**	**p-level**	**median slope**
1939-1998 (60 years)	minimum	-0.189	0.034*	-0.333
1949-1998 (50 years)	minimum	-0.364	0.000*	-0.750
1949-1998 (50 years)	90 percent exceedance	-0.239	0.015*	-0.891
1959-1998 (40 years)	minimum	-0.360	0.001*	-0.881
1959-1998 (40 years)	90 percent exceedance	-0.255	0.021*	-1.200

* significant ($p \leq 0.05$)

In addition to mean daily streamflow, trends in total annual runoff from the Dungeness and Elwha Rivers were investigated. Similar to peak discharge, annual runoff from these two basins is highly correlated (Figure 12). Based on data from 1938 through 1996, mean runoff for the

Elwha River (76.2 inches) is 2.3 times the annual runoff from the Dungeness River (Figure 12). No statistically significant trends for the period of record and for interdecadal periods were identified for the Dungeness and Elwha Rivers, or for the runoff ratio of the two sites. Annual runoff trend results are attached as Appendix C.

CONCLUSIONS

1. Flooding in the Dungeness River basin is caused primarily by warm rains from winter storm frontal systems. The November 1990 floods are a good analog for extreme floods in the Dungeness River basin. Instantaneous peak discharge data indicate that the largest-magnitude floods occur in winter and are predominately from rainfall with some snowmelt. However some annual peaks occur in the spring and are from snowmelt. Daily mean streamflow exhibit a distinct bimodal pattern with increased runoff in winter and late spring.

2. Peak discharge probability estimates indicate the so-called 100-year flood ranges between 7,040 and 11,400 ft^3/s with a 95 percent probability; the model estimate is 8,960 ft^3/s. Volume frequency curves are similar in shape to the peak discharge curve. The most extreme flood volumes are caused by rainfall with some snowmelt. One- and 3-day annual maximum mean discharges are 6,310 ft^3/s and 4,360 ft^3/s, respectively for a 1 in 100 annual exceedance probability.

3. A period-of-record FDC for the water year indicated that mean daily flows are typically less than about 480 ft^3/s for 75 percent of the time. The snowmelt high runoff occurs in the April through July season; flows in this season were nearly always greater than other seasons. Mean daily flows in a "typical" runoff year exceed 292 ft^3/s 50 percent of the time, and can range between 154 and 414 ft^3/s with a 95 percent probability.

4. Statistically significant interdecadal downtrends were consistently identified for the annual minimum and 90 percent exceedance mean daily flows, for 40 and 50-year periods. No statistically significant trends were identified for any period of record mean daily flow percentiles for the Dungeness River. Likewise, no statistically significant period of record or interdecadal trends were identified for annual runoff from the Dungeness and Elwha Rivers.

This memorandum was peer reviewed by Kenneth L. Bullard (D-8530). If you have any questions regarding the contents of this report, please contact John England at 303-445-2541.

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Figure 1
Instantaneous Peak Discharge Seasonality
Dungeness River near Sequim, WA (67 years)

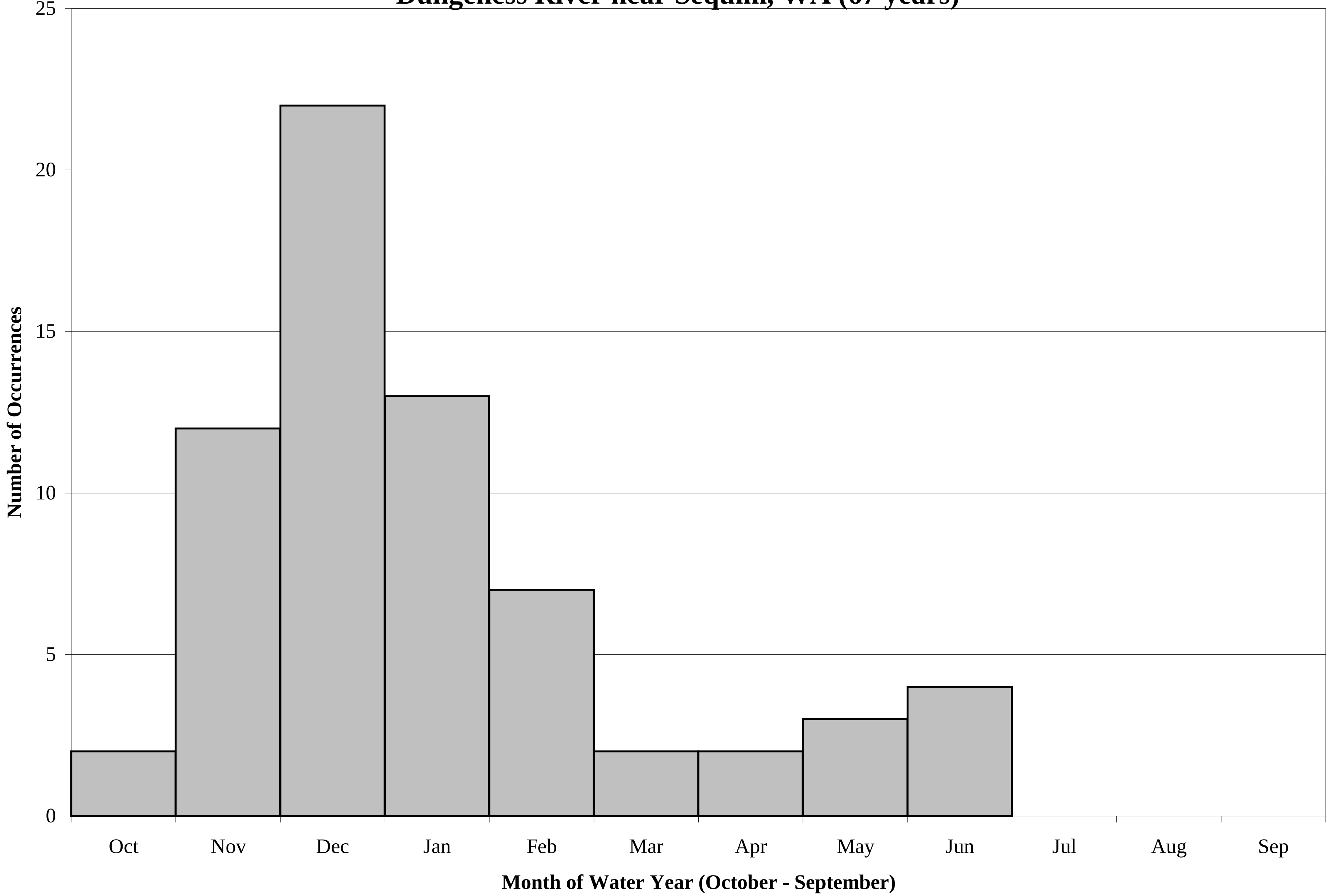


Figure 2
Dungeness River near Sequim, WA
Example Winter Rain and Spring Snowmelt Hydrographs

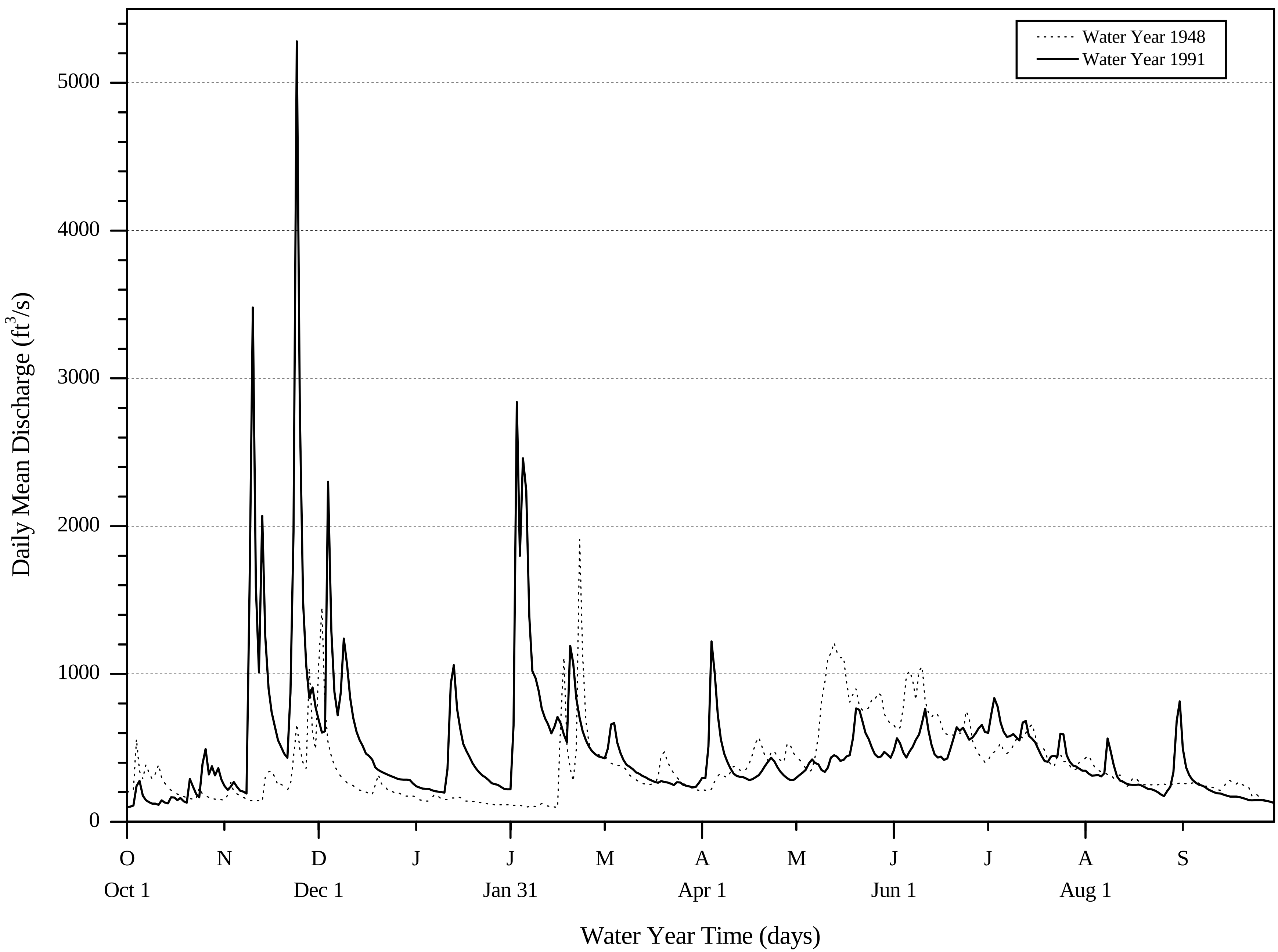


Figure 3
Dungeness River near Sequim, WA
Period-of-Record Mean Daily Flow Duration Hydrograph
06/01/1923 - 09/30/1930, 06/01/1937 - 09/30/1998

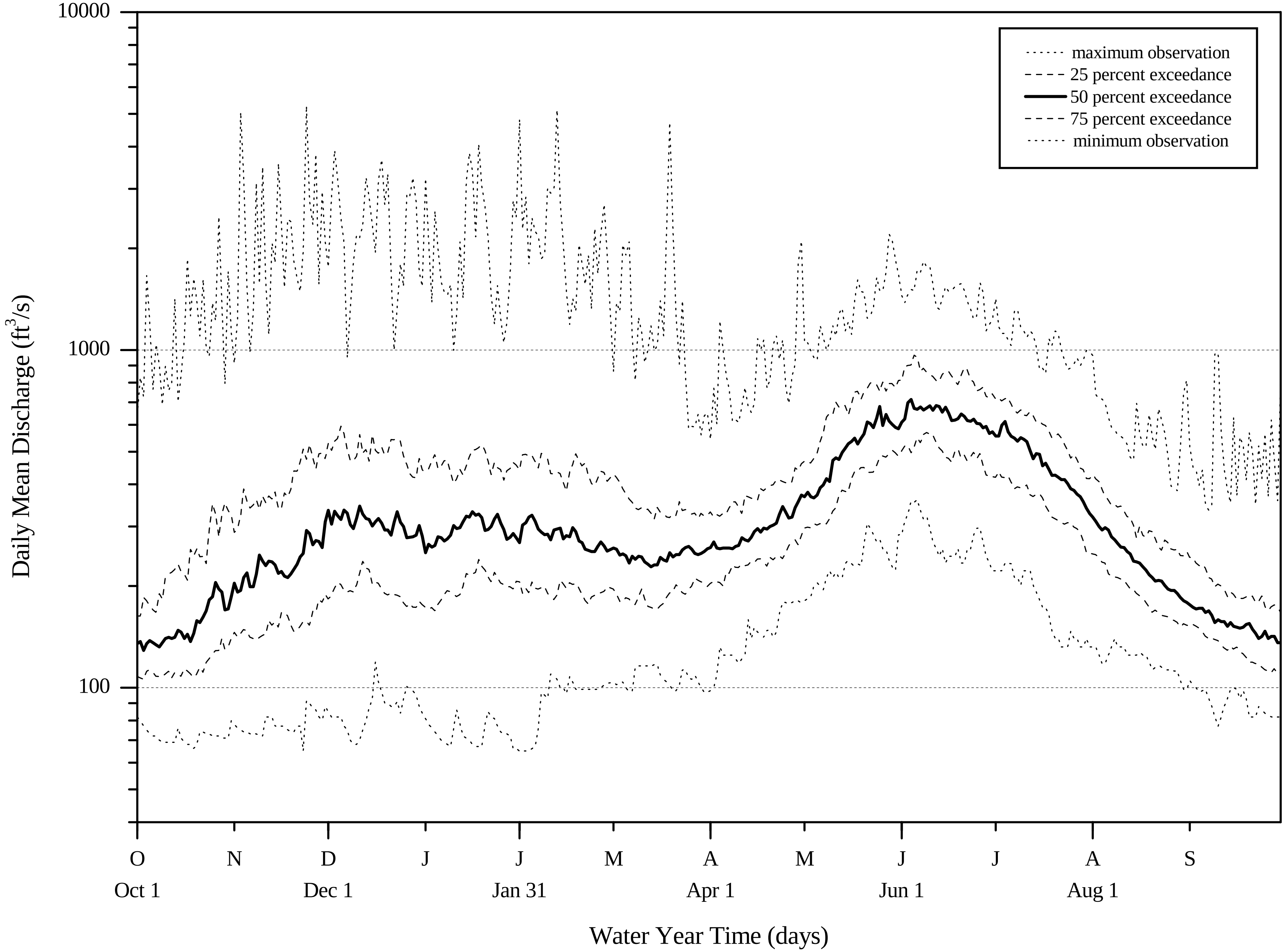


Figure 4
Peak Discharge Relation
Dungeness and Elwha Rivers, WA

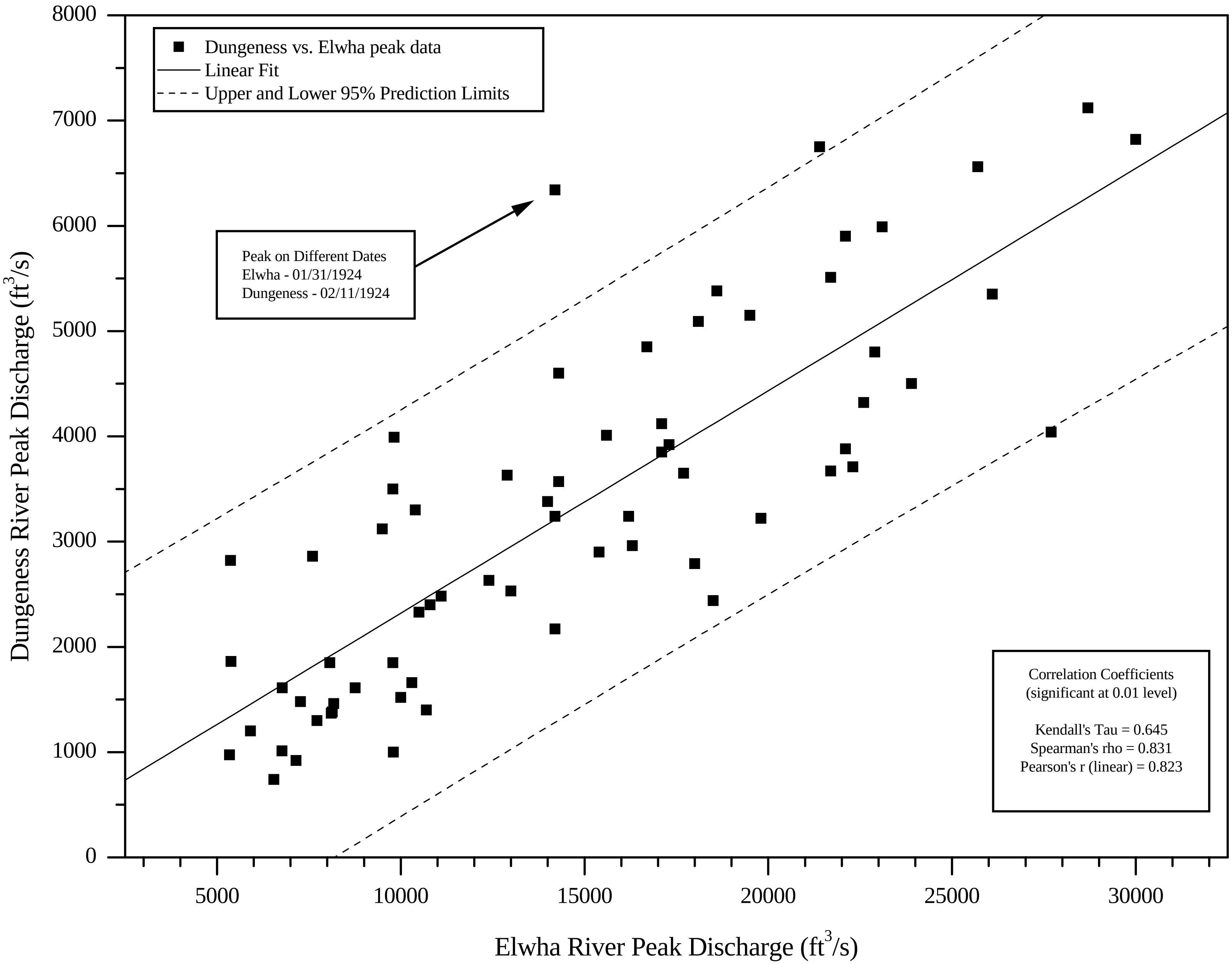


Figure 5
Peak Discharge Relation
Dungeness and Quinault Rivers, WA

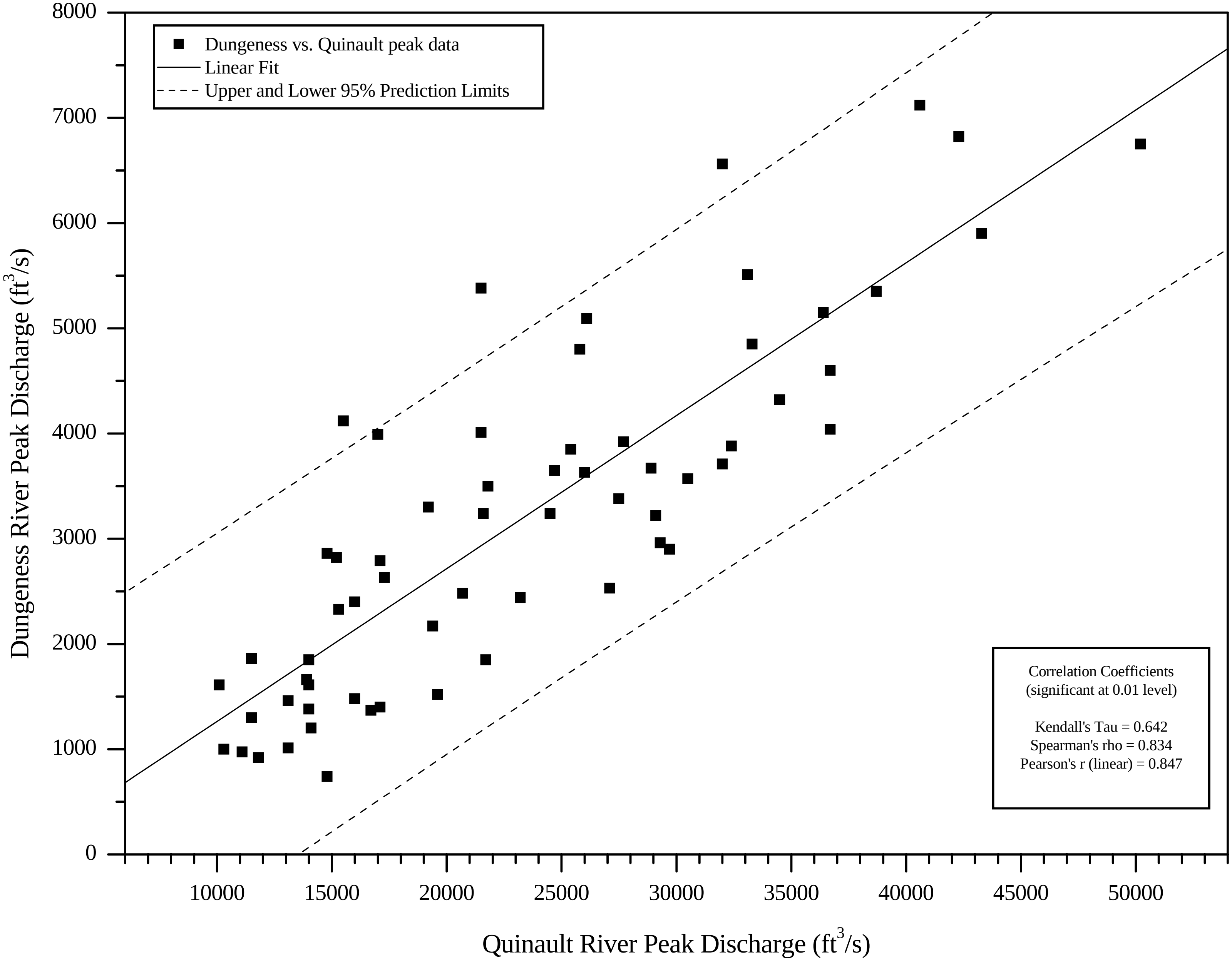


Figure 6
Peak Discharge Estimates
Dungeness River, WA

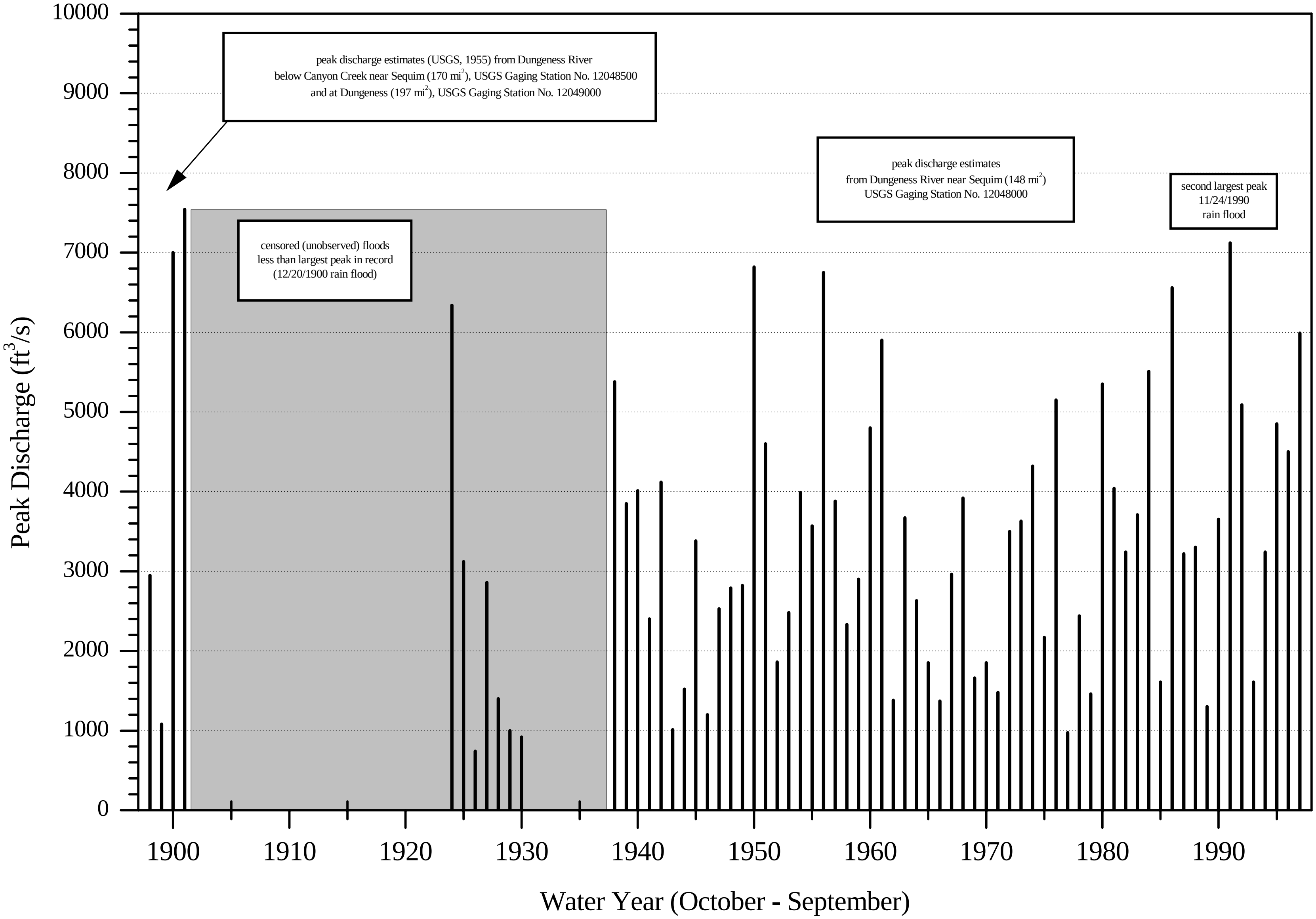


Figure 7
Flood Frequency Curve - Annual Peak Discharge
Dungeness River, Washington

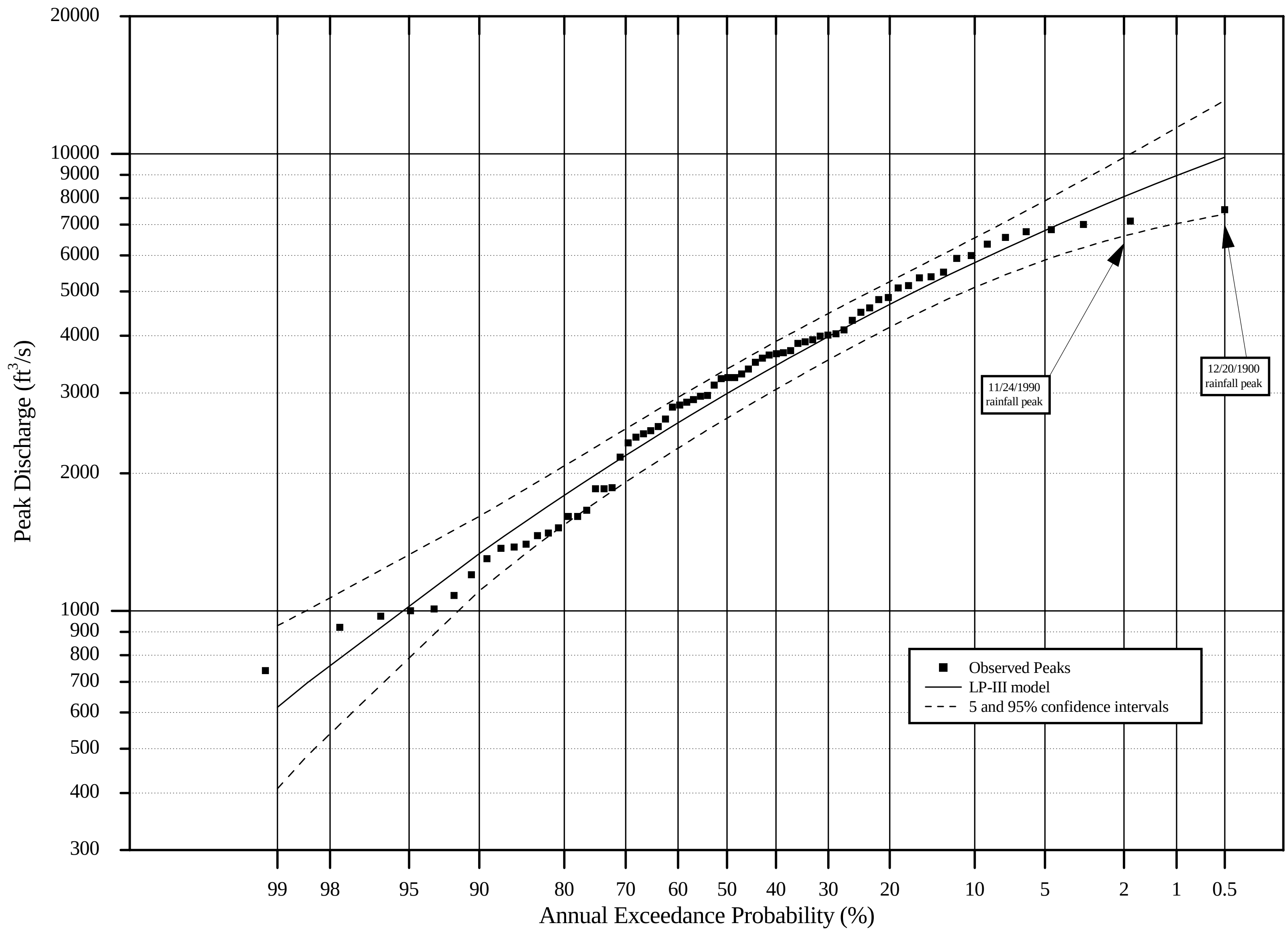


Figure 8
Flood Frequency Curves
Annual Peak, 1-Day and 3-Day Max Mean Values
Dungeness River near Sequim, Washington

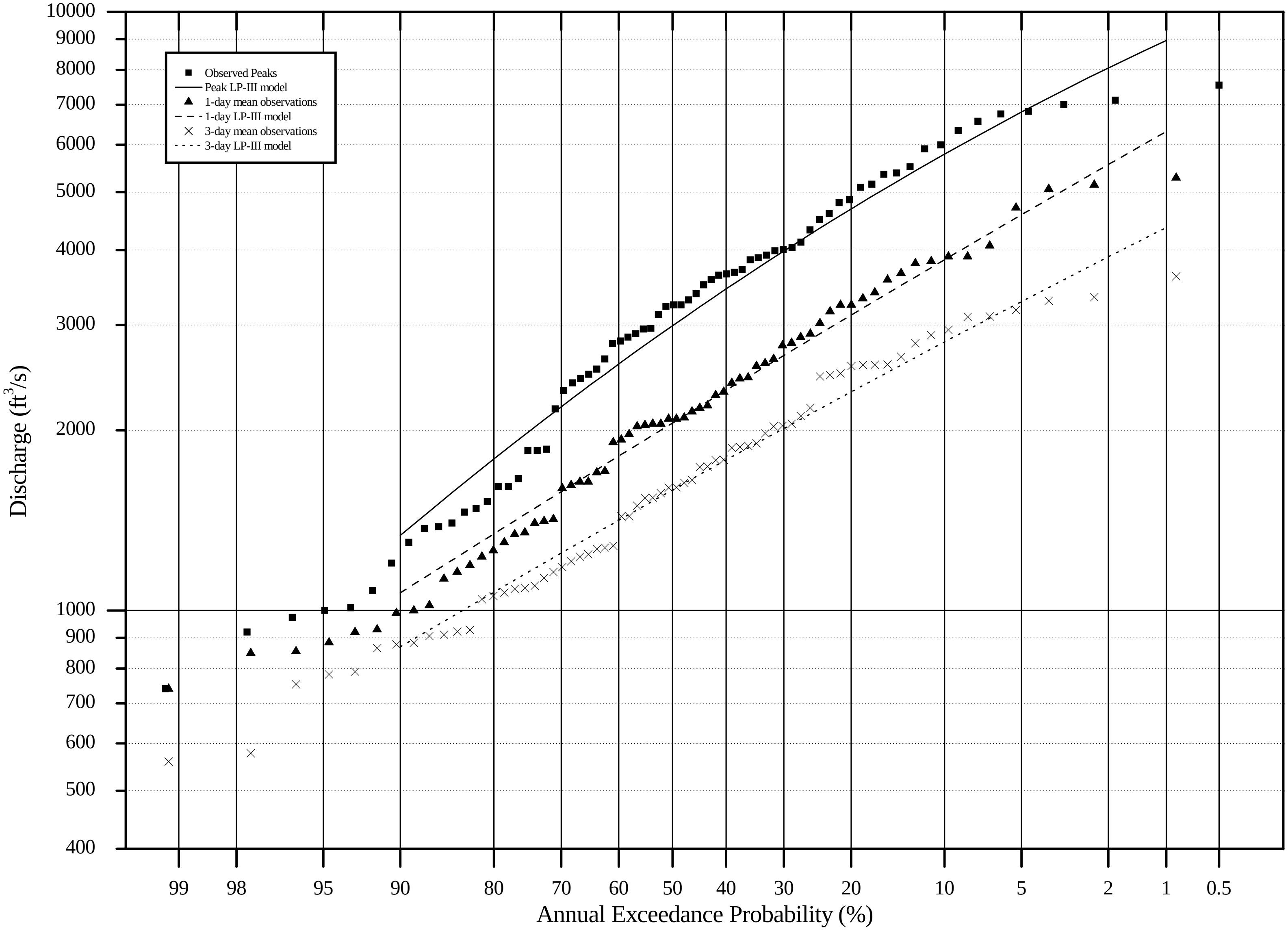


Figure 9
Dungeness River near Sequim, Washington
Seasonal Period of Record Mean Daily Flow-Duration Curves
06/01/1923-09/30/1937, 06/01/1937-09/30/1998

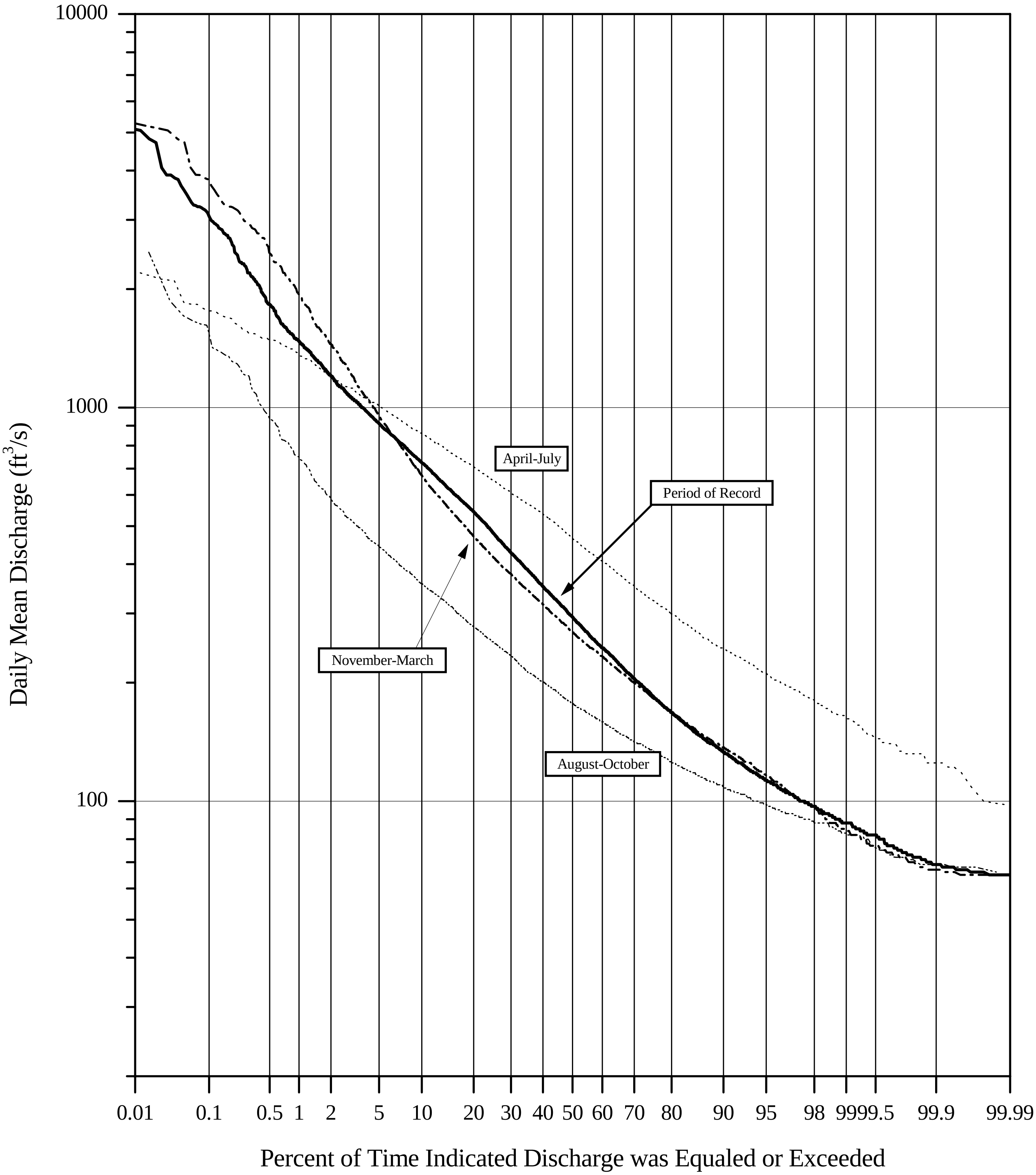


Figure 10
Dungeness River near Sequim, WA
Period-of-Record Daily Mean Discharge
06/01/1923-09/30/1930, 06/01/1937-09/30/1998

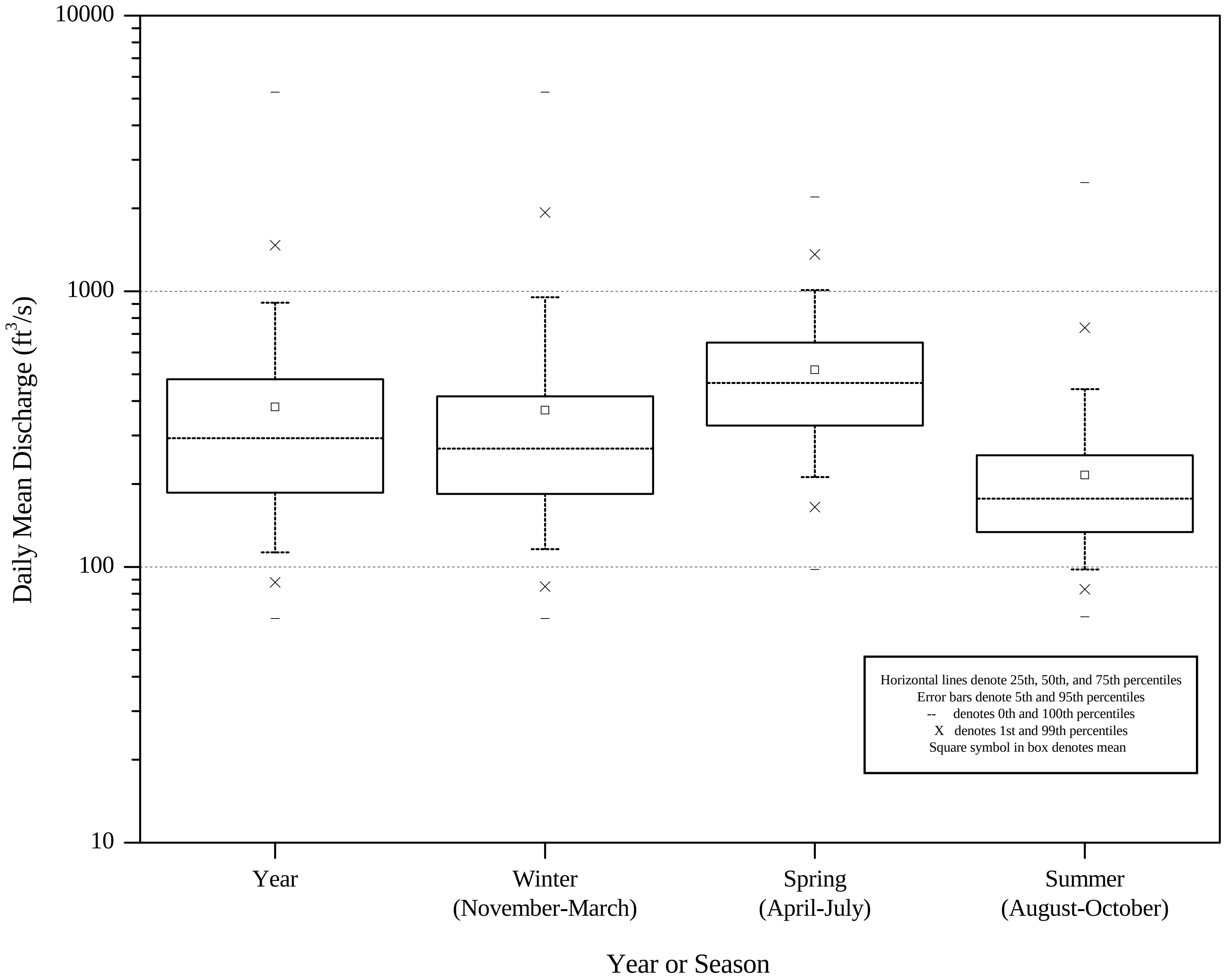


Figure 11
Dungeness River near Sequim, Washington
Annual Median Daily Flow-Duration Curve (FDC) for a Typical Year

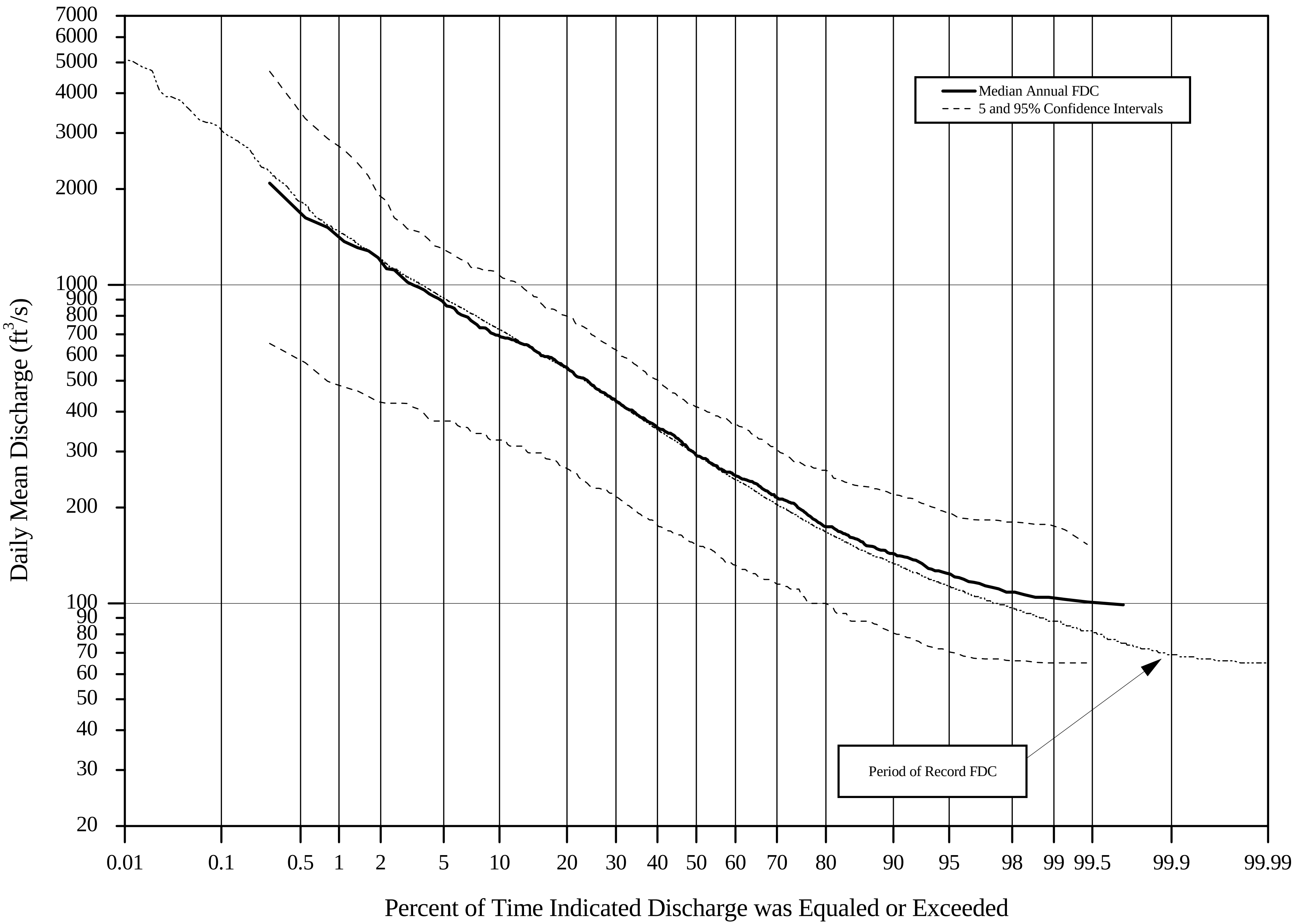
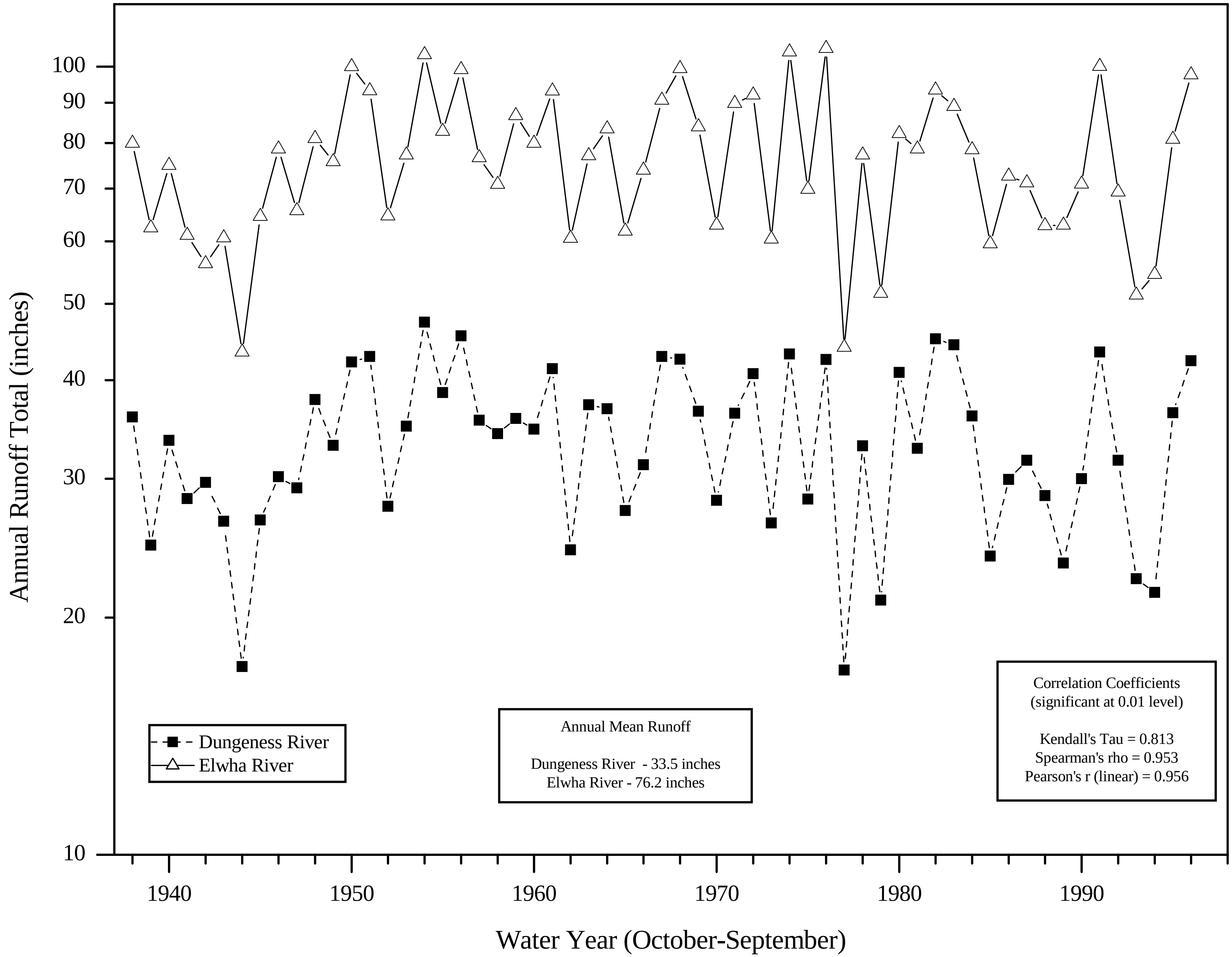


Figure 12
Annual Runoff Relations (1938-1996)
Dungeness and Elwha Rivers, WA



APPENDIX A

Flood Frequency Programs Input/Output

APPENDIX A
FLOOD FREQUENCY PROGRAMS INPUT/OUTPUT
DUNGENESS RIVER NEAR SEQUIM, WASHINGTON

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***************************************************
*     EXPECTED MOMENTS ALGORITHM PROGRAM EMA10    *
*      COMPUTES EXCEEDENCE PROBABILITIES AND      *
* RETURN PERIOD ESTIMATES VIA PLOTTING POSITIONS, *
*                                                 *
* AND COMPUTES MOMENTS, PARAMETERS, AND QUANTILES *
*          ASSUMING A LP-III DISTRIBUTION         *
*         FOR  HISTORICAL, PALEOHYDROLOGIC        *
*           AND SYSTEMATIC PEAK FLOW DATA         *
*                                                 *
*                 CSU VERSION 98.01               *
*              VERSION DATE: 03-17-98             *
***************************************************
```

EMA10 Program Input File Name is: dun-em3.in
EMA10 Program Output File Name is: dun-em3.out
EMA10 Program Log File Name is: dun-em3.log

Dungeness River Estimated Peak Discharges near Sequim, WA
Historical Information to 1898

INPUT AND CALCULATED CONSTANTS

Number of User-Input Bounds is: 1

Bound	nh	neprim	tl	tu	nn	kk	kt	pe
1	29	0	0.0	7500.0	100	1	0	0.010000

Alpha	ns	ne	nqt
.400	71	1	71

INPUT YEAR AND DISCHARGE VALUES FOR PLOTTING

Year	Discharge	tl	tu
1898	2950.0	2950.0	2950.0
1899	1080.0	1080.0	1080.0
1900	7000.0	7000.0	7000.0
1901	7540.0	7540.0	7540.0
1924	6340.0	6340.0	6340.0
1925	3120.0	3120.0	3120.0
1926	740.0	740.0	740.0
1927	2860.0	2860.0	2860.0
1928	1400.0	1400.0	1400.0
1929	1000.0	1000.0	1000.0
1930	920.0	920.0	920.0
1938	5380.0	5380.0	5380.0
1939	3850.0	3850.0	3850.0
1940	4010.0	4010.0	4010.0
1941	2400.0	2400.0	2400.0
1942	4120.0	4120.0	4120.0
1943	1010.0	1010.0	1010.0
1944	1520.0	1520.0	1520.0
1945	3380.0	3380.0	3380.0
1946	1200.0	1200.0	1200.0

APPENDIX A
FLOOD FREQUENCY PROGRAMS INPUT/OUTPUT
DUNGENESS RIVER NEAR SEQUIM, WASHINGTON

1947	2530.0	2530.0	2530.0
1948	2790.0	2790.0	2790.0
1949	2820.0	2820.0	2820.0
1950	6820.0	6820.0	6820.0
1951	4600.0	4600.0	4600.0
1952	1860.0	1860.0	1860.0
1953	2480.0	2480.0	2480.0
1954	3990.0	3990.0	3990.0
1955	3570.0	3570.0	3570.0
1956	6750.0	6750.0	6750.0
1957	3880.0	3880.0	3880.0
1958	2330.0	2330.0	2330.0
1959	2900.0	2900.0	2900.0
1960	4800.0	4800.0	4800.0
1961	5900.0	5900.0	5900.0
1962	1380.0	1380.0	1380.0
1963	3670.0	3670.0	3670.0
1964	2630.0	2630.0	2630.0
1965	1850.0	1850.0	1850.0
1966	1370.0	1370.0	1370.0
1967	2960.0	2960.0	2960.0
1968	3920.0	3920.0	3920.0
1969	1660.0	1660.0	1660.0
1970	1850.0	1850.0	1850.0
1971	1480.0	1480.0	1480.0
1972	3500.0	3500.0	3500.0
1973	3630.0	3630.0	3630.0
1974	4320.0	4320.0	4320.0
1975	2170.0	2170.0	2170.0
1976	5150.0	5150.0	5150.0
1977	973.0	973.0	973.0
1978	2440.0	2440.0	2440.0
1979	1460.0	1460.0	1460.0
1980	5350.0	5350.0	5350.0
1981	4040.0	4040.0	4040.0
1982	3240.0	3240.0	3240.0
1983	3710.0	3710.0	3710.0
1984	5510.0	5510.0	5510.0
1985	1610.0	1610.0	1610.0
1986	6560.0	6560.0	6560.0
1987	3220.0	3220.0	3220.0
1988	3300.0	3300.0	3300.0
1989	1300.0	1300.0	1300.0
1990	3650.0	3650.0	3650.0
1991	7120.0	7120.0	7120.0
1992	5090.0	5090.0	5090.0
1993	1610.0	1610.0	1610.0
1994	3240.0	3240.0	3240.0
1995	4850.0	4850.0	4850.0
1996	4500.0	4500.0	4500.0
1997	5990.0	5990.0	5990.0

SORTED DISCHARGE VALUES, CALCULATED EXCEEDENCE PROBABILITIES
AND RETURN PERIOD ESTIMATES

APPENDIX A
FLOOD FREQUENCY PROGRAMS INPUT/OUTPUT
DUNGENESS RIVER NEAR SEQUIM, WASHINGTON

i	Year	Discharge	Exceed. Prob. P (%)	Rt. Per. T
1	1901	7540.0	0.5000	200.0000
2	1991	7120.0	1.8462	54.1667
3	1900	7000.0	3.2564	30.7087
4	1950	6820.0	4.6667	21.4286
5	1956	6750.0	6.0769	16.4557
6	1986	6560.0	7.4872	13.3562
7	1924	6340.0	8.8974	11.2392
8	1997	5990.0	10.3077	9.7015
9	1961	5900.0	11.7179	8.5339
10	1984	5510.0	13.1282	7.6172
11	1938	5380.0	14.5385	6.8783
12	1980	5350.0	15.9487	6.2701
13	1976	5150.0	17.3590	5.7607
14	1992	5090.0	18.7692	5.3279
15	1995	4850.0	20.1795	4.9555
16	1960	4800.0	21.5897	4.6318
17	1951	4600.0	23.0000	4.3478
18	1996	4500.0	24.4103	4.0966
19	1974	4320.0	25.8205	3.8729
20	1942	4120.0	27.2308	3.6723
21	1981	4040.0	28.6410	3.4915
22	1940	4010.0	30.0513	3.3276
23	1954	3990.0	31.4615	3.1785
24	1968	3920.0	32.8718	3.0421
25	1957	3880.0	34.2821	2.9170
26	1939	3850.0	35.6923	2.8017
27	1983	3710.0	37.1026	2.6952
28	1963	3670.0	38.5128	2.5965
29	1990	3650.0	39.9231	2.5048
30	1973	3630.0	41.3333	2.4194
31	1955	3570.0	42.7436	2.3395
32	1972	3500.0	44.1538	2.2648
33	1945	3380.0	45.5641	2.1947
34	1988	3300.0	46.9744	2.1288
35	1994	3240.0	48.3846	2.0668
36	1982	3240.0	49.7949	2.0082
37	1987	3220.0	51.2051	1.9529
38	1925	3120.0	52.6154	1.9006
39	1967	2960.0	54.0256	1.8510
40	1898	2950.0	55.4359	1.8039
41	1959	2900.0	56.8462	1.7591
42	1927	2860.0	58.2564	1.7165
43	1949	2820.0	59.6667	1.6760
44	1948	2790.0	61.0769	1.6373
45	1964	2630.0	62.4872	1.6003
46	1947	2530.0	63.8974	1.5650
47	1953	2480.0	65.3077	1.5312
48	1978	2440.0	66.7179	1.4988
49	1941	2400.0	68.1282	1.4678
50	1958	2330.0	69.5385	1.4381
51	1975	2170.0	70.9487	1.4095
52	1952	1860.0	72.3590	1.3820
53	1970	1850.0	73.7692	1.3556
54	1965	1850.0	75.1795	1.3302

55	1969	1660.0	76.5897	1.3057
56	1993	1610.0	78.0000	1.2821
57	1985	1610.0	79.4103	1.2593
58	1944	1520.0	80.8205	1.2373
59	1971	1480.0	82.2308	1.2161
60	1979	1460.0	83.6410	1.1956
61	1928	1400.0	85.0513	1.1758
62	1962	1380.0	86.4615	1.1566
63	1966	1370.0	87.8718	1.1380
64	1989	1300.0	89.2821	1.1200
65	1946	1200.0	90.6923	1.1026
66	1899	1080.0	92.1026	1.0857
67	1943	1010.0	93.5128	1.0694
68	1929	1000.0	94.9231	1.0535
69	1977	973.0	96.3333	1.0381
70	1930	920.0	97.7436	1.0231
71	1926	740.0	99.1538	1.0085

Number of Iterations for EMA Convergence is: 4

FINAL EMA CALCULATED MOMENTS

MEAN	VARIANCE	SKEW
3.456284	0.062718	-0.464700

FINAL EMA LP-III PARAMETERS

LOCATION (TAU)	SHAPE (ALPHA)	SCALE (BETA)
4.533474	18.492469	-0.058245

QUANTILES OF THE LOG-PEARSON TYPE III DISTRIBUTION

i	Q	EXCEED PROB P (%)	T
1	616.	99.00000	1.010
2	697.	98.50000	1.015
3	1335.	90.00000	1.111
4	1460.	87.50000	1.143
5	1576.	85.00000	1.176
6	1686.	82.50000	1.212
7	1791.	80.00000	1.250
8	1893.	77.50000	1.290
9	1993.	75.00000	1.333
10	2092.	72.50000	1.379
11	2189.	70.00000	1.429
12	2286.	67.50000	1.481
13	2317.	66.70000	1.499
14	2384.	65.00000	1.538
15	2481.	62.50000	1.600
16	2580.	60.00000	1.667
17	2680.	57.50000	1.739
18	2781.	55.00000	1.818
19	2884.	52.50000	1.905
20	2990.	50.00000	2.000

APPENDIX A
FLOOD FREQUENCY PROGRAMS INPUT/OUTPUT
DUNGENESS RIVER NEAR SEQUIM, WASHINGTON

21	3098.	47.50000	2.105
22	3210.	45.00000	2.222
23	3325.	42.50000	2.353
24	3445.	40.00000	2.500
25	3570.	37.50000	2.667
26	3700.	35.00000	2.857
27	3838.	32.50000	3.077
28	3984.	30.00000	3.333
29	4139.	27.50000	3.636
30	4306.	25.00000	4.000
31	4487.	22.50000	4.444
32	4685.	20.00000	5.000
33	4905.	17.50000	5.714
34	5153.	15.00000	6.667
35	5441.	12.50000	8.000
36	5784.	10.00000	10.000
37	6214.	7.50000	13.333
38	6801.	5.00000	20.000
39	7116.	4.00000	25.000
40	7761.	2.50000	40.000
41	8060.	2.00000	50.000
42	8592.	1.33400	74.963
43	8962.	1.00000	100.000
44	9827.	0.50000	200.000

APPENDIX A
FLOOD FREQUENCY PROGRAMS INPUT/OUTPUT
DUNGENESS RIVER NEAR SEQUIM, WASHINGTON

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***************************************************
*                                                 *
*                 PROGRAM CONFLP                  *
*         LOG-PEARSON III CONFIDENCE LIMITS       *
*               BASE 10 LOGARITHMS                *
*                                                 *
*              USBR/CSU VERSION 98.01             *
*             VERSION DATE: 02-25-98              *
***************************************************
```

CONFLP10 Program Output File Name is: dun-cl3.out

INPUT CONSTANTS

MEAN	VARIANCE	SKEW
3.456284	0.062718	-0.464700

NUMBER OF YEARS OF RECORD = 100

QUANTILES OF THE LOG-PEARSON TYPE III DISTRIBUTION

i	EXCEED PROB P (%)	T	Q LOW	Q	Q UP
1	99.00000	1.010	409.	616.	929.
2	98.50000	1.015	483.	697.	1004.
3	90.00000	1.111	1106.	1335.	1611.
4	87.50000	1.143	1228.	1460.	1736.
5	85.00000	1.176	1340.	1576.	1854.
6	82.50000	1.212	1445.	1686.	1967.
7	80.00000	1.250	1545.	1791.	2077.
8	77.50000	1.290	1641.	1893.	2185.
9	75.00000	1.333	1734.	1993.	2292.
10	72.50000	1.379	1825.	2092.	2398.
11	70.00000	1.429	1914.	2189.	2503.
12	67.50000	1.481	2003.	2286.	2609.
13	66.70000	1.499	2032.	2317.	2643.
14	65.00000	1.538	2092.	2384.	2716.
15	62.50000	1.600	2181.	2481.	2823.
16	60.00000	1.667	2270.	2580.	2932.
17	57.50000	1.739	2361.	2680.	3042.
18	55.00000	1.818	2452.	2781.	3153.
19	52.50000	1.905	2546.	2884.	3267.
20	50.00000	2.000	2641.	2990.	3384.
21	47.50000	2.105	2739.	3098.	3503.
22	45.00000	2.222	2841.	3210.	3627.
23	42.50000	2.353	2945.	3325.	3754.
24	40.00000	2.500	3054.	3445.	3886.
25	37.50000	2.667	3167.	3570.	4023.
26	35.00000	2.857	3286.	3700.	4167.
27	32.50000	3.077	3411.	3838.	4318.
28	30.00000	3.333	3544.	3984.	4478.
29	27.50000	3.636	3685.	4139.	4650.
30	25.00000	4.000	3835.	4306.	4834.
31	22.50000	4.444	3998.	4487.	5035.
32	20.00000	5.000	4175.	4685.	5257.
33	17.50000	5.714	4369.	4905.	5507.

34	15.00000	6.667	4584.	5153.	5793.
35	12.50000	8.000	4827.	5441.	6132.
36	10.00000	10.000	5107.	5784.	6550.
37	7.50000	13.333	5440.	6214.	7099.
38	5.00000	20.000	5858.	6801.	7896.
39	4.00000	25.000	6064.	7116.	8350.
40	2.50000	40.000	6451.	7761.	9338.
41	2.00000	50.000	6613.	8060.	9824.
42	1.33400	74.963	6877.	8592.	10734.
43	1.00000	100.000	7043.	8962.	11404.
44	0.50000	200.000	7379.	9827.	13088.

APPENDIX A
FLOOD FREQUENCY PROGRAMS INPUT/OUTPUT
DUNGENESS RIVER NEAR SEQUIM, WASHINGTON

Dungeness River 1-day volume frequency

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
3.3098	0.2172	-0.0926	0.0000	-0.0926

RANK	m-.4/N+.2	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.00880	1991	5280.0	0.99000	616	492	735
2	0.02346	1924	5140.0	0.98000	713	581	838
3	0.03812	1956	5060.0	0.97500	749	615	876
4	0.05279	1997	4710.0	0.96000	837	698	968
5	0.06745	1986	4070.0	0.95000	885	743	1018
6	0.08211	1976	3900.0	0.90000	1070	920	1212
7	0.09677	1992	3900.0	0.80000	1343	1184	1498
8	0.11144	1961	3830.0	0.70000	1579	1411	1749
9	0.12610	1950	3800.0	0.60000	1811	1631	2001
10	0.14076	1980	3660.0	0.57040	1882	1697	2079
11	0.15543	1984	3570.0	0.50000	2057	1860	2275
12	0.17009	1974	3400.0	0.42960	2247	2033	2492
13	0.18475	1995	3320.0	0.40000	2333	2111	2592
14	0.19941	1938	3240.0	0.30000	2667	2407	2988
15	0.21408	1996	3240.0	0.20000	3115	2793	3536
16	0.22874	1968	3160.0	0.10000	3854	3406	4476
17	0.24340	1951	3020.0	0.05000	4584	3993	5440
18	0.25806	1981	2900.0	0.04000	4819	4179	5758
19	0.27273	1942	2860.0	0.02500	5319	4570	6441
20	0.28739	1990	2800.0	0.02000	5558	4755	6772
21	0.30205	1960	2770.0	0.01000	6312	5331	7831
22	0.31672	1967	2630.0	0.00500	7084	5911	8938
23	0.33138	1973	2590.0	0.00200	8138	6689	10481
24	0.34604	1939	2560.0	0.00100	8961	7289	11711
25	0.36070	1982	2450.0	0.00050	9810	7899	12997
26	0.37537	1955	2440.0	0.00010	11881	9361	16214
27	0.39003	1925	2400.0				
28	0.40469	1940	2320.0				
29	0.41935	1957	2290.0				
30	0.43402	1948	2200.0				
31	0.44868	1963	2180.0				
32	0.46334	1927	2150.0				
33	0.47801	1959	2100.0				
34	0.49267	1953	2090.0				
35	0.50733	1972	2090.0				
36	0.52199	1947	2050.0				
37	0.53666	1987	2050.0				
38	0.55132	1994	2040.0				
39	0.56598	1958	2030.0				
40	0.58065	1983	1970.0				
41	0.59531	1954	1930.0				
42	0.60997	1949	1910.0				
43	0.62463	1998	1710.0				
44	0.63930	1975	1700.0				
45	0.65396	1988	1640.0				
46	0.66862	1969	1640.0				
47	0.68328	1964	1620.0				
48	0.69795	1945	1600.0				

49	0.71261	1941	1420.0
50	0.72727	1970	1410.0
51	0.74194	1928	1400.0
52	0.75660	1978	1350.0
53	0.77126	1971	1340.0
54	0.78592	1965	1300.0
55	0.80059	1952	1260.0
56	0.81525	1993	1230.0
57	0.82991	1962	1190.0
58	0.84457	1985	1160.0
59	0.85924	1966	1130.0
60	0.87390	1946	1020.0
61	0.88856	1929	1000.0
62	0.90323	1979	990.0
63	0.91789	1943	930.0
64	0.93255	1930	920.0
65	0.94721	1944	884.0
66	0.96188	1989	855.0
67	0.97654	1977	849.0
68	0.99120	1926	740.0

APPENDIX A
FLOOD FREQUENCY PROGRAMS INPUT/OUTPUT
DUNGENESS RIVER NEAR SEQUIM, WASHINGTON

Dungeness River 3-day volume frequency

Mean of Logs	Std.Dev	Data Skew	Reg.Skew	Final Skew
3.1969	0.1990	-0.1352	0.0000	-0.1352

RANK	m-.4/N+.2	YEAR	Q	EXCEED.	FREQ.Q	LOW	HIGH
1	0.00880	1924	3616.7	0.99000	518	421	610
2	0.02346	1991	3336.7	0.98000	594	492	690
3	0.03812	1956	3290.0	0.97500	623	519	719
4	0.05279	1980	3176.7	0.96000	691	584	790
5	0.06745	1976	3100.0	0.95000	728	620	828
6	0.08211	1997	3093.0	0.90000	869	757	974
7	0.09677	1974	2943.3	0.80000	1074	957	1186
8	0.11144	1992	2883.3	0.70000	1247	1125	1369
9	0.12610	1986	2796.7	0.60000	1415	1286	1550
10	0.14076	1968	2653.3	0.57040	1465	1333	1606
11	0.15543	1996	2576.7	0.50000	1590	1450	1744
12	0.17009	1951	2573.3	0.42960	1724	1573	1896
13	0.18475	1950	2570.0	0.40000	1784	1628	1965
14	0.19941	1938	2560.0	0.30000	2015	1835	2237
15	0.21408	1984	2490.0	0.20000	2320	2099	2606
16	0.22874	1981	2473.3	0.10000	2810	2510	3223
17	0.24340	1961	2460.0	0.05000	3283	2895	3838
18	0.25806	1995	2180.0	0.04000	3434	3015	4038
19	0.27273	1955	2113.3	0.02500	3749	3265	4462
20	0.28739	1948	2050.0	0.02000	3899	3382	4665
21	0.30205	1957	2033.3	0.01000	4364	3743	5305
22	0.31672	1963	2030.0	0.00500	4832	4101	5962
23	0.33138	1947	1976.7	0.00200	5458	4572	6857
24	0.34604	1967	1903.3	0.00100	5938	4929	7556
25	0.36070	1960	1883.3	0.00050	6426	5287	8275
26	0.37537	1940	1876.7	0.00010	7587	6127	10025
27	0.39003	1942	1870.0				
28	0.40469	1925	1786.7				
29	0.41935	1987	1783.3				
30	0.43402	1983	1740.0				
31	0.44868	1990	1735.0				
32	0.46334	1973	1650.0				
33	0.47801	1939	1633.3				
34	0.49267	1982	1606.0				
35	0.50733	1972	1603.3				
36	0.52199	1953	1570.0				
37	0.53666	1959	1543.3				
38	0.55132	1958	1540.0				
39	0.56598	1954	1496.7				
40	0.58065	1969	1436.7				
41	0.59531	1927	1436.7				
42	0.60997	1945	1283.3				
43	0.62463	1970	1273.3				
44	0.63930	1964	1266.0				
45	0.65396	1949	1241.0				
46	0.66862	1971	1230.0				
47	0.68328	1998	1208.0				
48	0.69795	1988	1181.7				

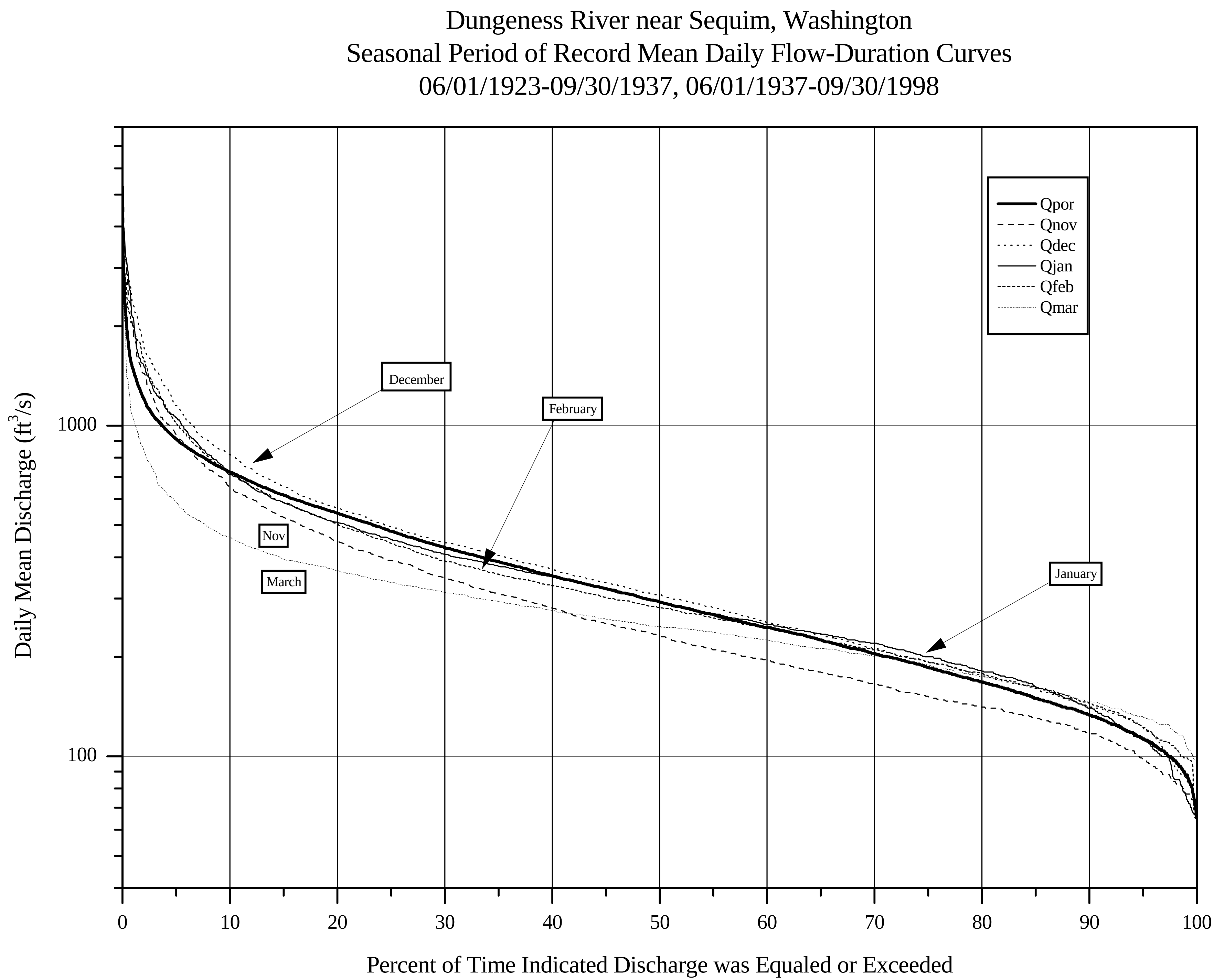
49	0.71261	1978	1159.7
50	0.72727	1994	1133.3
51	0.74194	1975	1100.0
52	0.75660	1993	1090.0
53	0.77126	1941	1086.0
54	0.78592	1928	1071.7
55	0.80059	1965	1058.0
56	0.81525	1966	1044.3
57	0.82991	1946	927.7
58	0.84457	1929	921.7
59	0.85924	1952	911.3
60	0.87390	1962	906.7
61	0.88856	1979	883.7
62	0.90323	1943	878.3
63	0.91789	1985	864.7
64	0.93255	1989	790.3
65	0.94721	1930	781.7
66	0.96188	1977	752.7
67	0.97654	1944	577.3
68	0.99120	1926	559.3

APPENDIX B

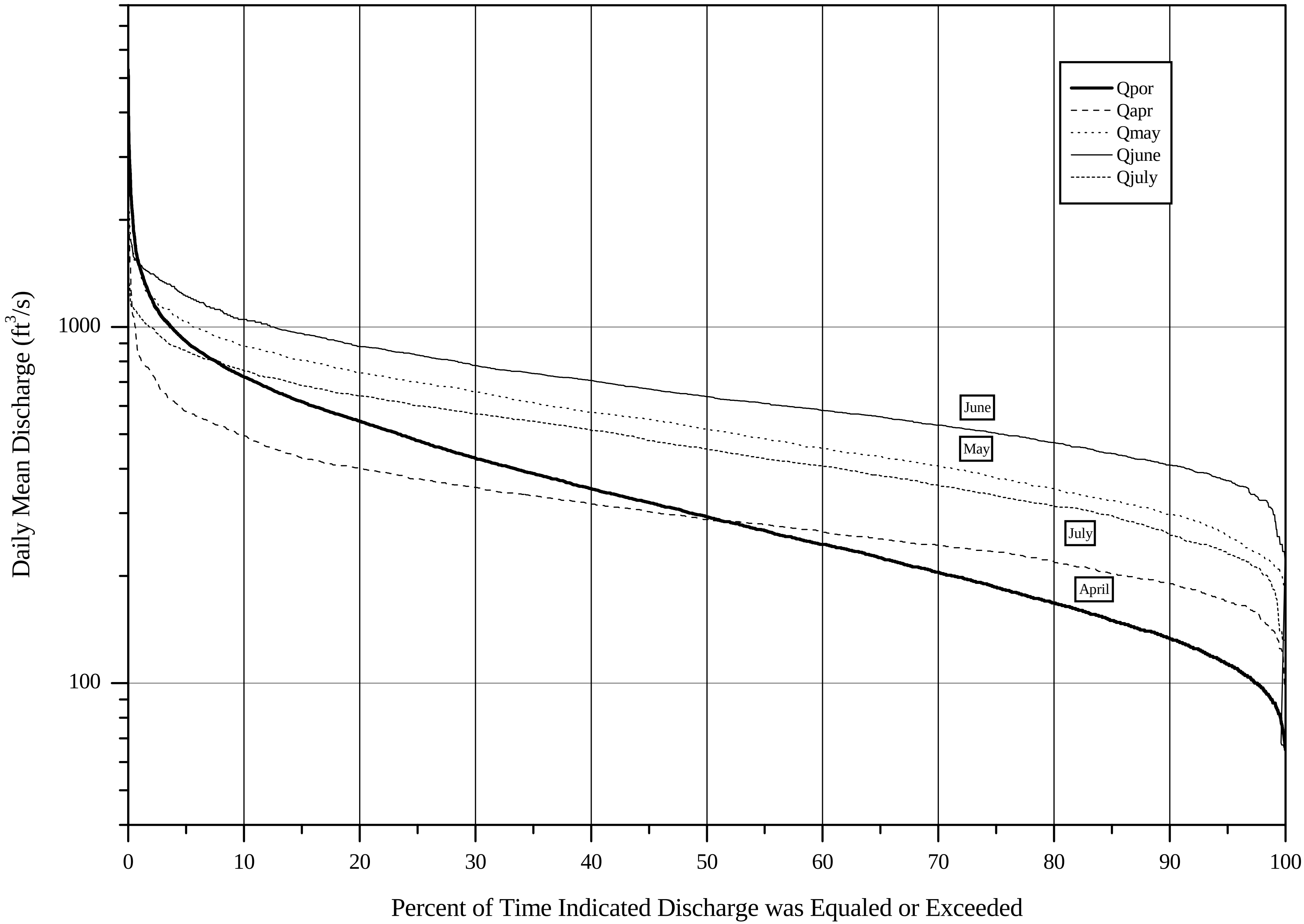
Flow Duration Curves and Results for each Month

Mean Daily Flow Duration Statistics for Each Month
Dungeness River near Sequim, Washington
Period of Record 06/01/1923-09/30/1930, 06/01/1937-09/30/1998

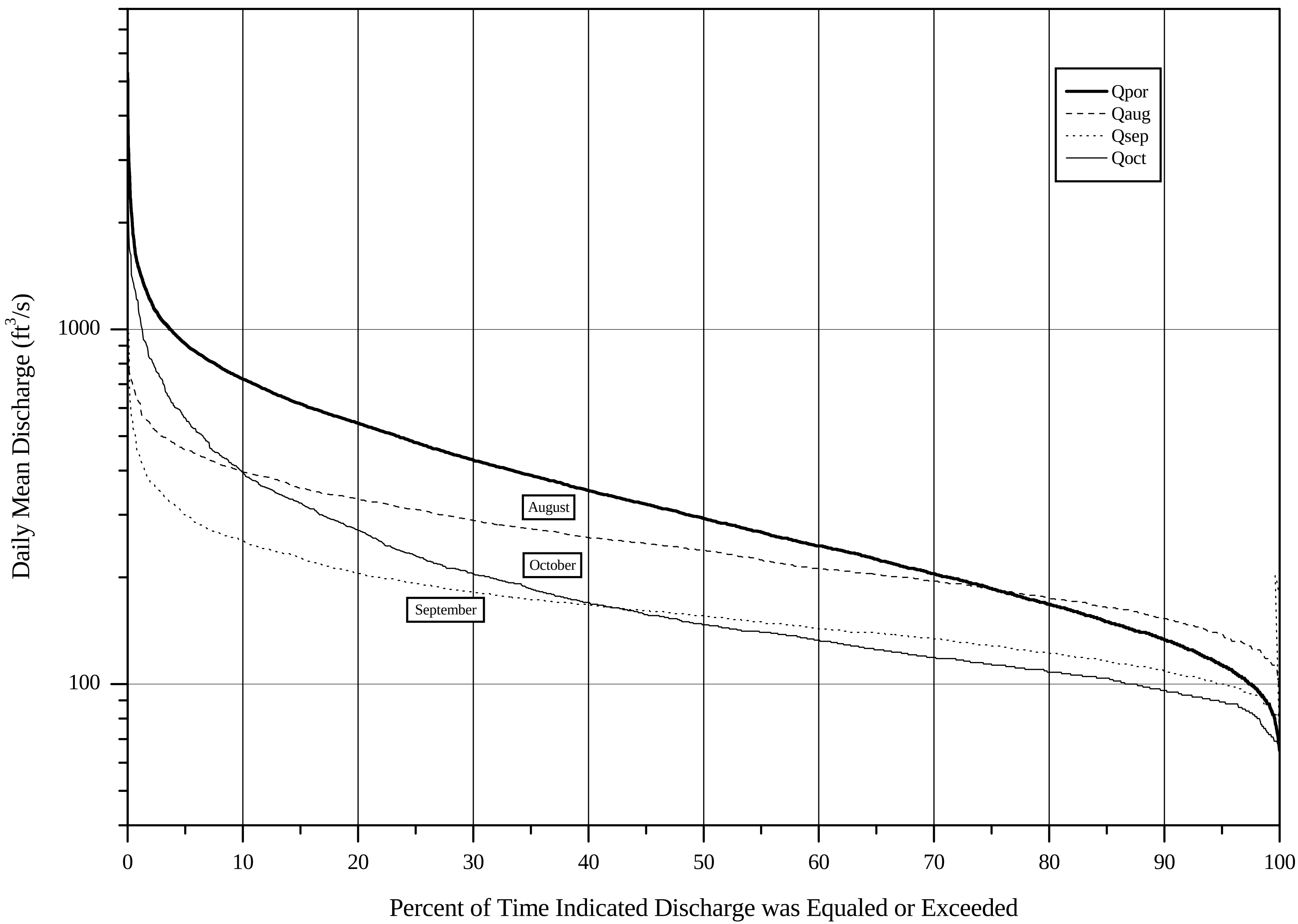
parameter	Year	Month											
		October	November	December	January	February	March	April	May	June	July	August	September
number of samples	25081	2108	2040	2108	2108	1921	2108	2040	2108	2100	2170	2170	2100
mean (ft^3/s)	380.7	213.9	343.9	427.0	398.7	388.8	293.5	323.5	564.9	693.7	487.4	259.4	171.9
standard deviation (ft^3/s)	304.9	194.1	377.0	409.1	384.5	360.4	208.0	149.2	252.1	263.1	195.8	103.8	72.7
maximum observation (ft^3/s)	5280	2480	5280	3900	4820	5140	4710	2100	2200	1830	1420	964	981
10 percent exceedance (ft^3/s)	724	395	653	816	711	720	459	495	886	1050	754	397	253
25 percent exceedance (ft^3/s)	480	230	391	495	453	441	335	374	700	834	600	311	192
50 percent exceedance (ft^3/s)	293	147	232	308	291.5	282	247	288	515.5	637	455	238	156
75 percent exceedance (ft^3/s)	186	113	152	193	200	193	189	233	376	503	335	185	128
90 percent exceedance (ft^3/s)	133	96	117	141	140	145	147	190	297	409	260	153	109
minimum observation (ft^3/s)	65	66	65	68	65	65	97	98	181	222	132	99	77


Dungeness River near Sequim, Washington
Seasonal Period of Record Mean Daily Flow-Duration Curves
06/01/1923-09/30/1937, 06/01/1937-09/30/1998
Daily Mean Discharge (ft³/s)
1000
100
0
10
20
30
40
50
60
70
80
90
100
Percent of Time Indicated Discharge was Equaled or Exceeded
Qpor
Qnov
Qdec
Qjan
Qfeb
Qmar
December
February
January
Nov
March

Dungeness River near Sequim, Washington
Seasonal Period of Record Mean Daily Flow-Duration Curves
06/01/1923-09/30/1937, 06/01/1937-09/30/1998



Dungeness River near Sequim, Washington
Seasonal Period of Record Mean Daily Flow-Duration Curves
06/01/1923-09/30/1937, 06/01/1937-09/30/1998



APPENDIX C

Trend Analyses Results

APPENDIX C
Trend Analyses Results

Trend Analysis Results Dungeness River near Sequim, WA 1924-1930, 1938-1998 (68 years)			
Percentile	**Kendall's Tau**	**p-level**	**median slope**
minimum	-0.077	0.354	-0.122
90 percent exceedance	-0.023	0.787	-0.061
70 percent exceedance	0.094	0.262	0.394
50 percent exceedance	0.123	0.140	0.680
30 percent exceedance	0.095	0.255	0.795
10 percent exceedance	0.099	0.236	1.163
maximum	0.131	0.115	10.301

Interdecadal Trend Analysis Results Dungeness River near Sequim, WA 1939-1998 (60 years)			
Percentile	**Kendall's Tau**	**p-level**	**median slope**
minimum	-0.189	0.034*	-0.333
90 percent exceedance	-0.072	0.422	-0.231
70 percent exceedance	0.069	0.440	0.342
50 percent exceedance	0.075	0.403	0.511
30 percent exceedance	0.024	0.789	0.225
10 percent exceedance	0.020	0.823	0.362
maximum	0.124	0.162	11.965

* significant ($p \leq 0.05$)

APPENDIX C
Trend Analyses Results

Interdecadal Trend Analysis Results Dungeness River near Sequim, WA 1949-1998 (50 years)			
Percentile	**Kendall's Tau**	**p-level**	**median slope**
minimum	-0.364	0.000*	-0.750
90 percent exceedance	-0.239	0.015*	-0.891
70 percent exceedance	-0.094	0.340	-0.591
50 percent exceedance	-0.078	0.432	-0.739
30 percent exceedance	-0.162	0.098	-1.433
10 percent exceedance	-0.184	0.060	-3.160
maximum	0.059	0.553	5.926

* significant ($p \leq 0.05$)

Interdecadal Trend Analysis Results Dungeness River near Sequim, WA 1959-1998 (40 years)			
Percentile	**Kendall's Tau**	**p-level**	**median slope**
minimum	-0.360	0.001*	-0.881
90 percent exceedance	-0.255	0.021*	-1.200
70 percent exceedance	-0.037	0.744	-0.280
50 percent exceedance	0.000	1.000	0.000
30 percent exceedance	-0.074	0.507	-0.795
10 percent exceedance	-0.097	0.382	-2.187
maximum	0.141	0.204	20.000

* significant ($p \leq 0.05$)

APPENDIX C
Trend Analyses Results

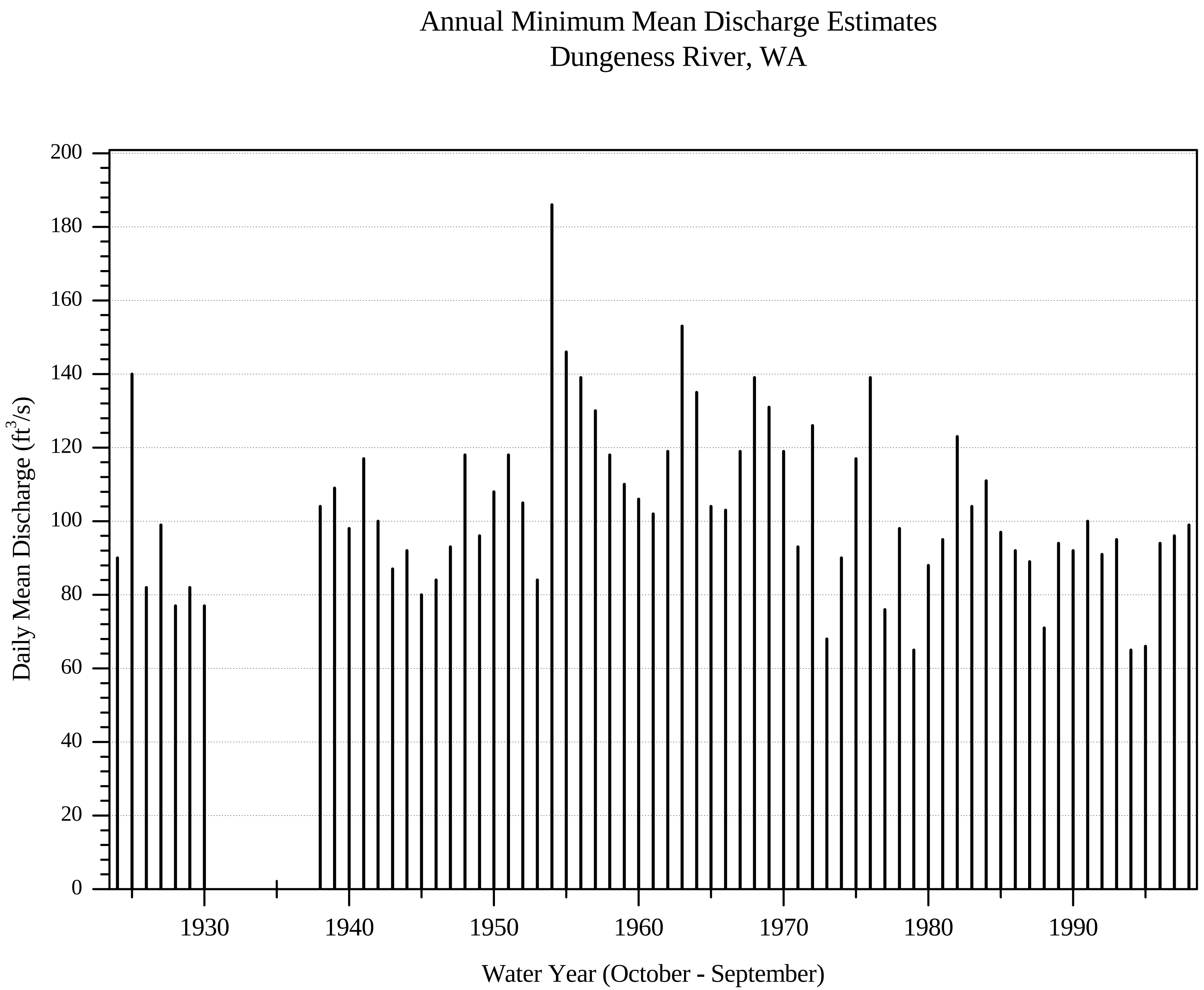
Interdecadal Trend Analysis Results Dungeness River near Sequim, WA 1969-1998 (30 years)			
Percentile	**Kendall's Tau**	**p-level**	**median slope**
minimum	-0.195	0.134	-0.667
90 percent exceedance	-0.195	0.134	-1.255
70 percent exceedance	-0.025	0.858	-0.333
50 percent exceedance	0.069	0.605	0.765
30 percent exceedance	-0.007	0.972	-0.055
10 percent exceedance	-0.090	0.498	-2.258
maximum	0.182	0.164	38.571

* significant ($p \leq 0.05$)

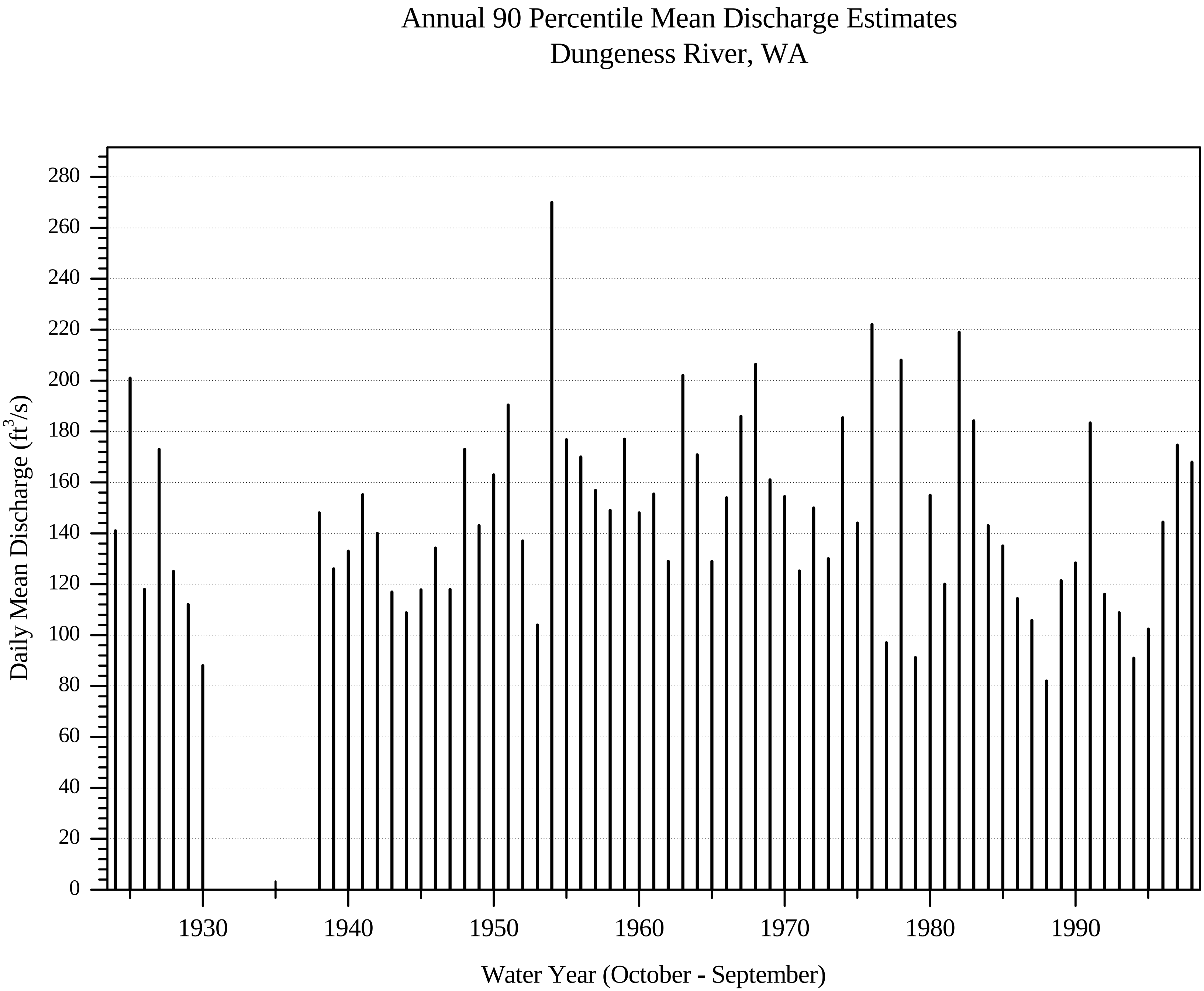
APPENDIX C
Trend Analyses Results

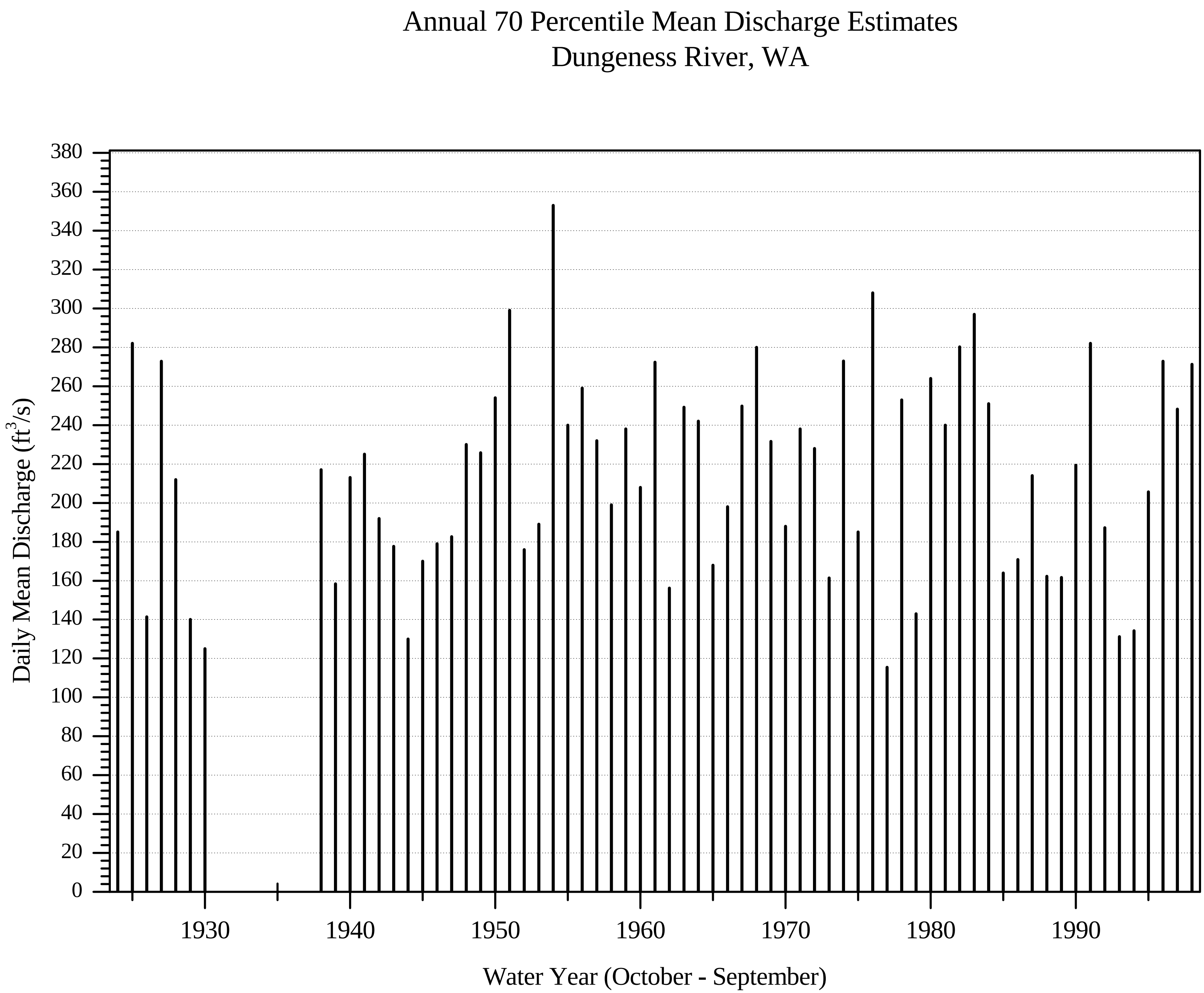
Annual Runoff Trend Analysis Results Dungeness and Elwha Rivers, WA				
Period	**Location**	**Kendall's Tau**	**p-level**	**median slope**
1924-1930, 1938-1996 (66 years)	Dungeness	0.078	0.358	0.052
	Elwha	0.097	0.250	0.111
	Elwha/Dungeness Ratio	0.056	0.507	0.001
1938-1996 (59 years)	Dungeness	0.012	0.896	0.012
	Elwha	0.026	0.774	0.037
	Elwha/Dungeness Ratio	0.099	0.272	0.001
1947-1996 (50 years)	Dungeness	-0.156	0.112	-0.130
	Elwha	-0.143	0.146	-0.227
	Elwha/Dungeness Ratio	0.171	0.082	0.003
1957-1996 (40 years)	Dungeness	-0.097	0.382	-0.114
	Elwha	-0.100	0.370	-0.225
	Elwha/Dungeness Ratio	0.087	0.435	0.002
1967-1996 (30 years)	Dungeness	-0.159	0.225	-0.248
	Elwha	-0.191	0.143	-0.649
	Elwha/Dungeness Ratio	0.011	0.943	0.000

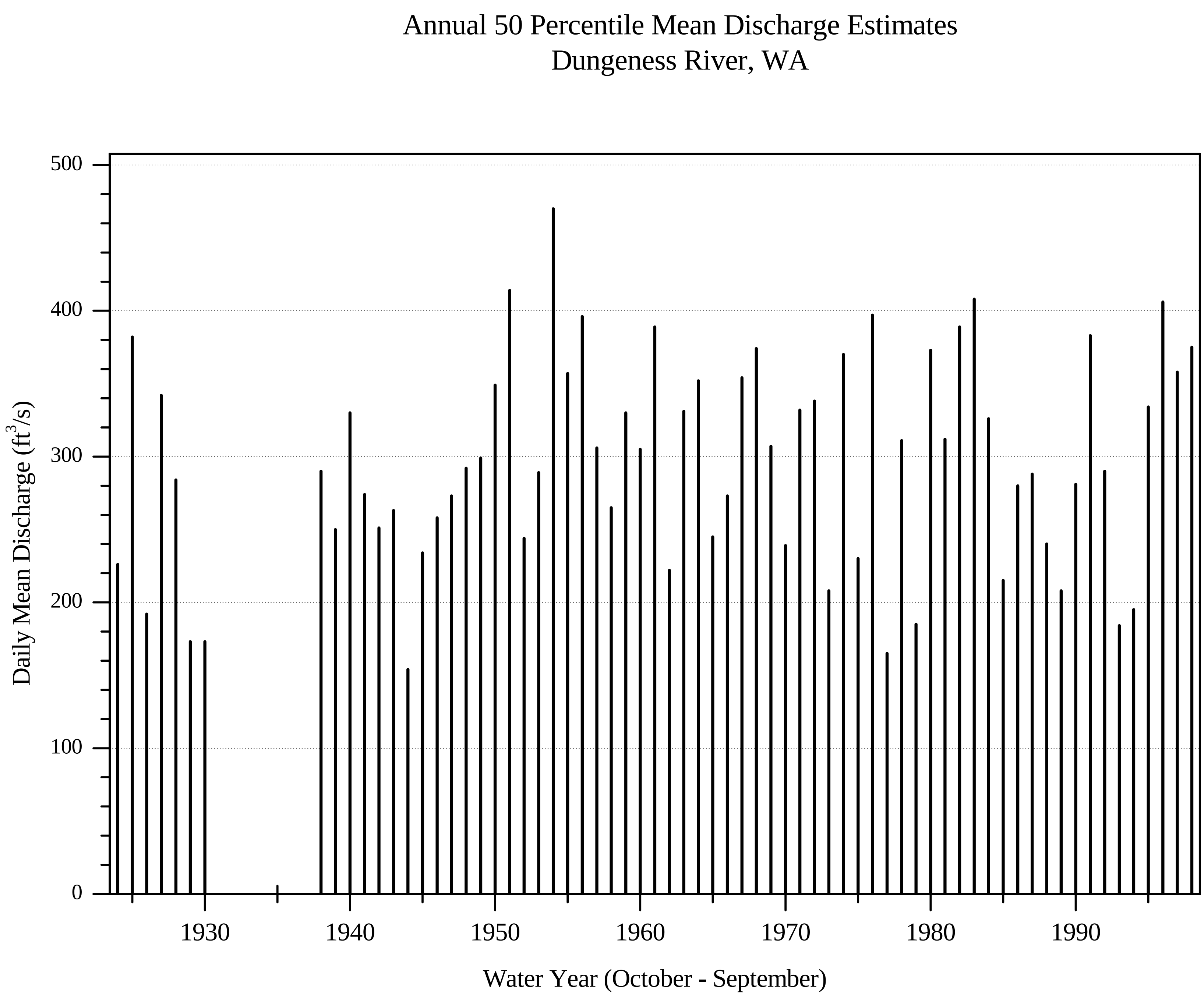
* significant ($p \leq 0.05$)



Annual Minimum Mean Discharge Estimates
Dungeness River, WA
Daily Mean Discharge (ft3/s)
200
180
160
140
120
100
80
60
40
20
0
1930
1940
1950
1960
1970
1980
1990
Water Year (October - September)

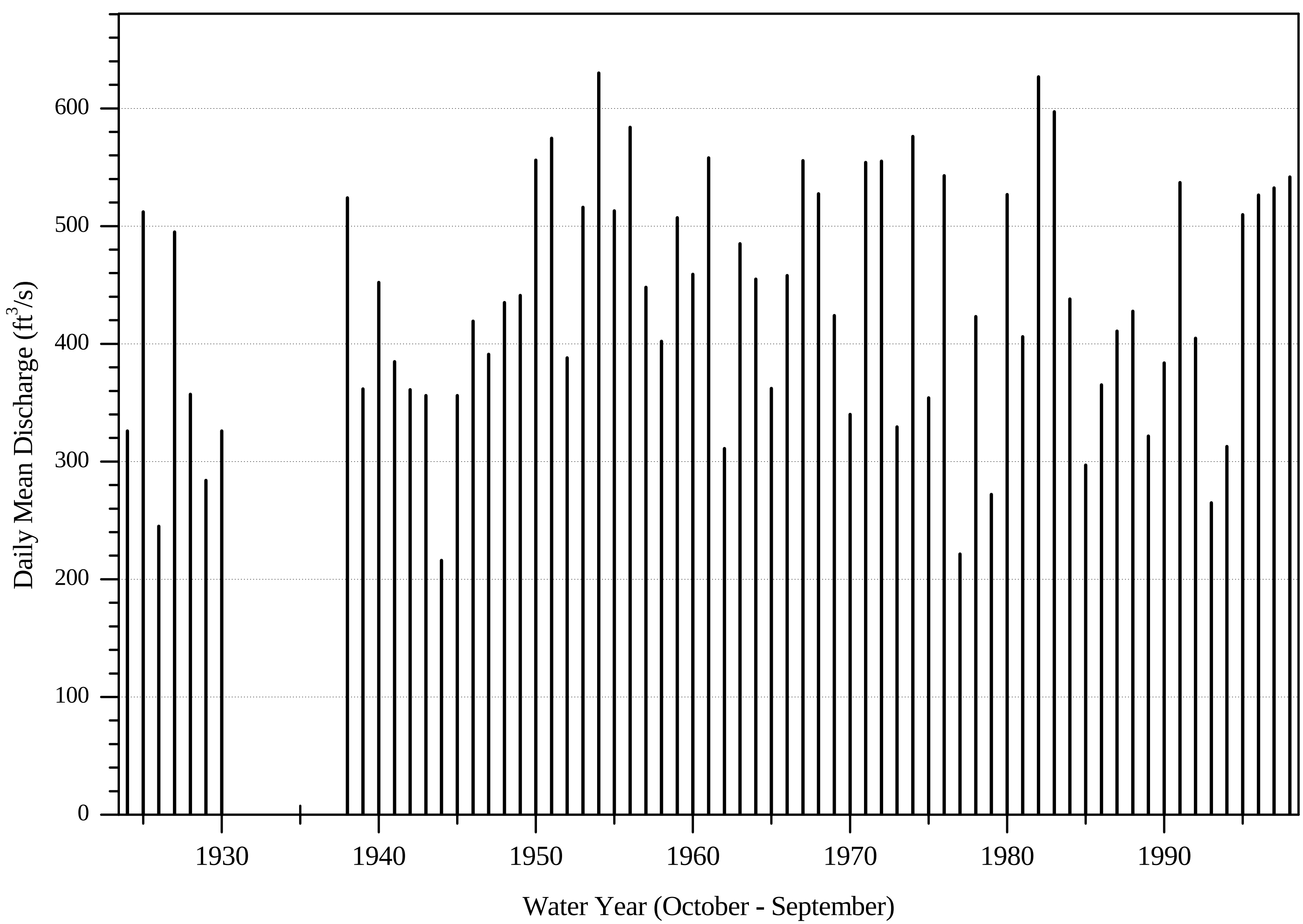

Annual 90 Percentile Mean Discharge Estimates
Dungeness River, WA
Daily Mean Discharge (ft3/s)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
1930
1940
1950
1960
1970
1980
1990
Water Year (October - September)

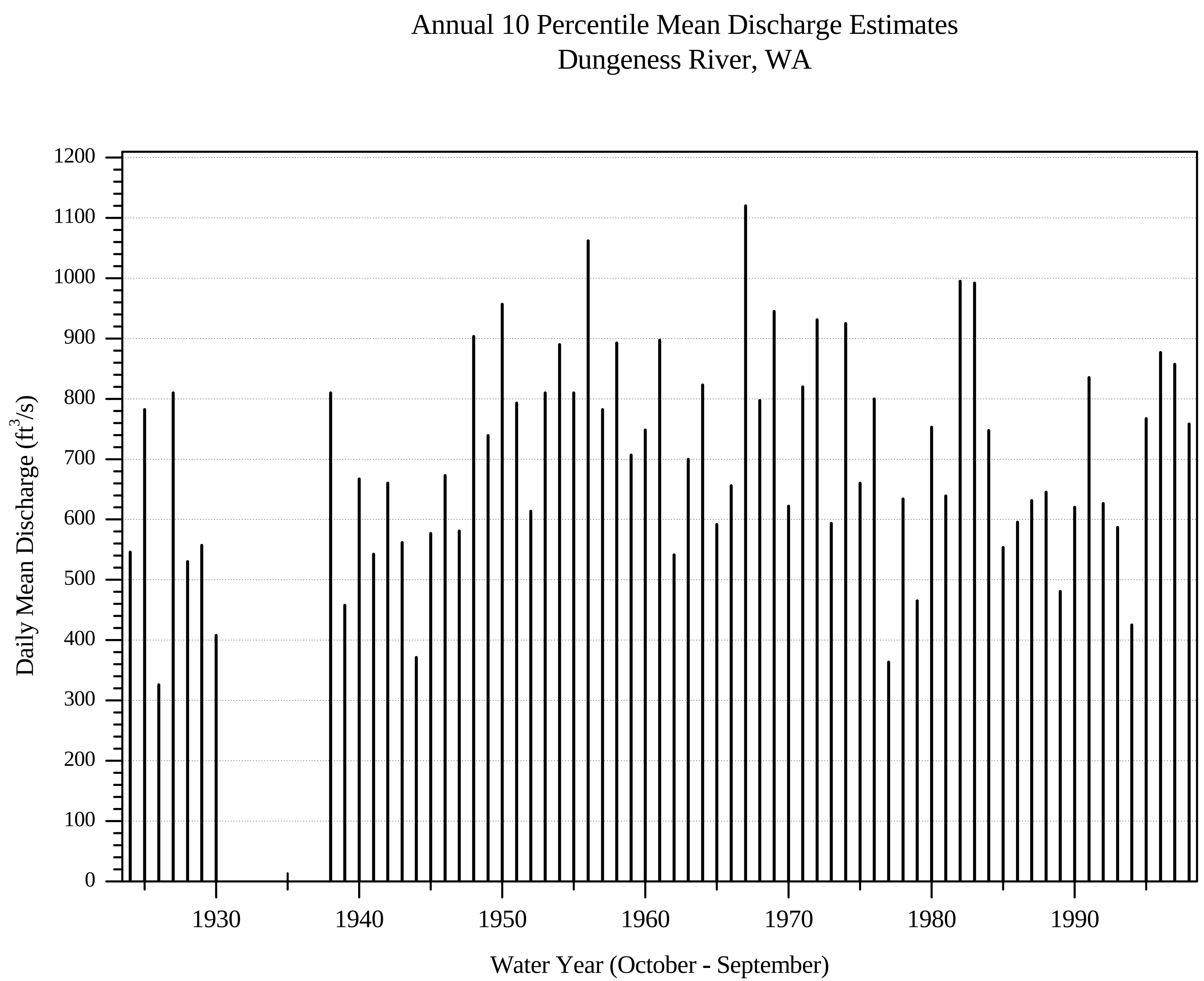

Annual 70 Percentile Mean Discharge Estimates
Dungeness River, WA
Daily Mean Discharge (ft3/s)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
1930
1940
1950
1960
1970
1980
1990
Water Year (October - September)



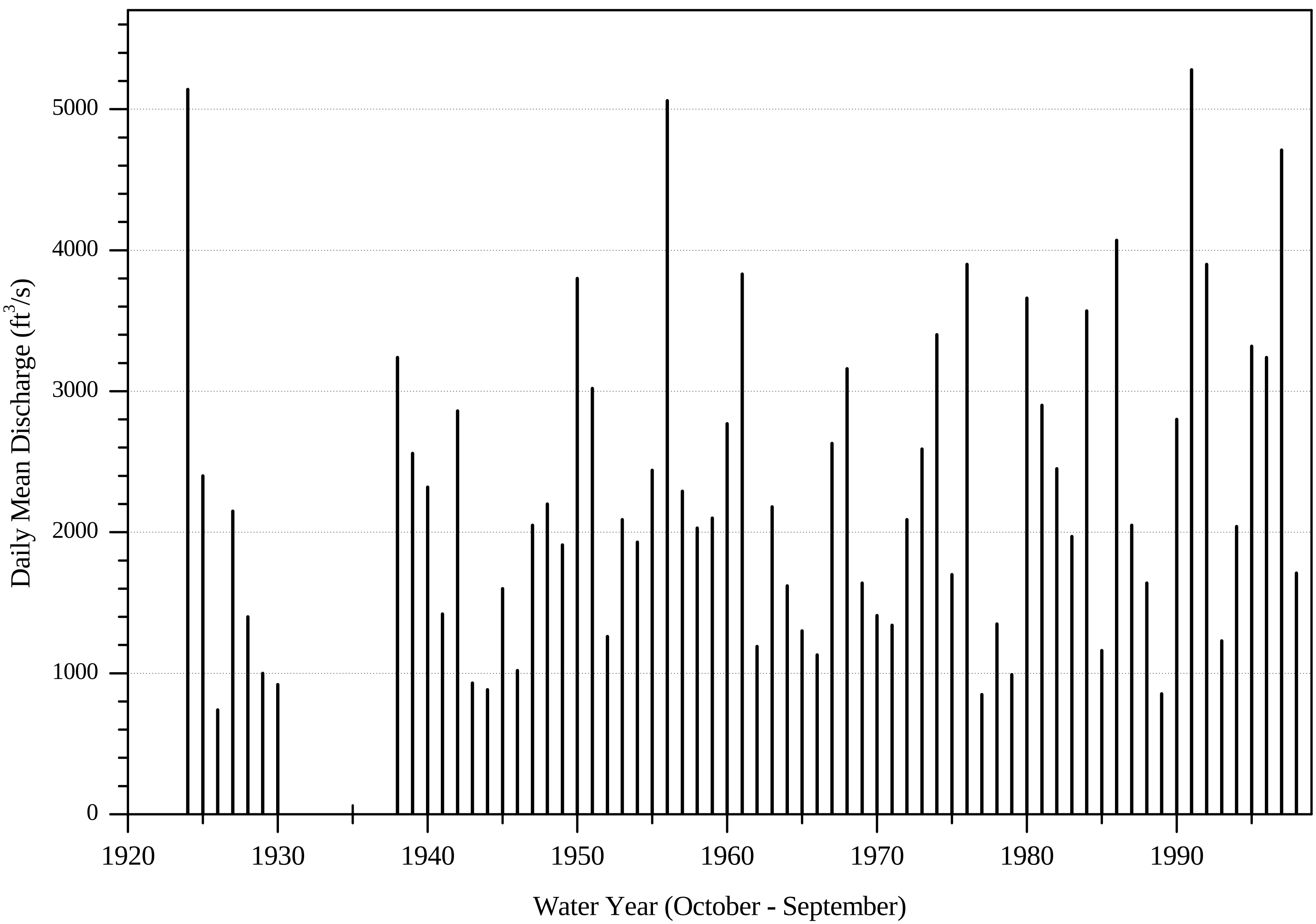
Annual 50 Percentile Mean Discharge Estimates
Dungeness River, WA
Daily Mean Discharge (ft3/s)
0
100
200
300
400
500
1930
1940
1950
1960
1970
1980
1990
Water Year (October - September)

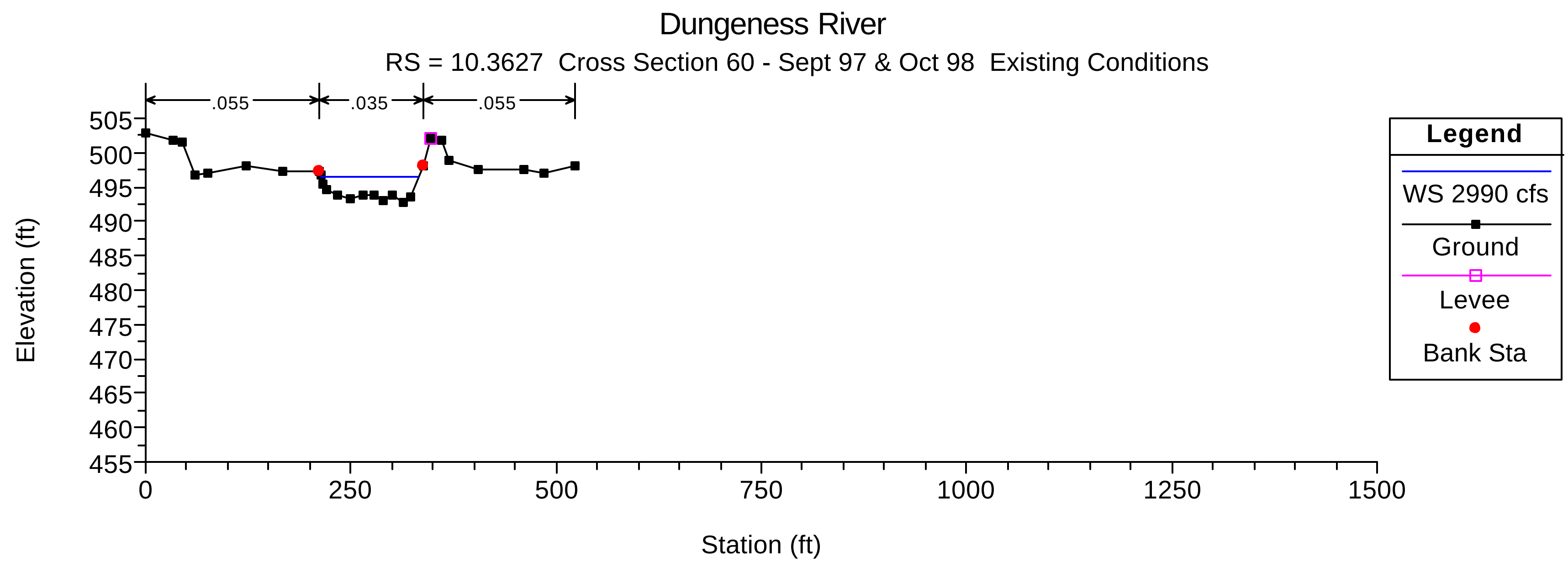
Annual 30 Percentile Mean Discharge Estimates
Dungeness River, WA



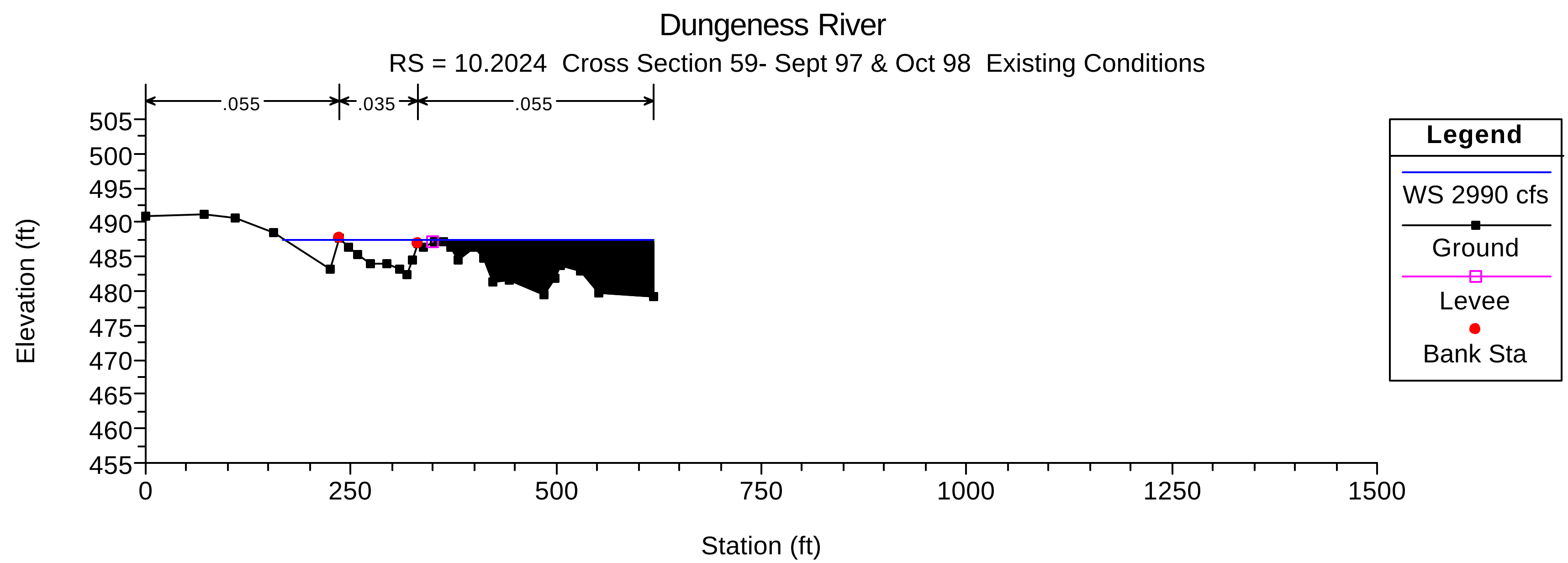

Annual 10 Percentile Mean Discharge Estimates
Dungeness River, WA
Daily Mean Discharge (ft³/s)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1930
1940
1950
1960
1970
1980
1990
Water Year (October - September)

Annual Maximum Mean Discharge Estimates
Dungeness River, WA

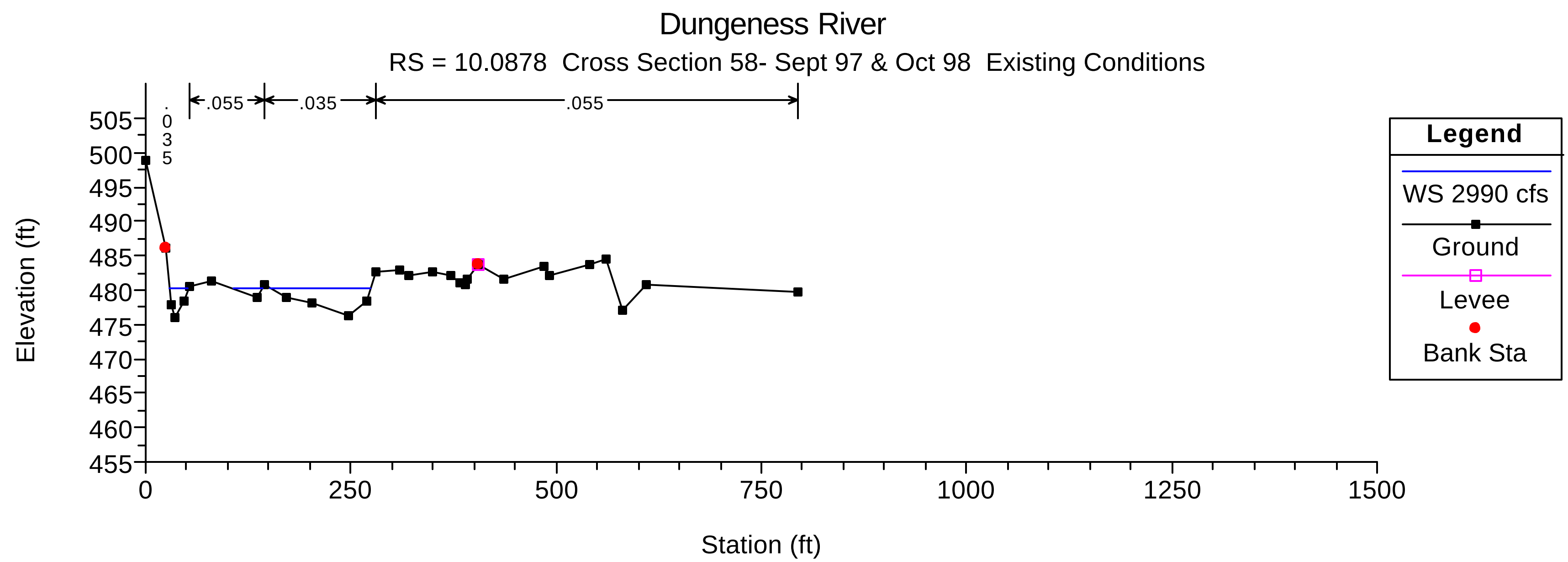


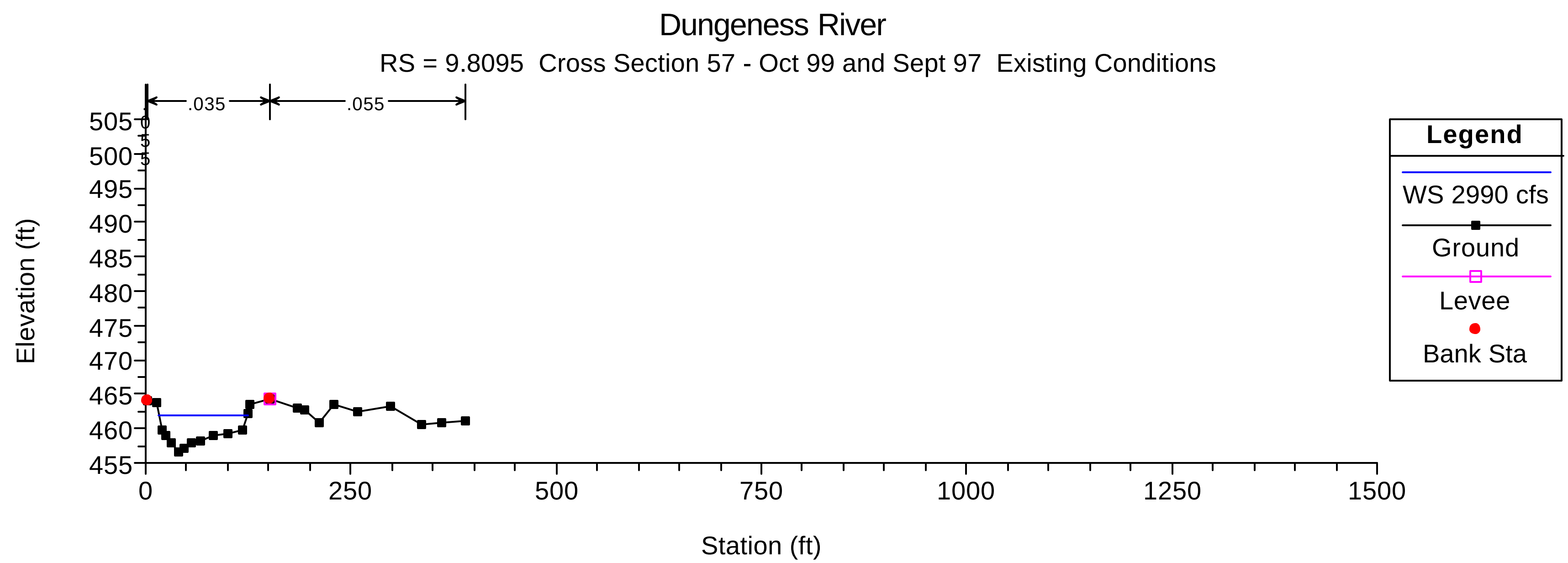


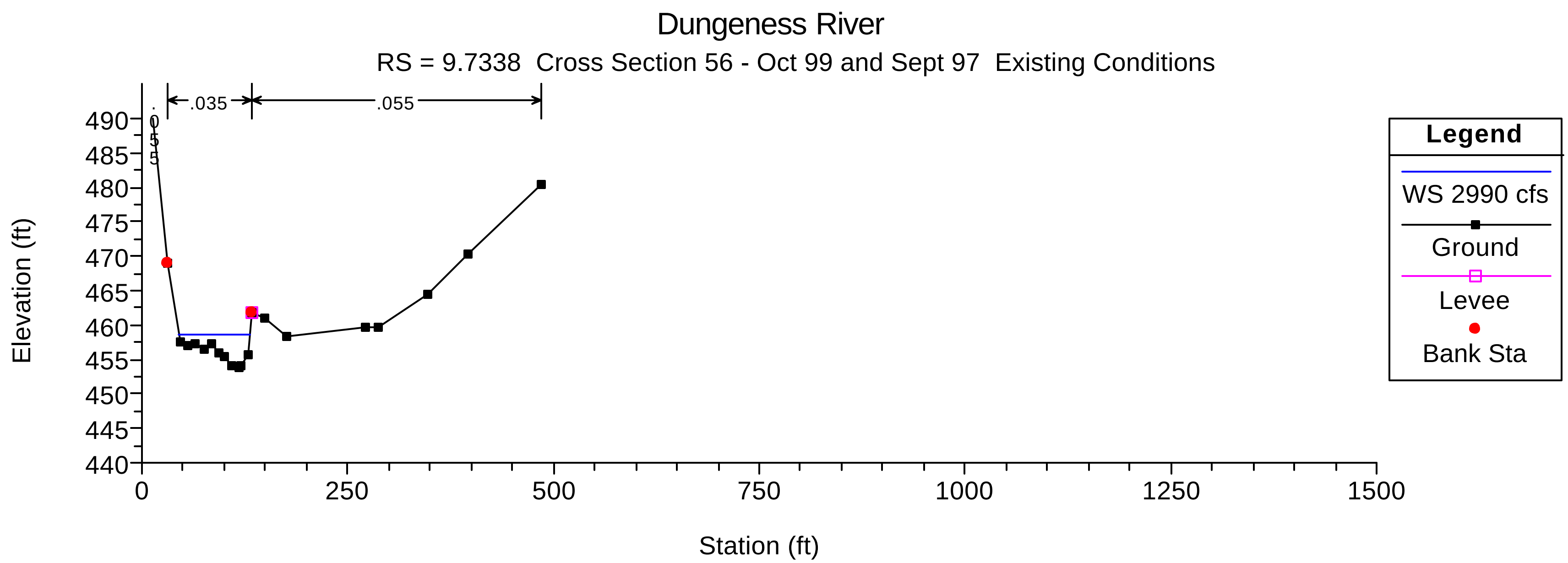
Dungeness River
RS = 10.3627 Cross Section 60 - Sept 97 & Oct 98 Existing Conditions
.055
.035
.055
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
505
500
495
490
485
480
475
470
465
460
455
0
250
500
750
1000
1250
1500
Station (ft)



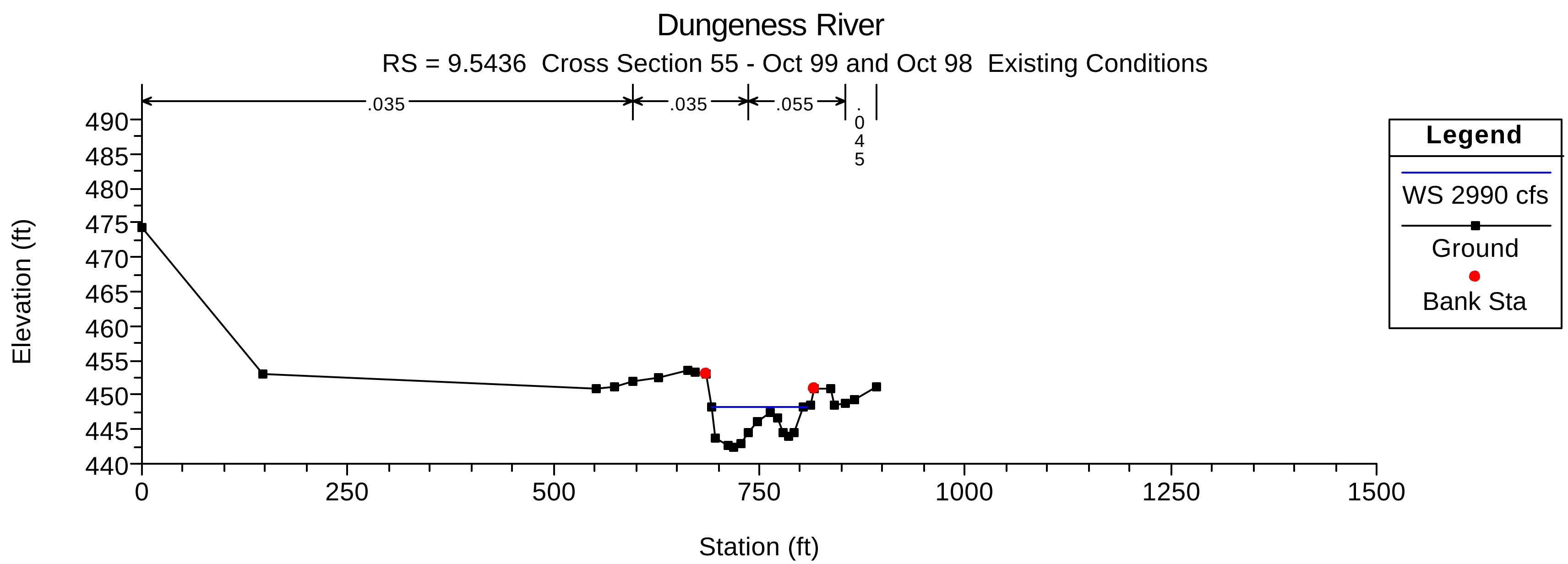
Dungeness River
RS = 10.2024 Cross Section 59- Sept 97 & Oct 98 Existing Conditions
.055
.035
.055
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
505
500
495
490
485
480
475
470
465
460
455
0
250
500
750
1000
1250
1500
Station (ft)


Dungeness River
RS = 10.0878 Cross Section 58- Sept 97 & Oct 98 Existing Conditions
.055
.035
.055
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

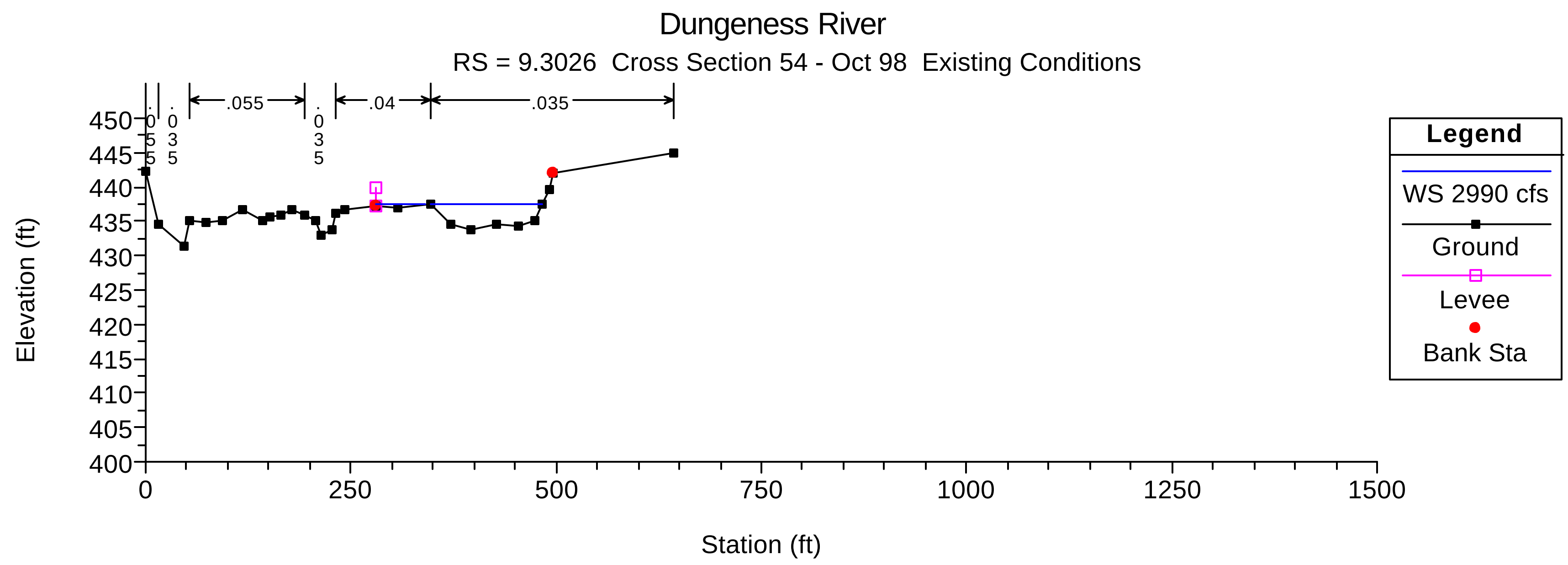

Dungeness River
RS = 9.8095 Cross Section 57 - Oct 99 and Sept 97 Existing Conditions
.035
.055
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

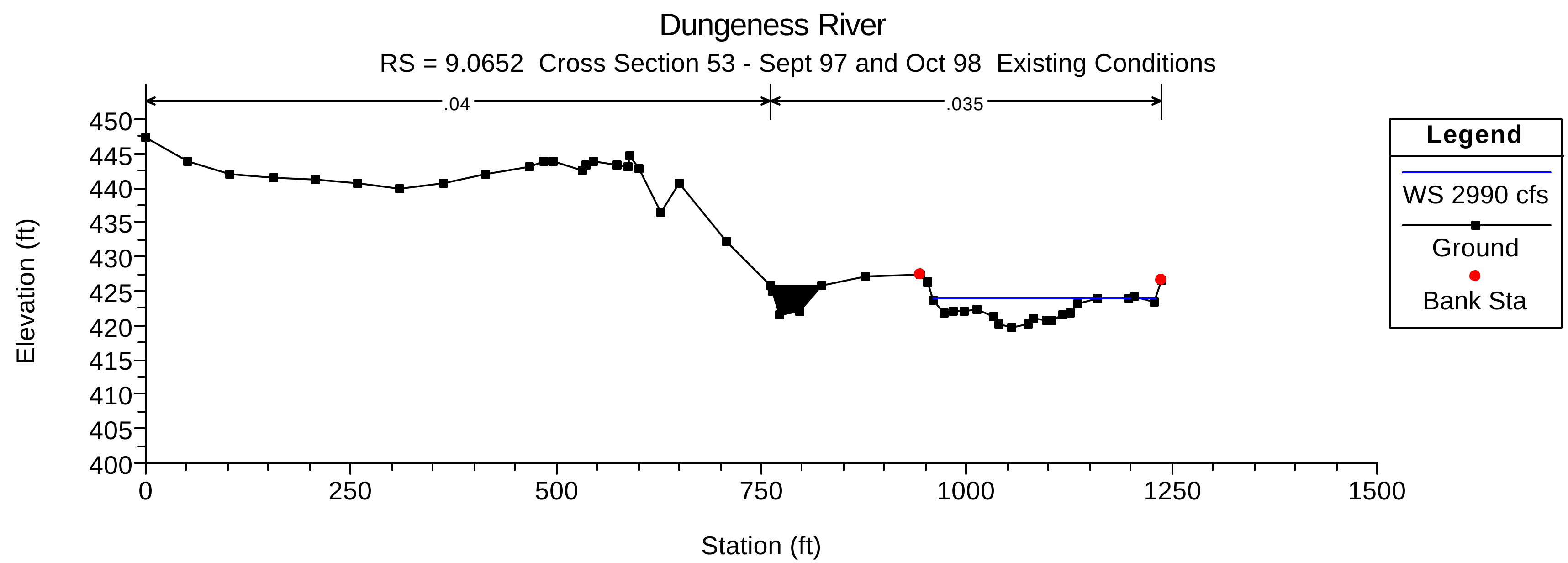


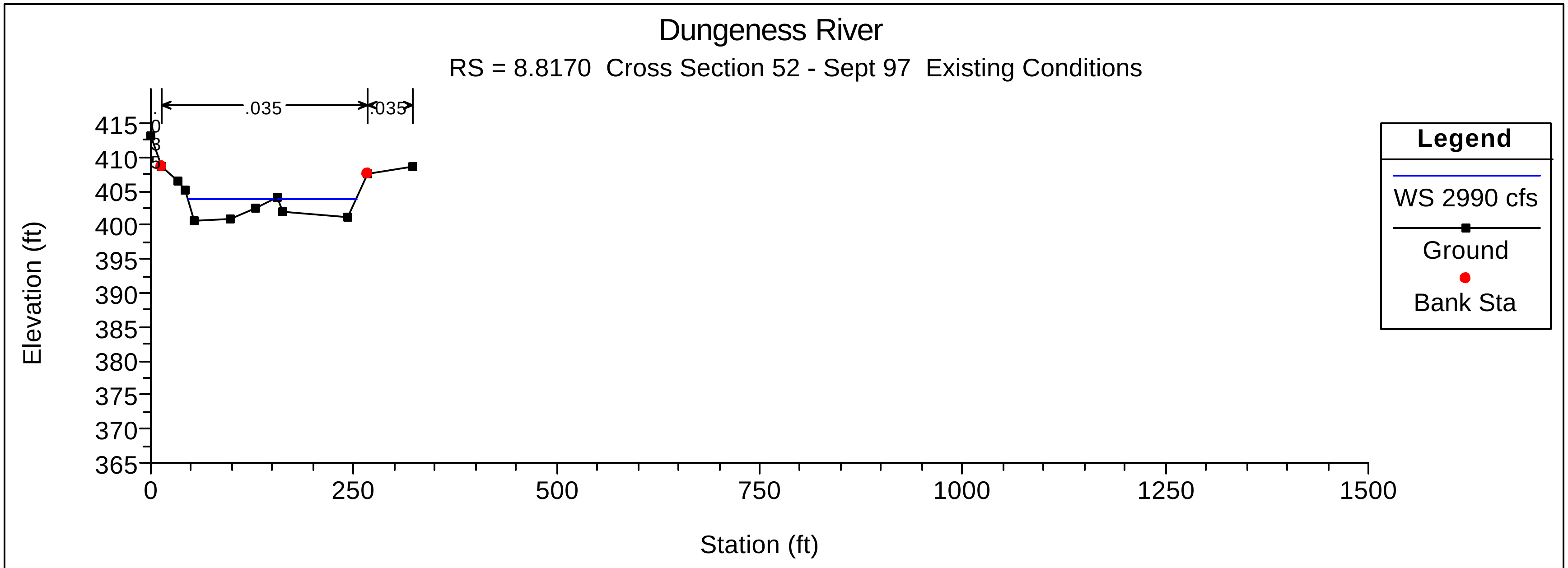
Dungeness River
RS = 9.7338 Cross Section 56 - Oct 99 and Sept 97 Existing Conditions
.035
.055
.055
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta



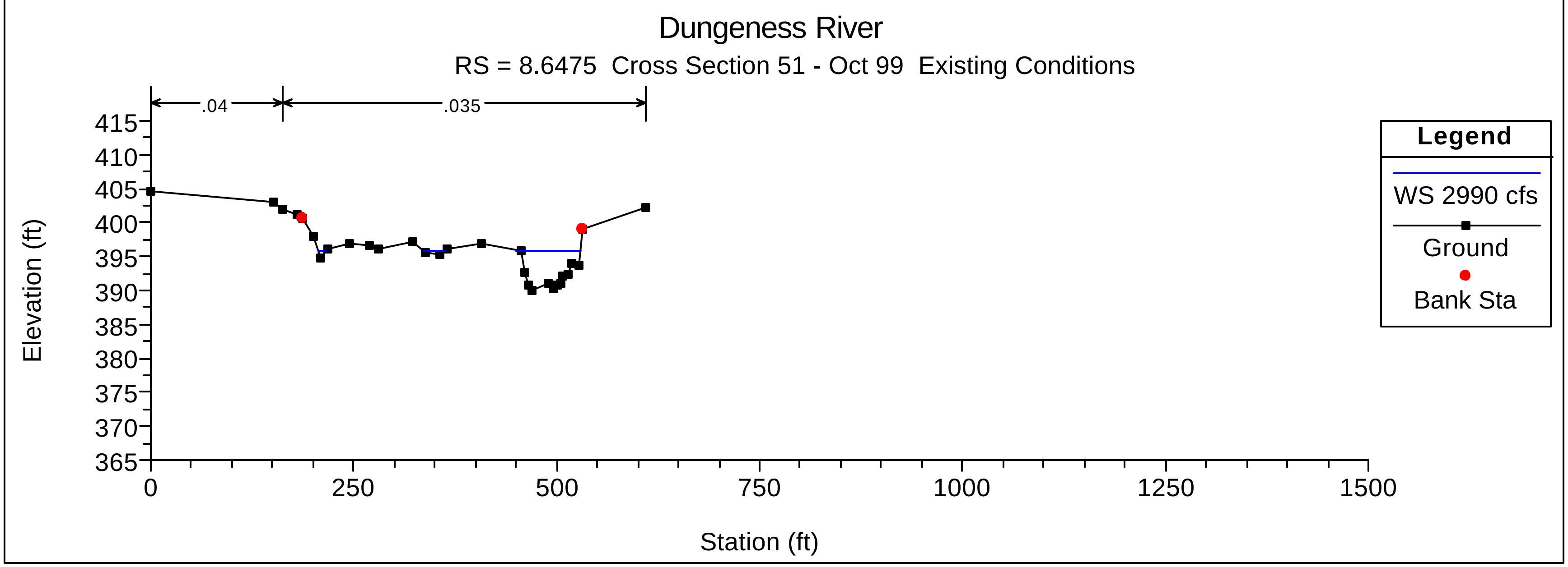
Dungeness River
RS = 9.5436 Cross Section 55 - Oct 99 and Oct 98 Existing Conditions
.035
.035
.055
.045
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 9.3026 Cross Section 54 - Oct 98 Existing Conditions
.055
.04
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

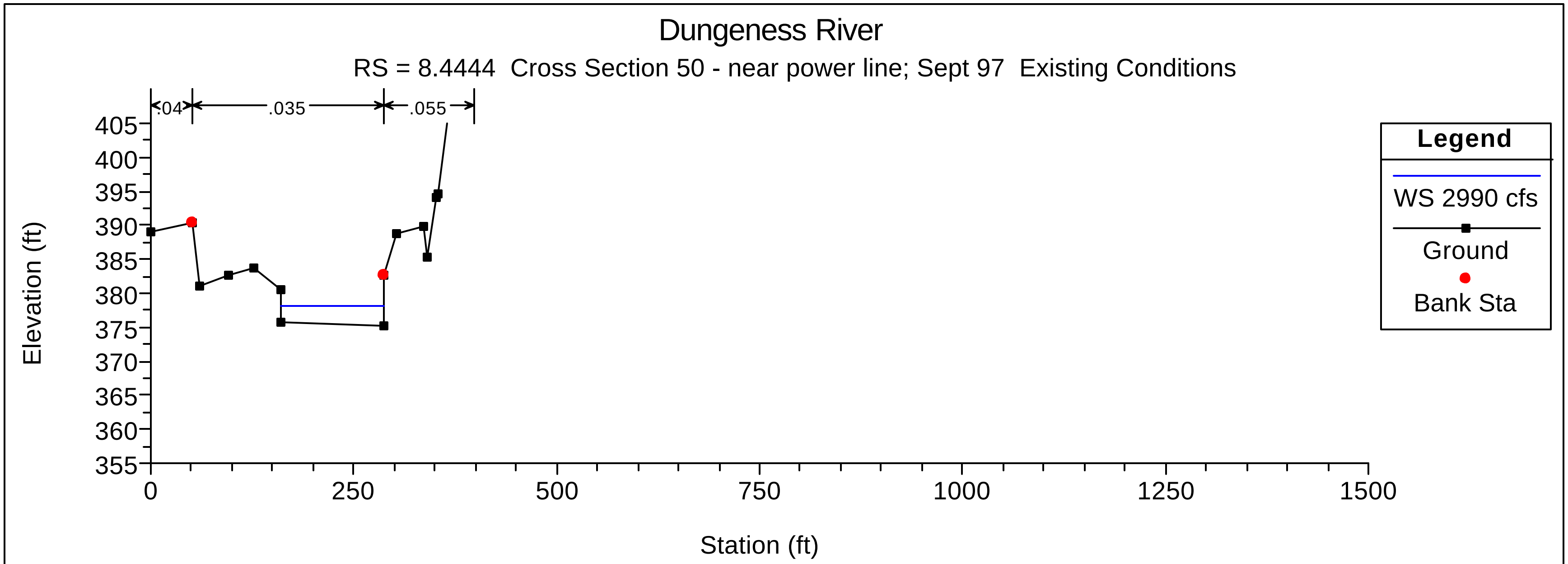

Dungeness River
RS = 9.0652 Cross Section 53 - Sept 97 and Oct 98 Existing Conditions
.04
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta



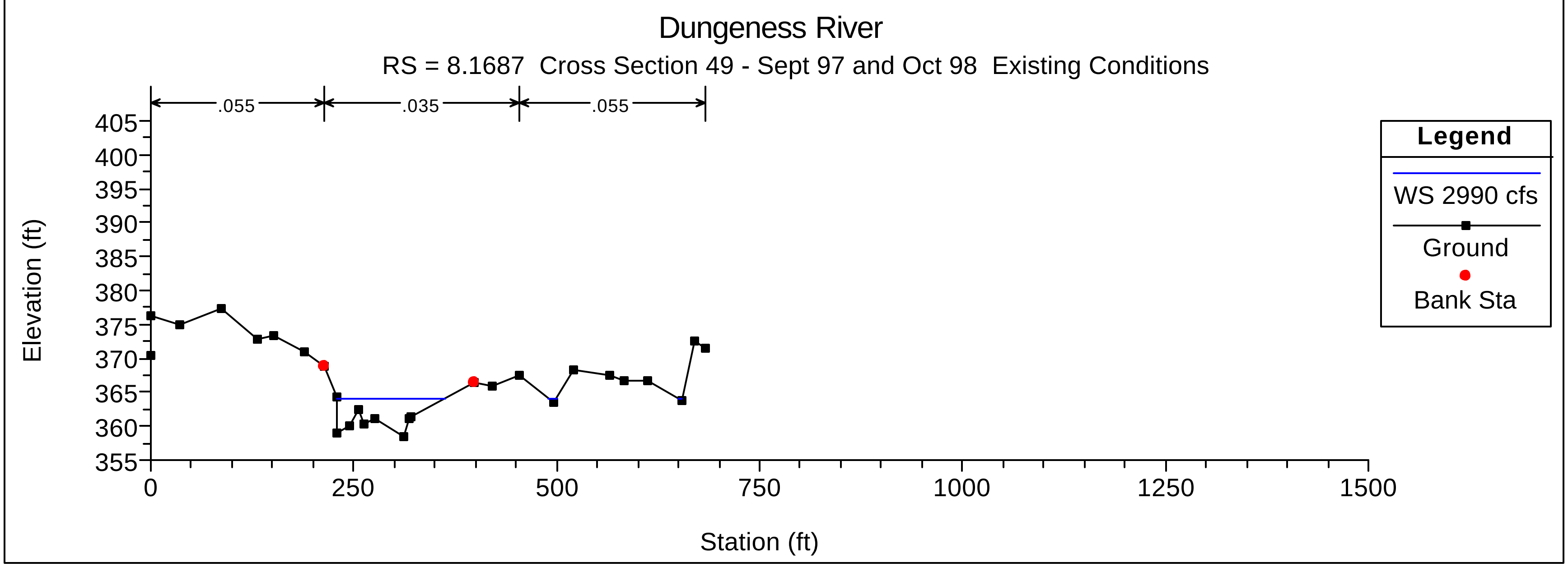
Dungeness River
RS = 8.8170 Cross Section 52 - Sept 97 Existing Conditions
.035
.035
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
415
410
405
400
395
390
385
380
375
370
365
0
250
500
750
1000
1250
1500
Station (ft)



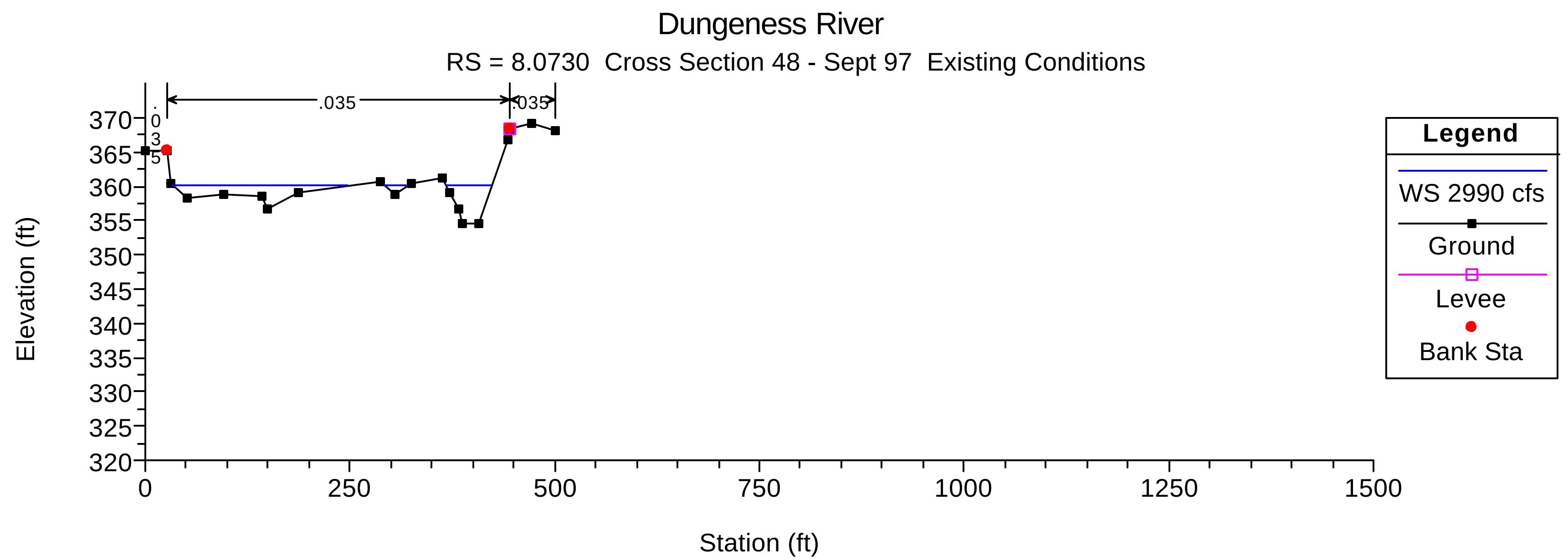
Dungeness River
RS = 8.6475 Cross Section 51 - Oct 99 Existing Conditions
.04
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
415
410
405
400
395
390
385
380
375
370
365
0
250
500
750
1000
1250
1500
Station (ft)

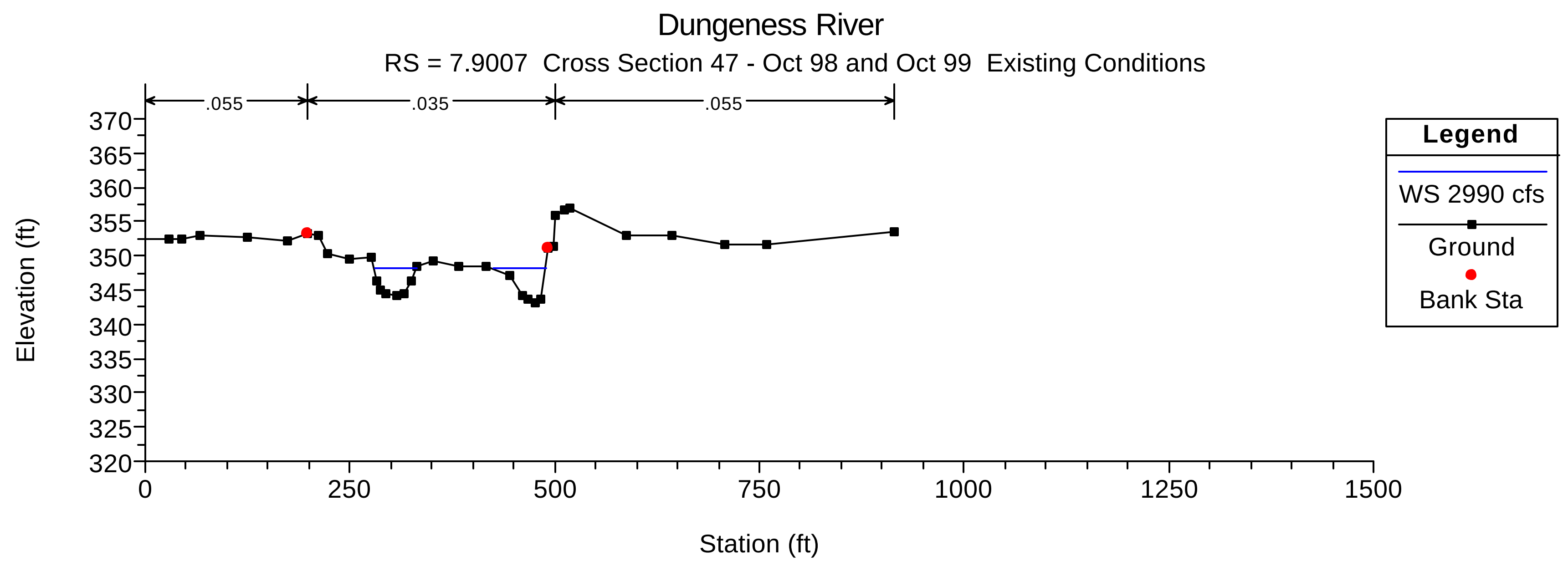


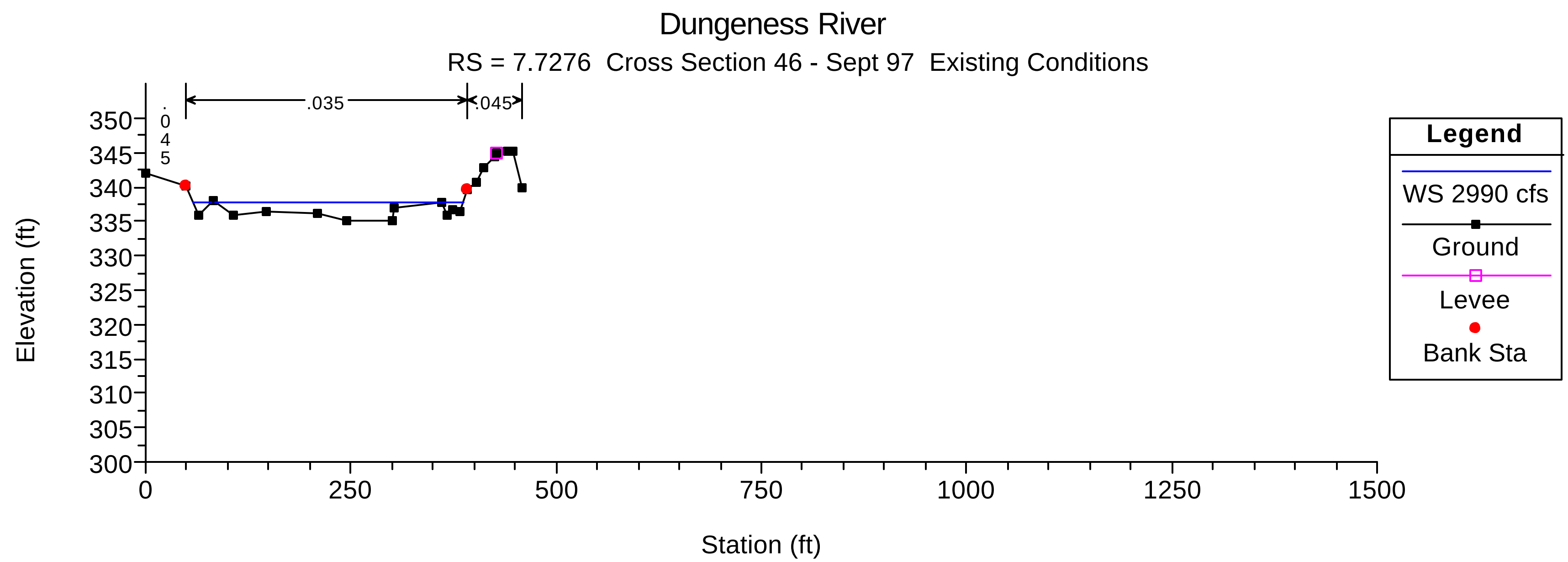
Dungeness River
RS = 8.4444 Cross Section 50 - near power line; Sept 97 Existing Conditions
.04
.035
.055
Elevation (ft)
405
400
395
390
385
380
375
370
365
360
355
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

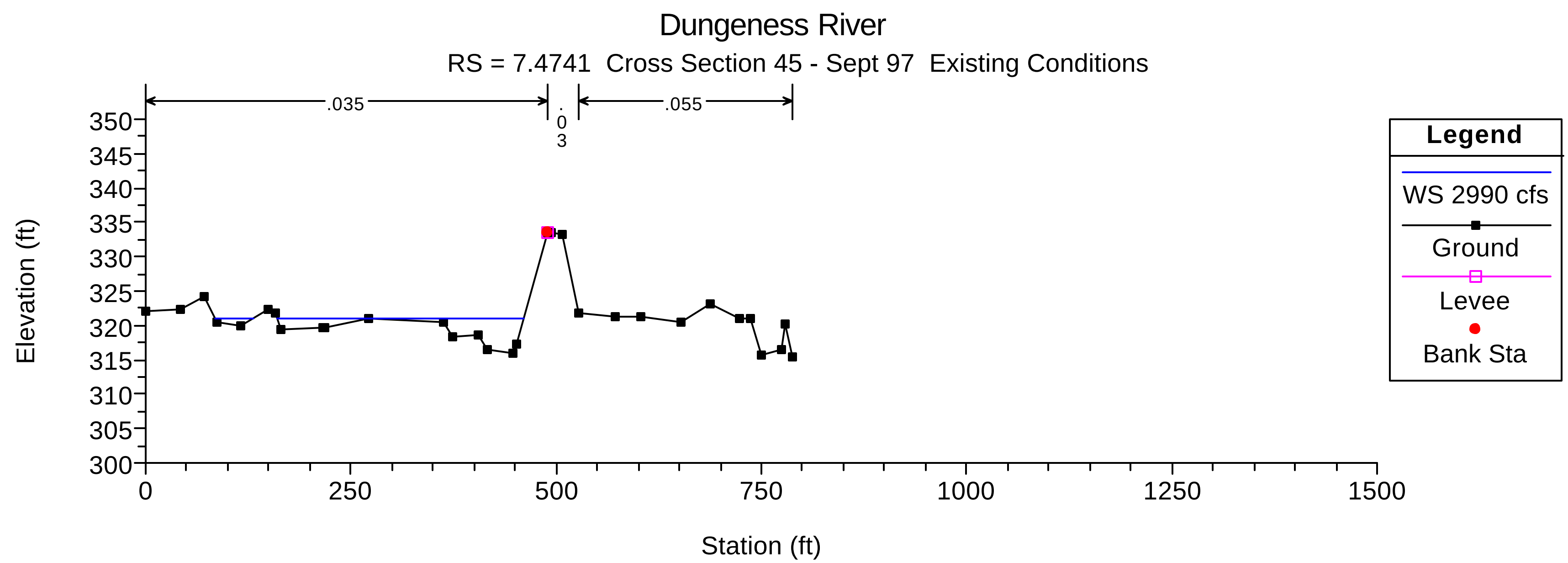


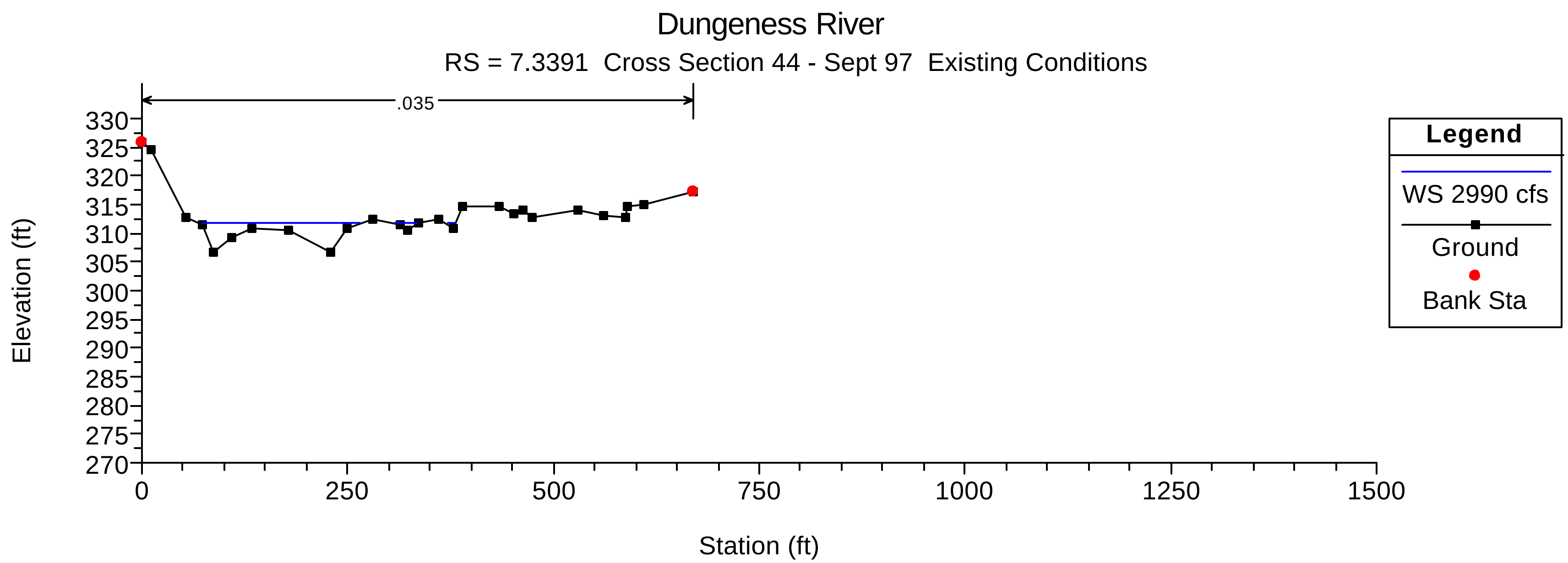
Dungeness River
RS = 8.1687 Cross Section 49 - Sept 97 and Oct 98 Existing Conditions
.055
.035
.055
Elevation (ft)
405
400
395
390
385
380
375
370
365
360
355
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 8.0730 Cross Section 48 - Sept 97 Existing Conditions
.035
.035
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

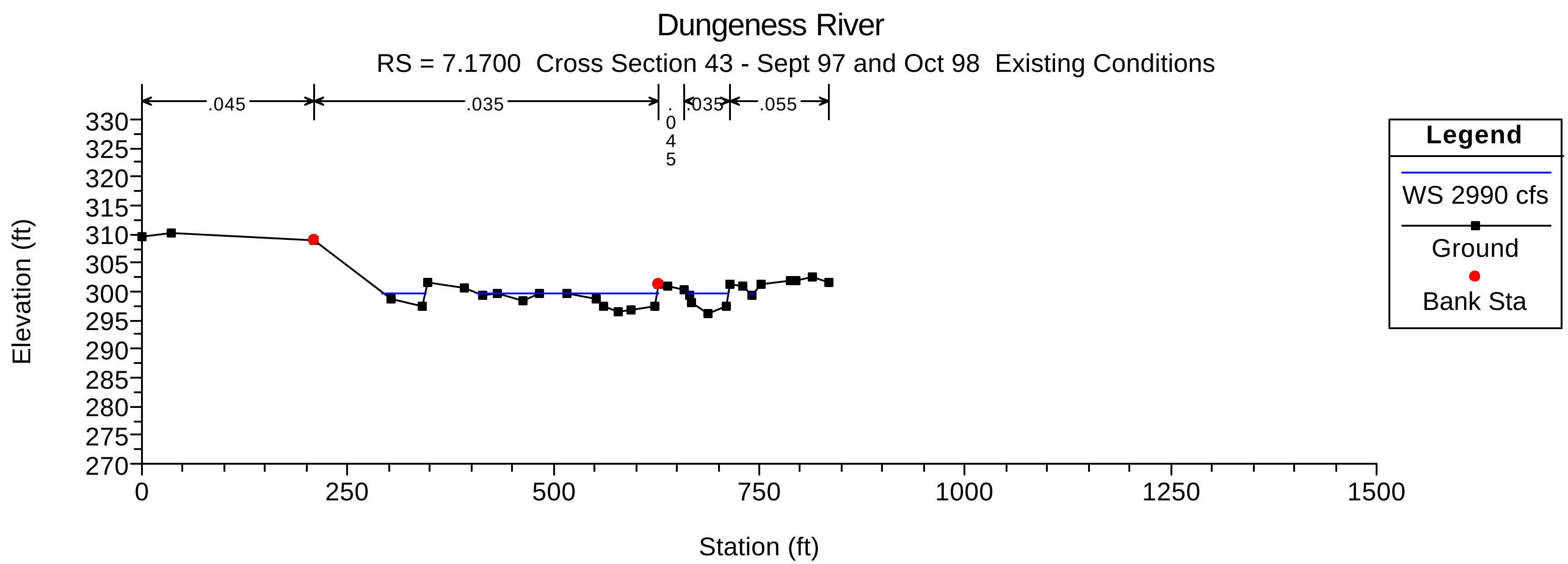

Dungeness River
RS = 7.9007 Cross Section 47 - Oct 98 and Oct 99 Existing Conditions
.055
.035
.055
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 7.7276 Cross Section 46 - Sept 97 Existing Conditions
.035
.045
.045
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

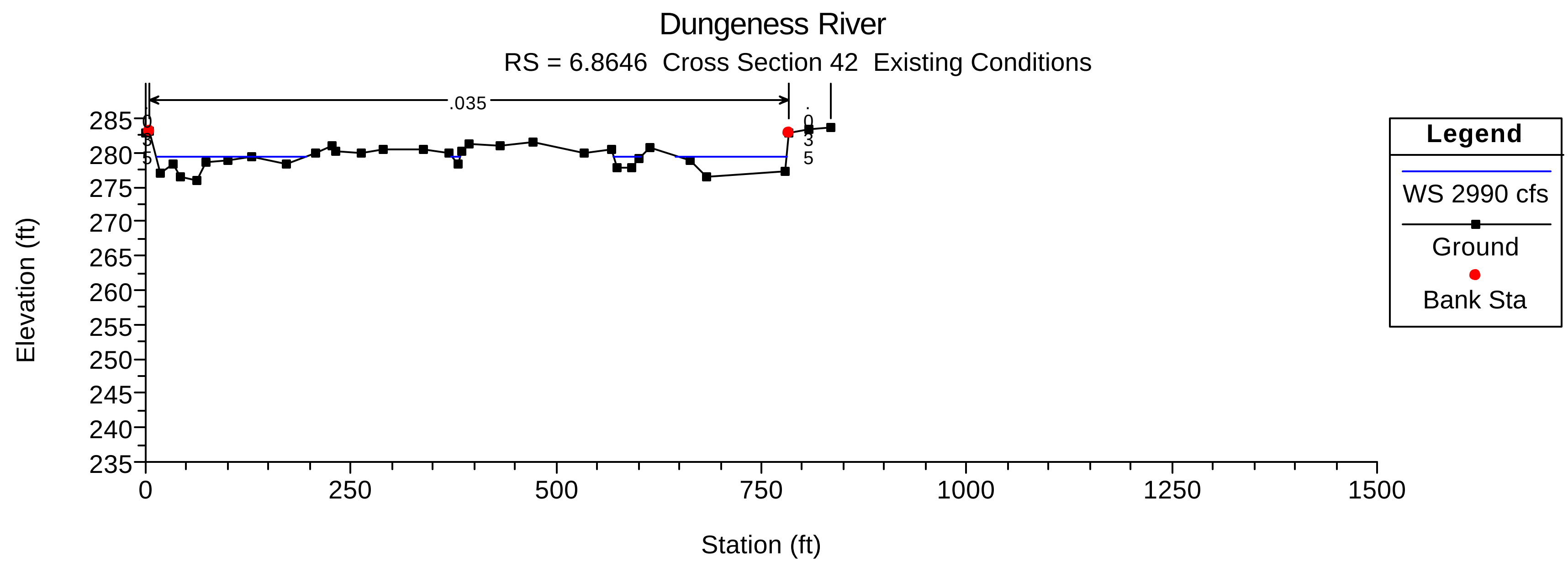

Dungeness River
RS = 7.4741 Cross Section 45 - Sept 97 Existing Conditions
.035
.03
.055
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

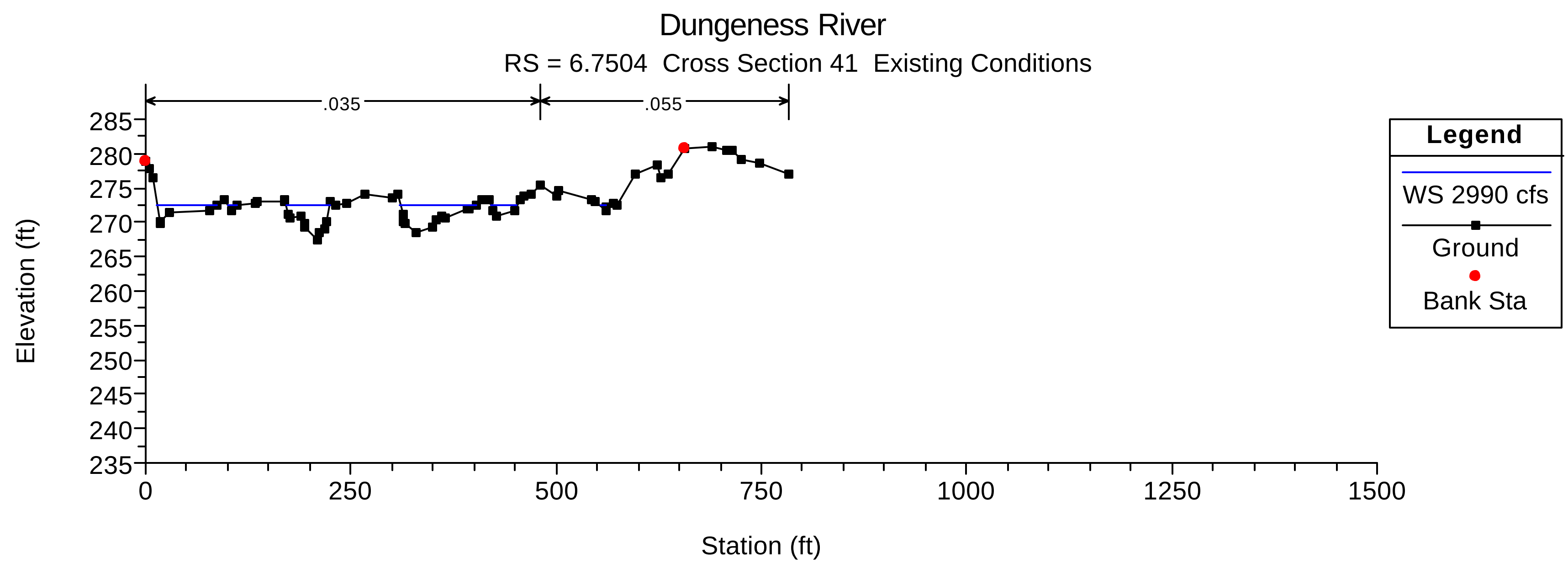


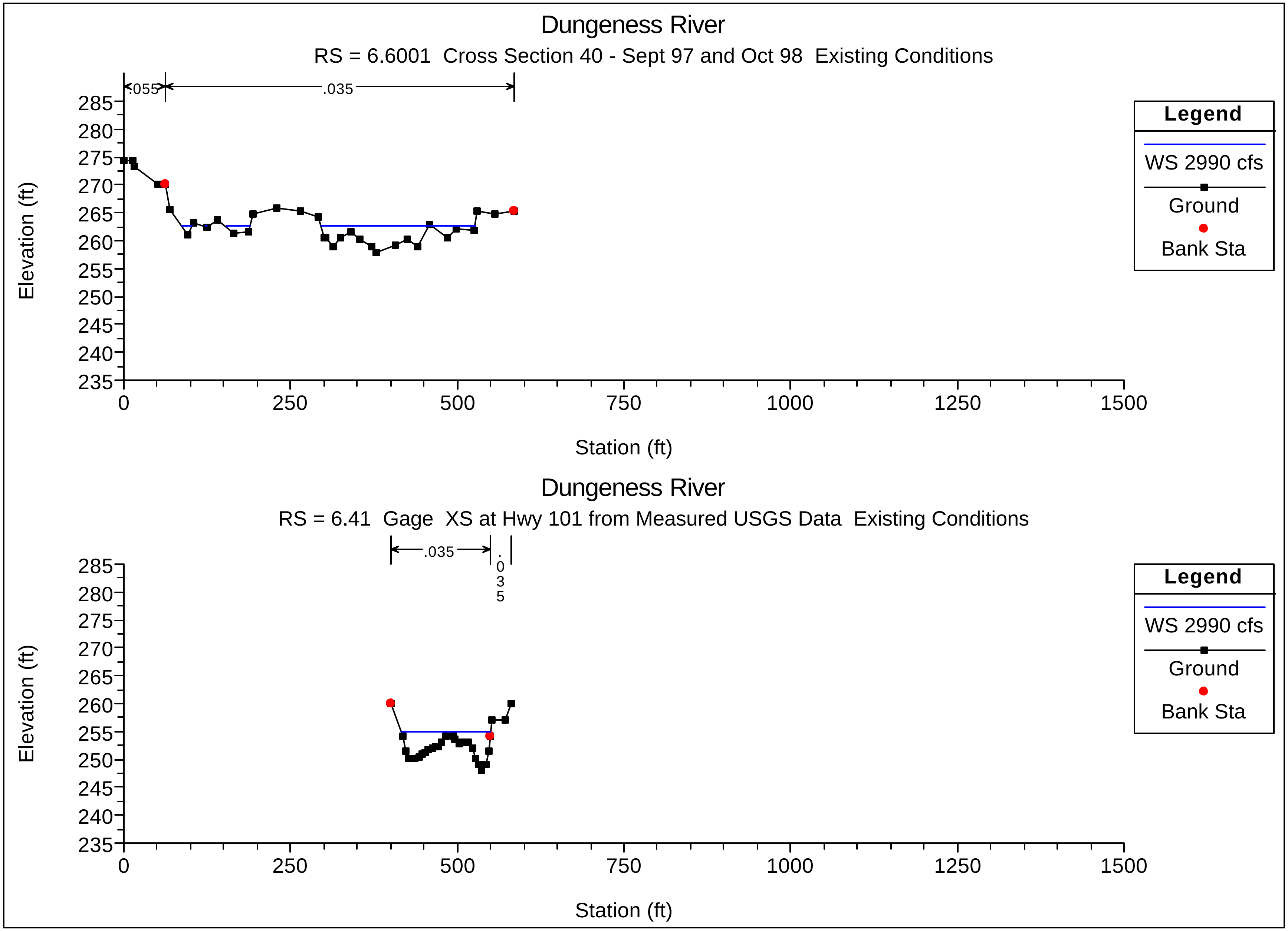
Dungeness River
RS = 7.3391 Cross Section 44 - Sept 97 Existing Conditions
.035
Elevation (ft)
330
325
320
315
310
305
300
295
290
285
280
275
270
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

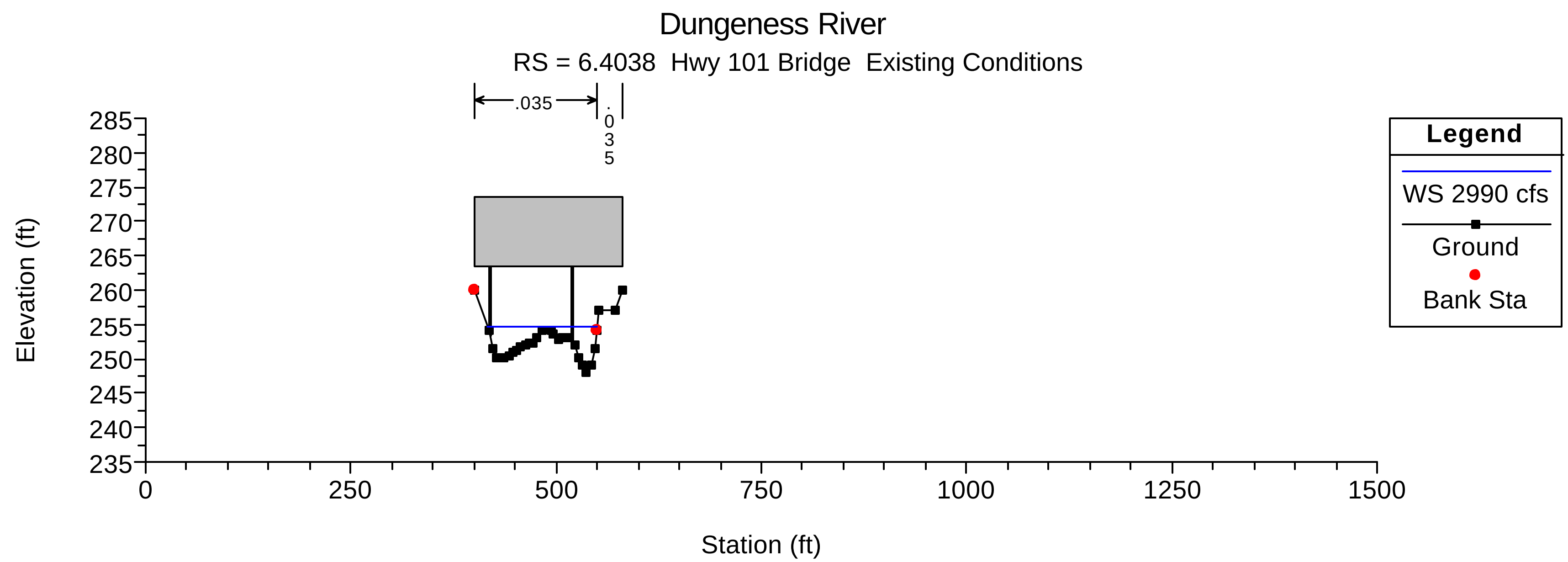


Dungeness River
RS = 7.1700 Cross Section 43 - Sept 97 and Oct 98 Existing Conditions
.045
.035
.045
.035
.055
Elevation (ft)
330
325
320
315
310
305
300
295
290
285
280
275
270
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

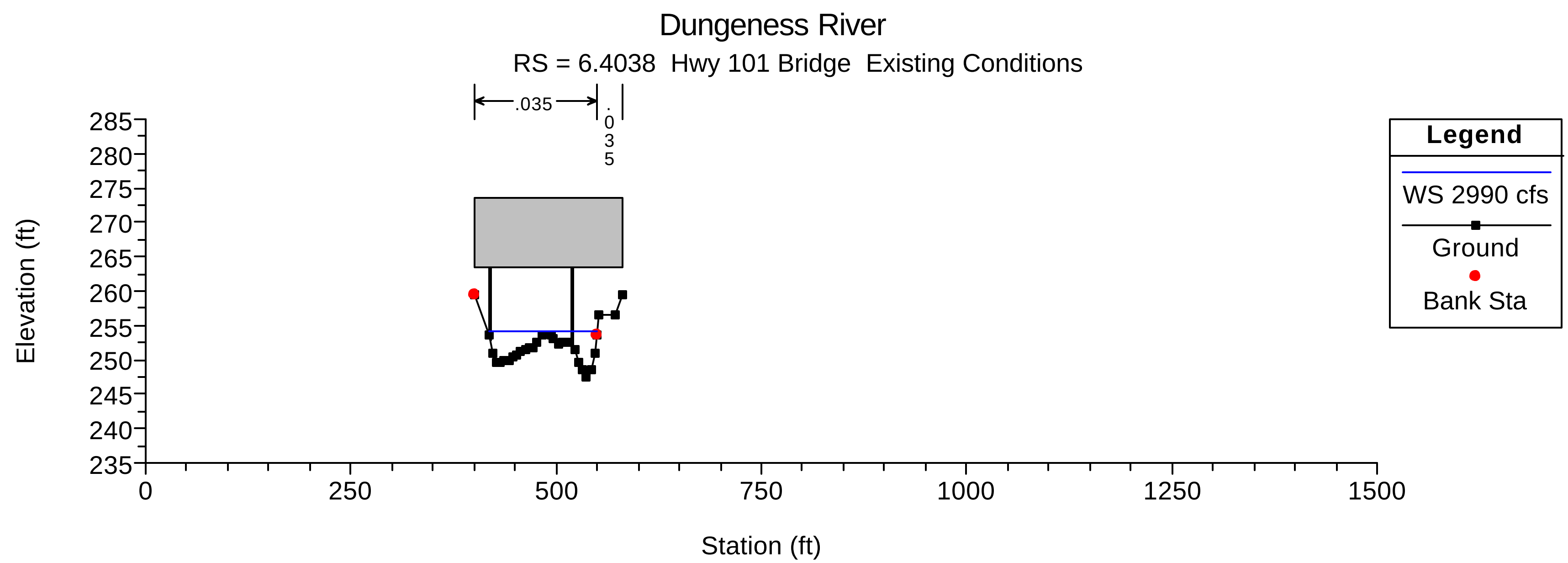

Dungeness River
RS = 6.8646 Cross Section 42 Existing Conditions
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 6.7504 Cross Section 41 Existing Conditions
.035
.055
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

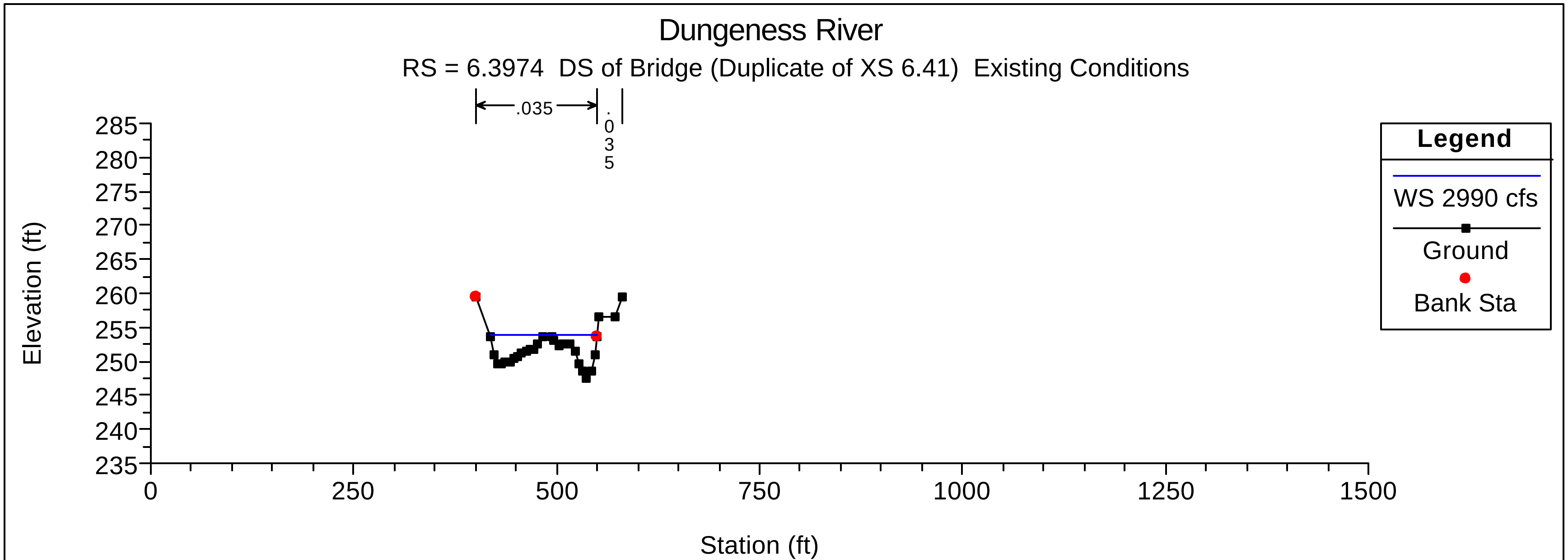

Dungeness River
RS = 6.6001 Cross Section 40 - Sept 97 and Oct 98 Existing Conditions
.055
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta
Dungeness River
RS = 6.41 Gage XS at Hwy 101 from Measured USGS Data Existing Conditions
.035
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

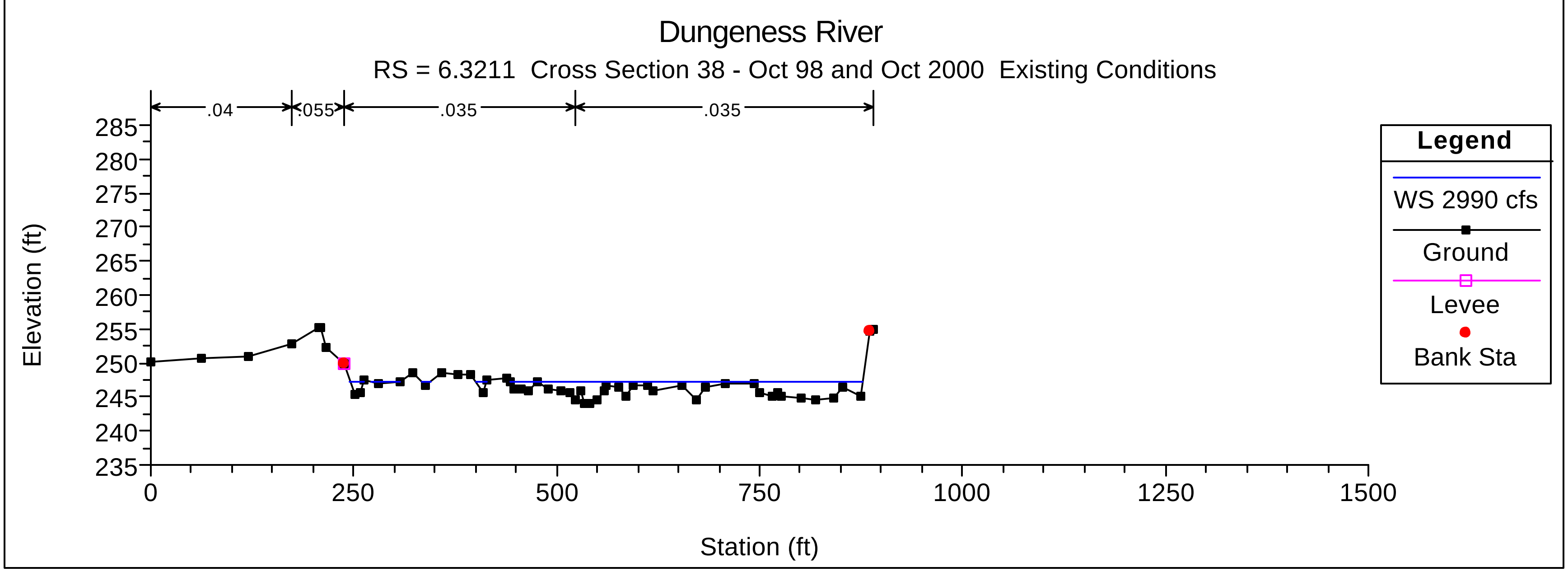


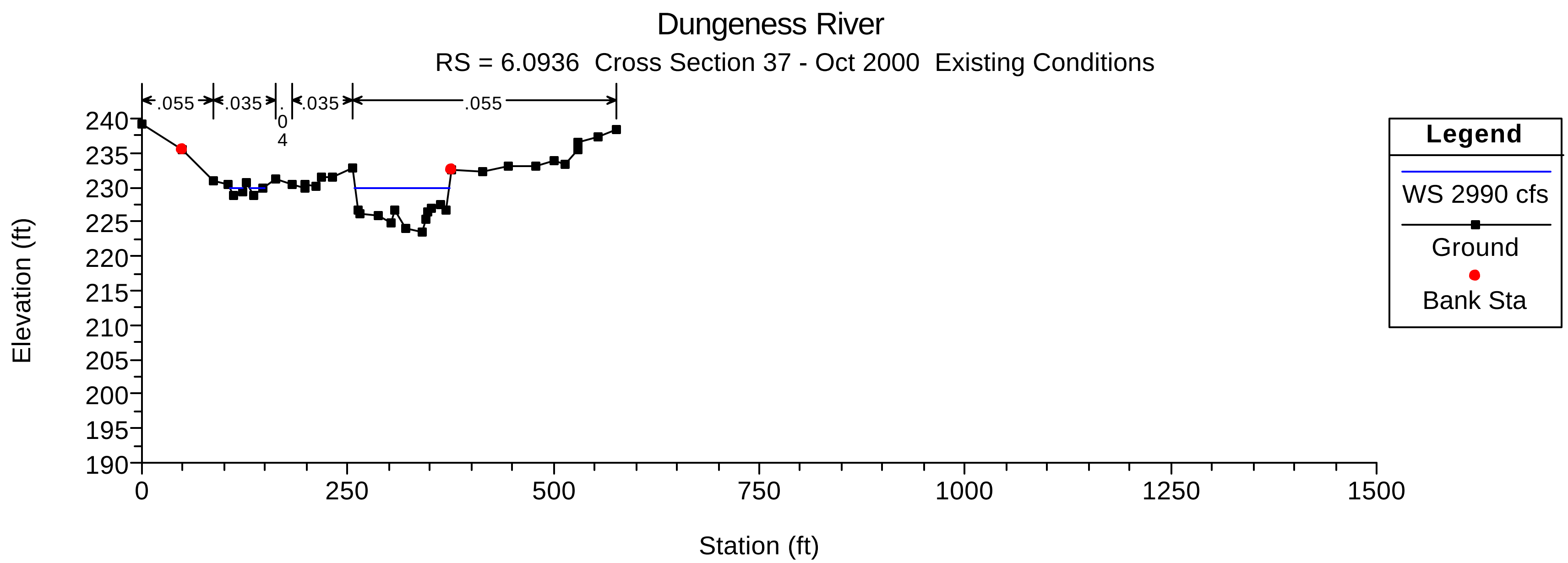
Dungeness River
RS = 6.4038 Hwy 101 Bridge Existing Conditions
.035
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
285
280
275
270
265
260
255
250
245
240
235
0
250
500
750
1000
1250
1500
Station (ft)

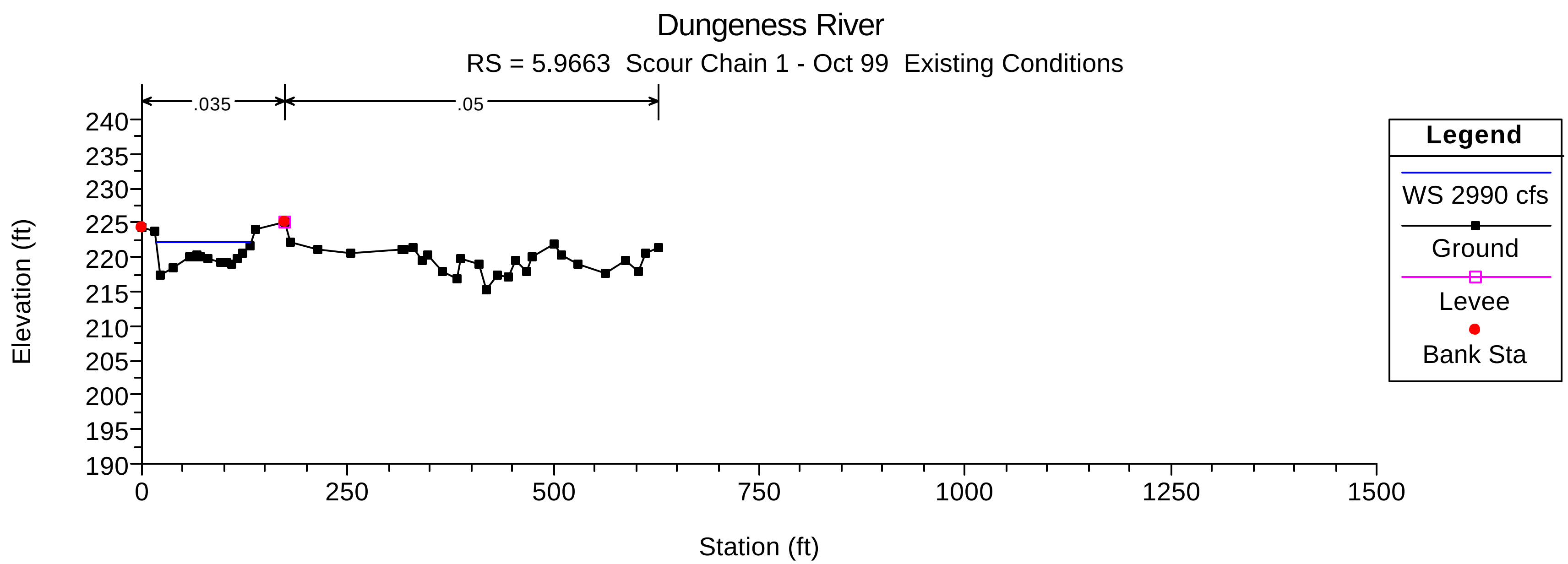


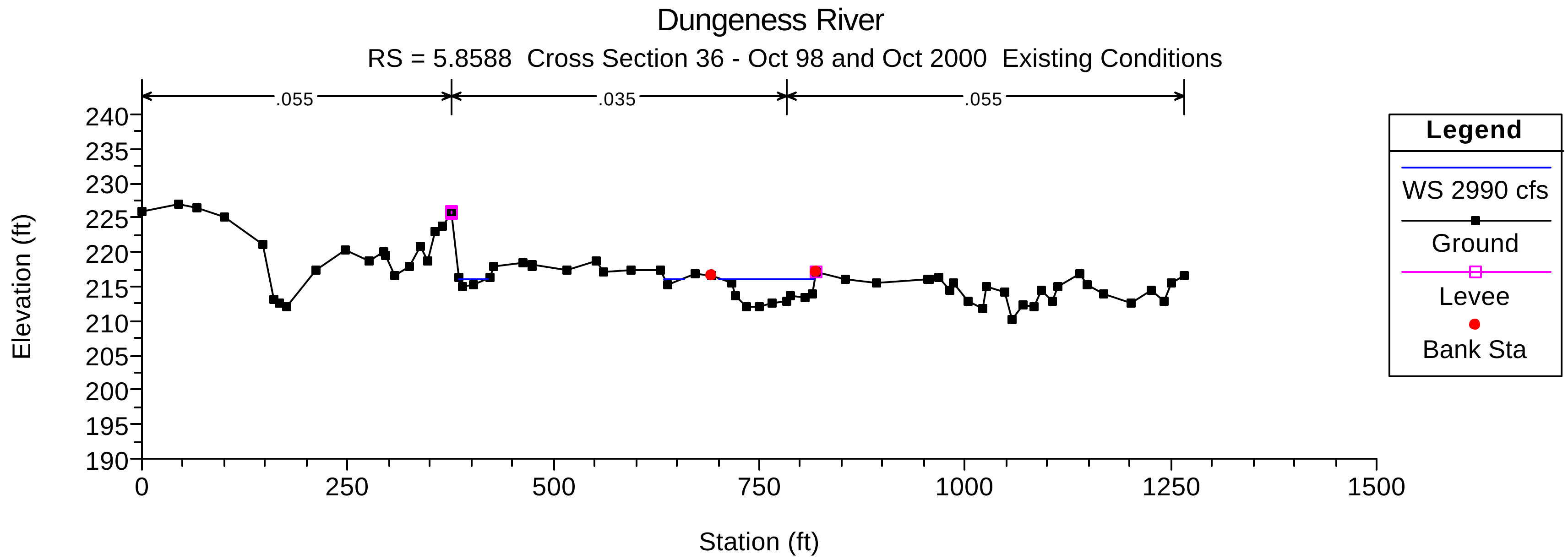
Dungeness River
RS = 6.4038 Hwy 101 Bridge Existing Conditions
.035
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
285
280
275
270
265
260
255
250
245
240
235
0
250
500
750
1000
1250
1500
Station (ft)


Dungeness River
RS = 6.3974 DS of Bridge (Duplicate of XS 6.41) Existing Conditions
.035
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
285
280
275
270
265
260
255
250
245
240
235
0
250
500
750
1000
1250
1500
Station (ft)

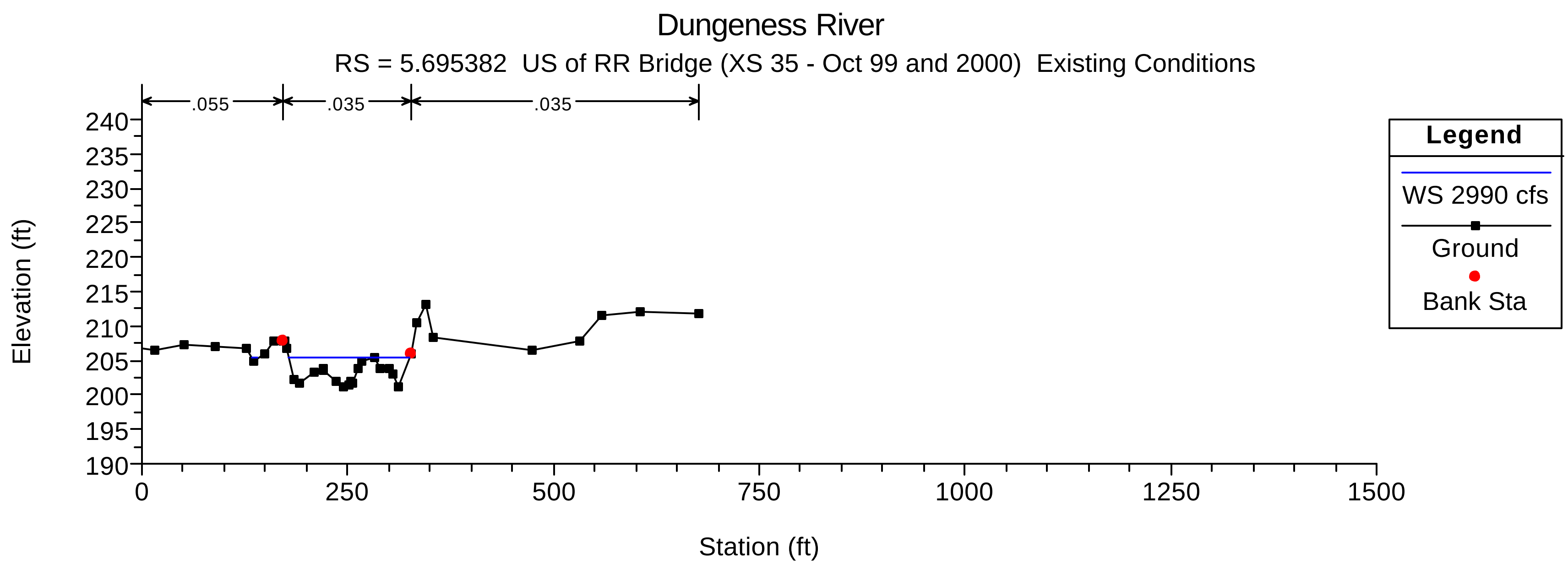

Dungeness River
RS = 6.3211 Cross Section 38 - Oct 98 and Oct 2000 Existing Conditions
.04
.055
.035
.035
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
285
280
275
270
265
260
255
250
245
240
235
0
250
500
750
1000
1250
1500
Station (ft)


Dungeness River
RS = 6.0936 Cross Section 37 - Oct 2000 Existing Conditions
.055
.035
.035
.055
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
Station (ft)
240
235
230
225
220
215
210
205
200
195
190
0
250
500
750
1000
1250
1500

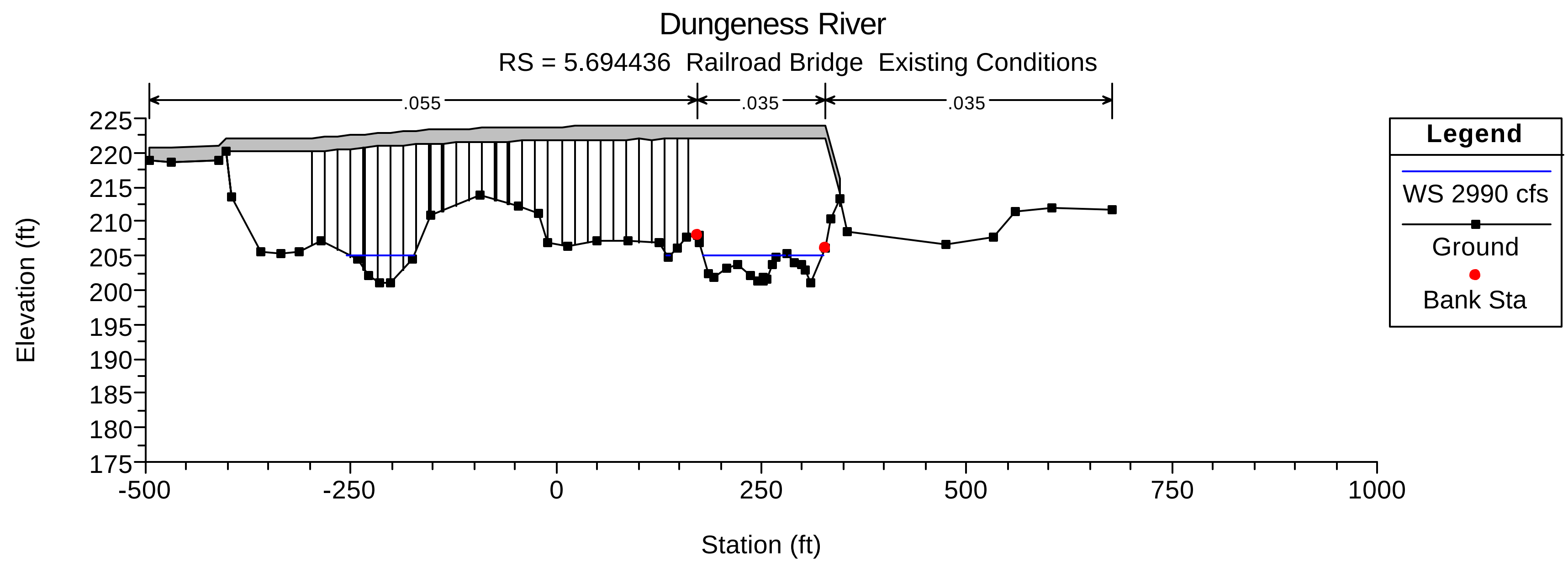

Dungeness River
RS = 5.9663 Scour Chain 1 - Oct 99 Existing Conditions
.035
.05
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
240
235
230
225
220
215
210
205
200
195
190
0
250
500
750
1000
1250
1500

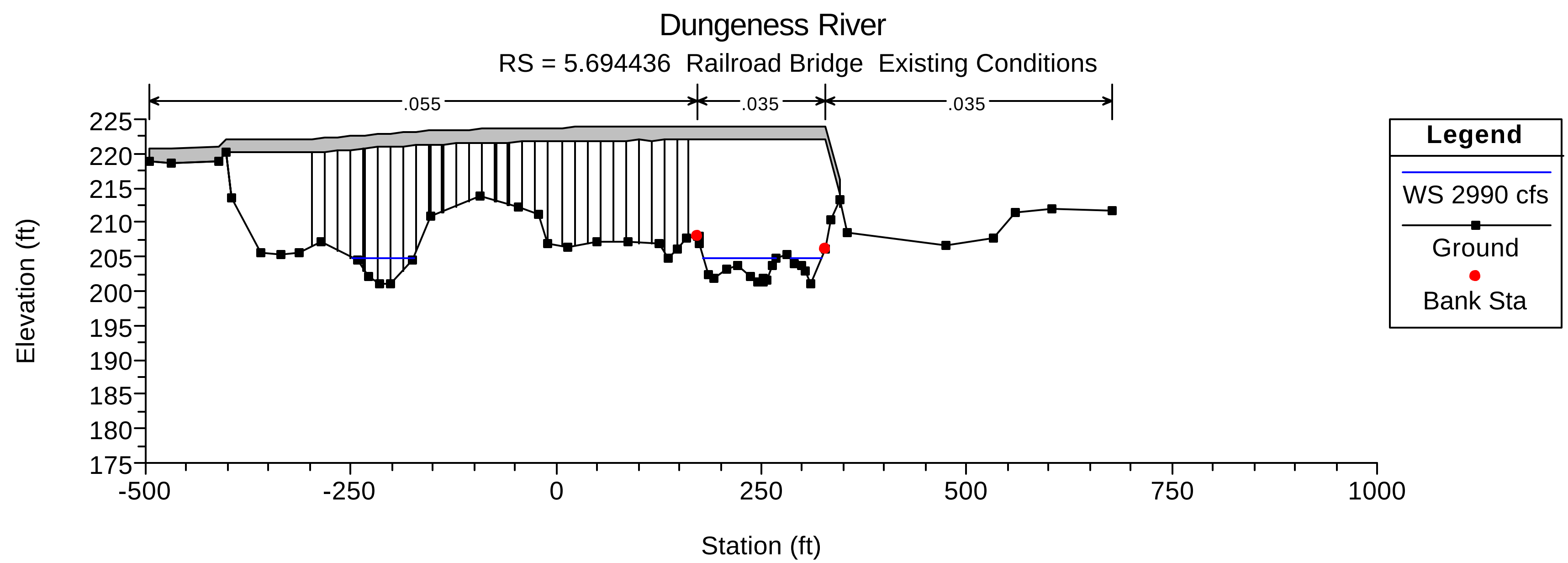


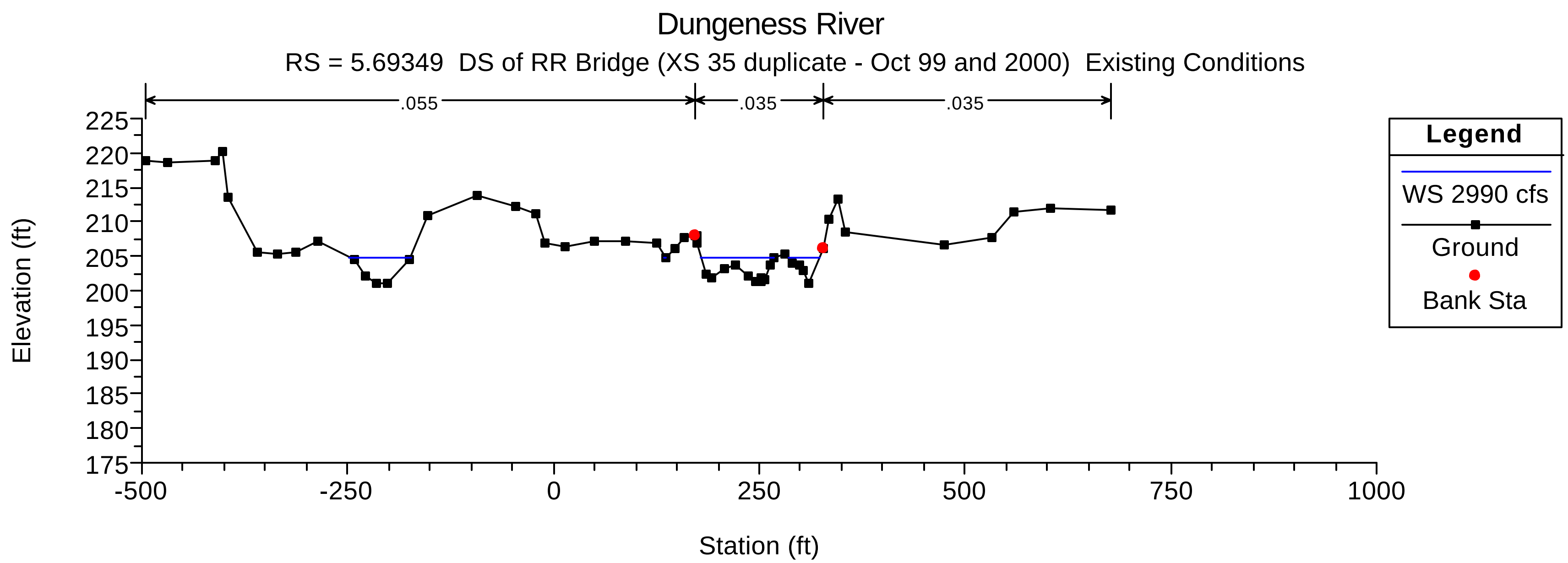
Dungeness River
RS = 5.8588 Cross Section 36 - Oct 98 and Oct 2000 Existing Conditions
.055
.035
.055
Elevation (ft)
240
235
230
225
220
215
210
205
200
195
190
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

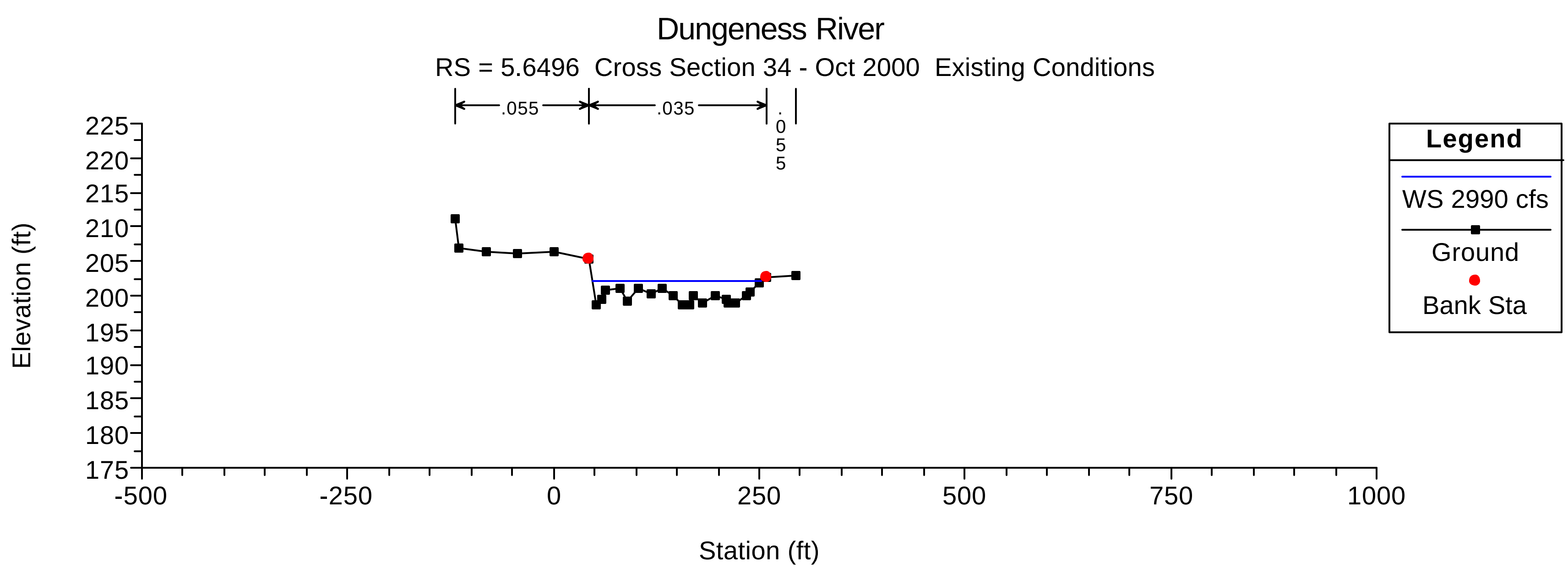


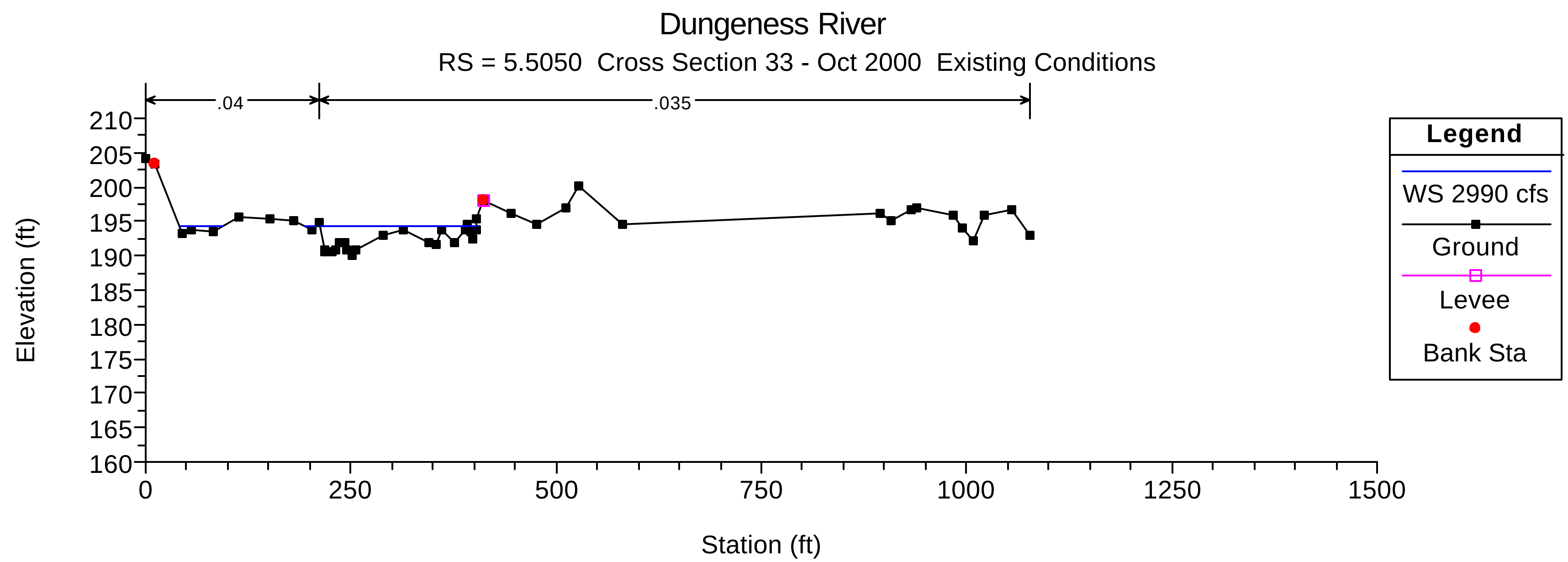
Dungeness River
RS = 5.695382 US of RR Bridge (XS 35 - Oct 99 and 2000) Existing Conditions
.055
.035
.035
Elevation (ft)
240
235
230
225
220
215
210
205
200
195
190
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

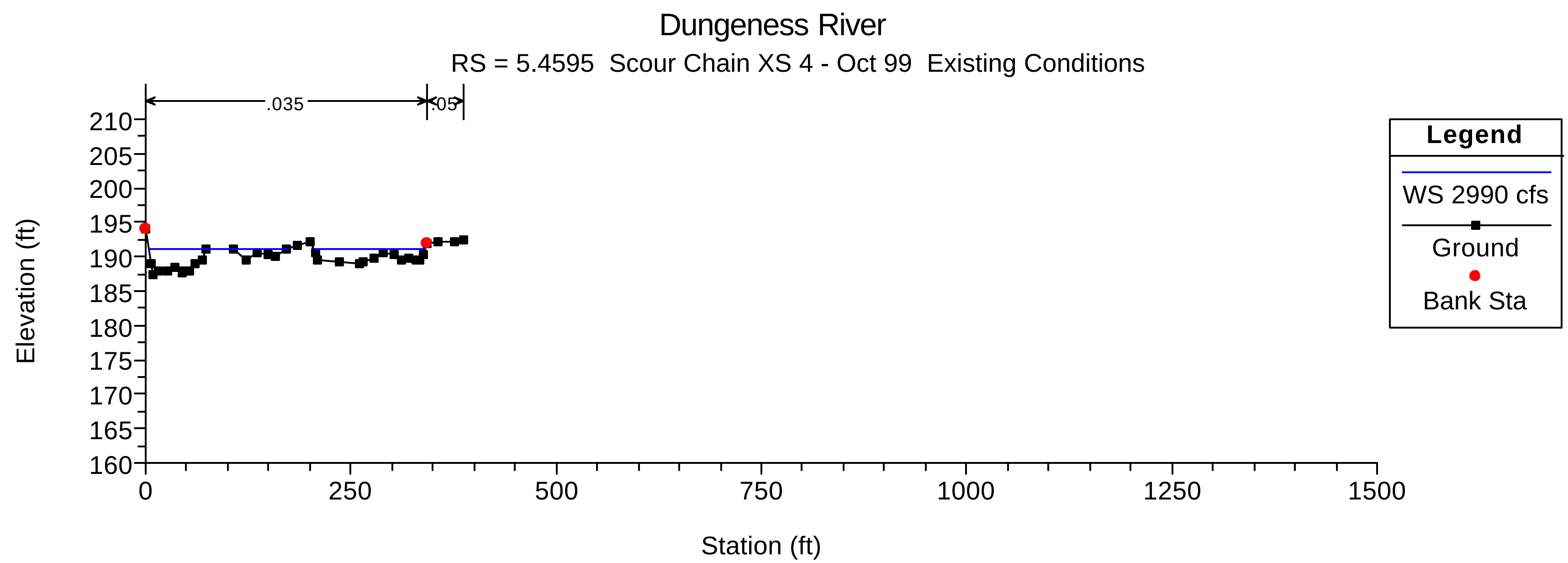

Dungeness River
RS = 5.694436 Railroad Bridge Existing Conditions
.055
.035
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
Station (ft)

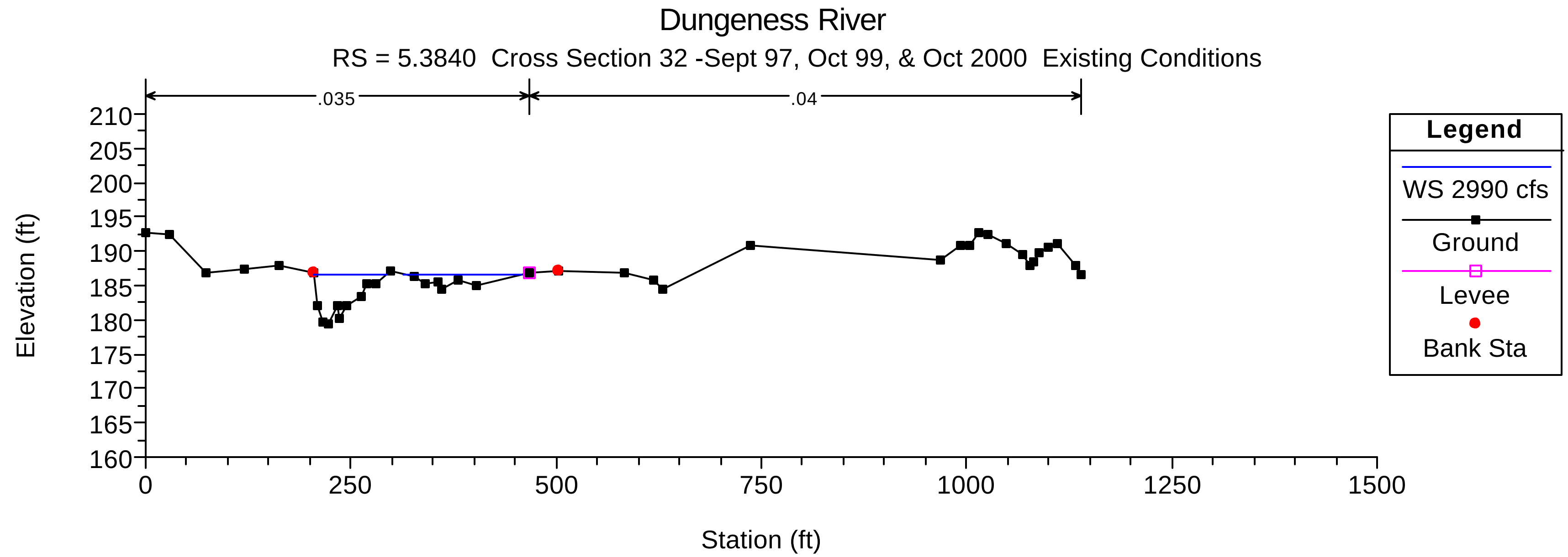

Dungeness River
RS = 5.694436 Railroad Bridge Existing Conditions
.055
.035
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
Station (ft)

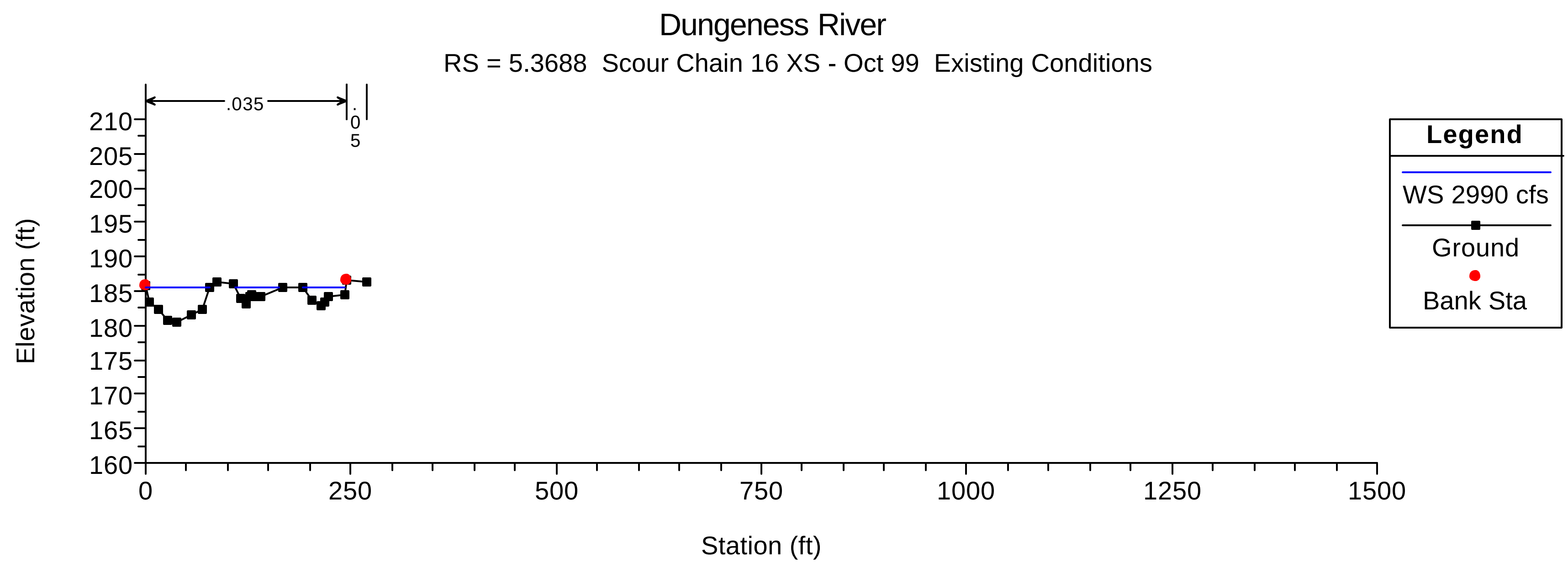

Dungeness River
RS = 5.69349 DS of RR Bridge (XS 35 duplicate - Oct 99 and 2000) Existing Conditions
.055
.035
.035
Elevation (ft)
225
220
215
210
205
200
195
190
185
180
175
-500
-250
0
250
500
750
1000
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

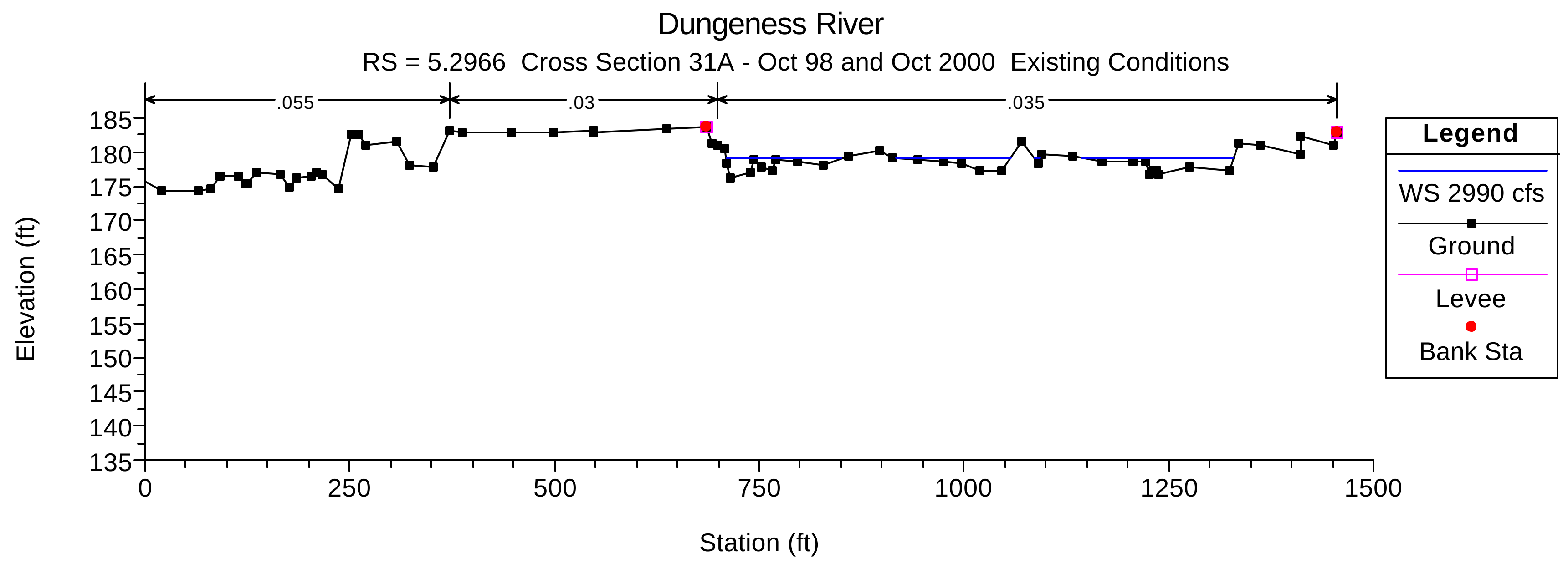

Dungeness River
RS = 5.6496 Cross Section 34 - Oct 2000 Existing Conditions
.055
.035
.055
Elevation (ft)
225
220
215
210
205
200
195
190
185
180
175
-500
-250
0
250
500
750
1000
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 5.5050 Cross Section 33 - Oct 2000 Existing Conditions
.04
.035
Elevation (ft)
210
205
200
195
190
185
180
175
170
165
160
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

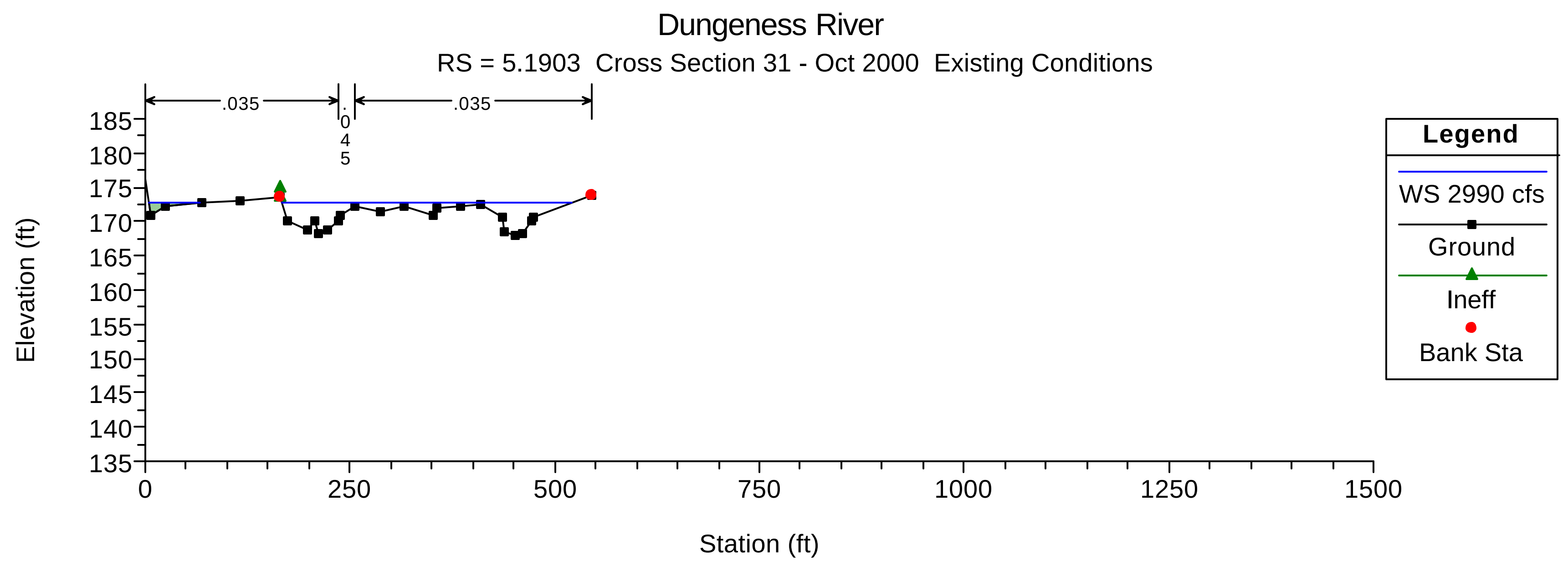

Dungeness River
RS = 5.4595 Scour Chain XS 4 - Oct 99 Existing Conditions
.035
.05
Elevation (ft)
210
205
200
195
190
185
180
175
170
165
160
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 5.3840 Cross Section 32 -Sept 97, Oct 99, & Oct 2000 Existing Conditions
.035
.04
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

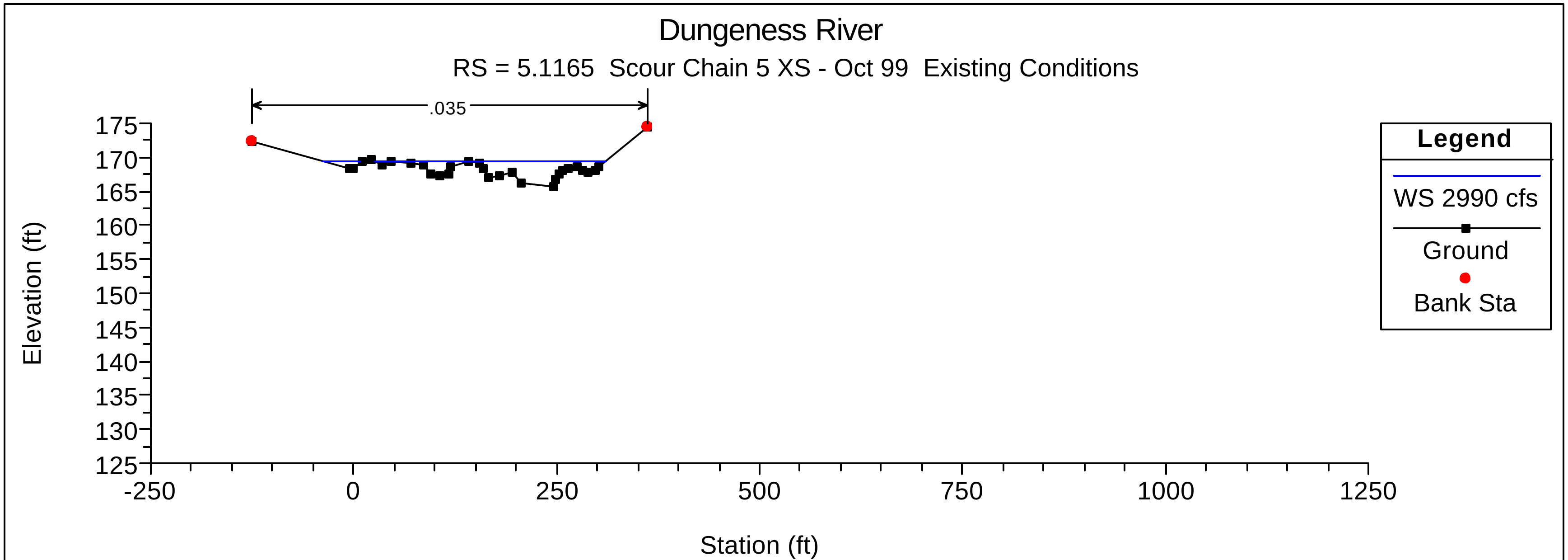

Dungeness River
RS = 5.3688 Scour Chain 16 XS - Oct 99 Existing Conditions
.035
.05
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta



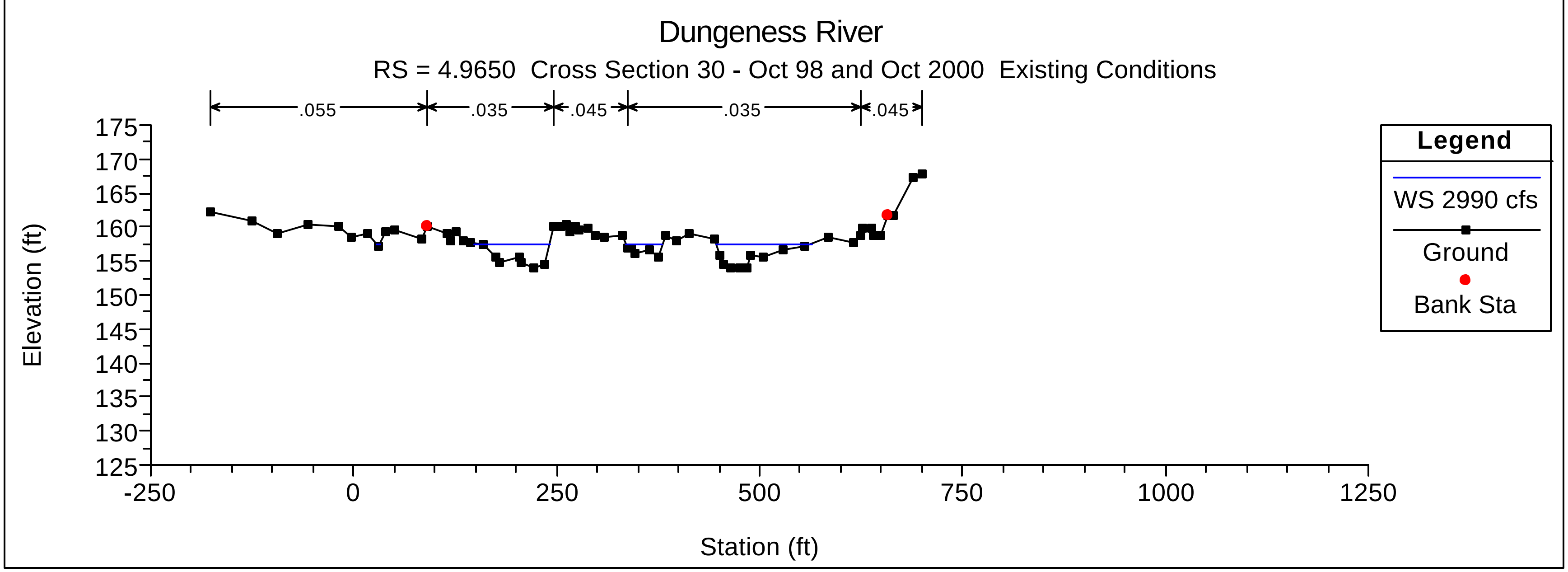
Dungeness River
RS = 5.2966 Cross Section 31A - Oct 98 and Oct 2000 Existing Conditions
.055
.03
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta



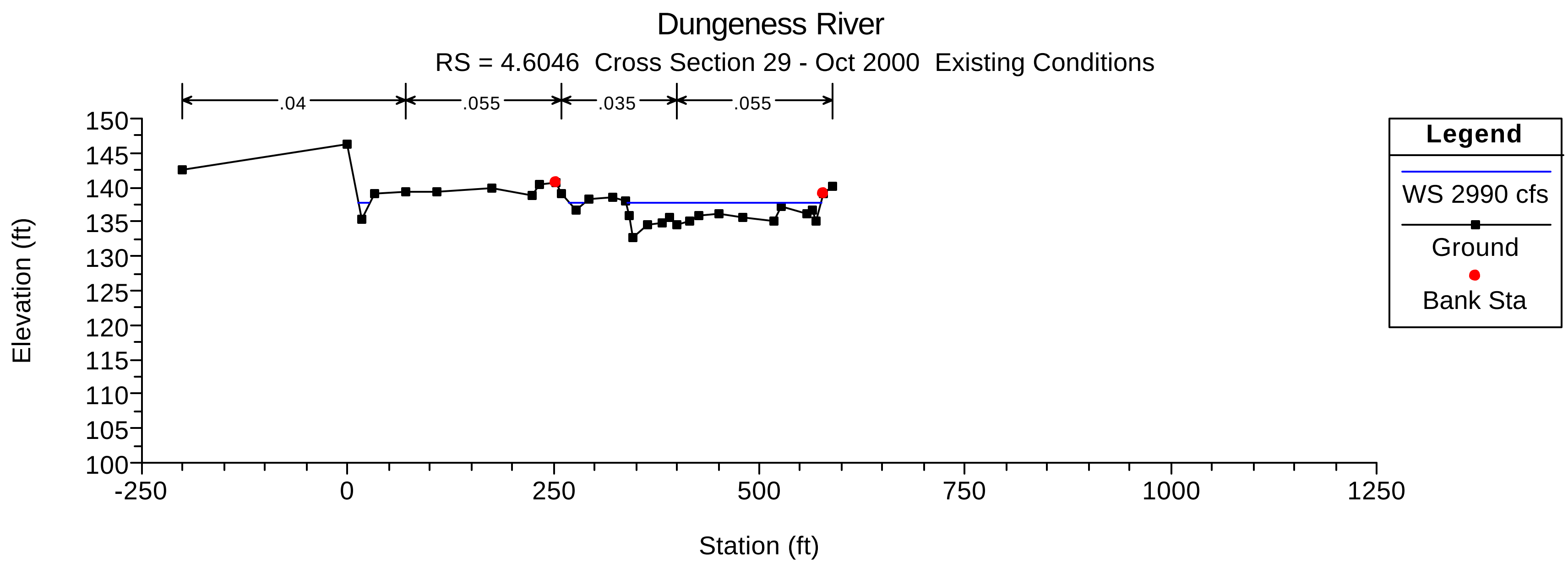
Dungeness River
RS = 5.1903 Cross Section 31 - Oct 2000 Existing Conditions
.035
.045
.035
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Ineff
Bank Sta

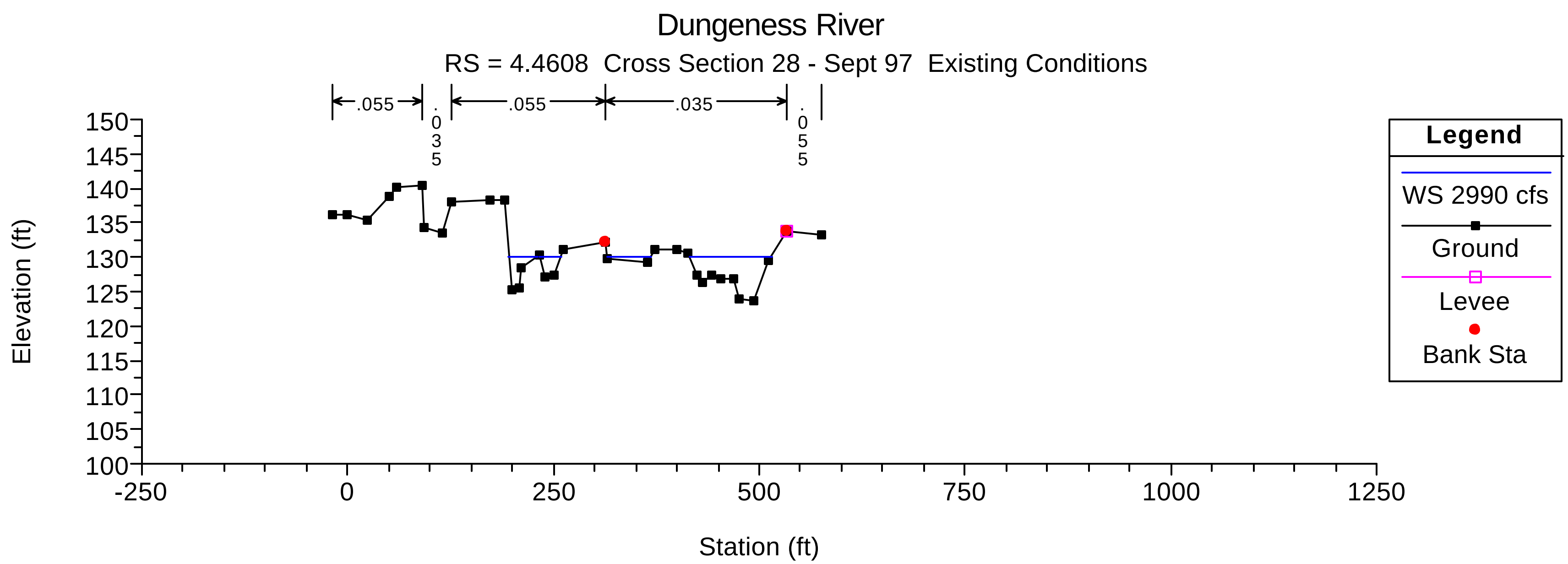


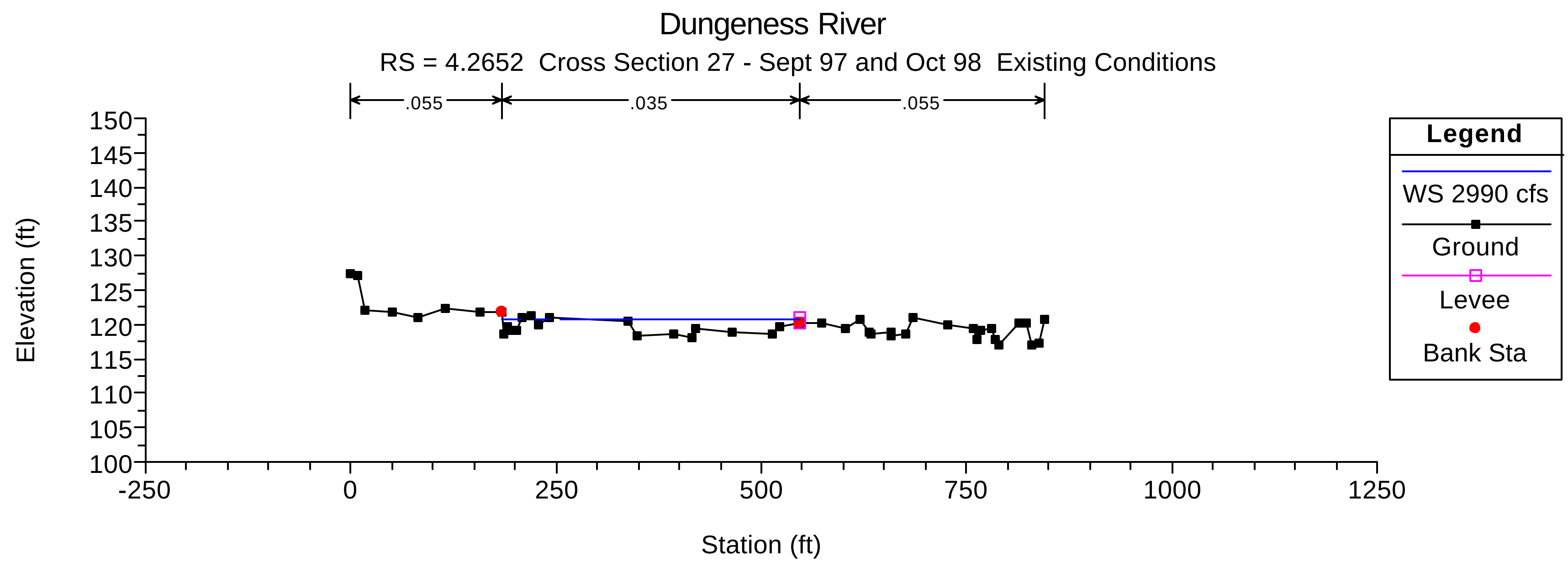
Dungeness River
RS = 5.1165 Scour Chain 5 XS - Oct 99 Existing Conditions
.035
Elevation (ft)
175
170
165
160
155
150
145
140
135
130
125
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta



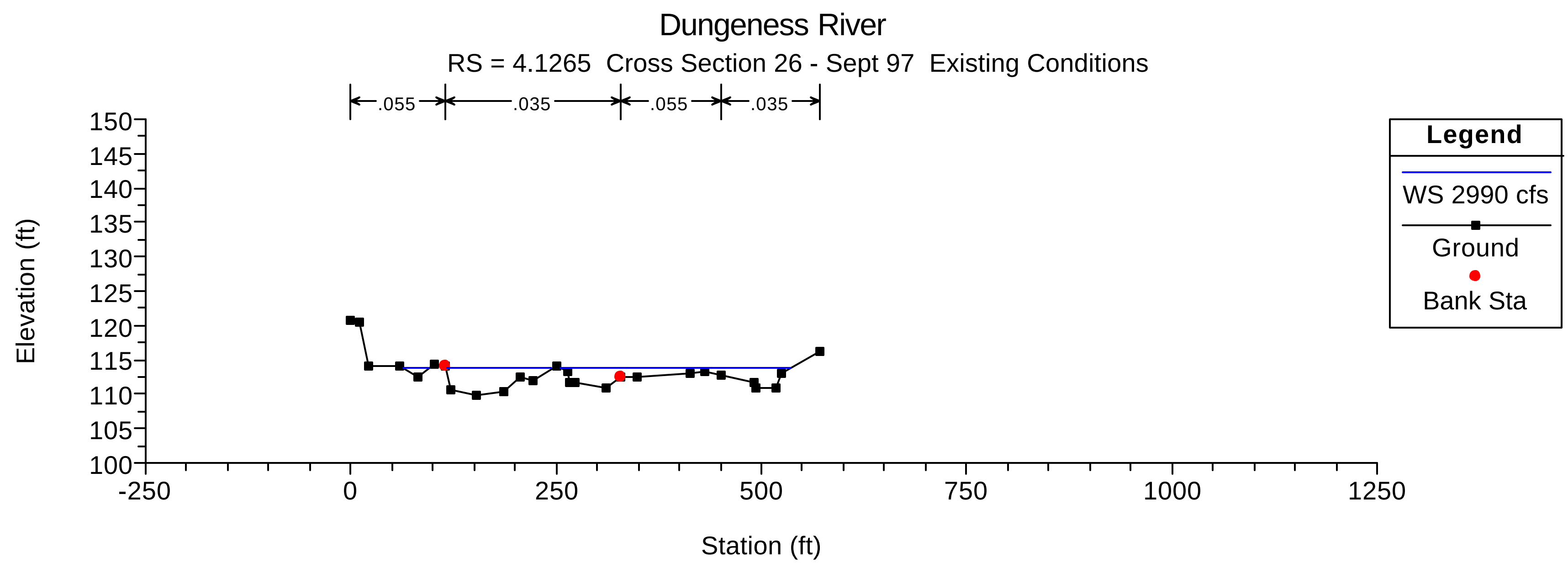
Dungeness River
RS = 4.9650 Cross Section 30 - Oct 98 and Oct 2000 Existing Conditions
.055
.035
.045
.035
.045
Elevation (ft)
175
170
165
160
155
150
145
140
135
130
125
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 4.6046 Cross Section 29 - Oct 2000 Existing Conditions
.04
.055
.035
.055
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
Station (ft)

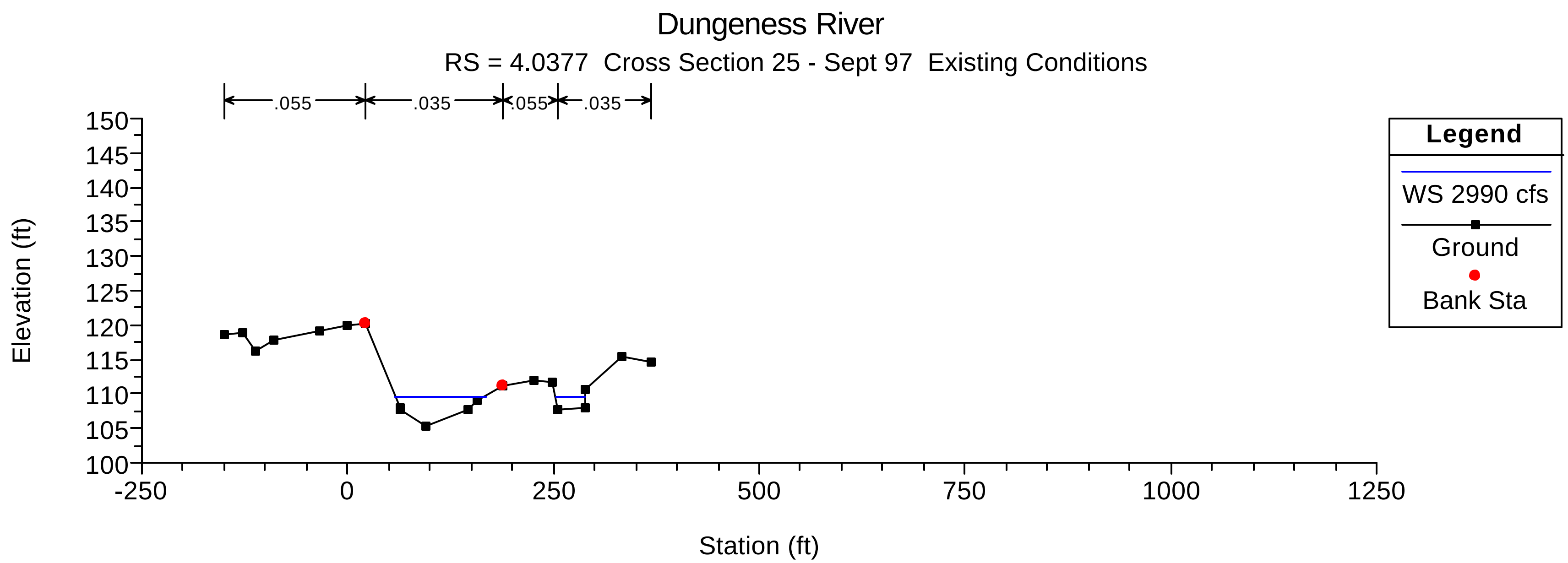

Dungeness River
RS = 4.4608 Cross Section 28 - Sept 97 Existing Conditions
.055
.035
.055
.035
.055
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)

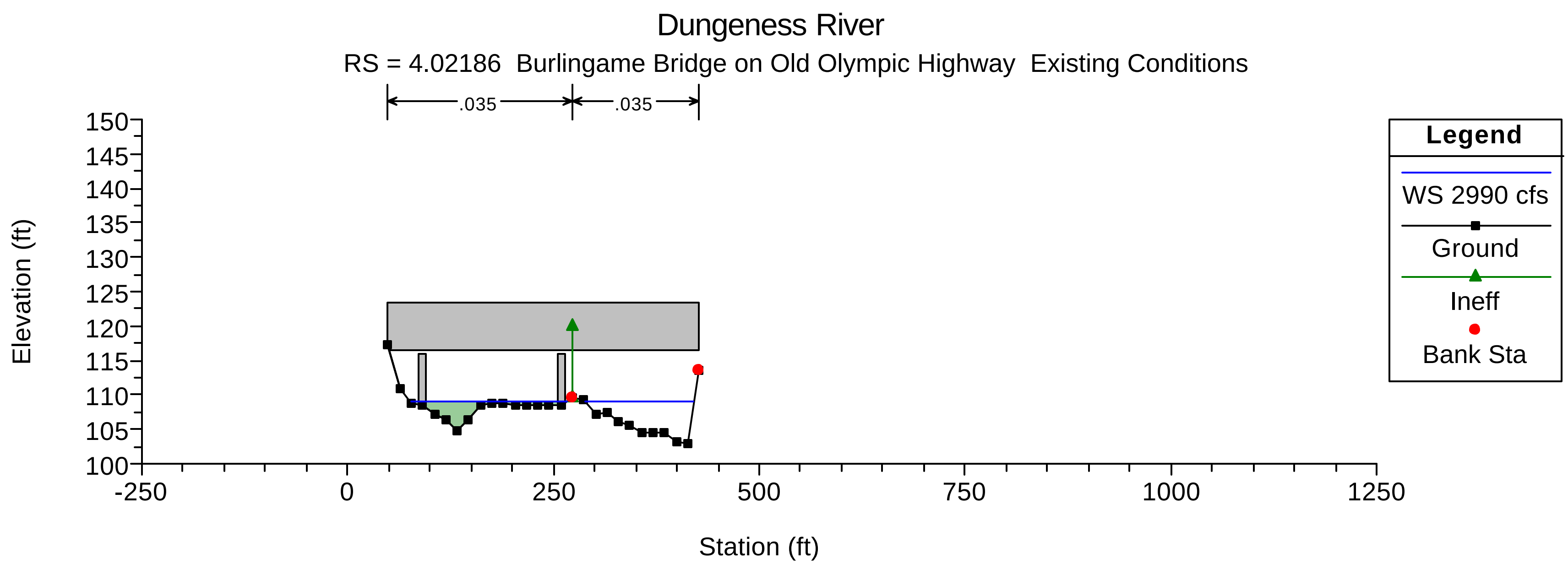


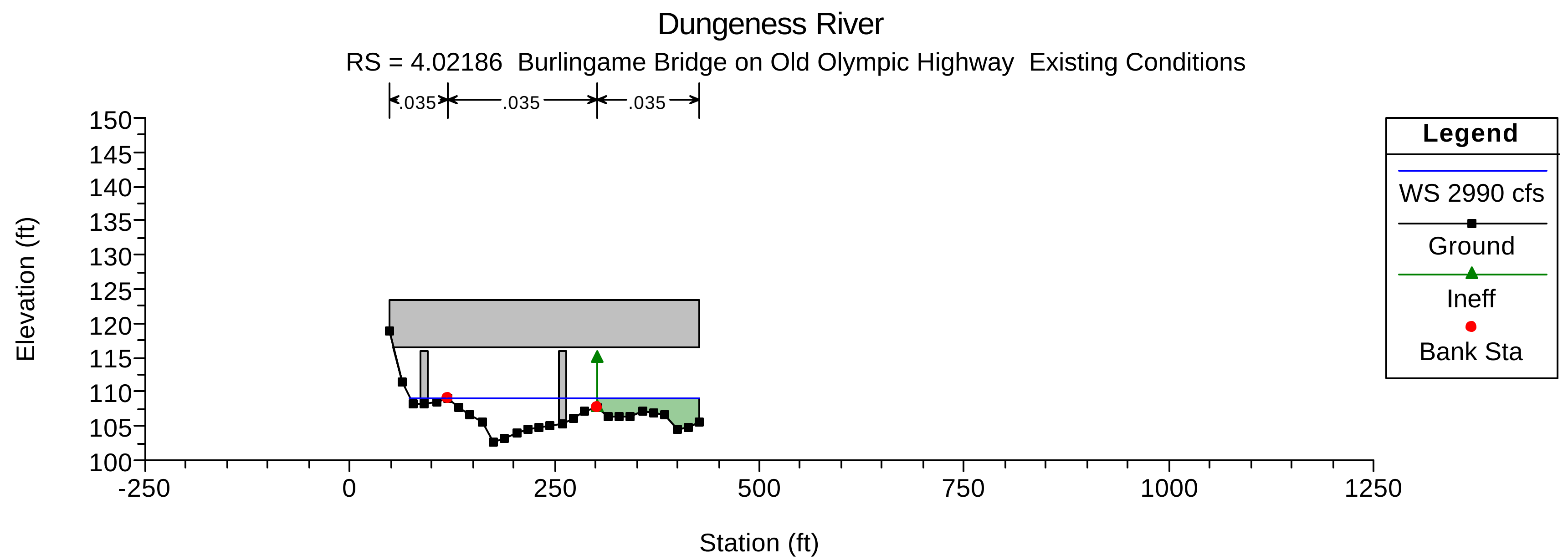
Dungeness River
RS = 4.2652 Cross Section 27 - Sept 97 and Oct 98 Existing Conditions
.055
.035
.055
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
150
145
140
135
130
125
120
115
110
105
100
-250
0
250
500
750
1000
1250
Station (ft)

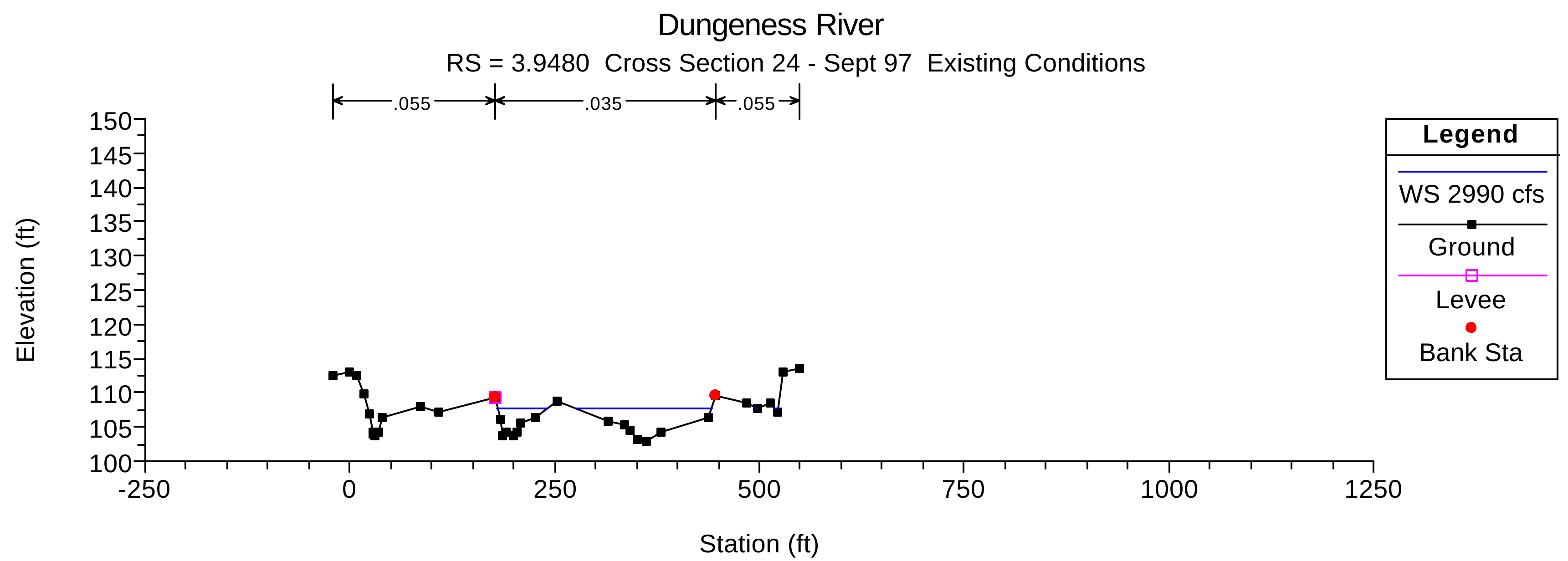


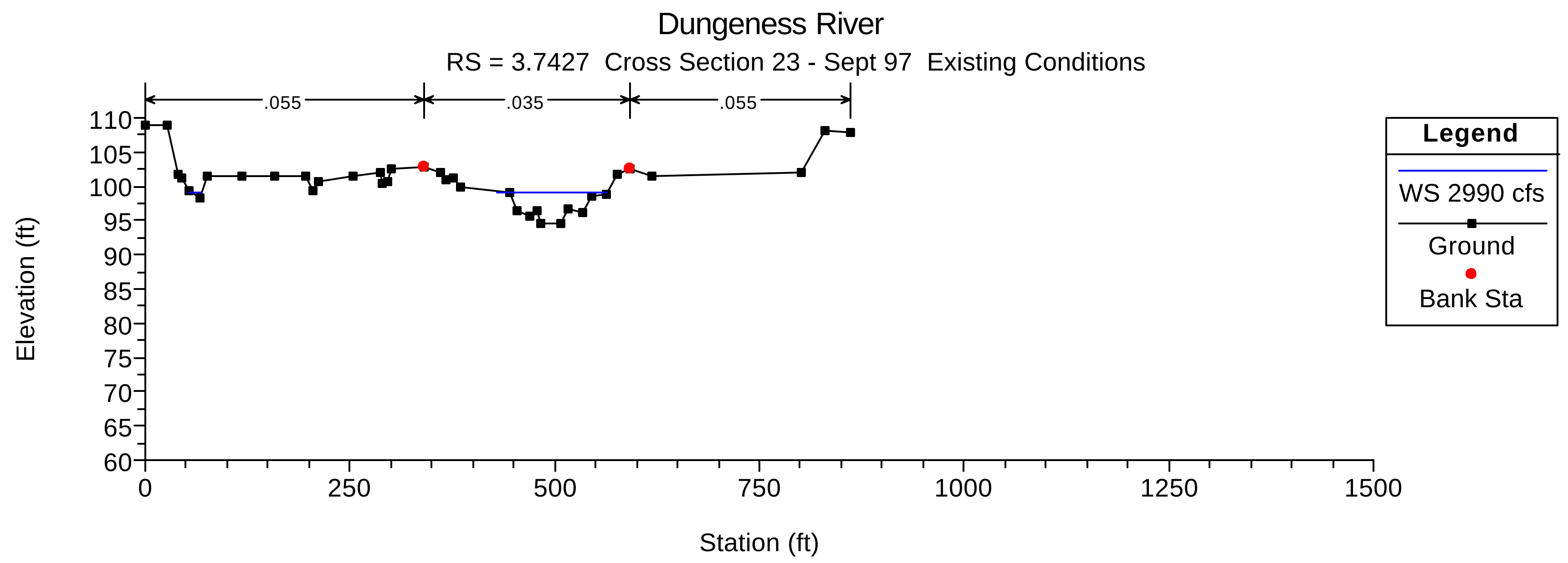
Dungeness River
RS = 4.1265 Cross Section 26 - Sept 97 Existing Conditions
.055
.035
.055
.035
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
150
145
140
135
130
125
120
115
110
105
100
-250
0
250
500
750
1000
1250
Station (ft)

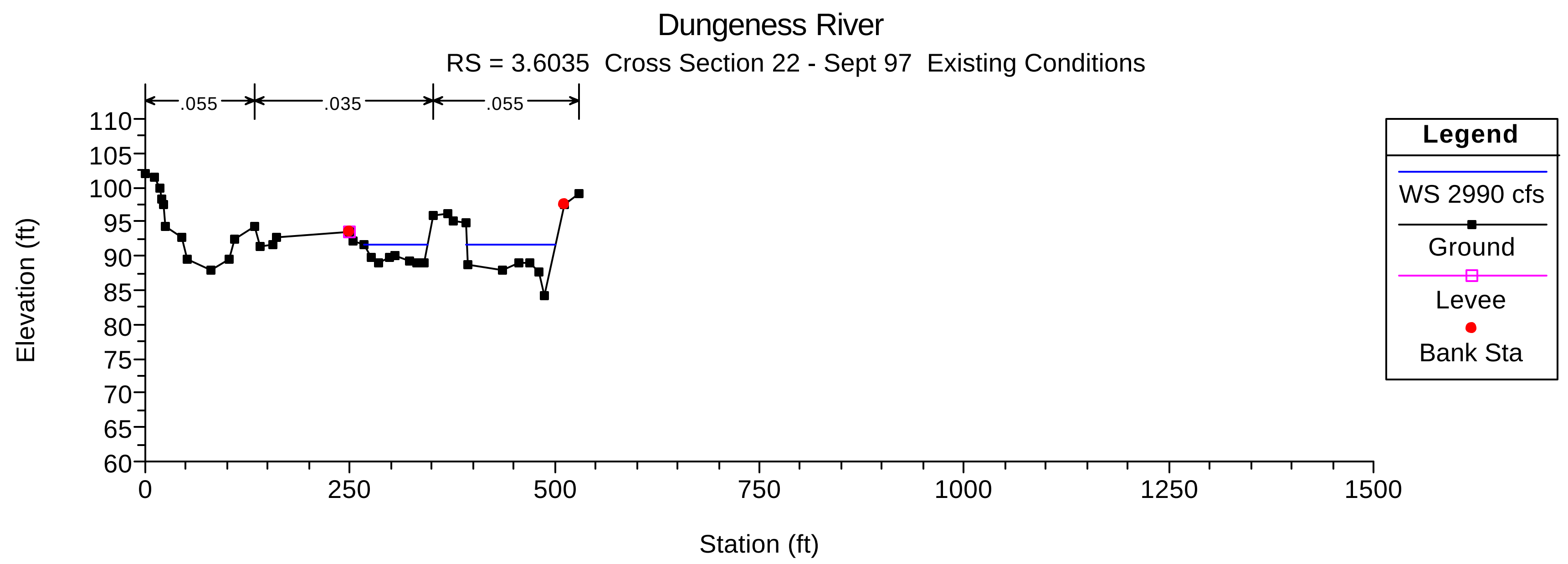

Dungeness River
RS = 4.0377 Cross Section 25 - Sept 97 Existing Conditions
.055
.035
.055
.035
Elevation (ft)
150
145
140
135
130
125
120
115
110
105
100
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

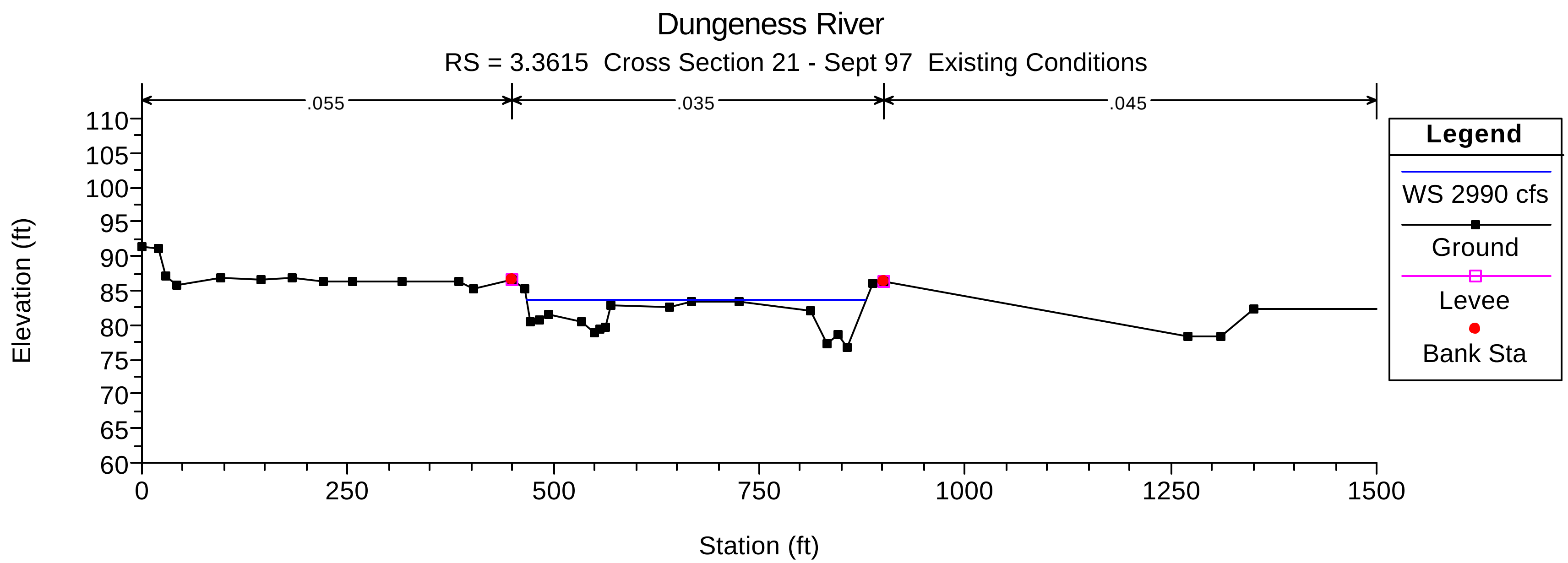

Dungeness River
RS = 4.02186 Burlingame Bridge on Old Olympic Highway Existing Conditions
.035
.035
Elevation (ft)
150
145
140
135
130
125
120
115
110
105
100
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Ineff
Bank Sta

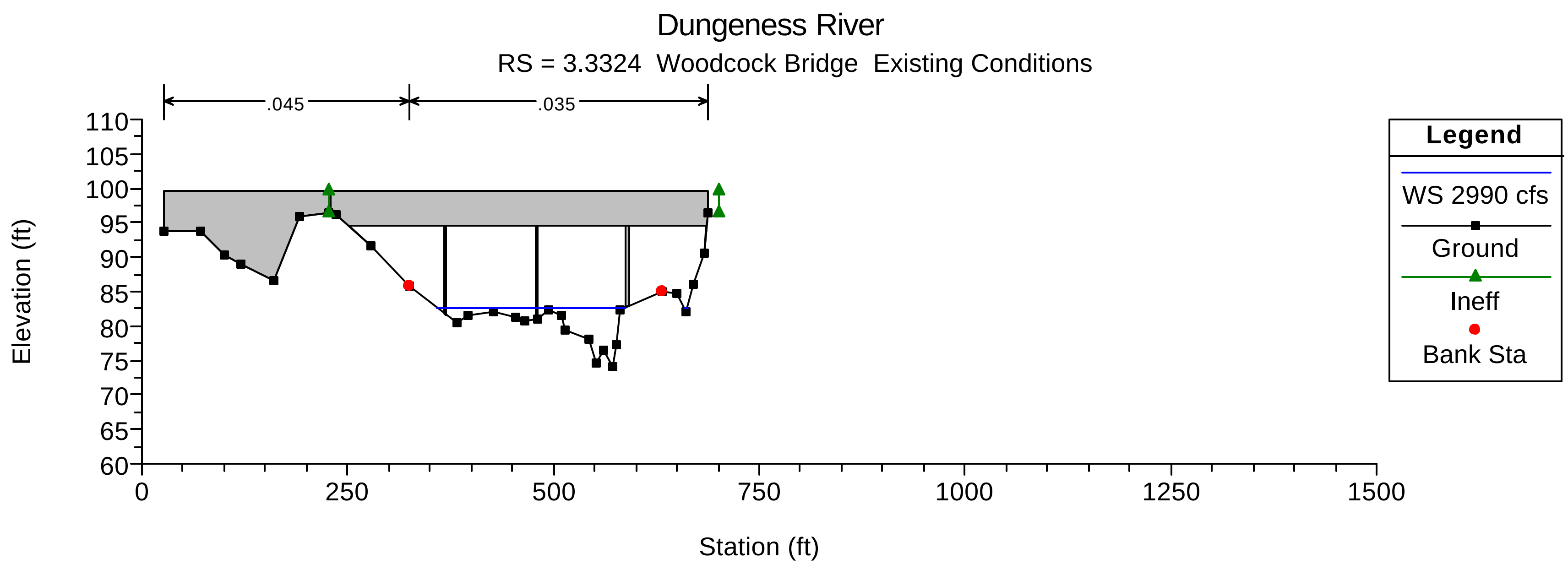

Dungeness River
RS = 4.02186 Burlingame Bridge on Old Olympic Highway Existing Conditions
.035
.035
.035
Elevation (ft)
150
145
140
135
130
125
120
115
110
105
100
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Ineff
Bank Sta

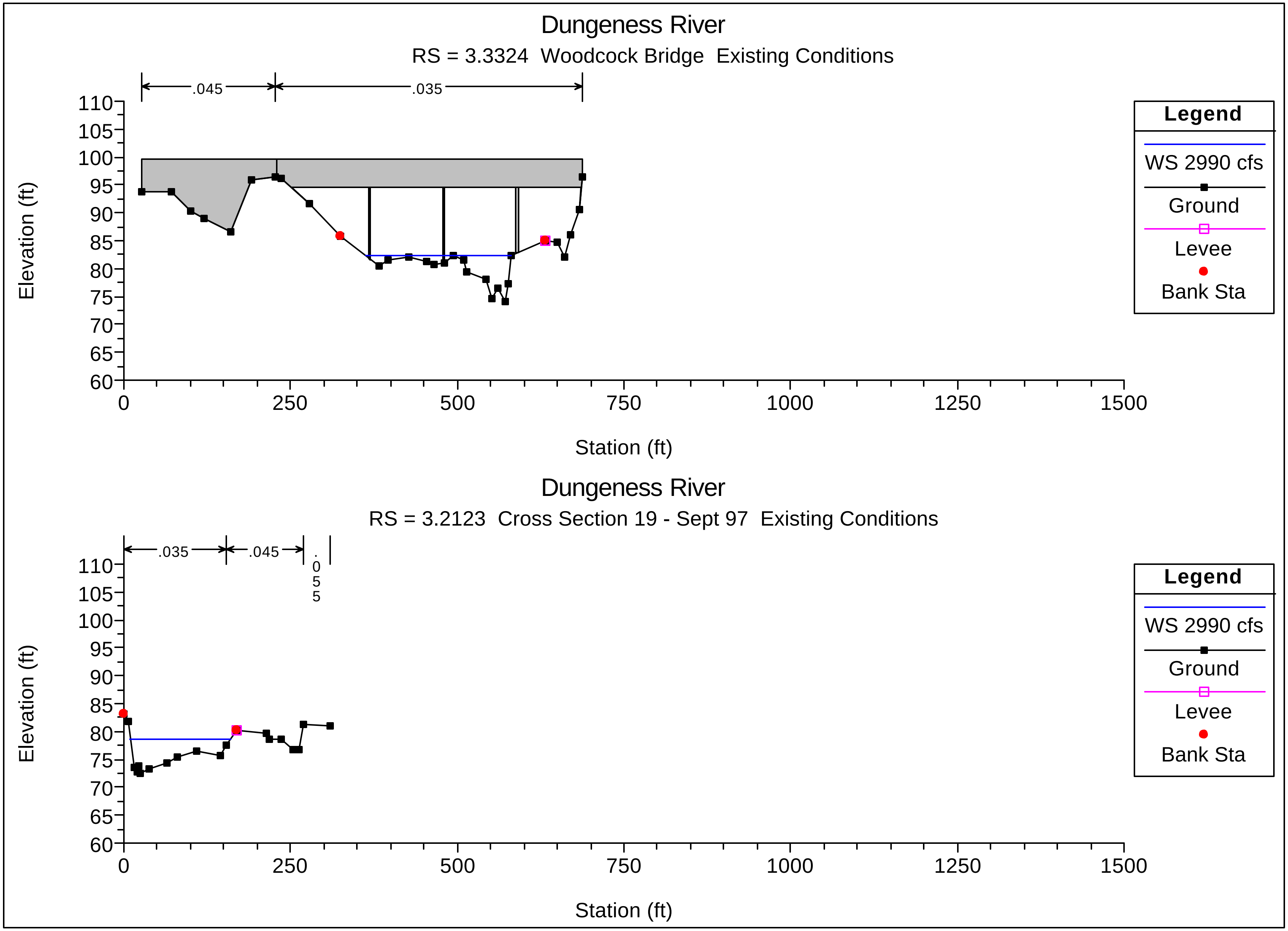

Dungeness River
RS = 3.9480 Cross Section 24 - Sept 97 Existing Conditions
.055
.035
.055
Elevation (ft)
150
145
140
135
130
125
120
115
110
105
100
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta


Dungeness River
RS = 3.7427 Cross Section 23 - Sept 97 Existing Conditions
.055
.035
.055
Elevation (ft)
110
105
100
95
90
85
80
75
70
65
60
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

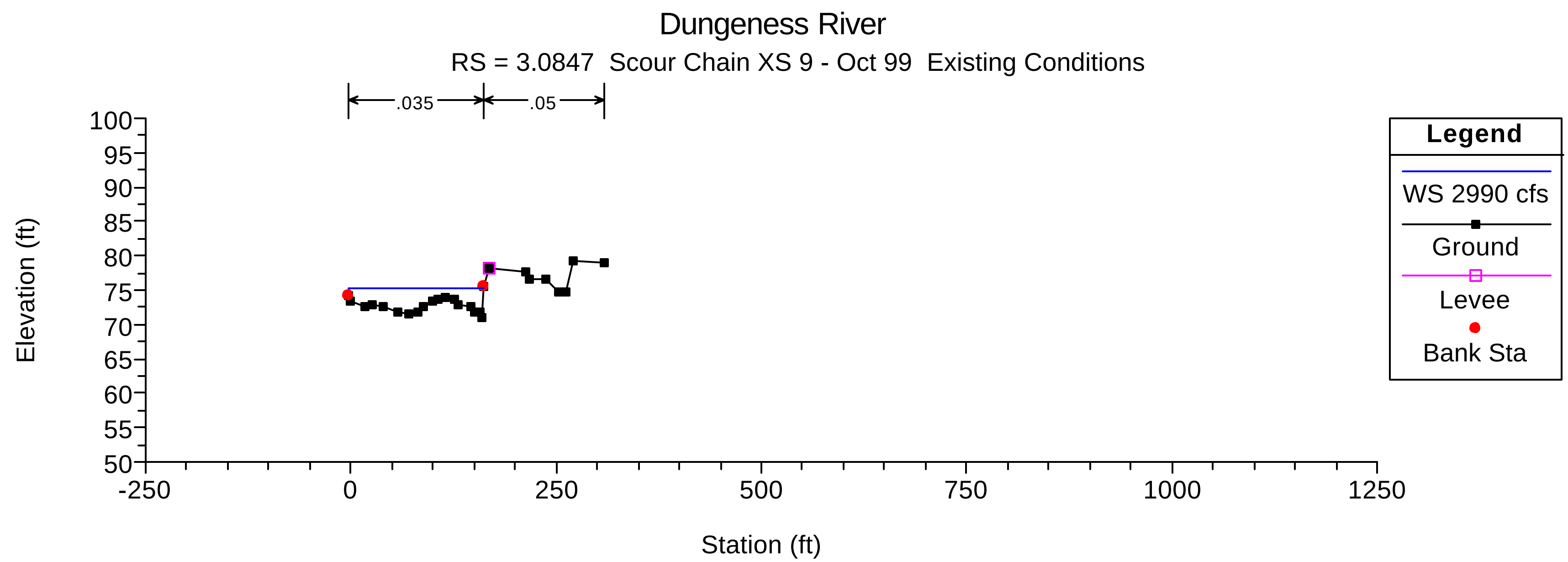

Dungeness River
RS = 3.6035 Cross Section 22 - Sept 97 Existing Conditions
.055
.035
.055
Elevation (ft)
110
105
100
95
90
85
80
75
70
65
60
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta


Dungeness River
RS = 3.3615 Cross Section 21 - Sept 97 Existing Conditions
.055
.035
.045
Elevation (ft)
110
105
100
95
90
85
80
75
70
65
60
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

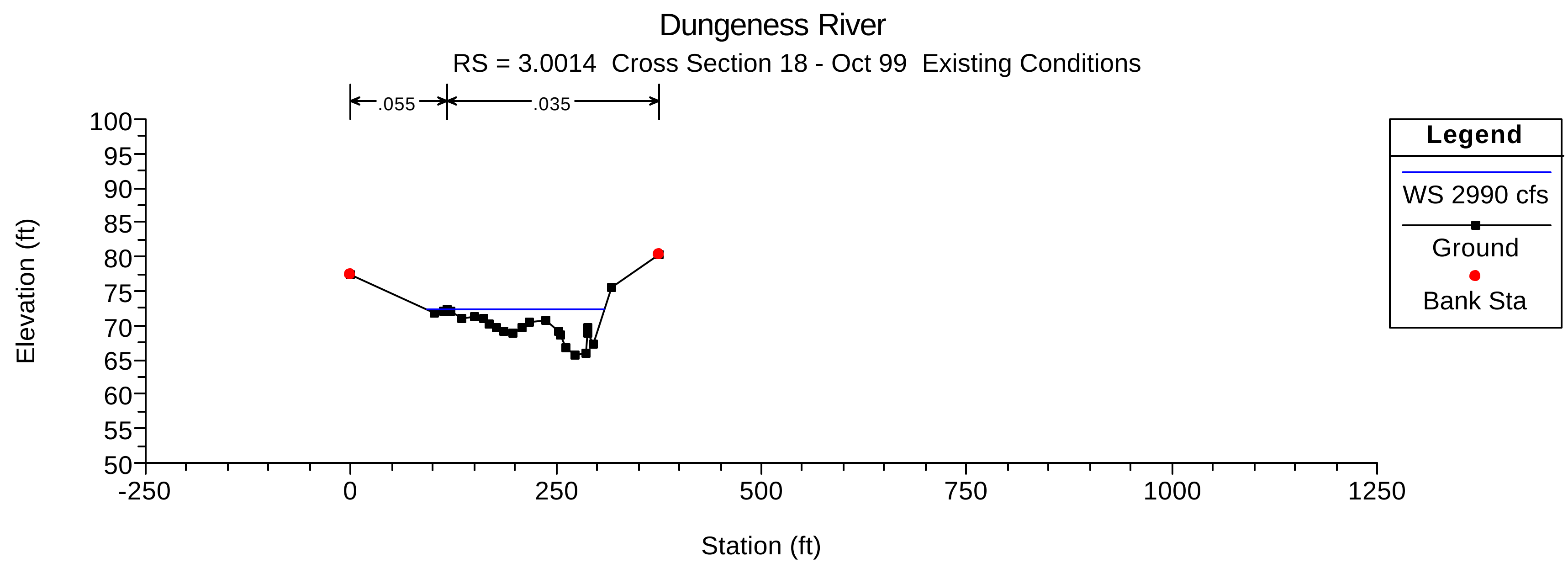

Dungeness River
RS = 3.3324 Woodcock Bridge Existing Conditions
.045
.035
Elevation (ft)
110
105
100
95
90
85
80
75
70
65
60
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Ineff
Bank Sta



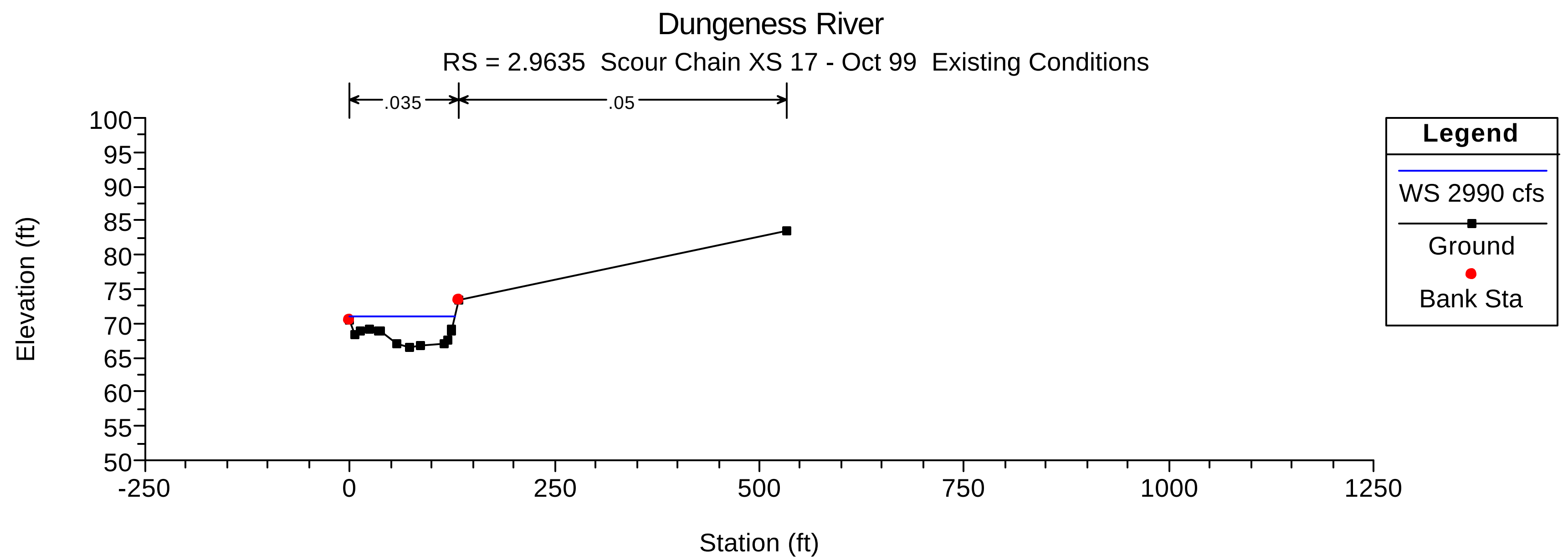
Dungeness River
RS = 3.3324 Woodcock Bridge Existing Conditions
.045
.035
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
110
105
100
95
90
85
80
75
70
65
60
0
250
500
750
1000
1250
1500
Dungeness River
RS = 3.2123 Cross Section 19 - Sept 97 Existing Conditions
.035
.045
.055
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)

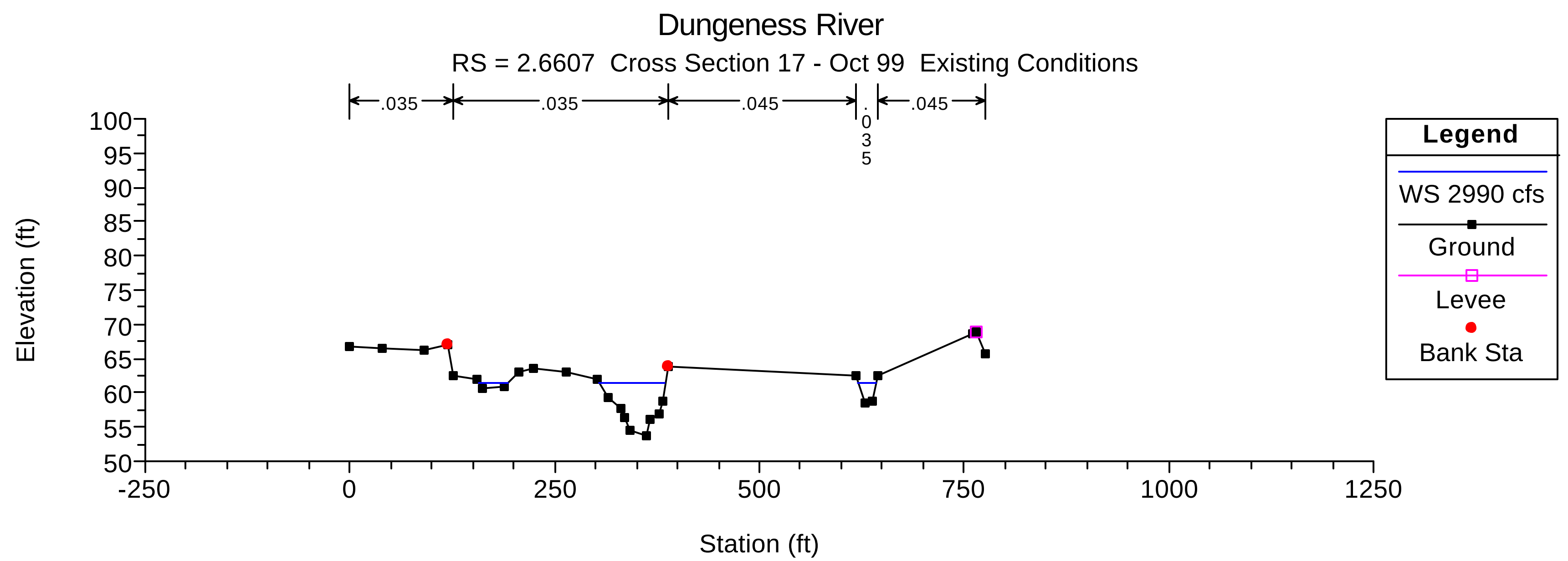


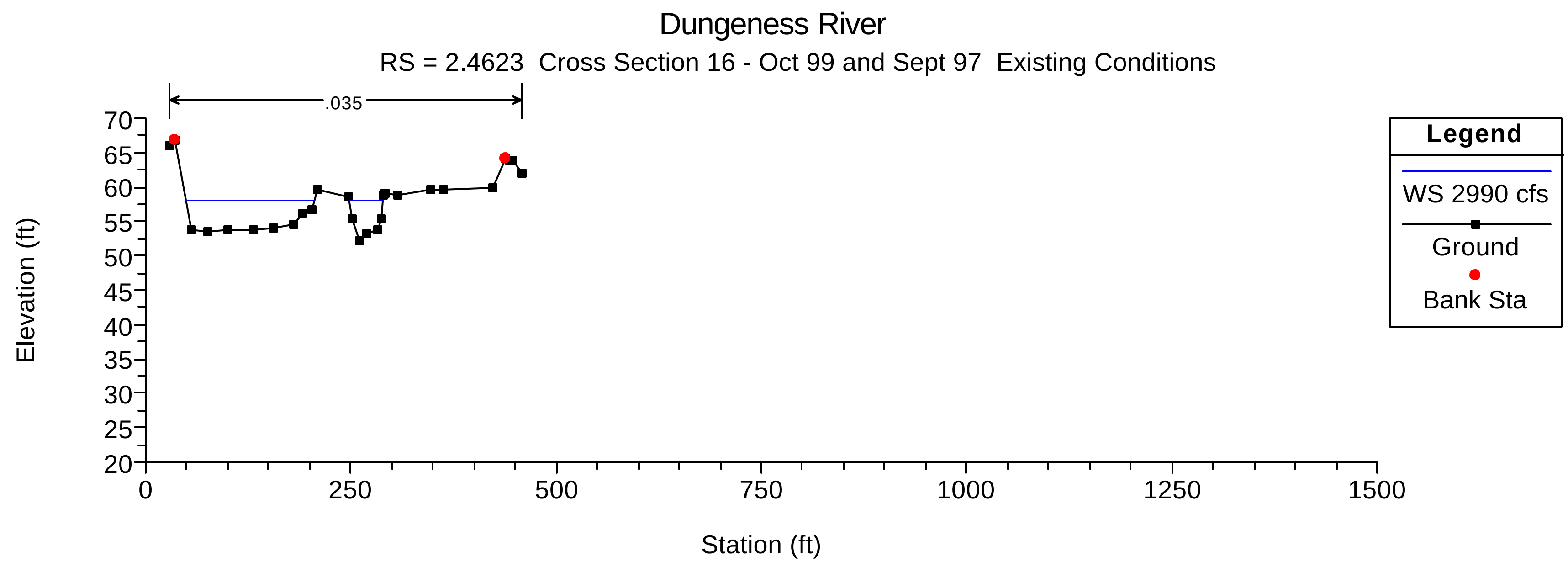
Dungeness River
RS = 3.0847 Scour Chain XS 9 - Oct 99 Existing Conditions
.035
.05
Elevation (ft)
100
95
90
85
80
75
70
65
60
55
50
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

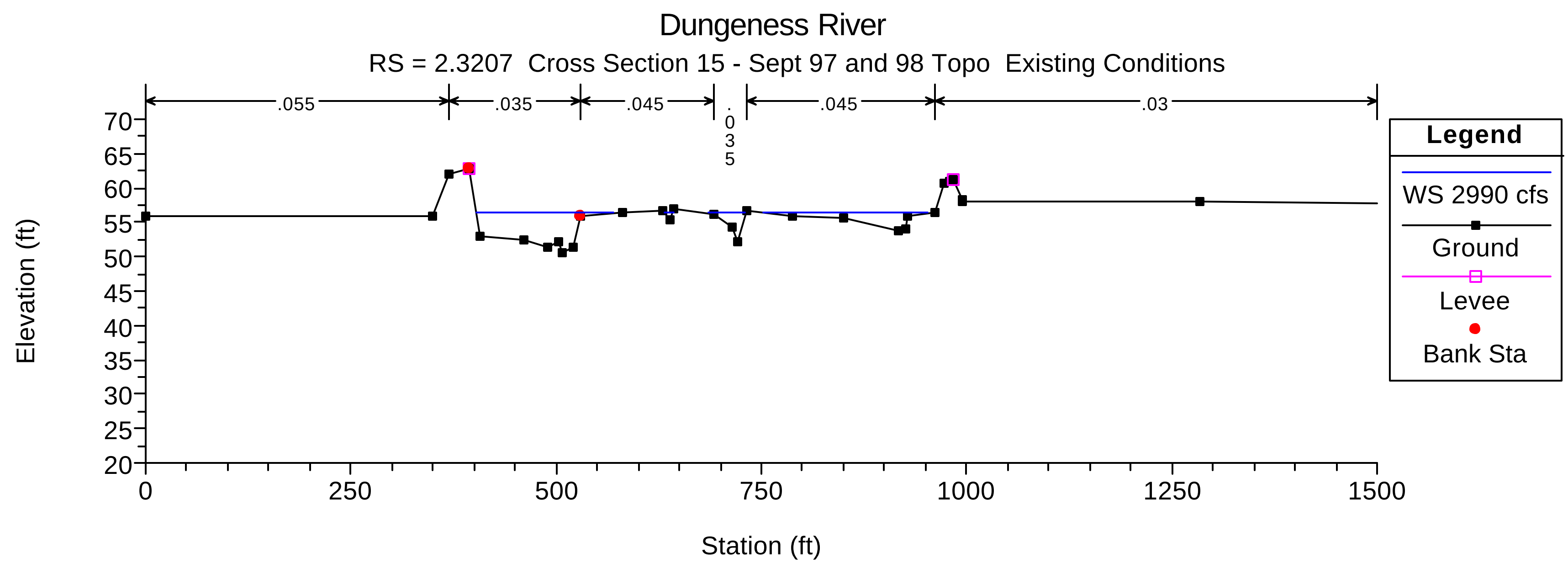


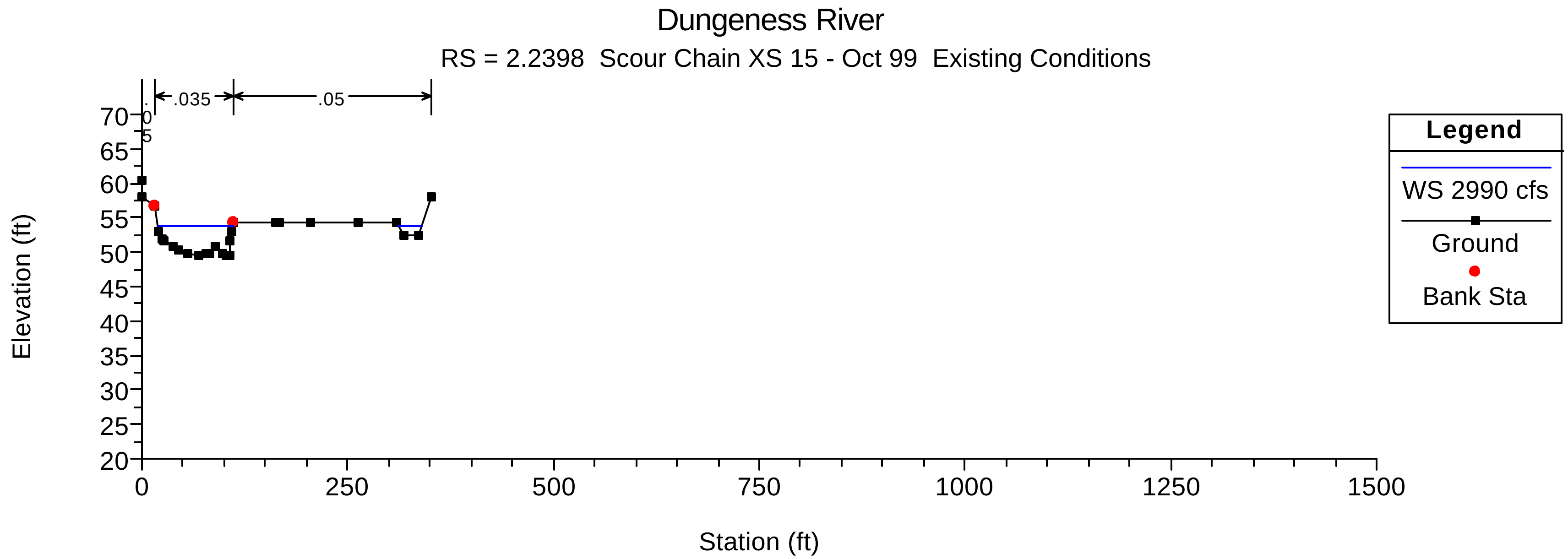
Dungeness River
RS = 3.0014 Cross Section 18 - Oct 99 Existing Conditions
.055
.035
Elevation (ft)
100
95
90
85
80
75
70
65
60
55
50
-250
0
250
500
750
1000
1250
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta


Dungeness River
RS = 2.9635 Scour Chain XS 17 - Oct 99 Existing Conditions
.035
.05
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

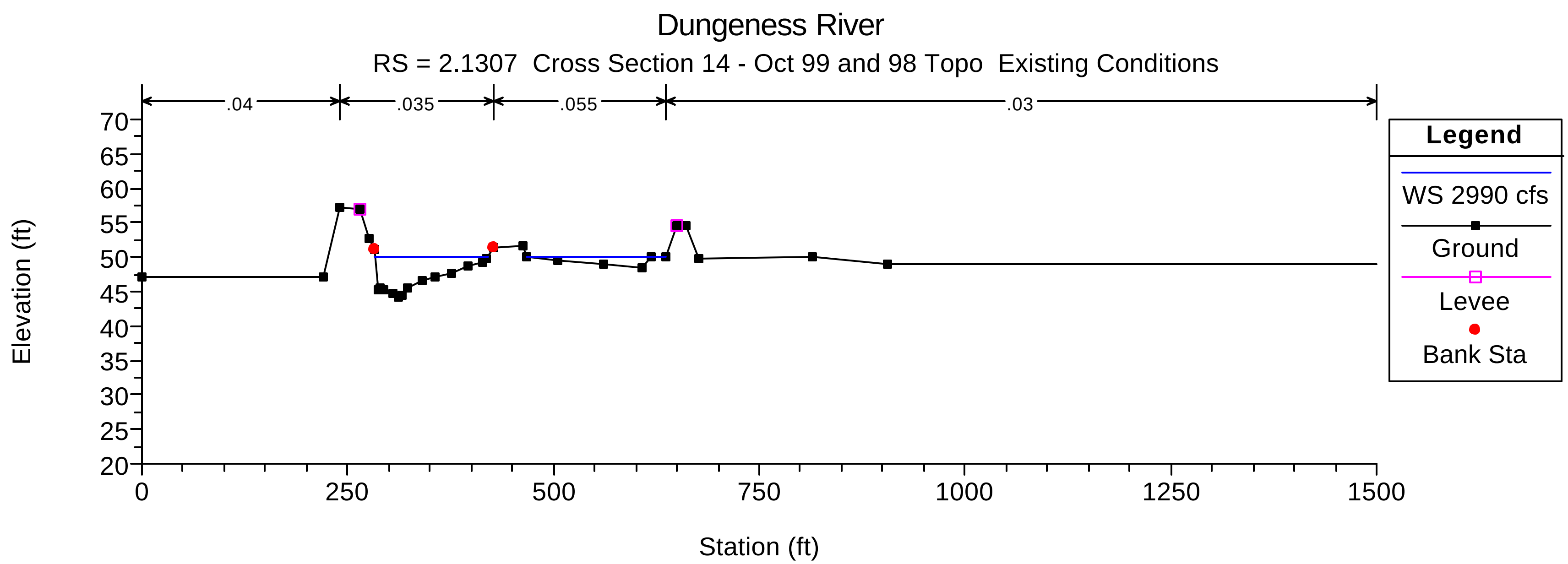

Dungeness River
RS = 2.6607 Cross Section 17 - Oct 99 Existing Conditions
.035
.035
.045
.035
.045
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta


Dungeness River
RS = 2.4623 Cross Section 16 - Oct 99 and Sept 97 Existing Conditions
.035
Elevation (ft)
70
65
60
55
50
45
40
35
30
25
20
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

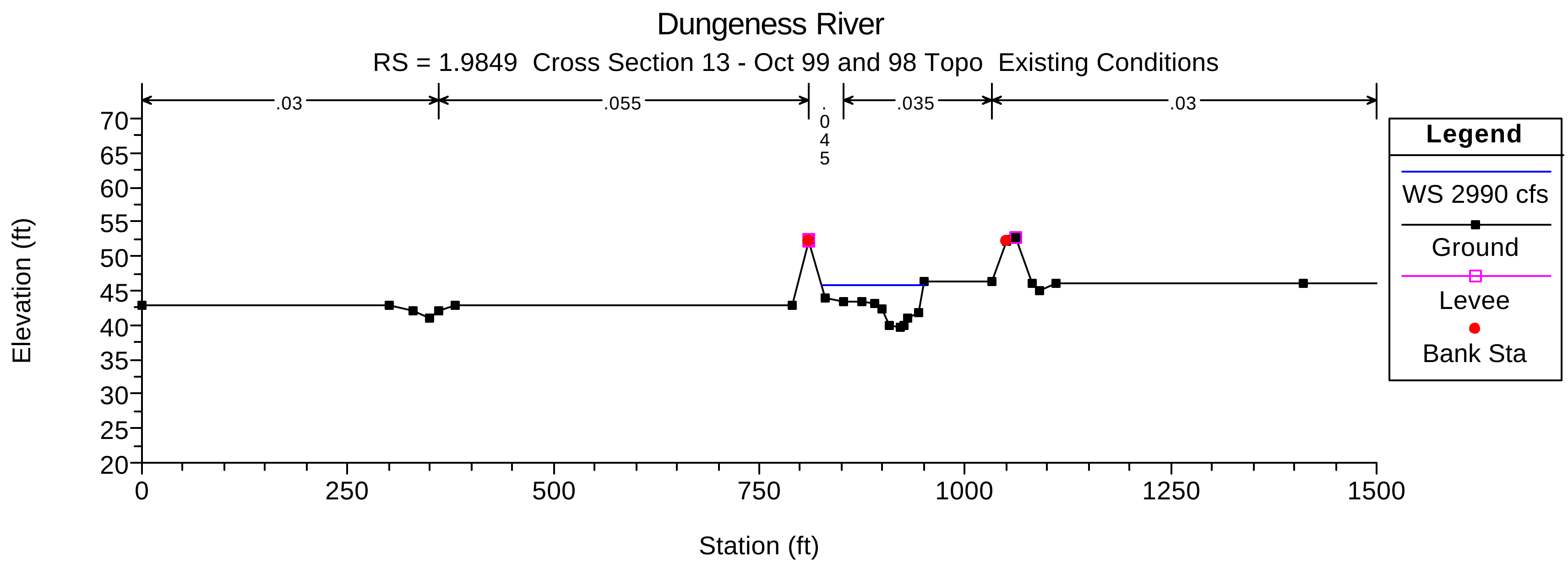

Dungeness River
RS = 2.3207 Cross Section 15 - Sept 97 and 98 Topo Existing Conditions
.055
.035
.045
.035
.045
.03
Elevation (ft)
70
65
60
55
50
45
40
35
30
25
20
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

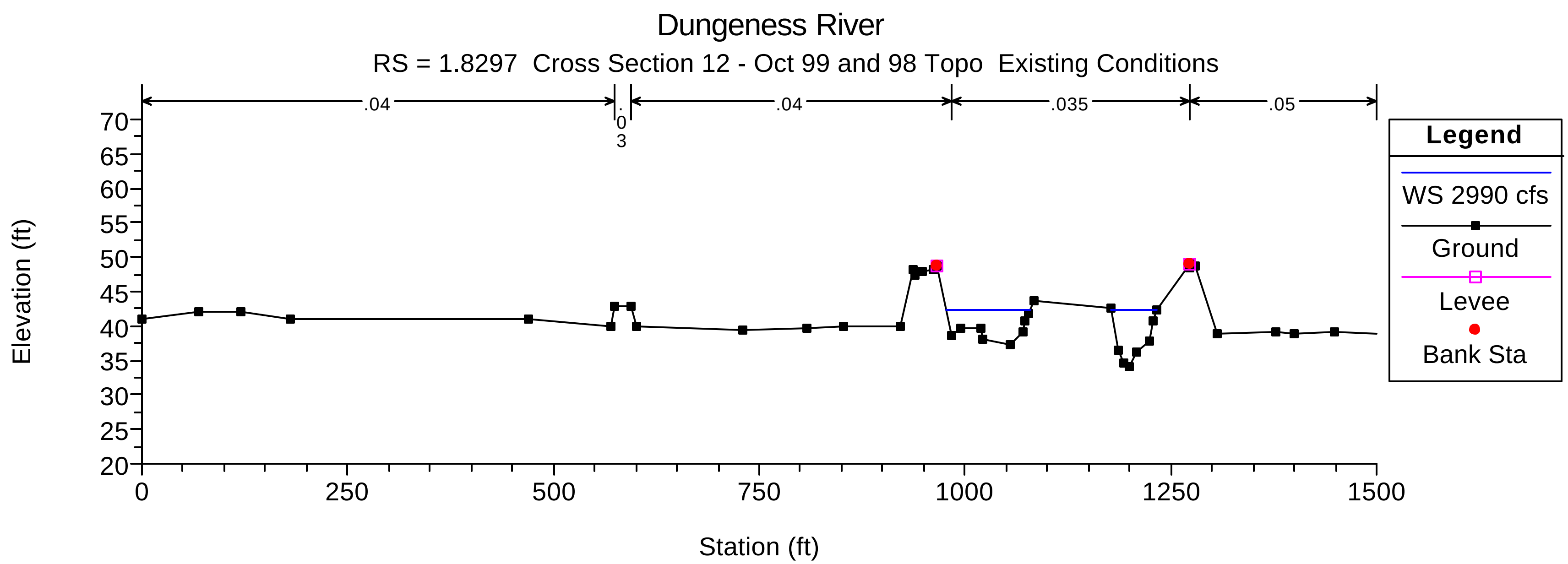


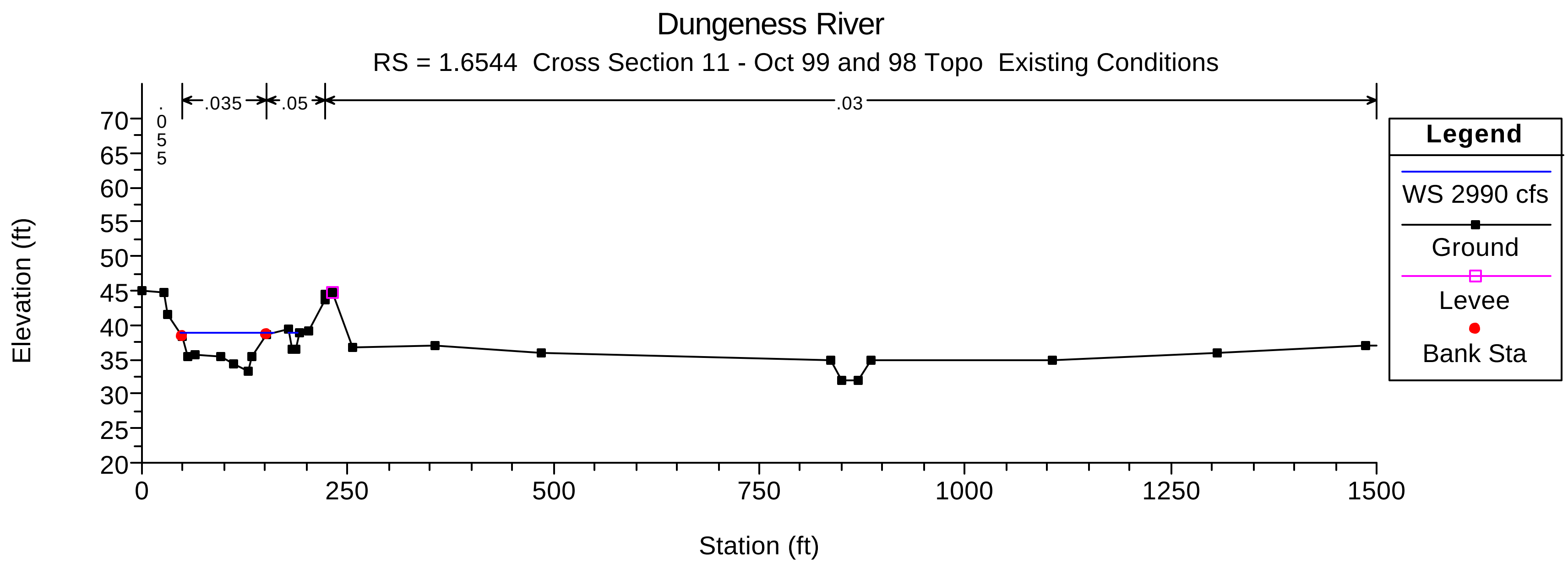
Dungeness River
RS = 2.2398 Scour Chain XS 15 - Oct 99 Existing Conditions
.035
.05
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Bank Sta

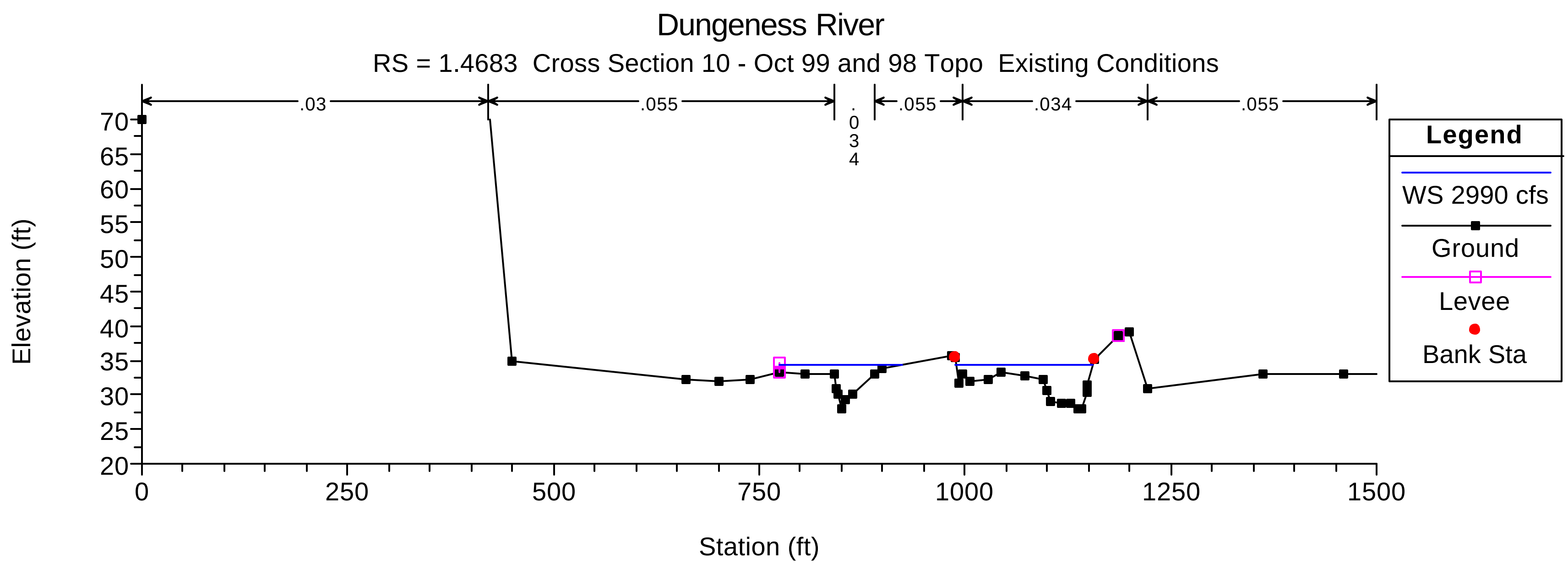


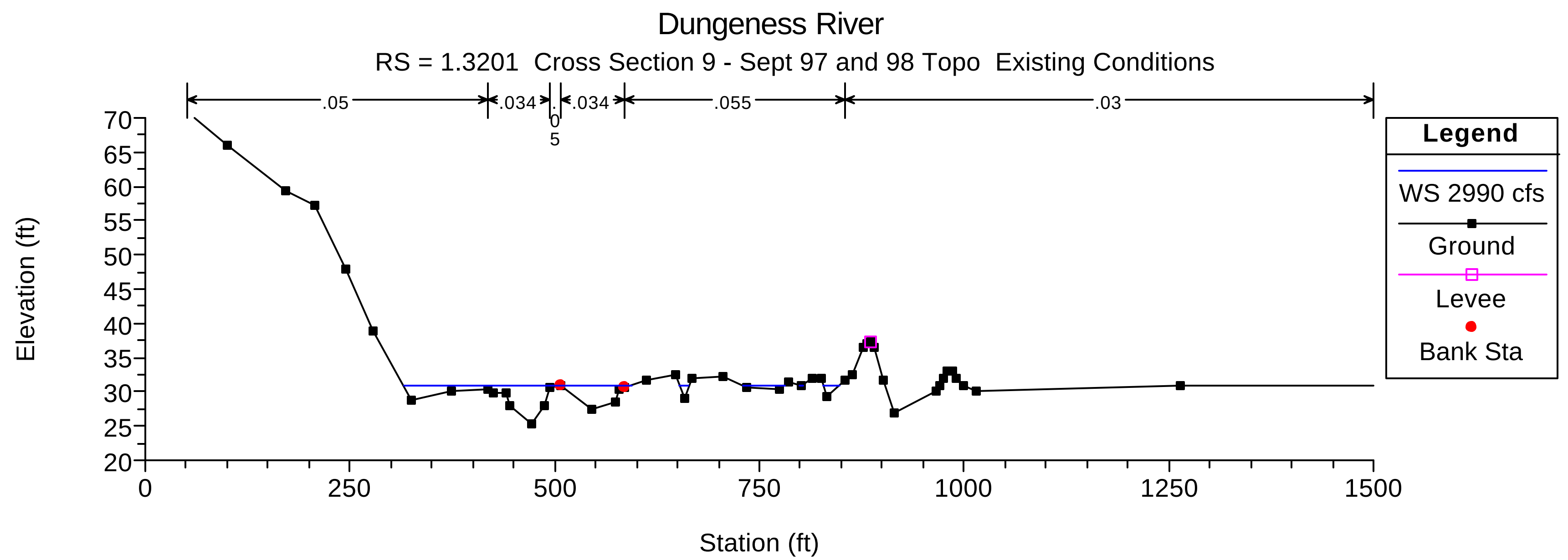
Dungeness River
RS = 2.1307 Cross Section 14 - Oct 99 and 98 Topo Existing Conditions
.04
.035
.055
.03
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta


Dungeness River
RS = 1.9849 Cross Section 13 - Oct 99 and 98 Topo Existing Conditions
.03
.055
.045
.035
.03
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

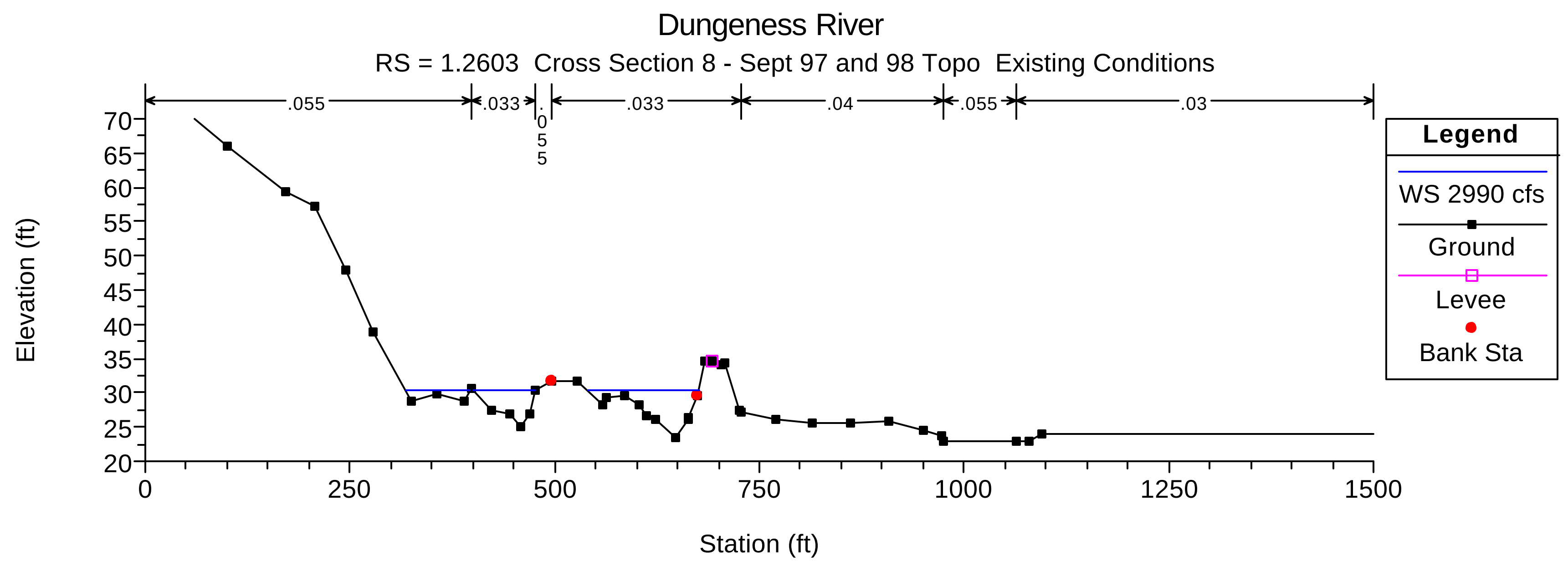

Dungeness River
RS = 1.8297 Cross Section 12 - Oct 99 and 98 Topo Existing Conditions
.04
.03
.04
.035
.05
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta


Dungeness River
RS = 1.6544 Cross Section 11 - Oct 99 and 98 Topo Existing Conditions
.055
.035
.05
.03
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
20
25
30
35
40
45
50
55
60
65
70
0
250
500
750
1000
1250
1500

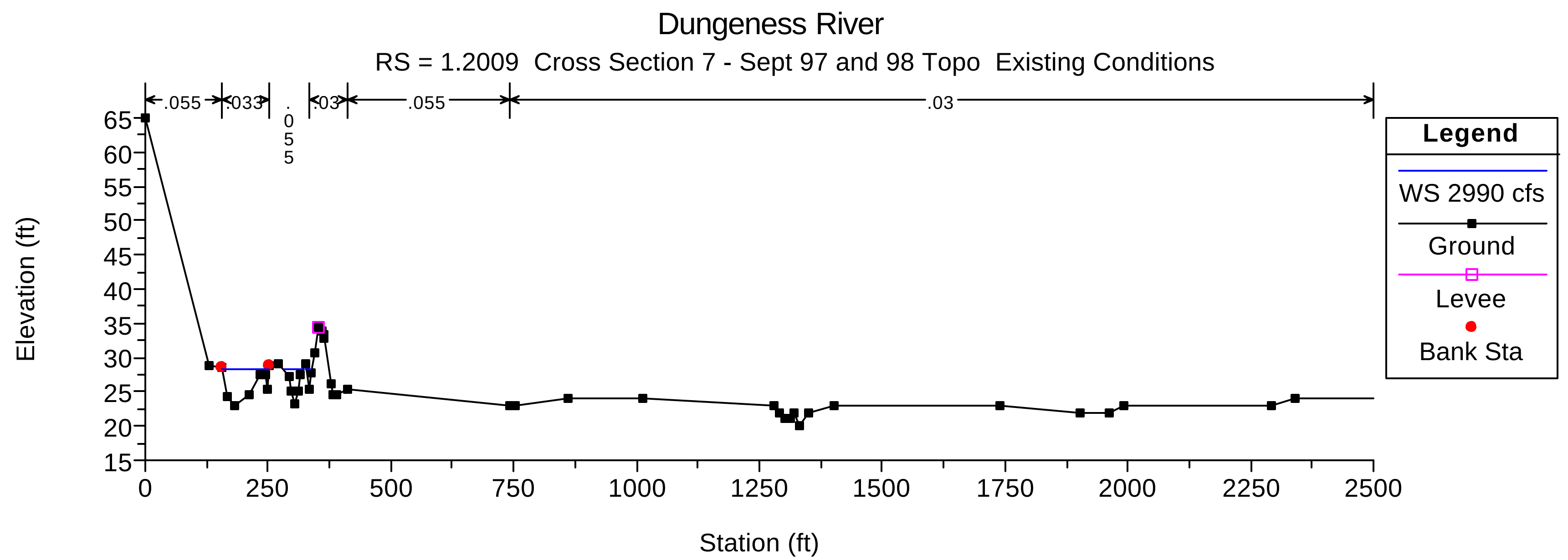

Dungeness River
RS = 1.4683 Cross Section 10 - Oct 99 and 98 Topo Existing Conditions
.03
.055
.034
.055
.034
.055
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
20
25
30
35
40
45
50
55
60
65
70
0
250
500
750
1000
1250
1500

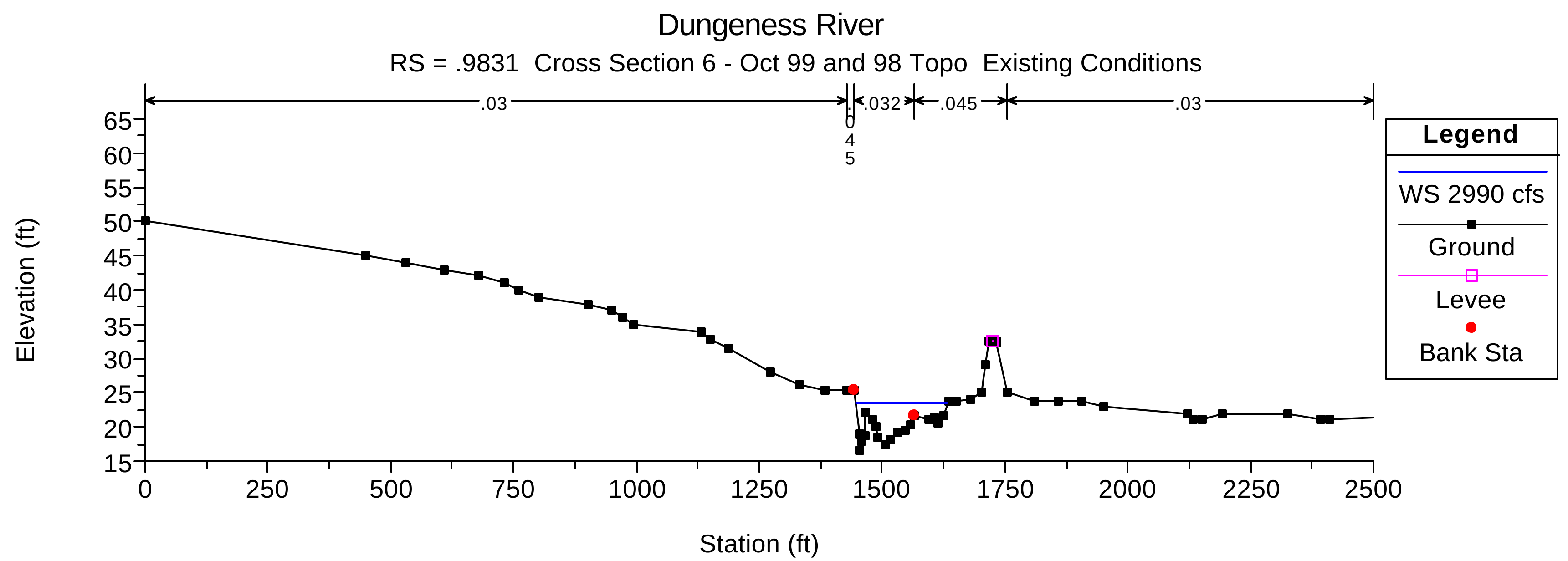


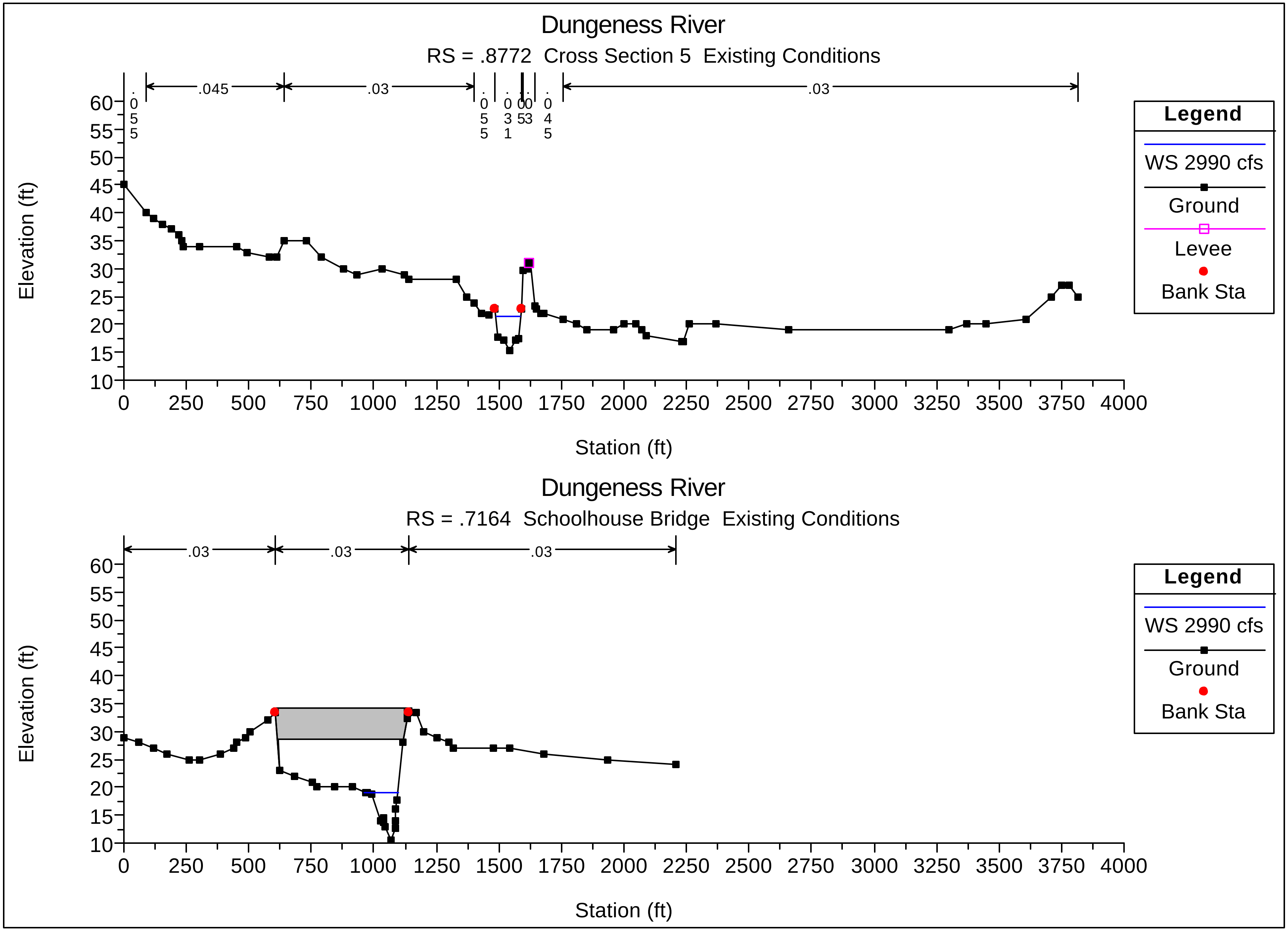
Dungeness River
RS = 1.3201 Cross Section 9 - Sept 97 and 98 Topo Existing Conditions
.05
.034
.
0
5
.034
.055
.03
Elevation (ft)
70
65
60
55
50
45
40
35
30
25
20
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta



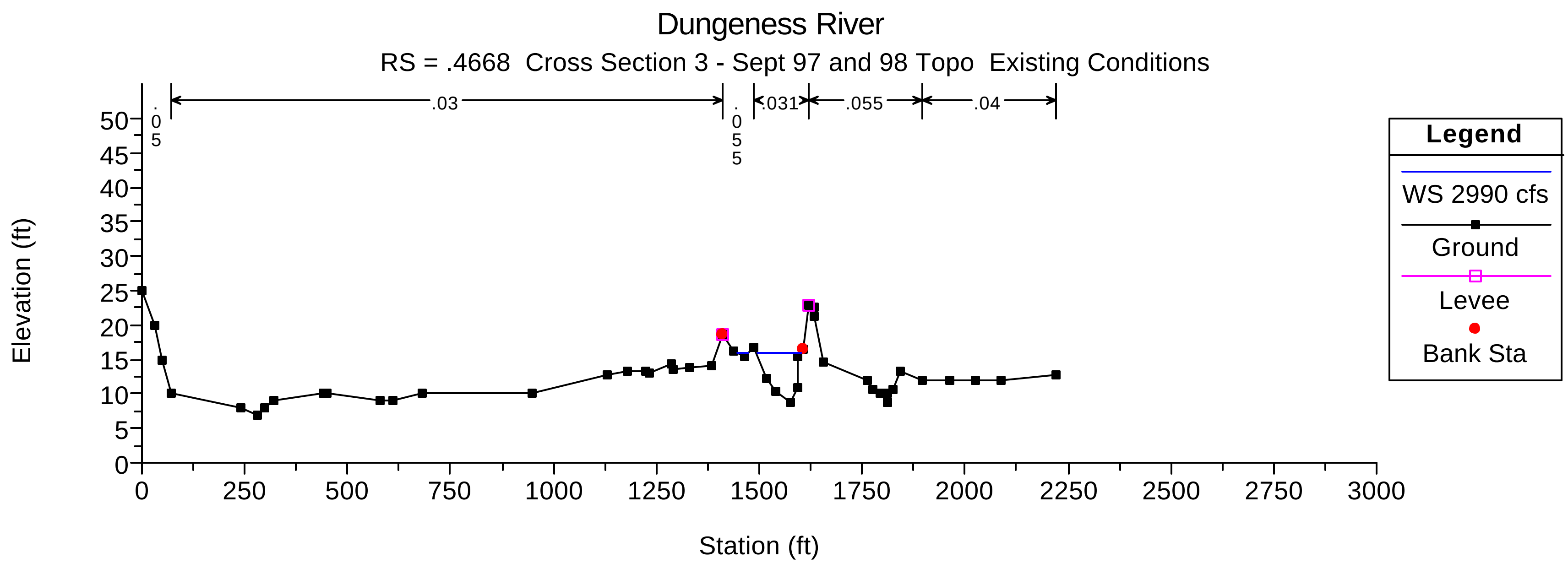
Dungeness River
RS = 1.2603 Cross Section 8 - Sept 97 and 98 Topo Existing Conditions
.055
.033
.
0
5
5
.033
.04
.055
.03
Elevation (ft)
70
65
60
55
50
45
40
35
30
25
20
0
250
500
750
1000
1250
1500
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

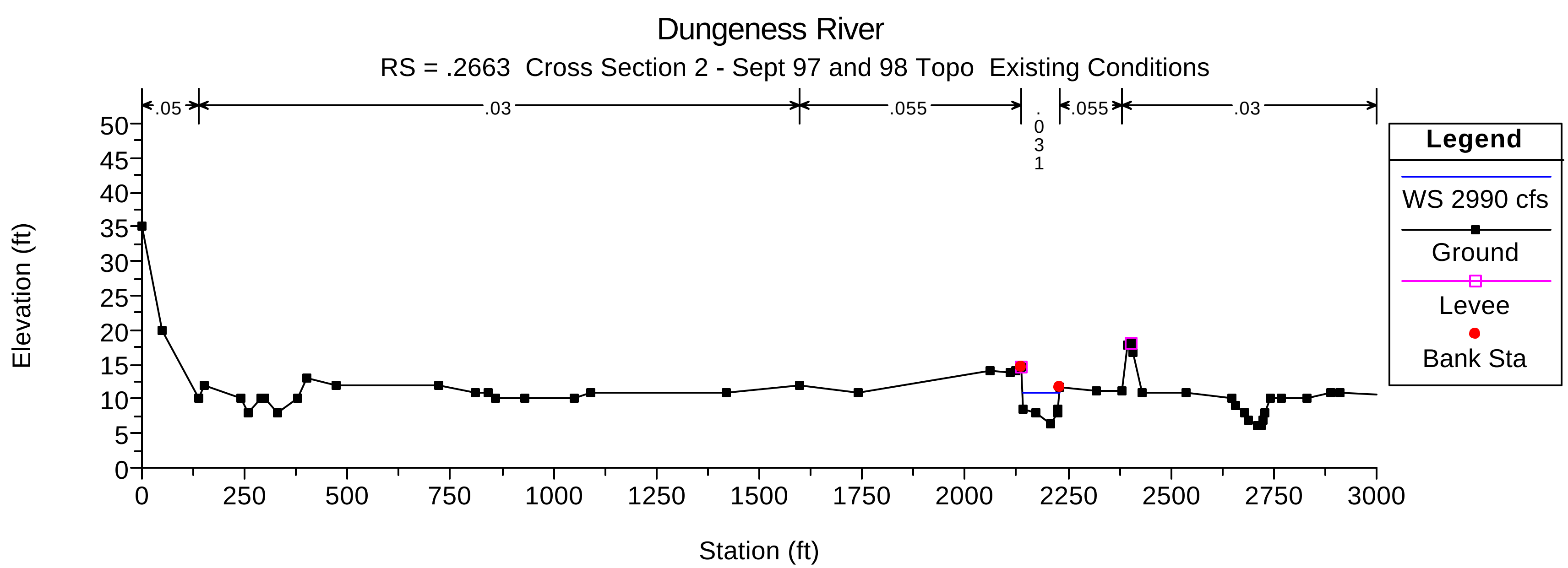

Dungeness River
RS = 1.2009 Cross Section 7 - Sept 97 and 98 Topo Existing Conditions
.055
.033
.055
.03
.055
.03
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

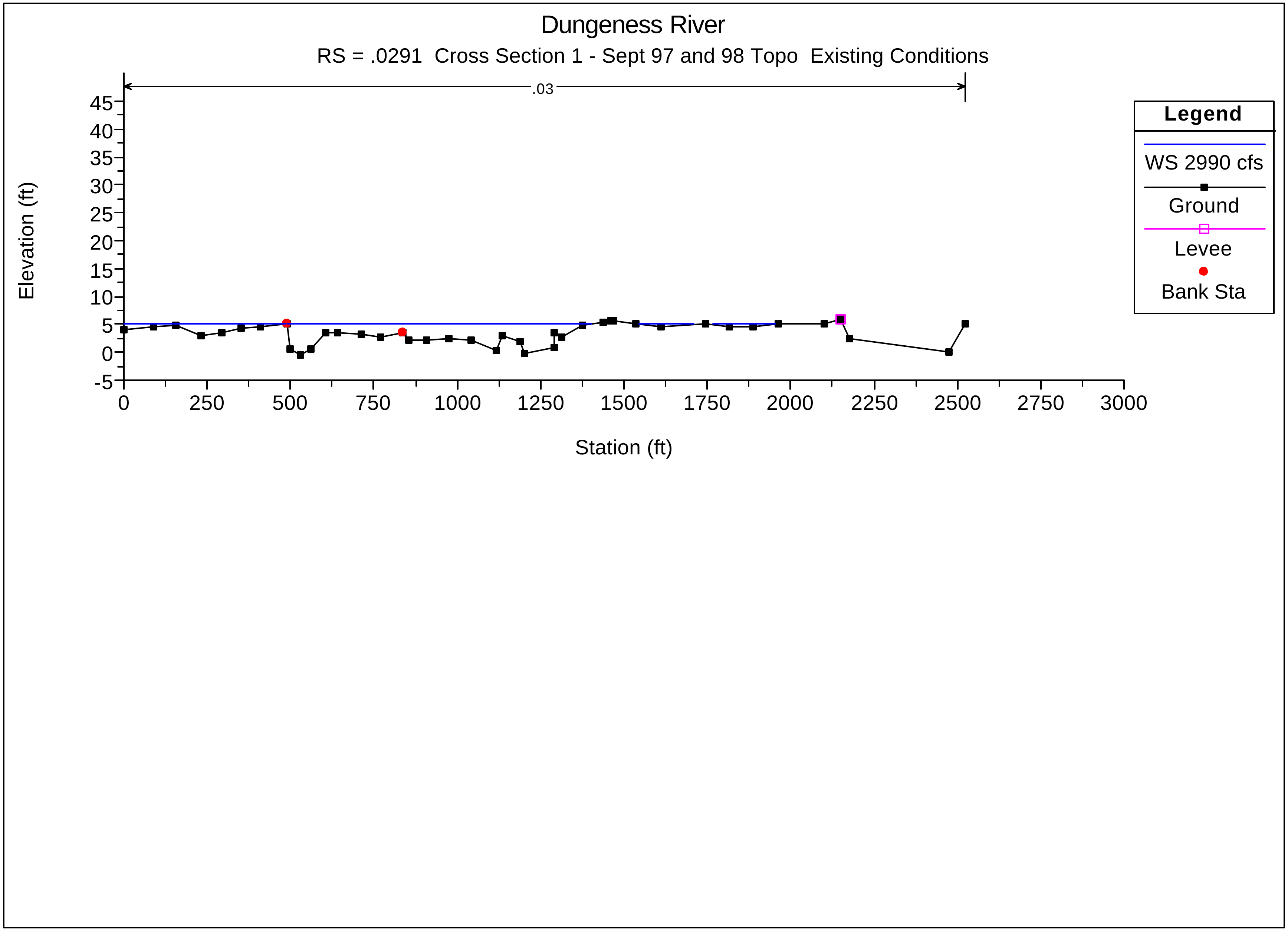

Dungeness River
RS = .9831 Cross Section 6 - Oct 99 and 98 Topo Existing Conditions
.03
.045
.032
.045
.03
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta



Dungeness River
RS = .8772 Cross Section 5 Existing Conditions
.045
.03
.03
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
Dungeness River
RS = .7164 Schoolhouse Bridge Existing Conditions
.03
.03
.03
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
Station (ft)


Dungeness River
RS = .4668 Cross Section 3 - Sept 97 and 98 Topo Existing Conditions
.05
.03
.055
.031
.055
.04
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta


Dungeness River
RS = .2663 Cross Section 2 - Sept 97 and 98 Topo Existing Conditions
.05
.03
.055
.031
.055
.03
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta


Dungeness River
RS = .0291 Cross Section 1 - Sept 97 and 98 Topo Existing Conditions
.03
Elevation (ft)
Station (ft)
Legend
WS 2990 cfs
Ground
Levee
Bank Sta

APPENDIX I.
SOIL DEVELOPMENT ON TERRACES OF THE DUNGENESS RIVER

I.1. Introduction

Soil development can be used to estimate the age of the surface on which the soil is formed. For terraces adjacent to the Dungeness River, this age would be the time since the river had flows that were high enough to cover the surface to a depth that caused significant erosion or deposition. Once the surface is no longer frequently eroded or buried, vegetation begins to grow on the surface. Simultaneously, a soil begins to form. Initially the soil would consist only of an accumulation of organic matter from the vegetation (an A horizon). As the vegetation becomes denser and better established, the A horizon becomes darker and thicker. Unless the surface, vegetation, or both are disturbed by the river returning to the location and causing erosion or deposition, the accumulation of organic matter continues and weathering of minerals in the sediment begins. As the silts and clays in the sediment oxidize and decompose, the sediment below the organic-rich A horizon becomes progressively browner and thicker, and, eventually, it will be richer in clay (B horizon) than the original sediment. Infiltrating rain water can move the clay down into the sediment where it accumulates at the depth of wetting. The weathering of the fine sediment and the accumulation of clay in the soil profile both contribute to the masking and disruption of bedding within the original sediment. In this way, the originally bedded sand, silt, clay, and gravel are transformed into two horizons, an A horizon just below the ground surface and a B horizon below the A horizon. Below these two soil horizons, unaltered, bedded sediment still exists.

The ages estimated for a surface on the basis of soil development are only very rough approximations. They can give an indication of only a minimum age for the surface for several reasons. First, it takes some time for a soil to start forming once the surface has been abandoned by the river. The close relationship between vegetation and soil development, especially the initial development of the A horizon, means that the vegetation must be established before significant soil development begins. Vegetation may become established relatively quickly in the relatively wet climate of the lower Dungeness River. The position of the surface adjacent to the river also may allow plants to utilize near-surface water. Once trees become established on the surface, the rate of soil development may increase (Fonda, 1974). Second, the Dungeness River may return to the surface after soil development begins. If the depth and velocity of the water are not great, then soil development may not be noticeably affected. However, if the water is deep enough and moves fast enough to destroy vegetation or erode part of the surface, then soil development will be interrupted. A return of the river to the abandoned surface also could result in burial of the soil by fine sediment. If only a thin layer of sediment is deposited, then the new sediment will quickly be incorporated into the soil. If a thick layer of sediment is deposited, then the soil will be buried, possibly to a depth that would remove it from the zone of soil formation. A new soil will begin to develop in the younger sediment. Third, other factors, such as plowing or other man-made disturbances, can cause disruption of soil development, especially in the upper 2 to 10 in (5 to 25 cm) of the soil profile.

The main goal in examining soil development on terraces adjacent to the lower Dungeness River was to get a better idea of the ages of the surfaces adjacent to the river and to infer the locations of the main channel and overbank deposition at various times during the last few thousand years to perhaps the last 10,000 years. By looking at the processes of the river during this long time interval, we can better assess if the processes that are acting today along the river are any different than those in the recent geologic past. The ages estimated using soil development are used in conjunction with the radiocarbon ages determined for charcoal collected from the sediments underlying the soils (Appendix J).

The soil moisture regime for the lower Dungeness River is xeric, which means that most of the moisture falls during the winter when it is cool and that summers are warm and dry (Soil Survey Staff, 1992, p. 37). This is when the potential evaporation is at a minimum, so that the moisture is particularly effective for leaching minerals into and through the soil profile (Soil Survey Staff, 1992, p. 37). At higher elevations (upstream of RM10.5), the moisture regime is probably perudic, meaning that precipitation is greater than evapotranspiration during all months of most years (Soil Survey Staff, 1992, p. 36). For occasional brief periods, stored moisture is used (Soil Survey Staff, 1992, p. 36). Water would move through the soil in all months when the ground is not frozen (Soil Survey Staff, 1992, p. 36). In the downstream portion of Reach 1, the moisture regime for soils is likely aquaic or peraquic. The soils in this reach are saturated with water for at least a few consecutive days and the level of the ground water likely fluctuates seasonally making it an aquic regime (Soil Survey Staff, 1992, p. 35). Downstream closer to the mouth of the Dungeness River, in the tidal marsh area, the water in the soils is probably continuously replenished and so the ground water is always very near the ground surface, a peraquic regime (Soil Survey Staff, 1992, p. 35).

The soil temperature class is inferred to be mesic (by definition a mean annual temperature between 8 and 15ºC) on the basis of the mean annual air temperature of about 51ºF (10.5ºC) and a difference of 27ºF (12ºC) between summer (June, July, August) and winter (December, January, February) mean temperatures (Section “Climate”, Table 1, Figure 4; Soil Survey Staff, 1992, p. 39). At higher elevations (upstream of RM10.5), temperatures may be cold enough so that the soil temperature class is cryic (mean annual temperature between 0 and 8ºC, Soil Survey Staff, 1992, p. 38).

Soil profiles were described on fluvial terraces adjacent to the Dungeness River at seven localities (DRsoil-1, DRsoil-2, DRsoil-3, DRsoil-4, DRsoil-5, DRsoil-6, and DRsoil-7) in the lower 10.5 mi (17 km) of the drainage (Figures 3A and 3B). The seven sites were selected to compare and contrast soil development on terraces thought to have a range of ages at the different localities. The soil profiles are described briefly in following sections, in order of their position along the river, downstream to upstream.

I.2. Soil Profile DRsoil-5

The soil profile that was described farthest downstream is on the surface on which the Dungeness School is located. The profile site is east of the Dungeness River and about 400 ft (122 m) east-southeast of the school in Reach 1 (Table I-1). This surface is about 20 ft (6 m) above the surrounding landscape and has been interpreted as glaciomarine drift from the Everson glaciation (Othberg and Palmer, 1979). The surface is interpreted to be above the historical floodplain and the present floodplain, which is defined by the ACOE levee. The soil was described in a utility trench that was dug with a backhoe by the landowner to a housing site. The depth of the trench varied from about 3 to 7 ft (1 to 2 m).

The upper 29 to 31 in (75 to 80 cm) of the profile is sandy. We interpret this unit to be fluvial or beach sand. The soil developed in this sediment is an Ap horizon (plow zone) about 7 in (17 cm) thick. The underlying B horizon, which is 10 in (25 cm) thick, is browner than the underlying unweathered sediment and lighter than the overlying Ap horizon. The color difference suggests that the sediment in the B horizon has been in this position without marked erosion or deposition for some time, although we cannot estimate the length of this interval on the basis of soil development alone. Radiocarbon ages on charcoal from a depth of about 1 m range between 4240 and 1580 cal yr BP (Appendix J). However, these ages are from the lower sedimentary unit, which is separated from the fluvial or beach sand by an unconformity that could represent several hundred to a couple thousand years.

The sediment below 29 to 31 in (75 to 80 cm) contains scattered pebbles and includes both sandy and silty beds. No soil development was recognized in these units. An unconformity exists between this sediment sequence and the overlying sand.

I.3. Soil Profile DRsoil-3

A soil profile was described on a broad surface east of the Dungeness River near RM 1.6 in Reach 1 (Profile DRsoil-3, Figure 3A, Table I-2). The surface is east of the ACOE dike. It is about 5 ft (1.5 m) above the present low-water channel of the Dungeness River. The surface at the location of the soil description was part of the historical floodplain and received overbank flooding until the ACOE levee was built. Because of the levee, the surface is now outside of the present floodplain. The surface has been cultivated. The profile was described in a east-west-trending trench that was dug by the landowner. The profile below a depth of about 2 in (5 cm) was wet even in September, which is a dry time of year, and water filled the bottom of the trench at about 31 in (80 cm). The sediment consists of nongravelly sand, silt, and clay. Roots are abundant.

The soil at this site has an Ap horizon (plow zone) that is about 1.5 in (4 cm) thick. In addition, the sediment is mottled with blue-green or gray-green and shades of brown (Table I-2). These mottles indicate recurrent wetting of the sediment to the point of saturation, which causes reduced conditions. The times of saturation alternate with times of drier conditions during which oxidation of the sediment occurs. In profile DRsoil-3, the mottled or gleyed sediment is present within 4 in (10 cm) of the ground surface and indicates that ground water is at this level for at least part of the year.

Although the minimal soil development that consists of a thin A horizon and gleyed sediment suggests that the surface is young, it is possible that the frequent high water table does not allow for additional soil properties to form. Consequently, at this locality, soil development may not be a very useful indicator of surface age. In addition, the position of this surface immediately adjacent to the river in Reach 1 suggests that fine sediment probably was added regularly to this surface (Section “Subdivision of the Lower Dungeness River Corridor into Reaches”). Consequently, as sediment was periodically deposited at this locality before the ACOE dike, the soil continuously thickened (cumulic profile) without further horizonation.

Abundant charcoal pieces were present near the bottom of the trench at a depths between 22.5 in (58 cm) and 23.5 in (60 cm). Three samples of these charcoal pieces were taken, and cleaned and separated by species (Appendix J). Two samples (DRSO-3-2PI and DRSO-3-3PI) of *Pinaceae* (Pine family) charcoal were submitted for radiocarbon dating. The dates of these samples range between 295 and 665 cal yr BP (Table J-1, Appendix J). A sample of charcoal fragments from the C2g horizon was taken from a depth of 8 to 17.5 in (20 to 45 cm), but, because of possible contamination at this shallow depth, the sample was not submitted for dating.

Halloin (1987, map sheet no. 23) shows the area where DRsoil-3 was described as Puget soil loam. This soil is formed in alluvium on low terraces and floodplains with 0 to 3% slopes (Halloin, 1987, p. 52-53). The soil usually is poorly drained and high water is a problem at least part of the year (Halloin, 1987, p. 52-53). The native vegetation is mainly mixed conifers, deciduous trees, grasses, shrubs, and sedges (Halloin, 1987, p. 52). If the seeds are present when the vegetation is disturbed, red alder will readily reforest the surface (Halloin, 1987, p. 53). Gleyed horizons are common is this soil (Halloin, 1987, p. 112).

I.4. Soil Profile DRsoil-6

A soil profile was described in a backhoe pit that was dug into the surface east of the Dungeness River and 200 ft (61 m) upstream of the upper end of the ACOE levee in Reach 2 (Figure 3A, Table I-3). The surface is bounded on the east by the steep slope of a Pleistocene deposit. The edge of the historical and present floodplain, as indicated by the extent of flooding in 1949 (approximately the size of the 100-year flood), is near the edge of this surface. The soil pit was dug above these floodplain boundaries.

The soil is developed in overbank sand and silt that is about 50 in (127 cm) thick. The overbank sediment overlies gravelly alluvium that was likely deposited by the main channel of the Dungeness River. The profile includes an Ap horizon (plow zone) that is about 3 in (7 cm) thick and a weakly developed Bt horizon that is about 10 in (26 cm) thick. Although the color of the Bt horizon is the same as that of the overlying Ap horizon, clay movement into the horizon is indicated by a few faint clay films on the surfaces of peds and in pores (Table I-3). The presence of the Bt horizon suggests that the surface at this locality has been relatively stable (no marked erosion or deposition) for some time, although the length of this interval cannot be estimated with any precision.

Radiocarbon ages on charcoal from sediment just above the gravelly alluvium (depth of 43 to 47 in (110 to 120 cm)) range from 1970 to 1170 cal yr BP (Appendix J). Ages from a depth of about 12 in (30 cm) are $\leq$430 cal yr BP (Appendix J). The presence of the weakly developed Bt horizon in the soil profile suggests that the older portion of this younger age range, if any, may be more realistic as some time is needed to form the Bt horizon.

I.5. Soil Profiles DRsoil-1 and DRsoil-2

Two soil profiles were described on two different terraces on the west side of the Dungeness River, between RM 5.1 (DRsoil-1) and RM5.5 (DRsoil-2) in the Reach 3 (Figure 3A; Tables I-4 and I-5). Soil profile DRsoil-1 was described in a near-vertical bank cut into a terrace immediately adjacent to the Dungeness River. This terrace is about 6 ft (2 m) above the low-water channel. Soil profile DRsoil-2 was described in a hand-dug pit on a terrace that is about 12 m (40 ft) higher than the terrace on which DRsoil-1 was described (Figure 3A). Both terraces have been cultivated. The surface of the terrace where DRsoil-2 was described has probably been disturbed. Both surfaces are above the historical and present floodplains, which are defined by the relatively high bank.

The two soils are developed in sandy and silty alluvium that contains fine to medium sand (0 to <10% gravel, Tables I-4 and I-5). These sediments are weakly bedded and overlie gravelly alluvium (50 to 75% gravel, Tables I-4 and I-5). At profile DRsoil-1, the fine sediment is 56.5 in (145 cm) thick and overlies coarse gravelly alluvium that was deposited in a channel of the Dungeness River. At profile DRsoil-2, the fine sediment is about 20 in (50 cm) thick, and overlies a 6-in-thick (15-cm-thick), cobbly gravel bed that contains cobbles through granules and was deposited in a channel. The gravelly alluvium, in turn, overlies sandy alluvium to a depth of at least 31 in (80 cm) (Table I-5). The thicknesses of the sandy and silty alluvium suggest that the main channel of the Dungeness River has not been at the location of these two profiles for some time.

Both profiles have A horizons that directly overlie C horizons (Tables I-4 and I-5). The color of the A horizon is darker in profile DRsoil-2 (10YR 4/3 (d), 10YR 3/2 (m)) than it is in the profile DRsoil-1 (2.5Y 6/2 (d), 2.5Y 3/2 (m)) (Tables I-4 and I-5). The A horizon also is thicker in the DRsoil-2 profile (14 in (36 cm)) than it is in the DRsoil-1 profile (9 in (24 cm)). Although these differences are not marked, they likely reflect the older age of the higher terrace at DRsoil-2.

Profile DRsoil-1 contains periodic layers of reddened sediment that we interpret as burn layers (sediment oxidized by burning in place or burned sediment that was eroded and redeposited by the Dungeness River). Charcoal is often present immediately above the reddened sediment. Charcoal was sampled from four of these layers, at depths of 42 to 44 in (108 to 113 cm), 45 to 46 in (116 to 119 cm), 50 to 52 in (128 to 134 cm), and 72.5 to 74.5 in (186 to 191 cm). Four samples from three of these layers were submitted for radiocarbon dating (Table J-1, Appendix J). An additional charcoal sample was taken between depths of 15 and16.5 in (38 and 43 cm), between two layers of reddened sediment. This sample was not submitted for dating because of the likelihood of contamination at this shallow depth in the soil. Dates for the four samples that were submitted for radiocarbon dating range between 1970 and 2700 cal yr B.P. (Table J-1, Appendix J). Three of these samples are *Pseudotsuga* (Douglas fir) and one is *Tsuga* (Hemlock) (Table J-1, Appendix J).

Profile DRsoil-2 had no visible charcoal. However, two samples of sediment were taken and charcoal from both of these were separated in the laboratory (Appendix J). One sample (DRSO-2-1PS) of *Pseudotsuga* (Douglas fir) charcoal was collected at a depth between 6 and 14 in (15 and 36 cm); the other sample (DRSO-2-2COv) of Conifer charcoal was collected at a depth between 20.5 and 31 in (53 and 80 cm) (Table J-1, Appendix J). The date on the upper sample is modern, probably due to contamination and continued additions of charcoal and organic matter to this depth in the soil profile. The date on the lower sample is between 2350 and 2700 cal yr BP (Table J-1, Appendix J). This overlaps with the dates from the DRsoil-1 profile, so these two terraces cannot be distinguished on the basis of the radiocarbon dates. However, the deeper burial on the lower terrace by sediments similar to those above the charcoal sample from the upper terrace suggests that the surface of the lower terrace is younger than the surface of the upper terrace.

The soils at both of the localities are shown by Halloin (1987, map sheet no. 34) as Dungeness silt loam. This soil is present in alluvium on low terraces and floodplains with slopes of 0 to 5% (Halloin, 1987, p. 27). Native vegetation on these surfaces is mainly mixed conifers and deciduous trees and shrubs (Halloin, 1987, p. 27). When the vegetation is disturbed, reforestation with Douglas fir occurs readily (Halloin, 1987, p. 28). In summer, irrigation is required for maximum crop production (Halloin, 1987, p. 28). This soil consists of an Ap horizon about 8 in (20 cm) thick over a series of C horizons (Halloin, 1987, p. 100). The color of the Ap horizon is 10YR or 2.5 Y with a chroma of 2 or 3 when dry and moist (Halloin, 1987, p. 100). The soils on both terraces at DRsoil-1 and DRsoil-2 fit this description (Tables I-4 and I-5).

I.6. Soil Profile DRsoil-7

A soil profile was described in a natural exposure on the west (left) side of the Dungeness River about 300 ft (92 m) downstream of the Railroad Bridge (Figure 3A, Table I-6). The top of the surface is about 10 ft (3 m) above the present river channel. It is the highest surface in the immediate area and may correlate to the surfaces where profiles DRsoil-1 and DRsoil-2 were described downstream. The surface is tree covered with maples, cedars, alder, fir, and conifer.

The soil is developed in overbank sand and silt beds and consists of an A horizon that is 9 in (22 cm) thick. It overlies unweathered sediment. Gravelly alluvium that was probably deposited by the main channel of the Dungeness River is present below the overbank sediment at a depth of about 47 in (120 cm). Radiocarbon dates on charcoal collected from sand that overlies and interfingers with gravelly channel alluvium range between1320 to 1240 cal yr BP (Appendix J). These ages suggest that the surface has received only overbank flow during the last 1,000 yr. Charcoal from overbank sediment at a depth between 15 to 19 in (39 and 49 cm) was dated between 500 to 290 cal yr BP (Appendix J). An age of a few hundred years for the surface since marked deposition or erosion is consistent with the weakly developed soil that is preserved on this surface.

I.7. Soil Profile DRsoil-4

The soil profile that was described farthest upstream is on a relatively high terrace that is likely Pleistocene (older than about 10,000 years). It is located near RM9, near the boundary between the upper two reaches (Figure 3B). The surface is graded to Pleistocene till and it is likely that the terrace formed as ice retreated from the Dungeness valley about 12,000 years ago (Peterson and others, 1983). Water flowing from the front of the ice deposited the alluvium that is now preserved in this terrace. The surface was selected because the soil here should be one of the best developed on a terrace of the Dungeness River. The profile (DRsoil-4, Table I-7) was described in a hand-dug pit that extended to a depth of nearly 3 ft (1 m). The sediment in which the soil is developed is primarily gravelly alluvium. In the upper 8 in (20 cm) of the soil profile, fine sediment is mixed with and overlies the gravel. The fine sediment may have an eolian (windblown) origin. If so, it was deposited on the surface after it had been abandoned by the river.

The soil developed on this surface has a Bt horizon that is at least 24 in (62 cm) thick (Table I-7). The base of this horizon was not exposed in the bottom of the pit. This horizon has a loamy texture and common, prominent clay films along ped faces and between grains. The A horizon here is about 8 in (20 cm) thick. The upper 2.5 in (7 cm) of this horizon is a plow zone. The surface has been cultivated. Below the A horizon is a horizon that may be the remnants of an E (or bleached) horizon. These typically form on forested surfaces. Although trees are not on the surface at present, it is likely that they were removed after 1942/43.

Four samples of charcoal were taken from the 2Bt horizon. Two of these were at a depth of about 13.5 in (35 cm); one was at a depth of 18.5 in (48 cm); and one was at a depth between 18 and 19 in (46 and 49 cm) (Table I-7). Two samples of *Pseudotsuga* (Douglas fir) charcoal, DRSO-4-3PSv at a depth of 18.5 in (48 cm) and DRSO-4-3aPS at a depth between 18 and 19 in (46 and 49 cm), were submitted for radiocarbon dating (Appendix J). The dates from these two samples are 1725 to 2000 cal yr BP (DRSO-4-3PSv) and 1975 to 2300 cal yr BP (DRSO-4-3PS) (Table J-1, Appendix J). These dates are minimum ages. Because younger charcoal and organic matter can be introduced into the upper part of the soil, these ages likely are much younger than the underlying alluvium. Geomorphic relationships suggest that the alluvium and related terraces are close to 10,000 years old.

Halloin (1987, map sheet no. 55) indicates that the soil at locality DRsoil-4 is part of the Carlsborg-Dungeness complex. These soils are developed on fine or coarse alluvium on terraces with slopes of 0 to 5% (Halloin, 1987, p. 18, 27). They are well drained (Halloin, 1987, p. 18, 27). Native vegetation on the Carlsborg gravelly sandy loam, which the soil at DRsoil-4 likely is, is mainly conifers and shrubs. For both the Carlsborg gravelly sandy loam and the Dungeness silt loam, Douglas fir readily revegetates the surfaces and grows well (Halloin, 1987, p. 19, 28). Both soils require irrigation in summer for maximum crop production (Halloin, 1987, p. 19, 28).

I.8. References

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Othberg, K.L, and Palmer, Pamela, 1979, Preliminary surficial geologic map of the Dungeness quadrangle, Clallam County, Washington: Washington Division of Geology and Earth Resources Open-File Report 79-17, 3 p., 1 pl., scale 1:24,000.

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Table I-1. Field description of the soil profile at Locality DRSoil-5

[Profile was described following the procedures outlined in Birkeland and others (1991, their appendix, p. 55-63).]

Profile Number: DRSoil-5 Described by: L.A. Piety and R.A. Link Date: 7/12/00 Time: 10:30 am
Parent Material(s): Fluvial or beach sand over glacial-marine deposit (Everson) Surface unit: Slope: Aspect:
Location: In trench about 400 ft (0.13 km) ESE of Dungeness School; NE wall ; RM 0.7? Aerial photograph(s): Dungeness River 2000 #2-10
Quadrangle: Dungeness, 7.5-minute Township and Range: T.31 N., R. 4 W. Section: NE1/4, SE1/4, 36 Elevation: 19 ft (6 m)
Survey Coordinates: Lat. 48º08'31.52"N.; Long. 123º07'36.87"W. (+/- 17 ft) Classification:

Horizon	Depth (thickness) (cm; in)	Boundaries	Structure	Clay Films	Wet Consistence Stickiness	Wet Consistence Plasticity	Dry Consistence	Texture	CaCO3	Gravel Percent	Color Dry; Moist
Ap	0-17; 0-7 (17; 7)	cs	2f sbk	--	so	po	so	L	--	<10	10YR 5/2
B1	17-29; 7-11 (12; 4)	gs	3c abk to 2c pl (at top)	--	so	po	h	SL	cw	<10	10YR 7/2
B2	29-42; 11-17 (13; 6)	gs	2c abk	--	so	po	sh	SL	cw	<10	10YR 7/2
C1	42-77; 17-30 (35; 13)	aw	sg to 1c abk	Possible lamallae at base	so	po	so	LS	--	<10	2.5Y 6/2
2C2	77-107; 30-42 (30; 12)	cw	sg to 1c abk	--	so-s	po-p	h-sh	LS and SiCL	cw	1-2	LS: 10YR 6/6; SiCL: 10YR 7/4
3C3	107-122+; 42-48+ (15+; 6+)	--	m	--	ss	ps	h	SiCL	cw	<1	10YR 7/4

Notes for Table I-1:

The A horizon contains abundant roots. Most roots are fine; a few are large. Sand in this horizon is medium. The larger than 2 mm fraction is pebbles.

The B1horizon is massive to finely bedded. Sand in this horizon is medium. The larger than 2 mm fraction is small pebbles.

The B2 horizon is slightly grayer than the B1 horizon. Sand in this horizon is medium. The larger than 2 mm fraction is small pebbles. Charcoal was sampled between 29 and 33 cm (11-13 in) depth in the upper part of the fluvial or beach sand (Charcoal Sample DRSO-5-A3).

The C1 horizon has clay lamellae and cobble-size clasts of glacial sediment at its base. Sand in this horizon is medium to coarse. The larger than 2 mm fraction is small pebbles. A bulk sediment sample was collected between 61 and 75 cm (24-30 in) depth for possible charcoal (Charcoal Sample DRSO-5-A2). Sample is from the lower part of the fluvial or beach sand.

The 2C2 horizon is sandy with silty lenses. Sand in this horizon is medium to coarse in the loamy sand portion and fine in the silty clay loam lenses. The larger than 2 mm fraction is mostly granitic pebbles with diameters up to 50 mm. Charcoal was sampled between 95 and 102 cm (37-40 in) depth in the upper part of the glacial-marine sediment (Charcoal Sample DRSO-5-A1).

The 3C3 horizon is silty; it contains no sand lenses. Sand in this horizon is very fine. The larger than 2 mm fraction is pebbles.

Abbreviations are explained in Table I-8.

Table I-2. Field description of the soil profile at Locality DRSoil-3

[Profile was described following the procedures outlined in Birkeland and others (1991, their appendix, p. 55-63).]

Profile Number: DRSoil-3 Described by: L.A. Piety and J.A. Keeley Date: 9/13/98 Time: 2:45 pm
Parent Material(s): Fluvial silt and clay Surface unit: Slope: Aspect:
Location: In trench on east side of Dungeness River on Brown's property; RM 1.6 Aerial photograph(s): Dungeness River 1998 #2-5
Quadrangle: Dungeness, 7.5-minute Township and Range: T.31 N., R. 4 W. Section: NE1/4, SW1/4, 36 Elevation: 25 ft (-3 ft, GPS) (8 m)
Survey Coordinates: Lat. 48º08'10.02"N.; Long. 123º08'20.27"W. (+/- 24 ft) Classification: Psammaquent

Horizon	Depth (thickness) (cm; in)	Boundaries	Structure	Clay Films	Wet Consistence Stickiness	Wet Consistence Plasticity	Dry Consistence	Texture	CaCO3	Gravel Percent	Color Dry; Moist
Ap	0-4; 0-2 (4; 2)	aw	3vf-f gr	--	so	vps	h	SL	--	0	2.5Y 5/2; 2.5Y 3/2
Cg1	4-10; 2-4 (6; 2)	cs	1f abk	--	so	po	sh	SL	--	0	2.5Y 5/2; 2.5Y 3/2
Cg2	10-52; 4-20 (42+; 16+)	--	1c abk	--	so	vps	--	SL	--	<5	–; 2.5Y 4/2
Cg3	52-80+; 20-31+ (28+; 11+)										

Notes for Table I-2:

Below the Ap horizon, the soil is moist or wet. The surface is lower to the west (toward the Army Corps of Engineer's levee. Water is near the bottom of the trench at this locality and fills the trench to the east.

The Ap horizon contains abundant fine roots. Sand in this horizon is fine.

The Cg1horizon contains common fine roots. Sediment is brown (oxidized) along roots. Sand in this horizon is fine. A bulk sediment sample was taken to extract charcoal for radiocarbon dating (Charcoal Sample DRSO-3-1PS).

The Cg2 horizon contains few fine roots. Sand in this horizon is very fine and fine. Prominent models of blue gray and red brown are common throughout the horizon. Horizon is wet to moist. Charcoal was sampled just above 52 cm (20 in; Charcoal Sample DRSO-3-5).

The Cg3 horizon includes some areas that are sandier and other areas that are siltier. Prominent mottles of blue gray and red brown are common throughout the horizon. Horizon is wet to moist. Gravel consists of scattered subangular granules. Charcoal was sampled at depths of 58 cm (23 in; Charcoal Sample DRSO-3-2PI), 59 cm (23 in; Charcoal Samples DRSO-3-4CO and DRSO-3-4PI), and 60 cm (23 in; Charcoal Sample DRSO-3-3PI).

Abbreviations are explained in Table I-8.

Table I-3. Field description of the soil profile at Locality DRSoil-6

[Profile was described following the procedures outlined in Birkeland and others (1991, their appendix, p. 55-63).]

Profile Number: DRSoil-6 Described by: L.A. Piety and R.A. Link Date: 7/14/00 Time: 12 pm
Parent Material(s): Fluvial sand and silt over fluvial gravel Surface unit: Slope: Aspect:
Location: East side of Dungeness River in backhoe pit on Moore's property; RM 2.5 Aerial photograph(s): Dungeness River 2000 #2-5
Quadrangle: Carlsborg, 7.5-minute Township and Range: T.30 N., R. 4 W. Section: West-central, 1 Elevation: 36 ft (11 m)
Survey Coordinates: Lat. 48º07'22.31"N.; Long. 123º08'25.87"W. (+/- 22 ft) Classification:

Horizon	Depth (thickness) (cm; in)	Boundaries	Structure	Clay Films	Wet Consistence Stickiness	Wet Consistence Plasticity	Dry Consistence	Texture	CaCO3	Gravel Percent	Color Dry; Moist
Ap	0-7; 0-3 (7; 3)	cs	2f sbk	--	ss	ps	sh	L	--	0	10YR 5/2; 10YR 2/2
Btj	7-33; 3-13 (26; 10)	cs	2-3c abk	v1 f pf-po	ss	ps	sh	L	--	0	10YR 5/2; 10YR 3/2
C1 (Sand)	33-72; 13-28 (39; 15)	aw	--	--	so	po	lo	LS	--	0	10YR 5/1; 10YR 3/1
C1 (Silt)			--	--	ss	po	so	L	--	0	2.5Y 5/2; 2.5Y 3/2
2C2	72-127; 28-50 (55; 22)	aw	sg	--	so	po	lo	LS	--	0	2.5Y 4/2; 10YR 3/1
3C3	127-155+; 39-57+ (28+; 18+)	--	sg	--	so	po	lo	gLS	--	50	10YR 6/1; 10YR 3/1

Notes for Table I-3:

The Ap horizon contains abundant roots. Most roots are fine; a few are large. Sand in this horizon is very fine.

The Btj horizon contains contains coarse-sand-size clasts of reddened silt between 29 and 30 cm (11-12 in) depth. Sand in this horizon is very fine. A bulk sediment sample was collected between 7 and 33 cm (3-13 in) depth for possible charcoal (Charcoal Sample DRSO-6-10). Charcoal was collected 29 and 30 cm (11-12 in) depth (Charcoal Sample DRSO-6-7 from the south wall of pit and Sample DRSO-6-8 from the north wall).

The C1 horizon extends to a depth of 100 cm (39 in) in the north wall of the pit, where a pebbly coarse sand lens in present at a depth of about 85 to 87 cm (33-34 in). The horizon sand and silt layers. The sandy layers are 6 to 13 cm (2-5 in) thick. The silty layers are 6 to 10 cm (2-4 in) thick. Sand in the sandy layers is mostly fine to medium, with a small amount of coarse sand. Sand in the silty layers is very fine and fine. A lens of reddened (burned) sediment about 1 cm (0.4 in) thick is present at a depth of about 37 cm (15 in). A bulk sediment sample was collected between 33 and 77 cm (13-30 in) depth for possible charcoal (Charcoal Sample DRSO-6-9 from the north wall of the pit). Additional charcoal samples were collected from the south wall of the pit: Charcoal Sample DRSO-6-6 at 43-53 cm (17-21 in) depth, DRSO-6-4 at 66 cm (26 in) depth, and DRSO-6-3 at 57 to 60 cm (22-24 in) depth. Charcoal Sample DRSO-6-5 was collected at 76 cm (30 in) depth from the north wall of the pit.

The 2C2 horizon is massive to finely bedded with some cross bedding. Sand in this horizon is fine and medium. The horizon extends to a depth of more than 145 cm (57 in) in the north wall of the pit. Charcoal is common in the upper part of the horizon and rare in the lower part. Two bulk sediment samples for possible charcoal were collected: one between 68 and 81 cm (27-32 in) depth (Charcoal Sample DRSO-6-2) and one between 110 and 120 cm (43-47 in) depth (Charcoal Sample DRSO-6-1).

The 3C3 horizon is a pebbly coarse sand. Diameters of the largest clasts (<1% of the gravel) is about 50 mm. Sand in this horizon is coarse and very coarse. The horizon extends to a depth of more than 155 cm (61 in) in the north wall of the pit.

Abbreviations are explained in Table I-8.

Table I-4. Field description of the soil profile at Locality DRSoil-1

[Profile was described following the procedures outlined in Birkeland and others (1991, their appendix, p. 55-63).]

Profile Number: DRSoil-1 Described by: L.A. Piety and R.A. Link Date: 9/12/98 Time: 1 pm
Parent Material(s): Fluvial sand and silt over fluvial gravel Surface unit: Slope: Aspect:
Location: West bank of Dungeness River channel on Severson's property; RM 5.1 Aerial photograph(s): Dungeness River 1998 #3-5
Quadrangle: Carlsborg, 7.5-minute Township and Range: T.30 N., R. 4 W. Section: NE1/4, SE1/4, 14 Elevation: 165 ft (50 m)
Survey Coordinates: Lat. 48º05'28.36"N.; Long. 123º09'04.69"W. (+/- 22 ft) Classification: Xerofluvent

Horizon	Depth (thickness) (cm; in)	Boundaries	Structure	Clay Films	Wet Consistence Stickiness	Wet Consistence Plasticity	Dry Consistence	Texture	CaCO3	Gravel Percent	Color Dry; Moist
Spoil	(68; 27)	as	n.d.	--	n.d.	n.d.	n.d.	n.d.	--	0	n.d.
Ap	0-24; 0-9 (24; 9)	aw	m to 1c abk (also v.wk. pr)	--	vss	vps	sh	L	--	0	2.5Y 6/2; 2.5Y 3/2
C1	24-63; 9-25 (39; 15)	cs	m	--	so	po	h	SiL	--	0	2.5Y 7/3; 2.5Y 4/3
C2	63-79; 25-31 (16; 6)	cs	m	--	ss	ps	h	SL	--	0	2.5Y 7/3; 2.5Y 4/3
C3	79-99; 31-39 (20; 8)	cs	sg	--	so	po	so	SL	--	0	2.5Y 6/3; 2.5Y 4/3
C4	99-145+; 39-57+ (46+; 18+)	cs	m	--	s	p	vh	SiL	--	<10	2.5Y 7/3; 2.5Y 4/3
2C5	145+-~250; 57-~98 (105; 41)	--	sg	--	so	po	lo	gS	--	75	2.5Y 7/3; 2.5Y 4/3

Notes for Table I-4: The spoil was not described.

The A horizon contains abundant roots. Most roots are fine; a few are large. This horizon has krotovinas throughout and dense roots between 0 and 1 cm (0-0.4 in) depth. Sand in this horizon is very fine and fine. The lower contact is marked by the reddened sediment of a burned layer at a depth of 24 cm (9 in) in the C1 horizon.

The C1horizon contains krotovinas. Sand in this horizon is very fine and fine. Burn layers are present at depths of 24 to 27 cm (9 to 11 in), 34 to 36 cm (13 to 14 in), and 44 to 46 cm (17 to 18 in).

The C2 horizon contains krotovinas. Sand in this horizon is fine. A bulk sediment sample was taken for possible charcoal (Charcoal Sample DRSO-1-4).

The C3 horizon is weakly bedded. Sand in this horizon is medium.

The C4 horizon contains burn layers and charcoal. Burn layers are at depths of 119 to 125 cm (46 to 49 in) and 128 to 143 cm (50 to 56 in). Charcoal is at depths of 108 to 133 cm (42 to 52 in; Charcoal Sample DRSO-1-3), 116 to 119 cm (45 to 46 in; Charcoal Sample DRSO-1-1) and 128 to 134 cm (50 to 52 in; Charcoal Sample DRSO-1-2). Sand in this horizon is very fine.

Charcoal was sampled from the 2C5 horizon between depths of 186 to 191 cm (73 to 74 in; Charcoal Sample DRSO-1-5).

Abbreviations are explained in Table I-8.

Table I-5. Field description of the soil profile at Locality DRSoil-2

[Profile was described following the procedures outlined in Birkeland and others (1991, their appendix, p. 55-63).]

Profile Number: DRSoil-2 Described by: L.A. Piety, R.A. Link, T.J. Randle, J.A. Keeley Date: 9/13/98 Time: 8 am
Parent Material(s): Fluvial sand and silt over fluvial gravel Surface unit: ________ Slope: ________ Aspect: ________
Location: Terrace on west side of Dungeness River on Severson's property; RM 5.5 Aerial photograph(s): Dungeness River 1998 #3-5
Quadrangle: Carlsborg, 7.5-minute Township and Range: T.30 N., R. 4 W. Section: NW1/4, NE1/4, 23 Elevation: 198 ft (60 m)
Survey Coordinates: Lat. 48º05'10.74"N.; Long. 123º09'07.82"W. (+/- 26 ft) Classification: Xerofluvent

Horizon	Depth (thickness) (cm; in)	Boundaries	Structure	Clay Films	Wet Consistence Stickiness	Wet Consistence Plasticity	Dry Consistence	Texture	CaCO3	Gravel Percent	Color Dry; Moist
Ap	0-15; 0-6 (15; 6)	cw	2vf-fgr	--	so	po	so	L	--	0	10YR 4/3; 10YR 3/2
A	15-36; 6-14 (21; 8)	aw	m to 1c-vc sbk and 2f gr	--	vss	po	sh	L	–	<10	10YR 5/3; 10YR 4/2
C1	36-41; 14-16 (5; 2)	aw	m to 1c-vc abk	--	vss	ps	sh	SL	--	0	2.5Y 6/3; 2.5Y 4/3
C2	41-46; 16-18 (5; 2)	aw	m to 1c sbk	--	so	po	so	LS	--	0	2.5Y 5/3-6/3; 2.5Y 4/2
2C3	46-53 (to 60); 18-21 (to 23) (7 to 14; 3 to 5)	aw	sg	--	so	po	lo	gLS	--	50	2.5Y 6/3; 2.5Y 4/2
3C4	53-80+; 21-31+ (27+; 11+)	--	sg to 1vc sbk	--	so	po	so	LS	--	0	2.5Y 6/3; 2.5Y 4/3

Notes for Table I-5:

The Ap horizon contains abundant fine roots. Sand in this horizon is fine.

The A horizon contains abundant fine roots. Gravel fraction is pebbles, which are mostly well rounded. Sand in this horizon is fine. Horizon contains charcoal fragments. A bulk sediment sample was taken for radiocarbon dating (Charcoal Sample DRSO-2-1PS).

The C1horizon contains common fine roots and scattered charcoal fragments. Sand in this horizon is very fine.

The C2 horizon contains common fine roots. Sand in this horizon is medium.

The 2C3 horizon contains common fine roots. The sediment in this horizon is weakly bedded. The gravel is composed of subangular, rounded, and well-rounded cobbles through granules. Sand in this horizon is coarse.

The 3C4 horizon contains few fine roots. Sand in this horizon is coarse. The sediment is weakly bedded with alternating lenses of light-colored silt and reddish clay. Although no charcoal was visible in this horizon, a bulk sediment sample was taken for radiocarbon dating (Charcoal Sample DRSO-2-2COv).

Abbreviations are explained in Table I-8.

Table I-6. Field description of the soil profile at Locality DRSoil-7

[Profile was described following the procedures outlined in Birkeland and others (1991, their appendix, p. 55-63).]

Profile Number: DRSoil-7 Described by: L.A. Piety and R.A. Link Date: 7/16/00 Time: 9 am

Parent Material(s): Fluvial sand and silt over fluvial gravel Surface unit: ___ Slope: ___ Aspect: ___

Location: West bank of Dungeness River channel about 300 ft downstream of Railroad Bridge; RM 5.5 Aerial photograph(s): Dungeness River 2000 #3-4

Quadrangle: Carlsborg, 7.5-minute Township and Range: T.30 N., R. 4 W. Section: NE1/4, NE1/4, 23 Elevation: 200.5 ft (61 m)

Survey Coordinates: Lat. 48º05'10.59"N.; Long. 123º08'59.45"W. (+/- 24 ft) Classification: ___

Horizon	Depth (thickness) (cm; in)	Boundaries	Structure	Clay Films	Wet Consistence Stickiness	Wet Consistence Plasticity	Dry Consistence	Texture	CaCO3	Gravel Percent	Color Dry; Moist
A	0-22; 0-9 (22; 9)	c-as	2-3m sbk	--	so	vps	h	L	--	0	10YR 6/2; 10YR 3/1
A/C	22-33; 9-13 (11; 4)	gs	2-3m-c abk+sbk	--	so	vps	h-sh	L	--	0	2.5Y 6/3; 2.5Y 3/2
C1 (Sand)	33-105; 13-41 (72; 28)	aw	sg-1m abk	--	so	po	so	SL	--	0	2.5Y 6/2; 2.5Y 3/2
C1 (Silt)			2c abk	--	ss	ps	h-sh	SiL-L	--	0	2.5Y 6/3; 2.5Y 3/3
2C2	105-149; 41-59 (44; 18)	aw	1f-m abk	--	so	po	lo-so	SL-LS	--	0	2.5Y 5/2; 2.5Y 3/1
3C3	149-205; 59-81 (56; 22)	aw	sg	--	so	po	lo	gLS	--	75	10YR 7/1; 10YR 4/1
4C4	205-230+; 81-91 (25+; 10+)	--	sg	--	so	po	lo	gS	--	25-50	10YR 5/1; 10YR 3/1

Notes for Table I-6:

The A horizon contains abundant roots. Most roots are fine; a few are large. Sand in this horizon is very fine.

The A/C horizon contains abundant roots. Most roots are fine; a few are large. Sand in this horizon is very fine and fine. Salts are visible on the surface of the exposure. Structure is similar to that in the A horizon, but is smaller and better developed. Structure is especially blocky in the upper part of horizon. Burn layers are present at depths of 24 to 27 cm (9 to 11 in), 34 to 36 cm (13 to 14 in), and 44 to 46 cm (17 to 18 in).

The C1 horizon extends to 137 cm (54 in) at north end of exposure. Horizon includes sandy layers and silty layers. Individual layers are between 2 and 10 cm (0.8-4 in) thick. Sand in sandy layers is fine; sand in the silty layers is very fine. Salts are visible on the surface of the exposure, especially along the silt beds. Reddened (burned) sediment layer occurs at a depth of 97 cm (38 in). No soil development seems to associated with this surface. A layer of scattered charcoal and reddened (burned) sediment occurs between depths of 39 and 49 cm (15-19 in). A bulk sediment sample was collected between depths of 39 and 49 cm (15-19 in) for possible charcoal (Charcoal Sample DRSO-7-6). A second bulk sediment sample was collected between depths of 51 and 70 cm (20-28 in) for possible charcoal (Charcoal Sample DRSO-7-5). Two charcoal samples were collected: DRSO-7-3 at a depth of 98 cm (39 in) and DRSO-7-4 at a depth of 46.5 cm (18 in).

The 2C2 horizon is weakly bedded. It contains several large roots. Sand in this horizon is medium. A bulk sediment sample was collected between depths of 139 and 149 cm (55-59 in) for possible charcoal (Charcoal Sample DRSO-7-2) in the sand immediately above the gravelly channel deposit (Horizon 3C3).

The 3C3 horizon is a cobble-boulder gravel with 45 to 50% of cobbles. Gravel clasts are rounded and subrounded. The horizon is weakly bedded with lenses of gravel and sand Sand in this horizon is coarse. Horizon grades into a unit with more gravel to the north.

The 4C4 horizon a pebble-cobble gravel with 10% cobbles. Gravel clasts are rounded and subrounded. Horizon is bedded with some beds with up to 75% gravel and some beds with only about 25% gravel. Sand in this horizon is coarse and very coarse. A bulk sediment sample was collected between depths of 208 and 211 cm (82-83 in) for possible charcoal (Charcoal Sample DRSO-7-1). Sample is from a pebbly sand near the base of the exposure.

Abbreviations are explained in Table I-8.

Table I-7. Field description of the soil profile at Locality DRSoil-4

[Profile was described following the procedures outlined in Birkeland and others (1991, their appendix, p. 55-63).]

Profile Number: DRSoil-4 Described by: L.A. Piety, R.A. Link, T.J. Randle, J.A. Keeley Date: 9/16/98 Time: 1 pm
Parent Material(s): Eolian sediment over fluvial gravel (fines upward) Surface unit: Slope: Aspect:
Location: Terrace on west side of Dungeness River along Fish Hatchery Road; RM 9.5 Aerial photograph(s): Dungeness River 1998 #3-14
Quadrangle: Carlsborg, 7.5-minute Township and Range: T.29 N., R. 4 W. Section: NW1/4, NE1/4, 2 Elevation: 444 ft (135 m)
Survey Coordinates: Lat. 48º02'25.89"N.; Long. 123º09'09.96"W. (+/- 22 ft) Classification: Haploxeroll

Horizon	Depth (thickness) (cm; in)	Boundaries	Structure	Clay Films	Wet Consistence Stickiness	Wet Consistence Plasticity	Dry Consistence	Texture	CaCO3	Gravel Percent	Color Dry; Moist
Ap	0-7; 0-3 (7; 3)	cs	2f gr	--	so	po	sh	L	--	<5	10YR 5/3; 10YR 3/3
A	7-21; 3-8 (14; 5)	aw	3c pr to 2c abk	1fpo	ss	ps	vh	L	--	<10	10YR 5/3; 10YR 3/3
2E/B	21-32; 8-12 (11; 4)	cw	1m abk	1ppo	s	p	vh	gL	--	50	10YR 7/4; 10YR 4/3
2Bt	32-50; 12-20 (18; 8)	gs	2f-m abk	2ppo, cobr	so	vps	sh	gSL	--	75	10YR 5/3; 10YR 4/4
3Bt2	50-74; 20-29 (24; 9)	gs	1vf abk to sg	--	so	po	lo-sh	gLS	--	75	10YR 5/3; 10YR 4/4
3Bt3	74-94+; 29-37+ (20+; 8+)	--	1vf abk to sg	2ppo, br, cobr	so	po	lo-so	gLS	--	>75	10YR 4/4; 10YR 3/6

Notes for Table I-7:

The Ap horizon contains abundant fine roots and a couple of angular to subangular pebbles. Sand in this horizon is fine. The parent material is probably eolian sediment.

The A horizon contains common fine roots and a few coarse roots. It has been mixed by worm activity. This horizon may contain clay films, which do not have the distinct color difference that the clay films do in the lower horizons making them difficult to see. The gravel consists of well-rounded to subangular pebbles. Sand in this horizon is fine and medium.

The 2E/B horizon varies in thickness around the pit. It contains clay films as very patchy molds around clasts. The gravel is chiefly well-rounded to subrounded pebbles of mixed lithology. Cobbles are <5% of the gravel. Sand in this horizon is medium and coarse. White, discontinuous coats (silica?) are present on clasts.

The 2Bt horizon contains clay films that are especially visible around clasts. The gravel is chiefly pebbles with about 10% cobbles. Sand in this horizon is coarse. White, discontinuous coats (silica?) are present on the tops of clasts. Two charcoal samples were taken at 35 cm (14 in) depth (Charcoal Samples DRSO-4-1 and DRSO-4-2). Another charcoal sample was taken at a depth of 48 cm (19 in; Charcoal Sample DRSO-4-3PSv). A second sample of charcoal in this same lens was taken at 46 to 49 cm depth (18 to 19 in; Charcoal Samples DRSO-4-3aCO and DRSO-4-3aPS).

The 3Bt2 horizon contains iron staining on clasts and sand grains. The gravel is about 50% pebbles, 50% cobbles, and <5% boulders. About 50% of the clasts are weathered or very weathered. Basalts are weathered; these clasts and those of other rock types (mixed) are easily cracked and oxidized along the cracks. Sand in this horizon is coarse and very coarse. White, discontinuous coats (silica?) are present on the tops of clasts.

The 3Bt3 horizon contains iron staining of clasts and sand grains. Clay films are present around the bottoms of clasts. The gravel contains about 10% boulders. Sand in this horizon is coarse and very coarse. White, discontinuous stringers (silica?) are present on the tops of clasts.

Gravel shows no imbrication or bedding.

Abbreviations are explained in Table I-8.

Table I-8. Explanation of abbreviations used in the field descriptions of the soil properties

Horizon boundaries					
Distinctness		Topography			
a	abrupt	s	smooth		
c	clear	w	wavy		
g	gradual				
Structure					
Grade		Size		Type	
m	massive	vf	very fine	gr	granular
sg	single grained	f	fine	abk	angular blocky
1	weak	m	medium	sbk	subangular blocky
2	moderate	c	coarse	pr	prismatic
3	strong	vc	very coarse		
Clay films					
Amount		Distinctness		Location	
1	few	f	faint	po	lining tubular or interstitial pores
2	common	d	distinct	br	as bridges holding mineral grains together
		p	prominent	cobr	coats on mineral grains and bridges
Wet consistence				**Dry consistence**	
Stickiness		Plasticity		lo	loose
so	nonsticky	po	nonplastic	so	soft
vss	very slightly sticky	vps	very slighty plastic	sh	slightly hard
ss	slightly sticky	ps	slightly plastic	h	hard
s	sticky	p	plastic	vh	very hard
Texture					
Modifier		Class			
g	gravelly	L	loam	LS	loamy sand
		SiL	silt loam	S	sand
		SiCL	silty clay loam		
		SL	sandy loam		

For further explanation of the soil properties, see Birkeland and others (1991, their appendix, p. 55-63).

APPENDIX J.
RADIOCARBON SAMPLES AND THEIR AGES

Twenty-seven samples of material that could be submitted for radiocarbon analysis were collected at nine sites where soil profiles or stratigraphy or both were described (Localities DRsoil-1, DRsoil-2, DRsoil-3, DRsoil-4, DRsoil-5, DRsoil-6, DRsoil-7, DRstrat-1, and DRstrat-2, Table J-1, Figures 3A and 3B; Appendices I and Q). The samples consist primarily of charcoal, but eight samples of bulk sediment also were collected. The samples were submitted to Paleo Research Laboratories (Denver, Colorado) for cleaning, separation, and identification. The organic matter was separated using flotation and a series of sieves (Puseman and Ruggiero, 1998, p. 1; Puseman, 2000, p. 1, attached as Appendix K). Identification was done with a binocular microscope at magnifications up to 70x (Puseman and Ruggiero, 1998, p. 1; Puseman, 2000, p. 1). Each sample yielded several pieces of charcoal, wood, or floral remains (Puseman and Ruggiero, 1998, their table 2; Puseman, 2000, her table 2) from which twenty-seven were submitted for radiocarbon analysis.

The twenty-seven samples were sent to Beta Analytic, Inc. (Miami, Florida) , where the samples were pre-treated with a series of acid and alkali washes and then analyzed for ^{14}C content using either conventional technique and extended counting or AMS technique for small samples. Measured radiocarbon ages were converted by Beta Analytic, Inc. to conventional radiocarbon ages using an appropriate C^{13}/C^{12} ratio (Table J-2). These ages, by convention, are reported as radiocarbon years before present (^{14}C yr BP) with “present” designated as 1950 AD (Table J-2). The ages are reported with 1 standard deviation (68% probability) to statistically account for uncertainties in the laboratory measurements (Table J-2). Because the activity of ^{14}C in the atmosphere varies over time, the conventional radiocarbon ages were calibrated to calender years by Beta Analytic, Inc. using a computer program created by a laboratory in South Africa and modified by Beta Analytic, Inc. (the Pretoria/Beta Analytic Program; Talma and Vogel, 1993; Vogel and others, 1993). The computer program is based on a large data set of precisely analyzed rings of oak, sequoia, and fir of known age (Stuiver and others, 1993). These ages are reported in cal yr BP with a 2 sigma standard deviation (95% probability) (Stuiver and Polach, 1977; Table J-2).

Some of the twenty-seven samples of charcoal or bulk samples of sediment were taken and cleaned but were not submitted for radiocarbon analysis. Some of these were from depths of 20 in (50 cm) or less where charcoal and organic matter is constantly being added and reworked into the soil. Thus, the ages from these samples would be very minimum estimates and would not represent the age of the terrace surface or underlying alluvium. After charcoal was sampled from deeper in the profiles, the samples at shallower depths were less important to date.

In order for the radiocarbon dates to be comparable, dates on charcoal of the same species are best. We selected charcoal of Douglas fir (*Pseudotsug*a), if possible. However, Douglas fir was not always present or was only present in pieces too small for dating. In these cases, charcoal samples of other species for submited (Table J-2).

At one locality (DRsoil-1) samples of charcoal from two different species from the same soil horizon were submitted for radiocarbon analysis (Table J-2). This was done to determine, if possible, whether different ages would really result from the different species. For this soil profile, charcoal of *Pseudotsuga* (Douglas fir; Radiocarbon Sample DRSO-1-2PS) and *Tsuga* (Hemlock; Radiocarbon Sample DRSO-1-2TS) from a depth between 50 and 52 in (128 and 134 cm) were both submitted. The dates from the two different species overlap, although the date on the Sample DRSO-1-2TS of the *Tsuga* charcoal is slightly older (Table J-2).

In some cases the largest, best preserved charcoal was vitrified (Appendix K). Consequently, at another locality where nonvitrified and vitrified samples of the same species of charcoal were present in the same soil horizon both were submitted for radiocarbon analysis to determine, if possible, if vitrification influences the radiocarbon age. At locality DRsoil-4, two samples of *Pseudotsuga* (Douglas fir) charcoal (Radiocarbon Sample DRSO-4-3aPS and DRSO-4-3PSv) from a depth of about 19 in (48 cm) were submitted. The dates from the two samples overlap, although the vitrified sample (DRSO-4-3PSv) is slightly younger (Table J-2).

References

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Talma, A.S., and Vogel, J.C., 1993, A simplified approach to calibrating ^{14}C dates: Radiocarbon, v. 35, no. 1, p. 317-322.

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Table J-1. Locations sample sites

Locality (Sample Prefix)	Reach; River Mile	Location								Elevation (ft; m)	Aerial Photograph	Date Described and Sampled
		Description	USGS 1:24,000-scale quadrangle	From Topographic Map			Survey Coordinates					
				Town-ship	Range	Section	Latitude (N)	Longitude (W)	Error (± ft)			
DRsoil-1 (DRSO-1)	3 5.1	Vertical exposure in left (west) bank of active channel of Dungeness River on Severson's property; surface about 2.5 m (8 ft) above active channel	Carlsborg	T.30N.	R.4W.	NE1/4, SE1/4, 14	48°05'28.36"	123°09"04.69"	22	165; 50	Dungeness River 1998 #3-5	9/12/98
DRsoil-2 (DRSO-2)	3 5.5	Hand-dug pit on surface m (ft) west of and m (ft) above active channel of Dungeness River on Severson's property	Carlsborg	T.30N.	R.4W.	NE1/4, NE1/4, 23	48°05'10.74"	123°09"07.82"	26	198; 60	Dungeness River 1998 #3-5	9/13/98
DRsoil-3 (DRSO-3)	1 1.6	Backhoe trench on surface m (ft) east of and m (ft) above active channel of Dungeness River on Brown's property	Dungeness	T.31N.	R.4W.	NE1/4, SW1/4, 36	48°08'10.02"	123°08"20.27"	24	25; 8	Dungeness River 1998 #2-5	9/13/98
DRsoil-4 (DRSO-4)	4 9.5	Hand-dug pit on surface m (ft) west of and m (ft) above the active channel of the Dungeness River along Fish Hatchery Road	Carlsborg	T.29N.	R.4W.	NE1/4, NE1/4, 2	48°02'25.89"	123°09"09.96"	22	444; 135	Dungeness River 1998 #3-14	9/16/98
DRsoil-5 (DRSO-5)	1 0.7	Backhoe trench about 0.13 km (400 ft) east-southeast of Dungeness School; about m (ft) east of and m (ft) above the active channel of the Dungeness River	Dungeness	T.31N.	R.4W.	NE1/4, SE1/4, 36	48°08'31.52"	123°07"36.87"	17	19; 6	Dungeness River 2000 #2-10	7/12/00
DRsoil-6 (DRSO-6)	2 2.5	Backhoe pit on surface m (ft) east of and m (ft) above the active channel of the Dungeness River on Moore's property	Carlsborg	T.30N.	R.4W.	West-central, 1	48°07'22.31"	123°08"25.87"	22	35; 11	Dungeness River 2000 #2-5	7/14/00
DRsoil-7 (DRSO-7)	3 5.6	Vertical exposure in left (west) bank of active channel of Dungeness River about 90 m (300 ft) downstream of Railroad Bridge	Carlsborg	T.30N.	R.4W.	NE1/4, NE1/4, 23	48°05'10.59"	123°08"59.45"	24	200; 61	Dungeness River 2000 #3-4	7/16/00

Table J-1. Locations sample sites (Cont.)

Locality	Reach; River Mile	Location								Elevation (ft; m)	Aerial Photograph	Date Described and Sampled
		Description	USGS 1:24,000-scale quadrangle	From Topographic Map			Survey Coordinates					
				Town-ship	Range	Section	Latitude (N)	Longitude (W)	Error (± ft)			
DRstrat-1 (DRST-1)	1 0.8	Vertical exposure in left (west) bank of active channel of Dungeness River about m (ft) upstream of Schoolhouse Bridge; surface about 1 m (3 ft) above active channel	Dungeness	T.31N.	R.4W.	NW1/4, NE1/4, 36	48º08'37.65"	123º07"50.33"	22?	15; 5	Dungeness River 2000 #2-10	7/11/00
DRstrat-2 (DRST-2)	4.5	Vertical exposure in left (west) bank of overflow channel of Dungeness River on North Olympic Land Trust property; surface about m (ft) above active floodplain and about m (ft) above active channel	Carlsborg	T.30N.	R.4W.	NW1/4, NE1/4, 14	48º05'59.10"	123º09"19.88"	22?	135; 40	Dungeness River 2000 #3-6	7/15/00 7/17/00

Locations are shown on Figures 3A and 3B.

Table J-2. Ages for Dungeness River samples submitted to Beta Analytic, Inc. for radiocarbon analysis

Field sample number	Laboratory sample number	Type of material	C13/C12 ratio	Radiocarbon age (C^{14} yr. BP ± 1 s)	Calibrated age range (cal yr. BP ± 2 s)
DRSO-1-1PS	Beta-128652	*Pseudotsuga* (Douglas fir) charcoal	-24.3	2360 ± 40	2465 to 2330
DRSO-1-2PS	Beta-126544	*Pseudotsuga* (Douglas fir) charcoal	-25.0	2130 ± 50	2305 to 2240; 2180 to 1970
DRSO-1-2TS	Beta-128653	*Tsuga* (Hemlock) charcoal	-26.5	2280 ± 90	2690 to 2660; 2485 to 2065
DRSO-1-3PS	Beta-126545	*Pseudotsuga* (Douglas fir) charcoal	-25.0	2220 ± 40	2330 to 2125
DRSO-2-1PS	Beta-128654	*Pseudotsuga* (Douglas fir) charcoal	-25.1	180 ± 30	≤295
DRSO-2-2COv	Beta-128655	Conifer charcoal (vitrified)	-25.4	2410 ± 30	2700 to 2645; 2490 to 2350
DRSO-3-2PI	Beta-126546	*Pinaceae* (Pine family) charcoal	-25.0	590 ± 70	665 to 505
DRSO-3-3PI	Beta-126547	*Pinaceae* (Pine family) charcoal	-25.0	380 ± 60	525 to 295
DRSO-4-3PSv	Beta-126548	*Pseudotsuga* (Douglas fir) charcoal (vitrified)	-25.0	1940 ± 60	1995 to 1725
DRSO-4-3aPS	Beta-126549	*Pseudotsuga* (Douglas fir) charcoal	-25.0	2080 ± 70	2300 to 2250; 2165 to 1875
DRSO-5A-1BAPC	Beta-152787	Bark (Partially charred)	-25.8	?	?
DRSO-5B-1PS	Beta-157172	*Pseudotsuga* (Douglas fir) charcoal	-25.0	3740 ± 50	4240 to 3960
DRSO-5C-1PSv	Beta-153596	*Pseudotsuga* (Douglas fir) charcoal	-24.0	1780 ± 40	1820 to 1580
DRSO-6-1PS	Beta-153597	*Pseudotsuga* (Douglas fir) charcoal	-24.5	1160 ± 40	1170 to 970
DRSO-6-3PS	Beta-154925	*Pseudotsuga* (Douglas fir) charcoal	-25.0	680 ± 40	680 to 630; 600 to 560
DRSO-6-8TH	Beta-157173	*Thuja plicata* (Western Red-cedar) charcoal	-20.3	260 ± 40	≤430
DRSO-7-2PS	Beta-153599	*Pseudotsuga* (Douglas fir) charcoal	-23.4	1360 ± 40	1320 to 1240
DRSO-7-4BAc	Beta-154851	Bark charred	-23.8	510 ± 40	550 to 500
DRSO-7-6TH	Beta-157175	*Thuja plicata* (Western Red-cedar) charcoal	-26.2	330 ± 50	500 to 290

Table J-2. Ages for Dungeness River samples submitted to Beta Analytic, Inc. for radiocarbon analysis (Cont.)

Field sample number	Laboratory sample number	Type of material	C13/C12 ratio	Radiocarbon age (C^{14} yr. BP ± 1 s)	Calibrated age range (cal yr. BP ± 2 s)
DRST-1-0PSv	Beta-152784	*Pseudotsuga* (Douglas fir) charcoal (slightly vitrified)	-23.9	1610 ± 40	1570 to 1410
DRST-1-2TS	Beta-152785	*Tsuga* (Hemlock) charcoal	-27.1	1440 ± 50	1410 to 1280
DRST-1-4TS	Beta-152786	*Tsuga* (Hemlock) charcoal	-22.0	410 ± 40	520 to 430; 380 to 320
DRST-2-4PS	Beta-153598	*Pseudotsuga* (Douglas fir) charcoal	-22.4	3900 ± 40	4430 to 4230
DRST-2-5PS	Beta-154848	*Pseudotsuga* (Douglas fir) charcoal	-22.7	3910 ± 40	4430 to 4240
DRST-2-6COv	Beta-154849	Conifer charcoal (vitrified)	-28.9	3440 ± 40	3830 to 3600
DRST-2-7COBv	Beta-154850	Conifer bark charred (vitrified)	-24.7	1600 ± 40	1560 to 1400
DRST-2-8PS	Beta-157174	*Pseudotsuga* (Douglas fir) charcoal	-23.0	2190 ± 40	2330 to 2100

See the data sheets for the original data from Beta Analytic, Inc. (attached)

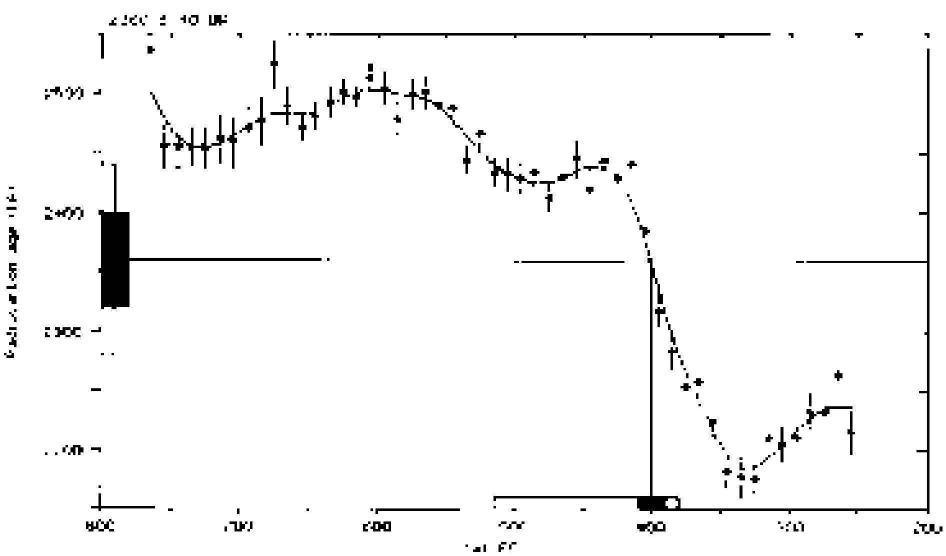
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12 = -24.3 lab mult. = 1) DRSO - I-1PS

Laboratory Number	Beta-128652
Conventional radiocarbon age:	**2360 ± 40 BP**
Calibrated results: (2 sigma, 95% probability)	**cal BC 515 to 380 (Cal BP 2465 to 2330)**

Intercept data:

Intercept of radiocarbon age with calibration curve:	cal BC 400 (Cal BP 2350)
1 sigma calibrated results: (68% probability)	cal BC 410 to 390 (Cal BP 2360 to 2340)



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Editorial Comment

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INTCAL98 Radiocarbon Age Calibration

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Mathematics

A Simplified Approach to Calibrating C14 Dates

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[illegible]

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: estimated C13/C12 = -25 : lab mult = 1)

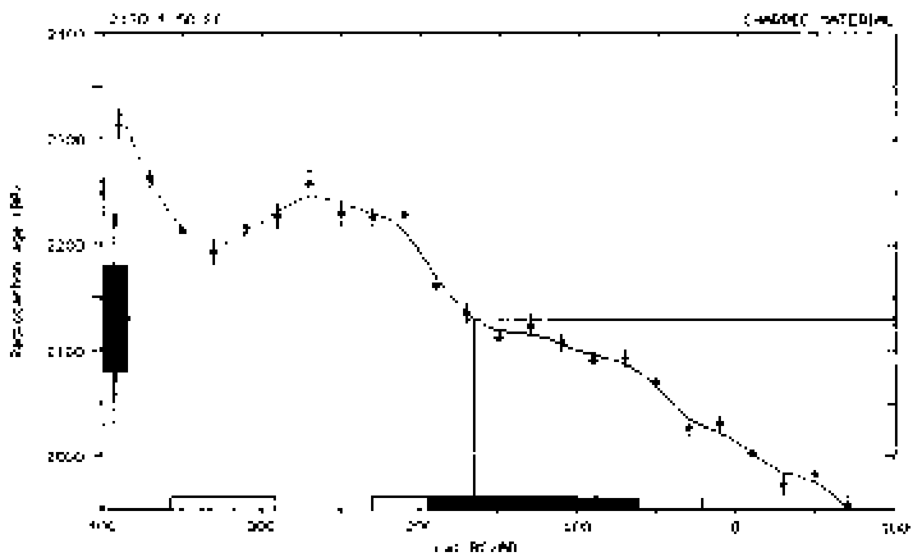
DR50-1-2.PS

Laboratory Number:	Beta-126544
Conventional radiocarbon age*:	**2130 ± 50 BP**
Calibrated results: **(2 sigma, 95% probability)**	**cal BC 355 to 290 and** **cal BC 230 to 20**

* C13/C12 ratio estimated

Intercept data:

Intercept of radiocarbon age with calibration curve:	cal BC 165
1 sigma calibrated results: (68% probability)	cal BC 195 to 60



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Calibration - 1998

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Calibration of Radiocarbon Dates for the Late Pleistocene Using U/Th Dates on Stalagmites

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26.5:lab mult=1)

DRSO - 6-275

Laboratory Number: Beta-128653

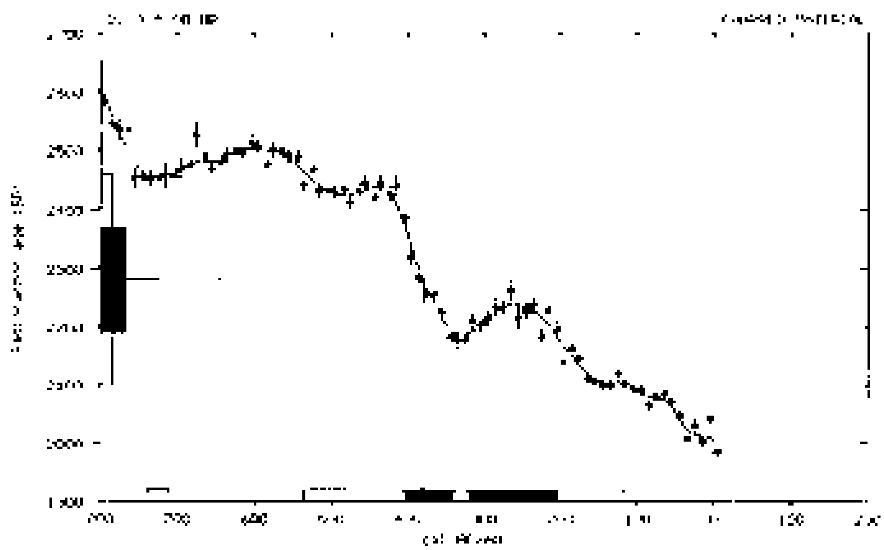
Conventional radiocarbon age: **2280 ± 90 BP**

Calibrated results: **(2 sigma, 95% probability)** **cal BC 740 to 710 (Cal BP 2690 to 2660) and cal BC 535 to 115 (Cal BP 2485 to 2065)**

Intercept data

Intercept of radiocarbon age with calibration curve: cal BC 380 (Cal BP 2330)

1 sigma calibrated results (68% probability): cal BC 405 to 340 (Cal BP 2355 to 2290) and cal BC 320 to 205 (Cal BP 2270 to 2155)



References:

Calibration Database

Editorial Comment

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: estimated C13/C12=-25:lab mult=1) DR02-V-5P5

Laboratory Number: Beta-126545

Conventional radiocarbon age*: **2220 ± 40 BP**

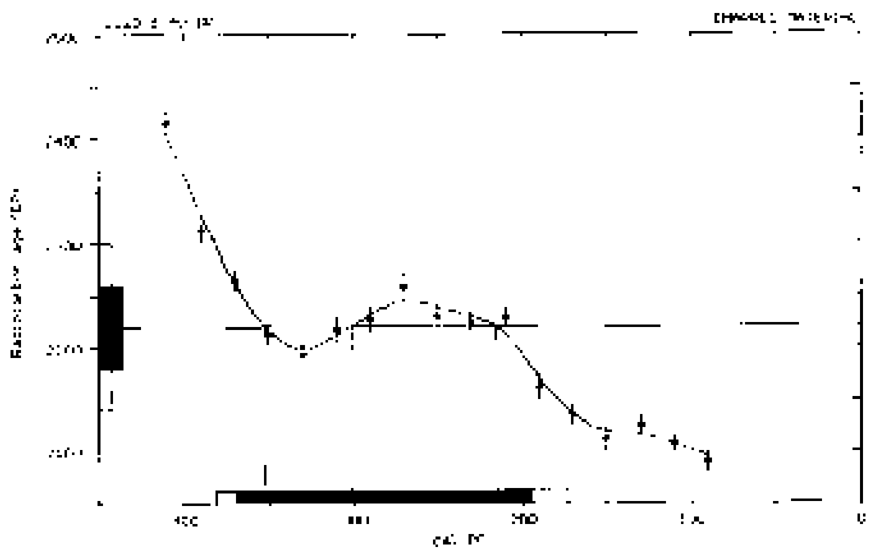
Calibrated results: cal BC 380 to 175
(2 sigma, 95% probability)

* C13/C12 ratio estimated

Intercept data

Intercepts of radiocarbon age with calibration curve: cal BC 350 and cal BC 300 and cal BC 215

1 sigma calibrated results: cal BC 370 to 195
(68% probability)



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J.10

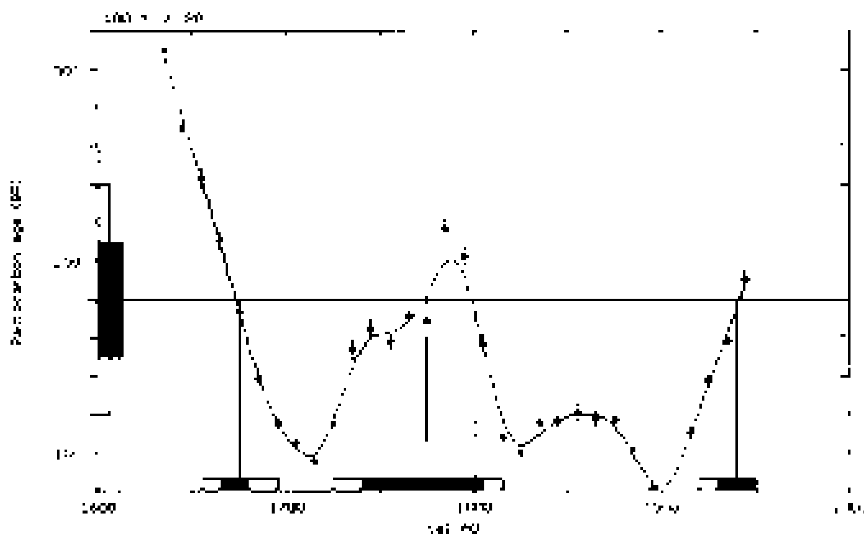
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:C13/C12=-25:lab mult=1)

Laboratory Number:	Beta-128654 DR50 - 2-185
Conventional radiocarbon age:	**190 ± 30 BP**
Calibrated results: (2 sigma, 95% probability)	**cal AD 1655 to 1695 (Cal BP 295 to 255) and cal AD 1725 to 1815 (Cal BP 225 to 135) and cal AD 1920 to 1950 (Cal BP 30 to 0)**

Intercept data

Intercepts of radiocarbon age with calibration curve:	cal AD 1675 (Cal BP 275) and cal AD 1775 (Cal BP 175) and cal AD 1800 (Cal BP 150) and cal AD 1940 (Cal BP 10)
1 sigma calibrated results: (68% probability)	cal AD 1665 to 1680 (Cal BP 285 to 270) and cal AD 1740 to 1805 (Cal BP 210 to 145) and cal AD 1930 to 1950 (Cal BP 20 to 0)



References:
Calibration Database
Editorial Comment
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INTCAL98 Radiocarbon Age Calibration
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Mathematics
A Simplified Approach to Calibrating C14 Dates
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J.11

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25.4:lab mult.=1)

Laboratory Number: Beta-128655

DESO-2-2CAV

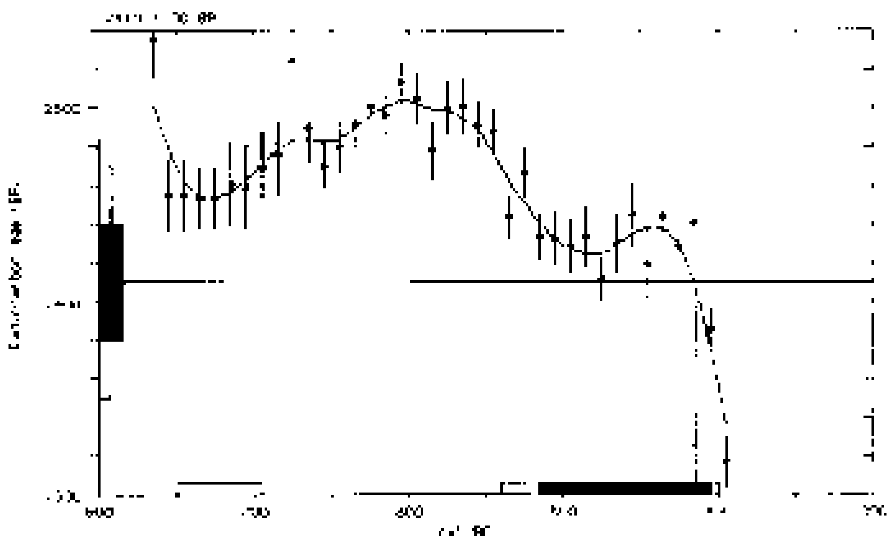
Conventional radiocarbon age: **2410 ± 30 BP**

Calibrated results: **cal BC 750 to 695 (Cal BP 2700 to 2645) and**
(2 sigma, 95% probability) **cal BC 540 to 400 (Cal BP 2490 to 2350)**

Intercept data:

Intercept of radiocarbon age with calibration curve: cal BC 415 (Cal BP 2365)

1 sigma calibrated results (68% probability): cal BC 515 to 405 (Cal BP 2465 to 2355)



References:

Calibration Database

Editorial Comment

INTCAL98 Radiocarbon Age Calibration

Mathematics

A Simplified Approach to Calibrating C14 Dates

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J.12

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

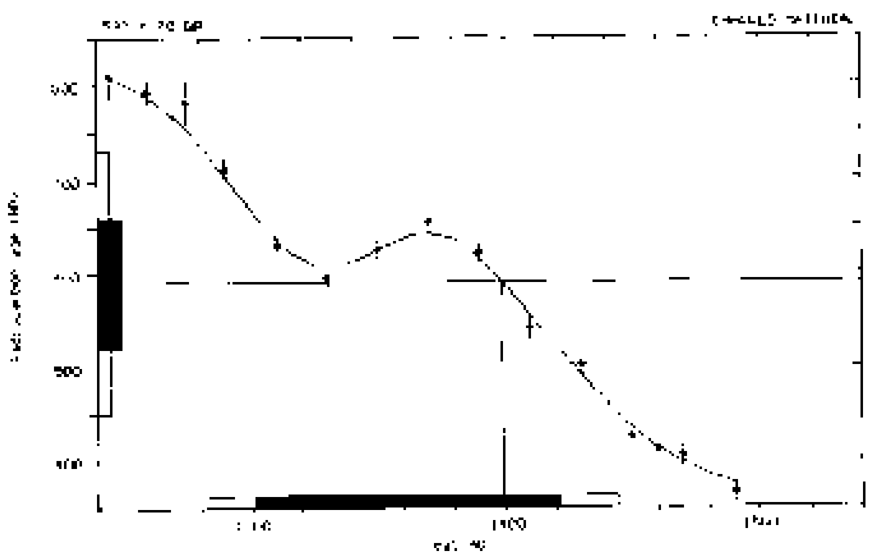
DRGO-3 2.PI

(Variables: estimated C13/C12=-25:lab mult.=1)

Laboratory Number:	Beta-126546
Conventional radiocarbon age*:	**590 ± 70 BP**
Calibrated results: (2 sigma, 95% probability)	**cal AD 1285 to 1445**

Intercept data

Intercept of radiocarbon age with calibration curve:	cal AD 1400
1 sigma calibrated results: (68% probability)	cal AD 1300 to 1430



References:
A Simplified Approach to Calibrating C14 Dates
Calibration - 1998

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J.13

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:estimated C13/C12=-25:lab mult.=1) DR5c 3 80T

Laboratory Number: Beta-126547

Conventional radiocarbon age*: 380 ± 60 BP

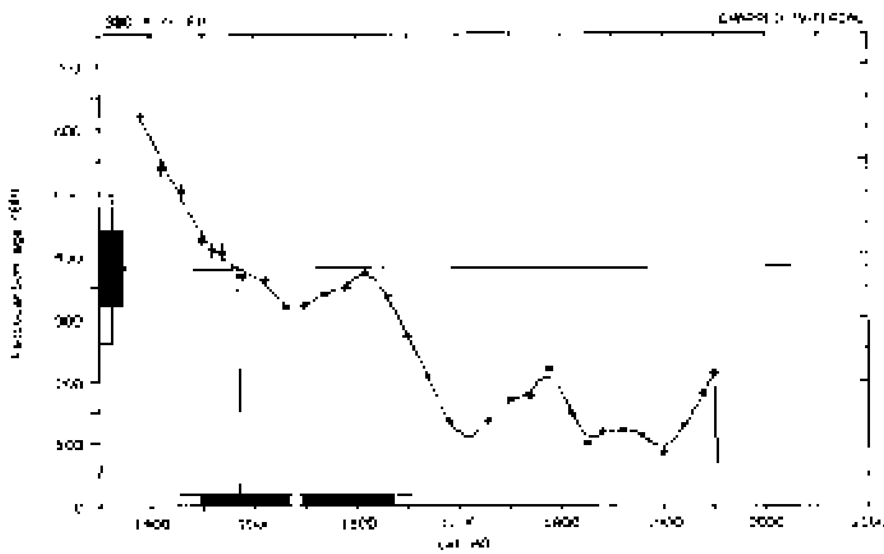
Calibrated results: cal AD 1425 to 1655
(2 sigma, 95% probability)

* C13/C12 estimated

Intercept data:

Intercept of radiocarbon age with calibration curve: cal AD 1485

1 sigma calibrated results: (68% probability) cal AD 1450 to 1535 and cal AD 1545 to 1635



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Calibration - 1993
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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

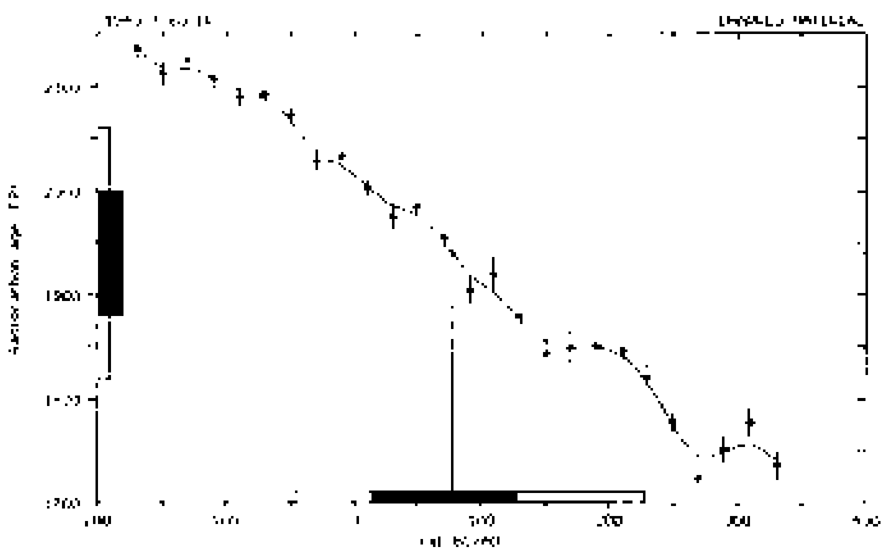
(Variables: estimated C13/C12 = -25; lab mult = 1) DRSC-4-3P5V

Laboratory Number:	Beta-126548
Conventional radiocarbon age*:	**1940 ± 60 BP**
Calibrated results: (2 sigma, 95% probability)	**cal BC 45 to cal AD 225**

* C13/C12 was estimated

Intercept data:

Intercept of radiocarbon age with calibration curve	cal AD 75
1 sigma calibrated results (68% probability)	cal AD 15 to 130



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Calibration - 1998

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Calibration of Radiocarbon Dates for the Last Thousand Years Using U-Th Dates on Stalagmites

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J 15

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

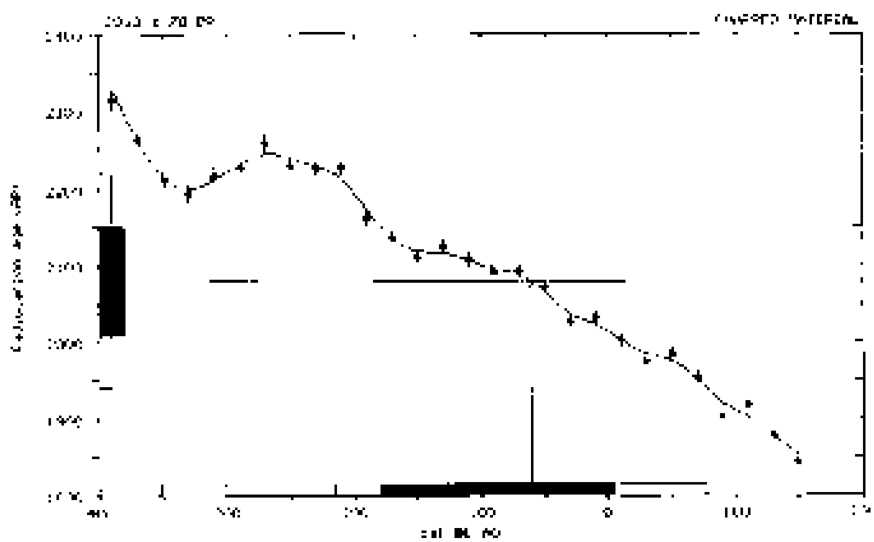
(Variables:estimated C13/C12=-25:lab mult=1) [illegible]

Laboratory Number:	Beta-126549
Conventional radiocarbon age*:	**2080 ± 70 BP**
Calibrated results: (2 sigma, 95% probability)	**cal BC 350 to 300 and cal BC 215 to cal AD 75**

* C13/C12 ratio estimated

Intercept data

Intercept of radiocarbon age with calibration curve:	cal BC 60
1 sigma calibrated results: (68% probability)	cal BC 180 to cal AD 5



References:

Pretoria Calibration Curve for Short Lived Samples

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DRSO-SB-1PS

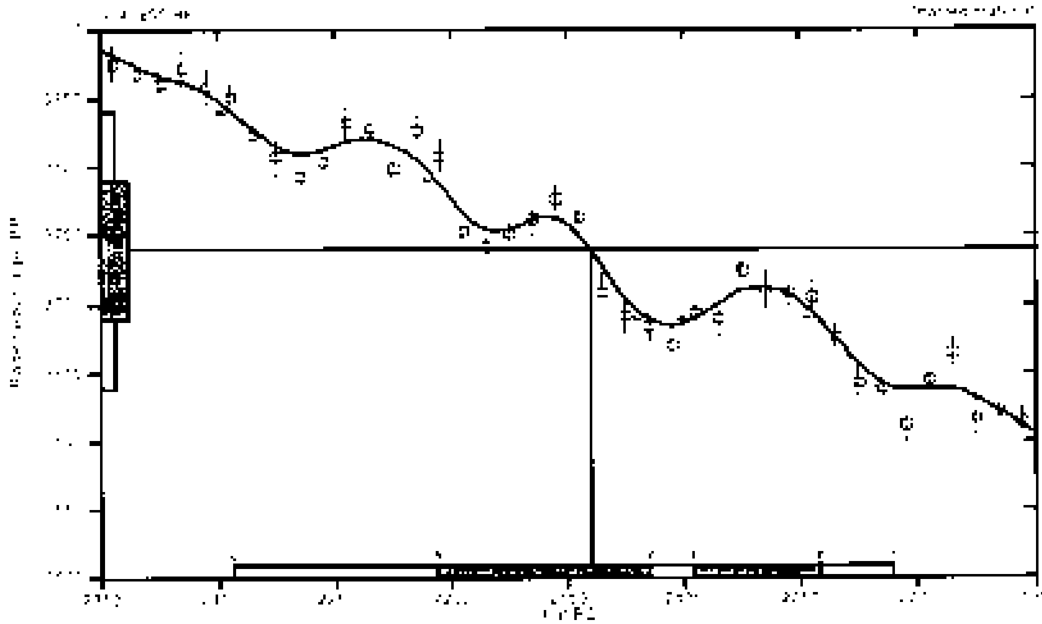
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

Laboratory number: Beta-157172

Conventional radiocarbon age: 3740±50 BP

2 Sigma calibrated result: (95% probability) Cal BC 2290 to 2010 (Cal BP 4240 to 3960)

Intercept data



Beta Analytic Inc.

DRSC-SC-1PSV

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

[illegible]

Laboratory number: Beta-153596

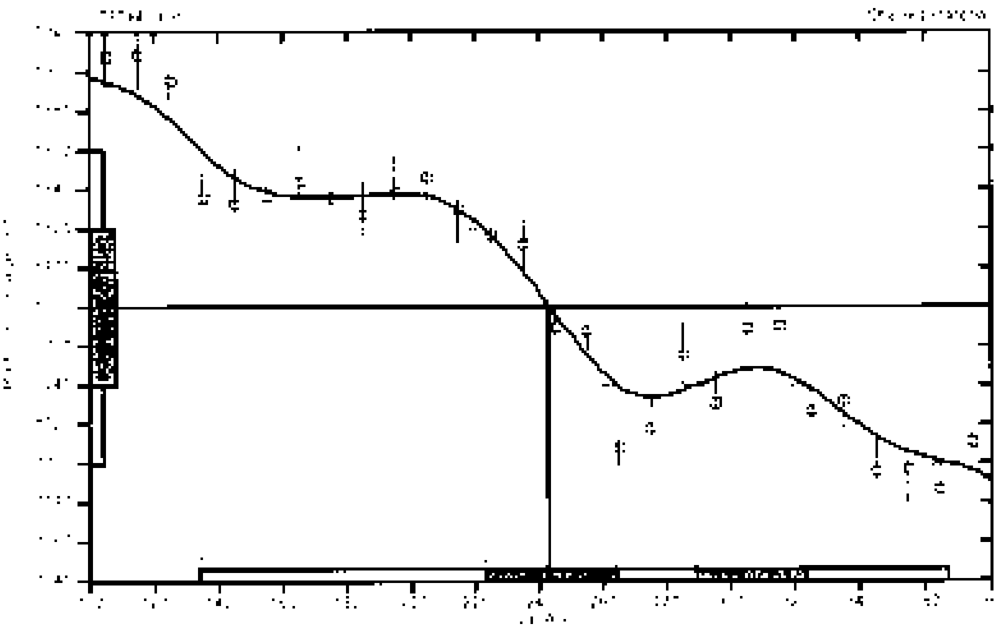
Conventional radiocarbon age: 1780±40 BP

2 Sigma calibrated result: Cal AD 130 to 370 (Cal BP 1820 to 1580)
(95% probability)

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal AD 240 (Cal BP 1710)

1 Sigma calibrated results: Cal AD 220 to 260 (Cal BP 1730 to 1690) and
(68% probability) Cal AD 290 to 320 (Cal BP 1660 to 1630)



References:
Database used
Calibration Database
Editorial Comment
INTCAL98 Radiocarbon Age Calibration
Mathematics
A Simplified Approach to Calibrating C14 Dates

Beta Analytic Inc.

DRSO-6-IPS

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24 [illegible])

Laboratory number: Beta-155597

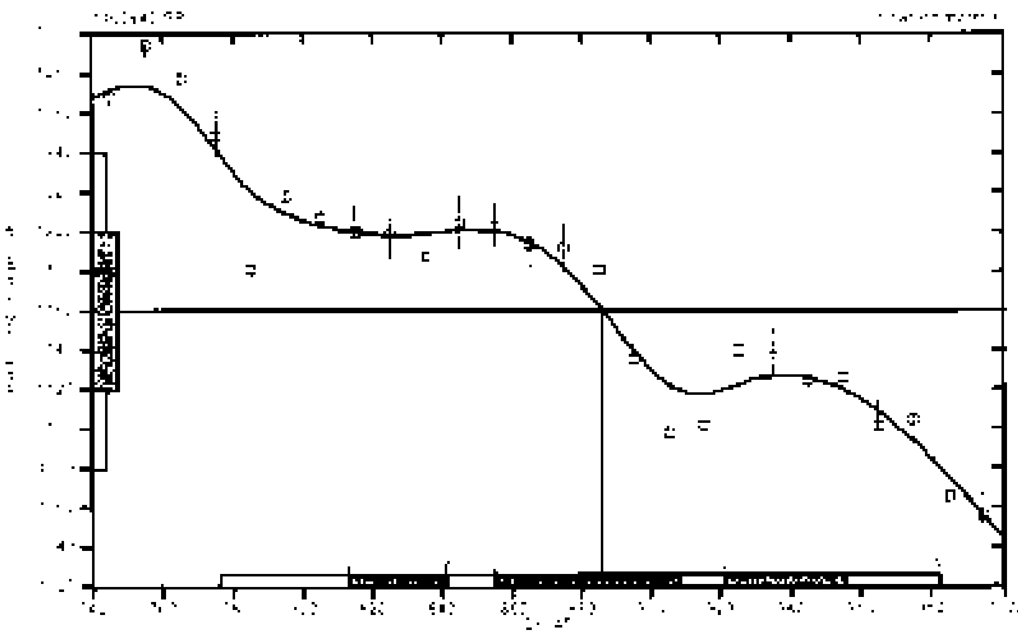
Conventional radiocarbon age: 1160±40 BP

2 Sigma calibrated result: Cal AD 780 to 980 (Cal BP 1170 to 970)
(95% probability)

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal AD 890 (Cal BP 1060)

1 Sigma calibrated results: Cal AD 810 to 840 (Cal BP 1140 to 1110) and
(68% probability) Cal AD 860 to 910 (Cal BP 1090 to 1040) and
Cal AD 920 to 960 (Cal BP 10[illegible] to [illegible])



References:

[illegible]

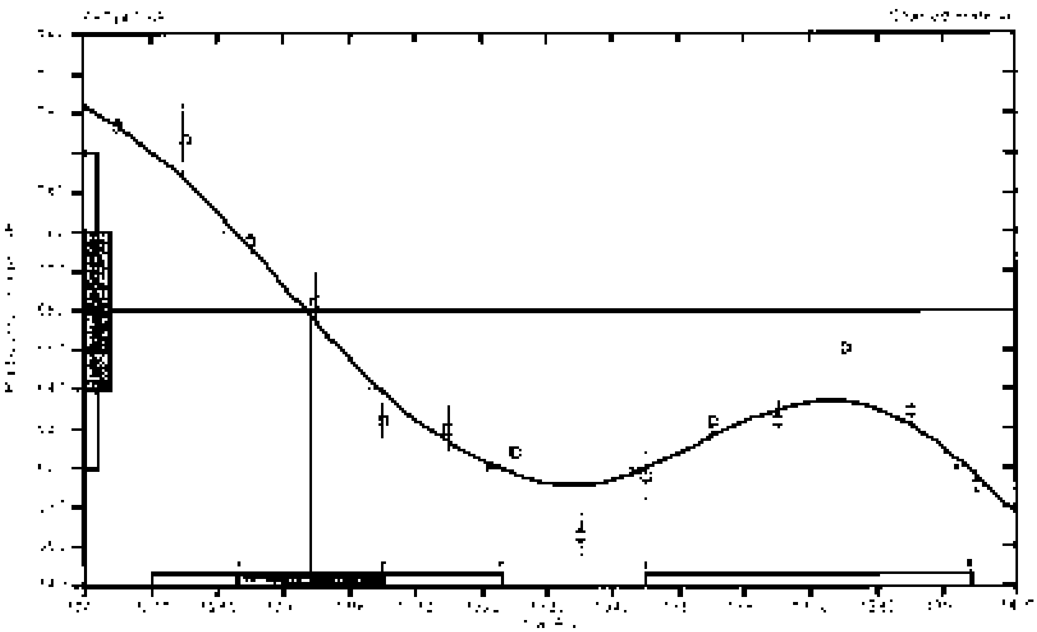
Beta Analytic Inc.

J.19

DR50-6-3PS

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

Laboratory number:	154925
Conventional radiocarbon age:	680±40 BP
2 Sigma calibrated results: (95% probability)	Cal AD 1270 to 1320 (Cal BP 680 to 630) and Cal AD 1340 to 1390 (Cal BP 600 to 560)



References

Beta Analytic Inc.

J.20

DRSC-6-8TH

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

[illegible]

Laboratory number: Beta-157173

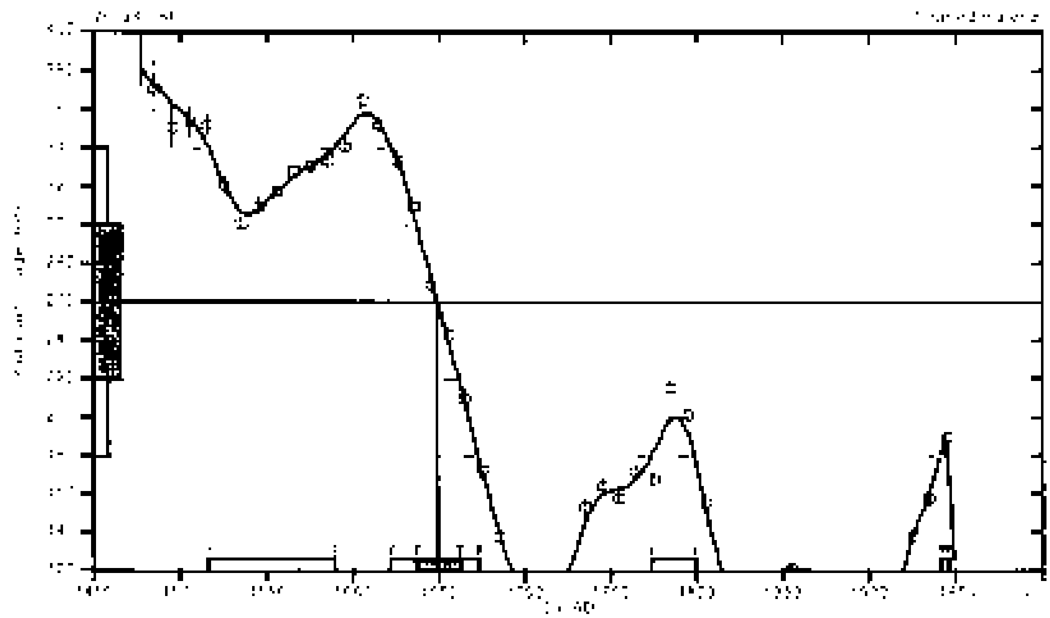
Conventional radiocarbon age: 260 ± 40 BP

2 Sigma calibrated results: Cal AD 1520 to 1590 (Cal BP 430 to 360) and
(95% probability) Cal AD 1620 to 1670 (Cal BP 330 to 280) and
Cal AD 1770 to 1800 (Cal BP 180 to 150) and
Cal AD 1940 to 1950 (Cal BP 10 to 0)

Intercept data

Intercept of radiocarbon age with calibration curve: Cal AD 1650 (Cal BP 300)

1 Sigma calibrated result (68% probability): Cal AD 1640 to 1660 (Cal BP [illegible])



References:

[illegible]

Beta Analytic Inc.

[illegible]

J.21

DRSc-7-2PS

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

Laboratory number: Beta-153599

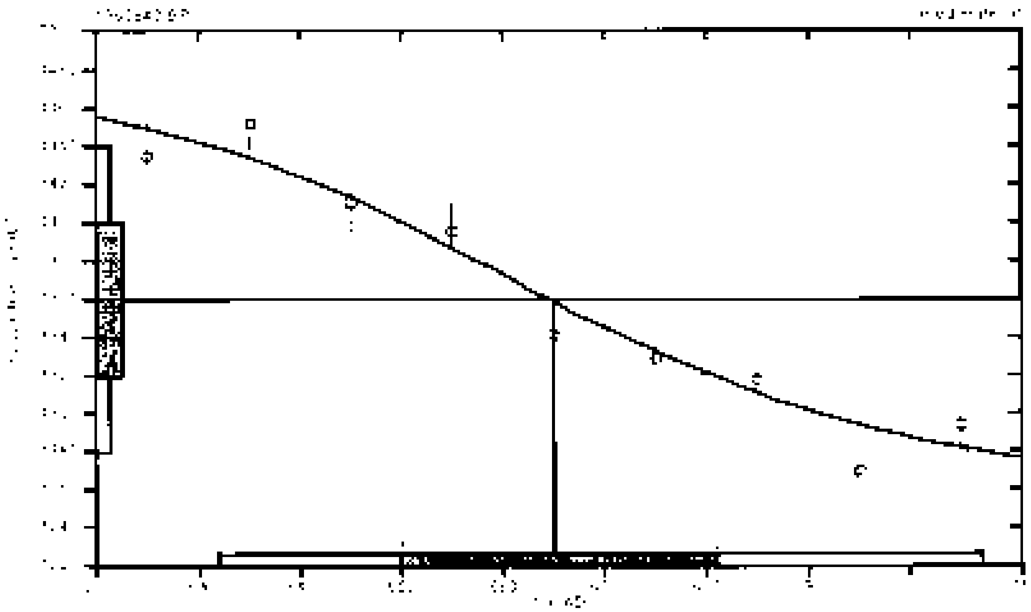
Conventional radiocarbon age: 1360±40 BP

2 Sigma calibrated result: Cal AD 630 to 710 (Cal BP 1320 to 1240)
(95% probability)

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal AD 660 (Cal BP 1290)

1 Sigma calibrated result: Cal AD 650 to 680 (Cal BP 1300 to 1270)
(68% probability)



References:

Beta Analytic Inc.

J.22

DRSC-7-4BAC-

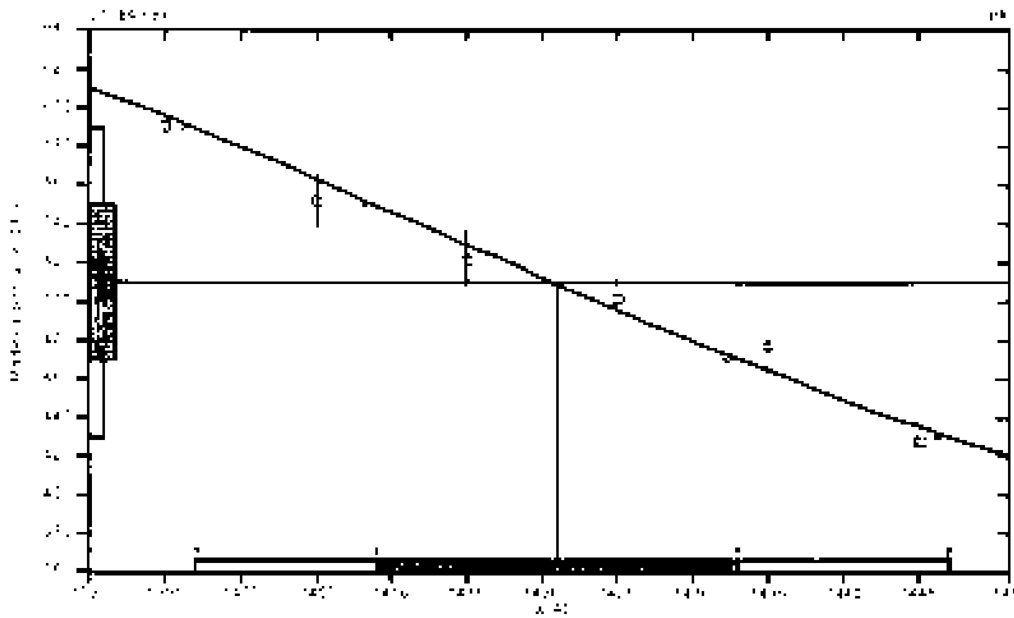
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

Laboratory number: 154851

Conventional radiocarbon age: 510±40 BP

2 Sigma calibrated result: Cal AD 1400 to 1450 (Cal BP 550 to 500)
(95% probability)

Intercept data



References:

Beta Analytic Inc.

J.23

TDRSO-7-6TH

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

[illegible]

Laboratory number: Beta-157175

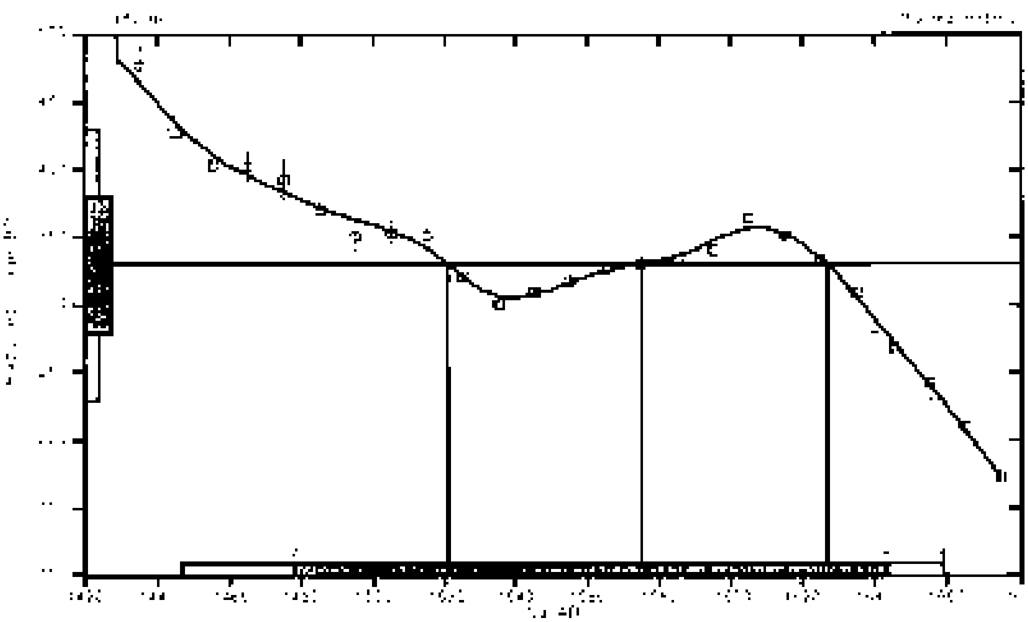
Conventional radiocarbon age: 330±50 BP

2 Sigma calibrated result: (95% probability) Cal AD 1450 to 1660 (Cal BP 500 to 290)

Intercept data

Intercepts of radiocarbon age with calibration curve: Cal AD 1520 (Cal BP 430) and Cal AD 1580 (Cal BP 380) and Cal AD 1630 (Cal BP 320)

1 Sigma calibrated result: (68% probability) Cal AD 1480 to 1640 (Cal BP 470 to 310)



References:
Database used
Calibration Database
Editorial Comment
INTCAL98 Radiocarbon Age Calibration
Mathematics
A Simplified Approach to Calibrating C14 Dates

Beta Analytic Inc.

[illegible]

J.24

DRST-1-C PSv

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-23.9:lab. mult=1)

Laboratory number: Beta-152784

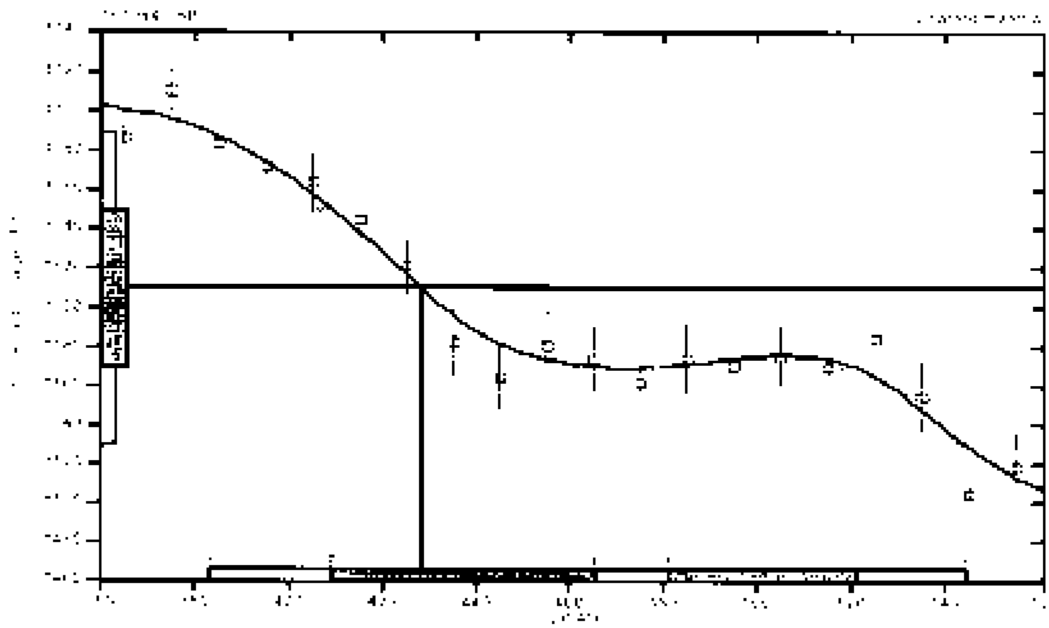
Conventional radiocarbon age: 1610±40 BP

2 Sigma calibrated result: Cal AD 380 to 540 (Cal BP 1570 to 1410)
(95% probability)

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal AD 450 (Cal BP 1500)

1 Sigma calibrated results: Cal AD 410 to 460 (Cal BP 1540 to 1490) and
(68% probability) Cal AD 480 to 520 (Cal BP 1470 to 1430)



References:
Database used
Calibration Database
Editorial Comment
INTCAL98 Radiocarbon Age Calibration
Mathematics
A Simplified Approach to Calibrating C14 Dates

Beta Analytic Inc.

J.25

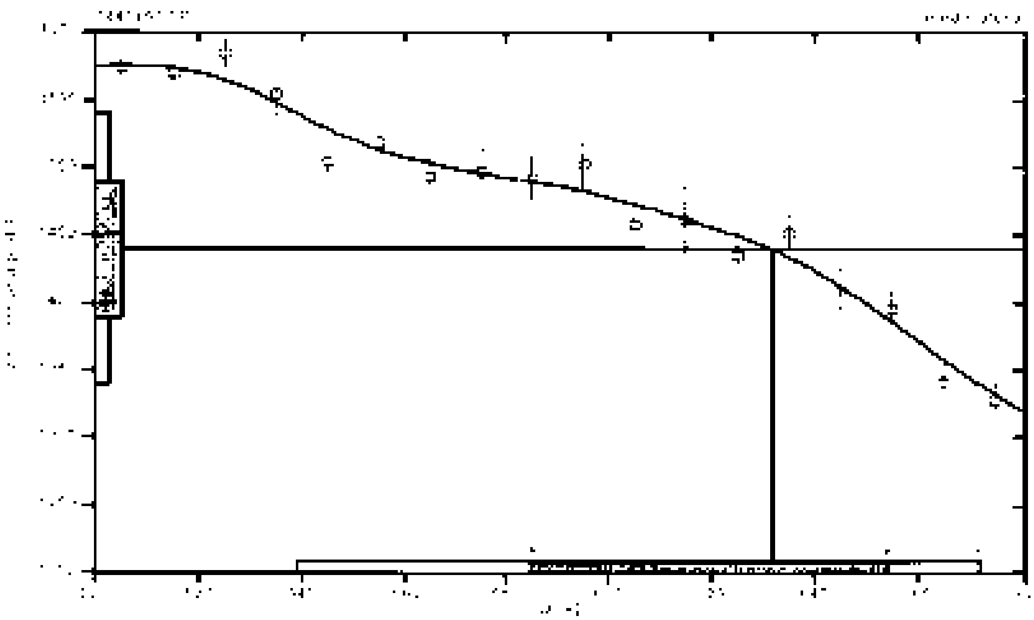
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12 = [illegible])

Laboratory number:	Beta-152785
Conventional radiocarbon age:	1440±50 BP
2 Sigma calibrated result: (95% probability)	Cal AD 540 to 670 (Cal BP 1410 to 1280)

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD [illegible] (Cal BP [illegible])
1 Sigma calibrated result: (68% probability)	Cal AD [illegible]



References:

[illegible]

Beta Analytic Inc.

[illegible]

J.26

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25:lab mult=1)

Laboratory number: Beta-152786

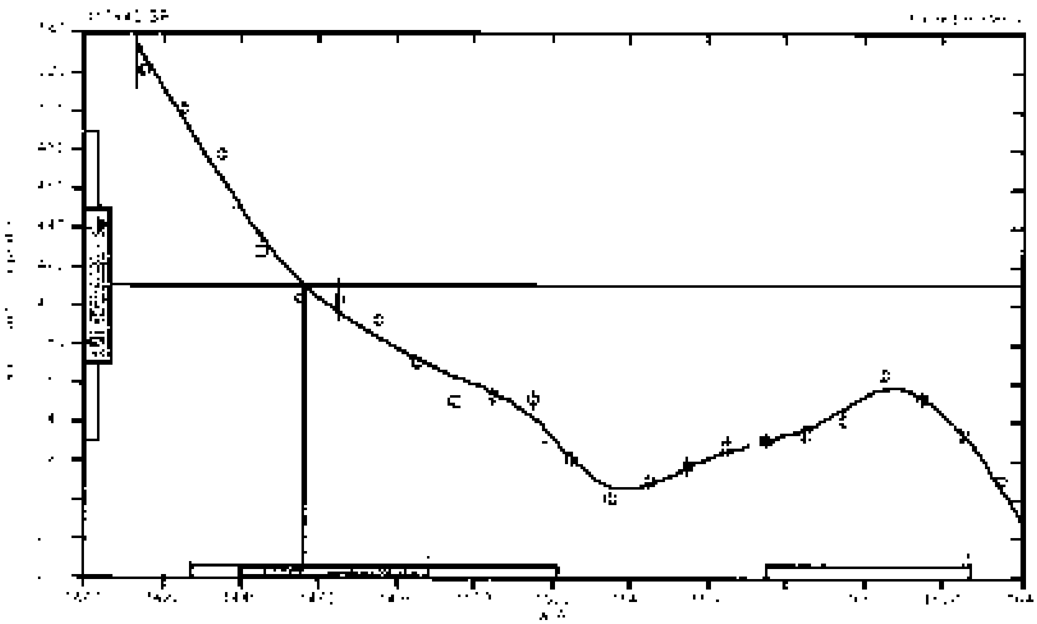
Conventional radiocarbon age: 410±40 BP

2 Sigma calibrated results: Cal AD 1430 to 1520 (Cal BP 520 to 430) and
(95% probability) Cal AD 1580 to 1630 (Cal BP 380 to 320)

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal AD 1460 (Cal BP 490)

1 Sigma calibrated result: Cal AD 1440 to 1490 (Cal BP 510 to 460)
(68% probability)



References:

Database used

Calibration Database

[illegible]

INTCAL98 Radiocarbon Age Calibration

[illegible]

Mathematics

A Simplified Approach to Calibrating C14 Dates

[illegible]

Beta Analytic Inc.

[illegible]

J27

DRST-2-4PS

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-22.4:lab. mult=1)

Laboratory number: Beta-153598

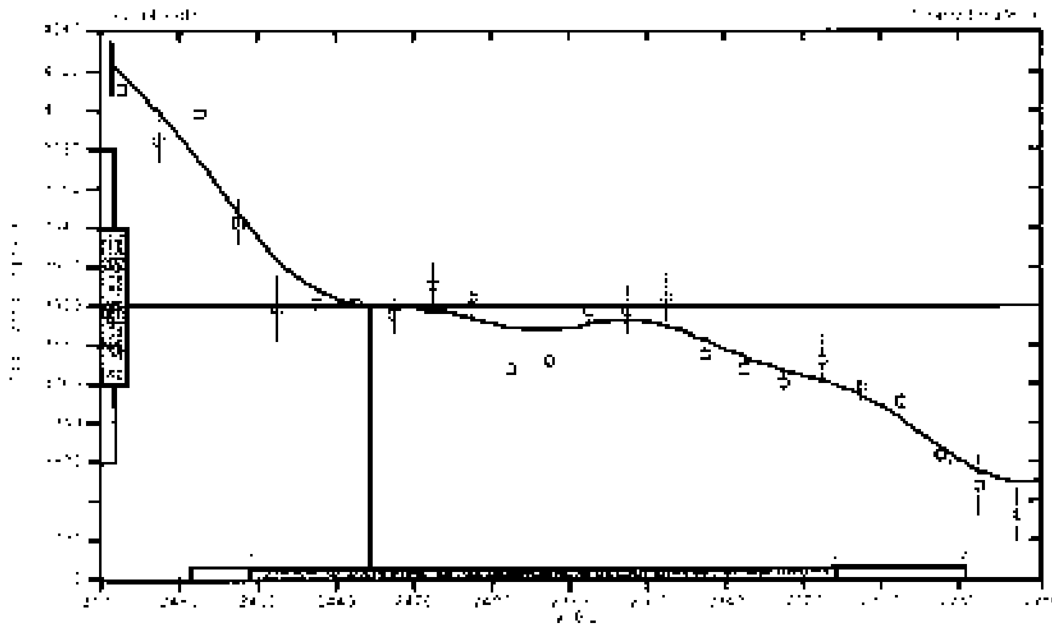
Conventional radiocarbon age: 3900±40 BP

2 Sigma calibrated result: Cal BC 2480 to 2280 (Cal BP 4430 to 4230)
(95% probability)

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal BC 2430 (Cal BP 4380)

1 Sigma calibrated result: Cal BC 2460 to 2310 (Cal BP 4410 to 4260)
(68% probability)



References:
Database used

Calibration Database
Editorial Comment

INTCAL98 Radiocarbon Age Calibration

Mathematics
A Simplified Approach to Calibrating C14 Dates

Beta Analytic Inc.

J.28

DRST-2-SP5

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-22 [illegible])

Laboratory number: 154848

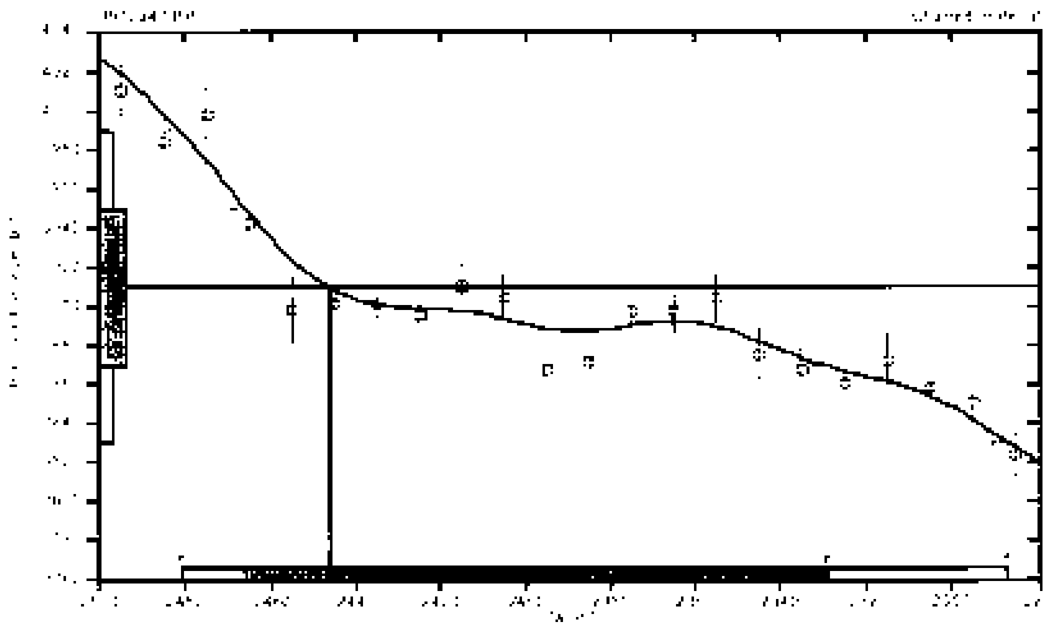
Conventional radiocarbon age: 3910±40 BP

2 Sigma calibrated result: Cal BC 2480 to 2290 (Cal BP 4430 to 4240)
(95% probability)

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal BC 2450 (Cal BP 4400)

1 Sigma calibrated result: Cal BC 2470 to 2330 (Cal BP 4420 to 4280)
(68% probability)



References:

[illegible]

Beta Analytic Inc.

J.29

DRST-2-60v

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-28.9: lab. mult=1)

Laboratory number: 154549

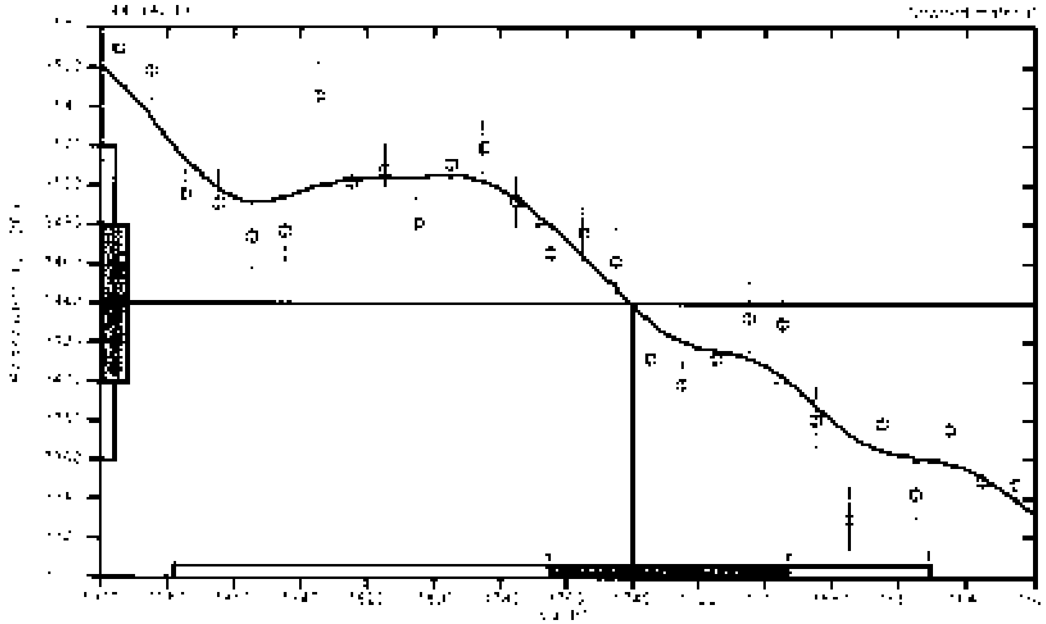
Conventional radiocarbon age: 3440±40 BP

2 Sigma calibrated result: (95% probability) Cal BC 1880 to 1650 (Cal BP 3830 to 3600)

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 1740 (Cal BP 3690)

1 Sigma calibrated result: (68% probability) Cal BC 1790 to 1690 (Cal BP 3720 to 3640)



References:

Beta Analytic Inc.

J.30

DRST-2-7-CCBV

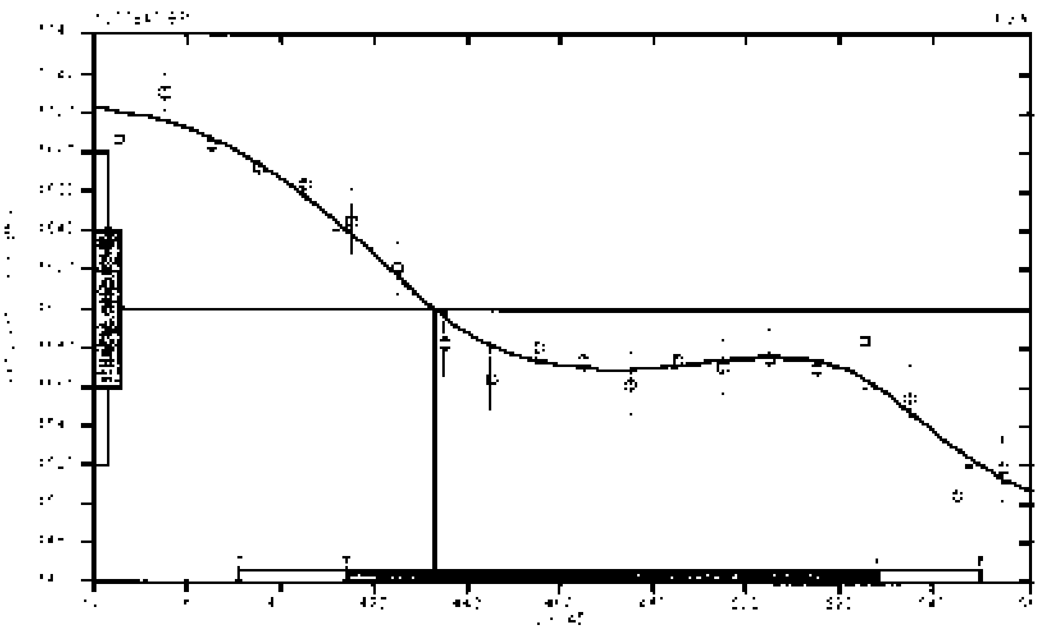
CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12 = -23.7 lab. mult = 1)

Laboratory number:	154850
Conventional radiocarbon age:	1600±40 BP
2 Sigma calibrated result: (95% probability)	Cal AD 390 to 550 (Cal BP 1560 to 1400)

Intercept data

Intercept of radiocarbon age with calibration curve:	Cal AD 430 (Cal BP 1520)
1 Sigma calibrated results: (68% probability)	Cal AD 420 to 530 (Cal BP 1540 to 1420)



References:
Database used
Calibration Database
Editorial Comment
INTCAL98 Radiocarbon Age Calibration
Mathematics
A Simplified Approach to Calibrating C14 Dates

Beta Analytic Inc.

JB

DRST-2-8PS

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-23.6:lab. mult=1)

Laboratory number: Beta-157174

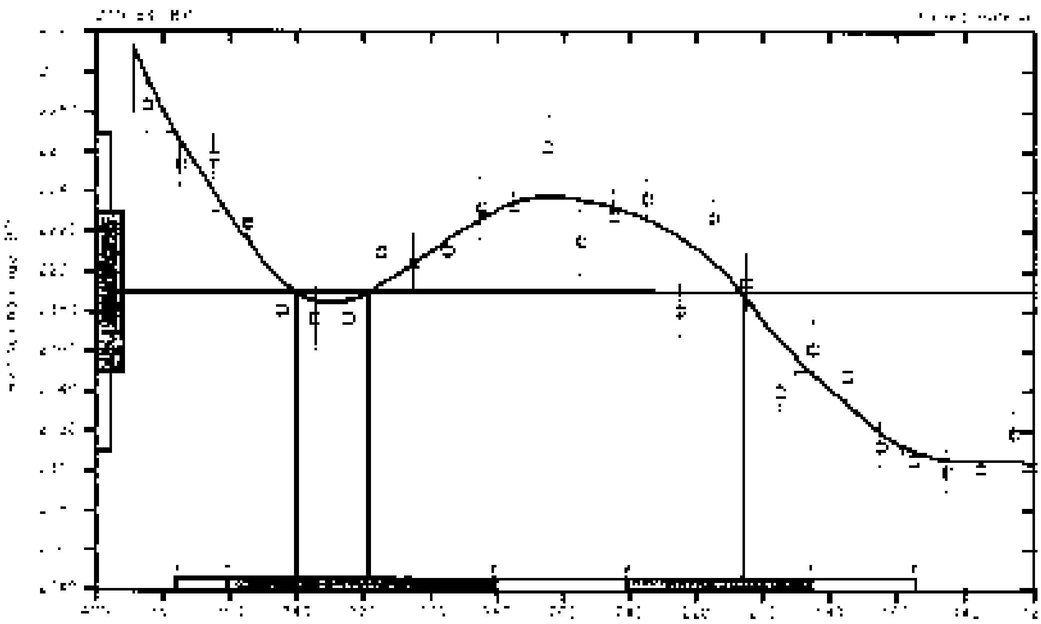
Conventional radiocarbon age: 2190±40 BP

2 Sigma calibrated result: Cal BC 380 to 160 (Cal BP 2330 to 2100)
(95% probability)

Intercept data

Intercepts of radiocarbon age
with calibration curve: Cal BC 340 (Cal BP 2290) and
Cal BC 320 (Cal BP 2270) and
Cal BC 210 (Cal BP 2160)

1 Sigma calibrated results: Cal BC 360 to 280 (Cal BP 2310 to 2230) and
(68% probability) Cal BC 240 to 190 (Cal BP 2190 to 2140)



References:
Database used
Calibration Database
Editorial Comment
INTCAL98 Radiocarbon Age Calibration
Mathematics
A Simplified Approach to Calibrating C14 Dates

Beta Analytic Inc.

J.32

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

Variables used in the calculation of age calibration → (Variables: est. C13/C12=-25:lab. mult=1)

Laboratory number: **Beta-123456**

Conventional radiocarbon age[1]**:** **2400±60 BP** ← The uncalibrated Conventional Radiocarbon Age (± 1 sigma)

The calendar age range in both calendar years (AD or BC) and in Radiocarbon Years (BP) → **2 Sigma calibrated result: (95% probability)** **Cal BC 770 to 380 (Cal BP 2720 to 2330)**

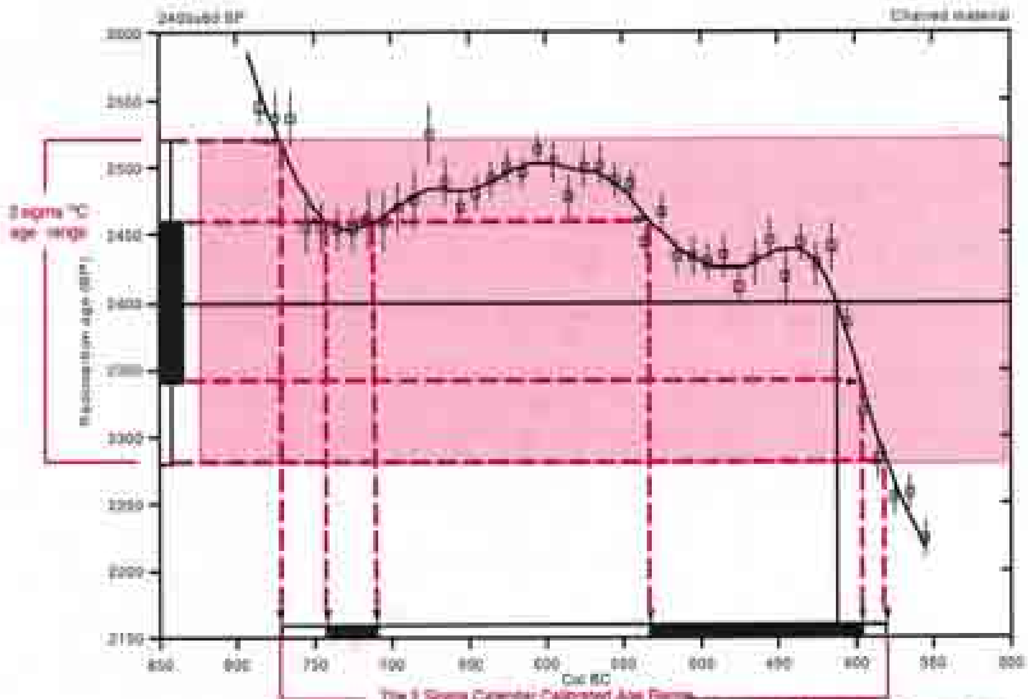
[1] C13/C12 ratio estimated

Intercept data

The intercept between the average radiocarbon age and the calibrated curve time scale. This value is illustrative and should not be used by itself.

Intercept of radiocarbon age with calibration curve: Cal BC 410 (Cal BP 2360)

1 Sigma calibrated result: (68% probability) Cal BC 740 to 710 (Cal BP 2690 to 2660) and Cal BC 535 to 395 (Cal BP 2485 to 2345)



This range is determined by the portion of the curve that is in a "box" drawn from the 2 sigma limits on the radiocarbon age. If a section of the curve goes outside of the "box", multiple ranges will occur as shown by the two 1 sigma ranges which occur from sections going outside of a similar "box" which would be drawn at the 1 sigma limits.

References:

Database used
Intcal 98
Calibration Database
Editorial Comment
Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii
INTCAL98 Radiocarbon Age Calibration
Stuiver, M., et al., 1998, Radiocarbon 40(3), p1041-1083
Mathematics
A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

References for the calibration data and the mathematics applied to the data. These references, as well as the Conventional Radiocarbon Age and the 13C/12C ratio used should be included in your papers.

Beta Analytic Radiocarbon Dating Laboratory

J.33

EXAMINATION OF DETRITAL CHARCOAL AND BULK SOIL FOR THE DUNGENESS RIVER GEOMORPHIC STUDY, WASHINGTON

By

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Paleo Research Labs Technical Report 98-97

Prepared For

U.S. Bureau of Reclamation
Denver Federal Center
Denver, Colorado

December 1998

INTRODUCTION

Detrital charcoal and bulk sediment samples were recovered from the Dungeness River drainage basin in the northeast Olympic Peninsula, Washington, as part of the Dungeness River Geomorphic study. Samples were recovered from natural exposures or soil pits on stream terraces adjacent to the lower 10.5 km of the Dungeness River. Detrital charcoal and other botanic components were identified in each of the samples, and potentially radiocarbon datable material was separated.

METHODS

Samples were floated using a modification of the procedures outlined by Matthews (1979). Each sample was added to approximately 3 gallons of water. The sample was stirred until a strong vortex formed, which was allowed to slow before pouring the light fraction through a 150 micron mesh sieve. Additional water was added and the process repeated until all visible macrofloral material was removed from the sample (a minimum of 5 times). The material which remained in the bottom (heavy fraction) was poured through a 0.5 mm mesh screen. The floated portions were allowed to dry.

The light fractions were weighed, then passed through a series of graduated screens (US Standard Sieves with 4 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm openings to separate charcoal debris and to initially sort the remains. The contents of each screen were then examined. Charcoal pieces larger than 1 mm in diameter were broken to expose a fresh cross-section and examined under a binocular microscope at magnifications up to 140x. The remaining light fraction in the 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm sieves was scanned under a binocular stereo microscope at a magnification of 10x, with some identifications requiring magnifications of up to 70x. The material which passed through the 0.25 mm screen was not examined. The coarse or heavy fractions also were screened and examined for the presence of botanic remains, when present.

Macrofloral remains, including charcoal, were identified using manuals (Core et al. 1976; Martin and Barkley 1973; Panshin and Zeeuw 1980; Petrides and Petrides 1992) and by comparison with modern and archaeological references. The term "seed" is used to represent seeds, achenes, caryopses, and other disseminules. Remains from both the light and heavy fractions were recorded as charred and/or uncharred, whole and/or fragments. Because charcoal and possibly other botanic remains were to be sent for radiocarbon dating, clean laboratory conditions were used during the flotation and identification to avoid contamination. All instruments were washed between samples, and samples were protected from contact with modern charcoal.

DISCUSSION

The Dungeness River Geomorphic study area is located in the northeast Olympic Peninsula, Washington. The Dungeness River drains the eastern Olympic Mountains and flows into the Strait of Juan de Fuca at Dungeness Bay. Detrital charcoal and bulk sediment samples were recovered from terraces incised into the alluvial plain between the mountains and the strait. The upper terraces are currently cultivated but were once covered with trees. The lower terraces are densely vegetated with a variety of riparian species. A total of 17 samples were submitted for analysis.

Sample DRsoil-1-1 was collected from a depth of 116-119 cm (Table 1). This sample yielded AMS radiocarbon datable quantities of charred conifer bark, conifer root charcoal, Chamaecyparis charcoal, Juniperus-type charcoal, Tsuga charcoal, Pseudotsuga charcoal, and unidentified charcoal (Tables 2 and 3). These charcoal types represent local conifer trees that burned. Several pieces of Tsuga charcoal exhibited traumatic resin ducts, which are a result of injury (Core et al. 1976:90). The sample also contained a few uncharred rootlets from modern plants, an insect chitin fragment, and a small amount of sand.

Conifer bark also was present in sample DRsoil-1-2 from a depth of 128-134 cm. Pseudotsuga charcoal was present in sufficient quantity for regular radiocarbon dating. Conifer, Juniperus-type, and Tsuga charcoal were present in lesser quantities and may be submitted for AMS radiocarbon dating. A few uncharred rootlets and a small amount of rock/gravel complete the record.

Sample DRsoil-1-3 was recovered from a depth of 108-113 cm. Charred conifer bark and/or Pseudotsuga charcoal may be submitted for radiocarbon dating. Unidentified charcoal most likely also represents Pseudotsuga charcoal. Non-floral remains include an insect chitin fragment and a small amount of sand.

Sample DRsoil-1-4 was taken from a depth of 38-43 cm and yielded conifer, Abies, and Tsuga charcoal that may be submitted for AMS radiocarbon dating. The sample also contained a few uncharred rootlets from modern plants, an insect chitin fragment, and a small amount of sand.

Charred conifer bark was present in sample DRsoil-1-5 from a depth of 186-191 cm. This bark was present in sufficient quantities for radiocarbon dating. A charred bulb fragment also was recovered that is most similar to those in the Liliaceae family and may be submitted for AMS radiocarbon dating. A few uncharred rootlets and a small amount of rock/gravel also were present.

Several charcoal types were present in sample DRsoil-2-1 from a depth of 15-36 cm including Alnus, conifer root, conifer, Abies, Chamaecyparis-type, Pseudotsuga, Tsuga, unidentifiable, and unidentified. All of these charcoal types were present in sufficient quantities for AMS radiocarbon dating. Other charred remains include a charred Rubus seed and three charred Abies/Pseudotsuga needle fragments. Several uncharred seeds, numerous rootlets, and conifer and Pseudotsuga wood represent modern plants. The sample also contained insect chitin fragments, rock/gravel, and sclerotia. Sclerotia are commonly called "carbon balls". They are small, black, solid or hollow balls that range from 0.5 to 4 mm in size. Sclerotia are associated with mycorrhizae fungi, such as Cenococcum graniforme, that have a mutualistic relationship with tree roots. Sclerotia are the resting structures of the fungus, identified by Dr. Kristiina Vogt, Professor of Ecology in the School of Forestry and Environmental Studies at Yale University. Many trees are noted to depend heavily on mycorrhizae and may not be successful without them. "The mycelial strands of these fungi grow into the roots and take some of the sugary compounds produced by the tree during photosynthesis. However, mycorrhizal fungi benefit the tree because they take in minerals from the soil, which are then used by the tree" (Kricher and Morrison 1988:285). Sclerotia appear to be ubiquitous and are found with coniferous and deciduous trees including Abies (fir), Juniperus communis (common juniper), Larix (larch), Picea (spruce), Pinus (pine), Pseudotsuga (Douglas fir), Acer pseudoplatanus (sycamore maple), Alnus (alder), Betula (birch), Carpinus caroliniana (American hornbeam), Carya (hickory), Castanea dentata (American chestnut), Corylus (hazelnut), Crataegus monogyna (hawthorn), Fagus (beech), Populus (poplar, cottonwood, aspen), Quercus (oak), Rhamnus fragula (alder bush), Salix (willow), Sorbus (chokecherry), and Tilia (linden) (McWeeney 1989:229-130; Trappe 1962).

Sample DRsoil-2-2 was collected from a depth of 53-80 cm. This sample contained a few small pieces of Alnus, conifer, vitrified conifer, and unidentified charcoal. Only the vitrified conifer and the unidentified charcoal are present in sufficient quantities for AMS radiocarbon dating. An uncharred Chenopodium seed. numerous uncharred rootlets, an insect chitin fragment, and sand also were present.

Sample DRsoil-3-1 was taken from a depth of 20-45 cm and contained several charred remains. Pieces of charred PET starchy tissue most likely represent a starchy root or tuber that burned and may be submitted for AMS radiocarbon dating. Pieces of Alnus, conifer, Pseudotsuga, and unidentifiable charcoal also were present in sufficient quantities for AMS radiocarbon dating. Two charred Sambucus seed fragments, a piece of Abies charcoal, a piece of Chamaecyparis charcoal, and a piece of Tsuga charcoal are too small for radiocarbon dating. The sample also contained numerous uncharred seeds and rootlets from modern plants, uncharred conifer wood, insect chitin fragments, and a small amount of sand.

Numerous pieces of Pinaceae charcoal were present in sample DRsoil-3-2 from a depth of 58 cm that may be submitted for radiocarbon dating. The unidentified charcoal in this sample also most likely represents Pinaceae. Uncharred seeds and rootlets, a few insect chitin fragments, and a small amount of sand complete the record.

Sample DRsoil-3-3 was taken from a depth of 60 cm and yielded pieces of Pinaceae charcoal that may be submitted for radiocarbon dating. The unidentified charcoal again probably is Pinaceae. A charred conifer bud fragment, charred conifer bark, and a charred unidentified seed also were present. Uncharred seeds and rootlets represent modern plants. Non-floral remains include insect chitin fragments and a small amount of sand.

Sample DRsoil-3-4 from a depth of 59 cm contained pieces of conifer, Pinaceae, and Thuja-type charcoal that may be submitted for AMS radiocarbon dating. Unidentified charcoal and a charred unidentified seed fragment also were present. Uncharred seeds and rootlets represent modern plants. A few insect chitin fragments and a small amount of sand complete the record.

Small pieces of conifer and unidentified charcoal were present in sample DRsoil-3-5 from a depth of 10-52 cm that may be submitted for AMS radiocarbon dating. The sample also contained unidentified hardwood charcoal, conifer wood, a variety of uncharred seeds, rootlets, and a small amount of sand.

Sample DRsoil-4-1 from a depth of 35 cm yielded sufficient quantities of charred conifer bark for AMS radiocarbon dating. One charred conifer root fragment also was present but is too small for radiocarbon dating. A few uncharred rootlets and a small amount of sand were the only other remains to be recovered.

Sample DRsoil-4-2 also was collected from a depth of 35 cm and yielded sufficient quantities of charred conifer bark for AMS radiocarbon dating. No other charred remains were recovered. The sample did contain a few uncharred rootlets, a few sclerotia, and rock/gravel.

Sample DRsoil-4-3 was recovered from a depth of 48 cm. This sample contained vitrified pieces of Pseudotsuga charcoal and unidentified charcoal that may be submitted for standard radiocarbon dating. Smaller amounts of vitrified conifer charcoal and charred conifer bark may be sent for AMS radiocarbon dating. The sample also contained an uncharred Trifolium seed, a few uncharred rootlets, and rock/gravel.

Sample DRsoil-4-3a from a depth of 46-49 cm also yielded Pseudotsuga and unidentified charcoal that may be submitted for standard radiocarbon dating, as well as smaller amounts of conifer charcoal, and conifer bark. A moderate amount of rock/gravel were the only other remains to be recovered.

Sample DRsoil-4-4 was taken from a depth of 7-21 cm and yielded a variety of charred remains. Pieces of charred conifer bark, Alnus charcoal, charred conifer root, conifer charcoal, vitrified conifer charcoal, Abies charcoal, and unidentified charcoal were present in sufficient quantities for AMS radiocarbon dating. Charred unidentified seeds also were present. Numerous uncharred seeds, rootlets, and conifer wood represent modern plants. The sample also contained sclerotia, insect chitin fragments, and rock/gravel.

SUMMARY AND CONCLUSIONS

Detrital charcoal and bulk sediment samples from the Dungeness River Geomorphic study in the northeast Olympic Peninsula, Washington, were examined for macrofloral remains. This analysis resulted in recovery of charcoal and other charred botanic remains that may be sent for radiocarbon dating. All of the samples yielded some charred remains that may submitted for dating. The majority of the charred remains represent coniferous trees that once covered the terraces.

TABLE 1
PROVENIENCE DATA FOR SAMPLES FROM THE DUNGENESS RIVER GEOMORPHIC STUDY

Sample No.	Depth below surface	Description
DRsoil-1-1	116-119 cm	Detrital charcoal
DRsoil-1-2	128-134 cm	Detrital charcoal
DRsoil-1-3	108-113 cm	Detrital charcoal
DRsoil-1-4	38-43 cm	Detrital charcoal
DRsoil-1-5	186-191 cm	Detrital charcoal
DRsoil-2-1	15-36 cm	Organic-rich sediment with detrital charcoal
DRsoil-2-2	53-80 cm	Bulk sediment
DRsoil-3-1	20-45 cm	Organic-rich sediment with detrital charcoal
DRsoil-3-2	58 cm	Detrital charcoal
DRsoil-3-3	60 cm	Detrital charcoal
DRsoil-3-4	59 cm	Detrital charcoal
DRsoil-3-5	10-52 cm	Detrital charcoal
DRsoil-4-1	35 cm	Detrital charcoal
DRsoil-4-2	35 cm	Detrital charcoal
DRsoil-4-3	48 cm	Detrital charcoal
DRsoil-4-3a	46-49 cm	Detrital charcoal
DRsoil-4-4	7-21 cm	Bulk sediment

TABLE 2
MACROFLORAL REMAINS FROM THE DUNGENESS RIVER GEOMORPHIC STUDY

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-1-1	Liters Floated						0.30 L
116-119 cm	Sample weight after floating						20.33 g
	FLORAL REMAINS:	Charcoal					
	Conifer	Bark		X			0.415 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer root	Charcoal		2			0.202 g
	Chamaecyparis	Charcoal		13			0.742 g
	Juniperus-type	Charcoal		4			0.217 g
	Tsuga	Charcoal		28			1.160 g
	Pseudotsuga	Charcoal		1			0.019 g
	Unidentified	Charcoal		X			3.344 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				1	
	Sand					X	Few
DRsoil-1-2	Liters Floated						0.7 L
128-134 cm	Light Fraction Weight						73.19 g
	FLORAL REMAINS:						
	Conifer	Bark		X			3.89 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		1			0.06 g
	Juniperus-type	Charcoal		7			0.39 g
	Pseudotsuga	Charcoal		68			4.60 g
	Tsuga	Charcoal		34			1.60 g
	Unidentified	Charcoal		X			30.60 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Few
DRsoil-1-3	Liters Floated						0.35 L
108-113 cm	Sample weight after floating						66.66 g
	FLORAL REMAINS:						
	Conifer	Bark		X			3.66 g

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-1-3	CHARCOAL/WOOD:						
108-113 cm	<u>Pseudotsuga</u>	Charcoal		20			15.10 g
	Unidentified	Charcoal		X			25.50 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				1	
	Sand					X	Few
DRsoil-1-4	Volume Floated						50 ml
38-43 cm	Sample weight after floating						1.40 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		X			0.133 g
	<u>Abies</u>	Charcoal		9			0.022 g
	<u>Tsuga</u>	Charcoal		25			0.099 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				1	
	Sand					X	Few
DRsoil-1-5	Liters Floated						0.35 L
186-191 cm	Light Fraction Weight						12.66 g
	FLORAL REMAINS:						
	Conifer	Bark		X			7.049 g
	Liliaceae-type	Bulb		1			0.047 g
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-2-1	Liters Floated						1.3 L
15-36 g	Light Fraction Weight						15.23 g
	FLORAL REMAINS:						
	Abies/Pseudotsuga	Needle		3			<0.001 g
	Rubus	Seed	1		2	1	
	Carex	Seed			1		
	Chenopodium	Seed			86	79	
	Polygonum	Seed			6	6	
	Trifolium	Seed			4		
	Rootlets					X	Numerous
	Sclerotia				X		Few
	CHARCOAL/WOOD:						
	Alnus	Charcoal		2			0.016 g
	Conifer root	Charcoal		8			0.072 g
	Conifer	Charcoal		22			0.156 g
	Abies	Charcoal		8			0.181 g
	Chamaecyparis-type	Charcoal		2			0.013 g
	Pseudotsuga	Charcoal		3			0.040 g
	Tsuga	Charcoal		12			0.163 g
	Unidentifiable	Charcoal		14			0.219 g
	Unidentified	Charcoal		X			0.456 g
	Conifer	Wood				4	0.052 g
	Pseudotsuga	Wood				1	0.044 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				14	
	Rock/Gravel					X	Moderate
DRsoil-2-2	Liters Floated						1.7 L
53-80 cm	Light Fraction Weight						1.25 g
	FLORAL REMAINS:						
	Chenopodium	Seed			1		
	Rootlets					X	Numerous

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-2-2	CHARCOAL/WOOD:						
53-80 cm	Alnus	Charcoal		1			<0.001 g
	Conifer (vitrified)	Charcoal		6			0.048 g
	Conifer	Charcoal		1			<0.001 g
	Unidentified (small)	Charcoal		X			0.026 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				1	
	Sand					X	Moderate
DRsoil-3-1	Liters Floated						1.6 L
20-45 cm	Sample weight after floating						7.70 g
	FLORAL REMAINS:						
	Sambucus	Seed		2	2	92	
	PET Starchy	Tissue		7			0.029 g
	Chenopodium	Seed			61	106	
	Juncus	Seed			53		
	Poaceae	Seed			6		
	Polygonum	Seed			65	66	
	Ranunculus	Seed			9		
	Solanum	Seed			27	2	
	Stellaria	Seed			2		
	Trifolium	Seed			2		
	Rootlets					X	Numerous
	CHARCOAL/WOOD:						
	Alnus	Charcoal		19			0.122 g
	Conifer	Charcoal		15			0.082 g
	Abies	Charcoal		1			0.004 g
	Chamaecyparis	Charcoal		1			0.004 g
	Pseudotsuga	Charcoal		1			0.027 g
	Tsuga	Charcoal		1			0.004 g
	Unidentifiable	Charcoal		13			0.151 g
	Conifer	Wood				14	0.096 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				25	
	Sand					X	Few

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-3-2	Liters Floated						0.9 L
58 cm	Sample weight after floating						27.04 g
	FLORAL REMAINS:						
	<u>Ranunculus</u>	Seed			1		
	<u>Sambucus</u>	Seed			12	1	
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Pinaceae	Charcoal		100			3.90 g
	Unidentified	Charcoal		X			4.86 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				5	
	Sand					X	Few
DRsoil-3-3	Liters Floated						0.8 L
60 cm	Sample weight after floating						26.90 g
	FLORAL REMAINS:						
	Conifer	Bark		2			0.002 g
	Conifer	Bud		1			0.005 g
	Unidentified	Seed		1			<0.001 g
	<u>Chenopodium</u>	Seed				1	
	<u>Ranunculus</u>	Seed			1		
	<u>Sambucus</u>	Seed				10	
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Pinaceae	Charcoal		100			4.70 g
	Unidentified	Charcoal		X			5.29 g
	NON-FLORAL REMAINS:						
	Insect	Chitin		1		8	
	Sand					X	Few

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-3-4	Liters Floated						1.0 L
59 cm	Sample weight after floating						30.62 g
	FLORAL REMAINS:						
	Unidentified	Seed		1			<0.001 g
	cf. Alnus	Seed			2		
	Sambucus	Seed			1	9	
	Solanum	Seed			1		
	Rootlets					X	Numerous
	CHARCOAL/WOOD:						
	Conifer	Charcoal		7			0.054 g
	Pinaceae	Charcoal		40			0.048 g
	Thuja-type	Charcoal		3			0.065 g
	Unidentified	Charcoal		X			2.860 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				5	
	Sand					X	Few
DRsoil-3-5	Volume Floated						50 ml
10-52 cm	Sample weight after floating						1.46 g
	FLORAL REMAINS:						
	Chenopodium	Seed				6	
	Polygonum	Seed			1	4	
	Solanum	Seed			1		
	Stellaria	Seed			1		
	Tsuga-type	Seed				4	
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		13			0.006 g
	Unidentified hardwood	Charcoal		4			0.001 g
	Unidentifiable (small)	Charcoal		X			0.005 g
	Conifer	Wood				3	0.002 g
	NON-FLORAL REMAINS:						
	Sand					X	Few

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-4-1	Volume Floated						50 ml
35 cm	Sample weight after floating						6.92 g
	FLORAL REMAINS:						
	Conifer ≥ 1 mm	Bark		X			0.33 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer root	Charcoal		1			0.003 g
	NON-FLORAL REMAINS:						
	Sand					X	Few
DRsoil-4-2	Volume Floated						75 ml
35 cm	Light Fraction Weight						1.86 g
	FLORAL REMAINS:						
	Conifer ≥ 1 mm	Bark		X			1.21 g
	Rootlets					X	Few
	Sclerotia				X		Few
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate
DRsoil-4-3	Liters Floated						0.35 L
48 cm	Light Fraction Weight						23.72 g
	FLORAL REMAINS:						
	Conifer ≥ 2 mm	Bark		X			0.135 g
	Trifolium	Seed			1		
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer (vitrified)	Charcoal		X			0.733 g
	Pseudotsuga (vitrified)	Charcoal		75			4.972 g
	Unidentified	Charcoal		X			5.188 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate
DRsoil-4-3a	Liters Floated						0.15 L
46-49 cm	Light Fraction Weight						20.98 g
	FLORAL REMAINS:						
	Conifer > 2 mm	Bark		X		X	0.03 g

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-4-3a	CHARCOAL/WOOD:						
46-49 cm	Conifer	Charcoal		5			0.278 g
	Pseudotsuga	Charcoal		95			3.50 g
	Unidentified	Charcoal		X			3.842 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate
DRsoil-4-4	Liters Floated						1.3 L
7-21 cm	Light Fraction Weight						12.52 g
	FLORAL REMAINS:						
	Conifer	Bark		5		1	0.040 g
	Unidentified	Seed	4	1			
	Amaranthus	Seed			39		
	Chenopodium	Seed			92	54	
	Chrysanthemum	Seed			16		
	Descurainia	Seed			10		
	Poaceae	Floret			1		
	Polygonum	Seed			10	3	
	Rubus	Seed			2	2	
	Solanum	Seed			55	21	
	Stellaria	Seed			20	6	
	Trifolium	Seed			7		
	Unidentified	Seed			4	1	
	Rootlets					X	Numerous
	Sclerotia				X		Few
	CHARCOAL/WOOD:						
	Alnus	Charcoal		10			0.1130 g
	Conifer root	Charcoal		1			0.012 g
	Conifer (vitrified)	Charcoal		6			0.151 g
	Conifer	Charcoal		11			0.066 g
	Abies	Charcoal		2			0.020 g
	Unidentified	Charcoal		X			0.125 g
	Conifer	Wood				8	0.058 g

Table 2 (continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-4-4	NON-FLORAL REMAINS:						
7-21 g	Insect	Chitin				19	
	Rock/Gravel					X	Moderate

W = Whole
F = Fragment
X = Presence noted in sample
g = grams

TABLE 3
INDEX OF MACROFLORAL REMAINS RECOVERED FROM THE DUNGENESS RIVER

Scientific Name	Common Name
FLORAL REMAINS:	
cf. Alnus	Alder
Amaranthus	Pigweed, Amaranth
Carex	Sedge
Chenopodium	Goosefoot
Chrysanthemum	Chrysanthemum
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Abies/Pseudotsuga	Fir/Douglas-fir
Tsuga-type	Hemlock-type
Descurainia	Tansy mustard
Juncus	Rush
Liliaceae-type	Lily family
Poaceae	Grass family
Polygonum	Smartweed, Knotweed
Ranunculus	Buttercup
Rubus	Raspberry, blackberry, etc.
Sambucus	Elderberry
Solanum	Nightshade
Stellaria	Chickweed, Starwort
Trifolium	Clover
PET Starchy	Tissues with starchy storage cells, likely from roots, tubers, bulbs, rhizomes, or corms
CHARCOAL/WOOD:	
Alnus	Alder

Table 3 (continued)

Scientific Name	Common Name
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Chamaecyparis	
Juniperus	Juniper, Cedar
Thuja-type	
Pinaceae	Pine family
Abies	Fir
Pseudotsuga	Douglas-fir
Tsuga	Hemlock

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EXAMINATION OF BULK SOIL AND DETRITAL CHARCOAL FOR DATABLE MATERIAL FROM THE DUNGENESS RIVER GEOMORPHIC STUDY, WASHINGTON

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INTRODUCTION

Bulk soil and detrital charcoal samples were recovered from natural exposures or soil pits on stream terraces adjacent to the Dungeness River in the northeastern portion of the Olympic Peninsula, Washington. These samples are from terraces incised into the alluvial plain between the eastern Olympic Mountains and the Strait of Juan de Fuca at Dungeness Bay. Botanic components and detrital charcoal were identified in each of the samples, and potentially radiocarbon datable material was separated.

METHODS

The bulk samples were floated using a modification of the procedures outlined by Matthews (1979). Each sample was added to approximately 3 gallons of water. The sample was stirred until a strong vortex formed, which was allowed to slow before pouring the light fraction through a 150 micron mesh sieve. Additional water was added and the process repeated until all visible macrofloral material was removed from the sample (a minimum of 5 times). The material which remained in the bottom (heavy fraction) was poured through a 0.5 mm mesh screen. The floated portions were allowed to dry.

The light fractions were weighed, then passed through a series of graduated screens (US Standard Sieves with 4 mm, 2 mm, 1 mm, 0.5 mm and 0.25 mm openings to separate charcoal debris and to initially sort the remains. The contents of each screen were then examined. Charcoal pieces larger than 1 mm in diameter were broken to expose a fresh cross-section and examined under a binocular microscope at a magnification of 70x. Individual detrital charcoal/wood samples also were broken to expose a fresh cross-section and examined under a binocular microscope at a magnification of 70x. The remaining light fraction in the 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm sieves was scanned under a binocular stereo microscope at a magnification of 10x, with some identifications requiring magnifications of up to 70x. The material which passed through the 0.25 mm screen was not examined. The coarse or heavy fractions also were screened and examined for the presence of botanic remains. Remains from both the light and heavy fractions were recorded as charred and/or uncharred, whole and/or fragments. The term "seed" is used to represent seeds, achenes, caryopses, and other disseminules.

Macrofloral remains, including charcoal, were identified using manuals (Core *et al*. 1976; Martin and Barkley 1973; Panshin and Zeeuw 1980; Petrides and Petrides 1992) and by comparison with modern and archaeological references. Because charcoal and possibly other botanic remains were to be sent for radiocarbon dating, clean laboratory conditions were used during flotation and identification to avoid contamination. All instruments were washed between samples, and samples were protected from contact with modern charcoal.

DISCUSSION

All of the samples were collected from natural exposures or soil pits on stream terraces along the lower 10.5 km of the Dungeness River. The Dungeness River drains the eastern Olympic Mountains and flows in the Strait of Juan de Fuca at Dungeness Bay. The samples are from terraces incised into the alluvial plain between the mountains and the strait. The sampled terraces were comprised of fine-grained sand, silt, and clay that was deposited as alluvium, glacial till, outwash, or glaciomarine sediments. The localities sampled are situated at elevations ranging from 10 to 500 feet asl. Tree species present in the study area include red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), Grand fir (*Abies grandis*), western white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) (Lucy Piety, personal communication, January 16, 2001).

Locality DRsoil-5

A total of 13 samples were recovered from DRsoil-5. Sample DRsoil-5-A1 was collected at a depth of 95-102 cmbs from an organic-rich sediment with detrital charcoal (Table 1). This sample contained pieces of partially charred bark weighing 0.346 g that can be submitted for AMS radiocarbon dating (Table 2). The minimum requirement of charcoal for AMS radiocarbon dating reported by Beta Analytic, Inc. is 5 mg or 0.005 g. A moderate amount of rootlets in the sample represents modern plants. A small amount of rock and sand also were present.

Bulk sample DRsoil-5-A2 represents lower alluvium at a depth of 61-75 cmbs. The very small pieces of charcoal present in this sample were too small for identification and too small for AMS dating, weighing less than 0.001 g. A few uncharred rootlets from modern plants and a moderate amount of rock/gravel and sand were the only other remains to be recovered.

Sample DRsoil-5-A3 represents upper alluvium at a depth of 29-33 cmbs. This sample contained pieces of probable *Tsuga* (Tables 2 and 3) charcoal that exhibited some rootlet intrusion. These charcoal fragments weighed 0.136 g and can be submitted for AMS radiocarbon dating. Five pieces of mostly charred bark weighing 0.087 g also are of a sufficient weight for AMS radiocarbon dating. The sample contained additional pieces of unidentified charcoal and bark, as well as a few uncharred rootlets from modern plants and a small amount of rock/gravel and sand.

Sample DRsoil-5-B1 consists of charcoal from a depth of 36-39 cmbs. This charcoal was identified as *Pseudotsuga* with a weight of 7.34 g. Sufficient charcoal is present for radiocarbon dating.

Charcoal sample DRsoil-5-B2 was collected at a depth of 47-57 cmbs and consists of pieces of probable conifer bark. Some of the probable conifer bark is charred and vitrified, with a weight of 3.97 g. Vitrified material has a shiny, glassy appearance due to fusion by heat. The presence of vitrified bark might indicate that the bark had a high moisture content when it burned. A total of 10.58 g of bark is partially charred, and the charred areas are vitrified.

Pieces of mostly charred, vitrified probable conifer bark also are present in charcoal sample DRsoil-5-B3 collected at a depth of 28-36 cmbs. These bark fragments weigh 15.04 g and can be submitted for radiocarbon dating. One piece of charred conifer root charcoal also was present, weighing 0.09 g.

Charcoal sample DRsoil-5-C1 from a depth of 70-82 cmbs contained 6.519 g of slightly vitrified *Pseudotsuga* charcoal, representing Douglas-fir trees that burned. A total of 7.556 g of charcoal and bark remain unidentified. The sample also contained a few uncharred rootlets from modern plants and a moderate amount of rock/gravel and sand.

Bulk sample DRsoil-5-D1 was recovered from glacial sand at a depth of 113-135 cmbs. This sample contained a few pieces of uncharred bark weighing 0.035 g, as well as a few uncharred rootlets and a small amount of rock and sand. No charcoal or other charred organic remains were present.

A few pieces of uncharred bark fragments weighing 0.003 g were present in sample DRsoil-5-D2. No charred remains were recovered in this sample. This sample also yielded a few uncharred rootlets and a small amount of sand.

Sample DRsoil-5-E1 was taken from a depth of 81-87 cmbs. This sample yielded uncharred pieces of unidentified root wood weighing 0.037 g. A few uncharred rootlets and a small amount of rock/gravel and sand also were present.

Sample DRsoil-5-F1 from a depth of 122 cmbs contained fragments of mostly charred bark weighing 0.412 g. The sample also contained two pieces of uncharred conifer wood, a few uncharred rootlets, and a small amount of sand.

Samples DRsoil-5-G1 and DRsoil-5-G2 were recovered from a peaty layer in glacial sediments. Sample DRsoil-5-G1 represents the lower portion of the peaty layer at a depth of 117-118 cmbs. This sample yielded pieces of uncharred bark weighing 0.025 g, as well as a moderate amount of uncharred rootlets and a small amount of rock/gravel and sand. Sample DRsoil-5-G2 was collected from a depth of 94 cmbs in the upper portion of the peaty layer. This sample also contained pieces of uncharred bark, which weighed 0.519 g. In addition, a few uncharred rootlets and a small amount of rock/gravel and sand were present.

Locality DRsoil-6

Locality DRsoil-6 is represented by 10 samples. Bulk sample DRsoil-6-1 was recovered from lower sand at a depth of 110-120 cmbs. This sample contained a variety of charcoal in sufficient quantities for AMS radiocarbon dating, including three pieces of *Abies* charcoal with smooth, rounded edges weighing 0.064 g, three pieces of *Juniperus* charcoal with rounded edges weighing 0.028 g, two pieces of *Pseudotsuga* charcoal weighing 0.461 g, one piece of *Pseudotsuga* charcoal with rounded edges weighing 0.077 g, five pieces of probable *Thuja plicata* charcoal weighing 0.121 g, conifer charcoal not identified to genus weighing 0.151 g, pieces of conifer charcoal with rounded edges weighing 0.022 g, one piece of conifer charcoal weighing 0.006 g with a slightly vitrified appearance and containing traumatic resin ducts, and pieces of unidentified charcoal and uncharred wood. Traumatic resin ducts are formed in conifers when trees experience an injury. They can occur in species that normally contain resin ducts and in species that normally are devoid of resin ducts (Panshin and Zeeuw 1980:148). Recovery of a piece of conifer charcoal exhibiting a slightly vitrified appearance and traumatic resin ducts is consistent with living trees burned in a forest fire. One piece of vitrified tissue weighing 0.004 g was present and represents charcoal or other plant tissue too vitrified for identification. The sample also contained six charred bark fragments weighing 0.031 g, a few rootlets from modern plants, a few insect chitin fragments, a small amount of rock/gravel, an abundance of sand, and a few sclerotia.

Sclerotia are commonly called "carbon balls". They are small, black, solid or hollow spheres that can be smooth or lightly sculpted. These forms range from 0.5 to 4 mm in size. Sclerotia are associated with mycorrhizae fungi, such as *Cenococcum graniforme*, that have a mutualistic relationship with tree roots. Sclerotia are the resting structures of the fungus, identified by Dr. Kristiina Vogt, Professor of Ecology in the School of Forestry and Environmental Studies at Yale University. Many trees are noted to depend heavily on mycorrhizae and may not be successful without them. "The mycelial strands of these fungi grow into the roots and take some of the sugary compounds produced by the tree during photosyntheses. However, mycorrhizal fungi benefit the tree because they take in minerals from the soil, which are then used by the tree" (Kricher and Morrison 1988:285). Sclerotia appear to be ubiquitous and are found with coniferous and deciduous trees including *Abies* (fir), *Juniperus communis* (common juniper), *Larix* (larch), *Picea* (spruce), *Pinus* (pine), *Pseudotsuga* (Douglas-fir), *Alnus* (alder), *Betula* (birch), *Populus* (poplar, cottonwood, aspen), *Quercus* (oak), *Salix* (willow), and others (McWeeney 1989:229-130; Trappe 1962).

Bulk sample DRsoil-6-2 was collected at a depth of 68-81 cmbs from organic sediments with detrital charcoal. This sample contained pieces of *Abies* charcoal weighing 0.039 g, *Chamaecyparis*-type charcoal weighing 0.045 g, pieces of *Pseudotsuga* charcoal weighing 0.021 g, and conifer charcoal not identified to genus weighing 0.097 g. All of these charcoal types are present in sufficient quantities for AMS radiocarbon dating. Very small pieces of Salicaceae charcoal and unidentifiable central pith from a branch or twig were present in amounts too small for radiocarbon dating. The sample also contained a moderate amount of uncharred rootlets from modern plants, an abundance of sclerotia, insect chitin fragments, and a moderate amount of rock/gravel and sand.

Charcoal sample DRsoil-6-3 from a depth of 57-60 cm contained *Abies* charcoal weighing 0.013 g, *Pseudotsuga* charcoal weighing 0.021 g, and conifer charcoal weighing 0.008 g that can be submitted for AMS radiocarbon dating. A single piece of *Chamaecyparis*-type charcoal weighing 0.003 g is too small for radiocarbon dating. The sample also yielded a few uncharred rootlets and a moderate amount of sand.

Charcoal sample DRsoil-6-4 was taken from a depth of 66 cmbs. This sample contained pieces of charred bark weighing 0.029 g and pieces of conifer charcoal weighing 0.009 g that can be submitted for AMS radiocarbon dating. Fragments of conifer charcoal with rounded edges, a piece of *Chamaecyparis*-type charcoal, and a piece of probable *Tsuga* charcoal were present but did not meet the minimum weight requirements for AMS radiocarbon dating reported by Beta Analytic, Inc. The sample also yielded fragments of unidentified charcoal and bark, unidentified uncharred wood, a few modern rootlets, and a moderate amount of sand.

Pseudotsuga charcoal weighing 0.035 g was present in sample DRsoil-6-5 from a depth of 76 cmbs. This charcoal is of a sufficient weight for AMS radiocarbon dating. In addition, the sample contained pieces of unidentified charcoal, a few uncharred rootlets, and a moderate amount of sand.

Charcoal sample DRsoil-6-6 was recovered from a depth of 51-53 cmbs. Pieces of *Chamaecyparis*-type charcoal weighing 0.007 g and *Juniperus* charcoal weighing 0.012 g were present in this sample and can be submitted for AMS radiocarbon dating. The sample also yielded vitrified pieces of conifer charcoal not identified to genus, three pieces of unidentifiable central pith from a woody plant, and pieces of uncharred bark fragments.

Charcoal samples DRsoil-6-7 and DRsoil-6-8 were collected at a depth of 29-30 cmbs. Sample DRsoil-6-7 consists of a single piece of *Juniperus* charcoal weighing 0.047 g, which is a sufficient weight for AMS radiocarbon dating. Sample DRsoil-6-8 contained slightly vitrified pieces of *Chamaecyparis*-type charcoal weighing 0.101 g and probable *Thuja plicata* charcoal weighing 0.292 g. These charcoal types are of a sufficient weight for AMS radiocarbon dating. The sample also contained charcoal weighing 0.033 g with a cross-section morphology most similar to *Platanus* (sycamore), although symamore is not noted to grow in this area. Pieces of unidentified charcoal, a few uncharred rootlets, and a small amount of sand also were present.

Bulk sample DRsoil-6-9 was removed from a depth of 33-77 cm. Pieces of slightly vitrified *Alnus* charcoal weighing 0.007 g, conifer charcoal weighing 0.010 g, and charred bark fragments weighing 0.009 g were present in this sample and can be submitted for AMS radiocarbon dating. Pieces of conifer and *Juniperus* charcoal exhibiting rounded edges were present but yielded weights below the minimum requirement for AMS radiocarbon dating. The sample also contained a few uncharred rootlets, an insect chitin fragment, a few insect puparia fragments, and a small amount of sand.

Bulk sample DRsoil-6-10 was collected from the B horizon at a depth of 7-33 cm. This sample contained a piece of *Alnus* charcoal weighing 0.015 g, pieces of *Chamaecyparis*-type charcoal weighing 0.037 g, a partially charred *Chamaecyparis*-type twig fragment weighing 0.034 g, and conifer charcoal weighing 0.031 g that can be submitted for AMS radiocarbon dating. Pieces of uncharred conifer wood also were present. Recovery of several uncharred seeds and numerous rootlets, as well as several insect chitin fragments and a moderate amount of insect eggs, reflect the proximity of this sample to the modern ground surface.

<u>Locality DRsoil-7</u>

Six samples were examined from DRsoil-7. Bulk sample DRsoil-7-1 represents the deepest sample taken from a depth of 208-211 cmbs. This sample contained one piece of conifer charcoal weighing less than 0.001 g. No other charred remains were recovered. The sample did contain uncharred wood and bark from an unidentified hardwood root, as well as an uncharred Asteraceae seed, a moderate amount of uncharred rootlets, a moderate amount of rock/gravel, and an abundance of sand.

Bulk sample DRsoil-7-2 was collected at a depth of 139-149 cmbs from a layer of finer sand just above gravel. Pieces of *Chamaecyparis*-type charcoal weighing 0.01 g, *Pseudotsuga* charcoal weighing 0.05 g, and pieces of conifer charcoal weighing 0.26 g were present in sufficient quantities for AMS radiocarbon dating. Pieces of unidentifiable central pith weighing 0.01 g and a moderate amount of charred bark fragments also were present. A few uncharred rootlets from modern plants, an abundance of sclerotia, a few insect chitin fragments, and a moderate amount of rock and sand complete the record for this sample.

Charcoal sample DRsoil-7-3 was recovered from a depth of 98 cmbs. This sample contained pieces of charred bark fragments weighing 0.197 g that can be submitted for AMS radiocarbon dating. These bark fragments exhibited some rootlet intrusion. Two charred conifer root fragments weighing 0.001 g, a few uncharred rootlets, and a small amount of sand also were present.

Charred bark fragments with rootlet intrusion weighing 1.715 g and two charred conifer root fragments weighing less than 0.001 g also were present in sample DRsoil-7-4 from a depth of 46.5 cmbs. A few uncharred rootlets, a few sclerotia, a few uncharred insect fecal pellets, and a small amount of sand also were recovered.

Bulk sample DRsoil-7-5 was taken from a depth of 51-70 cm and contained pieces of conifer charcoal not identified to genus weighing 0.013 g and a single piece of *Chamaecyparis*-type charcoal with slightly rounded edges weighing 0.005 g that can be sent for AMS radiocarbon dating. No other charred remains were present in this sample. Uncharred conifer wood, an uncharred *Descurainia* seed, an uncharred *Sambucus* seed, and numerous rootlets represent modern plants. The presence of uncharred remains from modern plants, several insect chitin fragments, and a few insect puparia fragments indicates some subsurface disturbance in this area. The sample also contained a few sclerotia and a small amount of sand.

Charcoal in sample DRsoil-7-6 from a depth of 39-49 cmbs that can be submitted for AMS radiocarbon dating includes a piece of *Abies* charcoal weighing 0.021 g, partially charred fragments of *Juniperus* charcoal weighing 1.901 g, two pieces of probable *Thuja plicata* charcoal weighing 0.075 g, conifer charcoal not identified to genus weighing 0.055 g, and partially charred bark fragments weighing 0.625 g. A mixture of partially charred charcoal and bark weighing 0.897 g remains unidentified. The sample also contained a piece of uncharred conifer wood weighing 0.018 g, numerous rootlets from modern plants, and a few insect remains.

Locality DRstrat-1

Locality DRstrat-1 is represented by five detrital charcoal samples. Sample DRstrat-1-0 from a depth of 98 cmbs contained slightly vitrified pieces of *Pseudotsuga* charcoal weighing 3.431 g that can be submitted for AMS radiocarbon dating. An uncharred *Betula* seed and an uncharred Poaceae floret represent modern birch trees and grasses. A few uncharred rootlets and a small amount of sand also were present.

Sample DRstrat-1-1 was collected at a depth of 73 cmbs and consists of probable *Tsuga* charcoal weighing 15.084 g. This charcoal was moderately vitrified, suggesting that the tree was living when it burned. Some rootlet intrusion also was noted.

Pieces of moderately vitrified probable *Tsuga* charcoal weighing 4.536 g and exhibiting some rootlet intrusion also was present in sample DRstrat-1-2 from a depth of 78 cmbs. A mixture of charcoal and bark weighing 3.804 g remains unidentified. One probable *Thuja plicata*-type leaf and a few uncharred rootlets represent modern western redcedar trees and other herbaceous plants.

Sample DRstrat-1-3 from a depth of 43 cmbs contained pieces of probable *Tsuga* charcoal weighing 0.028 g and pieces of conifer charcoal not identified to genus weighing 0.007 g that can be submitted for AMS radiocarbon dating. One charred conifer root fragment weighing 0.003 g and a charred conifer needle fragment weighing less than 0.001 g do not meet the minimum weight requirements for AMS radiocarbon dating. A few uncharred rootlets also were present.

Sample DRstrat-1-4 was removed from a depth of 39 cmbs. This sample contained pieces of probable *Tsuga* charcoal weighing 0.674 g and partially charred probable *Tsuga* wood weighing 0.121 g. These charcoal and partially charred wood fragments consistently broke in single growth ring sections. One piece of conifer charcoal weighing 0.026 g also was recovered. A mixture of charcoal and charred bark fragments weighing 0.0759 g remains unidentified. A few uncharred rootlets, an insect puparia fragment, and a small amount of rock/gravel complete the record.

Locality DRstrat-2

A total of eight samples were examined from DRstrat-2. Charcoal sample DRstrat-2-1 from a depth of 105 cmbs contained an abundance of slightly vitrified *Pseudotsuga* charcoal weighing 22.44 g and pieces of charred, slightly vitrified *Pseudotsuga* bark and xylem (wood structure) weighing 17.74 g that can be sent for radiocarbon dating. The sample also contained unidentified charcoal and charred bark fragments weighing 44.85 g, a moderate amount of heat-altered sediment, a few uncharred rootlets, and a few insect chitin fragments.

Charcoal sample DRstrat-2-2 was recovered from a depth of 135 cmbs. This sample contained pieces of *Abies* charcoal weighing 0.252 g and pieces of *Pseudotsuga* charcoal weighing 0.614 g that can be submitted for AMS radiocarbon dating. Other remains present in this sample include an unidentified uncharred leaf, a moderate amount of uncharred rootlets, and a small amount of sand.

Charcoal sample DRstrat-2-6 from a depth of 60 cm consisted of partially charred probable conifer bark weighing 2.75 g. The charred areas of the bark were vitrified, suggesting that these bark fragments represent a living tree that burned.

Sample DRstrat-2-4 was taken at a depth of 158-182 cm from organic sediments with detrital charcoal. Pieces of conifer charcoal weighing 0.028 g and *Pseudotsuga* charcoal weighing 0.008 g were present in sufficient quantities for AMS radiocarbon dating. This sample also yielded two uncharred leaves, a moderate amount of uncharred rootlets, and a moderate amount of rock/gravel and sand.

Sample DRstrat-2-5 from a depth of 143-145 cmbs represents charcoal from Burn 1. This sample consists of *Abies* charcoal weighing 0.392 g and *Pseudotsuga* charcoal weighing 0.016 g that can be submitted for AMS radiocarbon dating.

Pieces of conifer charcoal weighing 0.87 g were present in sample DRstrat-2-6 from a burn layer (Burn 2) at a depth of 114 cmbs. These charcoal fragments exhibited a "twisted" appearance and areas of vitrification. Six pieces of unidentifiable vitrified charcoal also were present.

Sample DRstrat-2-7 was recovered from Burn 3 at a depth of 92 cmbs. This sample contained pieces of charred probable conifer bark weighing 1.82 g. These bark fragments also exhibited vitrified areas.

A variety of charcoal types were present in sample DRstrat-2-8 from Burn 4 at a depth of 24-57 cmbs. Charcoal present in sufficient quantities for AMS radiocarbon dating include a piece of *Juniperus* charcoal weighing 0.010 g, *Pseudotsuga* charcoal weighing 0.103 g, conifer charcoal weighing 0.023 g, and conifer root charcoal weighing 0.035 g. A piece of probable *Thuja plicata*-type charcoal weighing only 0.001 g does not meet the minimum weight requirement for AMS radiocarbon dating. Other charred remains present in this sample include unidentifiable charcoal fragments, charred unidentifiable central pith from a woody plant, charred bark fragments weighing 0.920 g, and a piece of charred bark with charred insect fecal pellets. Several types of uncharred seeds and other plant remains represent components of the modern vegetation community. A few insect chitin fragments and a small amount of sand also were present.

SUMMARY AND CONCLUSIONS

Examination of bulk sediment and detrital charcoal samples and from stream terraces adjacent to the Dungeness River in the northeastern portion of the Olympic Peninsula, Washington, resulted in recovery of several types of charcoal and other charred botanic remains that can be sent for radiocarbon dating. Samples from Locality DRsoil-5 contained mostly charred, partially charred, and/or uncharred bark fragments. *Pseudotsuga* charcoal was present in samples DRsoil-5-B1 and DRsoil-5-C1, and probable *Tsuga* charcoal was recovered from sample DRsoil-5-A3. Samples from Locality DRsoil-6 contained a variety of conifer charcoal, including *Abies*, *Chamaecyparis*-type, *Juniperus*, *Pseudotsuga*, probable *Thuja plicata*, probable *Tsuga*, and conifer charcoal not identified to genus. Samples from DRsoil-6 also contained the only hardwood charcoal recovered for this project. Salicaceae charcoal was present in sample DRsoil-6-2, *Platanus*-type charcoal was found in sample DRsoil-6-8, and *Alnus* charcoal was recovered from samples DRsoil-6-9 and DRsoil-6-10. Conifer charcoal present in samples from Locality DRsoil-7 includes *Abies*, *Chamaecyparis*-type, *Juniperus*, *Pseudotsuga*, probable *Thuja plicata*, and conifer charcoal not identified to genus, as well as charred bark fragments. Samples from Locality DRstrat-1 yielded mostly probable *Tsuga* charcoal, with *Pseudotsuga* charcoal present in sample DRstrat-1-0. Samples from Locality DRstrat-2 consisted mainly of *Abies* and *Pseudotsuga* charcoal, as well as some conifer charcoal and bark. Single pieces of *Juniperus* and probable *Thuja plicata* charcoal were present in sample DRstrat-2-8.

TABLE 1
PROVENIENCE DATA FOR SAMPLES FROM
THE DUNGENESS RIVER GEOMORPHIC STUDY, WASHINGTON

Locality	Sample No.	Depth (cmbs)	Provenience/ Description	Analysis
DRsoil-5	A1	95-102	Organic sediments with detrital charcoal; glacial/marine surface at schoolhouse	Float/Charcoal ID
	A2	61-75	Bulk sediment sample; lower alluvium	Float/Charcoal ID
	A3	29-33	Organic sediments with detrital charcoal	Float/Charcoal ID
	B1	36-39	Detrital charcoal	Charcoal ID
	B2	47-57	Detrital charcoal	Charcoal ID
	B3	28-36	Detrital charcoal	Charcoal ID
	C1	70-82	Detrital charcoal	Charcoal ID
	D1	113-135	Bulk sediment sample; glacial sand	Float/Charcoal ID
	D2	112	Detrital charcoal	Charcoal ID
	E1	81-87	Detrital charcoal	Charcoal ID
	F1	122	Detrital charcoal	Charcoal ID
	G1	117-118	Peaty layer in glacial sediments	Float/Charcoal ID
	G2	94	Peaty layer in glacial sediments	Float/Charcoal ID
DRsoil-6	1	110-120	Bulk sediment sample; lower sand	Float/Charcoal ID
	2	68-81	Organic sediments with detrital charcoal; upper sand	Float/Charcoal ID
	3	57-60	Detrital charcoal	Charcoal ID
	4	66	Detrital charcoal	Charcoal ID
	5	76	Detrital charcoal	Charcoal ID
	6	51-53	Detrital charcoal	Charcoal ID
	7	29-30	Detrital charcoal	Charcoal ID
	8	29-30	Detrital charcoal	Charcoal ID
	9	33-77	Bulk sediment sample; Al’s field	Float/Charcoal ID
	10	7-33	Bulk sediment sample; B horizon - Al’s field	Float/Charcoal ID

Locality	Sample No.	Depth (cmbs)	Provenience/ Description	Analysis
DRsoil-7	1	208-211	Bulk sediment sample	Float/Charcoal ID
	2	139-149	Bulk sediment sample; finer sand just above gravel	Float/Charcoal ID
	3	98	Detrital charcoal	Charcoal ID
	4	46.5	Detrital charcoal	Charcoal ID
	5	51-70	Bulk sediment sample	Float/Charcoal ID
	6	39-49	Bulk sediment sample	Float/Charcoal ID
DRstrat-1	0	98	Detrital charcoal	Charcoal ID
	1	73	Detrital charcoal	Charcoal ID
	2	78	Detrital charcoal	Charcoal ID
	3	43	Detrital charcoal	Charcoal ID
	4	39	Detrital charcoal	Charcoal ID
DRstrat-2	1	105	Detrital charcoal	Charcoal ID
	2	135	Detrital charcoal	Charcoal ID
	3	60	Detrital charcoal	Charcoal ID
	4	158-182	Organic sediments with detrital charcoal; charcoal in silt	Float/Charcoal ID
	5	143-145	Detrital charcoal; Burn 1	Charcoal ID
	6	114	Detrital charcoal; Burn 2	Charcoal ID
	7	92	Detrital charcoal; Burn 3	Charcoal ID
	8	24-57	Bulk sediment sample; Burn 4	Float/Charcoal ID

TABLE 2
MACROFLORAL REMAINS IN SAMPLES FROM
THE DUNGENESS RIVER GEOMORPHIC STUDY, WASHINGTON

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-5-A1	Volume Floated/ Waterscreened						250 mL
95-102 cmbs	Light Fraction Weight						4.46 g
	FLORAL REMAINS:						
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Bark					Xpc	0.346 g
	NON-FLORAL REMAINS:						
	Rock/Sand					X	Scant
DRsoil-5-A2	Volume Floated/ Waterscreened						1.00 L
61-75 cmbs	Light Fraction Weight						2.68 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Unidentifiable - small	Charcoal		X			<0.001 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate
	Sand					X	Moderate
DRsoil-5-A3	Volume Floated/ Waterscreened						100 ml
29-33 cmbs	Light Fraction Weight						2.39 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Bark			5pc			0.087 g
	cf. *Tsuga* - some rootlet intrusion	Charcoal		20			0.136 g
	Unidentified $\geq$ 1 mm	Charcoal and Bark		X			0.181 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Scant
	Sand					X	Scant

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-5-B1	CHARCOAL/WOOD:						
36-39 cmbs	Total charcoal ≥ 2 mm						
	Pseudotsuga	Charcoal		40			7.34 g
DRsoil-5-B2	CHARCOAL/WOOD:						
47-57 cmbs	cf. Conifer - vitrified	Bark		10			3.97 g
	cf. Conifer - charred areas are vitrified	Bark			40pc		10.58 g
DRsoil-5-B3	CHARCOAL/WOOD:						
28-36 cmbs	cf. Conifer - vitrified	Bark		Xpc			15.04 g
	Conifer root	Charcoal		1			0.09 g
DRsoil-5-C1	Volume Floated/ Waterscreened						100 mL
70-82 cmbs	Screened Sample Weight						17.757 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Pseudotsuga - slightly vitrified	Charcoal		20			6.519 g
	Unidentified	Charcoal and Bark		X			7.556 g
	NON-FLORAL REMAINS:						
	Rock/Gravel and Sand					X	13.212 g
DRsoil-5-D1	Volume Floated/ Waterscreened						2.80 L
113-135 cmbs	Light Fraction Weight						5.04 g
	FLORAL REMAINS:						
	Bark					X	0.035 g
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	Rock/Sand					X	Scant

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-5-D2	Volume Floated/ Waterscreened						15 mL
112 cmbs	Light Fraction Weight						0.77 g
	FLORAL REMAINS:						
	Bark ≥ 0.5 mm					X	0.003 g
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	Sand					X	Scant
DRsoil-5-E1	Volume Floated/ Waterscreened						20 mL
81-87 cmbs	Screened Sample Weight						2.504 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Unidentified root ≥ 2 mm	Wood				X	0.037 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Scant
	Sand					X	Scant
DRsoil-5-F1	Volume Floated/ Waterscreened						20 mL
122 cmbs	Screened Sample Weight						2.91 g
	FLORAL REMAINS:						
	Bark ≥ 1 mm			Xpc			0.412 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer	Wood				2	0.002 g
	NON-FLORAL REMAINS:						
	Sand					X	Scant
DRsoil-5-G1	Volume Floated/ Waterscreened						100 mL
117-118 cmbs	Light Fraction Weight						1.23 g
	FLORAL REMAINS:						
	Bark ≥ 1 mm					X	0.025 g
	Rootlets					X	Moderate

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred		Uncharred		Weights/ Comments
			W	F	W	F	
DRsoil-5-G1	NON-FLORAL REMAINS:						
117-118 cmbs	Rock/Gravel					X	Scant
	Sand					X	Scant
DRsoil-5-G2	Volume Floated/ Waterscreened						25 mL
94 cmbs	Light Fraction Weight						3.47 g
	FLORAL REMAINS:						
	Bark ≥ 1 mm					X	0.519 g
	Rootlets					X	Few
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Scant
	Sand					X	Scant
DRsoil-6-1	Volume Floated/ Waterscreened						2.20 L
110-120 cmbs	Light Fraction Weight						5.47 g
	FLORAL REMAINS:						
	Vitrified tissue ≥ 2mm			1			0.004 g
	Bark			6			0.031 g
	Rootlets					X	Few
	Sclerotia					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		10			0.151 g
	Conifer - rounded	Charcoal		4			0.022 g
	Conifer - slightly vitrified, w/traumatic resin ducts	Charcoal		1			0.006 g
	Abies - rounded	Charcoal		3			0.064 g
	Juniperus - rounded	Charcoal		3			0.028 g
	Pseudotsuga	Charcoal		2			0.461 g
	Pseudotsuga - rounded	Charcoal		1			0.077 g
	cf. *Thuja plicata*	Charcoal		5			0.121 g
	Unidentified ≥ 2mm	Charcoal		X			0.260 g
	Unidentified	Wood				X	0.181 g

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-6-1	NON-FLORAL REMAINS:						
110-120 cmbs	Insect					4	
	Rock/Gravel					X	Few
	Sand					X	Abundant
DRsoil-6-2	Volume Floated/ Waterscreened						2.50 L
	Light Fraction Weight						2.86 g
	FLORAL REMAINS:						
	Rootlets					X	Moderate
	Sclerotia				X		Abundant
	CHARCOAL/WOOD:						
	Conifer	Charcoal		26			0.097 g
	Abies	Charcoal		25			0.039 g
	Chamaecyparis-type	Charcoal		30			0.045 g
	Pseudotsuga	Charcoal		15			0.021 g
	Salicaceae	Charcoal		6			0.001 g
	Unidentifiable central pith	Charcoal		5			0.001 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				X	Moderate
	Sand/Gravel				X	X	Moderate
DRsoil-6-3	FLORAL REMAINS:						
57-60 cmbs	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Total charcoal $\geq$ 2 mm						
	Conifer	Charcoal		10			0.008 g
	Abies	Charcoal		3			0.013 g
	Chamaecyparis-type	Charcoal		1			0.003 g
	Pseudotsuga	Charcoal		5			0.021 g
	NON-FLORAL REMAINS:						
	Sand					X	Moderate

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-6-4	Volume Floated/ Waterscreened						10 mL
66 cmbs	Light Fraction Weight						1.29 g
	FLORAL REMAINS:						
	Bark			X			0.029 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		9			0.009 g
	Conifer - rounded	Charcoal		2			0.002 g
	Chamaecyparis-type	Charcoal		1			0.003 g
	cf. *Tsuga*	Charcoal		1			0.004 g
	Unidentified ≥ 1 mm	Charcoal and Bark		X			0.008 g
	Unidentified	Wood				X	0.018 g
	NON-FLORAL REMAINS:						
	Sand					X	Moderate
DRsoil-6-5	Volume Floated/ Waterscreened						10 mL
76 cmbs	Light Fraction Weight						0.52 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Pseudotsuga	Charcoal		20			0.035 g
	Unidentified ≥ 1 mm	Charcoal		X			0.016 g
	NON-FLORAL REMAINS:						
	Sand					X	Moderate
DRsoil-6-6	FLORAL REMAINS:						
51-53 cmbs	Bark					X	0.021 g
	CHARCOAL/WOOD:						
	Total charcoal ≥ 2 mm						
	Conifer - vitrified	Charcoal		4			0.003 g
	Chamaecyparis-type	Charcoal		6			0.007 g
	Juniperus	Charcoal		6			0.012 g
	Unidentifiable central pith	Charcoal		3			0.002 g
DRsoil-6-7	CHARCOAL/WOOD:						

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
29-30 cmbs	*Juniperus*	Charcoal		1			0.047 g
	NON-FLORAL REMAINS:						
	Sand					X	
Drsoil-6-8	Volume Floated/ Waterscreened						10 mL
29-20 cmbs	Light Fraction Weight						1.46 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Chamaecyparis-type - slightly vitrified	Charcoal		16			0.101 g
	Platanus-type	Charcoal		5			0.033 g
	cf. *Thuja plicata*	Charcoal		9			0.292 g
	Unidentified ≥ 1 mm	Charcoal		X			0.083 g
	NON-FLORAL REMAINS:						
	Sand					X	Scant
DRsoil-6-9	Volume Floated/ Waterscreened						0.80 L
33-77 cmbs	Light Fraction Weight						7.83 g
	FLORAL REMAINS:						
	Bark			4			0.009 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Alnus - slightly vitrified	Charcoal		3			0.007 g
	Conifer	Charcoal		12			0.010 g
	Conifer - slightly rounded	Charcoal		5			0.004 g
	Juniperus - slightly rounded	Charcoal		1			0.003 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				1	
	Insect	Puparia				4	
	Sand					X	Scant

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-6-10	Volume Floated/ Waterscreened						0.90 L
7-33 cmbs	Light Fraction Weight						3.89 g
	FLORAL REMAINS:						
	Caryophyllaceae	Seed			1		
	Chenopodium	Seed			7		
	Cirsium	Seed			1		
	Sambucus	Seed			1		
	Taraxacum	Seed			2		
	Unidentified	Seed			28		
	Rootlets					X	Numerous
	Sclerotia					X	Few
	CHARCOAL/WOOD:						
	Alnus	Charcoal		1			0.015 g
	Conifer	Charcoal		5			0.031 g
	Chamaecyparis-type	Charcoal		6			0.037 g
	Chamaecyparis-type twig	Charcoal		1pc			0.034 g
	Juniperus	Charcoal		4			0.042 g
	Conifer	Wood				X	0.117 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				22	
	Insect	Egg				X	Moderate
	Sand					X	Scant
DRsoil-7-1	Volume Floated/ Waterscreened						1.00 L
208-211 cmbs	Light Fraction Weight						8.61 g
	FLORAL REMAINS:						
	Asteraceae	Seed			1		
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Total charcoal ≥ 2 mm						
	Conifer	Charcoal		1			<0.001 g
	Unidentified hardwood root	Wood and Bark				X	0.015 g

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-7-1	NON-FLORAL REMAINS:						
208-211 cmbs	Rock/Gravel					X	Moderate
	Sand					X	Abundant
DRsoil-7-2	Volume Floated/ Waterscreened						2.00 L
139-149 cmbs	Light Fraction Weight						10.72 g
	FLORAL REMAINS:						
	Bark			X			Moderate
	Rootlets					X	Few
	Sclerotia				X	X	Abundant
	CHARCOAL/WOOD:						
	Conifer	Charcoal		18			0.260 g
	Chamaecyparis-type	Charcoal		7			0.010 g
	Pseudotsuga	Charcoal		12			0.050 g
	Unidentifiable central pith	Charcoal		3			0.010 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				X	Few
	Rock/Sand				X	X	Moderate
DRsoil-7-3	Volume Floated/ Waterscreened						20 mL
98 cmbs	Light Fraction Weight						2.357 g
	FLORAL REMAINS:						
	Bark $\geq$ 1 mm - some rootlet intrusion			X			0.197 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer root	Charcoal		2			0.001 g
	NON-FLORAL REMAINS:						
	Sand					X	Scant

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-7-4	Volume Floated/ Waterscreened						30 mL
46.5 cmbs	Light Fraction Weight						8.161 g
	FLORAL REMAINS:						
	Bark ≥ 2mm - some rootlet intrusion			X			1.715 g
	Rootlets					X	Few
	Sclerotia				X		Few
	CHARCOAL/WOOD:						
	Conifer root	Charcoal		2			<0.001 g
	NON-FLORAL REMAINS:						
	Insect fecal pellet				X		Few
	Sand					X	Scant
DRsoil-7-5	Volume Floated/ Waterscreened						2.20 L
51-70 cmbs	Light Fraction Weight						14.84 g
	FLORAL REMAINS:						
	Descurainia	Seed			1		
	Sambucus	Seed			1		
	Rootlets					X	Numerous
	Sclerotia				X	X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		17			0.013 g
	Chamaecyparis-type - slightly rounded	Charcoal		1			0.005 g
	Conifer	Wood				X	0.100 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				27	
	Insect	Puparia				X	Few
	Sand					X	Scant
DRsoil-7-6	Volume Floated/ Waterscreened						1.90 L
39-49 cmbs	Light Fraction Weight						19.81 g
	FLORAL REMAINS:						
	Bark			30pc			0.625 g
	Rootlets					X	Numerous

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRsoil-7-6	CHARCOAL/WOOD:						
39-49 cmbs	Conifer	Charcoal		3			0.055 g
	Abies	Charcoal		1			0.021 g
	Juniperus	Charcoal		6pc			1.901 g
	cf. *Thuja plicata*	Charcoal		2			0.075 g
	Unidentified ≥ 2 mm	Charcoal and Bark		Xpc			0.897 g
	Conifer	Wood				1	0.018 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				12	
	Insect	Puparia			1		
DRstrat-1-0	Volume Floated/ Waterscreened						50 mL
98 cmbs	Screened Sample Weight						9.986 g
	FLORAL REMAINS:						
	Betula	Seed			1		
	Poaceae	Floret			1		
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Total charcoal ≥ 2 mm						
	Pseudotsuga - slightly vitrified	Charcoal		15			3.431 g
	NON-FLORAL REMAINS:						
	Sand					X	Scant
DRstrat-1-1	CHARCOAL/WOOD:						
73 cmbs	cf. *Tsuga* - moderately vitrified and some rootlet intrusion	Charcoal		30			15.084 g
DRstrat-1-2	Volume Floated/ Waterscreened						60 mL
78 cmbs	Screened Sample Weight						12.063 g
	FLORAL REMAINS:						
	cf. *Thuja plicata*-type	Leaf				1	
	Rootlets					X	Few

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRstrat-1-2	CHARCOAL/WOOD:						
78 cmbs	cf. *Tsuga*	Charcoal		20			4.536 g
	Unidentified ≥ 2mm	Charcoal and Bark		X			3.804 g
	NON-FLORAL REMAINS:						
	Sand					X	Scant
DRstrat-1-3	Volume Floated/ Waterscreened						10 mL
43 cmbs	Screened Sample Weight						0.423 g
	FLORAL REMAINS:						
	Conifer	Needle		1			<0.001 g
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer root	Charcoal		1			0.003 g
	Conifer	Charcoal		13			0.007 g
	cf. *Tsuga*	Charcoal		13			0.028 g
DRstrat-1-4	Volume Floated/ Waterscreened						50 mL
	Floated Sample Weight						3.766 g
	FLORAL REMAINS:						
	Rootlets					X	Few
	CHARCOAL/WOOD:						
	Conifer	Charcoal		1			0.026 g
	cf. *Tsuga*	Charcoal		25			0.674 g
	cf. *Tsuga*	Wood				9pc	0.121 g
	Unidentified ≥ 2mm	Charcoal and Wood		X			0.759 g
	NON-FLORAL REMAINS:						
	Insect	Puparia				1	
	Rock/Gravel					X	Few
DRstrat-2-1	Sample Weight						150.33 g
105 cmbs	FLORAL REMAINS:						
	Rootlets					X	Few

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRstrat-2-1	CHARCOAL/WOOD:						
105 cmbs	*Pseudotsuga* - slightly vitrified	Charcoal		20			22.44 g
	Pseudotsuga - slightly vitrified	Bark and Xylem		10			17.74 g
	Unidentified	Charcoal and Bark		X			44.85 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				5	
	Heat-altered soil					X	Moderate
DRstrat-2-2	Volume Floated/ Waterscreened						250 mL
135 cmbs	Light Fraction Weight						7.66 g
	FLORAL REMAINS:						
	Unidentified	Leaf			1		
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Abies	Charcoal		17			0.252 g
	Pseudotsuga	Charcoal		23			0.614 g
	NON-FLORAL REMAINS:						
	Sand					X	Scant
DRstrat-2-3	CHARCOAL/WOOD:						
60 cmbs	cf. Conifer w/vitrified areas	Bark		Xpc			2.75 g
DRstrat-2-4	Volume Floated/ Waterscreened						2.10 L
158-182 cmbs	Light Fraction Weight						4.07 g
	FLORAL REMAINS:						
	Leaf				2		
	Rootlets					X	Moderate
	CHARCOAL/WOOD:						
	Conifer	Charcoal		X			0.028 g
	Pseudotsuga	Charcoal		3			0.008 g
	NON-FLORAL REMAINS:						
	Rock/Gravel					X	Moderate
	Sand					X	Moderate

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRstrat-2-5	Volume Floated/ Waterscreened						100 mL
143-145 cmbs	Light Fraction Weight						6.15 g
	CHARCOAL/WOOD:						
	Total charcoal ≥ 2 mm						0.870 g
	Abies	Charcoal		38			0.392 g
	Pseudotsuga	Charcoal		2			0.016 g
DRstrat-2-6	CHARCOAL/WOOD:						
114 cmbs	Conifer - wood is twisted with vitrified areas	Charcoal		30			0.870 g
	Unidentifiable - vitrified	Charcoal		6			
DRstrat-2-7	CHARCOAL/WOOD:						
92 cmbs	cf. Conifer - with vitrified areas	Bark		Xpc			1.820 g
DRstrat-2-8	Volume Floated/ Waterscreened						1.10 L
24-57 cmbs	Light Fraction Weight						14.53 g
	FLORAL REMAINS:						
	Bark ≥ 2mm			X			0.920 g
	Bark with charred insect fecal pellets			1			
	Abies/Pseudotsuga	Needle				X	Few
	Cirsium	Seed			X	X	Numerous
	Juniperus	Leaf				X	Few
	Lactuca	Seed			1		
	Prunus emarginata-type	Seed (pit)			5		
	Trifolium	Seed			77		
	Rootlets					X	Moderate
	Sclerotia					X	Few

TABLE 2 (Continued)

Sample No.	Identification	Part	Charred W	Charred F	Uncharred W	Uncharred F	Weights/ Comments
DRstrat-2-8	CHARCOAL/WOOD:						
24-57 cmbs	Total charcoal ≥ 2 mm						0.375 g
	Conifer	Charcoal		6			0.023 g
	Conifer root	Charcoal		2			0.035 g
	Juniperus	Charcoal		1			0.010 g
	Pseudotsuga	Charcoal		13			0.103 g
	cf. *Thuja plicata*	Charcoal		1			0.001 g
	Unidentifiable	Charcoal		2			0.015 g
	Unidentifiable central pith	Charcoal		12			0.113 g
	NON-FLORAL REMAINS:						
	Insect	Chitin				7	
	Sand					X	Scant

W = Whole
F = Fragment
X = Presence noted in sample
g = grams
pc = partially charred

TABLE 3
INDEX OF MACROFLORAL REMAINS RECOVERED IN SAMPLES FROM
THE DUNGENESS RIVER GEOMORPHIC STUDY, WASHINGTON

Scientific Name	Common Name
FLORAL REMAINS:	
Asteraceae	Sunflower family
Circium	Thistle
Lactuca	Lettuce
Betula	Birch
Descurainia	Tansy mustard, Flixweed
Caryophyllaceae	Pink family
Chenopodium	Goosefoot
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Abies/Pseudotsuga	Fir/Douglas-fir
Juniperus	Juniper
cf. *Thuja plicata*-type	Western redcedar
Poaceae	Grass family
Prunus emarginata-type	Bitter cherry
Sambucus	Elderberry
Taraxacum	Dandelion
Trifolium	Clover
PET fruity tissue	Fruity epitheloid tissues; resemble sugar-laden fruit or berry tissue without the seeds, or succulent plant tissue such as cactus pads
Sclerotia	Resting structures of mycorrhizae fungi
CHARCOAL/WOOD:	
Alnus	Alder
Conifer	Cone-bearing, gymnospermous trees and shrubs, mostly evergreens, including the pine, spruce, fir, juniper, cedar, yew, and cypress
Abies	Fir
CHARCOAL/WOOD:	

TABLE 3 (Continued)

Scientific Name	Common Name
Chamaecyparis-type	Alaska-cedar, Port Orford-cedar
Juniperus	Juniper
Pseudotsuga	Douglas-fir
cf. *Thuja plicata*	Western redcedar
Tsuga	Hemlock
Platanus-type	Sycamore
Salicaceae	Willow Family

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SCHOOLHOUSE BRIDGE ANALYSIS
DUNGENESS RIVER
WASHINGTON STATE

Interim Study Report

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U.S. Department of the Interior
Bureau of Reclamation

NOVEMBER 2000

United States Department of the Interior

The mission of the Department of the Interior
is to protect and provide access to our
Nation's natural and cultural heritage and
honor our trust responsibilities to tribes.

Bureau of Reclamation

The mission of the Bureau of Reclamation
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and related resources in an environmentally and
economically sound manner in the interest
of the American public.

Executive Summary

The Dungeness River is a gravel and cobble-bed stream located on the Olympic Peninsula of northwestern Washington State. The river flows northward about 30 miles from the base of Mount Deception in the Olympic Mountains to the Strait of Juan De Fuca near the town of Sequim, Washington. On the lower 2.8 miles of the Dungeness River, several levees have been built to provide flood protection (see figure 1). As part of a river restoration effort to restore access to the floodplain during peak flows, it has been proposed that a portion of the levees be laterally setback farther away from the river channel or removed entirely. A study by Reclamation has already been completed that analyzes the impacts of the levees on the river channel and various alternatives for setting them back (Reclamation draft progress report, March 2000). Schoolhouse Bridge, located approximately 0.8 river miles upstream from the mouth, is the only bridge in this reach. The bridge is located at a natural constriction along the Dungeness River. However, there is a concern that the bridge may be additionally constricting the river channel and causing a backwater effect upstream. The purpose of this study is to evaluate the hydraulic impacts of Schoolhouse Bridge and the levees located downstream of the bridge, and how those impacts would change if the bridge span were lengthened and the downstream levees removed.

It has not been determined which levees will be setback or removed as part of the river restoration effort. The Army Corps of Engineer's constructed the levee that is located on the east terrace of the river both upstream and downstream of Schoolhouse Bridge. It has been proposed that upstream of the Schoolhouse Bridge the Army Corps of Engineer's (Corps) levee be laterally set back to the east farther away from the river channel, but downstream of the bridge the Corps levee would remain in place along the east terrace to protect the town of Dungeness. It has also been proposed that downstream of Schoolhouse Bridge, a levee along the west terrace of the river would be removed (River's End levee). It has not been determined whether a private levee (Beebe's levee) located on the west terrace upstream of Schoolhouse Bridge would be setback in conjunction with the Corps levee setback.

Historically, the Dungeness River spilled over its banks during high flows depositing fine-grained materials (fine sand, silt, and clay) on both the east and west terraces of the river in the lower 2.8 miles. A portion of the flow that overtopped onto the east floodplain would enter Meadowbrook Creek and never return to the Dungeness River. This resulted in a reduction in magnitude of peak flows passing through Schoolhouse Bridge. With the current levee constrictions, all flows are maintained within the river channel and no flow has ever overtopped the Corps levee. However, the River's End levee downstream of Schoolhouse Bridge has been overtopped and breached during the 2-year flood (2,990 ft^3/s). It is estimated that upstream of Schoolhouse Bridge, flows greater than the 10-year flood (5,780 ft^3/s) could cause overtopping into the east floodplain if the levees were setback. With the currently proposed levee setback configurations, access to other drainages will continue to be cut off as they are now. This results in virtually all of the overbank flow eventually reentering the Dungeness River and passing through Schoolhouse Bridge as they do currently during floods. The overbank flow will return to the main river channel as either overland flow or through groundwater recharge and will lag the time the peak flow occurs at Schoolhouse Bridge. The impact on reducing the magnitude of the peak at Schoolhouse Bridge will depend on how far the levees are setback and the amount of overbank flow.

The majority of the time, at flows below the 2-year flood, the existing Schoolhouse Bridge has minimal impact on river channel flows. At higher flows, the River's End and Corps levees downstream of the bridge have a greater impact on water surface elevation than the actual bridge itself. Backwater effects from the downstream levees cause the west terrace just upstream of the bridge to be inundated, where historically (prior to the building of the levees) it was not.

Model results show that removal of the River's End levee would have a large enough impact on reducing water surface elevations at the bridge site to likely eliminate innundation of the upstream west terrace that now occurs. Lengthening the bridge and excavating the west terrace down to 1930's topography will likely cause velocities at the bridge site to reduce, but the current flooding can only be prevented if the downstream levee is also removed. Removal of the Corps levee in addition to or in place of the River’s End levee would also reduce flooding impacts at the bridge site but this is not being proposed at this time. If the bridge were to be lengthened, the west terrace must be excavated down to the 1930's topography or the lengthening would have no benefit to improving river hydraulics (reducing velocities). Modeling the typical high tide elevation in Dungeness Bay and peak river flows, wetted widths at the bridge are estimated to extend only 200 feet from the existing left bridge deck if the surface is excavated down to the 1930's topography. This implies that lengthening the bridge span by 200 feet would be the maximum needed to eliminate possible channel constrictions at peak flows at the bridge site if the River’s End levee is also removed. If the main river channel were excavated to a lower elevation and widened, historical documentation suggest that the channel would quickly begin to aggrade on the inside of the river bend and return to its current geometry. This likelihood to aggrade was demonstrated when the channel was modified for the bridge construction in 1964. The channel bottom was widened by excavating a large portion of the channel bottom to the 1964 thalweg, but it subsequently aggraded back to the pre-construction topography similar to the existing geometry.

If modifications at the Schoolhouse Bridge site are to be implemented, it is recommended that the downstream west levee be removed first. After removal, the bridge site could be monitored to determine if flooding of the upstream west terrace has been eliminated. If it is determined that flooding is still a problem or that a reduction in velocities is desired, the bridge and west terrace could then be modified. The west terrace must be excavated down to the 1930's (natural) topography in addition to lengthening the bridge to have any benefit. However, the channel would likely deposit new sand and gravel on the left (west) side if too much of the channel bank were excavated.

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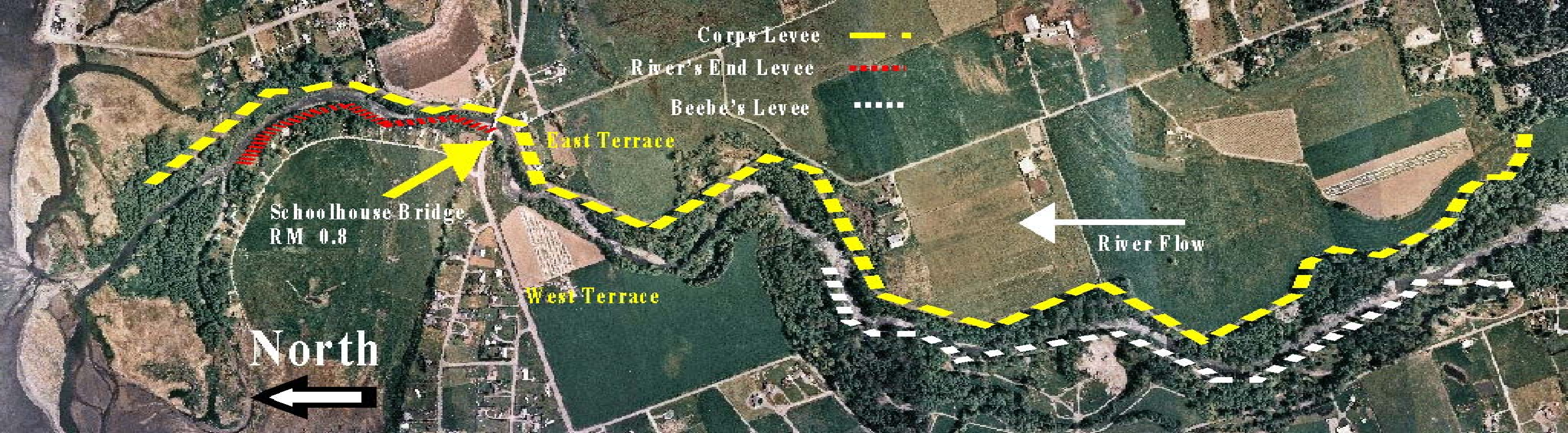
Study Purpose

An ongoing effort by local agencies and individuals has been undertaken to evaluate the benefits of setting back the Army Corps of Engineers (Corps) flood-control levee, located along the east terrace of the lower 2.8 river miles (RM) of the Dungeness River (figure 1). As part of this effort, Reclamation has been asked to evaluate the hydraulic impacts of Schoolhouse Bridge and the levees located downstream of the bridge, and how those impacts would change if the bridge span were lengthened and the downstream levees removed. Schoolhouse Bridge is the only bridge to cross the river channel in the lower 2.8 river miles. Reclamation is concurrently working on a study for the Jamestown S'Klallam Tribe to evaluate the natural processes of the Dungeness River in the lower 10 miles, and how human intervention has impacted and altered these processes.

Study Background

The lower portion of the Dungeness River has been impacted by human development for a number of decades (see figure 1). Several areas have been logged, levees have been built to protect development areas, and various structures have been used to protect river banks from eroding. Along the east terrace of the lower 2.8 river miles, a levee built by the Corps prevents flooding and protects the town of Dungeness, Washington. From RM 2.8 to 1.6, the west side of the river is bounded by a private levee (built to counteract increased flooding caused by the Corps levee). From RM 1.6 to 0.8 the west side of the river is bounded by natural high topography. In several areas, the river is very constricted and aggradation in the river channel has occurred upstream. At RM 0.8, Schoolhouse Bridge crosses the river channel (figure 2). This bridge was originally built at a location 150 feet upstream of its current location. It was rebuilt in 1963 and was tied into the Corps levee on the east terrace, and natural high topography on the west terrace. Downstream of Schoolhouse Bridge, the Corps levee continues on the east terrace of the river and a low (small in height) levee (noted



Corps Levee
River's End Levee
Beebe's Levee
East Terrace
Schoolhouse Bridge
RM 0.8
River Flow
West Terrace
North

as River's End levee) exists along the west terrace. The height of the River's End levee is significantly lower than the Corps levee (figure 3). The River's End levee continues downstream from Schoolhouse Bridge (RM 0.8) and ends near RM 0.4, just upstream of where a side channel passes flows to the northwest during high flows and/or tides.

Figure 2. Looking downstream at Schoolhouse Bridge from Corps levee in May, 1998.

Figure 3. Looking downstream from Schoolhouse Bridge at west floodplain and River's End levee (right side of picture).

As part of a restoration effort by the Dungeness River Management Team (DRMT) and the Jamestown S'Klallam Tribe to limit human impacts on the Dungeness River, it has been suggested that the Corps levee be setback away from the river so that its effects on natural processes are greatly reduced.   Although some development does exist upstream of Schoolhouse Bridge on the east terrace of the river, the greatest amount of development exists downstream. Because of the extensive development downstream of the bridge, including the town of Dungeness, only the portion of the Corps levee upstream of Schoolhouse Bridge is being considered for setback, although the downstream portion could also be considered at a later time. Part of the setback initiative involves addressing whether the span of Schoolhouse Bridge also needs to be lengthened to reduce any impacts it might cause on the river. Downstream of Schoolhouse Bridge, the River's End levee on the west terrace is being considered for removal to partially restore the delta processes of the Dungeness River as it enters the Straight of Juan de Fuca. This report focuses on the natural processes at Schoolhouse Bridge and how they have been altered, and whether the bridge needs to be lengthened as part of the restoration efforts.

Data Collection

<u>River channel, floodplain, and terrace topography</u>

River channel survey data were collected by Reclamation in 1997 and 1998 to document existing river channel conditions in the study reach. In addition, a 2-foot contour map, developed in 1999 by Walker and Associates for the Clallam County Road Department, was used to document out-of-water topography (portion of contour map represented on attached plan drawing). Historical river channel data from 1963 were obtained from a plan drawing developed for the construction of the existing Schoolhouse Bridge, which was built in 1964. The existing bridge replaced an older structure that was sited approximately 150 feet upstream of the present location. Historical floodplain and terrace data from a 1930's topographic map by the County were also utilized to develop an original ground surface that pre-dates construction of both the Army Corps of Engineers levee and the existing bridge.

<u>River Discharge</u>

Discharge data are recorded at the United States Geological Survey (USGS) gaging station located at River Mile (RM) 11.8, almost 2 miles upstream of the state fish hatchery. In addition, two temporary gages have been established at the Schoolhouse Bridge by the Washington Department of Ecology (DOE) and the USGS (figure 4). DOE data available for the past year include velocity, water surface elevation, discharge, and cross section measurements. USGS gage data consisting of cross section measurements, water surface elevations, and discharge measurements are estimated to be available in November 2000. These data will be used to evaluate short-term changes in channel bottom at the bridge site. Also, water surface elevation measurements from the Schoolhouse Bridge gaging stations may help in evaluating the influence of tides at the bridge site.

Figure 4. Looking at east bank below Schoolhouse Bridge showing USGS and DOE staff gages.

<u>Tidal Data</u>

Limited tidal data for Dungeness Bay were collected from June 8-24, 1926 and December 10, 1940 through January 11, 1941 by the National Oceanic and Atmospheric Administration (NOAA) (appendix A). During the 1926 data collection period, Dungeness River flows recorded at the USGS gage did not exceed 500 ft^3/s, and during the 1940-41 period they did not exceed 800 ft^3/s. Based on the tidal data collected, NOAA estimates the highest water level to the nearest half foot to be 11.5 feet (NGVD '88) (table 1). An estimate of the “typical” daily high tide of 9.1 feet is currently published. The estimate was generated using the Tides and Currents nautical software which bases its predictions on NOAA data (NOAA, 1998).

Table 1. - Tidal levels for Dungeness Bay, Strait of Juan de Fuca based on NOAA data

	Tide Level (feet)	Tide Level (NGVD ‘88 feet*)
Estimated highest water level	11.0	11.5
Mean higher high water	7.6	8.1
Mean high water	6.9	7.4
Mean tide level	4.7	5.2
Mean low water	2.5	3.0
Mean lower low water	0.0	0.5
Estimated lowest water level	- 4	-3.5

*An exact datum conversion to NGVD ‘88 was not published, but a datum conversion of +.5 feet was available from the nearby Port Angeles NOAA gaging station which was appropriate for this analysis.

Drilling Data

Subsurface data from explorations have been used to evaluate the site geology of Schoolhouse Bridge. These data have been compiled from a number of sources (site locations shown on the attached plan map). Two test holes (TH-1 and -2) were drilled by the County for the design of the existing structure. Logs for these holes are shown on a County Road Department drawing dated January 29, 1964 (sheet 2 of 5). These holes represent the deepest explorations conducted at the site to date with TH-1 reaching a bottom depth of 77.0 feet. Eleven auger holes (B-1 through -11, inclusive) were drilled in the vicinity of the bridge by Nelson-Couvrette and Associates, Inc., for the County in January 2000. Logs, a plan map, and a geologic cross section are documented in a report by Nelson-Couvrette to Clallam County dated February 28, 2000. The maximum depth attained in these explorations was 24.0 feet in B-1.

Additional field data in the vicinity of Schoolhouse Bridge were obtained by Reclamation during the 2000 field season. A stratigraphic profile (DRstrat-1) was described for an exposure of glacial materials on the west bank of the river about 450 feet upstream from the bridge. Maximum depth of this exposure was 3.2 feet, although a significant portion of the outcrop was submerged by river flows during field mapping. A detailed soil profile was prepared for materials exposed in a shallow utility trench (DRsoil-5) recently excavated on the topographic high east of Schoolhouse Bridge and the Dungeness Schoolhouse. This trench was 4.1 feet deep.

Geology of Dungeness River

<u>Natural Geologic Constriction at Schoolhouse Bridge Site</u>

Schoolhouse Bridge is located at a natural constriction of the Dungeness River where the channel passes between two low relief, topographic features. The west side of the river is bounded by the east end of a prominent sea cliff that is nearly 100 feet high near Dungeness Spit (about 2.5 miles west of the bridge). This sea cliff gradually slopes downward to the east and plunges beneath the ground surface at the bridge crossing. An erosional remnant of the sea cliff rises as a prominent knob on the east terrace of the river and bounds the Dungeness on the right side of the channel. This knob extends to the east for a distance of 1400 feet before plunging beneath the floodplain near Meadowbrook Creek. Geologic mapping of the sea cliff by Othberg and Palmer (1979) demonstrates that the sea cliff is composed largely of Pleistocene glacial deposits that have been exposed through isostatic rebound following retreat of the Pleistocene Juan de Fuca continental ice sheet about 13,000 years ago. At some point during isostatic rebound of the coast line, the Dungeness River became pinned between the two remnants of the glacial deposits, preventing the channel from moving across the extensive floodplain to the east toward Meadowbrook Creek.

Field mapping in 2000 located an extensive outcrop of compact fine sand, silt and clay along the west terrace of the Dungeness River about 450 feet upstream of Schoolhouse Bridge. These materials are very resistant to erosion by the river, thus the outcrop has deflected the course of the north-flowing Dungeness to the east in a broad bend. Schoolhouse Bridge is located near the apex of the bend, which then curves back to the northeast downstream from the bridge. A stratigraphic profile labeled DRstrat-1 marks the approximate eastward extent of the outcrop, as it is exposed along the west terrace (see the plan map for the location of DRstrat-1).

Materials very similar to the outcrop were exposed in a utility trench excavated in an open field on the glacial knob east of Schoolhouse Bridge and the Dungeness River. Soil profiles describing the exposed materials were recorded at several locations along the trench. DRsoil-5 marks the location of a typical soil profile for the trench (see the plan map for location of DRsoil-5). A comparison of the materials exposed in the river bank at DRstrat-1 and in the trench at DRsoil-5 with sea cliff exposures at Dungeness Spit and at Port Williams showed a very strong correlation with the uppermost unit cropping out in the cliffs: the Everson glaciomarine drift. This unit consists of pebbly silt and clay with silty sand of glacial origin that were deposited in a marine environment, as indicated by the presence of scattered shells throughout the deposit. The Everson drift appears to have been deposited in the Strait of Juan de Fuca as the continental ice sheet retreated north into Canada and marks the final stage of glaciation in this area. The drift is compact and has developed a series of high-angle fracture systems that give the unit a columnar appearance when exposed to weathering. Dethier and others (1995) reported a radiocarbon (^{14}C) date of 12,600 $\pm$ 200 year B.P. for a shell taken from Everson deposits exposed near the Potholes area to the south of Schoolhouse Bridge.

Using profiles from DRsoil-5, a layer of complexly interbedded and interfingered fine sand and silt overlying the Everson glaciomarine drift was identified. These overlying materials appear to be significantly younger than the drift and include three burn horizons within the unit. The origin of this layer and its relationship to the Everson is uncertain, but these materials may represent delta, beach, and/or estuary deposits laid down prior to or during emergence of the sea cliff as a result of isostatic rebound. Charcoal samples have been collected from the burn horizons for ^{14}C dating and the origin of the material may be more evident once age determinations are obtained for the samples. It is anticipated that the ^{14}C age dates will be available by January or February 2001. For the purposes of the present evaluation, the overlying layer has been included with the Everson glaciomarine drift on the attached geologic sections.

Dungeness River Alluvium

Following the retreat of the continental ice sheet at the end of the Pleistocene, the geology at Schoolhouse Bridge has been dominated by alluvial processes of the Dungeness River in the form of (1) coarse-grained river channel alluvium and (2) fine-grained floodplain and overbank deposits. River channel alluvium consists chiefly of cobbles, gravel, and sand and very minor amounts of silt and clay deposits. The extent of the alluvium is poorly known at the bridge site, as all exploratory drilling conducted to date has failed to intercept the unit outside the margins of the present river channel. These limited data suggest that the alluvium is confined to the main river channel and its immediate vicinity. The vertical extent of the alluvium shown on the attached geologic cross sections has been approximated from the interpreted depth of adjacent floodplain materials which have generally been deposited contemporaneously with the alluvium.

Dungeness River Floodplain Upstream of Schoolhouse Bridge

Prior to the construction of the Army Corps of Engineer’s flood-control levee in 1963 and the River’s End levee along the west terrace, the Dungeness River had built an extensive flood plain within the lower 3 miles of the river. Flooding occurred because once the channel capacity was exceeded during high flows, a portion of the river flows spilled out over the banks of the river onto the adjacent floodplain and moved overland away from the channel. As these flows exited the main channel by laterally overtopping the banks, sediments that are transported by the river in suspension (fine sand, silt and clay) were carried onto the floodplain and deposited as flows receded.

During these high flows, river flows would access floodplains on both the east and west sides of the river from approximately RM 2.8 (upstream end of levee) downstream to RM 1.8. From RM 1.8 to Schoolhouse Bridge, natural high topography on the west terrace caused the majority of overbank flows to overflow onto floodplains along the east terrace of the river. Along all of the east floodplain from the upper end of the levee to Schoolhouse Bridge, higher volume flows would have easily crossed the floodplain and moved into the Meadowbrook Creek drainage to the east. Low-volume flood events were likely captured by the glacial knob east of the river and rerouted back into the Dungeness upstream of Schoolhouse Bridge. This was documented by the Army Corps of Engineers delineation of the flood of 1949 (peak of 6,820 ft^3/s) (figure 5).

Levee Impacts on Floodplain in the Vicinity of Schoolhouse Bridge

The west terrace of the river in the vicinity of Schoolhouse Bridge consists of glacial deposits which rise gently to the west. Therefore, the east floodplain near Schoolhouse Bridge is lower in elevation. As a result, prior to the levee construction high flows typically inundated the east floodplain just upstream of Schoolhouse Bridge much more frequently than the west side. This prevented any substantial floodplain development on the west terrace of the river. The Corps levee now cuts off all access to the east floodplain and the majority of flows are contained within the main channel. This results in a larger magnitude of flow passing through Schoolhouse Bridge than flows that occurred historically.

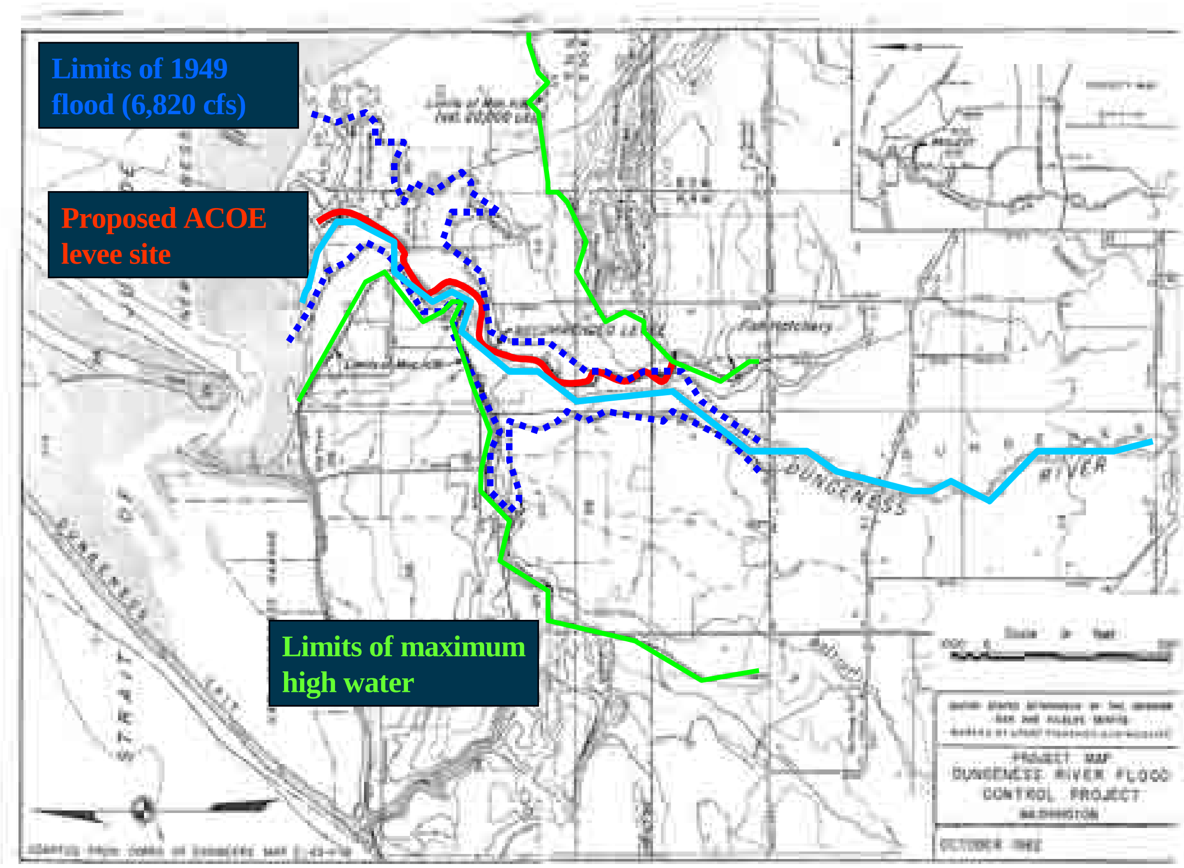


Figure 5. Map of lower Dungeness River developed during the ACOE levee design phase showing extent of 1949 flood of 6,820 ft^3/s.

The increased discharge (during high flows) causes an increased stage at the Schoolhouse Bridge and just upstream of the bridge. Aggradation of the river channel in several parts of the levee reach has probably aggravated the problem and increased the flood stages even further. As a result of the increased river stages, the west terrace upstream of the bridge becomes inundated and forms an eddy during high flows. This has resulted in a limited accumulation of floodplain deposits on the west terrace.   The County has installed a culvert beneath the roadway to direct excess flows onto the downstream west floodplain and prevent flooding of the road surface (see the culvert location on geologic cross section A-A' map). Prior to installing the culverts, the road was frequently overtopped, but since installation the road has not been inundated (Freudenthal, 11/9/2000 written communication).

The vertical extent of the floodplain deposits on both banks is not well understood. These materials are very similar to the underlying Everson glaciomarine drift and it is often difficult to distinguish the two. The vertical extent shown on the geologic cross sections is based on the log of test hole TH-2, which describes buried woody debris mixed in with the fine-grained floodplain deposits (see cross section A-A, B-B, and C-C). Woody debris are not present in the glaciomarine drift. This vertical extent should be viewed as a minimum value and the actual depth may be somewhat deeper than shown on the cross sections.

To further investigate the vertical extent of the deposits, a comparison of ground surface contours from 1999 and the 1930's was done for this area. The comparison showed that the 1999 ground surface line (county contour map) is consistently 2 to 4 feet higher than on the 1930's map, as shown on geologic cross sections B-B' and C-C'. This discrepancy in the ground surface elevations could represent the vertical extent of floodplain deposits since construction of the Corps levee in 1963. There is always a potential for a vertical datum difference between the two surveys. However, a comparison of 1930's and 1999 topography downstream from Schoolhouse Bridge shows a very close agreement, suggesting that a datum difference is not a problem. In addition, the elevation difference is not constant across the entire section which further supports the idea that this difference is not caused by a vertical datum shift between the two surveys.

Mapping of the bank exposure along the west terrace in this area at DRstrat-1 shows about 2.8 feet of floodplain sand and silt overlying an outcrop of the Everson glaciomarine drift. Charcoal samples were collected from two prominent burn horizons exposed in the floodplain deposits and ^{14}C age determinations for these samples should aid in establishing a chronology for the deposits (results will be available during January or February 2001).

Mechanical disturbance of the area may also explain the discrepancy between the 1930's and 1999 ground lines. This area has been the site of several bridge crossings over the Dungeness

River since construction of the first Dungeness River bridge was completed at the site in 1872. Both the 1930's and 1963 maps document construction of wooden bulkheads along the river bank to protect the abutments of the previous Dungeness River bridge. Note that the locations of test holes TH-1 and TH-2 on the plan map mark the alignment of the previous bridge which was replaced by Schoolhouse Bridge in 1964. Drilling in TH-2 and in B-4 show from 6.5 to 10 feet of fill materials behind the bulkhead and in the approach ramp to the old bridge, suggesting considerable disturbance in the area. On both cross sections B-B' and C-C', the difference between the ground elevation lines is near the minimum at the river bank and progressively becomes larger in the downstream direction as the ground line nears the existing road embankment. It is likely that at least a significant portion of the ground line difference results from construction of the existing roadway and bridge in 1964. Material that was unsuitable for construction of the road fill may have been wasted upstream of the bridge and spread out across the ground surface to avoid having it transported to another disposal site.

Downstream of Schoolhouse Bridge

Geologic conditions are poorly known downstream of Schoolhouse Bridge due to a lack of explorations in that area. The alignment of the sea cliff to the west of the bridge defines a prehistoric coast line etched into the glacial sequence that forms the deep foundation of the bridge. It is likely that these materials plunge to the north beneath a relatively extensive complex of floodplain deposits, delta, salt marsh, and estuary materials that have been deposited at the mouth of the Dungeness River. A review of historic maps of the area dating from 1855 show that the river channel has moved across this floodplain/coastal plain repeatedly, likely resulting in a complex sequence of channel deposits that are interfingered and interlayered with fine-grained sand, silt, and clay. The old 1855 channel is still visible in aerial photographs of the area and it is likely that overbank flows from the present channel could access this older channel if the present River's End levee is removed. Flooding in the winter of 1998-99 demonstrated this point when flows overtopped and breached the dike and flowed westward across the floodplain into the1855 channel. Any river restoration project to lengthen the existing bridge opening should consider test drilling downstream of the bridge on the west terrace to determine the configuration of the glacial materials and their relationship with overlying floodplain, delta, and estuary deposits.

Past and Present Conditions at Schoolhouse Bridge

1930's Bridge Site and Topography

A 2-foot contour map developed from 1930's survey data documents approximately 4.4 miles of the lower Dungeness River and surrounding topography. This map does not contain any underwater data documenting the channel thalweg at that time, but does include data for the out-of-water portion of the river channel and the adjacent flood plain. The 1930's map shows the location of the old Schoolhouse Bridge, called the Dungeness River Bridge, which was approximately 150 feet upstream from the current location of Schoolhouse Bridge.

The 1930's map shows that prior to the construction of the new bridge (built in 1964), the Dungeness River channel was naturally constricted between two topographic highs on both the east and west sides of the river at the existing location of Schoolhouse Bridge. At this location, the 1930 channel width was approximately 70 feet wide, as shown on geologic cross section A-A' (attached). Note that the thalweg of the channel is not documented since no bathymetric data were recorded for this map.

The 1930's map also shows the location of man-made structures along the river, including wooden bulkheads installed to protect the river bank from erosion and to prevent flooding of low-lying areas adjacent to the channel. The map shows that one of these bulkheads existed just upstream from the old Dungeness River bridge on the west terrace and was about 150 feet long. This bulkhead appears to have been constructed to protect the left (west) abutment of the old bridge. Another bulkhead was constructed about 250 feet downstream of

Schoolhouse Bridge on the east terrace of the river. This bulkhead was also about 150 feet long and protected a topographic low in that area.

1963 River Channel Prior to New Bridge

In 1964, the original Schoolhouse Bridge was taken down and a new bridge was built approximately 150 feet downstream. This bridge is still in existence today. A 2-foot contour map was developed for the new bridge construction (map dated May 1, 1963). This map documents bathymetric data in the river channel at the new bridge location and limited portions of the flood plain topography adjacent to the new bridge site.

The 1963 river channel was about 85 feet wide. The thalweg was located on the outside of the river bend (right side) where velocities are highest and erosion is possible. A gravel bar was located on the inside of the bend (left side) where secondary currents typically deposit sediment. Comparison of the 1963 map with the 1930's map shows that along the left side of the channel (inside of the river bend near the existing left abutment of Schoolhouse Bridge) the channel bed is consistently higher in 1963 than in 1930 (see geologic cross section A-A' on attachment). Comparison of the two channel bottoms suggests an average aggradation along the inside bend of 5 to 6 feet. This aggradation would most likely have been the accumulation on a gravel bar deposited on the inside of the river bend, but could have possibly been a small earthen dike constructed to protect the west terrace of the river from flooding. Also, between 1930 and 1963, the Dungeness River laterally eroded about 20 to 25 feet of the east terrace along the outside of the river bend. In accordance with the erosion, the thalweg shifted to the toe of the newly eroded bank, thus remaining on the outside of the river bend where velocities are highest.

The 1963 map also shows an "old" log bulkhead located upstream on both abutments of the old Dungeness River bridge and downstream of the old bridge along the east terrace. The bulkheads on the left bridge abutment and the downstream east terrace are in similar locations to the bulkhead locations shown on the earlier 1930's map. The bulkhead on the right bridge abutment appears to have been added subsequent to completion of the 1930's topographic map, as it does not appear on the earlier map.

1964 Bridge Relocation and Modifications to River Channel

Schoolhouse Bridge was moved to its current location in 1964, shortly after the Army Corps of Engineers construction of a flood-control levee in 1963 along the east terrace of the lower 2.8 miles of the Dungeness River. As part of the new bridge construction, the bridge was tied into the new Army Corps of Engineers levee along the east terrace of the river and the river channel was modified.

As part of either the levee or bridge construction, the river channel at the bridge site was altered. The existing thalweg on the right side of the1963 river channel was filled in (see attachment drawings). The remainder of the channel bottom, including the gravel bar on the inside of the bend, was then excavated in the approximate shape of a trapezoid to the depth of the 1963 thalweg (elevation 7 feet). As a result, a 100-foot wide, flat bottom channel was created that had significantly different geometry than the pre-construction channel. Both the east and west river banks were covered with riprap to provide stabilization. The dimensions of the 1964 channel modification are shown on geologic cross section A-A’ and are based on the limits of excavation (shown on a County Road Department drawing dated January 29, 1964). Note that the new, 100- foot wide 1964 channel was substantially wider than the 1930's or the 1963 river channel, exceeding the previous widths by 30 and 15 feet, respectively.

Figure 6 shows a County Road Department photograph of Schoolhouse Bridge taken shortly after completion of the work in 1964. The dimensions of the channel relative to the bridge illustrated in this photograph closely approximate the estimate of the 1964 widening dimensions shown on the drawing A-A’. The volume of the channel widening work was about 3900 cubic yards of material, as tabulated on a County Road Department drawing (dated February 5, 1963 and subsequently revised on May 2, 1964).

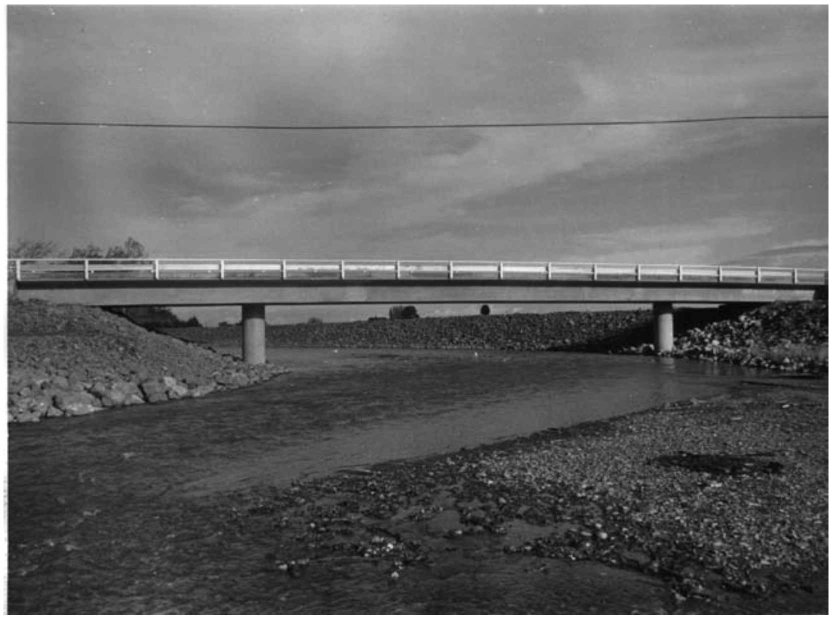


Figure 6. View downstream showing Schoolhouse Bridge after completion of construction and channel widening in 1964. Note the broad, flat configuration of the river channel bottom following channel widening. The Army Corps of Engineers flood-control levee is present on the east terrace. Photograph courtesy of the Clallam County Road Department.

<u>River Channel Comparison to Existing Conditions</u>

Reclamation obtained survey data at Schoolhouse Bridge in 1997 and in 1998 to establish current conditions at the site. Comparison of existing channel conditions to conditions prior to the new bridge construction (in 1963) show that a significant bar of gravel and cobbles has accumulated on the left side of the channel that was excavated in 1964 (drawing A-A'). The left side of the channel is located on the inside of a river bend and, as would be expected, about 12 feet of deposition has occurred since 1964 as a result of secondary currents. The thickness of the bar deposit decreases to the right (looking downstream) and restricts the low-flow channel to a width of about 40 feet. The high-flow channel width is about 90 to 120 feet, depending on the stage of the river. In addition, the right side of the channel (outside of the bend) was filled in during bridge construction and the existing thalweg, located slightly to the left of the old location, is not as deep as it was in 1963.

River Hydraulics Model

The HEC-RAS river hydraulics model (U.S. Army Corps of Engineers) was applied to the study reach to compare tidal influence, water surface elevation, average cross-section velocity, and water depth for existing conditions at Schoolhouse Bridge, and for alternatives for lengthening the bridge and removing the River's end levee. Removal of the Corps levee on the east terrace is not being considered at this time. The model can predict the following hydraulic parameters for any given discharge on the Dungeness River:

- Water surface elevation
- Average velocity
- Water depth for any given discharge

The data needed to create the model were tidal data, river channel geometry (see appendix B for plots), channel roughness (a flow resistance parameter), water discharge, and topography of floodplains and terraces in the study area. For this analysis, a combination of subcritical flow and critical flow were used . The tide elevation in Dungeness Bay was used as the downstream boundary condition (necessary for subcritical flow regime computations). The likelihood of a maximum tidal elevation occurring concurrently with peak river flows is not known at this time. Therefore, a typical high tide elevation of 9 feet was used as the downstream boundary condition to account for the typical tidal influence that could occur at any discharge. Modeled discharges were based on a flood frequency analysis completed by Reclamation (table 2) (England, 1999). As mentioned previously, if either or both of the levees are setback upstream of Schoolhouse Bridge, a portion of the river flows will overtop the banks during floods and causing a potential reduction in the magnitude of the peak flow through the bridge. The exact reduction in the peak discharge due to gained access to upstream floodplains can not be determined since the specifics of levees setbacks have not been decided. Therefore, the magnitudes of the peak floods were not reduced.

Table 2. River discharges for hydraulic modeling based on flood frequency analysis.

	Typical low flow	2-year	5-year	10-year	25-year	Flood of record
Discharge (ft^3/s)	1,000	2990	4690	5780	7120	7540

The study reach modeled extends from the Schoolhouse Bridge (RM 0.8) to the mouth of the Dungeness River in Dungeness Bay. Cross sections were developed from river channel data surveyed in 1997 and 1998, and out-of-water topography from the county contour map developed from 1999 data (cross section profiles documented in Appendix B). Two cross sections were developed in Dungeness Bay, also from the county contour map.

Existing Conditions

The longitudinal profile of the existing Dungeness River channel bottom has a break in slope in the vicinity of Schoolhouse Bridge which indicates the start of the delta (figure 7). Model results for existing conditions show that the existing channel at the bridge site can handle the peak flood of record without overtopping the bridge or the Corps levee on the east terrace. A typical maximum channel depth at the 2-year flood (2,990 ft^3/s) is 9 feet, which occurs at the thalweg on the right side (along the outside of the bend). As mentioned earlier, a gravel bar exists along the left side of the channel at the bridge site because deposition typically occurs on the inside of river bends. This gravel bar has persisted in the past and will likely continue to persist in the future based on historical channel comparisons (see geology section).

Just upstream of the bridge on the west side, a terrace exists that is 20 feet in elevation. It has been documented by Clallam County that this terrace is often overtopped during peak flows, and during one occasion was overtopped during a low river flow which indicates a possible tidal influence (table 3) (Freudenthal, 10/9/2000 written communication). Based on the typical high tide of 9.1 feet, there is more than a 10 foot elevation difference between the typical high tide of 9.1 feet in Dungeness Bay and the elevation of the west terrace at 20 feet. This suggests that it would take an extremely high tide, or more likely formation of a log jam, to cause inundation of this terrace at a low river discharge. However, at river discharges close to those observed (near the 5-year flood), the model does show that the water surface elevation at the bridge is above the 20 foot elevation of the west terrace indicating this surface would likely be overtopped as a result of a backwater effect. The longer the river discharge remained high, the greater the impact of flooding on this surface. This result matches the county's observations that at higher river discharges the west terrace, upstream of the bridge, is easily overtopped and culverts that have been installed under the road convey water.

Table 3. Observations by Clallam County that document when the west terrace upstream of Schoolhouse Bridge was inundated due to high river discharge and/or tidal influence.

Date of observation	River discharge (ft^3/s)
1/30/92	5,090
2/01/95 or 2/19/95	2,400 (average)
12/13/95	4,500
12/20/94	4,850

<u>Impacts of Levees Downstream of Schoolhouse Bridge</u>

Downstream of Schoolhouse Bridge, the Corps levee has never been overtopped by river flows because the River's End levee on the west terrace is much lower in elevation. This causes flooding of the west terrace rather than the east terrace during peak flows. Because it would endanger the town of Dungeness, it has been proposed that only the River's End levee be removed to allow high river flows to access the natural floodplain on the west terrace downstream of Schoolhouse Bridge. It is unknown when the River's End levee was constructed on the west terrace or who originally constructed it. The model was used to determine what impacts the levees downstream of the bridge have on water surface elevations and what impact it has on flooding of the west terrace just upstream of Schoolhouse Bridge.

Model results show that the River's End levee is not very effective in preventing any large magnitude floods from overtopping the west terrace. Just downstream of Schoolhouse Bridge, the levee protects the west terrace from overtopping up to the 25-year flood. However, just over ½ mile downstream from Schoolhouse Bridge protection provided by the River's End levee reduces to only the 2-year flood. In other words, even with the levee in place the west terrace likely gets overtopped frequently, an average of every 2 years. This was verified during a winter storm in 1998 when the west levee was breached and flooding occurred into the west floodplain. Without the levee, model results show the west terrace would get overtopped even more frequently, likely at any flow above 1,000 ft^3/s.

Even though the River's End levee provides minimal protection to the west floodplain downstream of Schoolhouse Bridge, the levee, combined with the impact of the downstream Corps levee, does cause a small backwater effect that would not naturally exist. The impact of this backwater effect at Schoolhouse Bridge is approximately a 1-foot increase in water surface elevation at a 2-year flood or a 2-foot increase at a 5-year flood (figure 8). The model results indicate that if the River's End levee were removed and the Corps levee were left in place, the west terrace would be inundated infrequently. Even at the peak flood of record the water surface elevation at the bridge would be just below 20 feet with the River's End levee removed.

Impacts of Altering Schoolhouse Bridge Site

Hydraulics were compared at the bridge site for the existing conditions and for excavating and widening the west terrace. For modeling purposes, the existing bridge was essentially removed and the west terrace was excavated down to the 1930's topography. It was also assumed that the Corps levee would remain in place along the east terrace, but the River's End levee would be removed to reduce any backwater effects that exist. With the bridge modified, the west terrace excavated, and the downstream west levee removed the 2-year flood just overtops the modified west terrace. The east terrace would still be contained by the Corps levee. Therefore, lengthening the bridge would have no hydraulic impact for flows less than the 2-year flood. The west terrace begins to be overtopped at a substantial distance by the 5-year flood or greater peak flow (figure 8).

At any flow magnitude with the River's End levee removed, the overtopping on the west terrace at the bridge never extends past 200 feet from where the existing left bridge abutment is. This suggests that the bridge does not need to be lengthened more than 200 feet to eliminate any constrictions on the river channel at high flows. The depth of overbank flows on the inside bend during these large peak flows would be on average 1-foot. It would be likely that when this surface is overtopped fine-grained material would deposit because the surface is located on the inside of a river bend where secondary currents cause deposition. Without excavating the west terrace down to the 1930's topography, there is no benefit to lengthening the existing Schoolhouse Bridge. The biggest impact on water surface elevation at the bridge site results from removing the River's End levee (downstream west side). Lengthening the bridge combined with excavating the west terrace down to the 1930's topography will likely reduce velocities at the bridge site due to the expansion in wetted width during peak flows.

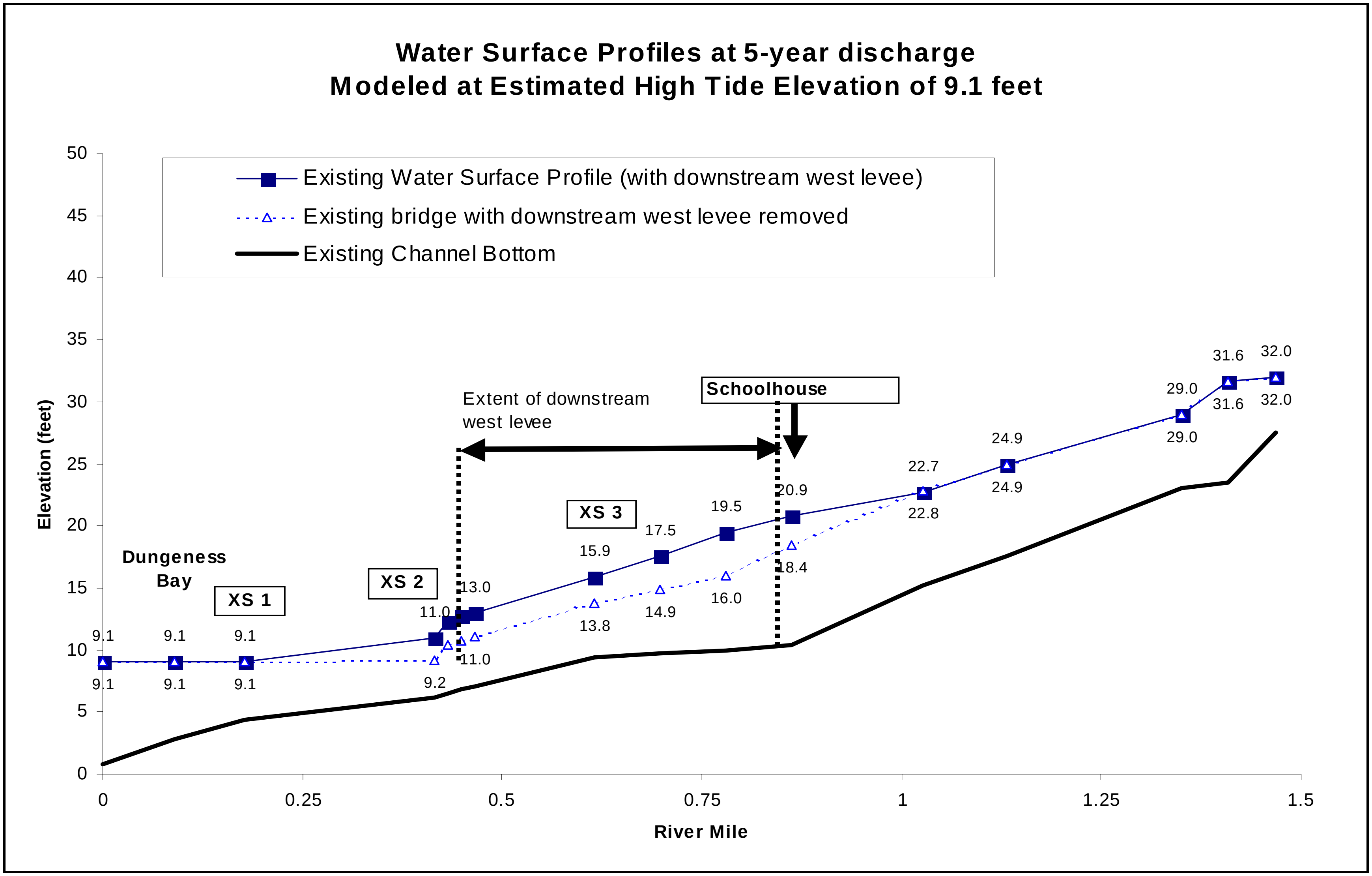


Figure 7. Water surface and channel bottom profile for lower 3 miles of Dungeness River.

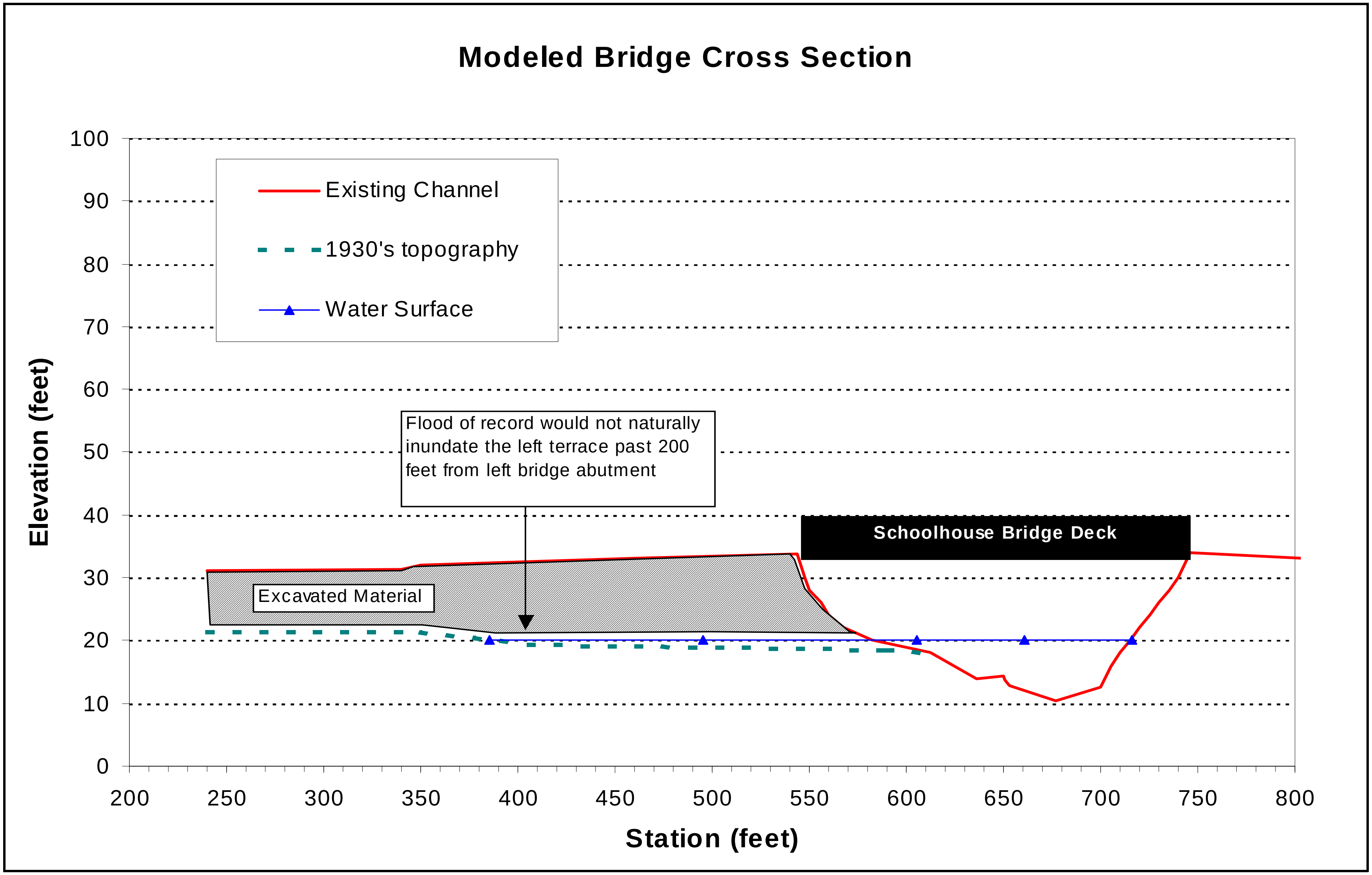


Figure 8. Results of hydraulic model at Schoolhouse Bridge cross section.

Conclusions

The Schoolhouse Bridge was evaluated to see if lengthening the bridge span, excavating the west terrace down to 1930's topography (pre-construction of bridge), and removing the River's End levee (downstream west side) would reduce water surface elevations at the bridge site and lower velocities to improve fish passage. The majority of the time, at flows below the 2-year flood, the existing Schoolhouse Bridge and downstream levees (on both sides) have no impact on river channel hydraulics. At higher flows, the combined effect from the downstream Corps and River's End levees have a greater impact on water surface elevations at the bridge than the bridge itself. Backwater effects from the downstream levees cause the west terrace just upstream of the bridge to be inundated, where historically (prior to the building of the levees) it was not.

Model results show that removal of the River's End levee would have a great enough impact on reducing water surface elevations at the bridge site to likely eliminate innundation of the upstream west terrace that now occurs. Lengthening the bridge and excavating the west terrace down to 1930's topography will likely cause velocities at the bridge site to reduce, but the flooding can only be prevented if the River's End levee is also removed. The downstream Corps levee could also be removed to reduce water surface elevations at the bridge. If the bridge were to be lengthened, the west terrace must be excavated down to the 1930's topography or the lengthening would have no benefit. Model results indicate that wetted channel widths at the bridge would not extend more than 200 feet past the existing left abutment, assuming the west terrace is excavated down to the 1930's topography. This implies that lengthening the bridge span by 200 feet would be the maximum needed to eliminate possible channel constrictions at peak flows at the bridge site if the River's End levee is also removed. If the main river channel were excavated to a lower elevation and widened, historical documentation suggest that the channel would quickly begin to aggrade on the inside of the river bend and return to its current geometry. This was demonstrated when the channel bottom was widened as part of the bridge construction in 1964, but later aggraded to its current geometry.

If modifications at the Schoolhouse Bridge site are to be implemented, it is recommended that the downstream west levee be removed first. After removal, the bridge site could be monitored to determine if flooding of the upstream west terrace has been eliminated. If it is determined that flooding is still a problem or that a reduction in flow velocities is desired, the bridge and west terrace could then be modified. The west terrace must be excavated down to the 1930's (natural) topography in addition to lengthening the bridge to have any benefit.

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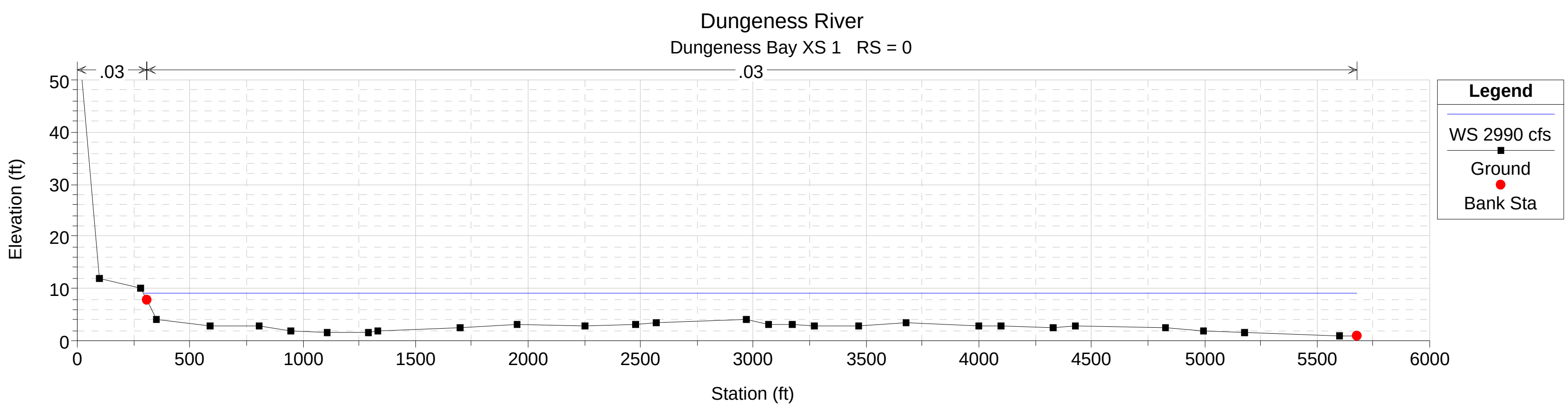
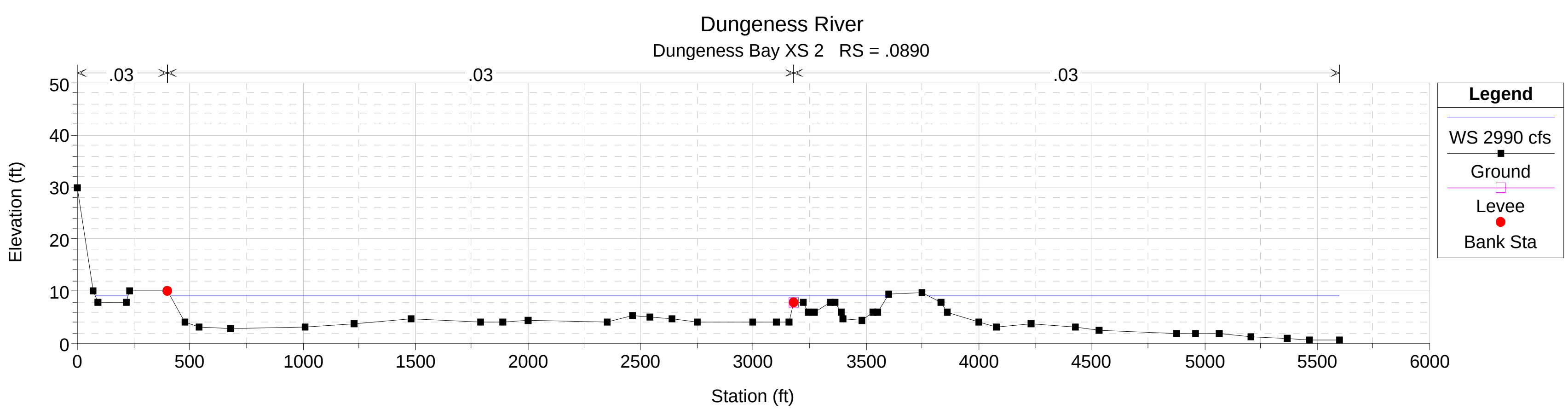
Appendix A

Tidal Data for Dungeness Bay

Appendix B

Cross Section Profiles of Existing Geometry
(Interpolated Cross Sections Used for Modeling Not Shown)


Dungeness River
Dungeness Bay XS 1 RS = 0
.03
.03
Legend
WS 2990 cfs
Ground
Bank Sta
Elevation (ft)
Station (ft)
0
10
20
30
40
50
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000


Dungeness River
Dungeness Bay XS 2 RS = .0890
.03
.03
.03
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
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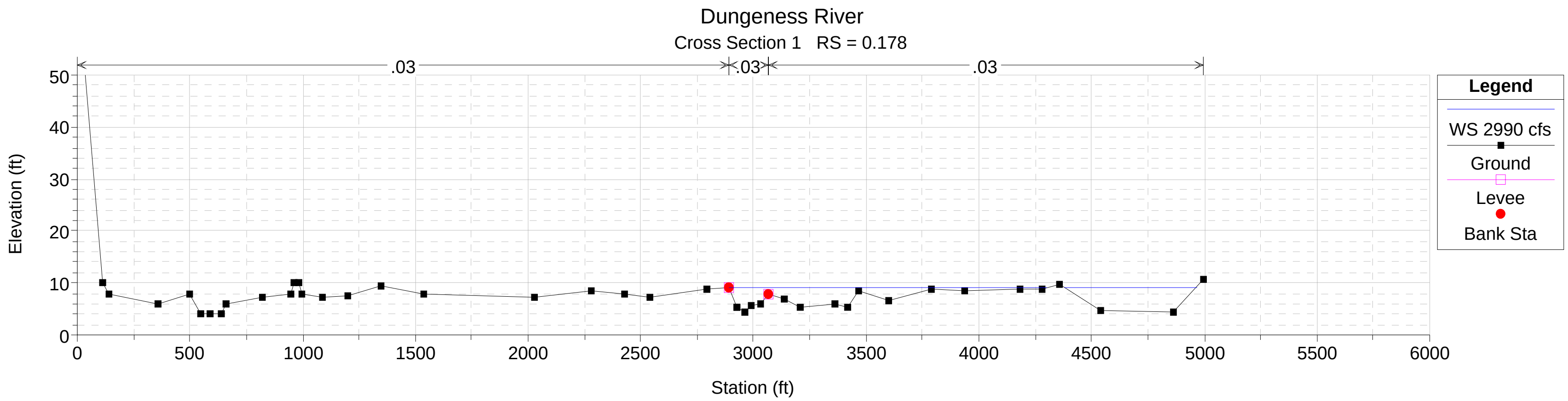
4000
4500
5000
5500
6000


Dungeness River
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.03
.03
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
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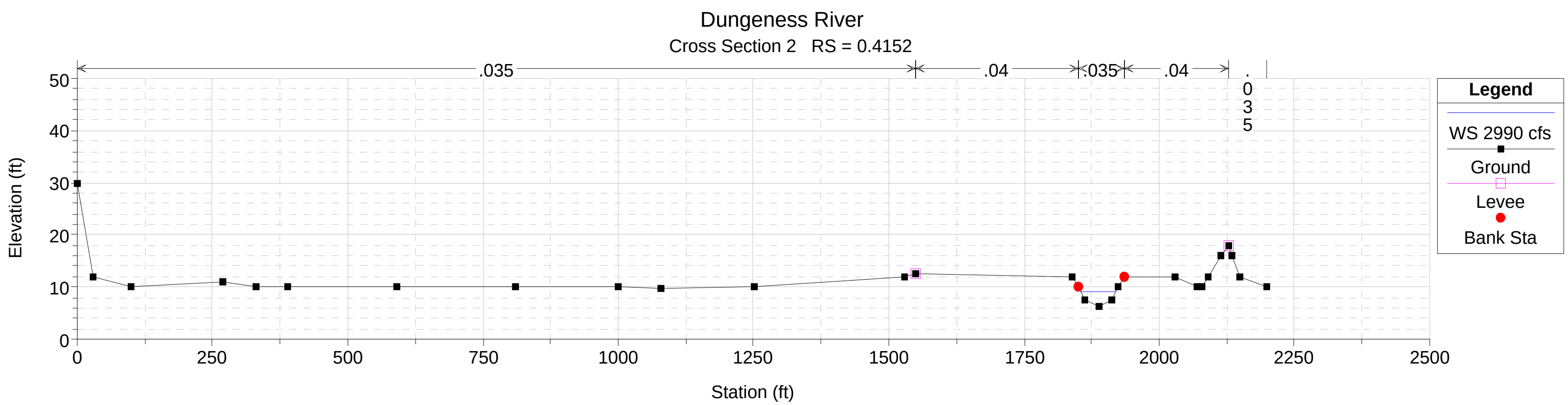
30
40
50
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000


Dungeness River
Cross Section 2 RS = 0.4152
.035
.04
.035
.04
.035
Legend
WS 2990 cfs
Ground
Levee
Bank Sta
Elevation (ft)
Station (ft)
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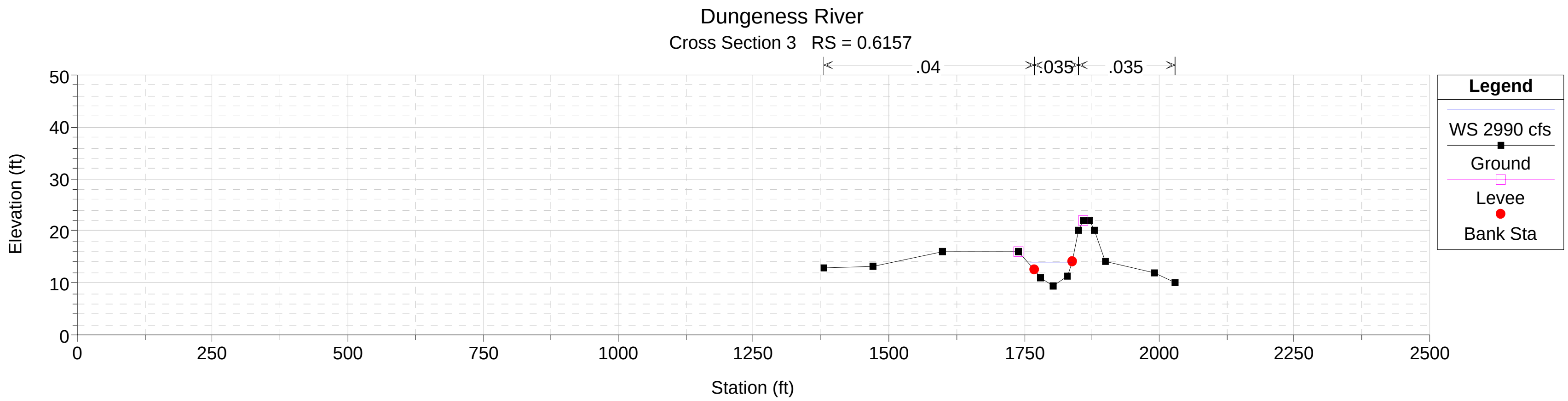
20
30
40
50
0
250
500
750
1000
1250
1500
1750
2000
2250
2500



Dungeness River
Cross Section 3 RS = 0.6157
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.035
.035
Elevation (ft)
Station (ft)
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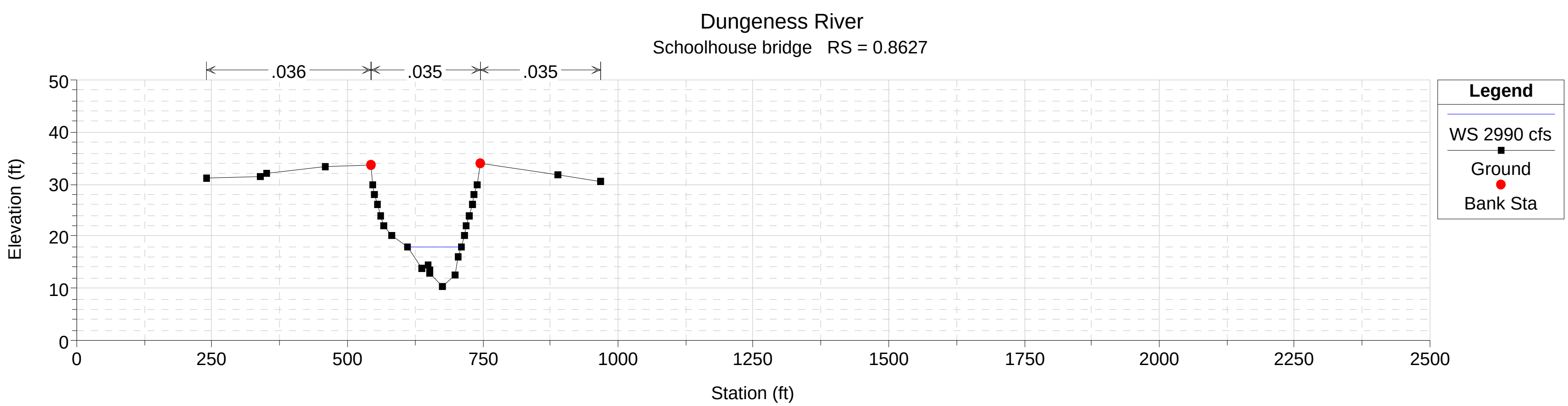
10
20
30
40
50
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Legend
WS 2990 cfs
Ground
Levee
Bank Sta



Dungeness River
Schoolhouse bridge RS = 0.8627
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.035
.035
Elevation (ft)
Station (ft)
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10
20
30
40
50
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Legend
WS 2990 cfs
Ground
Bank Sta

Technical Service Center
Denver, CO

Analysis of Alternatives for Levee Modifications Along the Dungeness River Lower 2.7 River Miles

PART A: Comparison of 1930's and Existing Hydraulic Conditions

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November, 2001

EXECUTIVE SUMMARY

The purpose of this report is to provide the Jamestown S'Klallam Tribe with preliminary results for the lower 2.7 river miles (RM) of Dungeness River characterizing river hydraulics in the 1930's, existing conditions, a comparison of changes, and an analysis of alternatives for setting back levees constructed along the east and west river banks. A hydraulic model was used to estimate the channel capacity and flooding impacts in the 1930's river channel compared to those for the existing channel. Further, levee setback alternatives for the U.S. Army Corps of Engineers (ACOE) right bank levee and private levees along the left bank were examined to look at the impacts on the Dungeness River.

From the upstream end of the levees at RM 2.7 downstream to RM 2.3, it was determined that the existing river channel can contain flows up to the flood of record even without the existing levees. Downstream of this reach, the ACOE levee constricts the river flow by cutting off the east (right) floodplain. Along the left river bank, the Olympic Game Farm levee (a private levee) cuts off the west overflow area downstream to RM 1.7. The combination of the two levees constrict the river to much smaller widths than were present in the 1930's. In the most constricted reaches, a pattern of aggradation in the main channel upstream from each constriction has occurred based on comparison of 1930's and existing conditions cross section plots. Because of aggradation, the relative elevation difference between the channel bed and east and west floodplains has been reduced, along with the channel capacity.

Setting back only the ACOE levee downstream of RM 2.3 will result in various degrees of flooding along the right floodplain. At RM 1.3, the riverbed has aggraded to an elevation higher than the right floodplain. If the ACOE levee is setback, even the smallest of floods would flow directly into the right floodplain.

If the Olympic Game Farm levee is also setback downstream of RM 2.3, even the 2-year flood will now result in flooding into the left overflow area, where historically it was contained within the channel. Allowing the flow to spill out of the main channel to the left will reduce the magnitude of flooding into the right floodplain. In some locations, the west overflow area (now blocked off by the Olympic Game Farm levee) is lower in elevation than the right floodplain. In these areas, all of the flooding spills into the left overflow area eliminating flooding in the right floodplain all together.

Historically, a portion of the east overbank flows could enter Meadowbrook Creek and these flows did not return to the Dungeness River until at the mouth. Under all of the levee setback options, access to Meadowbrook Creek will be cut off and all of the overbank flows will return to the main channel at some point upstream of the Schoolhouse Bridge. Analysis of levee setback options shows that as the ACOE levee is set back farther from the main channel, the impacts on floodplain flows, particularly the magnitudes of depths and velocities, are reduced. The precise depths and velocities of the floodplain flows can not be accounted for in the present model, but could be analyzed with a two-dimensional model.

Schoolhouse Bridge does constrict the channel when flows exceed the 5-year flood. The bridge would have to be widened 200 feet to eliminate all hydraulic constrictions (assuming a low tide).

Further analysis needs to be done to determine what impacts the tide has on this lower reach. Downstream of Schoolhouse Bridge, if the ACOE levee is left in place along river right and the private levee along river left is removed, flows greater than the 5-year flood will overtop the banks and spill into the left floodplain. These overbank flows will follow an 1855 channel out to the bay and never return to the main channel.

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1.0 OVERVIEW

In 1964, the U.S. Army Corps of Engineers (ACOE) built a levee along the east side (river right looking downstream) of the lower 2.7 river miles (RM) of the Dungeness River to protect residential and agricultural land from flooding. In response to this levee, two private levees have also been established along the west side (left side looking downstream) of the river to prevent flooding. These levees, in addition to other human impacts along the river, have altered the lower river affecting both the geomorphology of the river and the biologic species that depend on it. In an effort to restore critical fish habitat along the Dungeness River, the Jamestown S'Klallam Tribe and representatives from Clallam County have suggested that levee setbacks be considered.

1.1 Study Purpose

The purpose of this report is to provide the Jamestown S'Klallam Tribe with preliminary results for the lower 2.7 miles of Dungeness River characterizing river hydraulics in the 1930's, existing conditions, a comparison of changes, and an analysis of alternatives for setting back or removing levees along the east and west sides. This report is an addendum to the Bureau of Reclamation's draft progress report distributed in October of 1999. An additional addendum documenting the geomorphic history of this river reach provides an overview and background for this report. The next phase of this study will be to continue to link the results from this preliminary study with the ongoing interpretation of the geomorphic history of the river channel and an ongoing analysis of the river system as a whole to look at the impacts of levee setback alternatives in more detail.

While the impact of the construction of the levees is the primary focus of this report, many other human activities in the upper river and watershed also have played a role in effecting the river system, many of which have been going on even before the 1930's. These activities include irrigation withdrawals, gravel mining, logging and road building, and many other factors that will be looked at further as the study progresses.

The results provided in this report are based on a 1930's 1-foot-contour topographic map of the river channel (with limited coverage of the floodplain), 1997-99 channel survey data, a 1-foot-contour topographic map developed from 1998 aerial photographs, a river hydraulics model, and geomorphic interpretation and field observations in this river reach. A 1998 photo mosaic of this river reach including 5-foot contours generated from the 1-foot contour map is included as an attachment to this report for reference. Note that contours on the photo mosaic in wooded floodplains or in the vicinity of structures should not be considered representative of ground elevations.

2.0 HYDRAULIC MODEL DEVELOPMENT

HEC-RAS version 2.2, a hydraulic model developed by the ACOE, was used to model both 1930's and existing conditions based on the available data. The HEC-RAS model performs water surface profile and other hydraulic calculations for one-dimensional steady flow. The model predicts river stage and other hydraulic properties at each cross section along the river and for any specified discharge. The steady flow component of the HEC-RAS model is capable of modeling subcritical, critical, supercritical, and mixed-flow regimes. For this 2.7 river mile reach extending from the upstream end of the ACOE levee downstream to the mouth of the Dungeness River, the model was forced to work in the subcritical and critical flow regimes. Cross section locations used in the model are shown later in the report in figure 9.

A hydrologic analysis was completed for the Dungeness River system based on the USGS gage located at the Highway 101 bridge (England, 1999). The peak discharge flood frequency estimates determined from this analysis were used to model various flood events in the hydraulic model to determine hydraulics and channel capacity for the 1930's, existing, and levee setback options (table 1). Because the peak flood of record (7,540 ft^3/s) observed on December 20, 1900, is smaller than the model estimated 50-year and 100-year floods, only the 2-year, 5-year, 10-year, and 25-year peak discharge estimates were run in addition to the flood of record to stay within the limits of observed flood magnitudes. In addition, a range of flows, in 500 ft^3/s increments, were run through the model to establish a rating curve for the 1930's and existing conditions.

Table 1. - Peak Discharge Flood Frequency Estimates and Flood of Record Used in the Hydraulic Model.

Peak Discharge Flood	Peak Discharge
2-year flood	2,990 ft^3/s
5-year flood	4,690 ft^3/s
10-year flood	5,780 ft^3/s
25-year flood	7,120 ft^3/s
Flood of Record	7,540 ft^3/s

3.0 RIVER CONDITIONS IN THE 1930'S

By the 1930's, the lower reach of the Dungeness River was already impacted by structures including “bulkheads” (wooden wall structures), earthen dikes, Ward Road, Schoolhouse Bridge, and Towne Road (table 2). The bulkheads and dikes were designed to prevent bank erosion and flood waters from overflowing the channel. Schoolhouse Bridge was located at a natural channel constriction, but the bridge likely did constrict the channel width at higher flows. Ward Road and Towne Road may have limited the lateral extent of some floodplain flows, especially when floodplain flows were just overbank. Extensive floodplains existed on both sides of the Dungeness River, but these floodplains were interrupted by naturally occurring high topographic features. For example, the road crossing Schoolhouse Bridge (cross section 4 at RM 0.716) traversed high ground on both sides of the river. River and floodplain cross sections were generated from the 1930's contour map in the estimated location of the existing cross sections which were surveyed in 1997 and 1998. These cross sections were used in conjunction with historical maps and photographs to evaluate what the Dungeness River conditions were in the 1930's. Note that in a few locations, the 1930's cross sections had to be extended (based on present conditions) because the 1930's contour map did not include enough of the floodplains.

3.1 Dungeness River Upstream From Schoolhouse Bridge (Cross Sections 4 to 17, RM 0.719 to RM 2.661)

At the upstream end of this reach, water that overflowed into the right (east) floodplain could re-enter the Dungeness River channel downstream or enter the drainage of Meadowbrook Creek. Between the locations of cross sections 15 and 17, overbank flows that spilled into the right floodplain would follow a natural, broad drainage channel eastward along the base of the Potholes to Meadowbrook Creek. Flows entering this creek would only reconnect with the Dungeness River near the mouth. A bulkhead and dike, built near cross section 16, helped to prevent floodflows from accessing the right floodplain.

Overbank flows that spilled into the right floodplain between cross sections 10 and 14 did not escape to Meadowbrook Creek, but would instead re-enter the Dungeness River channel within this reach. The left (west) edge of the active river channel came into contact with Matriotti Creek and a high bluff just upstream from cross section 10. The bluff at this location marked the downstream end of the extensive left floodplain along Ward Road. Any water that overflowed into this left floodplain, upstream of cross section 10, was forced to re-enter the Dungeness River channel by the time it reached cross section 10.

The high left-side bluff at cross section 10 forced the Dungeness River to change slope and bend around a point in the bluff. Along the outside of this bend (right or east bank), at the location of cross section 8, a bulkhead and small dike helped to prevent overbank flows from spilling into an eastward drainage channel that led to Meadowbrook Creek.

Table 2. - Description of the 1930 channel features and modifications along lower 2.7 RM

Cross Section	River Miles (from mouth)	Channel Features and Modifications (left and right river banks are referenced looking downstream) LEFT BANK	RIGHT BANK
17	2.661		
16	2.462		Dike and bulkhead
15	2.321		
14	2.131		Dike
13	1.985		
12	1.830		
11	1.654		
10	1.468	High bluff; Confluence with Matriotti Creek near this cross section	Series of small dikes
9	1.320	High bluff	Bulkhead
8	1.260	High bluff	Bulkhead
7	1.201	High bluff	Small dike
6	0.983	High bluff	
5	0.880	High bluff	
4	0.719	Schoolhouse Bridge located at a different alignment just upstream of the existing bridge location. Bulkheads were present near old bridge site.	
3	0.467		Dike
2	0.266		Bulkhead
1	0.029	This section is located in the 1930's main channel that was further west than the main channel flow path utilized presently.	

Notes: Ward Road crosses the left floodplain from cross section 17 downstream to cross section 11; Towne Road crosses the right floodplain from cross section 14 downstream to cross section 5.

A narrow wooded floodplain existed along the left (west) side between cross sections 4 and 9. This narrow left floodplain was pinched between the river channel and the high bluff. Any left overbank flows occurring in this reach, and right overbank flows not diverted to Meadowbrook Creek, were forced by the natural topography to re-enter the Dungeness River channel upstream of Schoolhouse Bridge (cross section 4).

A flood control project map produced in October of 1962 by the U.S. Department of the Interior, Fish and Wildlife Service documents the high water surface limits of a 6,820 ft³/s flood that occurred on the Dungeness River in 1949. This map verifies the estimated flow pattern of floods spilling out of the main channel prior to the levees. Upstream of Schoolhouse Bridge, this flood inundated the left floodplain up to the embankment of Ward Road and backed up flow into Matriotti Creek. Downstream of the current location of cross section 10, a portion of the flood flows traveled through the right floodplain into Meadowbrook Creek.

A hydraulic model was established to estimate the discharge capacity of the main river channel in the 1930's (figure 1). The discharge capacity of the main river channel is the maximum river discharge that can be conveyed without water overflowing into either the left or right floodplains.

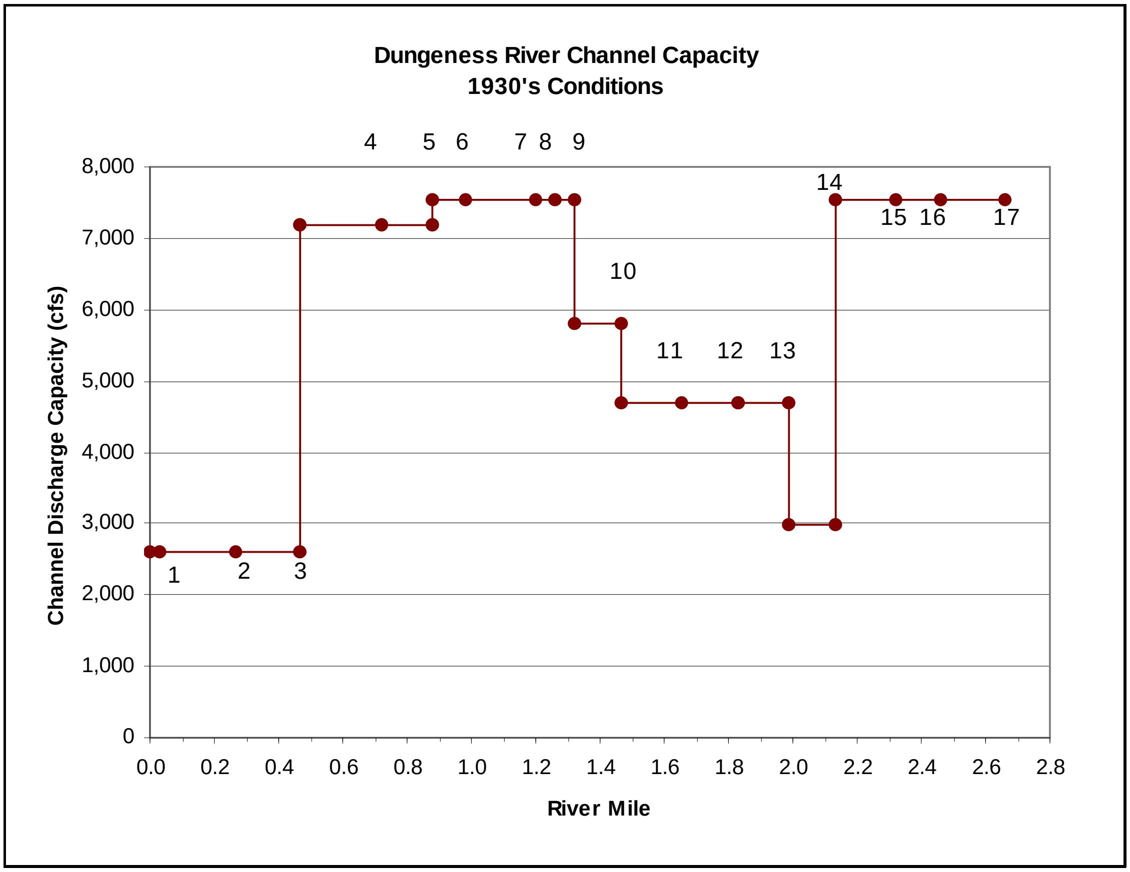


Figure 1. - Channel capacity and overbank flow paths for 1930's conditions.

The main channel in the 1930's had the capacity to contain the flood of record (7,540 ft^3/s) between cross sections 15 to 17. However, at cross section 14, flows beyond the 2-year flood (2,990 ft^3/s) would overflow into the left (west) floodplain. At cross section 13, flows at the 5-year flood (4,690 ft^3/s) would just start to overflow into the left floodplain. Cross section 12 could just contain the 5-year flood. At cross section 11, the 5-year flood would back flows up into Matriotti Creek on the left floodplain. Cross section 10, would contain the 10-year flood (5,780 ft^3/s). Any left overbank flow would return to the channel by cross section 9 which could contain the flood of record. A right-bank bulkhead at cross section 8 could contain flows up to the flood of record. Otherwise, flows beyond the 2-year flood would spill into the right floodplain at cross section 8. Cross sections 6 and 7 could contain flows up to the flood of record. Cross section 5 could contain the 25-year flood. Flows beyond the 25-year flood, would overflow into the right floodplain and enter Meadowbrook Creek.

3.2 Dungeness River Downstream From Schoolhouse Bridge (Cross Section 0 to 4, RM 0.000 to RM 0.719)

In the 1930's, Schoolhouse Bridge had a different alignment and was slightly upstream from its present location at cross section 4. Model results show that Schoolhouse Bridge had the capacity to contain the flood of record. Based on hydraulic model results, the capacity of the main channel in the 1930's, downstream from Schoolhouse Bridge, was only 2,600 ft^3/s, which is less than the 2-year flood (see figure 1). Downstream from Schoolhouse Bridge, the Dungeness River flowed through an extensive delta and entered Dungeness Bay approximately ½ mile west of its present location. A dike and bulkhead prevented flows from accessing older distributary channels to the east. These structures forced overbank flows to the west, but high overbank flows would have accessed both the east and west sides of the delta downstream of Schoolhouse Bridge.

4.0 EXISTING RIVER CONDITIONS (1997-99)

The existing lower 2.7 mile reach of the Dungeness River is heavily diked and leveed on both river banks. The principal levees in this reach are referred to as the ACOE levee and the Olympic Game Farm levee. The ACOE levee was established to prevent flooding along the right floodplain from RM 2.7 to near the mouth. The private Olympic Game Farm levee was established to protect the Olympic Game Farm property (RM 2.7 to RM 1.7) from flooding resulting from the ACOE levee construction (table 3). At the downstream end of the Olympic Game Farm 1-mile long levee, a natural high bluff constrains the channel along the left side downstream to the Schoolhouse Bridge. Downstream of Schoolhouse Bridge, the ACOE levee continues to constrict flows along the right side of the river, and a private levee, lower in elevation than the ACOE levee, constricts flows along river left. An unvegetated main channel exists between the two levees that transports the majority of flood flows and sediment. The main channel often contains several bars and islands. In addition to the main channel, several side channels exist in the wooded floodplains adjacent to the main channel. These side channels also transport water during flood events.

To estimate the existing channel capacity and hydraulics of the Dungeness River, the HEC-RAS model was used to simulate the discharges in table 1. Seventeen cross section profiles were developed to represent the existing channel geometry and floodplain along the lower 2.7 miles of the Dungeness River (table 3). A set of cross section profiles are contained in appendix A. These plots show the existing channel and floodplain geometry for the lower 2.7 river miles along with the modeled water surface profiles for the 2-year and peak flood of record.

4.1 Dungeness River Upstream from Schoolhouse Bridge (RM 2.7 to RM 0.7)

Model results show that upstream of Schoolhouse Bridge, the ACOE and Olympic Game Farm levees (RM 2.7 to 1.7) can contain the flood of record. At the very upstream extent of the levees at cross sections 16 and 17, the model shows that all flood flows are contained within the natural high banks and neither of the levees constrict the flows. However, the possibility of flood flows entering an old channel at the upstream end of the right floodplain needs to be studied in more detail.

From the downstream end of Olympic Game Farm levee to the Schoolhouse Bridge, the river is still constrained on the right by the ACOE levee, and is also constrained on the left by the natural high bluff. During floods, flows access the side channels in this reach along the narrow, left wooded floodplain between the main channel and the high bluff.

Table 3. - Description of the 1997 channel features and modifications along existing lower 2.7 miles of the Dungeness River.

Cross Section	River Miles (from mouth)	Channel Features and Modifications (left and right river banks are referenced in the downstream direction)	
		LEFT BANK	RIGHT BANK
17	2.661	Upstream end of Olympic Game Farm levee	Upstream end of ACOE Levee
16	2.462	Olympic Game Farm levee	ACOE Levee
15	2.321	Olympic Game Farm levee	ACOE Levee
14	2.131	Olympic Game Farm levee	ACOE Levee
13	1.985	Olympic Game Farm levee	ACOE Levee
12	1.830	Olympic Game Farm levee	ACOE Levee
11	1.654	Downstream end of Olympic Game Farm levee	ACOE Levee
10	1.468	High bluff; Confluence with Matriotti Creek near this cross section	ACOE Levee
9	1.320	High bluff	ACOE Levee
8	1.260	High bluff	ACOE Levee
7	1.201	High bluff	ACOE Levee
6	0.983	High bluff	ACOE Levee
5	0.880	High bluff	ACOE Levee
4	0.719	Schoolhouse Bridge	
3	0.467	Private levee	ACOE Levee
2	0.266	Private levee	Downstream end of ACOE Levee
1	0.029	Near mouth of Dungeness River, no manmade constrictions	

4.2 Dungeness River From Schoolhouse Bridge to the Mouth (RM 0.7 to 0.0)

The hydraulic model results (assuming no tide) show that the current configuration of Schoolhouse Bridge constricts the river width when flows exceed the 5-year flood water surface elevations (refer to cross section 4 at RM 0.72). However, even with the current configuration, the flood of record is at least 7 feet below the bottom of the bridge deck. Based on natural topography, the bridge would have to be widened 200 feet to the west to eliminate the constriction. To account for tidal influences at the bridge, an additional analysis should be done to determine how wide the bridge would need to be to completely eliminate any constriction from further increases in the water surface elevation due to tide.

A private levee has been built along the left bank just downstream of Schoolhouse Bridge and extends downstream to cross section 2. The top of this levee was constructed at a much lower elevation than the ACOE levee on the right river bank. There is an old channel (shown as the main channel on an 1855 map) that directs flow to the west just upstream of cross section 3. This channel is currently cut off by the private levee. During a December 1998 flood of 4,300 ft^3/s, it was observed that the flow overtopped the private levee and entered this old channel. However, the model shows that cross section 3 has a channel capacity up to the 25-year flood (7,120 ft^3/s), assuming a low tide. Since a low tide was assumed, the 25-year flood was modeled in the main channel from this cross section downstream to the mouth. Any flow overtopping the levee in this reach would take a separate path out to the bay and never return to the main channel. Tidal influences are not accounted for in the hydraulic model, but they undoubtably influence flood stage. This reach, including the location of Schoolhouse Bridge, will need to be studied in further detail to thoroughly understand the role of tidal influences near the mouth of the river and the upstream extent of the tidal influences.

5.0 WHAT CHANGES HAVE OCCURRED SINCE THE 1930'S?

One of the most significant changes in human activities since the 1930's is the construction of levees along the lower reach of river, including the ACOE levee along the right (east) bank and the two private levees along the left (west) bank. These modern levees have replaced the wooden “bulkheads” and earthen dikes used in the 1930's. The old Schoolhouse Bridge has also been replaced at a different alignment and the new bridge is just downstream of the old location. The constriction imposed by the old and new bridge is about the same.

5.1 Dungeness River Upstream from Schoolhouse Bridge (RM 2.7 to RM 0.7)

Presently, in the reach upstream of Schoolhouse Bridge, the levees along both sides of the river constrict the river preventing any flows from spilling into the floodplains and Meadowbrook Creek. These levees have also constricted the river channel width which, in turn, has increased the river depth for a given flow. During the 2-year flood (2,990 ft^3/s), water depths have increased by about 2 feet at cross sections 8, and 14 (figures 2 and 3). This general increase in water depth between the 1930's and present conditions is even greater during higher floods. The increased river depth during floods has increased the river’s capacity to float and transport large woody debris. The amount of large woody debris that was present in the river channel during the 1930's has not been quantitatively documented. However, field observations and geomorphic mapping of the existing channel show there is less woody debris in the constricted channel than in upstream reaches where the channel is not constricted by levees.

The levees are also the likely cause of riverbed aggradation. The Beebe levee along the left side is adjacent to the main river channel and completely cuts off the left floodplain and any side channels. The ACOE levee along the right side is generally setback some distance from the main river channel (up to 500 feet). However, the ACOE levee is aligned very close to the main river channel in some places and it especially constricts the river channel at cross sections 5, 7, 11, and 13. These levee constrictions would have created backwater conditions (increased water surface elevations) immediately upstream which, in turn, would have forced water depths to increase and the flow velocity and sediment transport capacity to decrease. Given the high sediment loads of the Dungeness River, aggradation of the riverbed would have likely occurred in these backwater reaches upstream of the levee constrictions. Indeed, up to 8 feet of riverbed aggradation has occurred upstream of these constrictions (figure 4). The estimates of riverbed aggradation are based on analysis of river cross-section overlays which were created to compare the 1930's channel geometry to the existing conditions (see appendix B). The riverbed aggradation in these backwater reaches has locally reduced water depths and again increased the flow velocities and sediment transport capacities. Today, mean channel velocities are within 1 ft/s of the channel velocities in the 1930's at cross sections 8 and 14 (figures 5 and 6). However, the channel could still be aggrading. For the 1930's cross section geometry, the average velocity increases with discharge until the bank of the main channel is overtopped. When the bank is overtopped and flow travels across the floodplain, the wetted width increases dramatically and the velocity decreases.

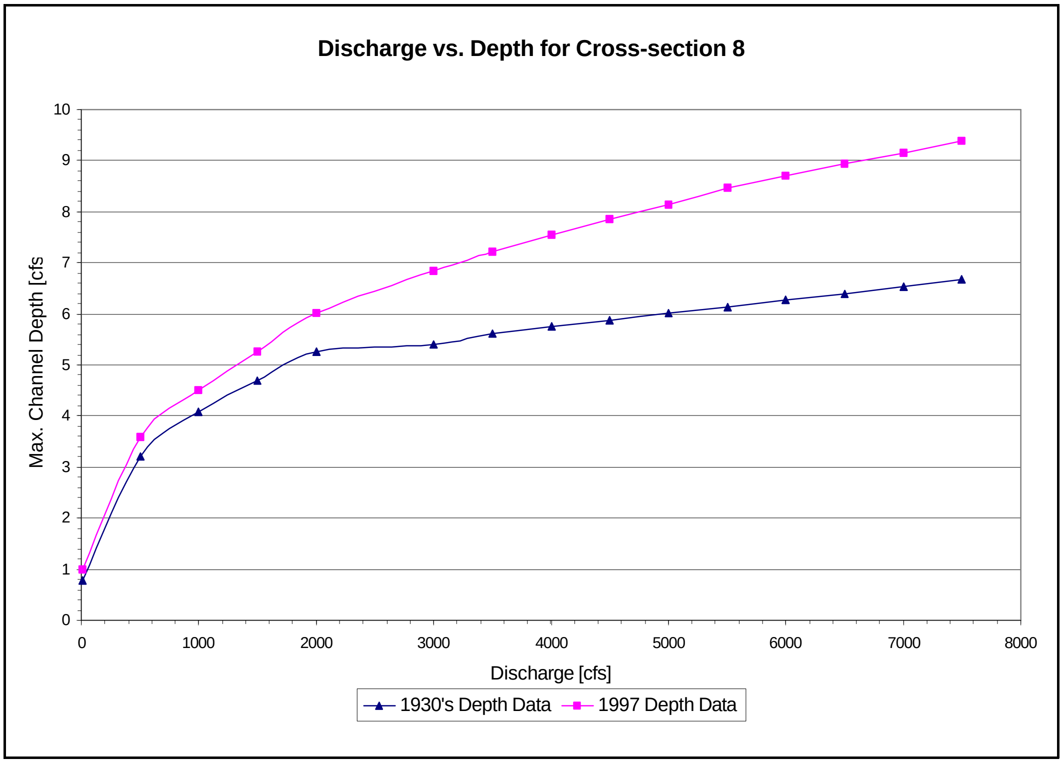


Figure 2. - Maximum channel depth rating curve for cross section 8

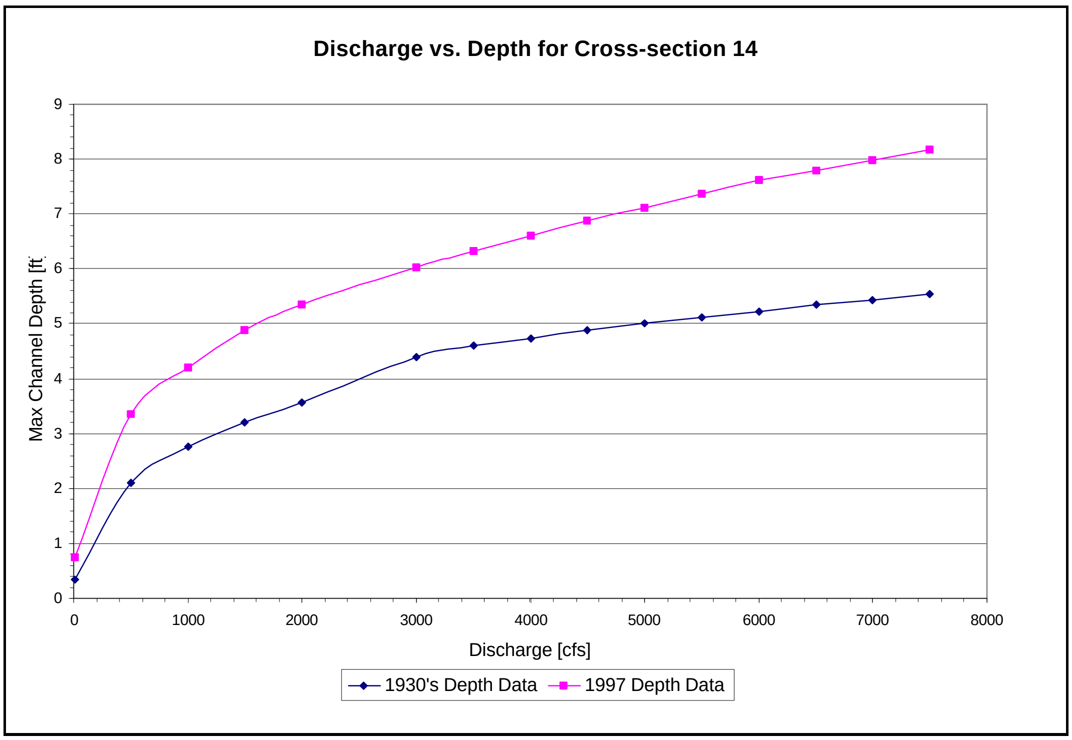


Figure 3. - Maximum channel depth rating curve for cross section 14

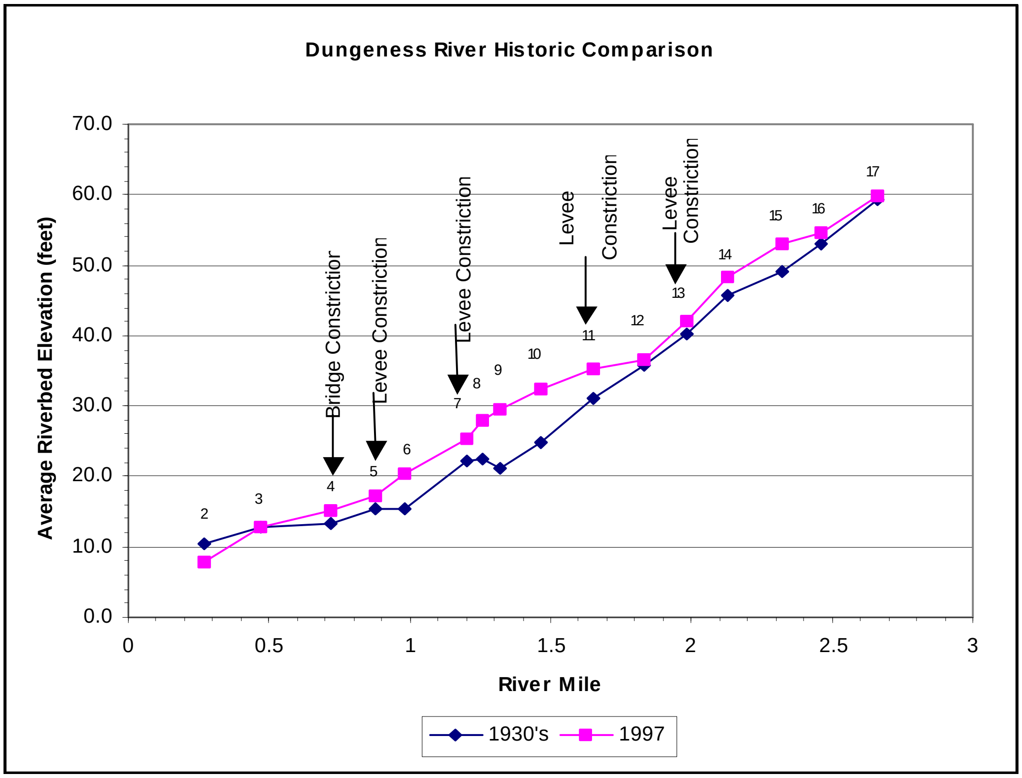


Figure 4. - Mean riverbed elevation for 1930's vs. existing channel conditions

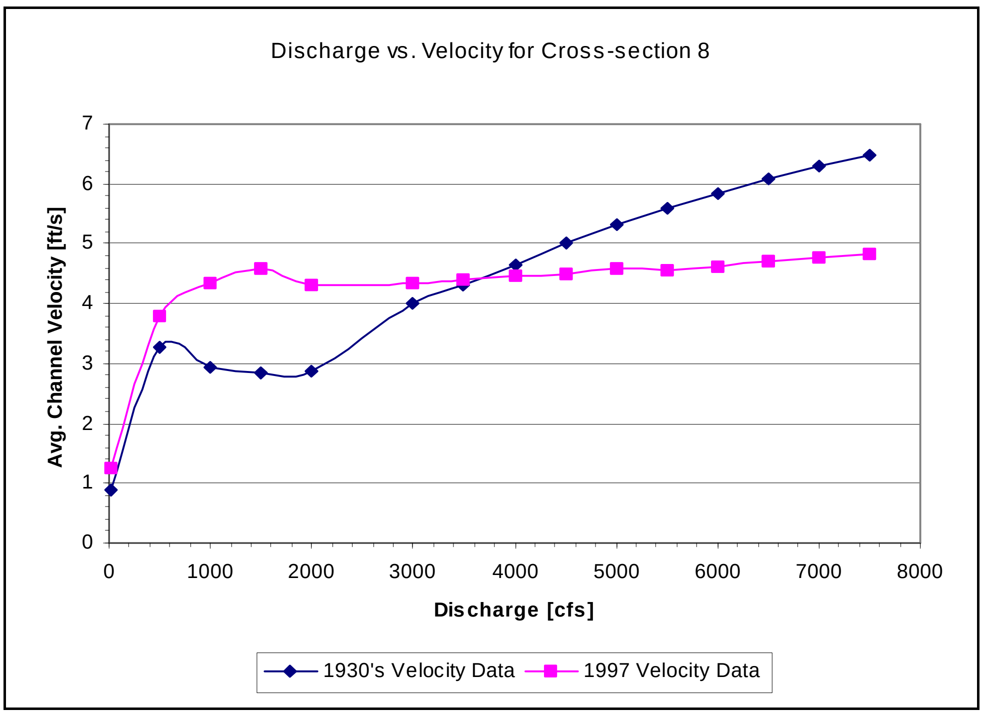


Figure 5. - Average velocity rating curve for XS 8 (channel and floodplain)

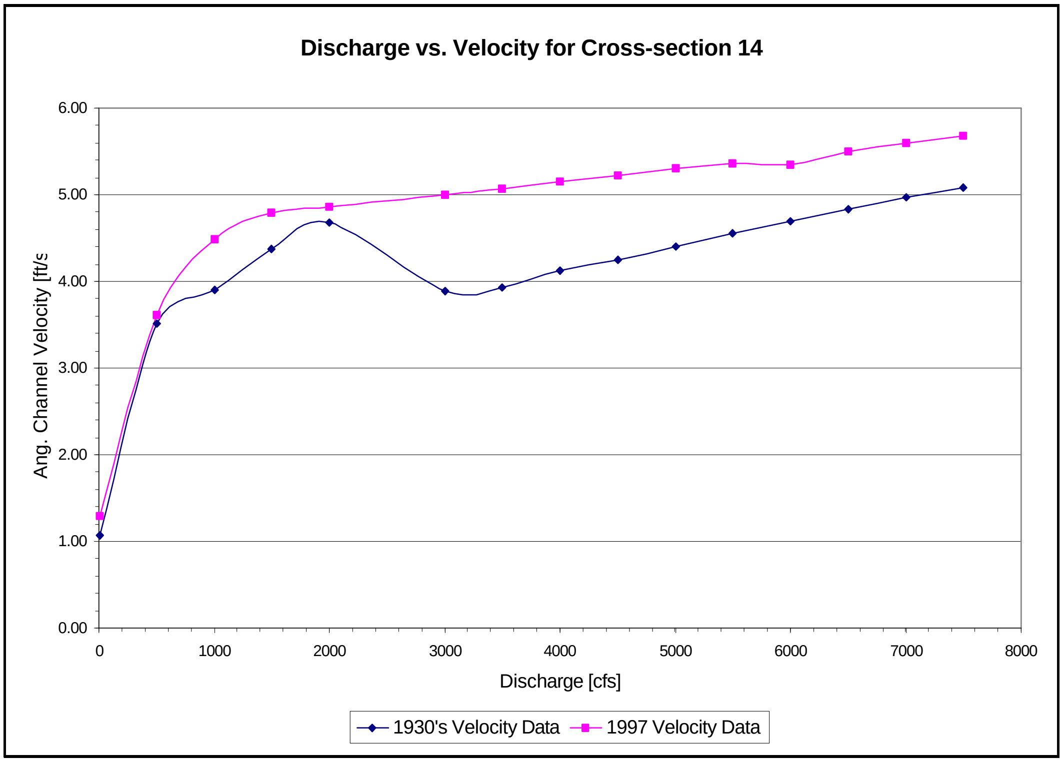


Figure 6. - Average velocity rating curve for XS 14 (channel and floodplain)

The amount of riverbed aggradation at cross sections 8, 9, and 10 is presently so large (5 to 8 feet) that if the ACOE levee were ever setback or removed, the river channel would suddenly change course and spill into the right floodplain. However, the gravel that has been deposited since the levee construction could be mechanically removed (from the river channel and the remnant wooded floodplain) prior to a levee setback so that river flows would stay in the present channel alignment.

5.2 Dungeness River From Schoolhouse Bridge Downstream to the Mouth (RM 0.7 to 0)

Downstream from Schoolhouse Bridge, levees on both sides have cutoff the floodplains and access to distributary channels of the delta. In the 1930's the channel capacity in this reach (assuming a low tide) was limited to 2,600 ft^3/s (less than the 2-year flood of 2,990 ft^3/s) and flows followed a different path to Dungeness Bay. With the levees, the channel is uniformly constricted and the flow capacity (assuming a low tide) has increased to 7,120 ft^3/s (25-year flood). During the 2-year flood, water depths in the channel increased by about 2 feet (figure 7) and velocities increased by 4 ft/s (figure 8). With more flow and velocity being forced into a single channel, the riverbed is actually 3 feet lower today at cross section 2 than in the 1930's.

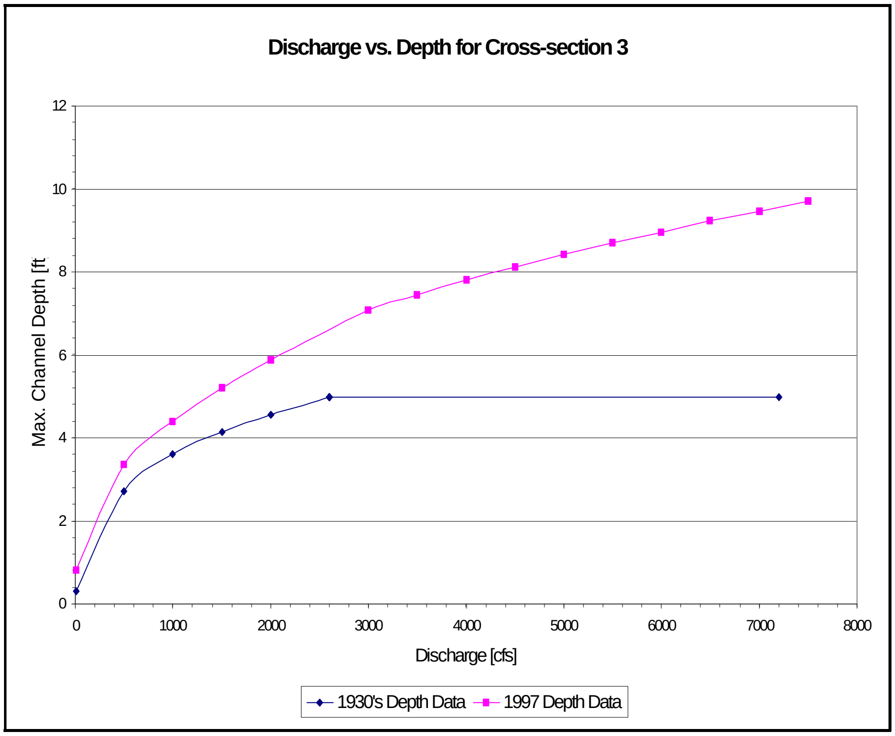


Figure 7. - Maximum channel depth rating curve for cross section 3

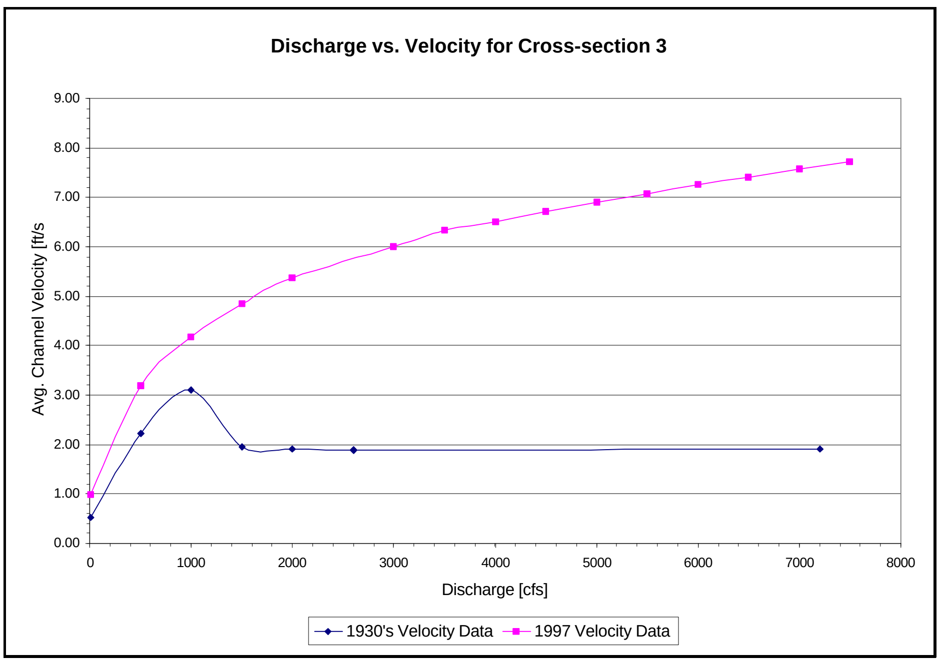


Figure 8. - Average velocity rating curve for XS 3 (channel and floodplain)

6.0 LEVEE SETBACK ALTERNATIVES AND CHANNEL CAPACITY CONCLUSIONS

Several alternatives have been discussed for setting back or removing both the ACOE and private levees along the lower 2.7 miles of Dungeness River. For this analysis, four alternatives were considered that were generated during a meeting in February 2000 with the Jamestown S'Klallam Tribe, Washington Department of Fish and Wildlife, and Clallam County (table 4 and figure 9). Note that although figure 9 shows straight lined levee alignments, in practice the levee would most likely have a more curved alignment.

Table 4. - Levee setback alternatives.

Option Number	Description of alternative
1	Upstream of Schoolhouse Bridge, setback the ACOE levee 500 feet from the current location as shown in figure 9
2	Upstream of Schoolhouse Bridge, setback the ACOE levee to Towne Road as shown in figure 9
3	Upstream of Schoolhouse Bridge, setback the ACOE levee to the west side of Meadowbrook Creek as shown in figure 9
4	Upstream of Schoolhouse Bridge, setback the ACOE levee as in Option 3, and setback the Olympic Game Farm levee to Ward Road as shown in figure 9

Upstream from Schoolhouse Bridge, the first three alternatives would setback the ACOE levee at various distances from the main channel. The fourth alternative includes the farthest ACOE levee setback (option 3), and an additional setback of Olympic Game Farm levee to Ward Road. All of the alternatives assume that, downstream of Schoolhouse Bridge, the ACOE levee (right bank) will remain in place, but the private levee along the left bank will be removed. This is due to the historical flooding that has occurred along the west (left) side during floods as low as the 5-year event. Further, in all of the alternatives Schoolhouse Bridge was initially widened on the left side to eliminate any constriction of river width.

The existing conditions model showed that all flows are contained in the main channel and wooded side channels throughout this reach of river due to the ACOE and private levees. The only exception is in the downstream end of this reach, particularly downstream of Schoolhouse Bridge where tidal influences cause some flood events to overtop levees and divert flow into the left floodplain (shown by increased downstream boundary condition). In order to evaluate how the channel capacity of the lower Dungeness River would change due to setting back or removing the levees, the hydraulic model was used to alter the existing levee alignments as described for each of the four setback options.

Based on topographic data provided on the 1930's map and profile drawings from the ACOE levee project development, the existing ground where the levees now exist was lowered to the ground elevation prior to construction of the levees. For each of the alternatives, the model provided results showing channel capacity at each cross section which, in turn, shows at what flood events the right and left floodplains are accessed (table 5). Cross section plots were generated at selected locations for options 1 and for option 4 (for RM 2.7 to 1.7 only) which show the maximum channel capacity (the largest flood the channel can handle before overtopping into the floodplain occurs). These plots show how flooding into the right and left floodplains will change from either setting back the ACOE levee or setting back both the ACOE and Olympic Game Farm levee.

The model results show that for all alternatives, at cross sections 16 and 17, the main channel and wooded side channels are capable of handling the peak flood of record simply from the natural high banks. The ACOE and Olympic Game Farm levees have no impact and, therefore, are not needed. However, this reach needs to be looked at in more detail to determine if there is any potential for overbank flooding in this reach.

At cross section 15, flows up to the flood of record are still not impacted by the ACOE levee. However, if the Olympic Game Farm levee is setback at this location, flooding will occur in the left overflow area during flood events greater than the 5-year flood. This is because the left floodplain is lower in elevation than the right floodplain, and channel capacity has been reduced due to aggradation, as shown in the 1930's versus existing conditions cross section plots. Downstream of cross section 15 to cross section 10, setting back the ACOE levee will again result in flooding of varying depths along the right floodplain during floods as low as the 2-year event. At cross sections 13 and 14, the left floodplain is substantially lower in elevation than the right floodplain. If the Olympic Game Farm levee is setback, flooding in the right floodplain will be eliminated altogether (figure 10 shows XS 14). This could result in a possible channel avulsion to the left. At cross sections 12 downstream to 10, setting back the Olympic Game Farm levee will not eliminate flooding along the right floodplain but will reduce the magnitude by allowing a portion of the flows to spill over into the left floodplain. Any flood flows that exit the channel in this reach will eventually enter back into the main channel near cross section 10 due to the natural topography of the floodplain.

Downstream of cross section 10, the Olympic Game Farm levee no longer constricts flows along the left, but the narrow wooded floodplain is constricted by the high natural bluff. The side channels in the narrow wooded floodplain are accessed during flood events as in existing conditions with all of the setback options. If the ACOE levee is setback, floods from the 2-year to the 10-year event cause overtopping into the right floodplain. None of the levee setback options allow access to Meadowbrook Creek which historically contained a portion of the flood flows that overtopped the natural river banks during flood events. Therefore, the flows are forced back into the main channel river system at some point upstream of Schoolhouse Bridge. Because of aggradation at cross section 8, the channel will spill into the right floodplain if the ACOE levee is setback (XS 8 shown in figure 11). Downstream of Schoolhouse Bridge with the private levee removed from the left bank, floods slightly greater than the 2-year flood (3,400 ft^3/s) would cause overtopping into the left floodplain (XS 3 shown in figure 12). These flows will never reenter the main channel and will instead follow an old channel path out to the bay.

Table 5. - Channel capacity and extent of flooding for levee setback alternatives.

River Reach Including ACOE and Olympic Game Farm Levee			
Cross Section	River Mile	Options 1, 2 and 3: ACOE Levee Setback	Option 4: Additional Beebe Levee Setback
17 16	2.661 2.462	For all setback options, all flows are contained within natural high banks of wooded floodplain (the ACOE levee and Olympic Game Farm levee have no impact on flooding)	
15	2.321	For all ACOE levee setbacks, all flows are contained within the natural high banks along river right and Olympic Game Farm levee along river left	By setting back Olympic Game Farm levee, the 10-year flood results in flooding the left floodplain.
14 13	2.131 1.985	By setting back the ACOE levee, the 5-year flood for cross section 14, and the 10-year flood for cross section 13 results in flooding of the right floodplain	By setting back Olympic Game Farm levee, all flows result in flooding along the left floodplain; the 25-year flood and flood of record result in minor flooding of right floodplain.
12	1.830	By setting back the ACOE levee, all flows result in flooding of the right floodplain	By setting back Olympic Game Farm levee, all flows result in flooding along both floodplains. However, the flooding along the left floodplain is stopped by a private road rather than Ward Road.
11	1.654	By setting back the ACOE levee, all flows result in flooding of the right floodplain	Olympic Game Farm levee is combined with a natural high bluff that continues downstream to the Schoolhouse Bridge and serves as a natural constraint on the river.

River Reach Downstream of Olympic Game Farm Levee		
Cross Section	River Mile	Options 1, 2 and 3: ACOE Levee Setback
10	1.468	By setting back the ACOE levee, all flows result in flooding of the left wooded side channels (constrained by the high bluff), and flooding out to the ACOE levee in the right floodplain.
9	1.320	By setting back the ACOE levee, all flows result in flooding of the left wooded side channels (constrained by the high bluff), but flows are constrained on the right bank by a natural levee (the ACOE levee setback has no impact).
8	1.260	By setting back the ACOE levee, all flows result in flooding of the right floodplain out to the ACOE levee.
7 6	1.201 0.983	By setting back the ACOE levee, the 10-year event and greater result in flooding in the right floodplain
5	0.880	A natural high bank along river right constrains flows up to the 10-year event, the 25-year event and the flood of record result in flooding in the right floodplain.
4	0.719	Schoolhouse Bridge was widened in the model to eliminate constriction by the flood of record.

River Reach Downstream of Schoolhouse Bridge		
Cross Section	River Mile	Options 1, 2 and 3: ACOE and Private Levee Setback
3	0.467	By removing the private levee along river left and leaving the ACOE levee in place, flows greater than 3,400 ft^3/s overtop the natural bank and enter the left floodplain. These flows will never re-enter the main channel, but instead enter an old 1800's channel that flows out to the bay.
2	0.266	Because flows over 3,400 ft^3/s leave the main channel system upstream of XS 2, the channel capacity at XS 2 was only modeled up to this flow. The model verified that with the ACOE levee left in place, XS 2 does have the capacity to hold up to 3,400 ft^3/s.
1	0.029	This is the most downstream cross section before flows enter the Dungeness Bay. At this cross section, flows at the 2-year event and greater flow out in all directions out to the bay.

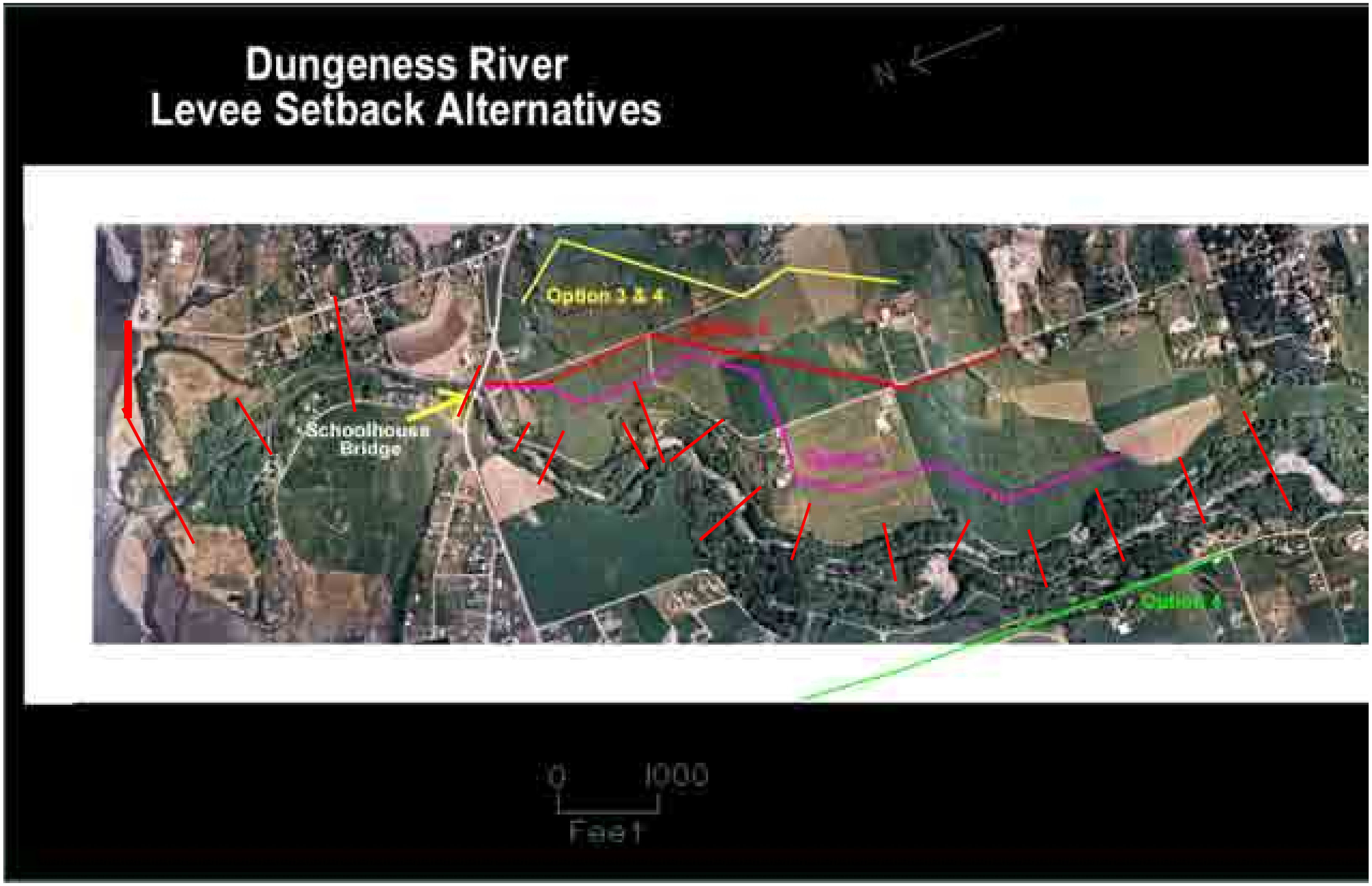


Figure 9. Dungeness River Levee Setback Options. XS's Shown in Red (1 at mouth in sequential order upstream to 17).

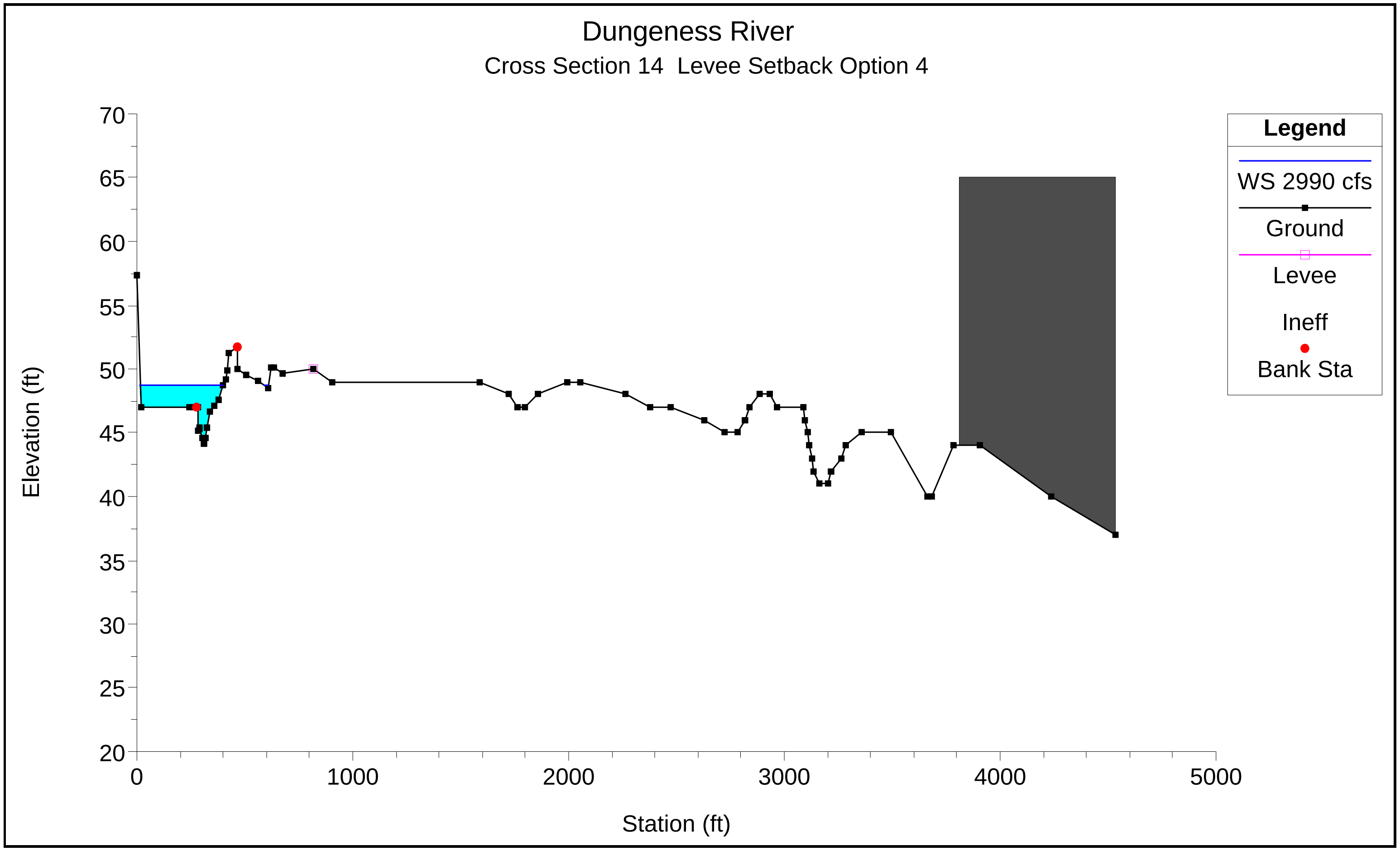


Figure 10. Model output at cross section 14. Olympic Game Farm Levee is setback to station 0 and new ACOE levee setback is at station 3810. Area shaded in green stripes is ineffective flow area where water would pond in floodplain during high flows.

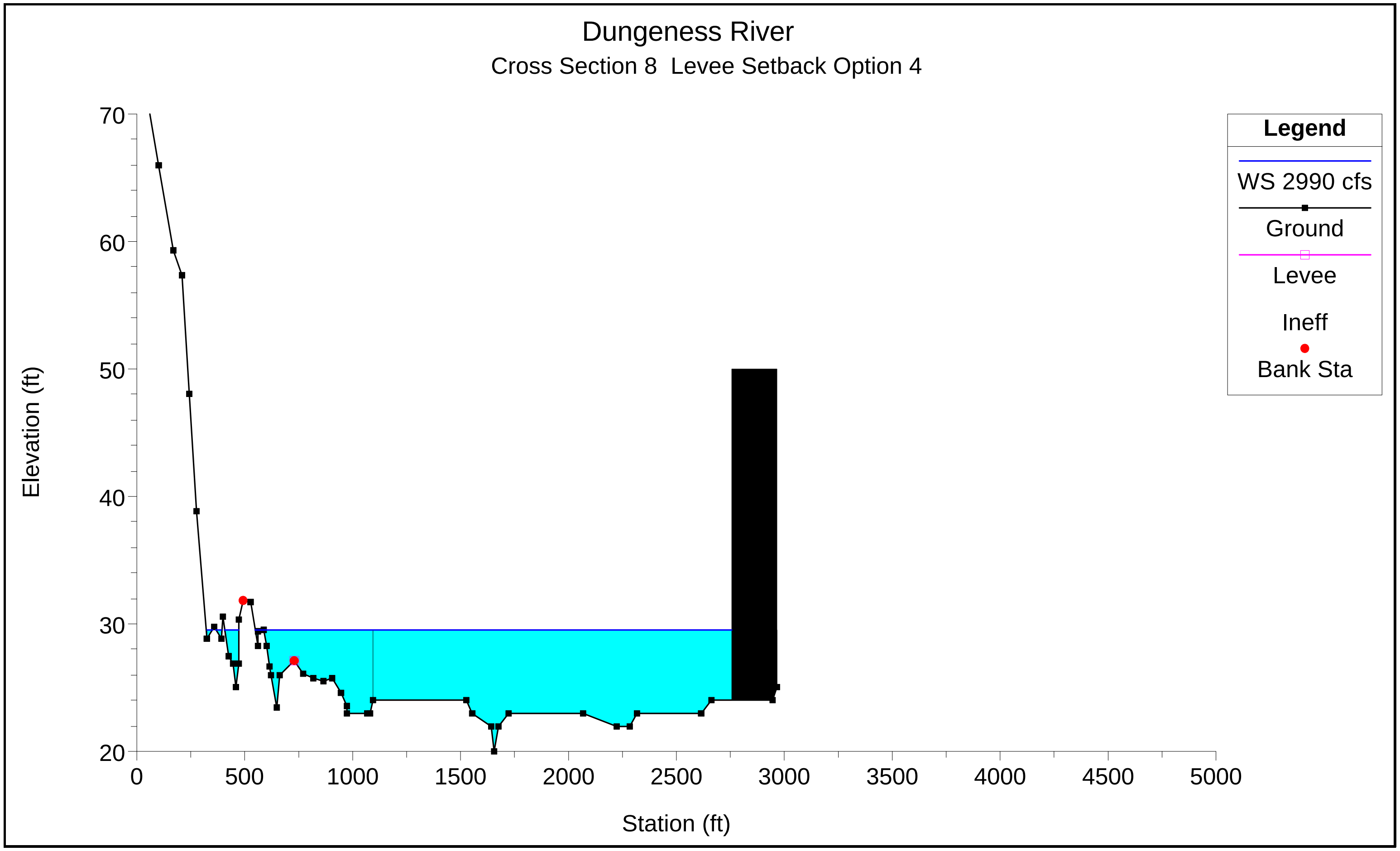


Figure 11. Model output at cross section 8. With levee setback, even during a 2-year flood flows would spill over into floodplain due to aggraded channel bed. High bluff is located on left side and new ACOE levee setback is at station 2760. Area shaded in green stripes is ineffective flow area where water would pond in floodplain during high flows.

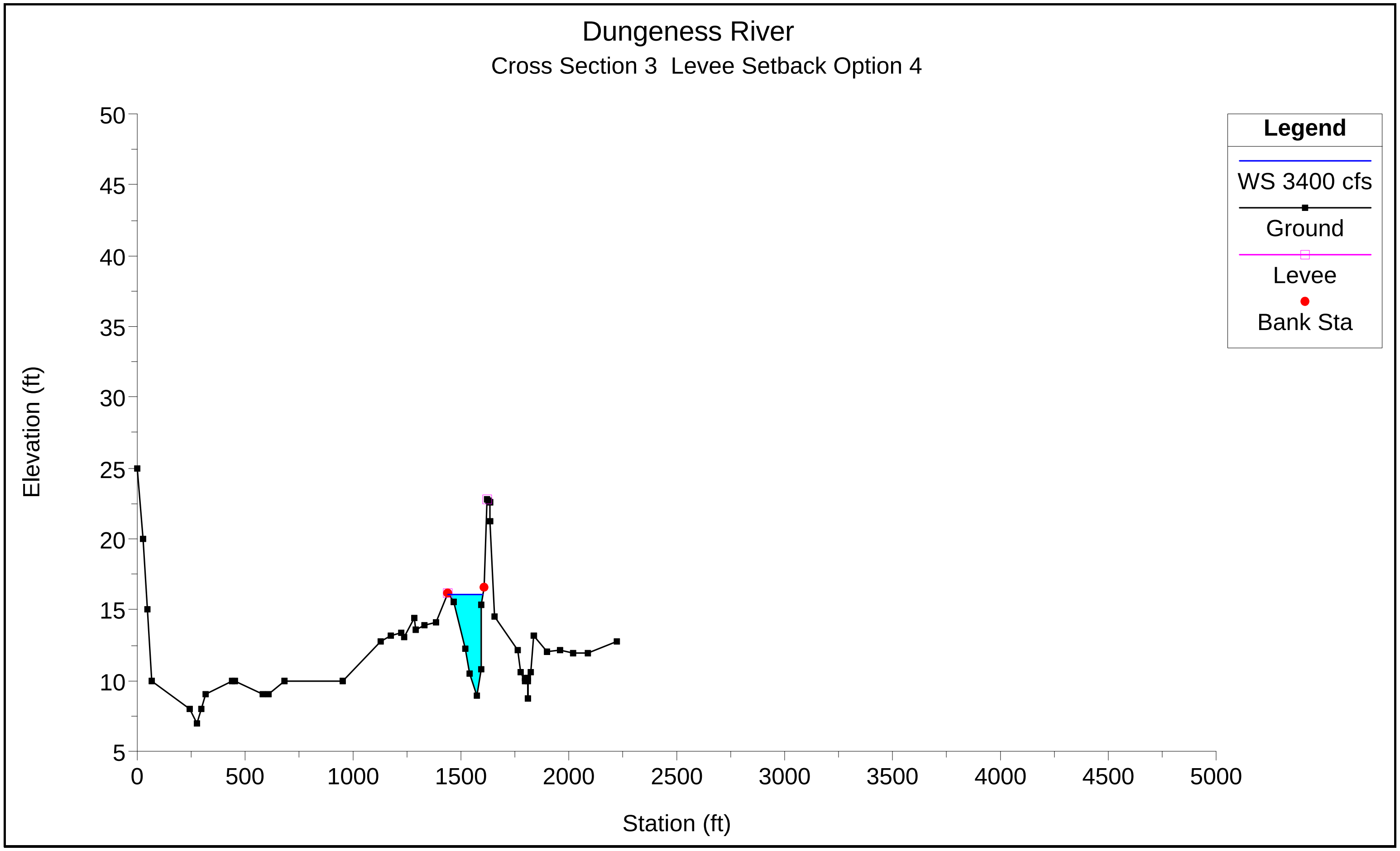


Figure 12. Model output at cross section 3. ACOE levee at station 1600 (in existing location) prevents flooding on right side. With levee removed on left side, area to left of station 1436 becomes floodplain area where water would overtop the bank and exit to the bay through a different path during flows greater than 3,400 cfs.

APPENDIX A

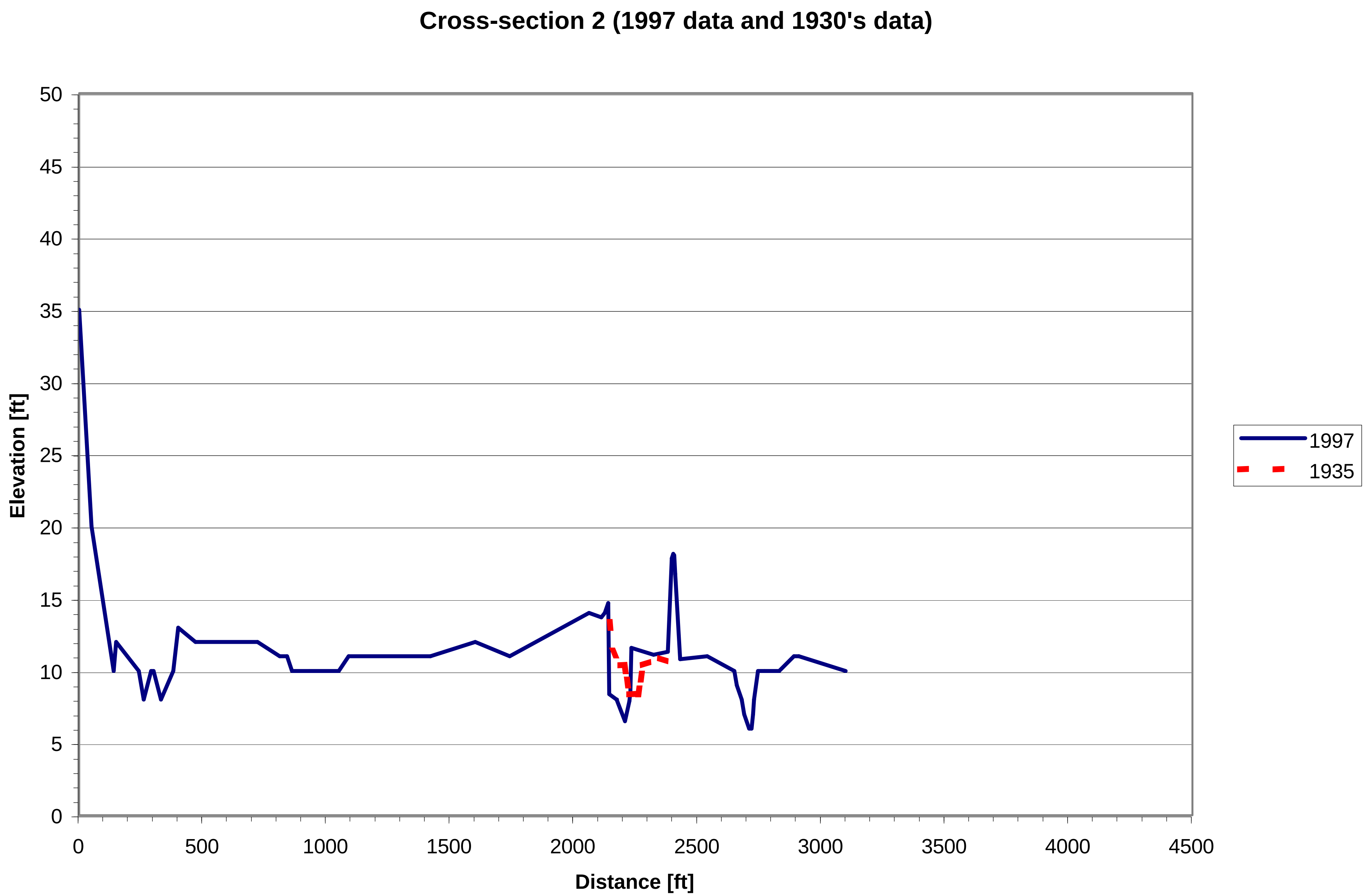
EXISTING CONDITIONS CROSS SECTION PROFILES
&
COMPUTED WATER SURFACE ELEVATIONS

LOWER 2.7 MILES OF DUNGENESS RIVER

APPENDIX B

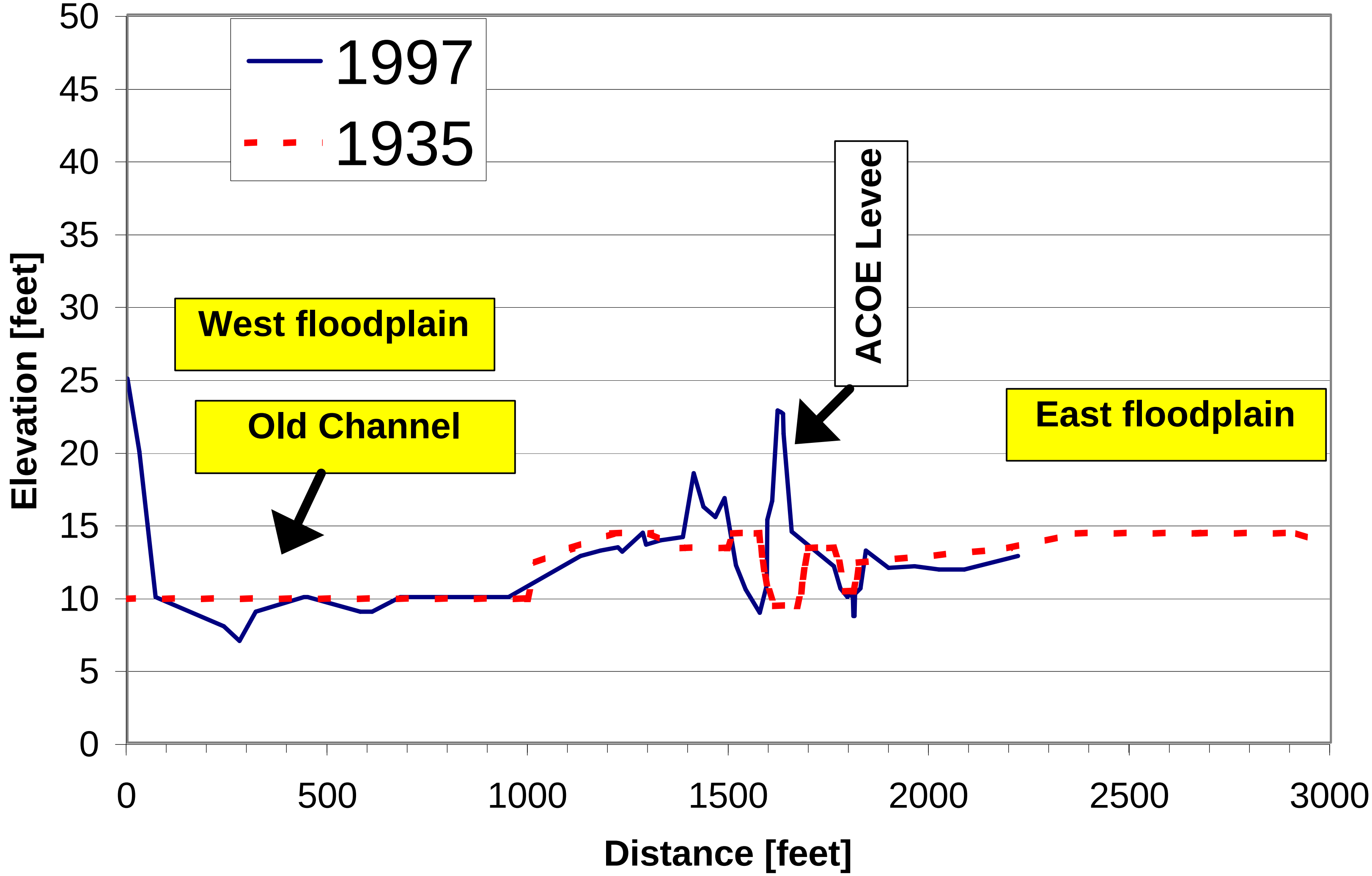
COMPARISON OF CHANNEL GEOMETRY FOR
EXISTING & 1930'S CONDITIONS

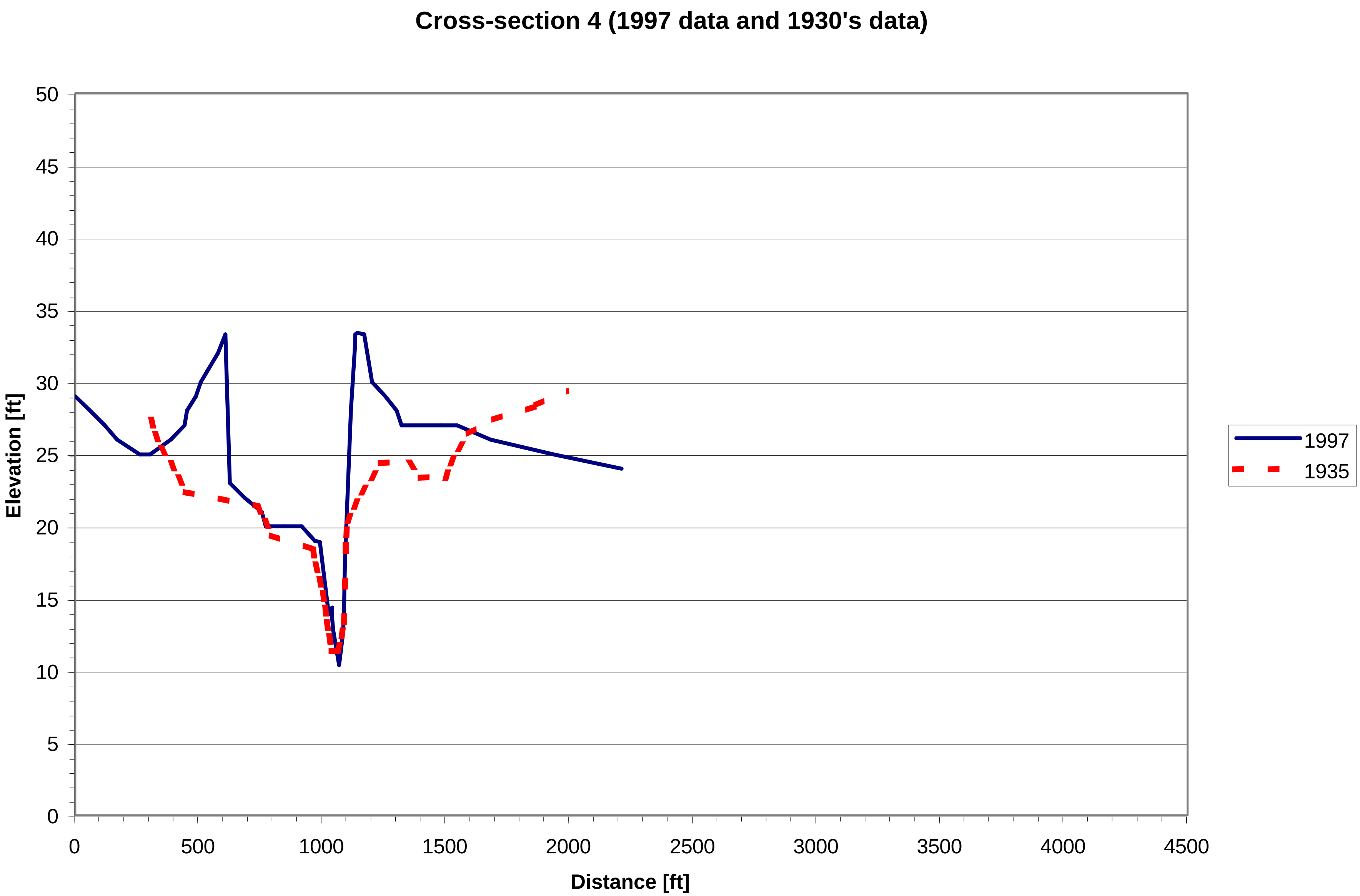
LOWER 2.7 MILES OF DUNGENESS RIVER



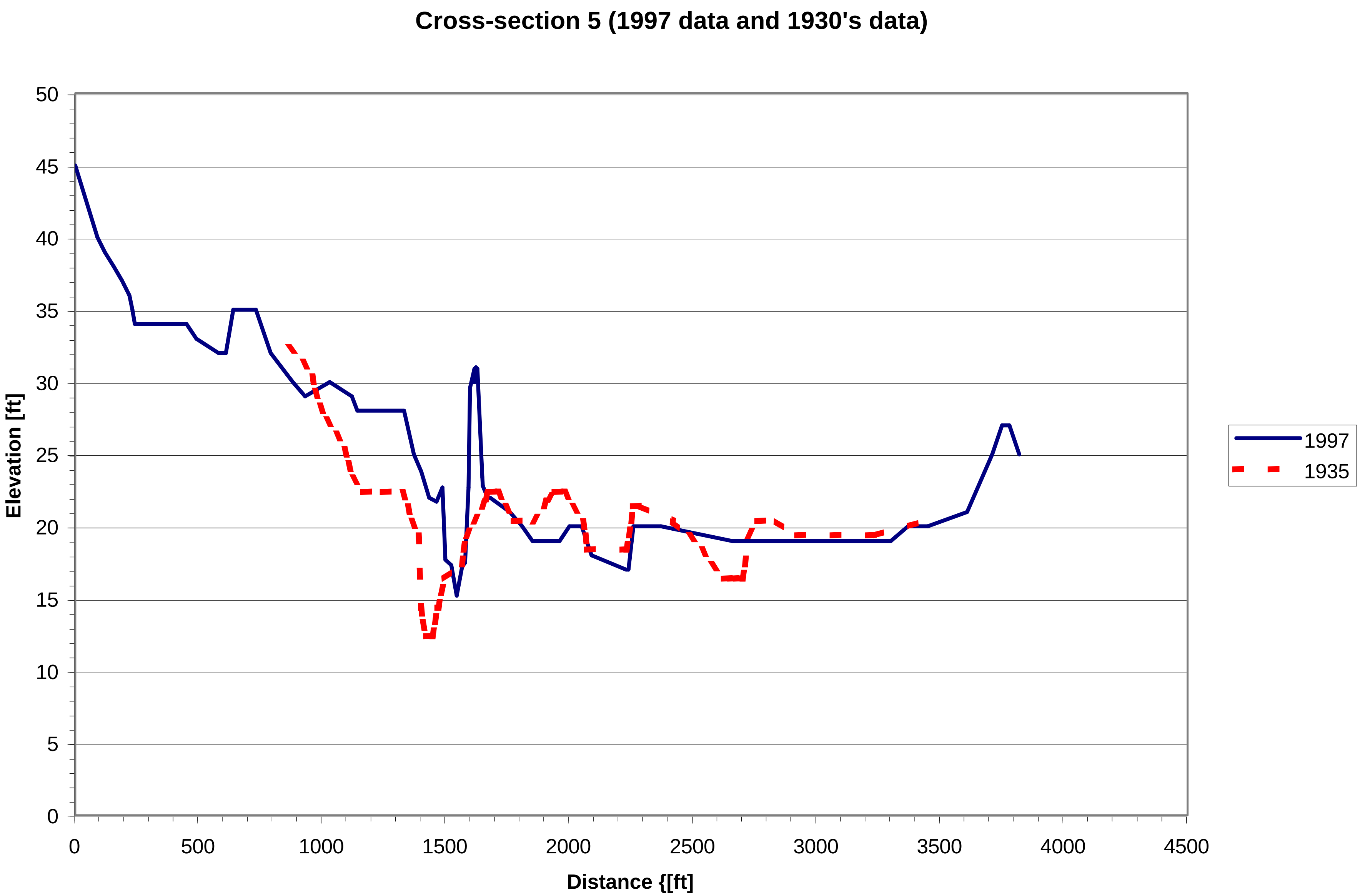
Cross-section 2 (1997 data and 1930's data)
Elevation [ft]
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935

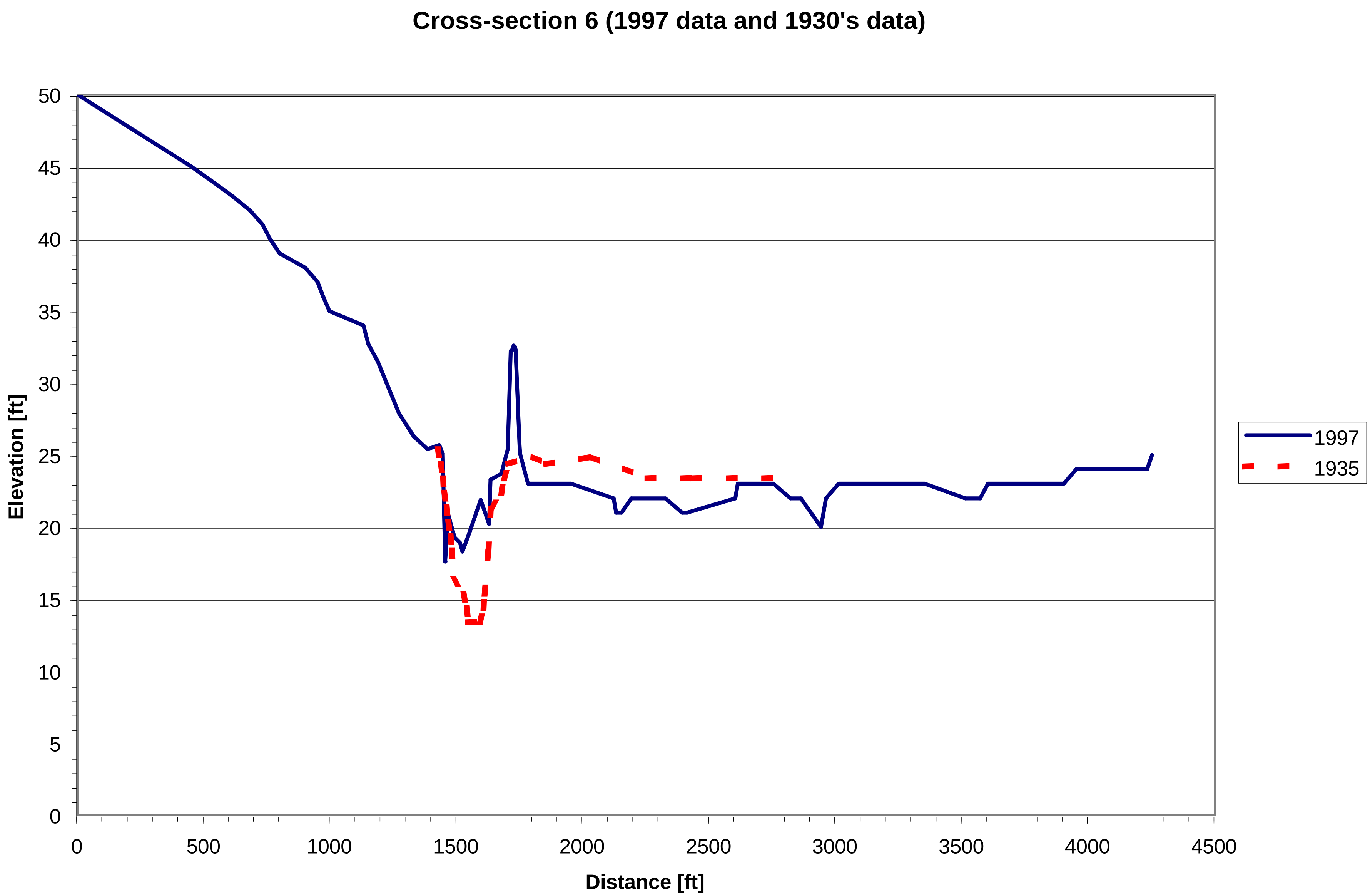
Cross-section 3 - River Mile .5



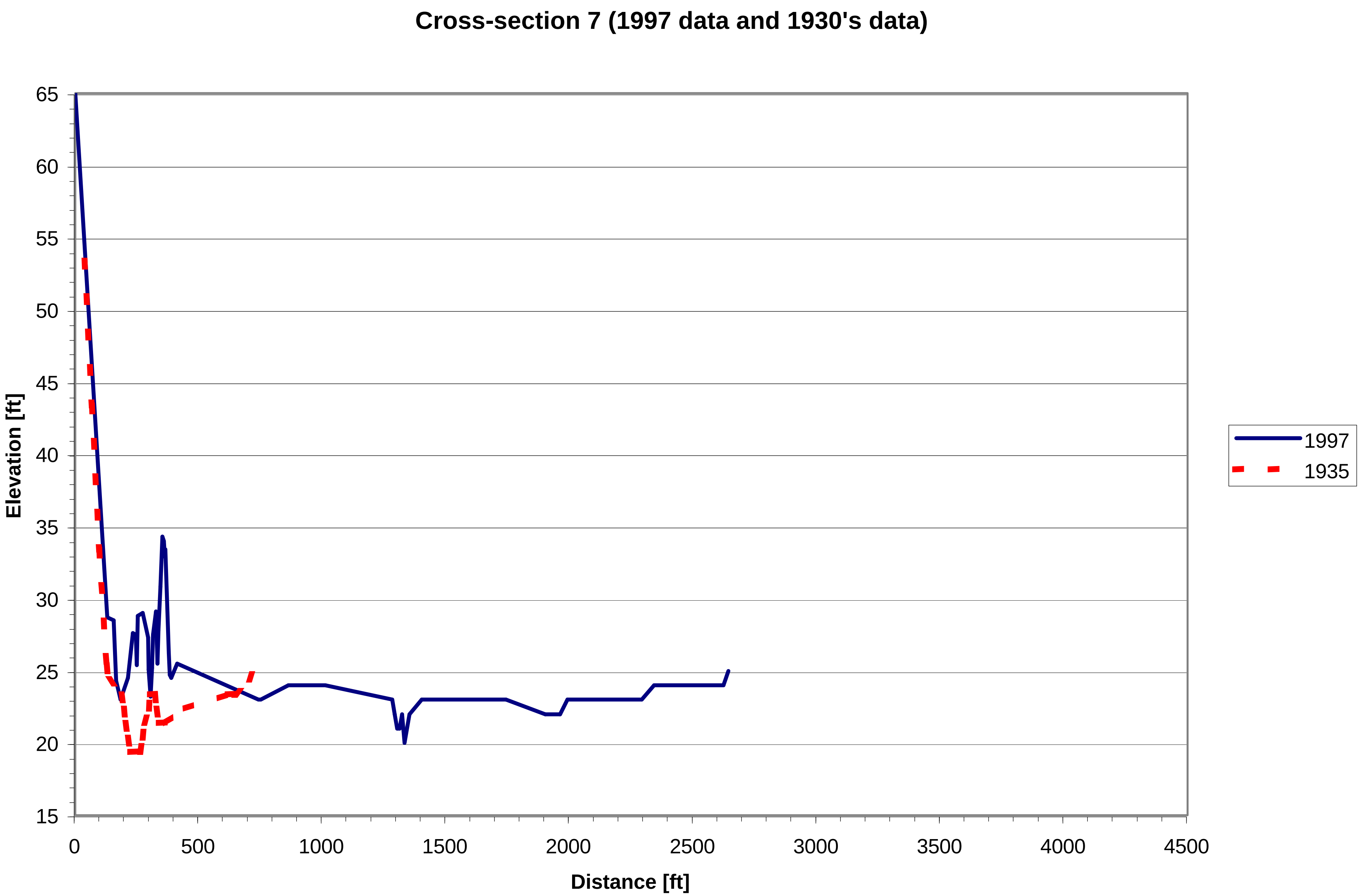


Cross-section 4 (1997 data and 1930's data)
Elevation [ft]
50
45
40
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935


Cross-section 5 (1997 data and 1930's data)
Elevation [ft]
50
45
40
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance {[ft]
1997
1935



Cross-section 6 (1997 data and 1930's data)
Elevation [ft]
Distance [ft]
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1997
1935


Cross-section 7 (1997 data and 1930's data)
Elevation [ft]
65
60
55
50
45
40
35
30
25
20
15
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935

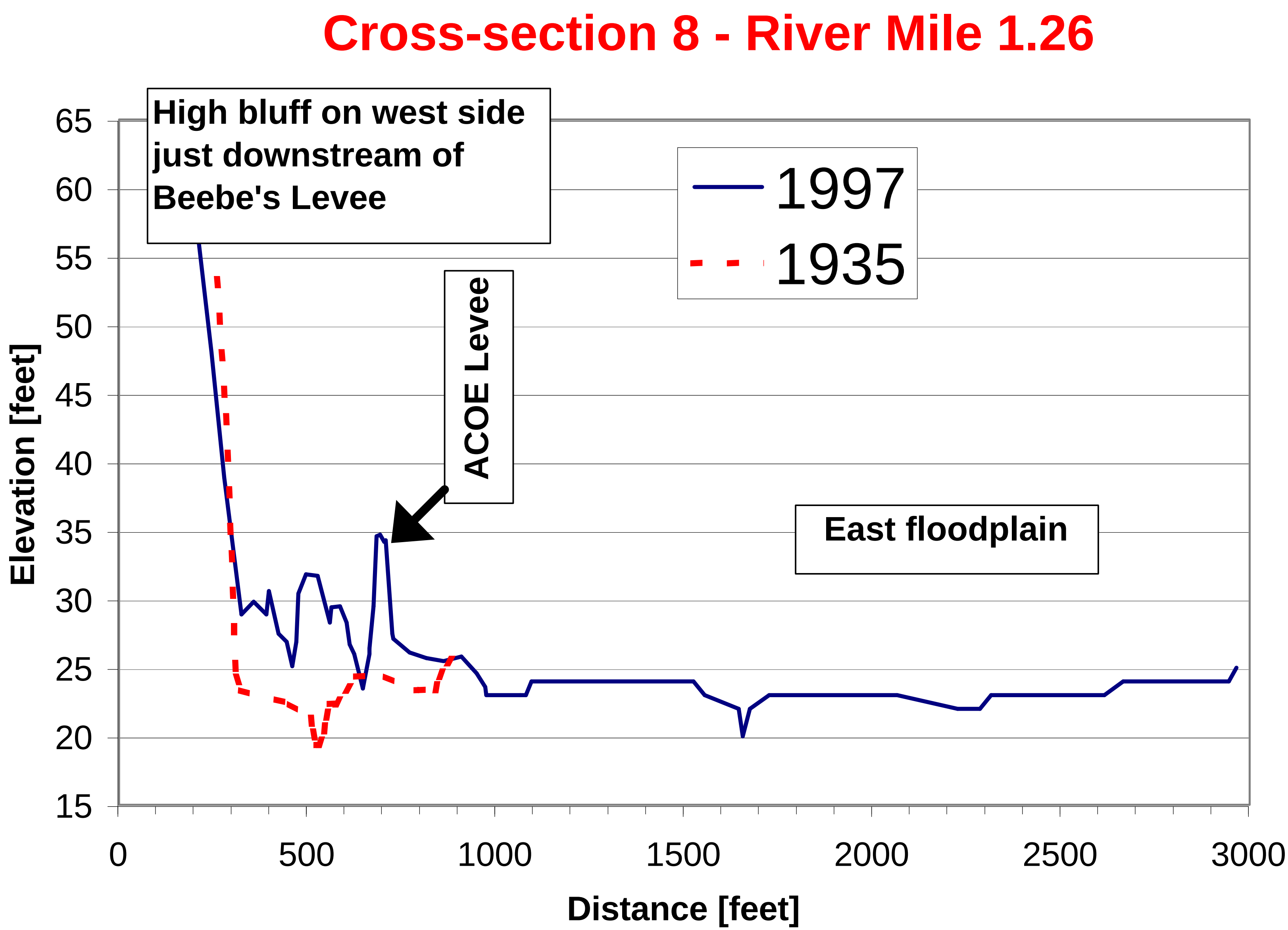
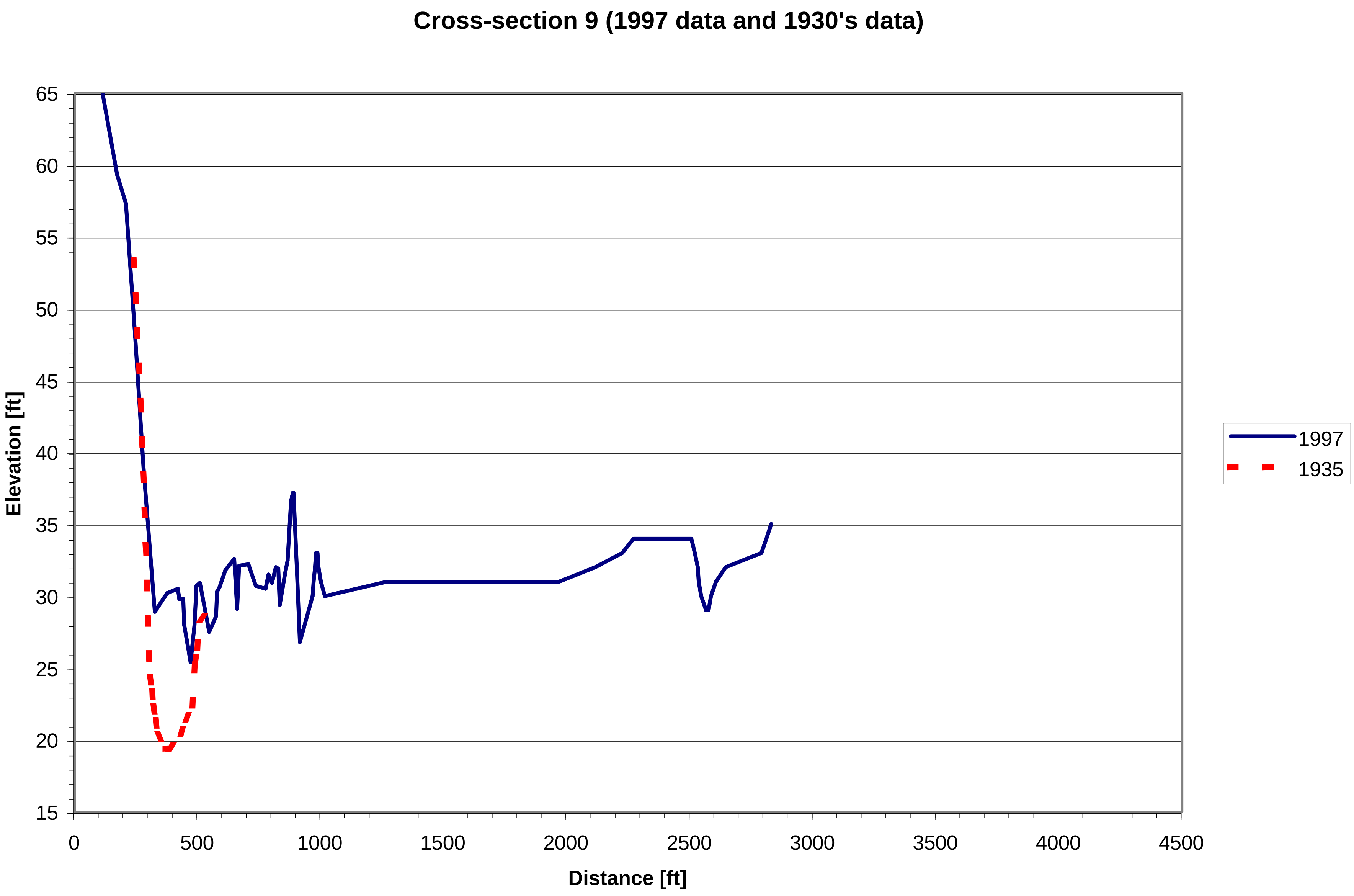
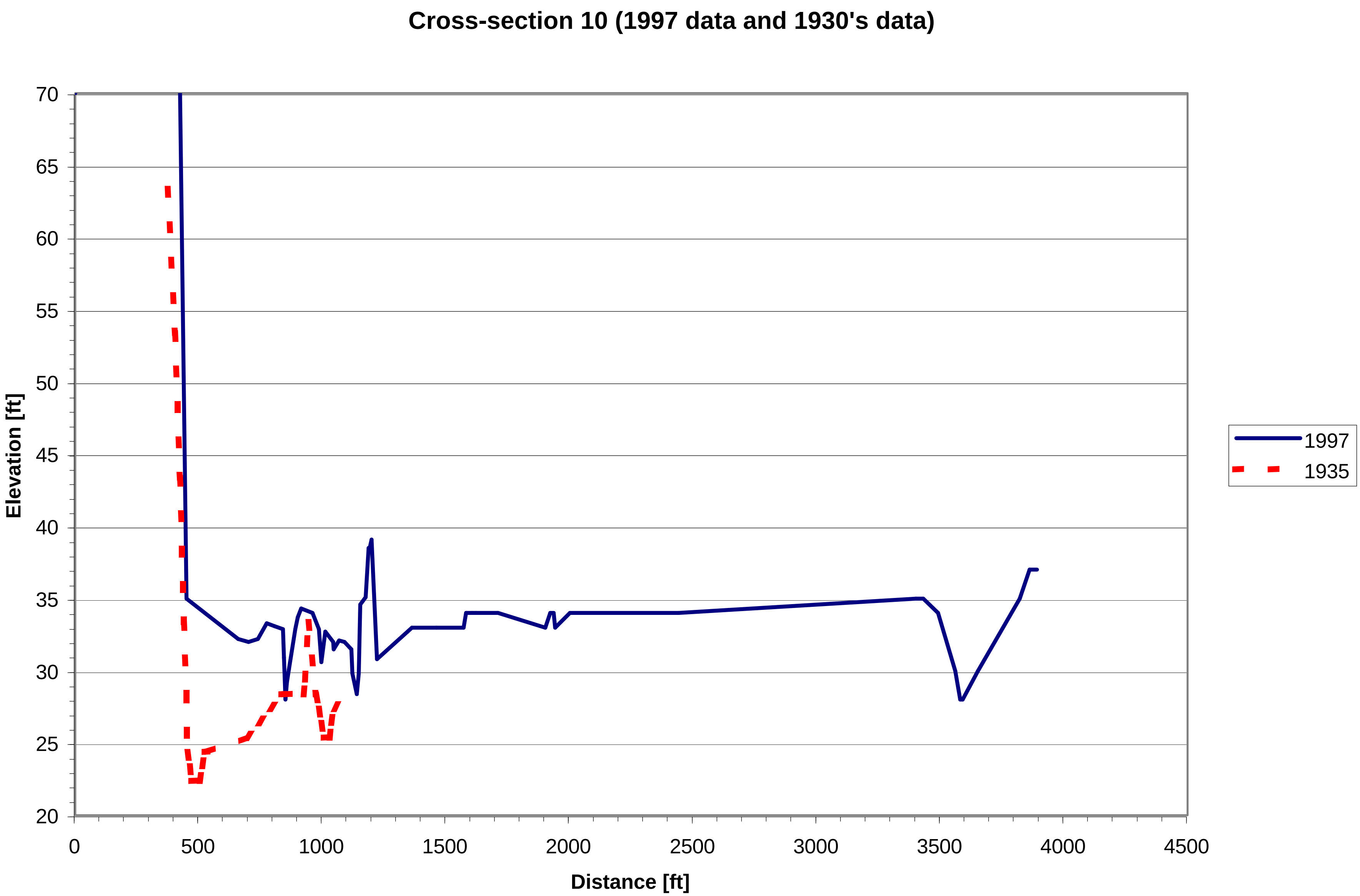
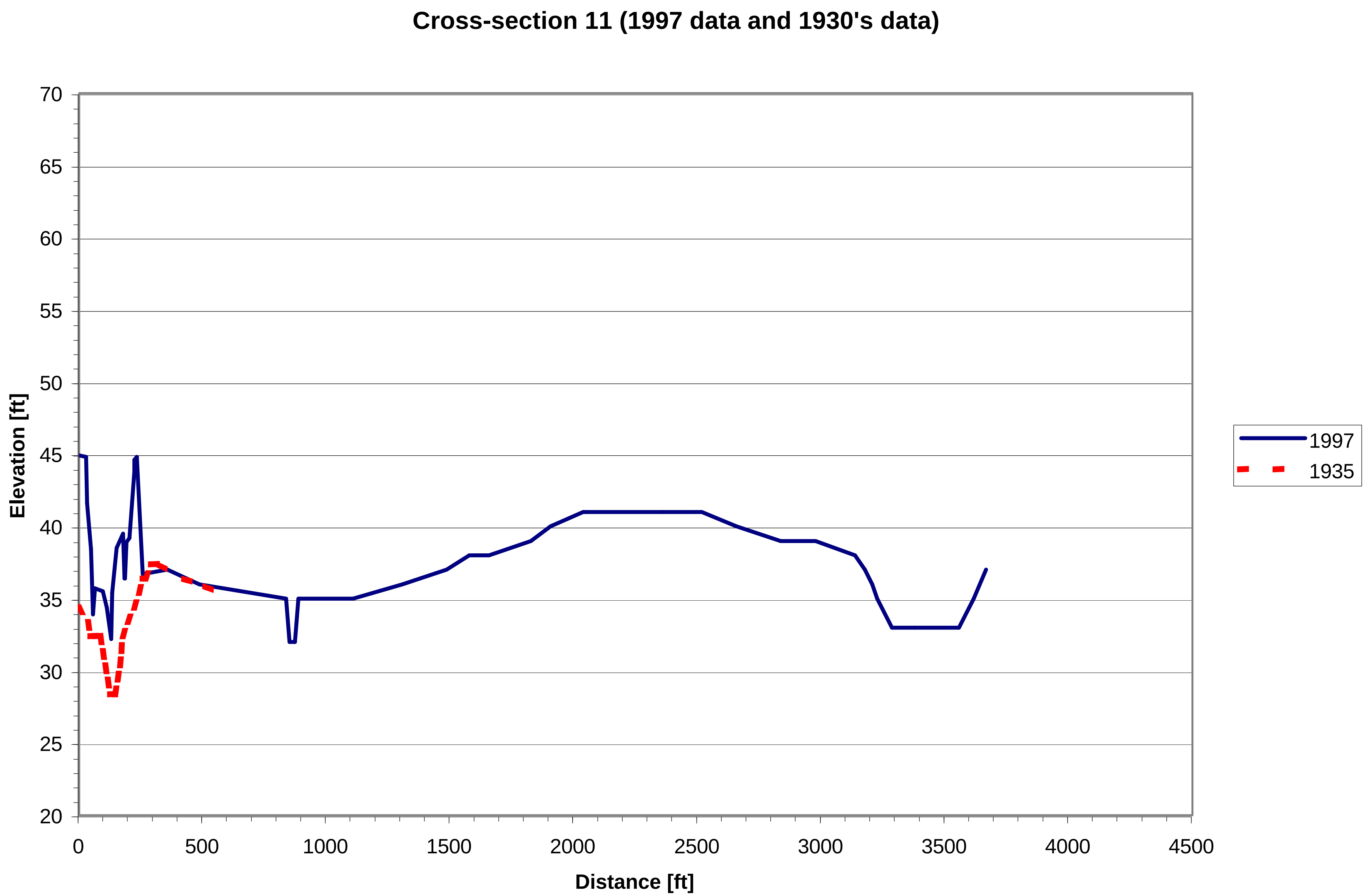


Figure 33: Existing versus 1935 cross section at RM 1.26 in Reach 1.



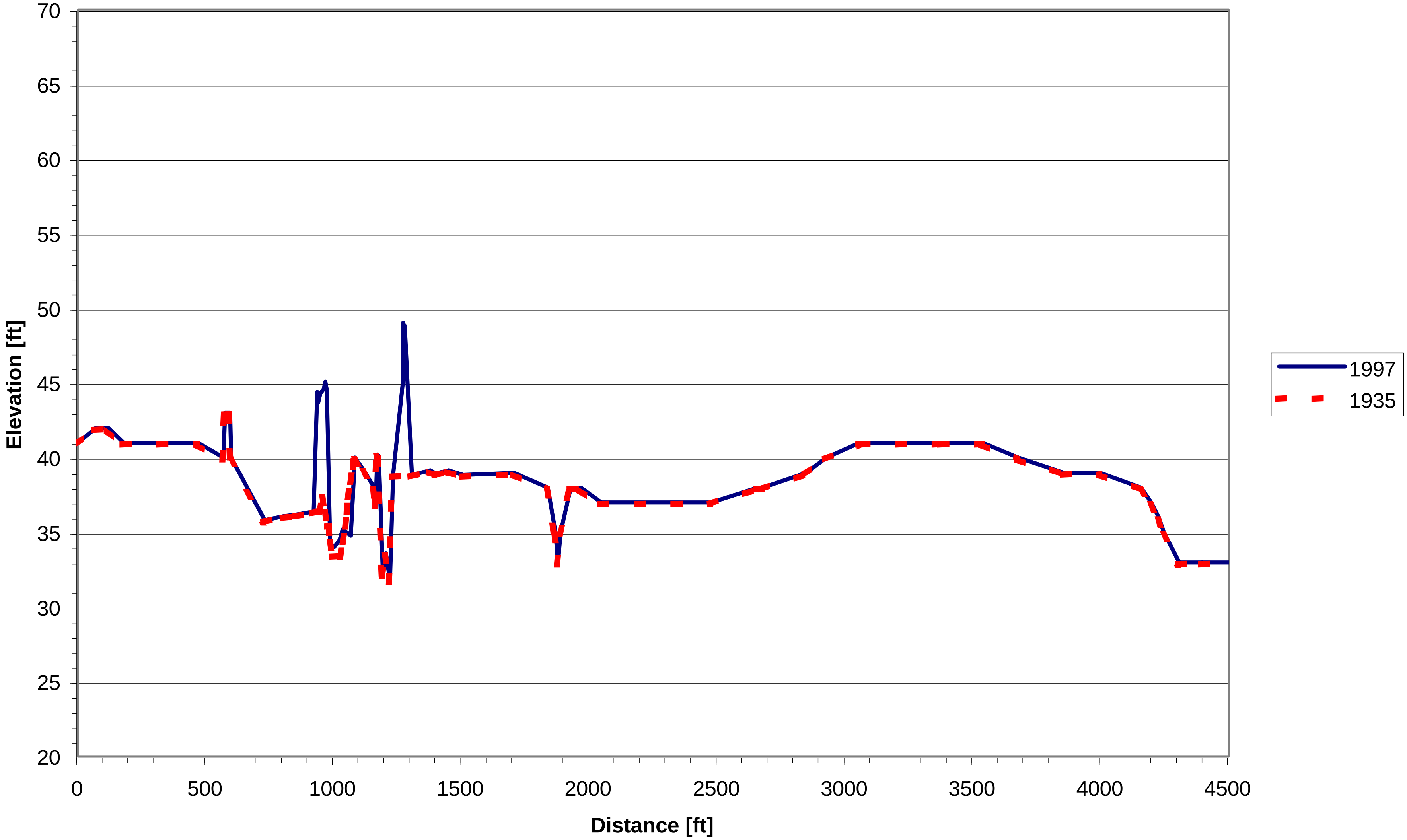
Cross-section 9 (1997 data and 1930's data)
Elevation [ft]
65
60
55
50
45
40
35
30
25
20
15
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935


Cross-section 10 (1997 data and 1930's data)
Elevation [ft]
70
65
60
55
50
45
40
35
30
25
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935

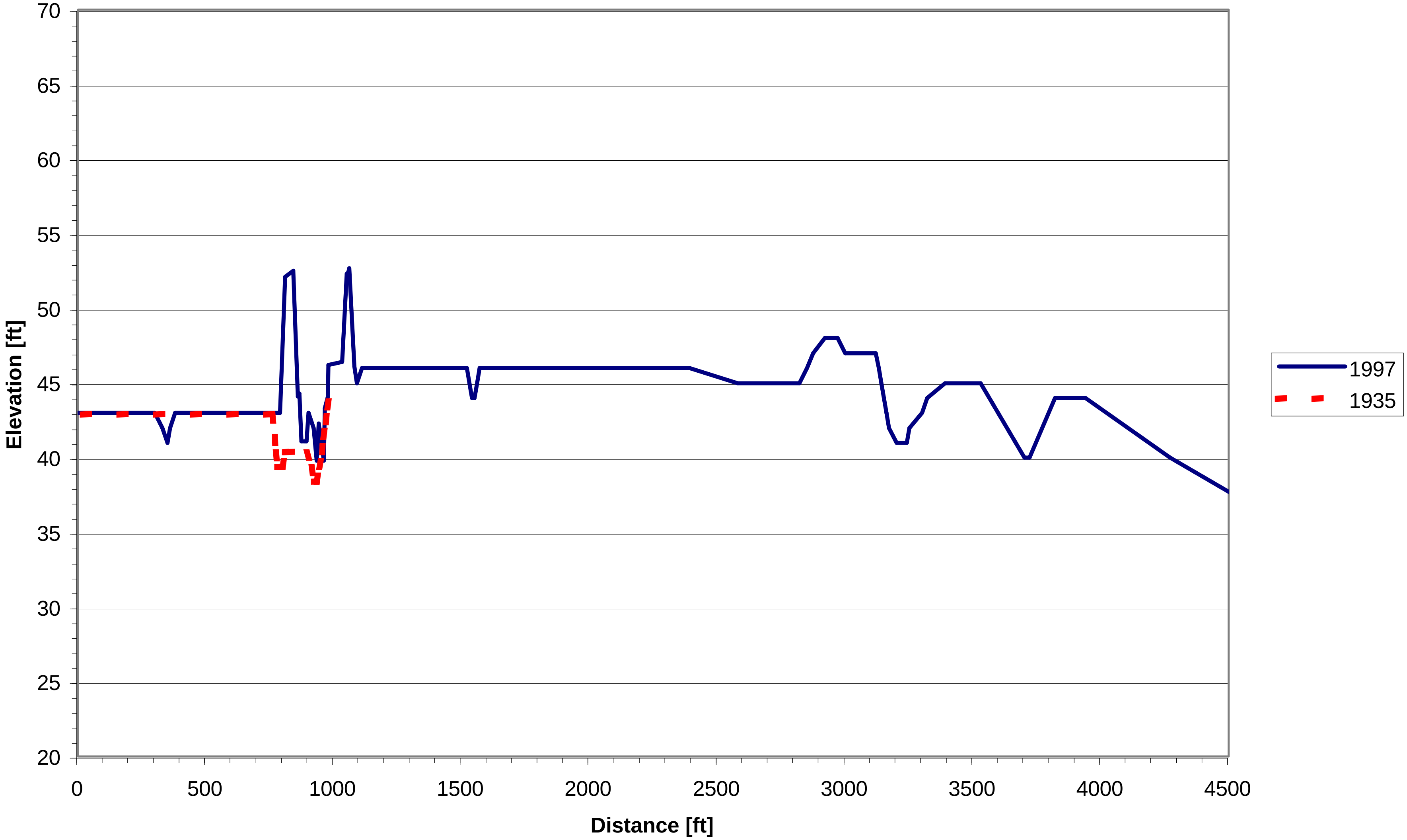


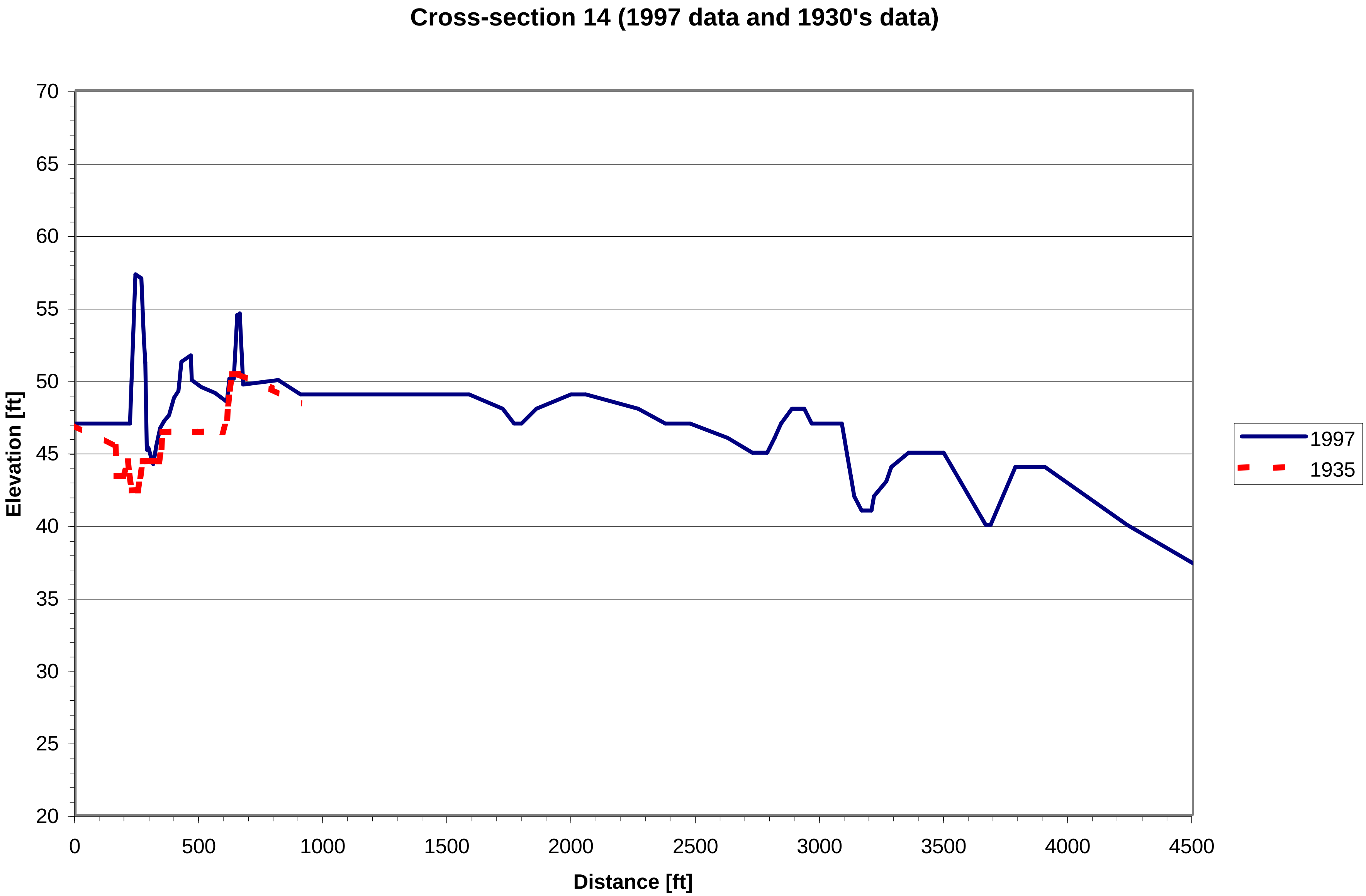
Cross-section 11 (1997 data and 1930's data)
Elevation [ft]
Distance [ft]
70
65
60
55
50
45
40
35
30
25
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1997
1935

Cross-section 12 (1997 data and 1930's data)

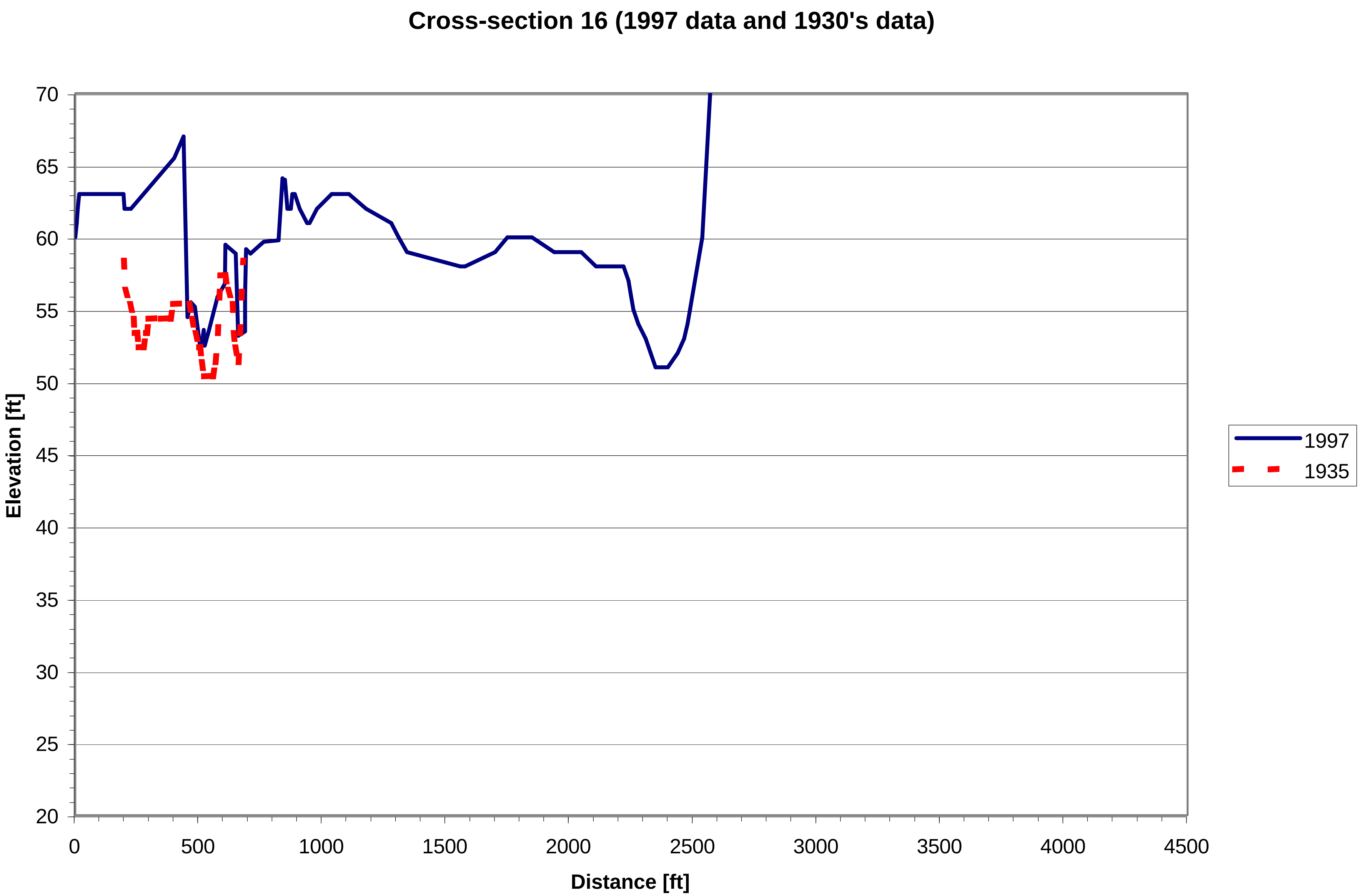


Cross-section 13 (1997 data and 1930's data)

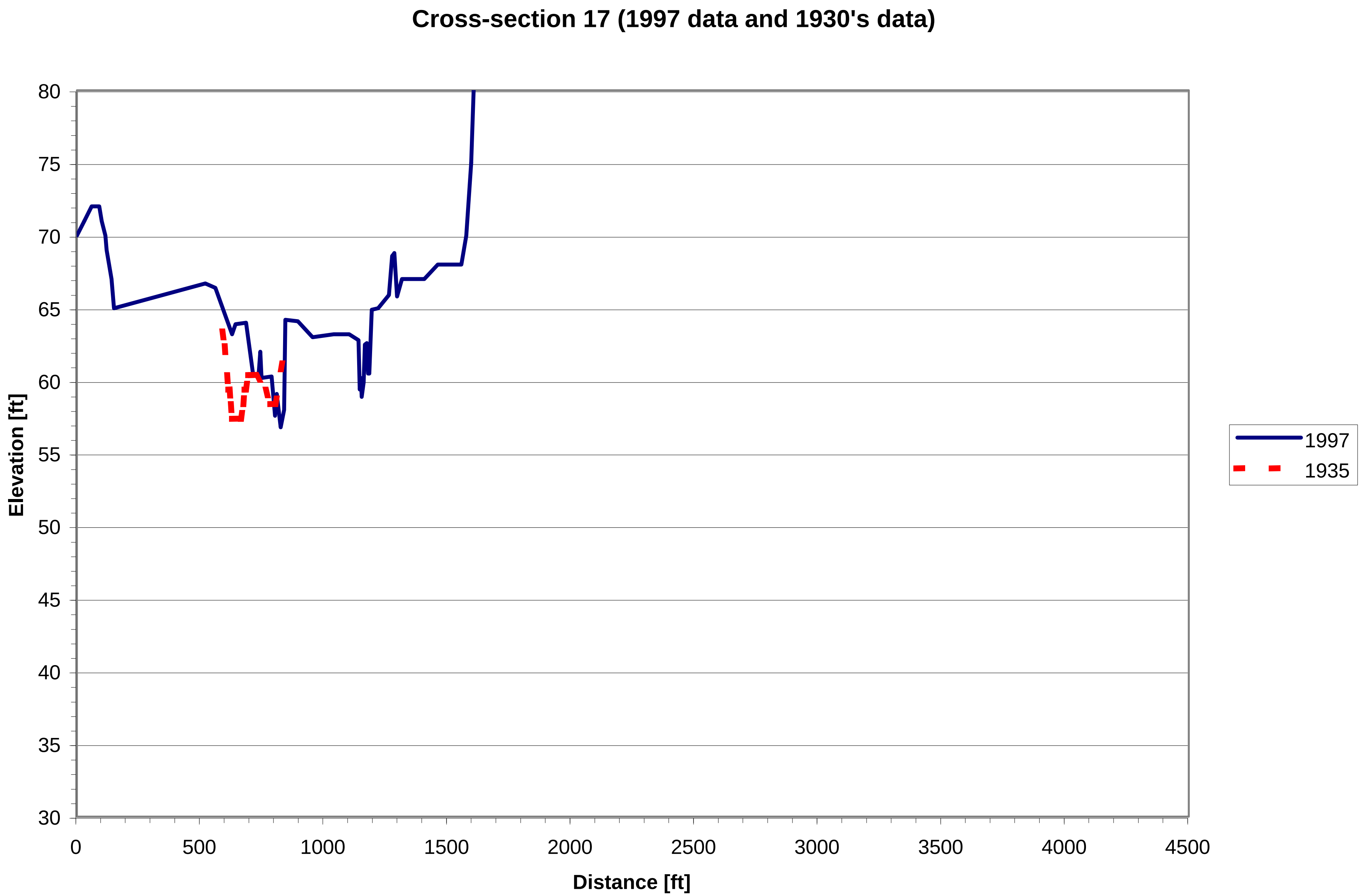



Cross-section 14 (1997 data and 1930's data)
Elevation [ft]
70
65
60
55
50
45
40
35
30
25
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935


Cross-section 15 (1997 data and 1930's data)
Elevation [ft]
70
65
60
55
50
45
40
35
30
25
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935



Cross-section 16 (1997 data and 1930's data)
Elevation [ft]
70
65
60
55
50
45
40
35
30
25
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935



Cross-section 17 (1997 data and 1930's data)
Elevation [ft]
80
75
70
65
60
55
50
45
40
35
30
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Distance [ft]
1997
1935

Technical Service Center
Denver, CO

Analysis of Alternatives for Levee Modifications Along the Dungeness River Lower 2.7 River Miles

PART B: The Dungeness River Corridor Downstream of Woodcock Road Bridge in 1942/43 and in 1998

Prepared by:
Lucy Piety and Richard Link

Bureau of Reclamation
U.S. Department of the Interior

November, 2001

MEASUREMENT OF SEDIMENT ON BARS ADJACENT TO SCOUR CHAIN TRANSECTS

Dungeness River, Washington

Prepared by

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U.S. Department of the Interior
Bureau of Reclamation

NOVEMBER 2001

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TABLES

(At end of report)

APPENDICES

MEASUREMENT OF SEDIMENT ON BARS ADJACENT TO SCOUR CHAIN TRANSECTS

Dungeness River, Clallam County, Washington

Purpose

The Jamestown S'Klallam Tribe (Tribe) has undertaken a study of the impacts of riverbed scouring during flood events on salmon spawning habitat in the Dungeness River. The depth of scour is measured through the installation of scour-chain transects across the riverbed at various locations along the Dungeness River. Initial scour chain installation was completed in 1999 and a second set of chains was installed in August 2000. In support of the Jamestown S'Klallam Tribe's study, the U.S. Bureau of Reclamation (Reclamation) conducted sampling of the riverbed materials present at selected scour-chain transects in September and October 2000. The sediment-size data measured at the transects will be combined with data obtained by the Tribe for the scour chains after the winter of 2000-2001 in order to estimate the sizes of any material that has eroded along the riverbed. In addition, the sizes of the sediment in and near salmon redds adjacent to the transects may be estimated. Furthermore, changes in the size distribution of the sediment samples may be assessed along the river downstream of the East Crossing Campground, the most upstream sample location. Sediment size data collected by Reclamation from gravel bars in 1998 may be added to the 2000 data set to extend the evaluation of the size distribution of the riverbed sediments downstream to the river's mouth at Dungeness Bay on the Strait of Juan de Fuca.

Introduction

Nineteen sediment samples were measured by dry sieving material excavated from gravel bars adjacent to or near scour-chain transects along the Dungeness River downstream of the former U.S. Forest Service East Crossing Campground near River Mile (RM) 17.5 to approximate RM 1.55 at the Army Corps of Engineers flood-control levee. The locations of the sample sites are shown in Figures 1 through 3, inclusive, and are summarized in Table A-1. The samples were measured in September and October 2000, after the scour chains had been installed by Fisheries Biologist Byron Rot of the Jamestown S'Klallam Tribe in the preceding August. Flows in the Dungeness River varied from 94 to 236 cubic feet per second (cfs) during the field investigation. Several of the sediment samples (DRsed-111, -114, and -115) were collected near scour-chain transects that had been installed in the summer of 1999 and subsequently exhumed in the 2000 field season to determine the depth of scour during the 1999/2000 flood season. Table 1 lists the scour-chain transect associated with each sediment sample.

Three samples were collected for a secondary purpose of evaluating the contribution of sediment derived from debris flows moving either directly into the river from adjacent side slopes or from tributary streams. Samples were collected on the main Dungeness both upstream (DRsed-106A) and downstream (DRsed-107) of Canyon Creek near river mile (RM) 11 and at the confluence with Canyon Creek (DRsed-106B). Of particular interest was the volume of fines (silt and clay) entrained within the deposits, as these materials can prove detrimental to salmon habitat.

Methods

The sediment present in the wetted river channel was not sampled due to potential impacts to migrating fall Coho and Chinook salmon runs and adverse implications to field sampling. Impacts to salmon included disturbance of migrating fish, potential disruption of spawning gravel beds, and localized increased turbidity resulting from excavation of the riverbed in the wet. The sampling problems included the difficulty in obtaining a representative sediment sample in flowing water and attendant problems with satisfactory dry-sieving of saturated materials which would tend to plug the sieves, and the tendency of fine-grained particles to adhere to larger particles leading to undercounting of the fine-grained fractions. Sample sites were located on exposed gravel bars adjacent to or near the respective scour-chain transects. Individual sites were selected where the bar sediment appeared to be similar to that of the riverbed along the scour-chain transect, based on visual inspection. The gravel bar locations allowed for sampling of relatively dry sediment that could be sieved and weighed by size fraction in the field without adversely impacting the salmon. Note that the water clarity of the Dungeness River during the field investigation was extremely clear with excellent visibility, greatly aiding the visual inspections of the riverbed.

At some sites, the sediment in the channel and adjacent bars was similar, so that any portion of the bar could have been used as a sample site. At other sites, the sediment was extremely variable, both between the channel and the bars and between different localities within each environment. At these localities, we tried to select a sample site where the sediment was representative of the sediment in the channel at one or more of the scour chains, if possible, as noted in the detailed discussion of the sample sites and on the accompanying sketches of each sample site (see Appendix A). In at least one instance, the sample site was selected to span two marked differences in sediment sizes on the bar to reflect the range of sediment sizes present in the channel along the transect.

At six sample sites, fine sediment had been winnowed from the bars and a lag deposit of gravel and cobbles (surface pavement or subarmor layer) had formed on the surface of the gravel bar. At most sites, the pavement was one particle diameter thick. At these sites, the pavement was sampled separately from the underlying bed material. At the remaining thirteen samples sites, the pavement was either not present or was only weakly formed and the surface pavement and bed material were combined into a single sample.

A one-meter square grid was laid out on the surface of the bar deposit and the dimensions of the sample pit were delineated with orange flagging for photographic documentation of the site. The sediment was excavated with shovels and loaded into buckets for processing. A pick was used to loosen the sediment where the material was tightly packed. The sediment in the 1-m square pit was sampled down to a depth necessary to obtain a representative field sample. Depths of the shallow pits varied from 0.2 to 0.7 ft. No major changes in sediment size or type were encountered with depth in any of the samples. Due to the close proximity of the wetted channel, a shallow water table was intercepted in many of the sample pits. A brief description of the sediment, including the pavement, if present, was prepared at each sample site. The sample description included particle shape, rock type, general size, imbrication, looseness, and weathering.

All of the sediment removed from the sample pit was manually sieved to separate the material into the following four sizes or fractions: finer than 8 mm, 8 to 16 mm, 16 to 32 mm, and larger than 32 mm. Material larger than 32 mm was passed through a pre-cut template or gravelometer to separate the larger material into the following sizes: 32 to 63 mm, 63 to 90 mm, 90 to 128 mm, 128 to 180 mm, and larger than 180 mm. These particles were passed through the gravelometer by their shortest dimension. For each particle greater than 180 mm in diameter, all three dimensions were measured and its weight determined; these measurements are listed separately on the sample sheets (Appendix B). The total weight of the samples ranged between about 80 to 300 lbs and the average weight of the samples was about 150 lbs. As the sediment was passed through the sieves, it was placed onto a tarp into separate piles for each size fraction. The sediment was photographed as close oblique stereo pairs. The material in each fraction was weighed to the nearest 0.1 lb using a scale suspended from a tripod. After its weight was recorded, the material was discarded into the sample pit, except for a fraction of the minus 8-mm material, which was retained in a sample bag for subsequent laboratory testing. If a pavement was present, the above procedure was performed twice, first for the pavement and then for the underlying bed material.

The sample of the minus 8-mm sediment, which was collected for all the samples except the pavement layers, was submitted for laboratory analyses for the smaller fractions as shown on Table C-1 (see Appendix C). These analyses were performed by Materials Testing and Inspection, Inc., of Boise, Idaho and included (1) particle-size distribution using standard Reclamation sieves and a hydrometer and (2) Atterberg limits to determine the plasticity of the fine sand, silt, and clay particles. These analyses were conducted to determine the distribution and properties of the particle sizes that are too small to separate in the field because of equipment and time constraints.

Limitations

The visual assessments of the similarities in the sediment sizes between those along the scour-chain transects and those on the adjacent or nearby gravel bars where the sample sites were located is highly subjective. Especially in areas where the sediment was variable, the sample may not be representative of the sediment in the channel along the scour-chain transect or may be representative of only a portion of the transect. We have noted those samples for which this consideration might be a problem, as described in the detailed discussion of the sample sites which follows.

In addition, sample site selection was based on a visual comparison of the riverbed surface with the surface of adjacent gravel bars. The composition of the bed material beneath the surface of the riverbed is unknown and is inferred to be similar to that observed in the bar deposits along the channel margin for the purposes of this report. Our examination of the riverbed materials has shown that a high degree of variability can be observed over very short distances in the river channel and the bed materials present within the wetted channel may vary significantly from those observed in the gravel bars. The composition of the bed material is important to the study, as this is the material in which the scour chains have been installed: this composition can only be approximated due to the limitations on sampling discussed previously.

Sample Sites

Former U.S. Forest Service Campground at East Crossing (RM 17.7)

Sample DRsed-101 was located about 250 ft upstream of scour-chain transect #00-1 on an unvegetated bar on the east side of the Dungeness River just upstream of the mouth of a small side channel (Figure A-1). Note that gravel bars were not present in the immediate vicinity of the transect. This bar was selected for sampling because it was the most accessible bar near transect #00-1 that had sediment sizes comparable to those in the channel along the transect. Pavement was not present at the site.

Sample DRsed-102 was located just downstream of scour-chain transect #00-2 on a small, unvegetated bar on a side channel on the east side of the Dungeness River (Figure A-2). The sampled bar is adjacent to a 0.5-m-high scarp that forms the riser of the vegetated surface on which the East Crossing Campground was located. This campground has been permanently closed following a series of recent debris flows which have buried camp sites on the east end of the campground. The sample area spanned the contact between sediment of different sizes on the bar. The area was about evenly divided between subangular to well-rounded pebble-rich sediment and subrounded to well-rounded cobble-rich sediment. Both sizes of sediment were visible along the transect and were visually similar to the sediment in the channel at scour chain 1. Coarse sand overlay the pebbly gravel in one corner of the sample area. Pavement was not present at the site.

Gray Wolf River near Dungeness River Confluence (RM 0.9)

Sample DRsed-103 was located at scour-chain transect #00-4. The sample pit was sited on a small, unvegetated bar along a side channel on the east side of the Gray Wolf River (Figure A-3) about one mile upstream from the confluence with the Dungeness River. Because the bar was exposed just above the low-water level, the highest part of the bar was used for sampling. The sample was wet and sand and finer sediment adhered to the larger particles. The sampled portion of the bar was pebbly and slightly more coarse at its upstream end. The pebbly area was visually similar to the sediment sizes in the side channel along the transect. Sand up to about 1.5 m thick covered part of the bar: the sand-covered area was not included in the sample. Pavement was not present at the site.

Sample DRsed-104 was located at scour-chain transect #00-5 and near transect #00-6. This sample pit was excavated on a large, unvegetated bar in the middle of the main channel of the

Gray Wolf River (Figure A-4). The sediment on the bar was variable, and a considerable amount of woody debris was present both in the channel and on the bar surface. The sample area was sited on a portion of the bar that had medium-sized sediment. This site was chosen because the sediment was visually comparable to that observed at chains 1 and 2 of transect #00-6. The entire surface of the sampled bar, including the sediment at the sample site, was more coarse grained than the riverbed exposed at chain 1 of transect #00-5. Consequently, a representative sample site on this bar was not available to evaluate the sediment in the channel at scour chain 1.

Pavement on the bar surface at sample site DRsed-104 was poorly developed, but was sampled separately. Sand and fines had been winnowed from the surface of the bar and the resulting pavement consisted primarily of loose, subangular to subrounded gravel and cobbles; a few particles were rounded to well rounded. Very intensely weathered to decomposed fragments of shale were observed disintegrating in place within the bar deposit at this site.

U.S. Geological Survey Stream Gage (RM 11.6)

Sample DRsed-105 was located at scour-chain transect #00-21 on a small, unvegetated bar adjacent to the low-water channel on the west side of the Dungeness River (Figure A-5) about 800 ft downstream from the USGS stream gaging station. The sample site was surrounded by large, mostly moss-covered boulders and some woody debris. The sampled bar was bounded on the west by a low scarp that delineates a tree-covered terrace. The sample pit was sited on a portion of the bar that was slightly finer grained than the sediment on the bar to the south and west of the sample site: this site was selected because the sediment was visually comparable to that observed in the wetted channel at chains 1 and 2 of transect #00-21. Sand covered part of the bar and these sandy areas were not included in the sample. The sample was loose and moist; water was reached at a depth of about 0.15 m (0.5 ft) in the sample area. Pavement was not present at the site.

Dungeness Fish Hatchery/Canyon Creek Confluence (RM 10.8)

Three sites were sampled near the mouth of Canyon Creek and just upstream of the Dungeness Fish Hatchery operated by the Washington State Department of Fish and Wildlife. Sample DRsed-107 was located just upstream of scour-chain transect #00-25 at the downstream end of a long, narrow, unvegetated bar that extends downstream from the mouth of Canyon Creek on the west side of the Dungeness River (Figure A-7). The sampled bar was bounded on the west by a 1.5-m-high scarp that delineates a terrace that is vegetated, mostly by alder. The surface of the bar included 5 to 10 percent very large boulders: the sample pit was sited to avoid most of these. The dimensions of five of the largest of the boulders adjacent to the sample site were measured to help estimate the range of sizes of the large boulder fraction (see the sediment sample forms in Appendix B), as the boulders were too large to weigh and likely exceeded the limit of the field scale. These dimensions are minimum values because the boulders were partially buried and were too large to be removed easily.

The source of the sediment at site DRsed-107 may be in part Canyon Creek, because the gravel bar at the sample site contained dark rocks that are concentrated at the mouth of the creek and probably derived from sources upstream on the creek, including debris flows (discussed in more detail later in this section). However, the source of most of the sediment at the sample site is probably the main channel of the Dungeness River, because most of the rocks on the bar are a mixture of size, shape, and lithology. It is likely that the sediment from Canyon Creek that is at the sample site has been reworked by the Dungeness River and, thus, has been mixed with sediment carried along the main channel from the upper basin.

Only one chain in transect #00-25 could be located at this site. This chain was observed near the middle of the main channel of the Dungeness River. The sediment at the sample site DRsed-107 was smaller than the largest particles that were visible near this chain. Sediment at the sample site was comparable to the finer sediment near the west edge of the low-water channel along the projected trace of transect #00-25. The sediment was loose and included angular to rounded particles that consisted of sand to large boulders. Pavement was not present at this site.

In order to estimate the size of the sediment supplied by Canyon Creek to the Dungeness River and potential impacts of fine sediment to salmon habitat, Sample DRsed-106A was located on an unvegetated bar just upstream of the mouth of Canyon Creek and Sample DRsed-106B was located on the same bar just downstream of the mouth (Figure A-6). These two sample sites were between scour-chain transects #00-24 and #00-25. DRsed-106A was selected to act as a control point to determine the character of the sediment present in the main Dungeness channel upstream of the confluence and, therefore, having no influence from Canyon Creek. Sample DRsed-106B was located within the active channel of Canyon Creek at the confluence, but above the wetted, low-water channel and was intended to measure the sediment being delivered into the Dungeness at that point. The location of sample DRsed-107 downstream from both of these sample sites permits evaluation of the downstream transport and mixing of the Canyon Creek sediment with the materials being transported by the main Dungeness.

Sample DRsed-106A was located just downstream of a large pile of woody debris and upstream of Canyon Creek on the west bank of the Dungeness River. The bar consisted of loose, subangular to rounded particles, which were mostly pebbles. Some cobbles and a few large boulders were present on the bar surface. The site was selected to avoid the large boulders, which are too large to excavate and weigh by hand. This bias in site selection for the sample should not effect interpretation of the field data, as the concentration of the fine sediment delivered by Canyon Creek to the Dungeness River was of most concern in this evaluation of the potential impacts to salmon habitat.

Sample DRsed-106B was located just downstream of the mouth of the low-water channel of Canyon Creek on a portion of a bar deposit that was an intricate mix of finer and coarser sediment. Part of the surface near Sample DRsed-106B was covered by sand, but these areas were avoided in the sample. The bar included a large percentage of dark, angular to subrounded rock fragments, which were mostly pebbles, but also included some small cobbles. The dark rocks were composed chiefly of gray basalt, shale, and limestone. The shale fragments were very intensely weathered to decomposed and disintegrated into small, angular, flat chips. The basalt fragments were finely fractured. The surface rocks also included subrounded to well-rounded cobbles of various rock types. On the basis of the distribution of the dark rock fragments and the morphology of the surface of their deposit, we infer that Sample DRsed-106B was located on sediment that was primarily an alluvial-fan or debris-flow deposit from Canyon Creek. The downstream end (or toe) of the sediment deposited by Canyon Creek has become mixed with sediment carried by the main channel of the Dungeness River. Surface pavement was not present at this site.

Cline-Clallam Irrigation Diversion/Bypass Pipeline (Downstream End of the Dungeness Meadows Levee - RM 7.75)

Sample DRsed-108 was located about 17 m (55 ft) downstream of scour-chain transect #00-8 near the intake for the Cline-Clallam irrigation diversion structure. The sample was sited on a large, unvegetated bar on the west side of the Dungeness River (Figure A-8) on the opposite bank from the downstream end of the Dungeness Meadows flood-control levee. This bar contained high concentrations of boulders and was mostly much more coarse grained than the adjacent riverbed. The sample site was located on a finer-grained portion of the bar, where the sediment was comparable, as much as possible, to that present in the channel at scour chain 1 of the transect. The west side of the bar was bounded mostly by a 1-m-high scarp that delineated a lower terrace vegetated with willow and grass and, in part, by a higher 2-m terrace vegetated with trees.

Pavement was not present at the site. However, the surface material was sampled separately as it appeared to be a surface veneer of finer-grained sediment overlying more coarse-grained material at depth, based on our visual inspection of the bar. The finer-grained surface sediment was the most comparable of any of the bar deposit to the riverbed sediment observed in the wetted channel at the scour-chain transect. The surface sediment at the sample site was loose and consisted of subangular to well-rounded large cobbles grading to sand.

Sample DRsed-109 was located about 17 m (55 ft) downstream of scour-chain transect #00-9. It was excavated on a large, unvegetated bar on the west side of the Dungeness River just upstream of the outlet of the Cline-Clallam bypass pipeline and downstream of sample site DRsed-108 (Figure A-9). The pit was sited on a finer-grained portion of the bar and was about 0.5 m higher than a coarser portion of the bar adjacent to the low-water channel. A large log was observed just upstream of the sample site. The west edge of the bar was defined by a still-wet channel that had alternating gravelly and sandy areas and appeared to have only recently been abandoned as a result of declining flows on the Dungeness River. This channel extended along the base of a 1.5-m-high scarp that delineated a terrace vegetated primarily by deciduous trees.

Pavement at sample site DRsed-109 was moderately developed and was sampled separately from the underlying bed material. The pavement was composed of loose, subrounded to well-rounded cobbles and pebbles.

Railroad Bridge Park/Severson Property (RM 5.0 to 5.5)

Sample DRsed-110 was located about 3 m (11 ft) upstream of scour-chain transect #00-27 on a small, unvegetated bar on the east side of the Dungeness River (Figure A-10) about 600 ft downstream from Railroad Bridge. The east side of the bar was bounded by a 1-m-high scarp of a terrace vegetated with alder and small conifers. The bar was fairly coarse grained and was covered primarily with subangular to rounded, large cobbles and small boulders . Pavement at the sample site was weakly to moderately developed. The surface was mostly loose, but the larger rocks had to be extracted with a pick.

Sample DRsed-111 was located adjacent to a hole created when chain 3 of scour-chain transect #99-16 was excavated by the Tribe during the 2000 field season. Thus, the sample was the same sediment as that present at chains 1, 2, and 3 of this transect. The sample pit was sited on an unvegetated, bouldery bar on the east side of the Dungeness River (Figure A-11) along a highly braided reach of the river adjacent to the Severson property. The bar was bounded on the east by a recently abandoned channel that had filled with sand. The channel extended along the base of a 1-m-high scarp that delineated a surface vegetated mainly with grass and a few willows. The bar consisted of a mix of sizes ranging from small boulders to sand. The particles were subangular to rounded and were composed of a variety of rock types. Pavement was not present at this site and the surface of the bar was loose.

Sample DRsed-112 was located at scour-chain transect #00-28. The sample site was excavated on a large, unvegetated bar on the east side of the Dungeness River (Figure A-12) near the downstream end of the Severson property. A large pile of woody debris had collected on the bar at its downstream end. The bar had formed about 0.5 m above the low-water channel in which the scour chains had been installed. The sediment on the bar was loose and consisted of small boulders and large cobbles ranging to sand. The particles were subangular to well rounded. The sediment at the sample site was composed primarily of pebbles and cobbles and was visually similar to the riverbed material in the channel at chain 2. The bar deposit was finer grained than the sediment in the channel at chain 1, where the sediment was mostly coarse cobbles and small boulders. Surface pavement had not developed at the site, although some sand had been winnowed from the surface and was preserved underneath surface particles.

An additional site, DRsed-113, was originally scheduled for scour chain transect #00-29 on a gravel bar complex about 1000 ft downstream from sample site DRsed-112. Testing at DRsed-113 was canceled after a storm increased flows on the Dungeness River and cut off access to the sample site.

Clallam County Parks Along Ward Road (RM 2.8 to 3.0)

Sample DRsed-114 is located downstream of scour-chain transect #99-9 on a large, unvegetated bar on the west side of the Dungeness River (Figure A-13). This site is downstream from the upper parking lot for Clallam County’s Mary Lukes Wheeler Park. Chains from the transect were not visible and had probably been removed in August 2000 by the Tribe. Consequently, the exact location of the sample site relative to the transect is not clear. The site is about 39 m

(128 ft) downstream from a rebar pin with pink survey flagging that may mark the transect location. The sample pit was also about 11 m (35 ft) downstream of a hole in the bar surface that may have marked the site of a scour chain that had been exhumed by the Tribe; a bush marked with flagging was noted adjacent to this site. The site also corresponded well to a sketch map of the transect location provided to us by Fisheries Biologist Byron Rot. Because the exact location of the chain transect could not be identified, the sample site was selected where sediment on the bar was visually comparable to that observed in the adjacent channel.

The bar on which the sample site was located included a mix of sediment sizes from small boulders to sand. The section of the bar where the sample site was located had coarser-grained sediment than other areas of the bar, including several poorly defined channels that probably had been recently abandoned as a result of declining river flows. These channels were avoided in the sample area. The bar was vegetated by scattered low plants. A loose pavement had developed on the surface of the bar and was sampled separately. The underlying bed material was compact and included some large rocks which made excavation of the sample pit slightly difficult to dig: this material was noticeably harder than the sediment sampled at other sites.

Sample DRsed-115 was located about 4 m (13 ft) upstream of scour-chain transect #99-17 on the downstream end of a large, unvegetated bar in the middle of the main channel of the Dungeness River (Figure A-14). DRsed-115 was located near the lower parking area for Mary Lukes Wheeler Park. The bar had a west-sloping surface and its east edge was about 1 m above the low-water level. The sediment on the bar was fairly uniform, although some sand was present on the gravel bar just west of the sample site. The sediment at the site was visually comparable to that observed in the wetted channel at chain 1 of the transect. The sediment was loose and consisted of subangular to well-rounded, large cobbles grading to sand. The particles were composed of a mix of rock types. This sample site was located in the same vicinity where samples DRsed-4A and -4B were measured in 1998. However, the channel of the Dungeness River at this locality has migrated so much since that time that the bar on which the earlier samples were taken was no longer preserved. Pavement was not present on the bar at sample DRsed-115.

Army Corps of Engineers and Beebe Levees (RM 1.5 to 2.4)

Sample DRsed-116 is located 500 ft upstream of scour-chain transect #00-18 on a large, unvegetated bar on the west side of the Dungeness River (Figure A15). The river channel at the scour-chain transect lacked any appreciable graver bars, except for a very small deposit on the west bank that was limited in extent and had only recently been exposed by declining river levels, resulting in a high degree of saturation in the bar materials. The sample site was moved upstream to the next available bar deposit where visually comparable materials were located. The sample site on the bar upstream of the transect was also selected because of its larger surface area and drier conditions. This bar was bounded on the west by the 2.5-m-high embankment of the Beebe levee, a privately constructed flood-control levee that protects property on the west bank of the river. The sample pit was sited on a portion of the bar that has medium-size sediment comparable to the riverbed sediment observed in the channel at the scour chains and to the sediment on the small bar adjacent to the chains, described previously. The margin of the gravel bar adjacent to the river was more coarse grained than the sample site. A dry channel along the base of the levee formed the west boundary of the medium-size portion of the bar where the sample site was located. Pavement was not present at the site. The surface of the bar was loose and consisted of subangular to rounded, large cobbles grading to sand. This site, along with sample site DRsed-118, appeared to have more rounded and well-rounded particles than the sample sites upstream.

Sample DRsed-117 was located about 15 m (49 ft) upstream of scour-chain transect #00-17 on the downstream end of a large, unvegetated bar on the east side of the Dungeness River adjacent to the Army Corps of Engineers flood-control levee (Figure A-16). The east side of the bar was bounded by a 1-m-high scarp that delineated a terrace vegetated with alder and cedar; this terrace surface was incised with several deep channels. The sediment at the sample site was visually comparable to that observed in the wetted channel at chain 4 of the transect. The higher portion of the bar was selected for sampling because a slightly lower bar immediately adjacent to chain 4 was too wet and the sediment on the lower and upper portions of the bar were similar. The sediment was loose and consisted of small cobbles ranging to sand. The larger particles were subrounded to well rounded and flat. The smaller particles were subangular to subrounded and flat and elongated. Pavement was not present at the site.

Sample DRsed-118 was located about 2 m (5.5 ft) upstream of scour-chain transect #00-16 on a large, unvegetated bar on the west side of the Dungeness River (Figure A-17). The sampled bar was bounded on the west by the 1.5-m-high embankment of the Beebe levee. The sediment at the sample site was comparable to the riverbed material observed at scour chain 1 of the transect and was finer grained than the sediment present at chain 2. The bar surface had been winnowed of sand and the resultant pavement was loose and weakly developed. The particles were subangular to rounded, small boulders grading to large cobbles and granules. The composition of the particles was a mixture of rock types.

Sample DRsed-119 was located downstream of scour-chain transect #00-13 on a large, unvegetated bar on the east side of the Dungeness River (Figure A-18) near the Army Corps of Engineers levee. This was the same gravel bar where samples DRsed-3A and DRsed-3B were measured in 1998. The east side of the bar was bounded by a 1-m-high scarp that delineated a terrace vegetated with cedar and deciduous trees. Deep channels were common on this terrace surface. The sample pit was sited on a relatively coarse portion of the bar that was comparable to the riverbed observed in the wetted channel along the transect. The sediment was loose and consisted of subangular to well-rounded cobbles grading to sand. Pavement was not present at the site, although sand had been winnowed from most of the surface; sand overlay the gravel bar in scattered small areas of the bar surface.

Data Analyses

The grain size data collected from the field measurements of the bar sediment and the laboratory tests conducted on field samples of the minus 8 mm fraction have been summarized on Table C-1 (see Appendix C). These data are tabulated as percent of the sediment retained on the corresponding sieve size or hydrometer reading. The grain size data have also been shown graphically in standard gradation distribution plots for each sample in figures C-1 through -14. The data for the surface pavement layers are shown separately from the underlying bed material, for those sample sites where pavement was observed, and multiple samples are shown on some plots where the sample sites were measured in the same geographic location (i.e., East Crossing Campground, Gray Wolf confluence, etc.). Note that the gradation plots have been prepared using the percent passing or percent finer grained for each sieve size: this is the inverse function of the percent retained used in Table C-1.

Table C-2 summarizes field observations of sediment particle shape and roundness for each fraction measured at the sample sites. These observations describe the physical shape of the sediment particles which is a function of both the original shape of the rock fragments as they entered the Dungeness River and in-stream mechanical abrasion effects as the particles have been transported down river from their source areas.

Sediment Composition

The composition of the sediment samples collected from the Dungeness River has been assessed using the following grain-size classes from a modified version of the Wentworth scale (Krumbein and Sloss, 1963, p. 96):

- boulders; particles larger than 180 mm in diameter
- cobbles; 64 to 180 mm
- gravel; 2 to 64 mm
- sand; 0.063 to 2 mm
- silt; 0.002 to 0.063 mm
- clay; particles less than 0.002 mm in diameter

Figure 4 summarizes the distribution of the sediment within these six size classes for all samples collected in the 2000 field season. The sample sites are ordered from upstream to downstream on the bar chart, extending from DRsed-101 at the East Crossing Campground to DRsed-119 at the ACOE flood-control levee upstream from Schoolhouse Bridge. The data used to prepare this graph are tabulated in Table 1. Note that the data appearing in both Figure 4 and in Table 1 are for the bed material only. Data for the surficial pavement layers have not been included in these illustrations as the pavement is variably developed, where present, and generally about one particle diameter thick. The data for the pavement have been tabulated separately in Table 2 and have been included here largely for informational purposes.

The sediments sampled in the channel of the Dungeness River in the 2000 field season consisted chiefly of variably mixed gravel and cobbles with sand, as shown on Figure 4. Gravel was common in all depositional environments in the Dungeness River and was the predominant size class at 16 of the 19 sites sampled in this investigation. The gravel fraction comprised from 26.5 to 81.6 percent of the samples; the average gravel content of the 19 field samples was 54.8 percent. Cobbles also comprised a significant portion of the sediment and were observed at 17 of 19 sample sites. The higher concentrations of cobbles generally correlated to main channel bar deposits and lower concentrations were noted in side channels and in finer-grained bars located on the inside curves of river channel bends were secondary currents resulted in localized sediment accumulation. The percentage of cobbles measured in the samples varied from 0.0 to 58.8 percent and averaged 27.6 percent for all samples. Note that all percentages used in this analysis are reported as percent by weight of the total sample. The third major component of the bed material samples was sand which was present in varying concentrations at all samples sites. The higher sand concentrations were observed in side channels and in finer-grained bars on the inside of river bends. Sand comprised from 7.7 to 31.3 percent of the sediment and the average sand content of the samples was 14.3 percent.

The remaining grain-size classes were present in much smaller concentrations, but may be locally significant depending on the source of the material and the depositional environment in which the sediment was deposited. Boulders were measured at only 4 of 19 sites (DRsed-106B, -107, -111, and -118) with concentrations ranging from 0.0 to 29.1 percent of the samples; the average boulder concentration was 2.9 percent for all nineteen samples. The highest concentration of boulders occurred at sample DRsed-106B, located on the debris fan at the mouth of Canyon Creek. The 9.9 percent boulders measured at DRsed-118 (RM 1.9) marks the most downstream observation of boulders within the river alluvium in either the 1998 or 2000 field investigations. Fines (silt and clay) were generally lacking in the sediment and were measured in trace concentrations only. Silt was measured at all sample sites and concentrations varied from 0.2 to 0.8 percent with an average silt content of 0.4 percent. Clay particles were detected in 7 of 19 samples with concentrations ranging from 0.0 to 0.2 percent. The average clay content calculated for the 19 samples was 0.0 percent. The highest measured fines content (i.e., combined silt and clay content) for any of the samples was 0.8 percent in sample DRsed-110, located about 600 ft downstream from Railroad Bridge. This fines concentration was composed entirely of silt, as no clay was measured at that site. Clay particles were not detected in any of the samples downstream from sample DRsed-108, located near the Cline-Clallam irrigation intake structure.

Grain-size classes for the surface pavement layer are compiled in Table 2 for the six sites where pavement was observed. These data illustrate the effect of the moving river water winnowing away the sand and fines fractions from the surface of gravel bars. As expected under these conditions, gravel and cobbles comprised the predominant sediment classes in the pavement layers with boulders representing about 8.3 percent of the sample at site DRsed-110. Materials smaller than 8 mm in diameter (i.e., fine gravel, sand, and fines) were virtually absent from the samples: the maximum concentration of the minus 8 mm fraction was 1.5 percent at sample site DRsed-109, located near the bypass pipeline outfall for the Cline-Clallam irrigation diversion structure.

Particle Diameter

Additional analyses of sediment size distribution can be performed through comparison of the diameters of sediment particles at statistically important points on the gradation distribution plots included in Appendix C. These diameters are calculated using graphs of the percent sediment passing (i.e., finer grained than) the respective sieve and hydrometer sizes. For the purposes of this study, diameters have been calculated for the following: D-16, D-35, D-50, D-65, D-84, and D-90. For example, the D-16 is that diameter measured for a given sample in which 16 percent of the particles measured at that site are smaller or finer grained than the D-16 diameter while 84 percent of the sample is larger. For D-50, half of the sediment is finer grained than the D-50 diameter and half the sediment is more coarse grained. These data are compiled on Table C-3 in Appendix C for all sample sites, including the surface pavement layers where observed. Figure 5 illustrates the diameter data in bar-chart form to show variations and trends between the 19 sampling sites along the Dungeness River. Additional discussion of the D-50 data is presented in a later section of this report discussing sediment samples in terms of salmon spawning habitat.

Sediment Distribution Along the Dungeness River

Previous sediment sampling along the Dungeness River conducted by Reclamation in 1998 (Piety and others, 2000) demonstrated a trend of downstream fining of the sediment deposited by the Dungeness. In general, this trend is also observed in the 2000 field data, as shown in figures 4 and 5. However, the 2000 data has considerably more scatter in the data than observed in 1998 which tends to mask the trends in the more recent data set. This data scatter is likely due to the differing intents of the field investigations which tend to develop a bias in the data. The 1998 data set was collected to obtain samples that were representative of the alluvium present in the river channel for specific reaches of the river. Although there is often considerable variation of sediment present at any single location on the Dungeness, collection of representative samples permitted analyses of trends in the sediment size distribution with distance down the river. The 2000 data set was collected to compliment the Tribe's scour chain study of the river bed materials which targeted specific ecological niches along the river. The 2000 sample sites were selected to approximate as closely as possible the riverbed materials observed at specific scour chain installations and included a variety of differing depositional environments, including point, mid-channel, and channel margin bars, side channels, and at least one example of an abandoned main channel (DRsed-111). Additional analysis of the sediment data by grouping of the sample sites according to depositional environment may reduce the observed scatter in the data and shed further light on sediment transport trends.

Canyon Creek Confluence

Two samples were measured near the confluence of Canyon Creek with the Dungeness River near the Dungeness Fish Hatchery to evaluate the contribution of sediment to the river by tributary streams. Of particular concern was the potential increase in fine-grained sediment originating from landslides and debris flows and subsequent impacts to salmon habitat resulting from higher fines content. The Canyon Creek drainage has a history of landslides and visual examination of the confluence area showed a distinct accumulation of dark colored rock

fragments and sediment forming a fan at the mouth of the creek which we interpret to be a debris fan. Samples were measured on a bar on the Dungeness River upstream of the confluence (DRsed-106A), at the debris fan at the mouth of Canyon Creek (DRsed-106B), and on a bar downstream of the confluence (DRsed-107) to evaluate the composition of the river channel sediment upstream of Canyon Creek, the character of the sediment being delivered to the Dungeness by Canyon Creek, and mixing of the Canyon Creek material with the Dungeness River sediment at the downstream bar location.
The sediment distribution at the three sites is summarized by Wentworth grain-size class in Table 4. The sample for DRsed-106A, located on the upstream bar, contained 12.1 percent sand and 0.4 percent fines occurring as silt with no clay fraction present. The sediment at the confluence with Canyon Creek included a nearly identical sand concentration (12.2 percent) and slightly less fines (0.2 percent silt with no clay). The downstream bar contained significantly less sand (only 7.7 percent) and concentrations of fines (0.3 percent silt and 0.1 percent clay or a total fines content of 0.4 percent) similar to the upstream bar at sample DRsed-106A.

These data do not show significant influence in the Dungeness River sediments from material contributed by Canyon Creek, particularly in the finer-grained sand and fines fractions. The sediment deposited at the confluence of Canyon Creek contained slightly less fines than either of the Dungeness River samples located upstream and downstream of the site. These data suggest (1) that fines are not present in large concentrations in the Canyon Creek drainage or (2) that fines are readily entrained as suspended sediment and flushed rapidly from the system before they can be deposited in sediments at either the confluence or downstream from Canyon Creek.

It is important to note that this analysis is based on a very limited data set that is not a statistically valid sample. Additional sampling and testing of this and other similar sites would be required to assess the impacts of sediment derived from landslides and debris flows. Sampling at or very near the sediment source (i.e., landslide or debris flow) would be desirable to quantify the character of the material being delivered directly to the stream while additional measurements at strategically placed downstream locations could then be used to evaluate transport of the material through the river system.

Dungeness River Sediment as Fish Habitat

Kondolf and Wolman (1993) have summarized sediment distribution studies performed on spawning habitat and fish redds for several different anadromous fish species in the western United States, including five that are present on the Dungeness River: Pink salmon, Coho salmon, Chum salmon, Chinook salmon, and Steelhead trout. The Pink salmon use the finest grained sediment whereas Chinook use the most coarse grained. Data collected from the 2000 field investigation is compared to that presented by Kondolf and Wolman to evaluate the suitability of the sediment as salmon habitat. Figure 6 compares the calculated D50 diameter for the Dungeness River samples with the maximum D50 observed by Kondolf and Wolman for the five species. Based on these data, the majority of the sediment samples measured on the Dungeness River in 2000 were too coarse grained to be used by Pink salmon, as only samples DRsed-105 and -117 had acceptable D50 values. These sites were located on channel margin bars on the inside curves of river bends where secondary eddy currents can develop and lead to finer-grained deposition. Most of the sample sites appear to be adequate for Chinook and Chum salmon with the exception of DRsed-107 near the Dungeness Fish Hatchery. Most of the samples obtained from the lower river downstream from the Cline-Clallam irrigation intake were too coarse grained to be used by Coho and Steelhead, based on the data presented by Kondolf and Wolman.

Figure 7 compares the Dungeness D50 values with the mean D50 for each of the species. This chart was originally produced to display the 1998 field data and has been updated to include that obtained in 2000. Trends are generally similar to those discussed above for the maximum D50, but with the smaller values for the mean D50 much of the lower river downstream from the Cline-Clallam irrigation intake at DRsed-108 is too coarse grained to function as spawning habitat, even for the Chinook salmon.

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Table 1. Summary of sediment sizes by Wentworth grain-size classes and measured maximum diameter

Sample	Maximum Diameter[2] (mm)	Percent of Total Sample[1]					
		Boulders (>180 mm)	Cobbles (180-64 mm)	Gravel (64-2 mm)	Sand (2-0.063 mm)	Silt (0.063-0.002 mm)	Clay (<0.002 mm)
DRsed-101	165	0	42.9	46.5	10.4	0.2	0.1
DRsed-102	100	0	10.5	75.1	13.8	0.5	0.2
DRsed-103	nd.	0	0	81.6	18.1	0.2	0.1
DRsed-104	100	0	13.8	67.5	18.0	0.5	0.2
DRsed-105	120	0	9.8	58.4	31.3	0.4	0.1
DRsed-106A	145	0	27.5	60.0	12.1	0.4	0
DRsed-106B	600	29.1	20.2	38.3	12.2	0.2	0
DRsed-107	235 [3](580)	6.7	58.8	26.5	7.7	0.3	0.1
DRsed-108	160	0	22.9	47.3	29.1	0.5	0.1
DRsed-109	155	0	43.0	47.0	9.7	0.3	0
DRsed-110	135	0	35.6	49.9	13.7	0.8	0
DRsed-111	300	9.1	34.5	45.4	10.8	0.2	0
DRsed-112	140	0	32.3	58.3	9.1	0.3	0
DRsed-114	175	0	45.0	42.7	11.7	0.6	0
DRsed-115	135	0	48.8	41.7	9.3	0.2	0
DRsed-116	95	0	13.2	74.5	11.8	0.5	0
DRsed-117	65	0	0	74.6	24.6	0.8	0
DRsed-118	195	9.9	35.9	44.1	9.7	0.4	0
DRsed-119	150	0	29.7	61.3	8.7	0.4	0

[1]Boulders, cobbles, and gravel were determined in the field by passing the sample through a set of sieves. Sand, silt, and clay were determined in the laboratory using sieves and hydrometer.

[2]This is the diameter of the maximum clast observed in the sediment sampling area. An entry of nd. means no measurement was made.

[3]This is the average diameter of largest of five rocks near but not within the sediment sampling area. The measurement is a minimum value because the rocks were partially buried.

Table 2. Summary of sediment sizes for the pavements by Wentworth grain-size classes and measured maximum diameter

Sample	**Maximum Diameter[2] (mm)**	**Percent of Total Sample[1]**			
		Boulders (>180 mm)	**Cobbles (180-64 mm)**	**Coarse Gravel (64-8 mm)**	**Fine Gravel and Finer (<8 mm)**
DRsed-104pv	nd.	0	32.3	66.2	1.4
DRsed-108pv	100	0	39.1	60.5	0.4
DRsed-109pv	nd.	0	40.4	76.1	1.5
DRsed-110pv	245	8.3	73.3	18.1	0.3
DRsed-114pv	160	0	44.3	98.6	1.3
DRsed-118pv	130	0	34.8	64.4	0.9

[1]Boulders, cobbles, and gravel were determined in the field by passing the sample through a set of sieves.

[2]This is the diameter of the maximum clast observed in the sediment sampling area. An entry of nd. means no measurement was made.

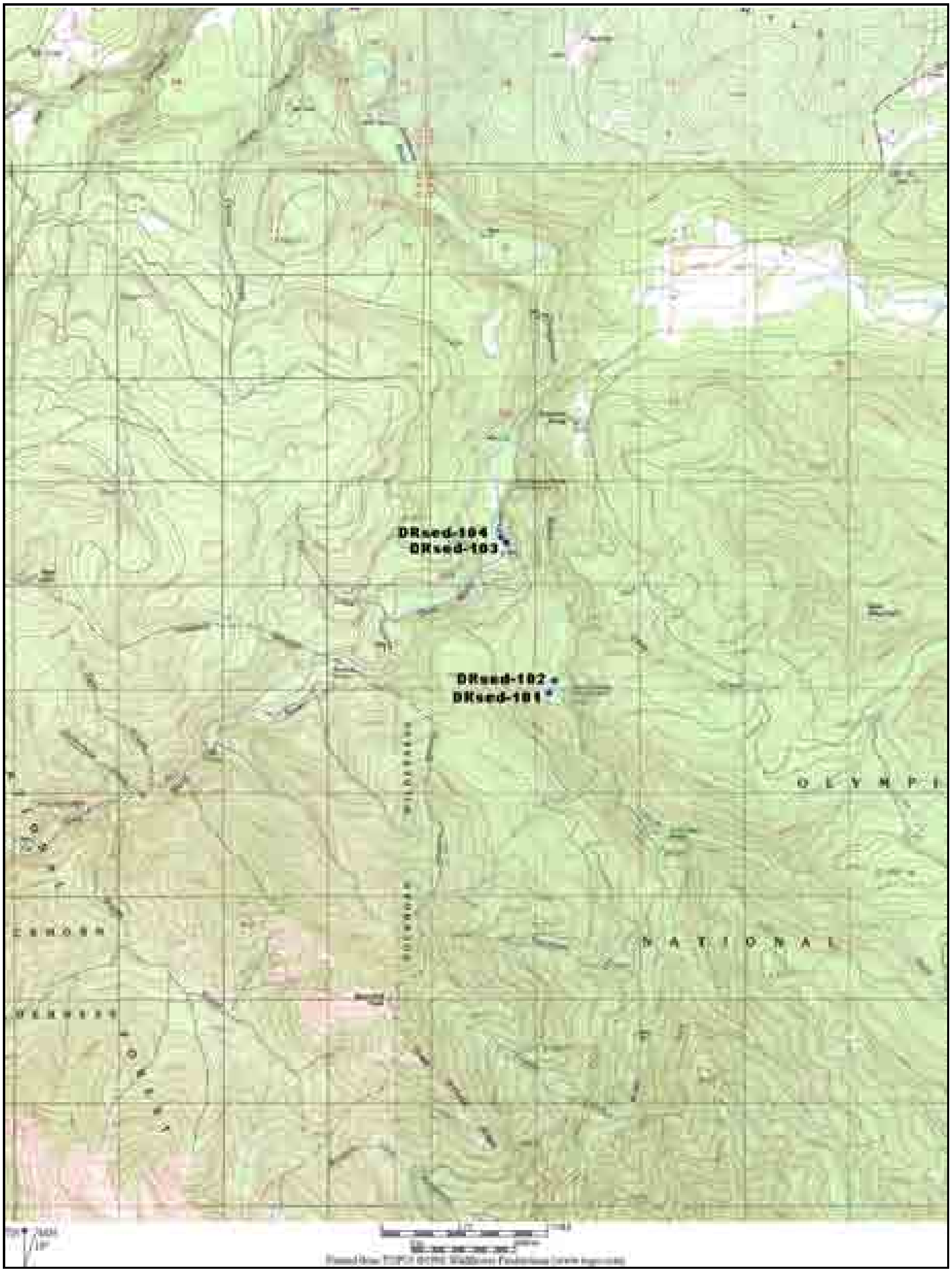


Figure 1. Location of sediment sample sites in the upper Dungeness River watershed.

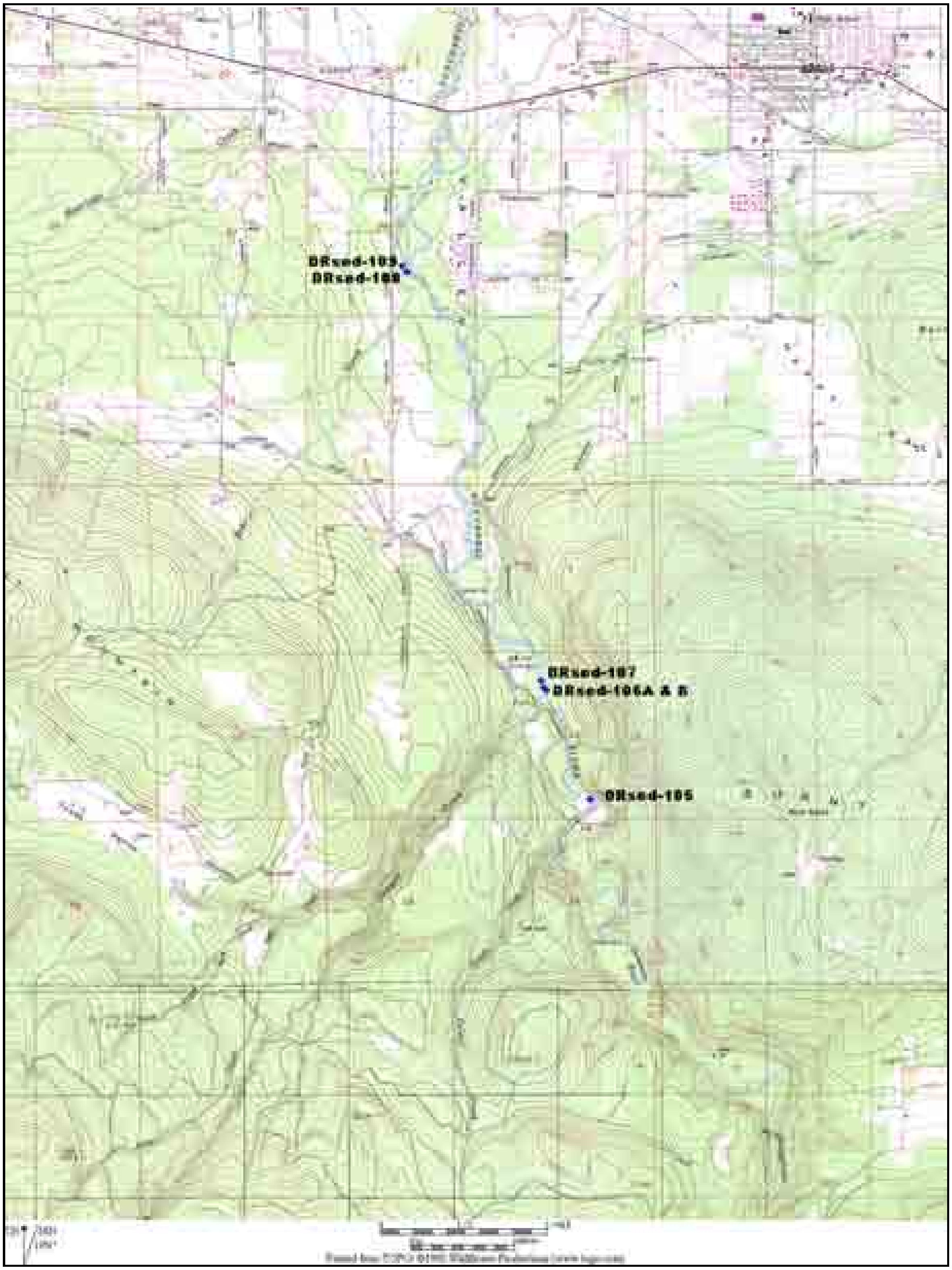


Figure 2. Location of sediment sample sites on the lower Dungeness River from the U.S. Geological Survey stream gaging station to U.S. Highway 101.

Figure 3. Location of sediment sample sites on the lower Dungeness River from U.S. Highway 101 downstream to Dungeness Bay.

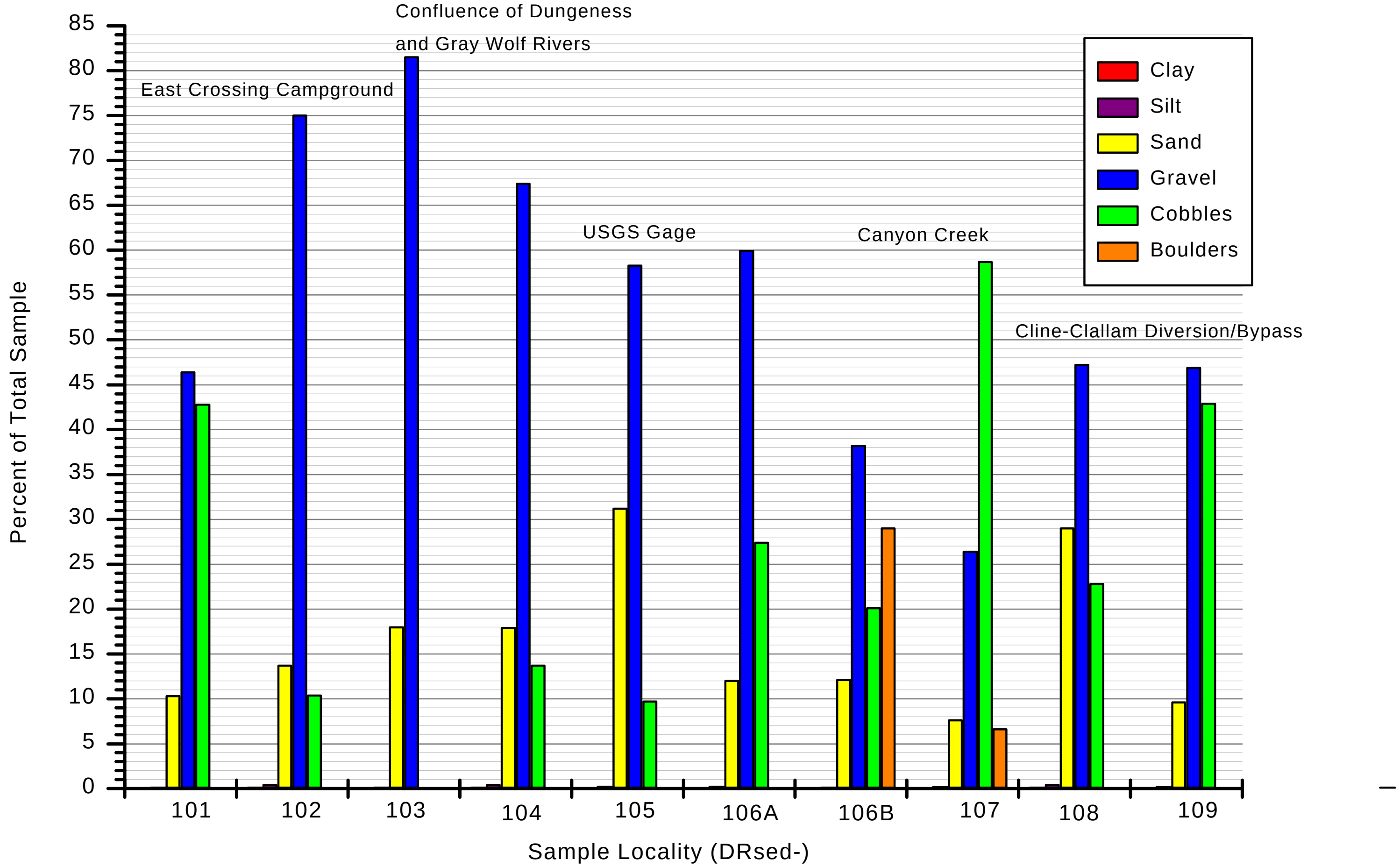


Figure 4. Summary of the distribution of Wentworth grain-size classes in bed-material samples from the Dungeness River

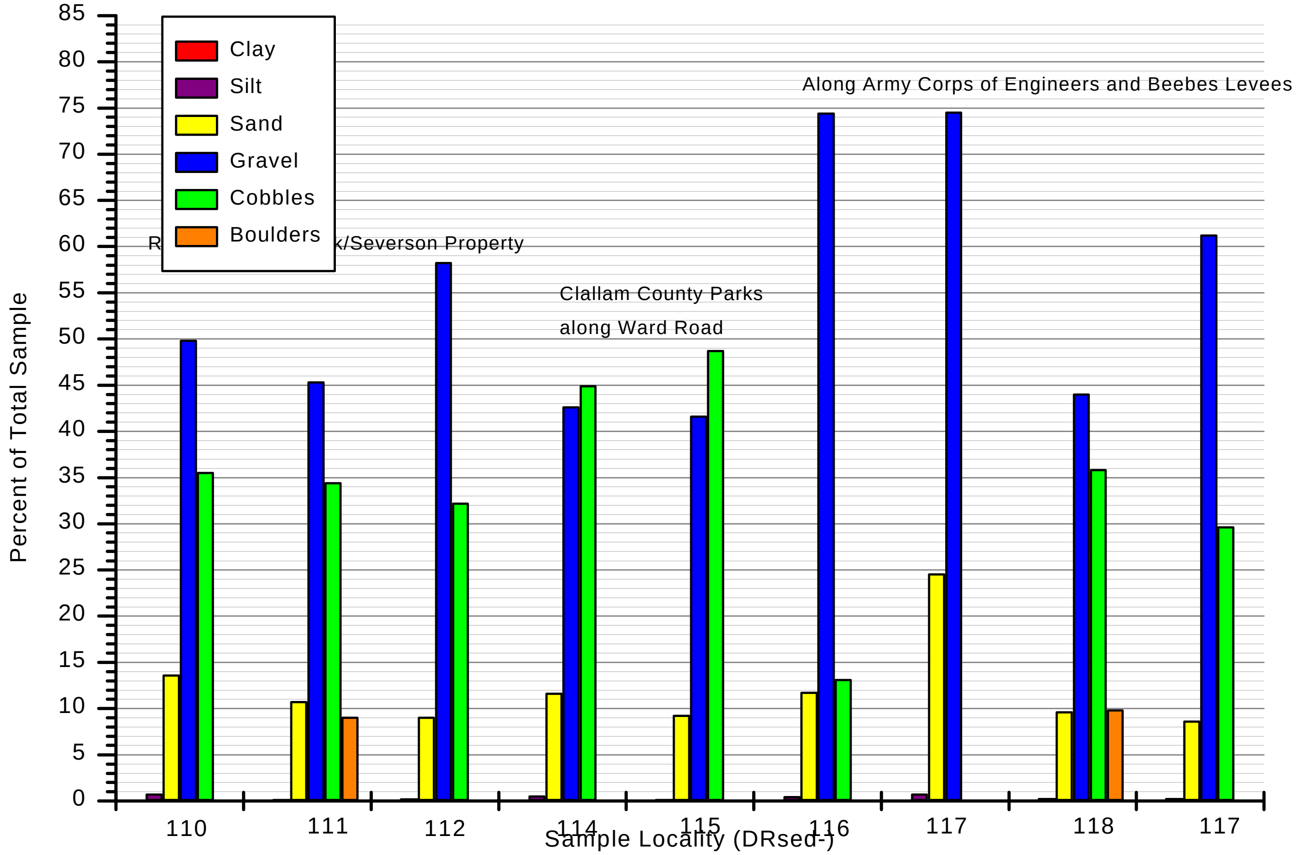


Figure 4. Summary of the distribution of Wentworth grain-size classes in bed-material samples from the Dungeness River (Cont.)

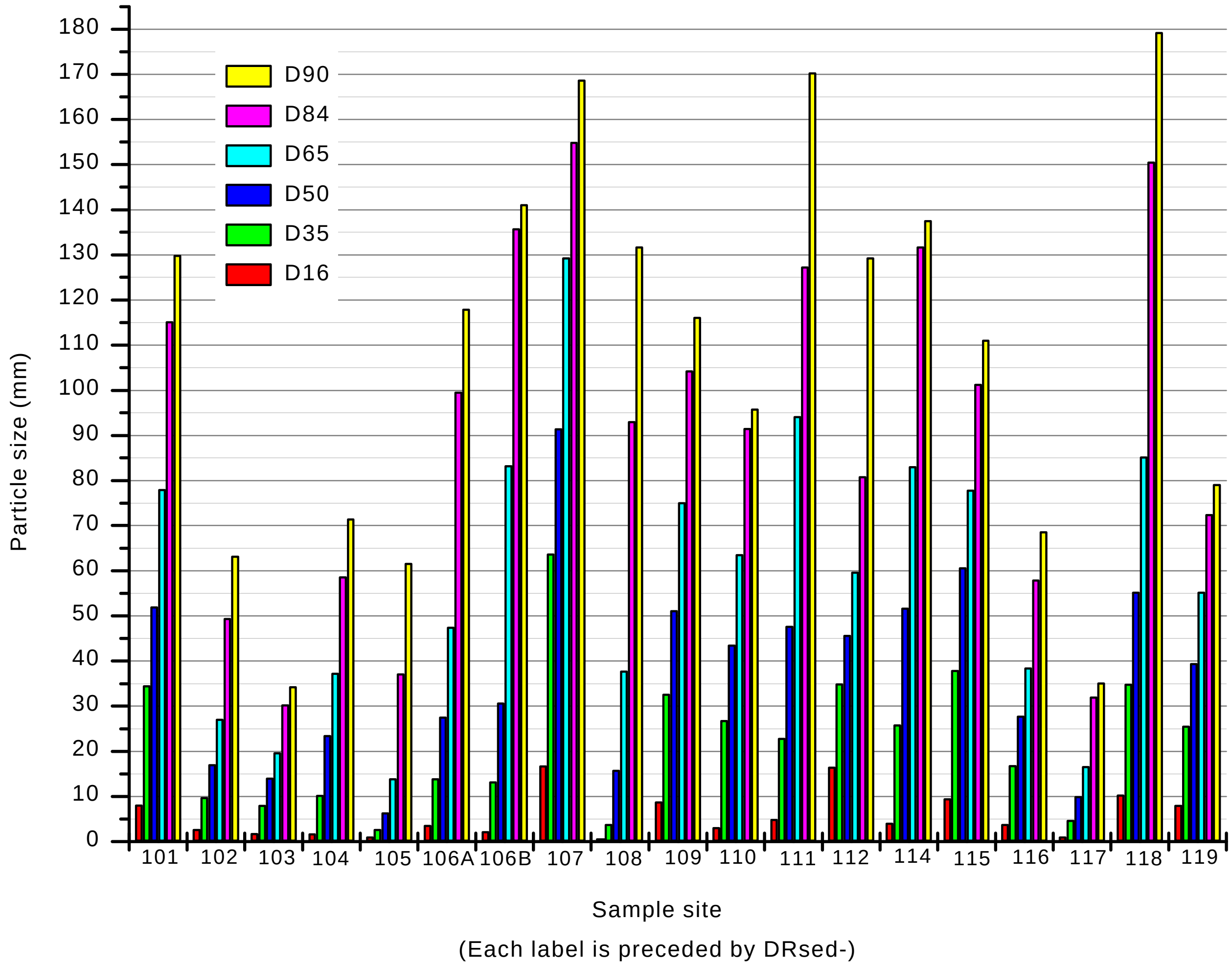


Figure 5. Summary of the distribution of particle diameters in bed-material samples from the Dungeness River.

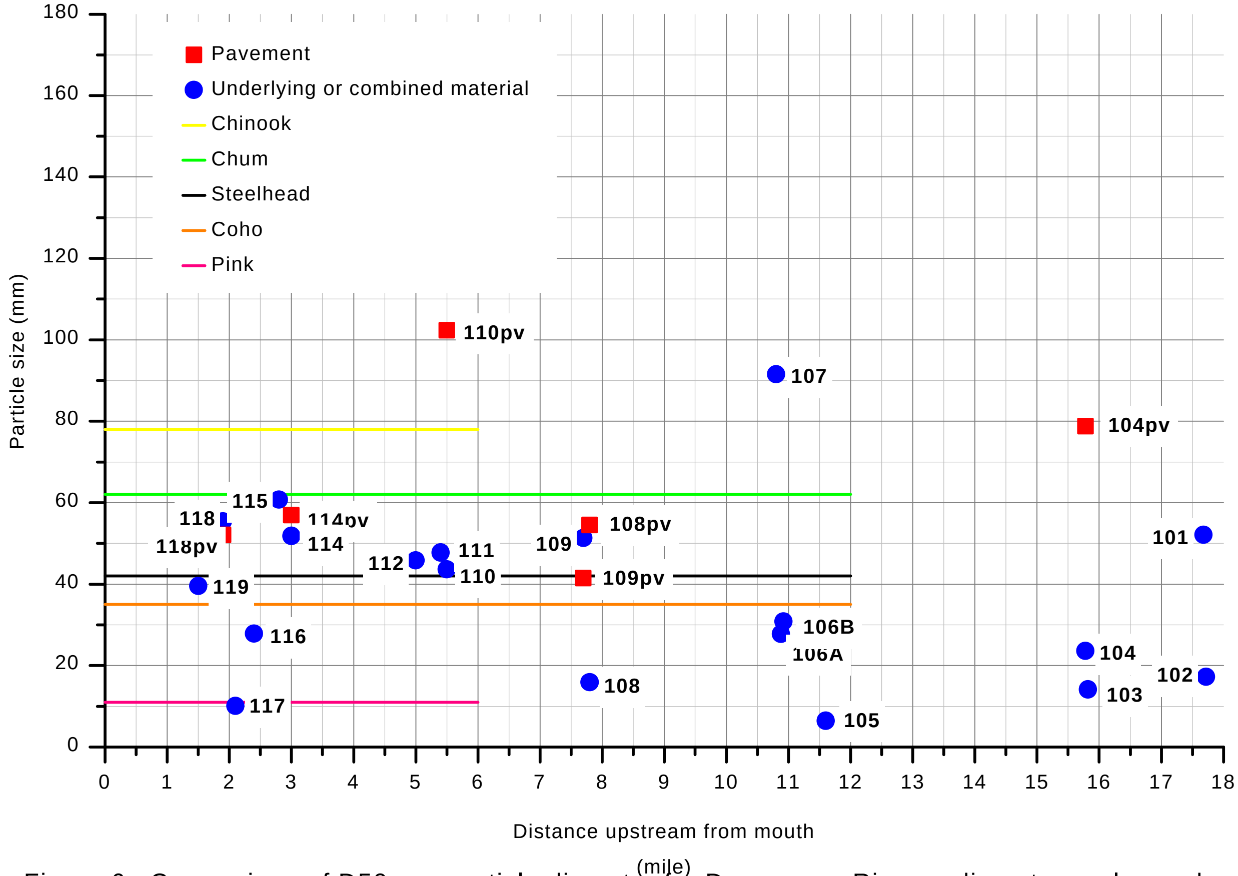


Figure 6. Comparison of D50max particle diameter for Dungeness River sediment samples and spawning redds for selected anadromous fish species.

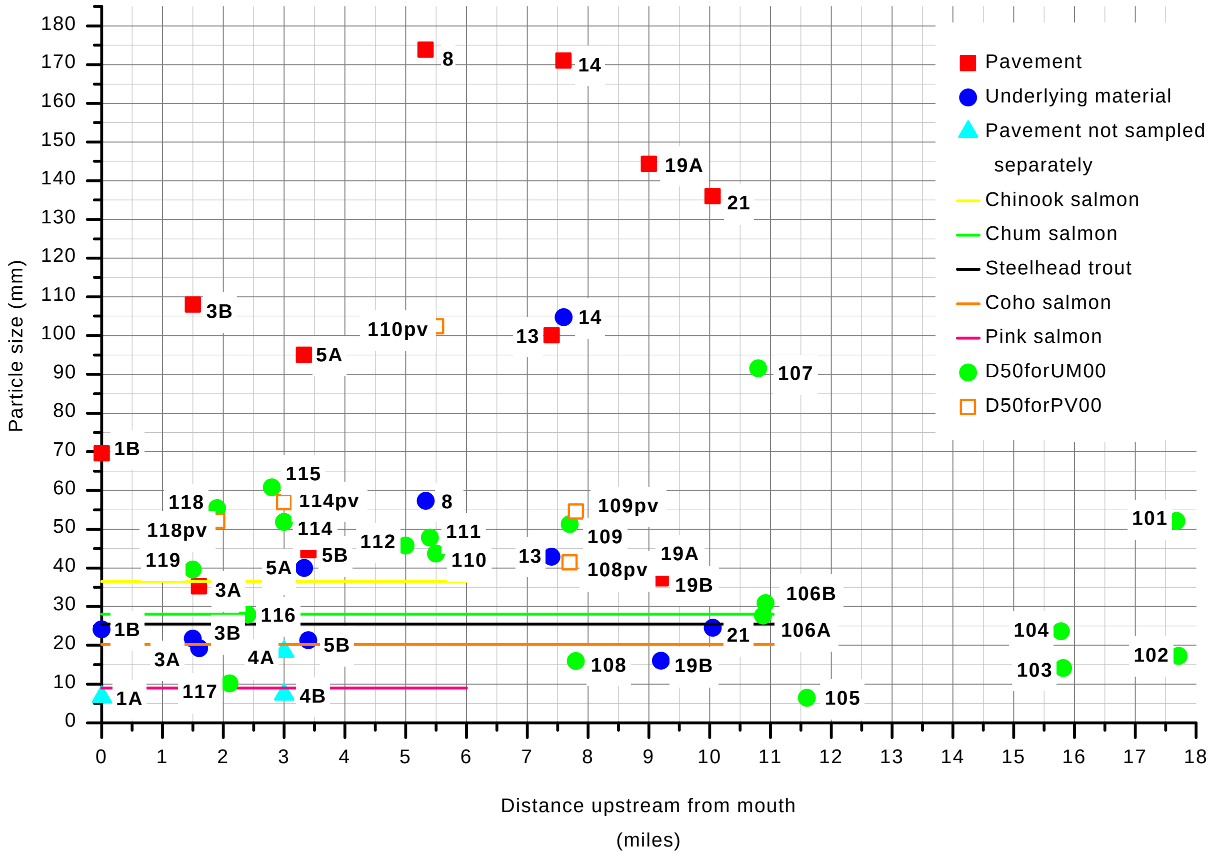


Figure 7. Comparison of D50mean particle diameter for Dungeness River sediment samples and spawning redds for selected anadromous fish species.

Appendix A - Sediment Sample Locations

Table A-1. Description of sample localities

Sample (DRsed-)	Location [Approximate River Mile]	Nearest Scour Chain Transect	Neareast Cross Section	From GIS Reading				From USGS Topographic Map			Notes
				Waypoint	Latitude (degrees North)	Longitude (degrees West)	Elevation (ft; m)	Quadrangle (1:24,000 scale)	Section, Township, Range	Elevation (ft; m)	
101	At former USFS East Crossing Campground; on bar on east side of Dungeness River upstream of transect [RM17.7]	00-1	--	SED101	47.95369	123.1066	1,067; 325	Mount Zion	NW, NE, sec. 6, T.28N. R.3W.	1,045; 319	
102	At former USFS East Crossing Campground; on small bar on east side of an auxiliary channel just downstream of chain #1 in transect [RM17.7]	00-2	--	SED102	47.9547	123.10588	1,044; 318	Mount Zion	NW, NE, sec. 6, T.28N. R.3W	1,045; 319	Sample at boundary between coarser and finer sediment on bar; sizes similar to those on bed at chain #1
103	Near the confluence of the Gray Wolf and Dungeness rivers; on small bar along a side channel at transect [RM1.0 on Gray Wolf River]	00-4	--	SED103	47.96669	123.11211	977; 298	Mount Zion	SE, NW, sec. 31, T.29N. R.3W	900; 275	
104	Near the confluence of the Gray Wolf and Dungeness rivers; on bar next to chain #1 of transect [RM0.9 on Gray Wolf River]	00-5	--	SED104	47.96715	123.11276	895; 273	Mount Zion	NE, NW, sec. 31, T.29N. R.3W	900; 275	Sizes similar to those of bed at chain #1
105	Near USGS gage; on small bar at transect [RM11.6]	00-21	--	SED105	48.0158	123.13113	561; 171	Carlsborg	SW, SW, sec. 1, T.29N. R.4W	560; 171	Sizes similar to those of bed at chains #1 and #2
106A	Just upstream of Canyon Creek; on bar on west side of Dungeness River [RM10.9]	Between 00-25 and 00-24	--	SED106	48.02533	123.13673	480; 146	Carlsborg	SE, NW, sec. 12, T.29N. R.4W	500; 153	Sampled along with 106B and 107 to determine the sizes of sediment added by Canyon Creek

106B	Just downstream of Canyon Creek; on an alluvial fan deposit from the creek; deposit has been modified by the Dungeness River [RM10.9]	Between 00-25 and 00-24	--		48.02556	123.13705	470; 143	Carlsborg	NE, NW, sec. 12, T.29N. R.4W	500; 153	Sampled along with 106A and 107 to determine the sizes of sediment added by Canyon Creek
107	Upstream of the Fish Hatchery and downstream of Canyon Creek; on bar of the Dungeness River; includes reworked sediment from Canyon Creek [RM10.8]	00-25	--	SED107	48.02613	123.13744	476; 145	Carlsborg	NE, NW, sec. 12, T.29N. R.4W	500; 153	Sampled along with 106A and 106B to determine the sizes of sediment added by Canyon Creek; sizes similar to those on margins of channel
108	Upstream of Cline Bypass (downstream end of Dungeness Meadows levee); bar on west side of Dungeness River near chain #1 [RM7.8]	00-8	At CS45	SED108	48.06171	123.15467	312; 95	Carlsborg	SW, SE, sec. 26, T.30N. R.4W	320; 98	Sizes at site most similar to those of the bed at chain #1; sizes on bar are primarily much coarser than those at the chain
109	Upstream of Cline Bypass (downstream end of Dungeness Meadows levee); bar on west side of Dungeness River [RM7.7]	00-9	Between CS44 and CS45	SED109	48.06228	123.15523	308; 94	Carlsborg	SW, SE, sec. 26, T.30N. R.4W	500; 153	
110	Downstream of Railroad Bridge; on bar on east side of Dungeness River [RM5.5]	00-27	Down-stream of CS34	SED110	48.08679	123.14953	186; 57	Carlsborg	SE, SE, sec. 14, T.30N. R.4W	190; 58	
111	Adjacent to Doc Severson's property downstream of Railroad Bridge; bar on east side of Dungeness River; near down-stream end of highly braided section [RM5.4]	99-16	At CS32	SED111	48.08924	123.15085	178; 54	Carlsborg	SE, SE, sec. 14, T.30N. R.4W	180; 55	Sample taken adjacent to chain #3; sediment similar at chains #1 and #2

112	At downstream end of Doc Severson’s hay field downstream of Railroad Bridge; bar on east side of Dungeness River [RM5.0]	00-28	Down-stream of CS31	SED112	48.09296	123.14989	144; 44	Carlsborg	NE, SE, sec. 14, T.30N. R.4W	160; 49	Sample similar to sediment at chain #2 (pebbles and cobbles) and slightly finer than sediment at chain #1 (coarse cobbles and small boulders)
114	Upstream Clallam County Park along Ward Road; bar on west side of Dungeness River [RM3.0]	99-9	Between CS18 and CS19	SED114	48.11916	123.14737	55; 17	Carlsborg	SE, SE, sec. 2, T.30N. R.4W	75; 23	Sediment similar to that in low-water channel adjacent to bar; no chains visible (removed?)
115	Downstream Clallam County Park along Ward Road; bar in middle of the Dungeness River [RM2.8]	99-17	At CS18	SED115	48.12055	123.14651	55; 17	Carlsborg	NE, SE, sec. 2, T.30N. R.4W	70; 21	Sample near chain #1; sample near DRsed-4A and DRsed-4B
116	In reach bounded by ACOE and Bebee’s levees; large bar on west side of the Dungeness River; about 0.12 mi upstream of scour chain transect [RM2.4]	00-18	Between CS14 and CS15	SED116	48.12742	123.14381	42; 13	Dungeness	NW, NW, sec. 1, T.30N. R.4W	40; 12	Sediment similar to that in the low-water channel at the chains and on an adjacent small bar; this bar chosen because it is drier
117	In reach bounded by ACOE and Bebee’s levees; bar on east side of the Dungeness River [RM2.1]	00-17	Between CS13 and CS14	SED117	48.13126	123.14372	26; 8	Dungeness	SW, SW, sec. 36, T.31N. R.4W	35; 11	Sediment similar to that at chain #4 and to that on a lower bar immediately adjacent to the transect
118	In reach bounded by ACOE and Bebee’s levees; bar on west side of the Dungeness River at the Olympic Game Farm [RM1.9]	00-16	At CS13	SED118	48.13239	123.14178	26; 8	Dungeness	SW, SW, sec. 36, T.31N. R.4W	35; 11	Sediment similar to that at chain #1 and finer than sediment at chain #2
119	In reach bounded by ACOE and Bebee’s levees; bar on east side of the Dungeness River [RM1.5]	00-13	Between CS10 and CS11	SED119	48.13717	123.13887	26; 8	Dungeness	SE, NW, sec. 36, T.31N. R.4W	25; 8	Sediment similar to that in low-water channel; sample taken near Drsed-3 that was done in 1999

Explanation for Sketch Maps of Sample Sites
Contact; dashed where gradational
2 m
Scarp; hatchures on lower side; estimated scarp height shown
Unvegetated bar; surface characteristics may be shown
Sparsely vegetated bar; main vegetation types indicated
Older bar
Tree-covered terrace or slope; main vegetation types indicated
Rock; only larger ones are shown
Moss-covered rock
Log or woody debris
Root ball
Human structure
Sample site
Sand
Chain (ball) and float (arrows) observed along transect
Scour-chain transect
X
Flagging marking the end of a scour-chain transect
Direction of flow on the Dungeness River (usually), Gray Wolf River, or side channel (labeled)
Riffle; arrow points downstream
42 ft
Distance measured with a tape

Sample Site DRsed-101

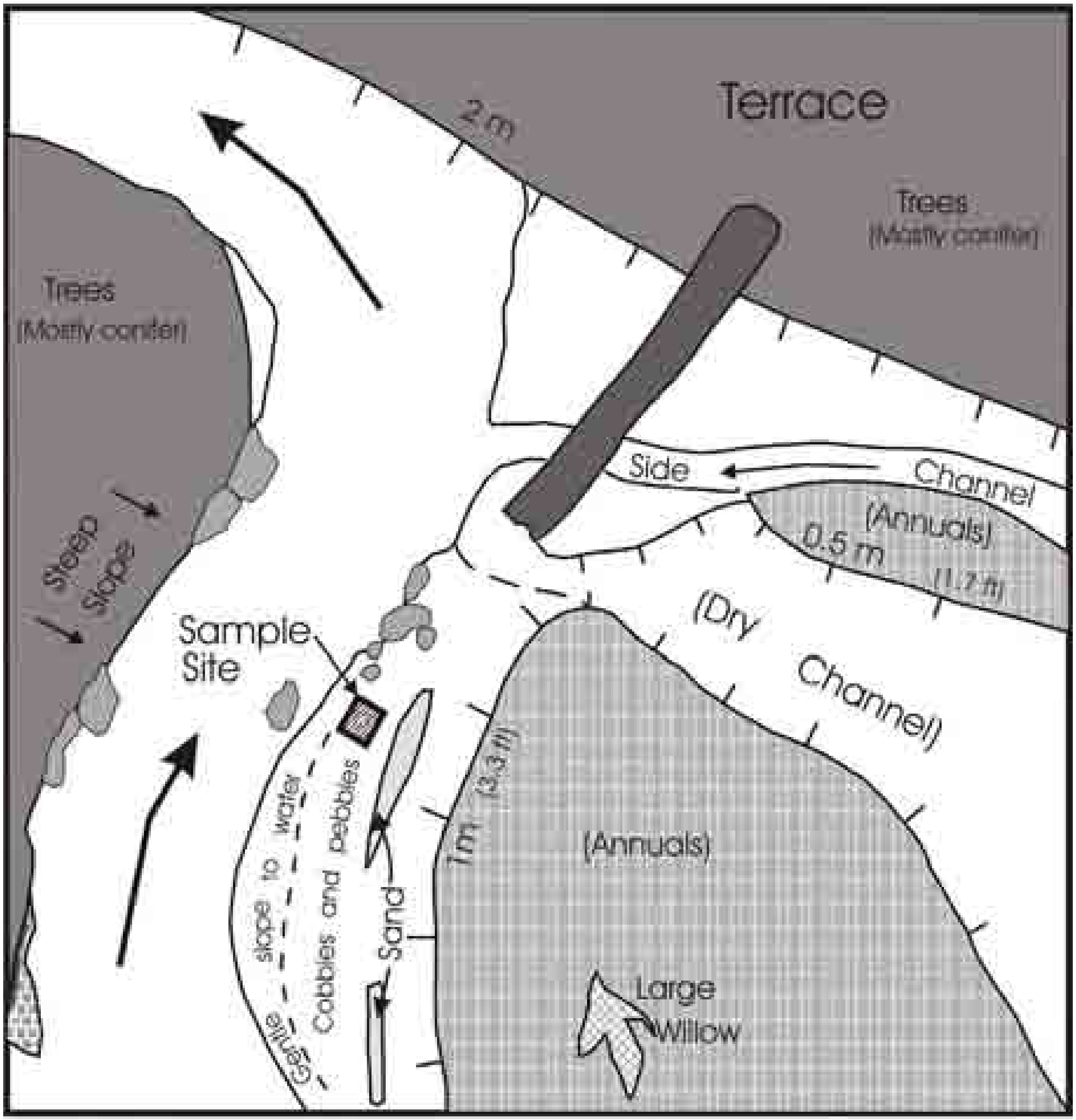


Figure A-1. Sketch map of the area surrounding sample site DRsed-101, which is located at the former East Crossing Campground on a bar on the east side of the Dungeness River upstream of scour-chain transect #00-1. Sampling was begun about 11:15 am of 9/29/00. Flow at the time was about 127 cfs. Drawing is not to scale.

Sample Site DRsed-102

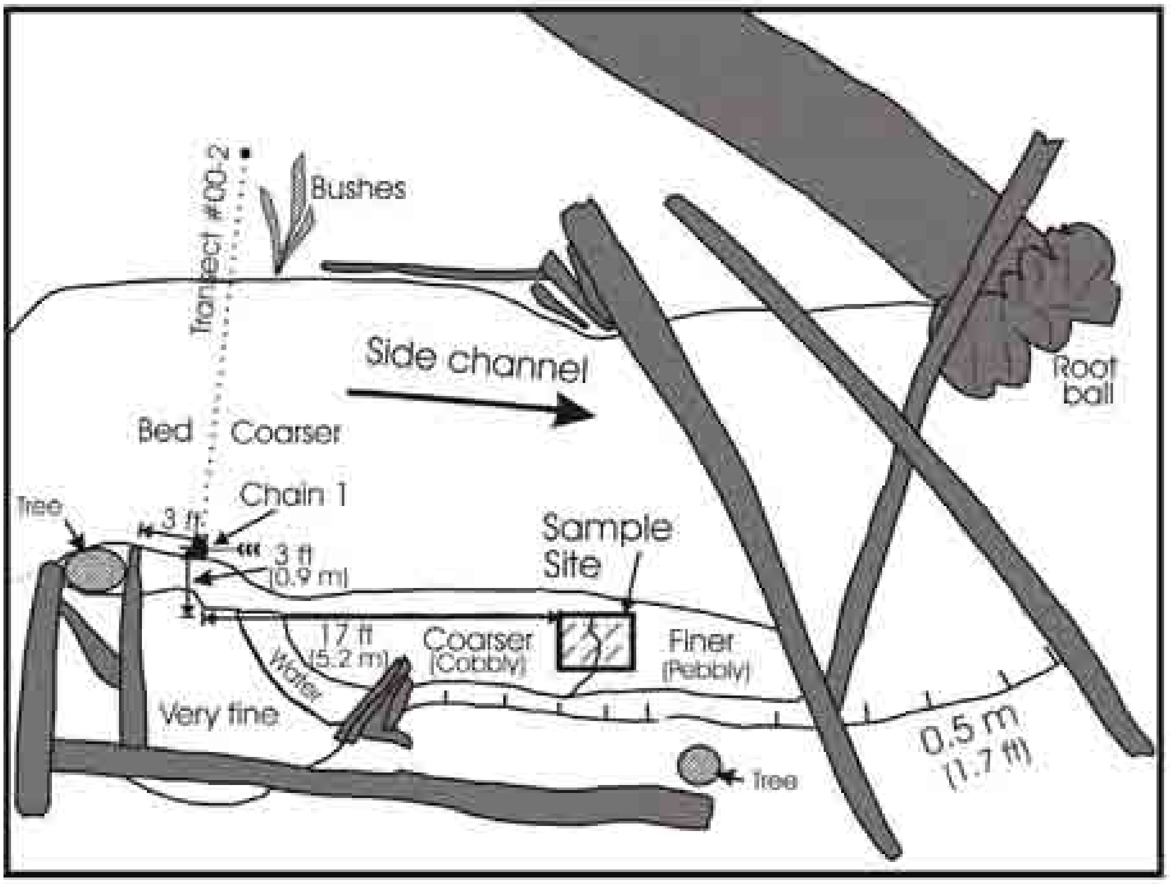


Figure A-2. Sketch map of the area surrounding sample site DRsed-102, which is located at the former East Crossing Campground on a small bar on the east side of a side channel of the Dungeness River just downstream of scour-chain transect #00-2. Sampling was begun about 10 am on 9/29/00. Flow at the time was about 127 cfs. Drawing is not to scale.

Sample Site DRsed-103

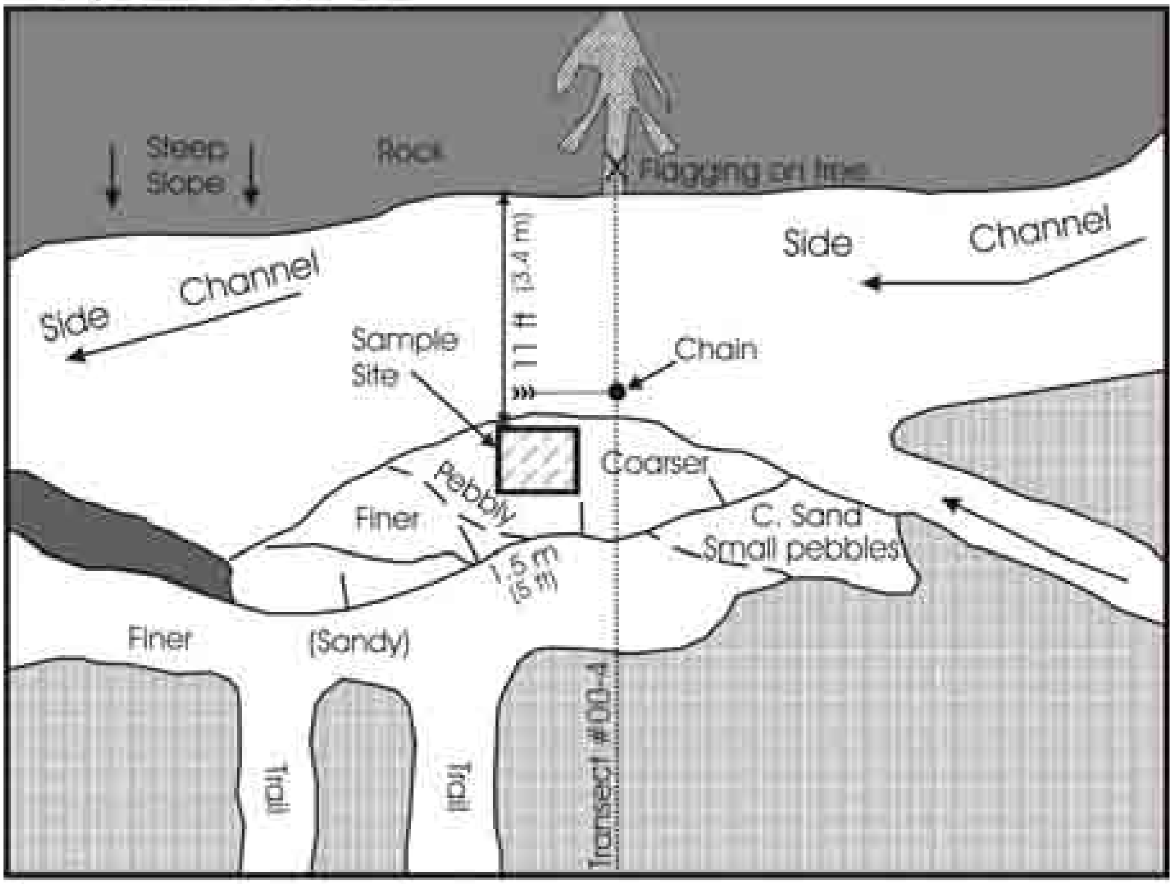


Figure A-3. Sketch map of the area surrounding sample site DRsed-103, which is located near the confluence of the Gray Wolf River and the Dungeness River on a small bar along at side channel of the Gray Wolf River at scour-chain transect #00-4. Sampling was begun about 10:45 am of 9/27/00. Flow at the time was about 127 cfs. Drawing is not to scale.

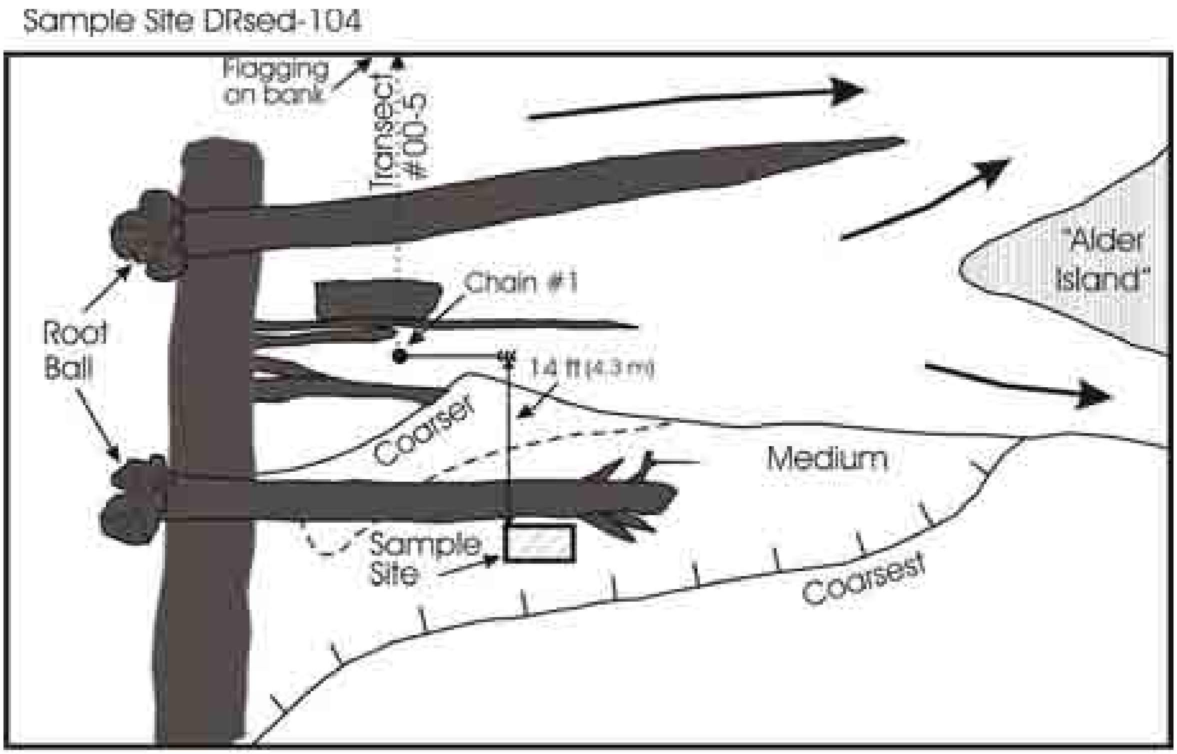


Figure A-4. Sketch map of the area surrounding sample site DRsed-104, which is located near the confluence of the Gray Wolf River and the Dungeness River on a bar of the Gray Wolf River at scour-chain transect #00-5. Sampling was begun about 1:30 pm of 9/27/00. Flow at the time was about 127 cfs. Sediment at sample site is coarser than that in the channel at chain #1, but similar to that at chains #1 and #2 of transect #00-6, which is located just downstream of the area shown in the sketch map. Drawing is not to scale.

Sample Site DRsed-105

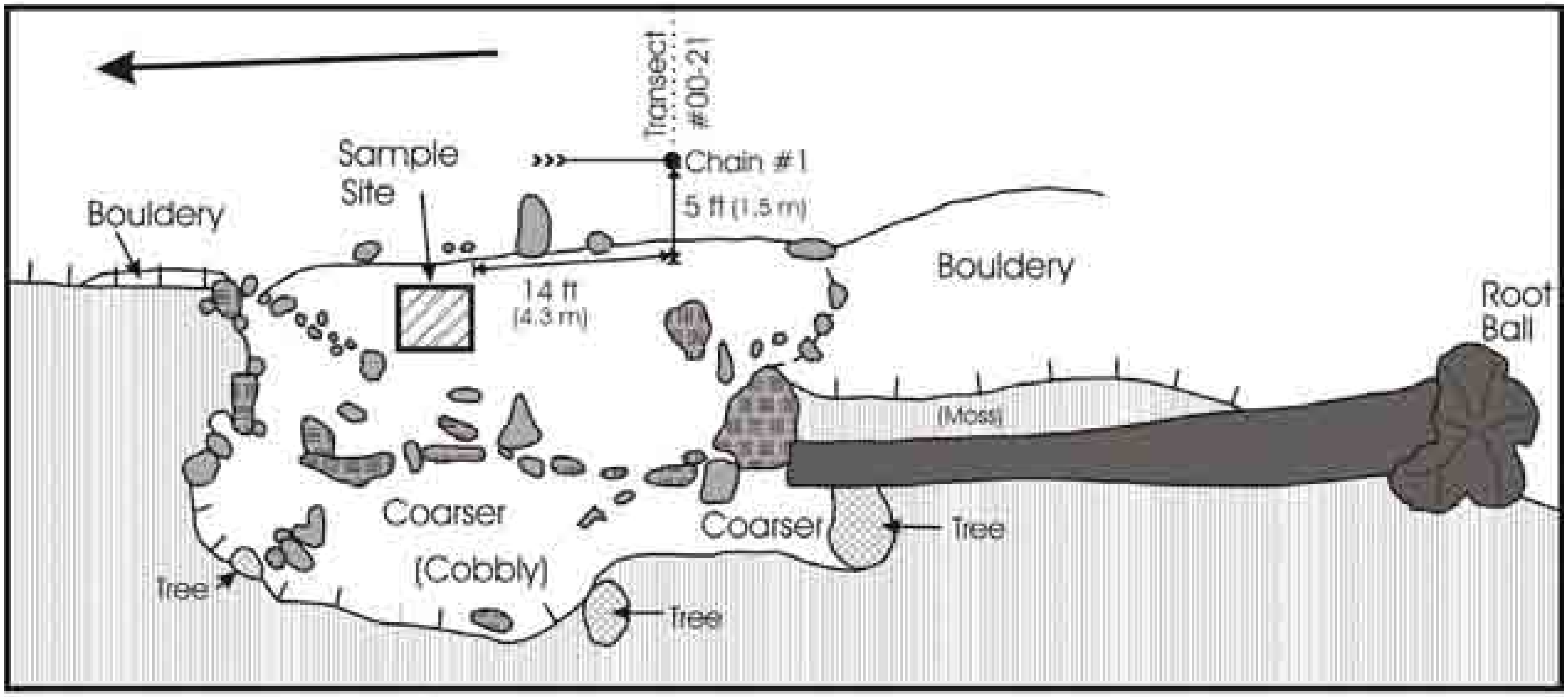


Figure A-5. Sketch map of the area surrounding sample site DRsed-105, which is located near the U.S. Geological Survey stream gage on a small bar of the Dungeness River at scour-chain transect #00-21. Sampling was begun about 12:45 pm of 9/28/00. Flow at the time was about 127 cfs. Sediment at sample site is similar to that in the channel at chains #1 and #2. Drawing is not to scale.

Sample Sites DRsed-106A, 106B, and 107

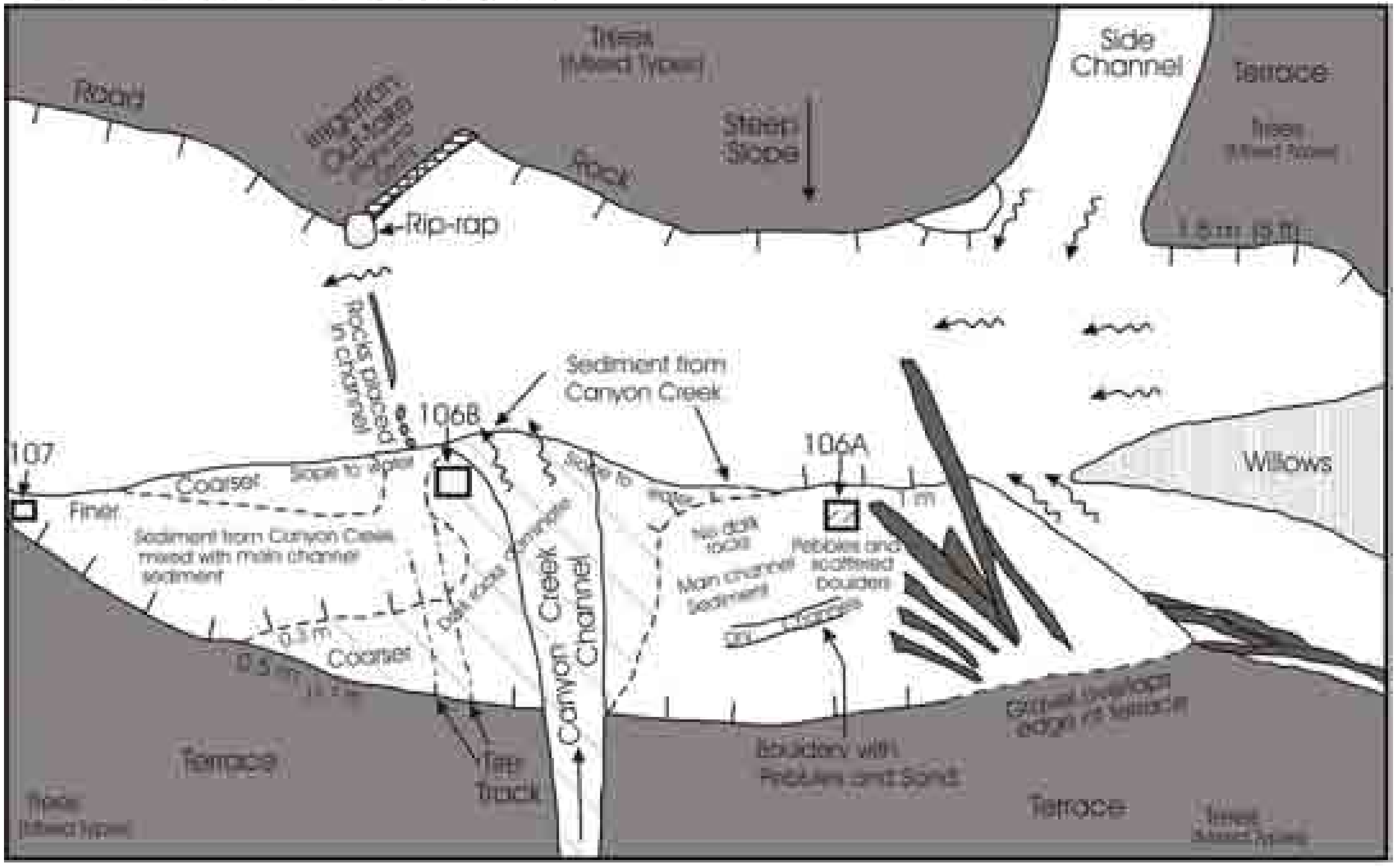


Figure A-6. Sketch map of the area surrounding sample sites DRsed-106A, DRsed-106B, and DRsed-107, which are located at the mouth of Canyon Creek between scour-chain transects #00-24 and #00-25. Sampling at sites DRsed-106A and DRsed-106B was done in the afternoon of 10/4/00. Flow at the time was about 110 cfs. Sampling was done at these three sites to evaluate the size of sediment contributed to the Dungeness River by Canyon Creek. For more detail on the location of Sample Site DRsed-107, see Figure A.7. Dark rocks from Canyon Creek are basalt, shale, and sandstone. Shale is breaking into pebble-size angular chips. Basalt has fine fractures. Drawing is not to scale.

Sample Site DRsed-107

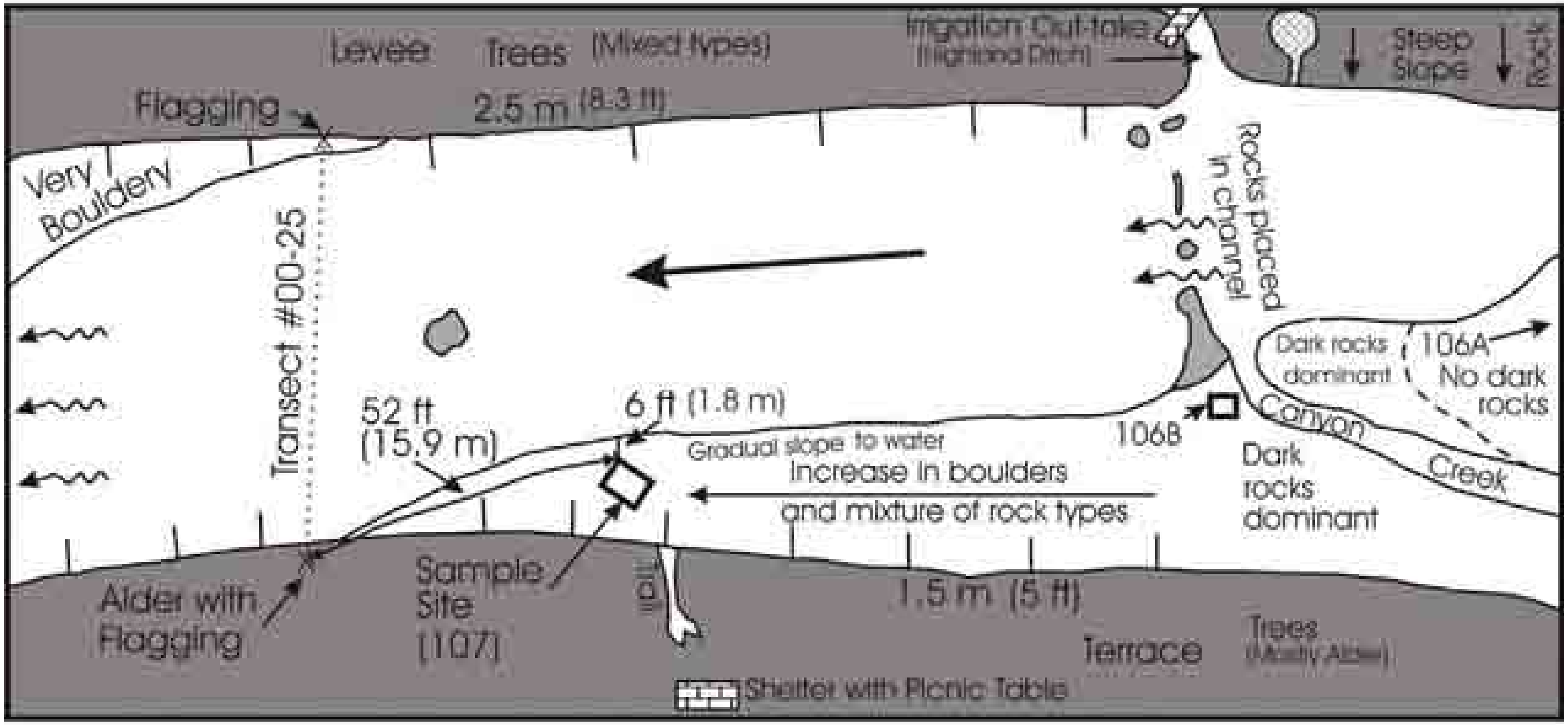


Figure A-7. Sketch map of the area surrounding sample site DRsed-107, which is located downstream of Canyon Creek on a bar of the Dungeness River near scour-chain transect #00-25. Sampling was begun about 3 pm of 10/1/00. Flow at the time was about 185 cfs. Sediment at sample site is similar to that along the margins of the channel, but sediment at the sample site is finer than that at the chain near the middle of the Dungeness River. Drawing is not to scale.

Sample Site DRsed-108

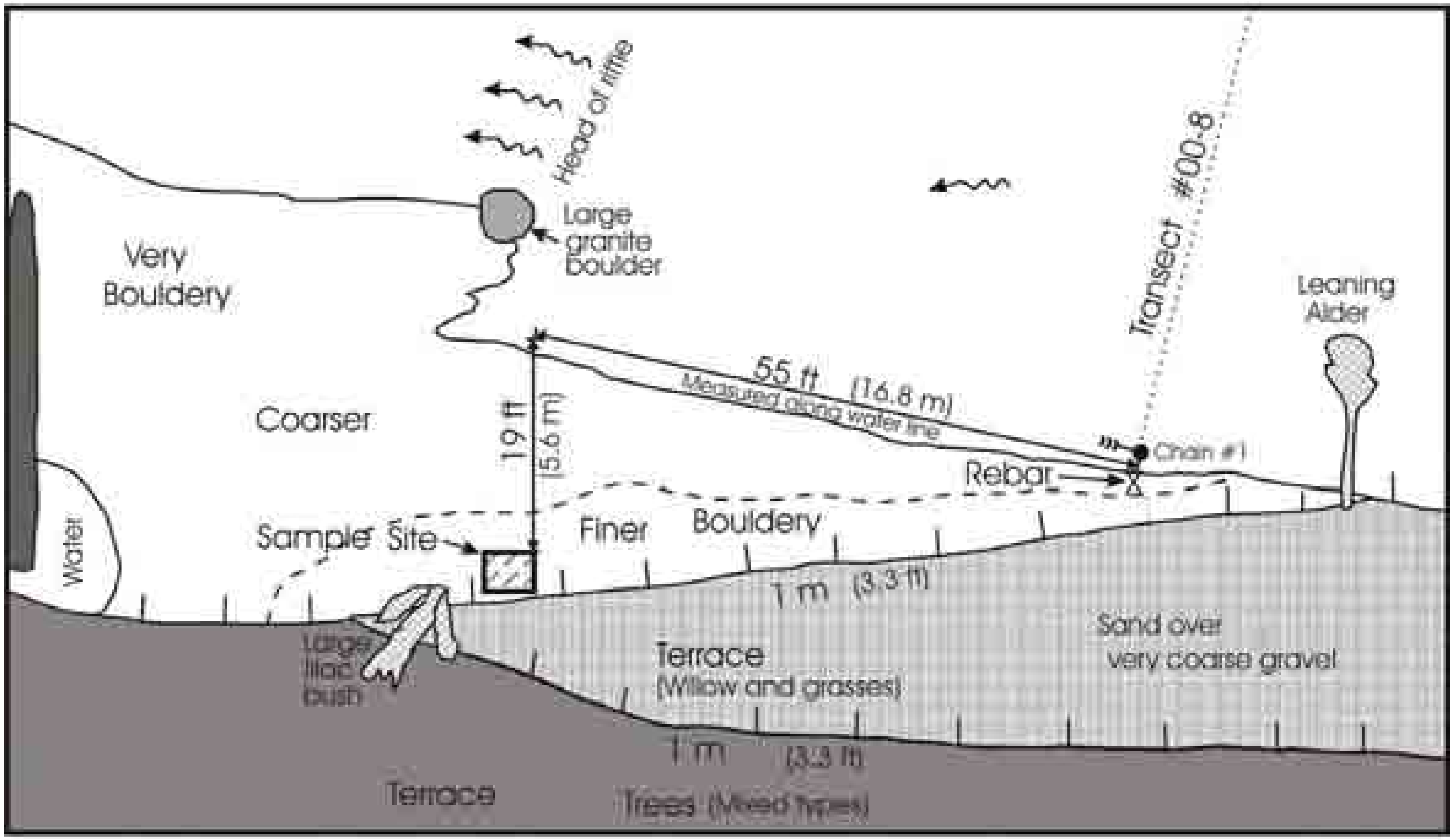


Figure A-8. Sketch map of the area surrounding sample site DRsed-108, which is located upstream of the Cline Bypass (downstream of Dungeness Meadows levee) on a bar on the west side of the Dungeness River near scour-chain transect #00-8. Sampling was begun about 2:30 pm of 9/30/00. Flow at the time was about 215 cfs. Sediment at sample site is similar to that in the channel at chain #1. The sampled bar in mostly much coarser than the channel. Drawing is not to scale.

Sample Site DRsed-109

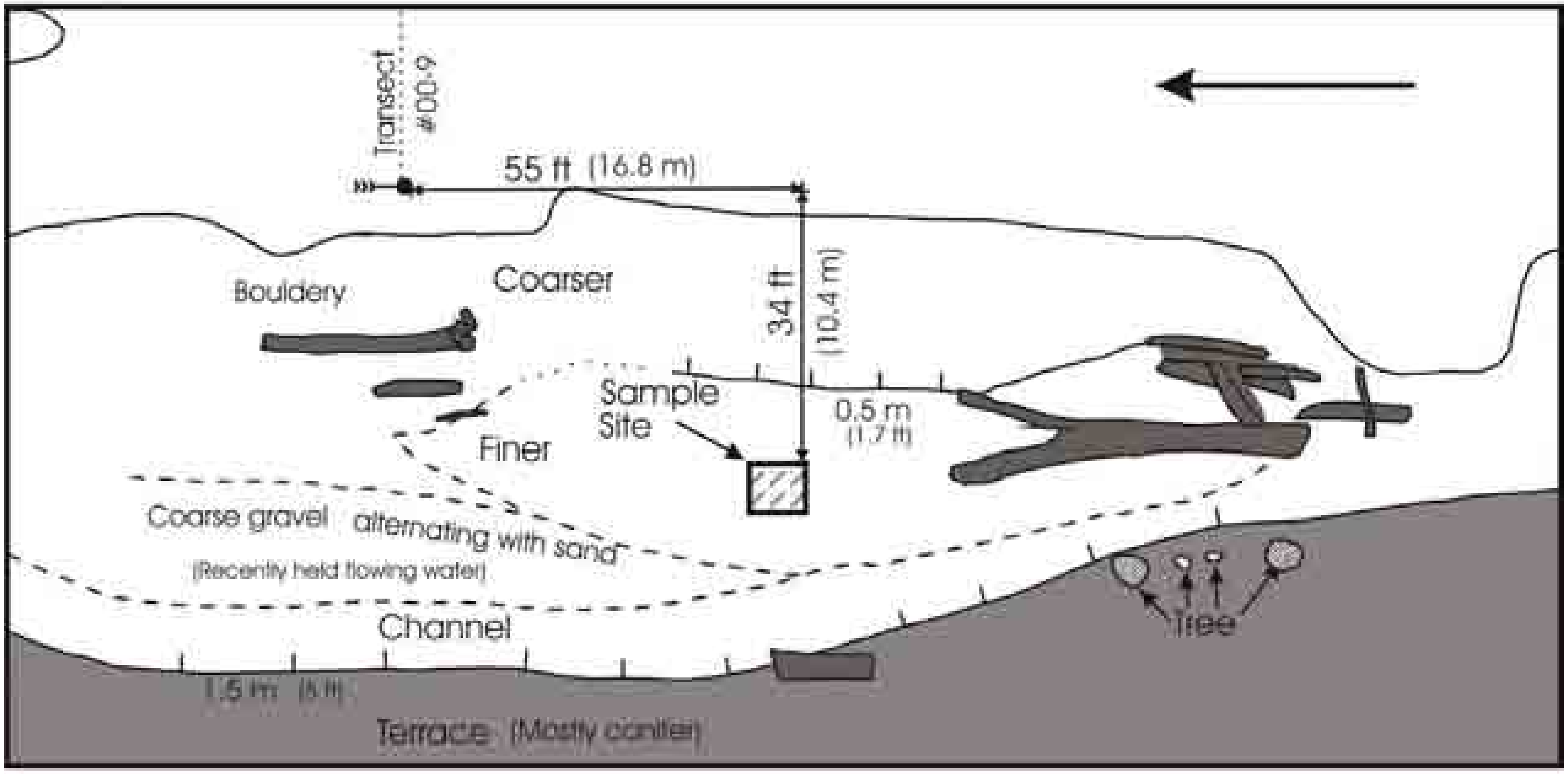


Figure A-9. Sketch map of the area surrounding sample site DRsed-109, which is located upstream of the Cline-Clallam Irrigation Diversion/Bypass Pipeline(downstream of Dungeness Meadows levee) on a bar on the west side of the Dungeness River near scour-chain transect #00-9. Sampling was begun about 3:15 pm of 9/28/00. Flow at the time was about 127 cfs. Drawing is not to scale.

Sample Site DRsed-110

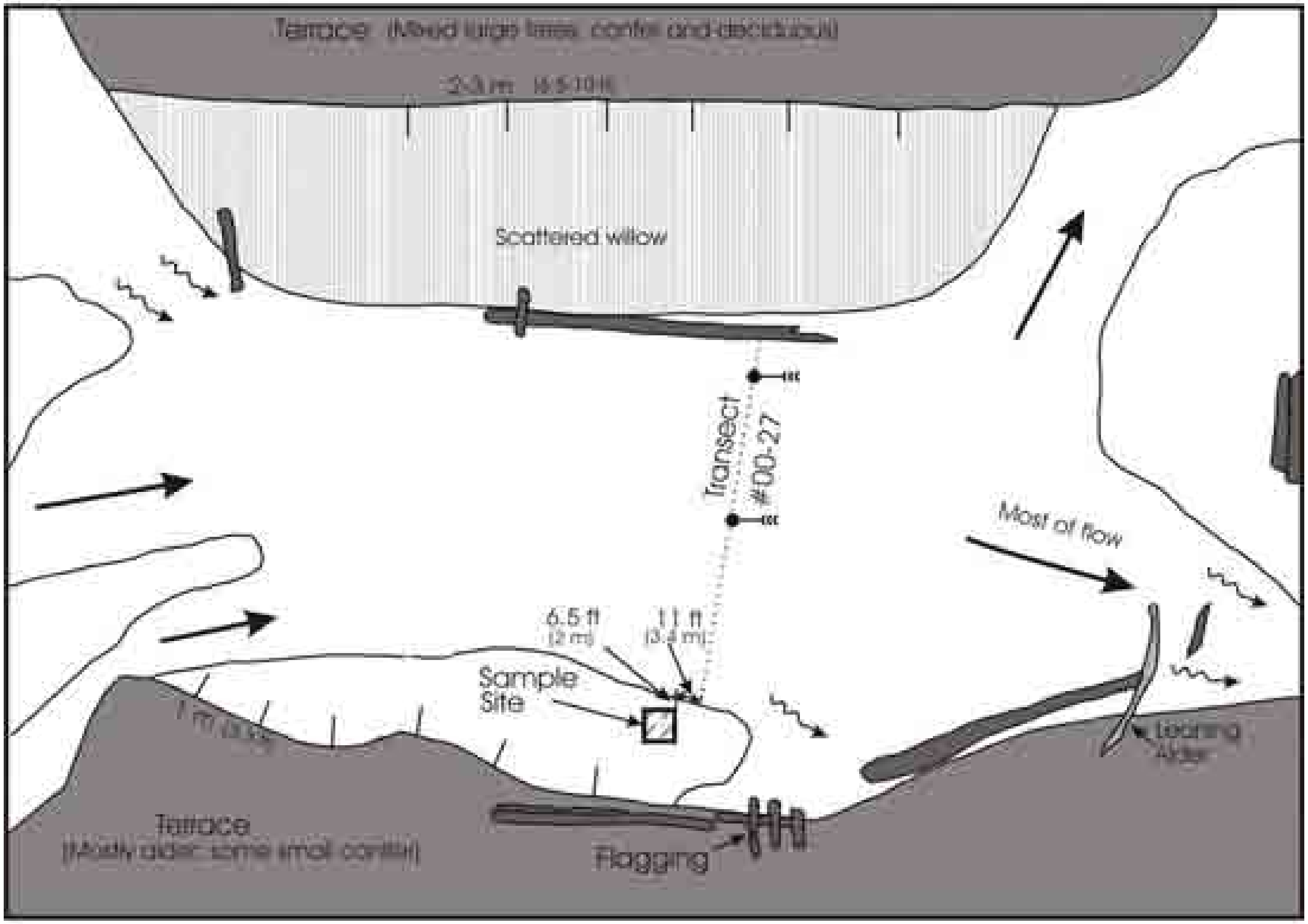


Figure A-10. Sketch map of the area surrounding sample site DRsed-110, which is located downstream of the Railroad Bridge on a bar on the east side of the Dungeness River near scour-chain transect #00-27. Sampling was begun about 1:45 pm of 10/2/00. Flow at the time was about 146 cfs. Drawing is not to scale.

Sample Site DRsed-111

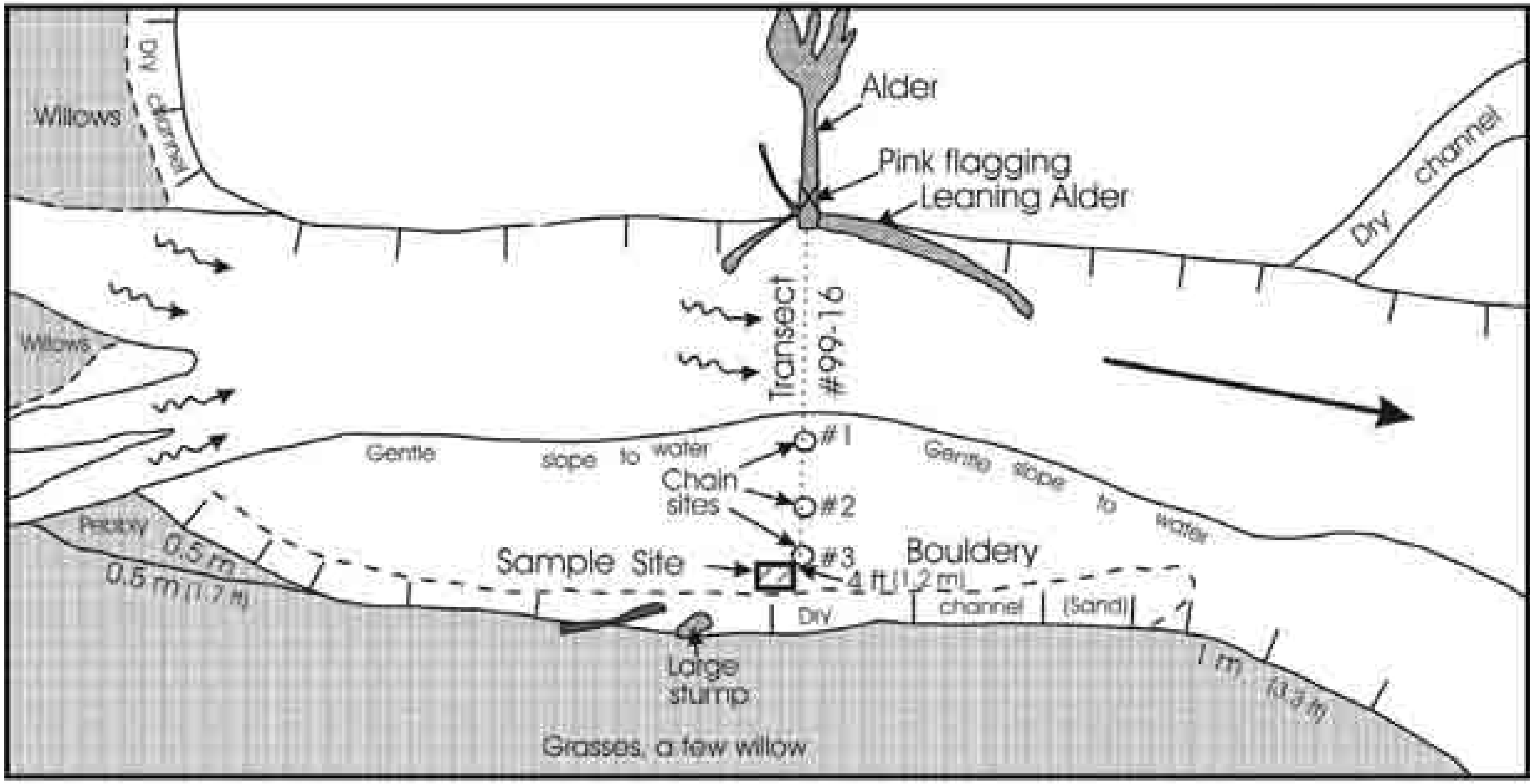


Figure A-11. Sketch map of the area surrounding sample site DRsed-111, which is located downstream of the Railroad Bridge adjacent to Doc Severson's property on a bar on the east side of the Dungeness River near the downstream end of the highly braided section. It is near scour-chain transect #99-16. The chains have been removed, but holes that were the likely chain sites are still visible. Sampling was begun about 11:30 am of 10/2/00. Flow at the time was about 149 cfs. Sampling was done near the site of chain #3. Sediment at the sites of chains #1 and #2 is similar. Drawing is not to scale.

Sample Site DRsed-112

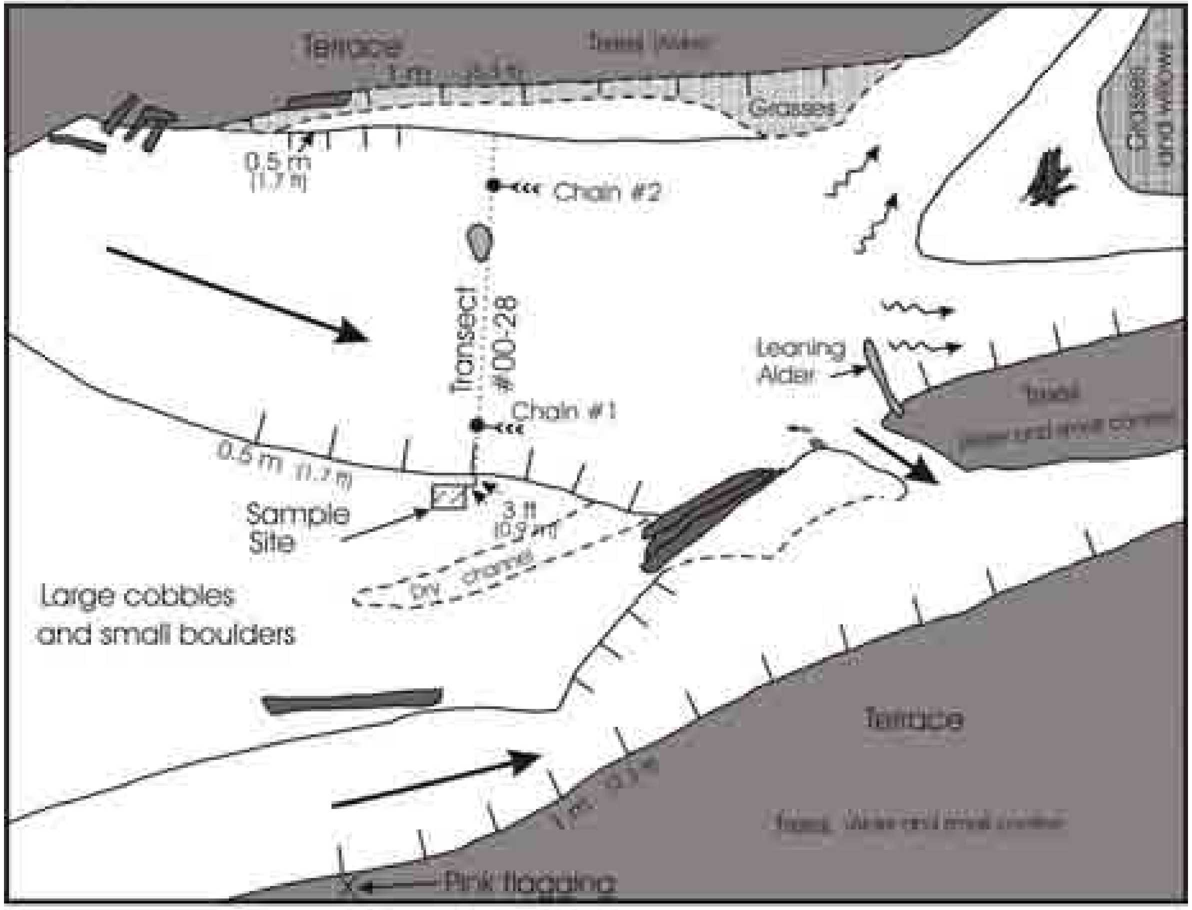


Figure A-12. Sketch map of the area surrounding sample site DRsed-112, which is located at the downstream end of Doc Severson's property downstream of the Railroad Bridge on a bar on the east side of the Dungeness River at scour-chain transect #00-28. Sampling was begun about 9:15 am of 10/2/00. Flow at the time was about 152 cfs. Sediment at the sample site is similar to that of the channel at chain #2 and slightly finer than the sediment at chain #1. Drawing is not to scale.

Sample Site DRsed-114

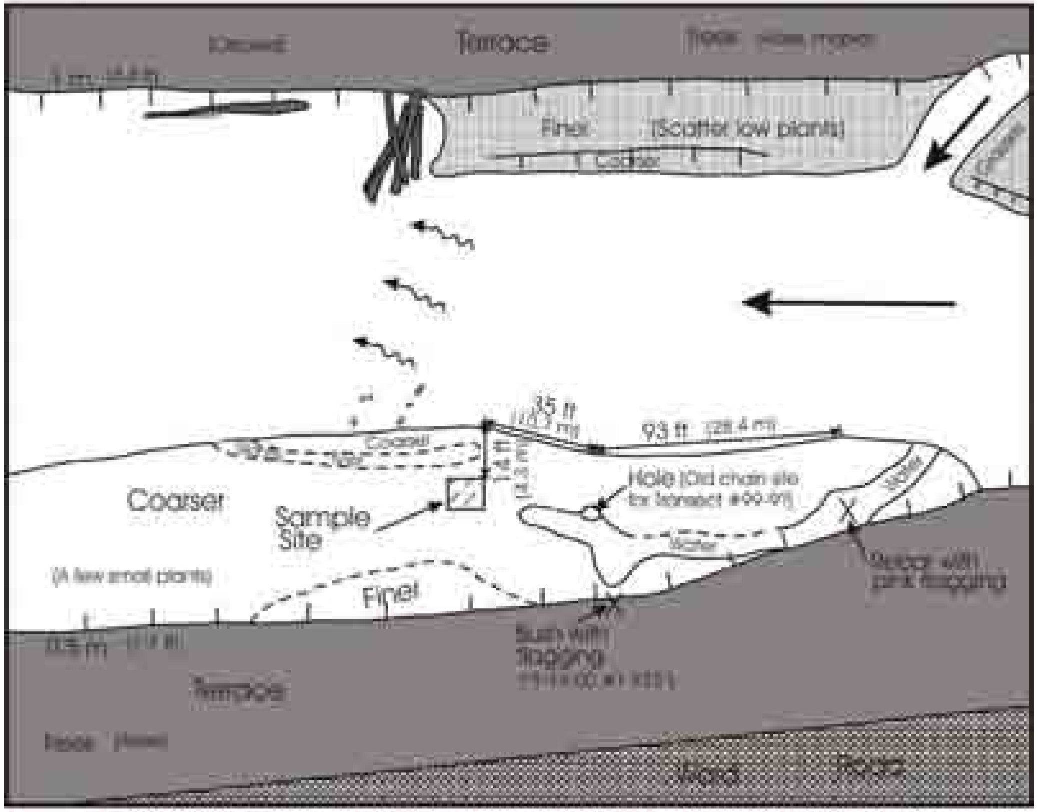


Figure A-13. Sketch map of the area surrounding sample site DRsed-114, which is located at the upstream Clallam County Park along Ward Road on a bar on the west side of the Dungeness River near scour-chain transect #9-99. Exact location of the transect could not be determined, so distance measurements were made to two possible locations as shown. Sampling was begun about 9:15 am of 10/1/00. Flow at the time was about 261 cfs. Sediment at sample site is similar to that in the low-water channel adjacent to the bar. Drawing is not to scale.

Sample Site DRsed-115

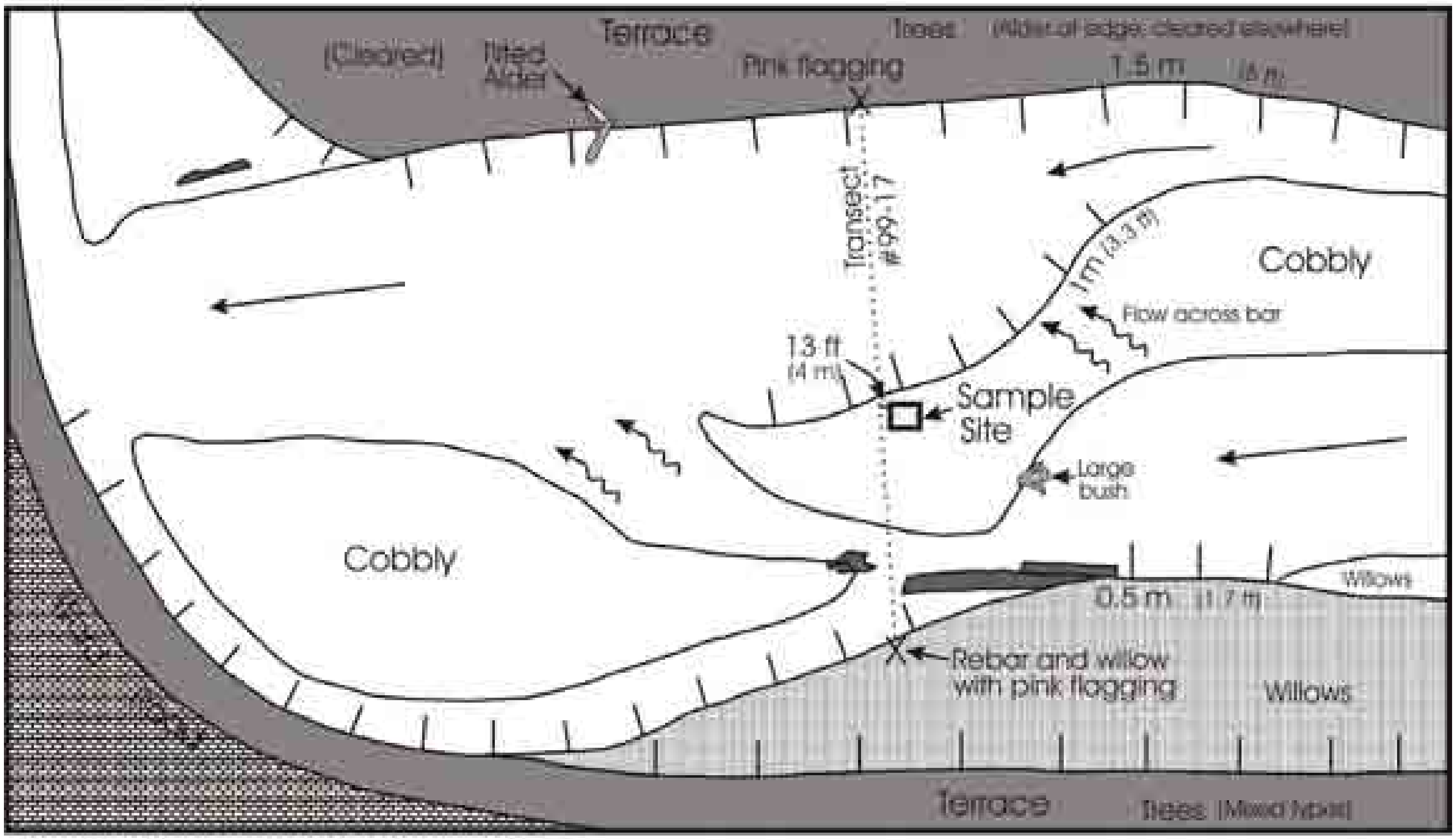


Figure A-14. Sketch map of the area surrounding sample site DRsed-115, which is located at the downstream Clallam County Park along Ward Road on a bar in the middle of the Dungeness River near scour-chain transect #99-17. Sampling was begun about 12:45 pm on 10/1/00. Flow at the time was about 191 cfs. Sediment at sample site near chain #1 is relatively uniform on the bar and adjacent channel. This sample is near samples DRsed-4A and DRsed-4B that were done in 1998. Drawing is not to scale.

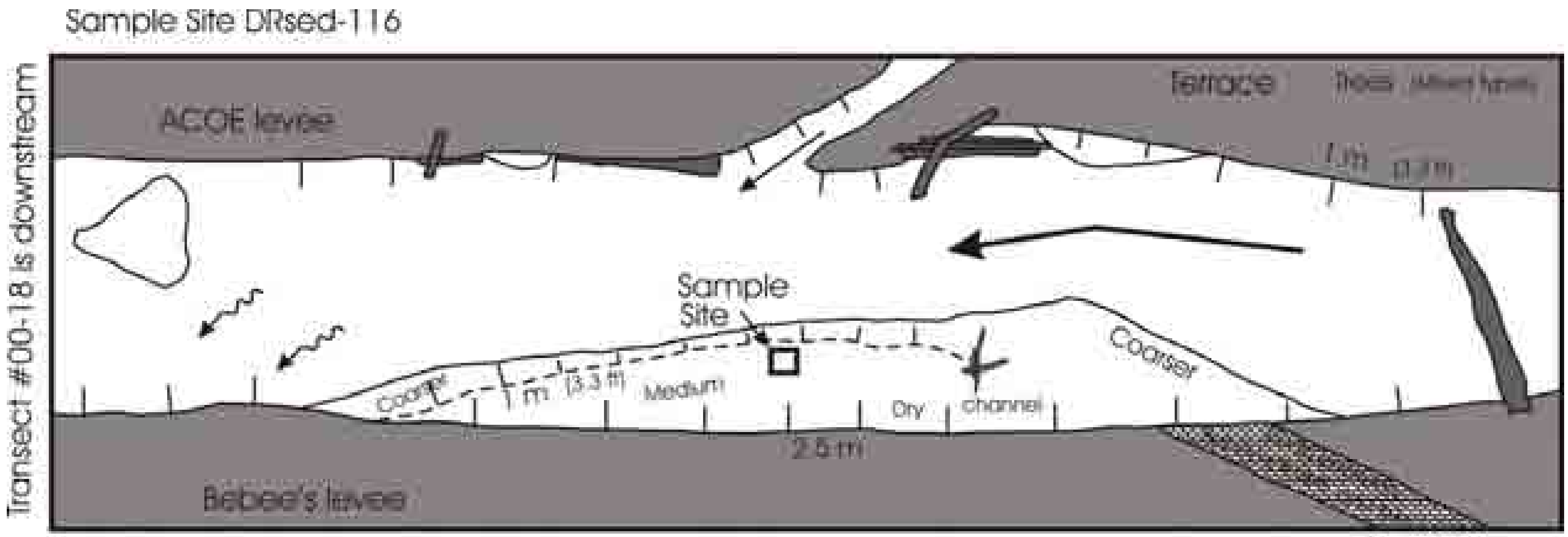


Figure A-15. Sketch map of the area surrounding sample site DRsed-116, which is located in the reach bounded by the ACOE and Bebee's levees on a bar on the west side of the Dungeness River upstream of scour-chain transect #00-18. Sampling was begun about 12:15 pm of 10/3/00. Flow at the time was about 125 cfs. Sediment at sample site is similar to that in the low-water channel at the transect and on a small bar adjacent to the chains. Drawing is not to scale.

Sample Site DRsed-117

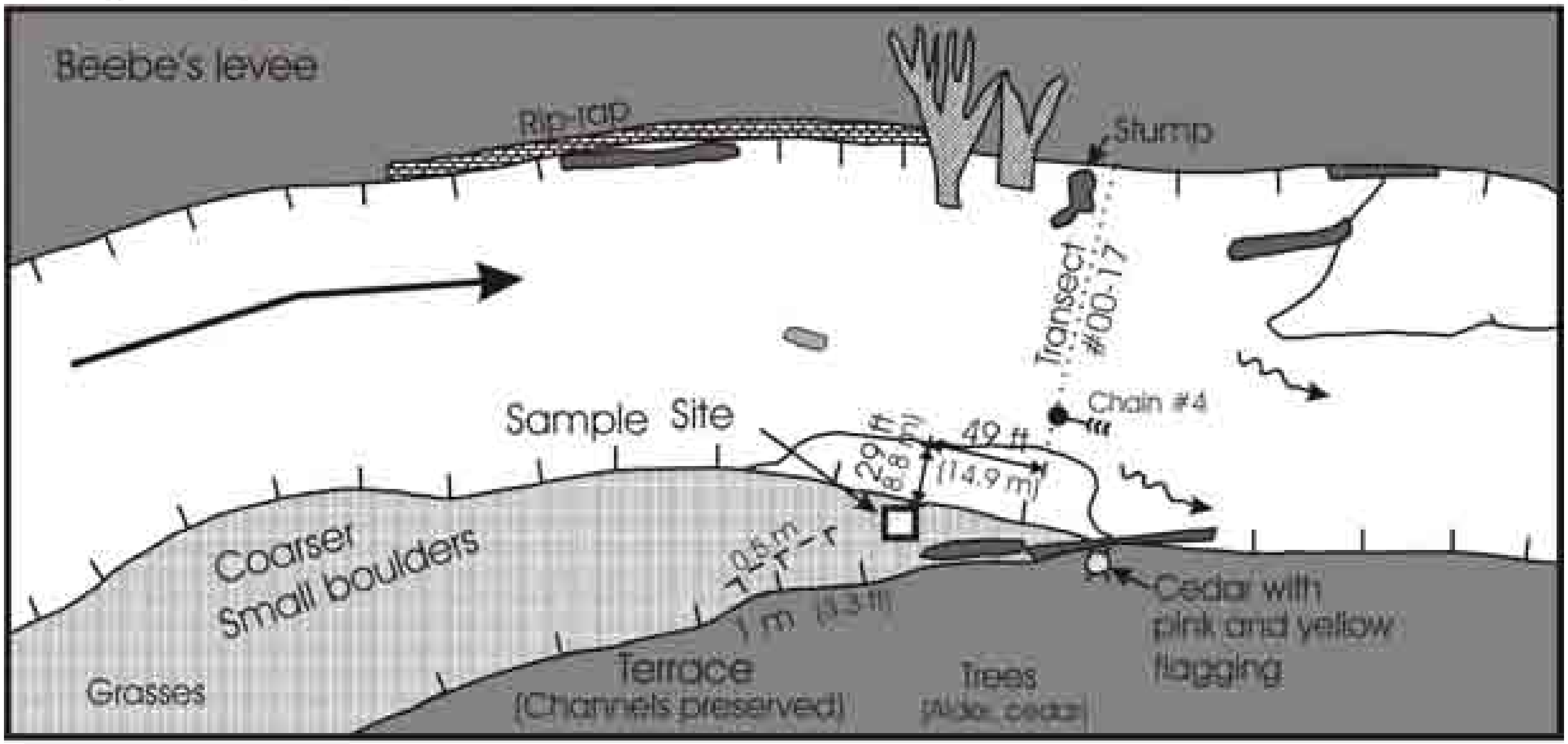


Figure A-16. Sketch map of the area surrounding sample site DRsed-117, which is located in the reach bounded by the ACOE and Bebee's levees on a bar on the east side of the Dungeness River near scour-chain transect #00-17. Sampling was begun about 8:15 am on 10/4/00. Flow at the time was about 115 cfs. Sediment at the sample site is similar to sediment at chain #4 and on a lower, unvegetated bar immediately adjacent to the sour-chain transect. Drawing is not to scale.

Sample Site DRsed-118

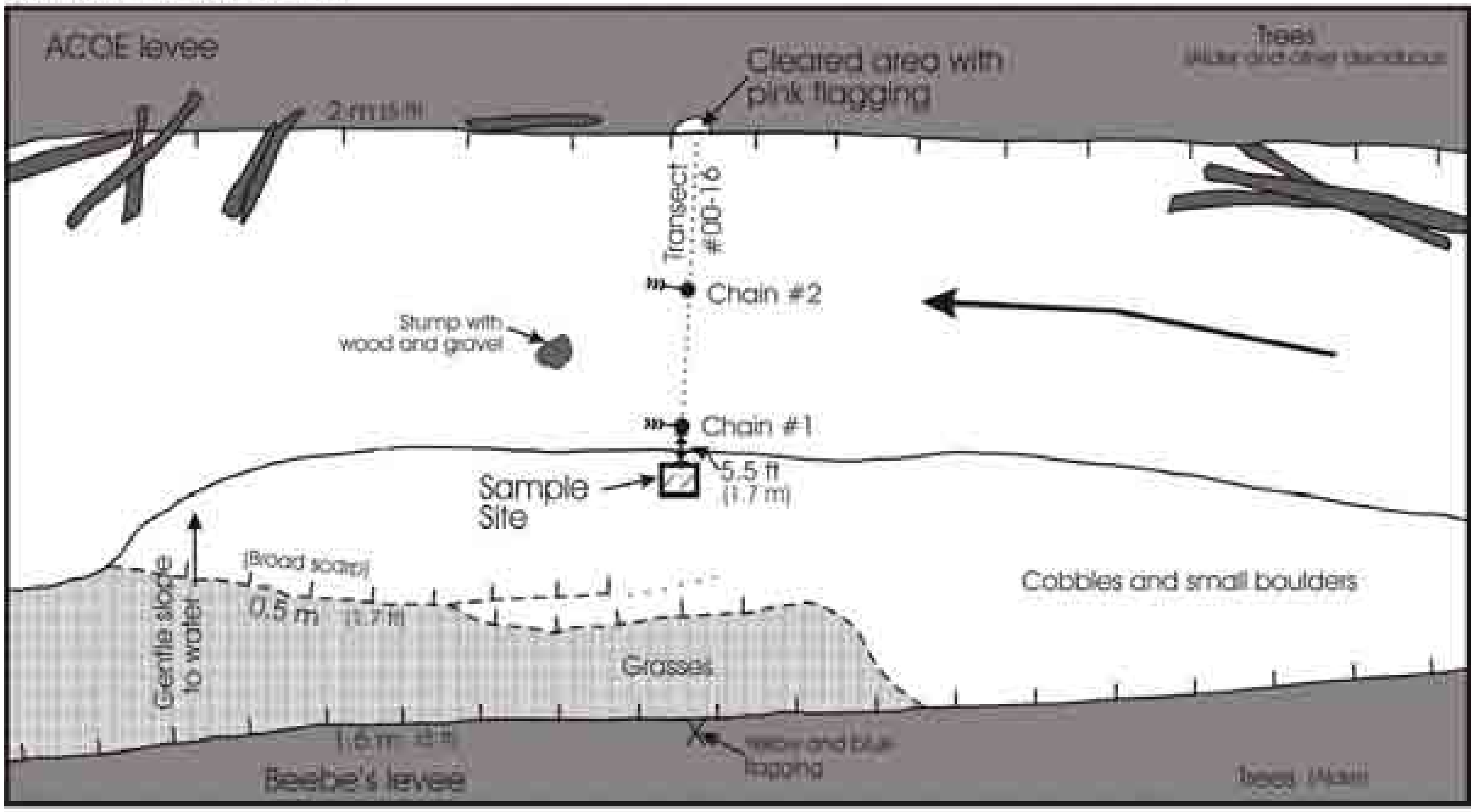


Figure A-17. Sketch map of the area surrounding sample site DRsed-118, which is located in the reach bounded by the ACOE and Bebee's levees on a bar on the west side of the Dungeness River at the Olympic Game Farm. The site is aligned with scour-chain transect #00-16. Sampling was begun about 8:25 am on 10/3/00. Flow at the time was about 130 cfs. Sediment at the sample site is similar to that in the channel at chain #1, but finer than the sediment in the channel at chain #2. Drawing is not to scale.

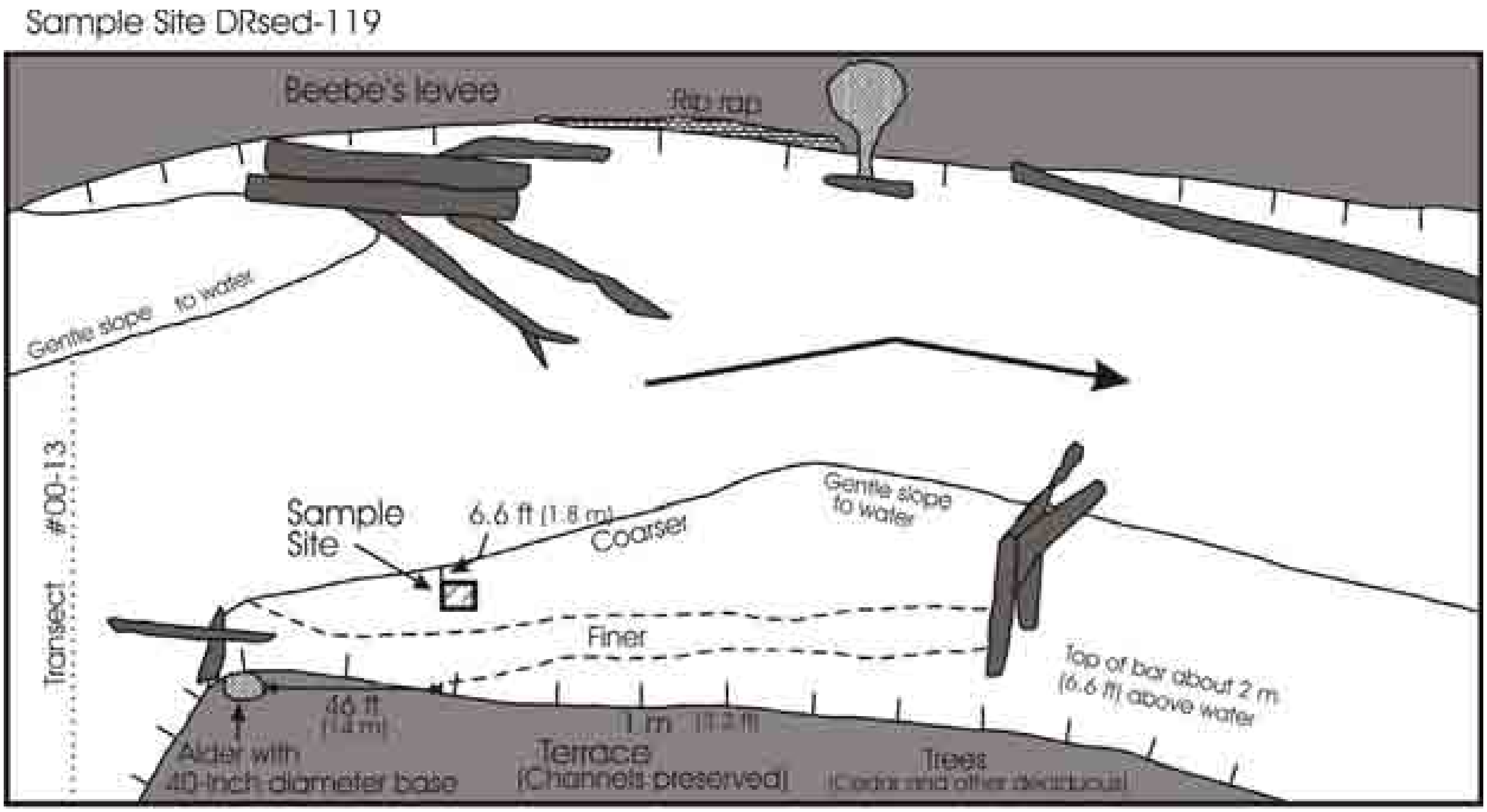


Figure A-18. Sketch map of the area surrounding sample site DRsed-119, which is located in the reach bounded by the ACOE and Beebe's levees on a bar on the east side of the Dungeness River near scour-chain transect #00-13. Sampling was begun about 10 am of 10/4/00. Flow at the time was about 112 cfs. Sediment at sample site is similar to that in the low-water channel. This site is near sample site DRsed-3, which was measured in 1998. Drawing is not to scale.

Appendix B - Sediment Sample Forms

Figure B-1. Sediment Sample: DRsed-101

Locality No.: DRsed-101 Sampled by: RAL and LAP Date: 9/29/00 Time: 11:15 am
Aerial Photograph: 2000 (Project No. 00-0194) Color No. 7-5 Closest Scour Chain Transect: #00-1
Quadrangle: Mount Zion Closest Cross Section: None River Mile: 17.7
Section: NW, NE, sec. 6 Township/Range: T. 28 N., R. 3 W. Elevation: 1,067 ft (GPS);1,045 ft (Topo. map)
Location: At the former East Crossing Campground; on bar on river right upstream of scour chain transect #00-1
Latitude: 47.95369ºN. Longitude: 123.1066ºW. Error: ________ Waypoint No.: SED101 Date: 9/29/00
Photographs Taken: RAL:
Description of Pavement: None
Description of Underlying Material: Loose. Includes cobbles, pebbles, and sand. Clasts are angular to well rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	19.5	19.5	16	16
2 to 8				
8 to 16	6.8	26.3	6	21
16 to 32	13.5	39.8	11	32
32 to 63	30.5	70.3	25	57
63 to 90	15.8	86.1	13	70
90 to 128	22.8	108.9	19	88
128 to 180	14.3	123.2	12	100
>180	--	--	--	--

Figure B-1. Sediment Sample: DRsed-101 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
165	Max. clast (diam)		

Figure B-2. Sediment Sample: DRsed-102

Locality No.: DRsed-102 Sampled by: RAL and LAP Date: 9/29/00 Time: 10:00 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 7-5 Closest Sour Chain Transect: #00-2
Quadrangle: Mount Zion Closest Cross Section: None River Mile: 17.7
Section: NW, NE, sec. 6 Township/Range: T. 28 N., R. 3 W. Elevation: 1,044 ft (GPS); 1,045 ft (Topo. map)
Location: At the former East Crossing Campground; on bar at scour chain transect #00-2
Latitude: 47.9547ºN. Longitude: 123.10588ºW. Error: ________ Waypoint No.: SED102 Date: 9/29/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. At the contact between coarser and finer sediment. Similar sizes to those at chain #1. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	24.7	24.7	30	30
2 to 8				
8 to 16	14.3	39.0	17	48
16 to 32	18.3	57.3	22	70
32 to 63	16.1	73.4	20	89
63 to 90	8.6	82.0	11	100
90 to 128	--	--	--	--
128 to 180	--	--	--	--
>180	--	--	--	--

Figure B-2. Sediment Sample: DRsed-102 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
100	Max. clast (diam)		

Figure B-3. Sediment Sample: DRsed-103

Locality No.: DRsed-103 Sampled by: RAL and LAP Date: 9/27/00 Time: 10:45 am
Aerial Photograph: 1998 (Project No. 98-0194) Color No. 7-2 Closest Scour Chain Transect: #00-4
Quadrangle: Mount Zion Closest Cross Section: None River Mile: 1 (GWR)
Section: SE, NW, sec. 31 Township/Range: T. 29 N., R. 3 W. Elevation: 977 ft (GPS); 900 ft (Topo. map)
Location: Near Gray Wolf and Dungeness rivers confluence; on small bar in side channel at scour chain transect #00-4
Latitude: 47.96669º N. Longitude: 123.11211º W. Error: ______ Waypoint No.: SED103 Date: 9/27/00
Photographs Taken: RAL: 4-1 through 4-8
Description of Pavement: None.
Description of Underlying Material: Loose. Includes cobbles, pebbles, and sand. Clasts are subangular to subrounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined. Water in hole.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	36.6	36.6	35	35
8 to 16	19.7	56.3	19	53
16 to 32	34.1	90.4	32	86
32 to 63	15.1	105.5	14	100
63 to 90	--	--	--	--
90 to 128	--	--	--	--
128 to 180	--	--	--	--
>180	--	--	--	--

Figure B-3. Sediment Sample: DRsed-102 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)

Figure B-4. Sediment Sample: DRsed-104

Locality No.: DRsed-104 Sampled by: RAL and LAP Date: 9/27/00 Time: 1:30 pm
Aerial Photograph: 19980 (Project No. 98-0194) Color No. 7-2 Closest Scour Chain Transect: #00-5
Quadrangle: Mount Zion Closest Cross Section: None River Mile: 0.9 (GWR)
Section: NE, NW sec. 31 Township/Range: T. 29 N., R. 3 W. Elevation: 895 ft (GPS); 900 ft (Topo. map)
Location: Near Gray Wolf and Dungeness rivers confluence; on bar near chain #1 of scour chain transect #00-5
Latitude: 47.96715º N. Longitude: 123.11276º W. Error: ______ Waypoint No.: SED104 Date: 9/27/00
Photographs Taken: RAL: 4?-12 through 4?-20
Description of Pavement: Loose. Poorly formed. Clasts mostly subrouded and subangular.
Description of Underlying Material: Loose. Sandy. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.4	0.4	0.4	0.4
2 to 8	0.9	1.3	1	1
8 to 16	2.7	4.0	3	4
16 to 32	14.1	18.1	16	20
32 to 63	42.2	60.3	47	68
63 to 90	21.3	81.6	24	92
90 to 128	7.5	89.1	8	100
128 to 180	--	--	--	--
>180 (see back)	--	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	29.1	29.1	32	32
8 to 16	8.7	37.8	10	41
16 to 32	14.6	52.4	16	57
32 to 63	26.9	79.3	29	86
63 to 90	7.9	87.2	9	95
90 to 128	4.8	92.0	5	100
128 to 180	--	--	--	--
>180	--	--	--	--

Figure B-4. Sediment Sample: DRsed-104 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
120	Max. clast (diam)		

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
100	Max. clast (diam)		

Figure B-5. Sediment Sample: DRsed-105

Locality No.: DRsed-105 Sampled by: RAL and LAP Date: 9/28/00 Time: 12:45 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 5-2 Closest Scour Chain Transect: #00-21
Quadrangle: Carlsborg Closest Cross Section: ________ River Mile: 11.6
Section: SW, SW, sec. 1 Township/Range: T.291 N., R. 4 W. Elevation: 561 ft (GPS); 560 ft (Topo. map)
Location: Near USGS gage; on small bar at scour chain transect #00-21. Sizes comparable to those at chains 1 + 2.
Latitude: 48.0158º N. Longitude: 123.13113º W. Error: ______ Waypoint No.: SED105 Date: 9/28/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	56.5	56.5	54	54
2 to 8				
8 to 16	14.2	70.7	14	67
16 to 32	15.0	85.7	14	82
32 to 63	8.8	94.5	8	90
63 to 90	2.6	97.1	3	93
90 to 128	7.7	104.8	7	100
128 to 180	--	--	--	--
>180	--	--	--	--

Figure B-5. Sediment Sample: DRsed-105 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
120	Max. clast (diam)		

Figure B-6. Sediment Sample: DRsed-106A

Locality No.: DRsed-106A Sampled by: RAL and LAP Date: 10/9/00 Time: 1:40 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 5-4 Closest Scour Chain Transect: #00-22
Quadrangle: Carlsborg Closest Cross Section: ______ River Mile: 10.9
Section: SE, NW, sec. 12 Township/Range: T. 29 N., R. 4 W. Elevation: 480 ft (GPS); 500 (Topo. map)
Location: Just upstream of Canyon Creek; on bar on river left between scour chain transects #00-25 and #00-24
Latitude: 48.02533º N. Longitude: 123.13673º W. Error: ______ Waypoint No.: SED106 Date: 10/9/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Chiefly pebbles, a few cobbles, and sand. Clasts are subangular to rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	30.5	30.5	25	25
2 to 8				
8 to 16	16.4	46.9	13	38
16 to 32	19.5	66.4	16	53
32 to 63	23.9	90.3	19	73
63 to 90	8.6	98.9	7	80
90 to 128	15.9	114.8	13	92
128 to 180	9.7	124.5	8	100
>180	--	--	--	--

Figure B-6. Sediment Sample: DRsed-106A (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
145	Max. clasts (diam)		

Figure B-7. Sediment Sample: DRsed-106B

Locality No.: DRsed-106B Sampled by: RAL and LAP Date: 10/4/00 Time: 2:55 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 5-4 Closest Scour Chain Transect: #00-22
Quadrangle: Carlsborg Closest Cross Section: ______ River Mile: 10.9
Section: NE, NW, sec. 12 Township/Range: T. 29 N., R. 4 W. Elevation: 470 ft (GPS); 500 ft (Topo. map)
Location: Downstream of Canyon Creek; on small alluvial fan from creek; between transects #00-25 and #00-24
Latitude: 48.02556º N. Longitude: 123.13705º W. Error: ______ Waypoint No.: ______ Date: 10/4/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Includes cobbles, pebbles, and sand. Clasts are angular to well rounded. High percent of dark rocks. Sample is moist, so the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	38.0	38.0	20	20
2 to 8				
8 to 16	14.1	52.1	7	27
16 to 32	21.2	73.3	11	38
32 to 63	24.5	97.8	13	51
63 to 90	15.1	112.9	8	59
90 to 128	15.7	128.6	8	67
128 to 180	8.2	136.8	4	71
>180	56.1	192.9	29	100

Figure B-7. Sediment Sample: DRsed-106A (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
75 x 350 x 600	25.4		
85 x 140 x 275	11.9		
130 x 165 x 250	18.8		
Total	56.1		

Figure B-8. Sediment Sample: DRsed-107

Locality No.: DRsed-107 Sampled by: RAL and LAP Date: 10/1/00 Time: 3:00 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 5-4 Closest Scour Chain Transect: #00-25
Quadrangle: Carlsborg Closest Cross Section: ________ River Mile: 10.8
Section: NE, NW, sec. 12 Township/Range: T. 29 N., R. 4 W. Elevation: 476 ft (GPS); 500 ft (Topo. map)
Location: Upstream of Fish Hatchery; on bar on river left near scour chain transect #00-25
Latitude: 48.02613º N. Longitude: 123.13744º W. Error: ______ Waypoint No.: SED107 Date: 10/1/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Includes small boulders to sand. Clasts are angular to rounded. Tried to avoid large boulders. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	33.2	33.2	11	11
2 to 8				
8 to 16	12.5	45.7	4	16
16 to 32	17.8	63.5	6	22
32 to 63	37.5	101.0	13	35
63 to 90	43.1	144.1	15	49
90 to 128	41.9	186.0	14	64
128 to 180	87.0	273.0	30	93
>180	19.5	292.5	7	100

Figure B-8. Sediment Sample: DRsed-107 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
100 x 220 x 235	19.5		
75 x 360 x 475	Five largest clasts near site; min. values as all partly buried		
90 x 270 x 500			
150 x 325 x 450			
300 x 370 x 580			
300 x 450 x 470			

Figure B-9. Sediment Sample: DRsed-108

Locality No.: DRsed-108 Sampled by: RAL and LAP Date: 9/30/00 Time: 2:35 pm
Aerial Photograph: 2000 (Project No. 00-01669) Color No. 4-6 Closest Scour Chain Transect: #00-8
Quadrangle: Dungeness Closest Cross Section: ______ River Mile: 7.8
Section: SW, SE, sec. 26 Township/Range: T. 30 N., R. 4 W. Elevation: 312 ft (GPS); 320 ft (Topo. map)
Location: Just upstream of Cline Bypass; on bar on river left just downstream of scour chain transect #00-8
Latitude: 48.06171º N. Longitude: 123.15467º W. Error: ______ Waypoint No.: SED108 Date: 9/30/00
Photographs Taken: RAL:
Description of Pavement: Loose. Includes large cobbles to sand. Clasts subangular to well rounded.
Description of Underlying Material: Loose. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	0.3	0.3	0.4	0.4
2 to 8				
8 to 16	1.9	2.2	2	3
16 to 32	10.5	12.7	13	16
32 to 63	37.3	50.0	45	61
63 to 90	25.4	75.4	31	92
90 to 128	6.7	82.1	8	100
128 to 180	--	--	--	--
>180 (see back)	--	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	44.3	44.3	41	41
2 to 8				
8 to 16	10.1	54.4	9	50
16 to 32	11.3	65.7	10	61
32 to 63	18.0	83.7	17	77
63 to 90	7.2	90.9	7	84
90 to 128	3.2	94.1	3	87
128 to 180	14.5	108.6	13	100
>180	--	--	--	--

Figure B-9. Sediment Sample: DRsed-108 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
100	Max. clasts (diam)		

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
160	Max. clasts (diam)		

Figure B-10. Sediment Sample: DRsed-109

Locality No.: DRsed-109 Sampled by: RAL and LAP Date: 9/28/00 Time: 3:20 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 4-6 Closest Scour Chain Transect: #00-9
Quadrangle: Carlsborg Closest Cross Section: ______ River Mile: 7.7
Section: SW, SE, sec. 26 Township/Range: T. 30 N., R. 4 W. Elevation: 308 ft (GPS); 500 ft (Topo. map)
Location: Just upstream of Cline Bypass; on bar on river left near scour chain transect #00-9
Latitude: 48.06228º N. Longitude: 123.15523º W. Error: ______ Waypoint No.: SED109 Date: 9/28/00
Photographs Taken: RAL: 5-7 through 5-17
Description of Pavement: Loose and dry. Moderately developed. Chiefly cobbles and pebbles, SR to WR.
Description of Underlying Material: Loose. Includes cobbles, pebbles, and sand. Clasts are angular to well rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	1.7	1.7	2	2
8 to 16	7.8	9.5	7	9
16 to 32	26.1	35.6	23	32
32 to 63	51.0	86.6	46	78
63 to 90	17.3	103.9	16	93
90 to 128	7.6	111.5	7	100
128 to 180	--	--	--	--
>180 (see back)	--	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	24.7	24.7	15	15
8 to 16	12.5	37.2	8	23
16 to 32	19.4	56.6	12	34
32 to 63	37.4	94.0	23	57
63 to 90	25.4	119.4	15	73
90 to 128	35.2	154.6	21	94
128 to 180	10.2	164.8	6	100
>180	--	--	--	--

Figure B-10. Sediment Sample: DRsed-109 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
155	Max. clast (diam)		

Figure B-11. Sediment Sample: DRsed-110

Locality No.: DRsed-110 Sampled by: RAL and LAP Date: 10/2/00 Time: 1:45 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 3-4 Closest Scour Chain Transect: #00-27
Quadrangle: Carlborg Closest Cross Section: ______ River Mile: 5.5
Section: SE, SE, sec. 14 Township/Range: T. 30 N., R. 4 W. Elevation: 186 ft (GPS); 190 ft (Topo. map)
Location: Downstream of Railroad Bridge; on bar on river right at scour chain transect #00-27
Latitude: 48.08679º N. Longitude: 123.14953º W. Error: ______ Waypoint No.: SED110 Date: 10/2/00
Photographs Taken: RAL:
Description of Pavement: Mostly loose. Includes up to small boulders. Clasts are subangular to rounded.
Description of Underlying Material: Small boulders through sand. Clasts are subangular to rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	0.8	0.8	0.3	0.3
8 to 16	1.0	1.8	0.4	1
16 to 32	5.7	7.5	2	3
32 to 63	40.4	47.9	16	18
63 to 90	50.7	98.6	20	38
90 to 128	84.7	183.3	33	70
128 to 180	55.5	238.8	21	92
>180 (see back)	21.5	260.3	8	100

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	39.5	39.5	20	20
8 to 16	12.8	52.3	7	27
16 to 32	20.8	73.1	11	38
32 to 63	51.3	124.4	27	64
63 to 90	32.2	156.6	17	81
90 to 128	36.6	193.2	19	100
128 to 180	--	--	--	--
>180	--	--	--	--

Figure B-11. Sediment Sample: DRsed-110 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
185 x 190 x 245	21.5		

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
135	Max. clast (diam)		

Figure B-12. Sediment Sample: DRsed-111

Locality No.: DRsed-111 Sampled by: RAL and LAP Date: 10/2/00 Time: 11:30 am
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 3-4 Closest Scour Chain Transect: #99-16
Quadrangle: Carlsborg Closest Cross Section: ______ River Mile: 5.4
Section: SE, SE, sec. 14 Township/Range: T. 30 N., R. 4 W. Elevation: 178 ft (GPS); 180 ft (Topo. map)
Location: Along Doc Severson's property; on bar on river right at scour chain transect #99-16 at chain #3
Latitude: 48.08924º N. Longitude: 123.15085º W. Error: ______ Waypoint No.: SED111 Date: 10/2/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Small boulders to sand. Clasts are subangular to rounded. Mixed lithology. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	40.1	40.1	21	21
8 to 16	15.9	56.0	8	29
16 to 32	22.8	78.8	12	41
32 to 63	30.2	109.0	16	56
63 to 90	9.9	118.9	5	62
90 to 128	43.8	162.7	23	84
128 to 180	13.0	175.7	7	91
>180	17.5	193.2	9	100

Figure B-12. Sediment Sample: DRsed-111 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
85 x 205 x 300	17.5		

Figure B-13. Sediment Sample: DRsed-112

Locality No.: DRsed-112 Sampled by: RAL and LAP Date: 10/2/00 Time: 9:15 am
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 3-4 Closest Scour Chain Transect: #00-28
Quadrangle: Carlsborg Closest Cross Section: ________ River Mile: 5.0
Section: NE, SE, sec. 14 Township/Range: T. 30 N., R. 4 W. Elevation: 144 ft (GPS); 160 ft (Topo. map)
Location: Just downstream of Severson's hay field; on bar on river right at scour chain transect #00-28
Latitude: 48.09296º N. Longitude: 123.14989º W. Error: ______ Waypoint No.: SED112 Date: 10/2/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Little sand on surface. Small boulders to sand. Clasts are subangular to well rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	13.8	13.8	11	11
2 to 8				
8 to 16	5.0	18.8	4	15
16 to 32	18.3	37.1	15	30
32 to 63	45.7	82.8	37	68
63 to 90	25.9	108.7	21	89
90 to 128	--	108.7	--	89
128 to 180	13.6	122.3	11	100
>180	--	--	--	--

Figure B-13. Sediment Sample: DRsed-112 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
140	Max. clast (diam)		

Figure B-14. Sediment Sample: DRsed-114

Locality No.: DRsed-114 Sampled by: RAL and LAP Date: 10/1/00 Time: 9:15 am
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 2-5; Byron: 1999 (Project No. 99-0423) #3-5
Closest Scour Chain Transect: #99-9
Quadrangle: Carlsborg Closest Cross Section: ______ River Mile: 3.0
Section: SE, SE, sec. 2 Township/Range: T. 30 N., R. 4 W. Elevation: 55 ft (GPS); 75 ft (Topo. map)
Location: Upstream county park along Ward Road; on bar on river left at scour chain transect #99-9
Latitude: 48.11916º N. Longitude: 123.14737º W. Error: ______ Waypoint No.: SED114 Date: 10/1/00
Photographs Taken: RAL:
Description of Pavement: Mix of sizes: small boulders to sand. Try to approximate sizes in channel. Moist.
Description of Underlying Material: Slightly difficult to dig (compact or large clasts). Small boulders to sand. Angular to subrounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	1.5	1.5	1	1
2 to 8				
8 to 16	2.3	3.8	2	3
16 to 32	19.5	23.3	17	21
32 to 63	39.2	62.5	35	56
63 to 90	27.6	90.1	25	80
90 to 128	14.5	104.5	13	93
128 to 180	7.6	112.2	7	100
>180 (see back)	--	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	40.1	40.1	20	20
2 to 8				
8 to 16	17.0	57.1	9	29
16 to 32	17.9	75.0	9	38
32 to 63	34.2	109.2	17	55
63 to 90	25.1	134.3	13	68
90 to 128	21.7	156.0	11	79
128 to 180	42.2	198.4	21	100
>180	--	--	--	--

Figure B-14. Sediment Sample: DRsed-114 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
160	Max. clast (diam)		

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
175	Max. clast (diam)		

Figure B-15. Sediment Sample: DRsed-115

Locality No.: DRsed-115 Sampled by: RAL and LAP Date: 10/1/00 Time: 12:45 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 2-5: Byron 1999 (Project No. 99-0432) #3-5
Closest Scour Chain Transect: #99-17
Quadrangle: Carlsborg Closest Cross Section: ____ River Mile: 2.8
Section: NE, SE, sec. 2 Township/Range: T. 30 N., R. 4 W. Elevation: 55 ft (GPS); 70 ft (Topo. map)
Location: Downstream county park along Ward Road; on bar on river left at scour chain transect #99-17
Latitude: 48.12055° N. Longitude: 123.14651° W. Error: t Waypoint No.: SED115 Date: 10/1/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Large cobbles to sand. Clasts are subangular to well rounded. Mixed lithology. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	35.1	35.1	15	15
2 to 8				
8 to 16	15.1	50.2	6	21
16 to 32	22.2	72.4	9	30
32 to 63	51.8	124.2	21	51
63 to 90	53.8	178.0	22	74
90 to 128	54.0	232.0	22	96
128 to 180	10.4	242.4	4	100
>180	--	--	--	--

Figure B-15. Sediment Sample: DRsed-115 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
135	Max. clast (diam)		

Figure B-16. Sediment Sample: DRsed-116

Locality No.: DRsed-116 Sampled by: RAL and LAP Date: 10/3/00 Time: 12:15 pm
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 2-7 Closest Scour Chain Transect: #00-18
Quadrangle: Dungeness Closest Cross Section: ________ River Mile: 2.4
Section: NW, NW, sec. 1 Township/Range: T. 30 N., R. 4 W. Elevation: 42 ft (GPS); 40 ft (Topo. map)
Location: ACOE section; on large bar on river left upstream about 0.12 mi from scour chain transect #00-18
Latitude: 48.12742º N. Longitude: 123.14381º W. Error: ______ Waypoint No.: SED116 Date: 10/3/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Large cobbles to sand. Clasts are subangular to rounded. Mixed lithology. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	34.6	34.6	22	22
8 to 16	17.4	52.0	11	34
16 to 32	32.1	84.1	21	54
32 to 63	50.7	134.8	33	87
63 to 90	14.7	149.5	10	96
90 to 128	5.8	155.3	4	100
128 to 180	--	--	--	--
>180	--	--	--	--

Figure B-16. Sediment Sample: DRsed-116 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
95	Max. clast (diam)		

Figure B-17. Sediment Sample: DRsed-117

Locality No.: DRsed-117 Sampled by: RAL and LAP Date: 10/4/00 Time: 8:15 am
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 2-8 Closest Scour Chain Transect: #00-17
Quadrangle: Dungeness Closest Cross Section: ______ River Mile: 2.1
Section: SW, SW, sec. 36 Township/Range: T. 31 N., R. 4 W. Elevation: 26 ft (GPS); 35 ft (Topo. map)
Location: ACOE levee section; on bar on river right at scour chain transect #00-17; sizes similar to bed at chain #4
Latitude: 48.13126º N. Longitude: 12314372º W. Error: ______ Waypoint No.: SED117 Date: 10/4/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Small cobbles to sand. Clasts are chiefly subrounded to well rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	53.8	53.8	43	43
2 to 8				
8 to 16	25.5	79.3	20	63
16 to 32	25.3	104.6	20	84
32 to 63	20.4	125.0	16	100
63 to 90	--	--	--	--
90 to 128	--	--	--	--
128 to 180	--	--	--	--
>180	--	--	--	--

Figure B-17. Sediment Sample: DRsed-117 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
65	Max. clast (diam)		

Figure B-18. Sediment Sample: DRsed-118

Locality No.: DRsed-118 Sampled by: RAL and LAP Date: 10/3/00 Time: 8:25 am
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 2-8; Byron 2000 (Project No. 00-0669) Color No. 2-7
Closest Scour Chain Transect: #00-15 and #00-16
Quadrangle: Dungeness Closest Cross Section: ________ River Mile: 1.9
Section: SW, SW, sec. 36 Township/Range: T. 31 N., R. 4 W. Elevation: 26 ft (GPS); 35 ft (Topo. map)
Location: ACOE levee section; on bar on river left near gravel pit at Game Farm at scour chain transect #00-16
Latitude: 48.13239º N. Longitude: 123.14178º W. Error: ______ Waypoint No.: SED118 Date: 10/3/00
Photographs Taken: RAL:
Description of Pavement: Loose. Weakly developed. Small boulders to granules. Mixed lithology. SA to R.
Description of Underlying Material: Loose. Small boulders to sand. Clasts are subangular to rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	1.6	1.6	1	1
8 to 16	3.9	5.5	2	3
16 to 32	24.0	29.5	13	16
32 to 63	92.0	121.5	49	65
63 to 90	31.2	152.7	17	82
90 to 128	16.7	169.4	9	91
128 to 180	16.9	186.3	9	100
>180 (see back)	--	--	--	--

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2 2 to 8	26.2	26.2	14	14
8 to 16	12.4	38.6	7	20
16 to 32	23.2	61.8	12	32
32 to 63	42.0	103.8	22	54
63 to 90	24.0	127.8	13	67
90 to 128	18.7	146.5	10	77
128 to 180	25.9	172.4	14	90
>180	18.9	191.3	10	100

Figure B-18. Sediment Sample: DRsed-118 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)
130	Max. clast (diam)		

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
165 x 170 x 195	18.9		

Figure B-19. Sediment Sample: DRsed-119

Locality No.: DRsed-119 Sampled by: RAL and LAP Date: 10/4/00 Time: 10:00 am
Aerial Photograph: 2000 (Project No. 00-0669) Color No. 2-8 Closest Scour Chain Transect: #00-13
Quadrangle: Dungeness Closest Cross Section: ______ River Mile: 1.5

Section: SE, NW, sec. 36 Township/Range: T. 31 N., R. 4 W. Elevation: 26 ft (GPS); 25 ft (Topo. map)
Location: ACOE levee section; on bar on river right at scour chain transect #00-13 near DRsed-3
Latitude: 48.13717º N. Longitude: 123.13887º W. Error: ______ Waypoint No.: SED119 Date: 10/4/00
Photographs Taken: RAL:
Description of Pavement: None.
Description of Underlying Material: Loose. Cobbles to sand. Clasts are subangular to well rounded. Sample is moist. Because of moisture the <2 mm fraction and 2 to 8 mm fraction were combined.

Pavement: Not sampled separately.

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2				
2 to 8				
8 to 16				
16 to 32				
32 to 63				
63 to 90				
90 to 128				
128 to 180				
>180 (see back)				

Underlying material:

Size range (mm)	Total weight (lbs)	Cumulative weight (lbs)	Percent	Cumulative percent
<2	22.5	22.5	16	16
2 to 8				
8 to 16	12.0	34.5	9	24
16 to 32	22.8	57.3	16	41
32 to 63	42.3	99.6	30	70
63 to 90	35.6	135.2	25	96
90 to 128	--	135.2	--	96
128 to 180	6.4	141.6	5	100
>180	--	--	--	--

Figure B-19. Sediment Sample: DRsed-119 (Cont.)

For material larger than 180 mm in pavement

Diam (mm)	Wgt (lbs)	Diam (mm)	Wgt (lbs)

For material larger than 180 mm in underlying material

Diam (mm)	Wgt (lbs)	Diam (mm	Wgt (lbs)
150	Max. clast (diam)		

Appendix C - Sediment Data for Dungeness River

Table C1. Summary of sediment data.

Sample (DRsed-)	Percent of Total Sample																				
	Material Retained by Sieve Size (mm)															Material Retained by Hydrometer (mm)					
	180	**128**	**90**	**63**	**32**	**16**	**8**	**4.75**	**2.36**	**1.18**	**0.600**	**0.300**	**0.150**	**0.075**	**0.063**	**0.037**	**0.019**	**0.009**	**0.005**	**0.002**	**0.001**
101	0	11.6	18.5	12.8	24.8	11.0	5.5	2.1	3.2	3.8	3.8	1.9	0.6	0.2	0	0.2	0	0	0	0	0
102	0	0	0	10.5	19.6	22.3	17.4	7.5	8.1	5.1	3.6	3.0	1.5	0.5	0.1	0.2	0.2	0	0.1	0.1	0.1
103	0	0	0	0	14.3	32.3	18.7	6.9	9.4	6.9	5.9	3.8	1.0	0.4	0	0	0.1	0.1	0	0	0.1
104	0	0	5.2	8.6	29.2	15.9	9.5	6.0	7.0	6.6	5.7	3.2	1.6	0.8	0.1	0.3	0.2	0	0	0.1	0.1
104pv	0	0	8.4	23.9	47.4	15.8	3.0	1.4													
105	0	0	7.3	2.5	8.4	14.3	13.5	9.2	12.9	14.6	10.2	4.3	1.6	0.5	0.1	0.3	0	0	0.2	0	0.1
106A	0	7.8	12.8	6.9	19.2	15.7	13.2	6.1	5.9	3.4	2.7	2.9	2.2	0.7	0.1	0.3	0	0	0.1	0	0
106B	29.1	4.3	8.1	7.8	12.7	11.0	7.3	3.5	3.7	3.2	3.7	3.3	1.4	0.5	0.1	0.2	0	0.1	0	0	0
107	6.7	29.7	14.3	14.8	12.8	6.1	4.3	1.2	2.0	1.9	2.0	2.0	1.2	0.4	0.1	0.2	0.1	0	0	0	0
108	--	13.4	2.9	6.6	16.6	10.4	9.3	3.7	7.3	9.8	10.2	6.5	2.0	0.4	0.1	0.3	0.1	0.1	0	0.1	0.1
108pv	0	0	8.2	30.9	45.4	12.8	2.3	0.4													
109	0	6.2	21.4	15.4	22.7	11.8	7.6	2.7	2.2	2.1	2.2	2.8	1.8	0.6	0.1	0.2	0	0	0	0	0
109pv	0	0	6.8	15.5	45.7	23.4	7.0	1.5													
110	0	0	18.9	16.7	26.6	10.8	6.6	2.2	3.7	3.5	3.5	3.9	2.0	0.8	0.1	0.8	0	0	0	0	0
110pv	8.3	21.3	32.5	19.5	15.5	2.2	0.4	0.3													
111	9.1	6.7	22.7	5.1	15.6	11.8	8.2	5.2	4.6	3.9	3.3	2.3	0.8	0.4	0	0.2	0	0	0	0	0
112	0	11.1	0	21.2	37.4	15.0	4.1	0.9	1.0	1.7	2.5	3.0	1.5	0.4	0	0.2	0	0	0	0	0
114	0	21.4	10.9	12.7	17.2	9.0	8.6	3.2	4.6	3.2	3.0	3.0	1.8	0.5	0	0.6	0	0	0	0	0
114pv	0	6.8	12.9	24.6	34.9	17.4	2.0	1.3													
115	0	4.3	22.3	22.2	21.4	9.2	6.2	2.3	2.6	2.6	2.6	2.3	1.4	0.3	0	0.2	0	0	0	0	0

Table C-1. Summary of sediment size data[1] (Cont.)

Sample (DRsed-)	Percent of Total Sample																				
	Material Retained by Sieve Size (mm)															Material Retained by Hydrometer (mm)					
	180	**128**	**90**	**63**	**32**	**16**	**8**	**4.75**	**2.36**	**1.18**	**0.600**	**0.300**	**0.150**	**0.075**	**0.063**	**0.037**	**0.019**	**0.009**	**0.005**	**0.002**	**0.001**
116	0	0	3.7	9.5	32.6	20.7	11.2	4.7	5.3	3.6	1.8	2.5	2.9	1.0	0.1	0.5	0	0	0	0	0
117	0	0	0	0	16.3	20.2	20.4	8.2	9.5	9.0	5.6	4.3	4.7	0.8	0.1	0.8	0	0	0	0	0
118	9.9	13.5	9.8	12.5	22.0	12.1	6.5	1.5	2.1	1.4	1.8	3.6	2.3	0.6	0.1	0.4	0	0	0	0	0
118pv	0	9.1	9.0	16.7	49.4	12.9	2.1	0.9													
119	0	4.5	0	25.1	29.9	16.1	8.5	2.9	4.0	3.5	1.6	1.9	1.3	0.4	0	0.4	0	0	0	0	0

[1]Detailed sieve and hydrometer analyses were not done for pavement samples (indicated by pv). For sample DRsed-108, one rock larger than 180 mm was present in the sample area but was too large to weigh.

Table C-2. Shape and roundness of the sampled sediment by size fraction[1]

Sample	[2]Material Retained by Sieve Size (mm)															
	180		128		90		63		32		16		8		Pan (<8)	
	Roundness[3]	Shape[4]	Roundness	Shape	Roundness	Shape	Roundness	Shape	Roundness	Shape	Roundness	Shape	Roundness	Shape	Roundness	Shape
DRsed-101	--	--	SR	Disc	SR, SA	Sphere, Disc	SR, SA	Disc [Sphere]	SR, SA	Mixed	SR, SA, A	Disc, Blade	SA, SR, A	Blade	SA, SR	nd.
DRsed-102	--	--	--	--	--	--	A-R	Sphere [Disc]	SA-R [A, WR]	Mixed	SA, SR	Mixed	SA, SR [A, R]	Blade, Disc	SA, SR	Blade, Disc
DRsed-103	--	--	--	--	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.	nd.
DRsed-104	--	--	--	--	nd.	nd.	SR, SA	Sphere, Blade	SA-R	Blade, Sphere	A-R	Blade, Sphere	SA, SR [A]	Blade	A, SA	Disc, Blade
DRsed-105	--	--	--	--	SR	Sphere	SR	Disc	SR, R [WR, SA]	Disc [Sphere]	SA-WR	Blade, Sphere	A-WR	Blade, Sphere	nd.	nd.
DRsed-106A	--	--	SR	Disc	SR, R	Disc	SR	Disc	SA-WR	Mixed	SR-WR [SA, A]	Mixed	SA-WR	Blade, Disc	nd.	nd.
DRsed-106B	SR	Disc, Sphere	SR	Disc	SR	Disc [Blade]	SA-R	Mixed	A-R	Disc [Blade]	A-WR	Mixed	A-R	Blade [Disc]	nd.	nd.
DRsed-107	SR	Disc (Broken)	SR, R	Disc, Sphere	SA, SR	Disc [Sphere, Blade]	SA-R	Mixed	A-R	Mixed	SA-SR	Disc [Blade]	SA-SR	Disc [Sphere, Blade]	nd.	nd.
DRsed-108	--	--	SR	Disc	SR	Disc	SA, SR	Sphere, Disc	SR, R	Disc, Blade	SA-R	Blade, Disc	SR, R	Mixed	nd.	nd.
DRsed-108 (Pavement)	--	--	--	--	SR	Sphere	SA-R	Disc, Sphere	A-R	Mixed	SA-SR	Disc [Blade]	SA, SR	Blade, Disc	nd.	nd.
DRsed-109	--	--	SR-A	(Broken fragment)	R, SR	Sphere	SR, R [WR]	Sphere [Blade]	SA-R	Mixed	SA-WR	Mixed	A-SR	Mixed	A, SR	Mixed

Table C-2. Shape and roundness of the sampled sediment by size fraction[1] (Cont.)

Sample	[2]Material Retained by Sieve Size (mm)															
	180		128		90		63		32		16		8		Pan (<8)	
	Round-ness[3]	Shape[4]	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape
DRsed-109 (Pave-ment)	--	--	--	--	SR	Sphere	SA, SR	Sphere	SR, R [SA]	Blade, Sphere	SR, SA	Sphere, Blade	SA, SR [A]	Blade [Disc, Sphere]	SA, A [SR]	Blade
DRsed-110	--	--	--	--	SR, R	Mixed	SA-R	Mixed	SA-R	Blade [Sphere, Disc]	SA-R	Blade, Disc [Sphere]	SA, SR	Blade, [Disc, Sphere]	nd.	nd.
DRsed-110 (Pave-ment)	R	Sphere	SR-R	Disc, Sphere	A-R	Sphere [Blade]	SA-R	Disc [Blade, Sphere]	A-R	Disc [Blade, Sphere]	SA-R	Blade, Sphere [Disc]	A-SR	Disc, Blade	nd.	nd.
DRsed-111	A	Disc (Broken)	SA	Disc, Blade	SR [SA, R]	Disc, Blade [Sphere]	SR, R	Sphere, Disc	SA-R	Disc, Blade [Sphere]	SA-WR	Mixed	SA-R	Disc [Blade, Sphere]	nd.	nd.
DRsed-112	--	--	R	Blade	--	--	SA-R	Sphere [Blade, Disc]	SA-R	Mixed	SA-R	Disc, Blade [Sphere]	SA-R	Mixed	nd.	nd.
DRsed-114	--	--	SR	Disc	SR, R	Sphere	SR	Blade [Disc, Sphere]	SA-WR	Mixed	A-SR	Disc [Blade]	SR-A	Blade, Disc	nd.	nd.
Drsed-114 (Pave-ment)	--	--	SR	Disc	SA-SR	Sphere	SA-R	Sphere, Disc	SA-R	Mixed	A-R	Mixed	A-SR	Disc, Blade	A-SR	Blade, Disc
DRsed-115	--	--	SR	Blade	SR, R	Disc, Sphere [Blade]	SA-WR	Disc, Sphere [Blade]	SA-R	Mixed	SA-R	Mixed	A-R	Blade, Disc [Sphere]	nd.	nd.
DRsed-116	--	--	--	--	SR	Sphere	SR, R	Mixed	SR-WR [SA]	Mixed	SR-R [SA, WR]	Mixed	SA, SR	Disc, Blade [Sphere]	nd.	nd.

Table C-2. Shape and roundness of the sampled sediment by size fraction[1] (Cont.)

Sample	[2]Material Retained by Sieve Size (mm)															
	180		128		90		63		32		16		8		Pan (<8)	
	Round-ness[3]	Shape[4]	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape	Round-ness	Shape
DRsed-117	--	--	--	--	--	--	--	--	SA-WR	Disc [Blade, Sphere]	SA-WR	Disc, Blade [Sphere]	SA-WR	Blade, Disc	nd.	nd.
DRsed-118	SR	Sphere	SR	Sphere, Disc	SR-R	Mixed	SA-R	Disc, Sphere	SA-R	Disc [Blade]	SA-R	Mixed	SA, SR	Blade, Disc	nd.	nd.
DRsed-118 (Pave-ment)	--	--	R	Sphere	R [SR]	Sphere, Disc	SR-R	Mixed	SA, SR [R, WR]	Blade [Disc, Sphere]	SA, SR	Disc, Blade	SA, SR [A]	Disc, Blade	nd.	nd.
DRsed-119	--	--	SR	Disc (Broken)	--	--	SA-WR	Disc, Sphere [Blade]	SA-WR	Mixed	SA-WR	Mixed	SA-R	Blade [Disc]	nd.	nd.

[1]Properties were visually estimated from subsamples of the various sizes after the sample was passed through a set of sieves. Properties are listed in order of predominance with more common properties first. A property that is not listed may be present, but as a lesser proportion of the subsample. An entry of mixed under shape means that all three shapes are present in approximately equal proportions. Properties that are shown in brackets are relatively minor.

[2]A dash indicates that material of that size was not present in the sample. An entry of nd. indicates that sediment properties were not recorded for that subsample.

[3]Abbreviations for roundness are A, angular; SA, subangular; SR, subrounded; R, rounded; WR, well rounded. A comma separating properties indicates that both properties shown are present. A dash separating properties indicates that the subsample includes particles with roundness between the two endpoints shown as listed in the abbreviations. For definitions of roundness, see Briggs (1977, p. 120).

[4]Shapes are subdivided into three general categories. Blade is long and flat, similar to a knife blade. Disc is rounded and flat, similar to a pancake. Sphere is rounded in all directions, similar to a baseball. For definitions, see Briggs (1977, p. 114).

Table C-3. Particle diameter distribution for the sediment size data

Sample (DRsed-)	Particle Size (mm)[1]					
	D-16	D-35	D-50	D-65	D-84	D-90
101	8.22	34.62	52.11	78.10	115.25	130.00
102	2.73	9.82	17.19	27.20	49.57	63.34
103	1.91	8.09	14.14	19.77	30.40	34.39
104	1.83	10.33	23.60	37.36	58.72	71.59
104pv	52.64	70.64	78.78	87.85	110.12	122.99
105	1.10	2.83	6.42	14.00	37.27	61.74
106A	3.65	14.02	27.69	47.63	99.71	118.08
106B	2.28	13.36	30.82	83.40	135.86	141.21
107	16.82	63.80	91.53	129.43	155.03	168.79
108	0.94	3.91	15.88	37.90	93.15	131.89
108pv	32.35	44.54	54.50	65.23	79.26	86.88
109	8.86	32.72	51.29	75.18	104.42	116.27
109pv	21.39	33.53	41.44	51.21	70.59	81.24
110	3.17	26.92	43.61	63.71	91.64	95.93
110pv	59.09	85.91	102.34	120.19	153.87	172.67
111	4.96	23.01	47.75	94.24	127.48	170.45
112	16.56	35.04	45.79	59.84	80.94	129.42
114	4.14	25.99	51.84	83.15	131.89	137.64
114pv	28.27	43.34	56.93	71.15	97.34	114.04
115	9.61	38.03	60.74	77.95	101.39	111.23
116	3.91	16.88	27.89	38.59	58.03	68.77
117	1.13	4.78	10.12	16.76	32.13	35.23
118	10.43	34.96	55.39	85.30	150.68	179.38
118pv	32.13	43.21	52.11	62.83	96.18	122.42
119	8.08	25.64	39.49	55.34	72.58	79.27

[1]Values were calculated using a FORTRAN program written by T.J. Randle (Bureau of Reclamation, D-8540, Denver, Colorado).

Table C-4. Percent of sample less than 0.85 mm

Locality[1]	Percent Finer Than 0.85 mm[2]
DRsed-101	8.8
DRsed-102	12.0
DRsed-103	15.0
DRsed-104	15.5
DRsed-105	24.8
DRsed-106A	10.8
DRsed-106B	10.9
DRsed-107	7.1
DRsed-108	25.1
DRsed-109	9.0
DRsed-110	12.8
DRsed-111	9.1
DRsed-112	8.6
DRsed-114	10.8
DRsed-115	8.3
DRsed-116	10.6
DRsed-117	21.0
DRsed-118	9.5
DRsed-119	7.4

[1]Because sieve and hydrometer analyses were not done for pavement samples, the less-than-0.85-mm fraction could not be calculated for them.

[2]Values were calculated using measured sediment data from sieve and hydrometer analyses and a FORTRAN program written by T.J.Randle (Bureau of Reclamation, Sedimentation and River Hydraulics Group, D-8540, Denver, Colorado)

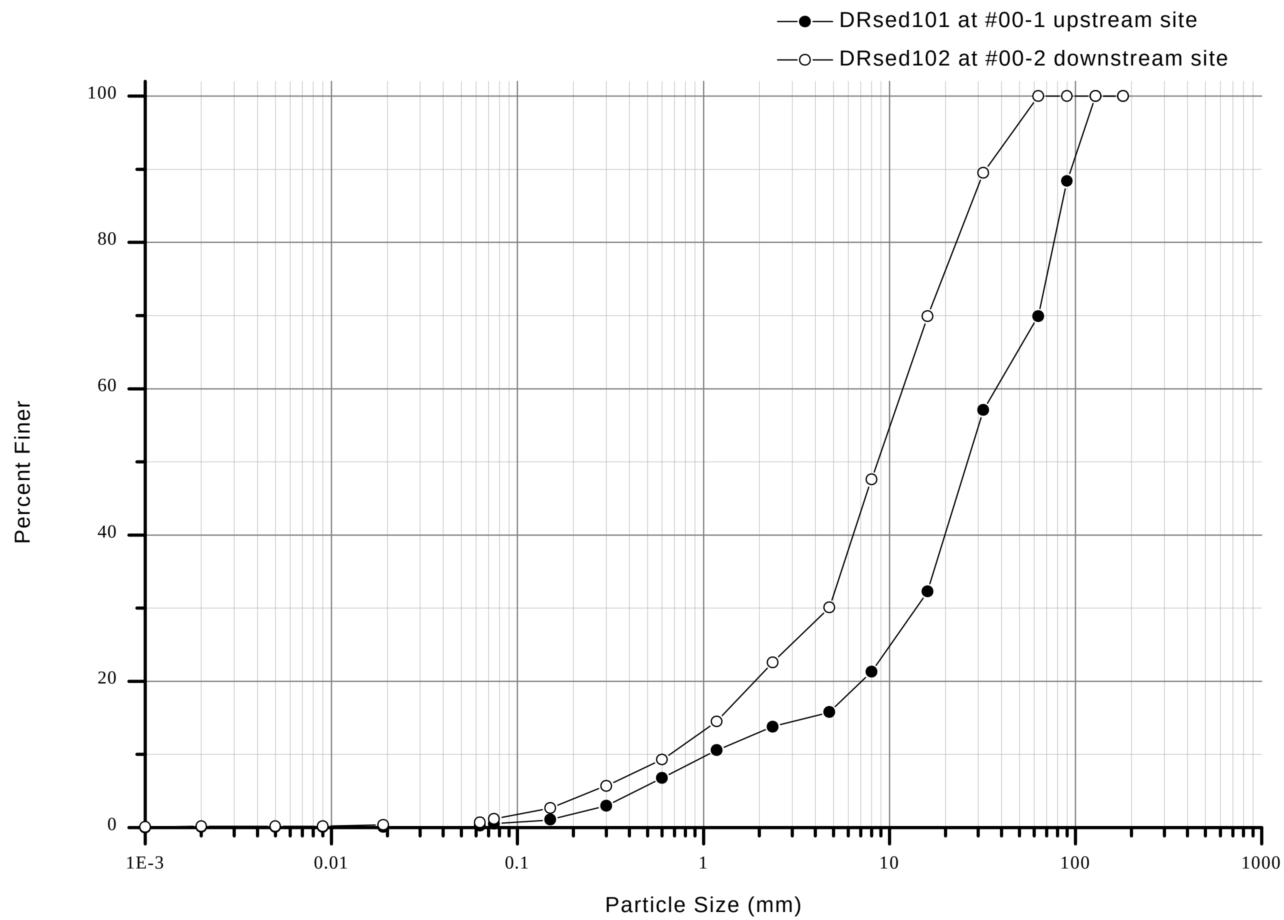


Figure C-1. Distribution plot for particle gradation for samples at East Crossing Campground (DRsed-101 and DRsed-102).

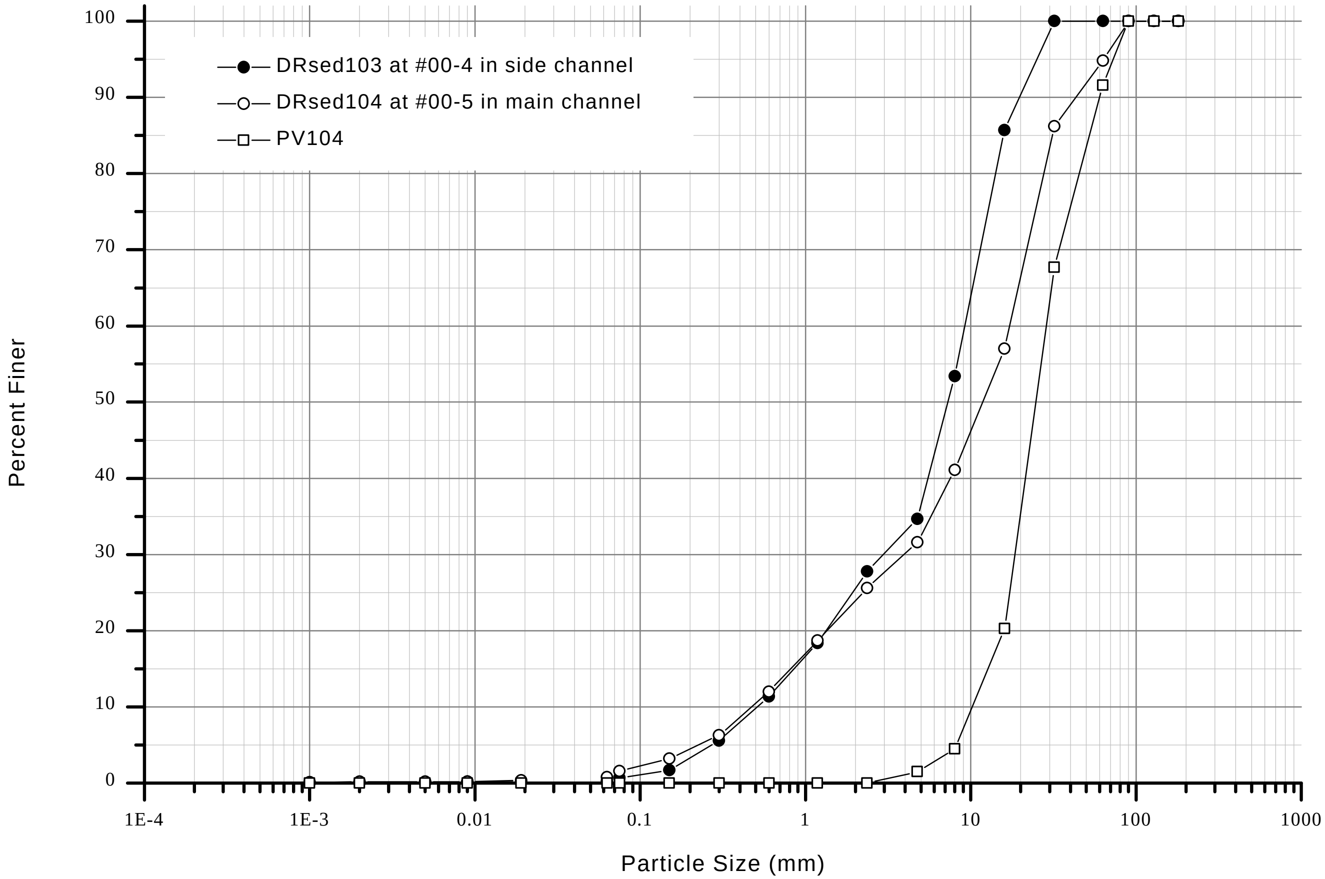


Figure C-2. Distribution plot for particle gradation for samples near the confluence of the Gray Wolf and Dungeness Rivers (DRsed-103 and DRsed-104).

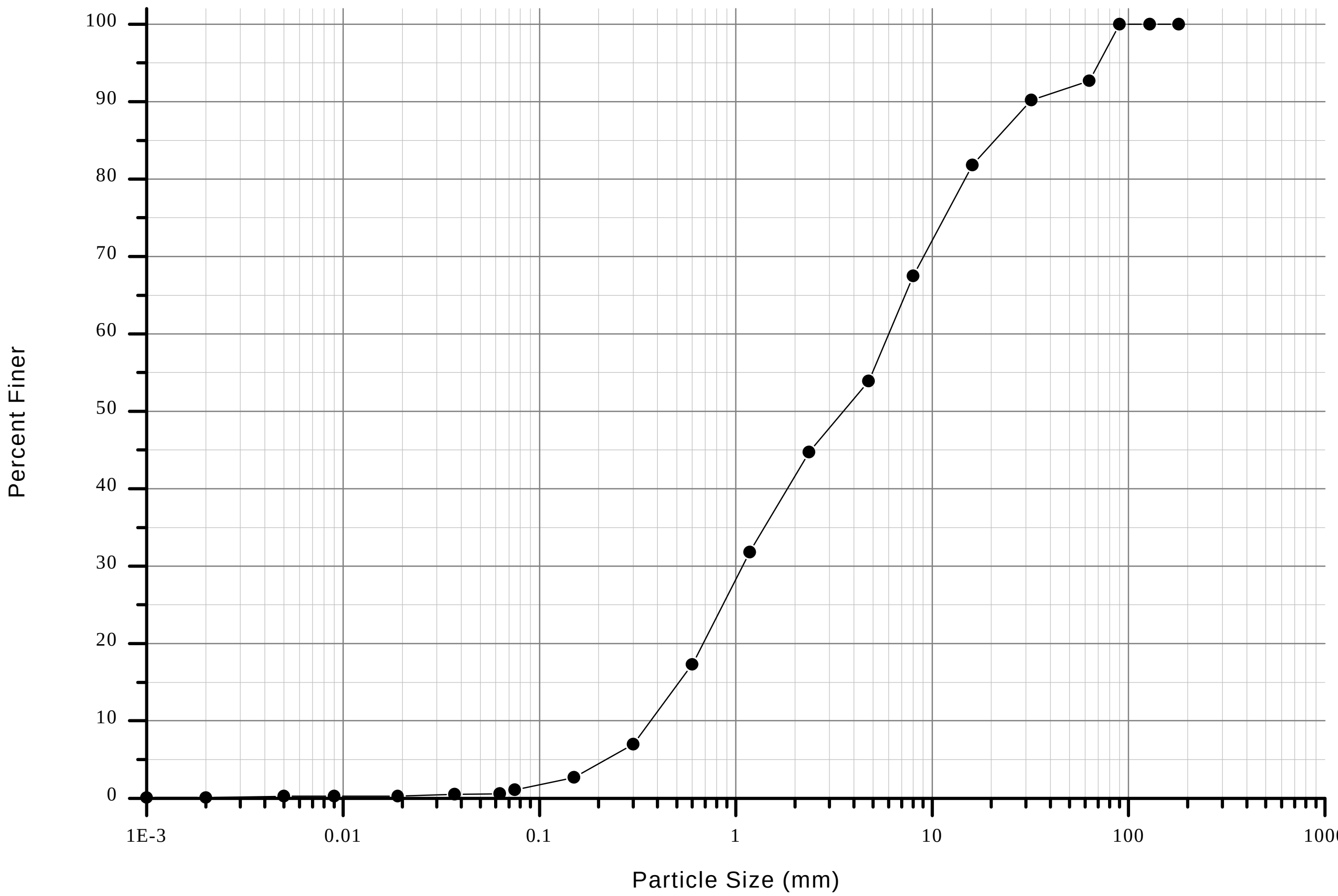


Figure C-3. Distribution plot for particle gradation for the samples at the USGS gaging station (DRsed-105).

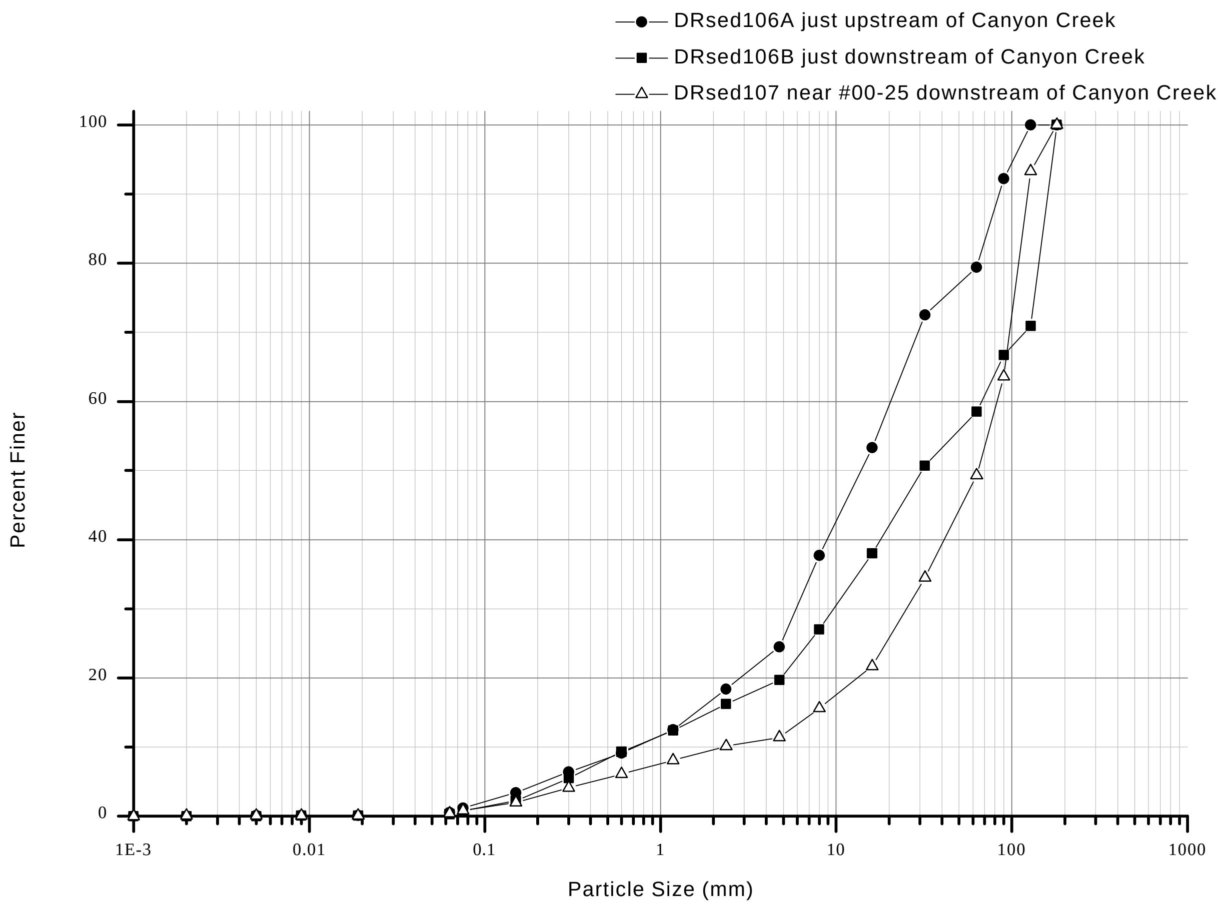


Figure C-4. Distribution plot for particle gradation for samples near Canyon Creek and the Dungeness Fish Hatchery (DRsed-106A, DRsed-106B, and DRsed-107).

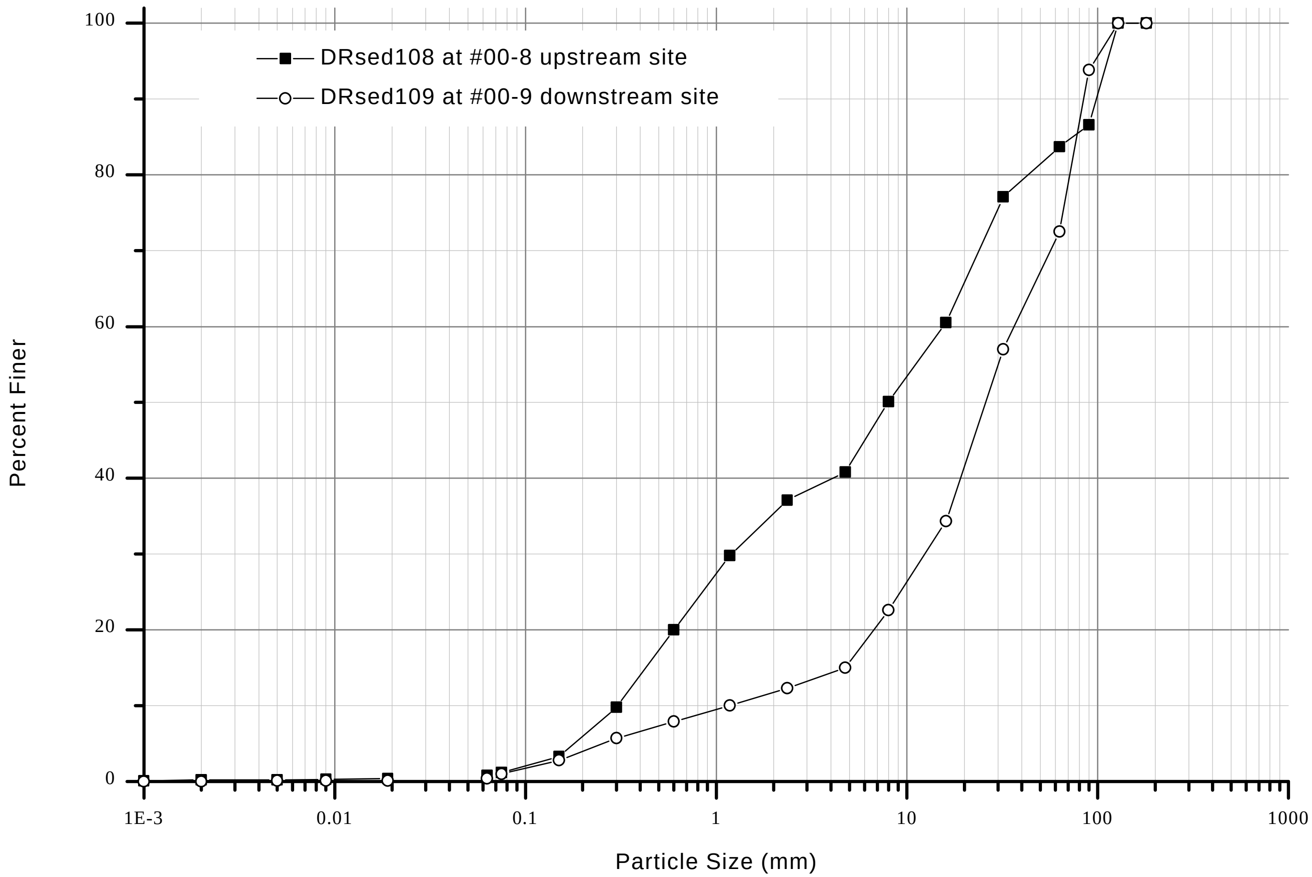


Figure C-5. Distribution plot for particle gradation for samples near Cline-Clallam Irrigation Diversion (DRsed-108 and DRsed-109).

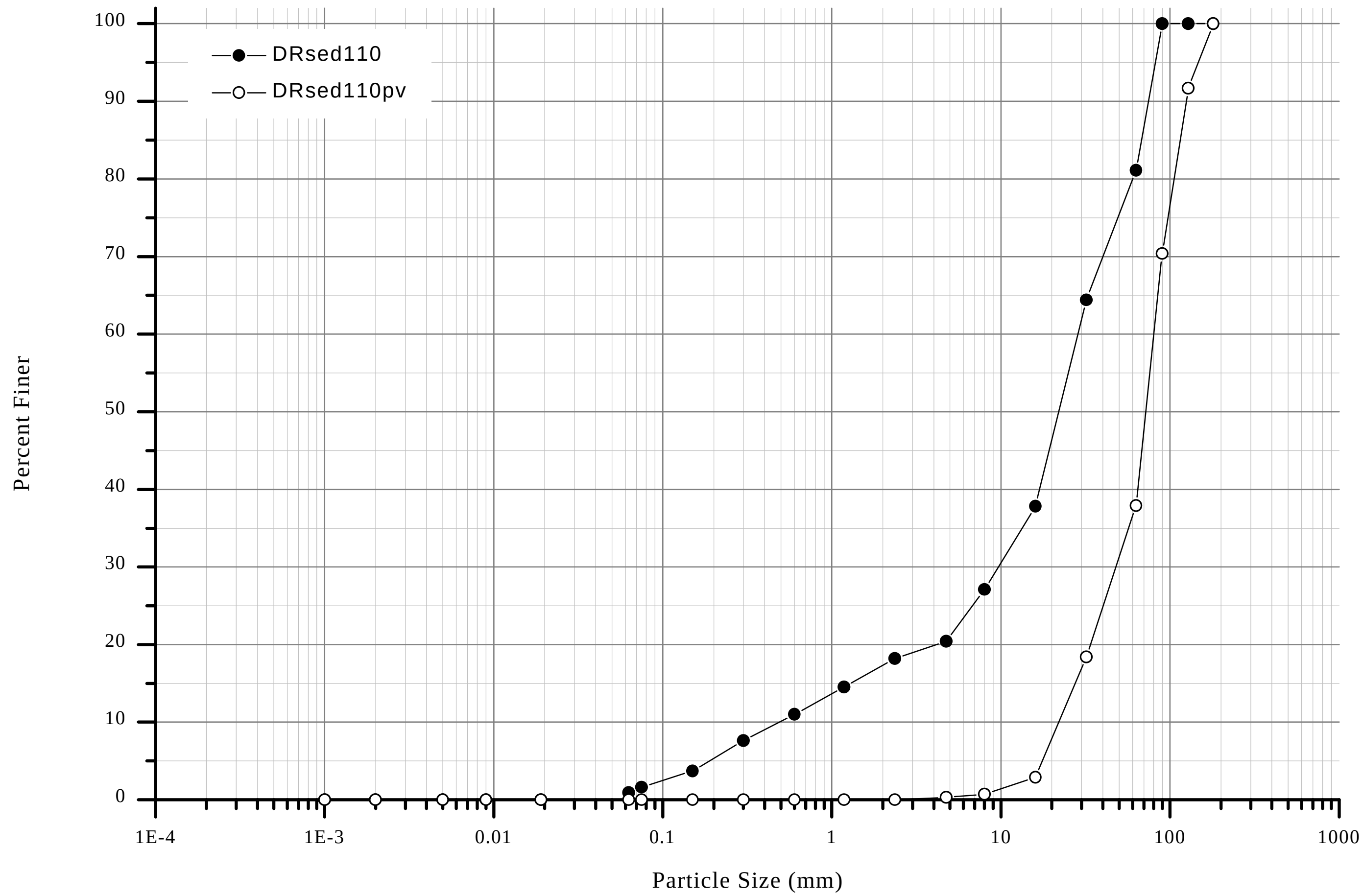


Figure C-6. Distribution plot for particle gradation for sample at Railroad Bridge Park (DRsed-110).

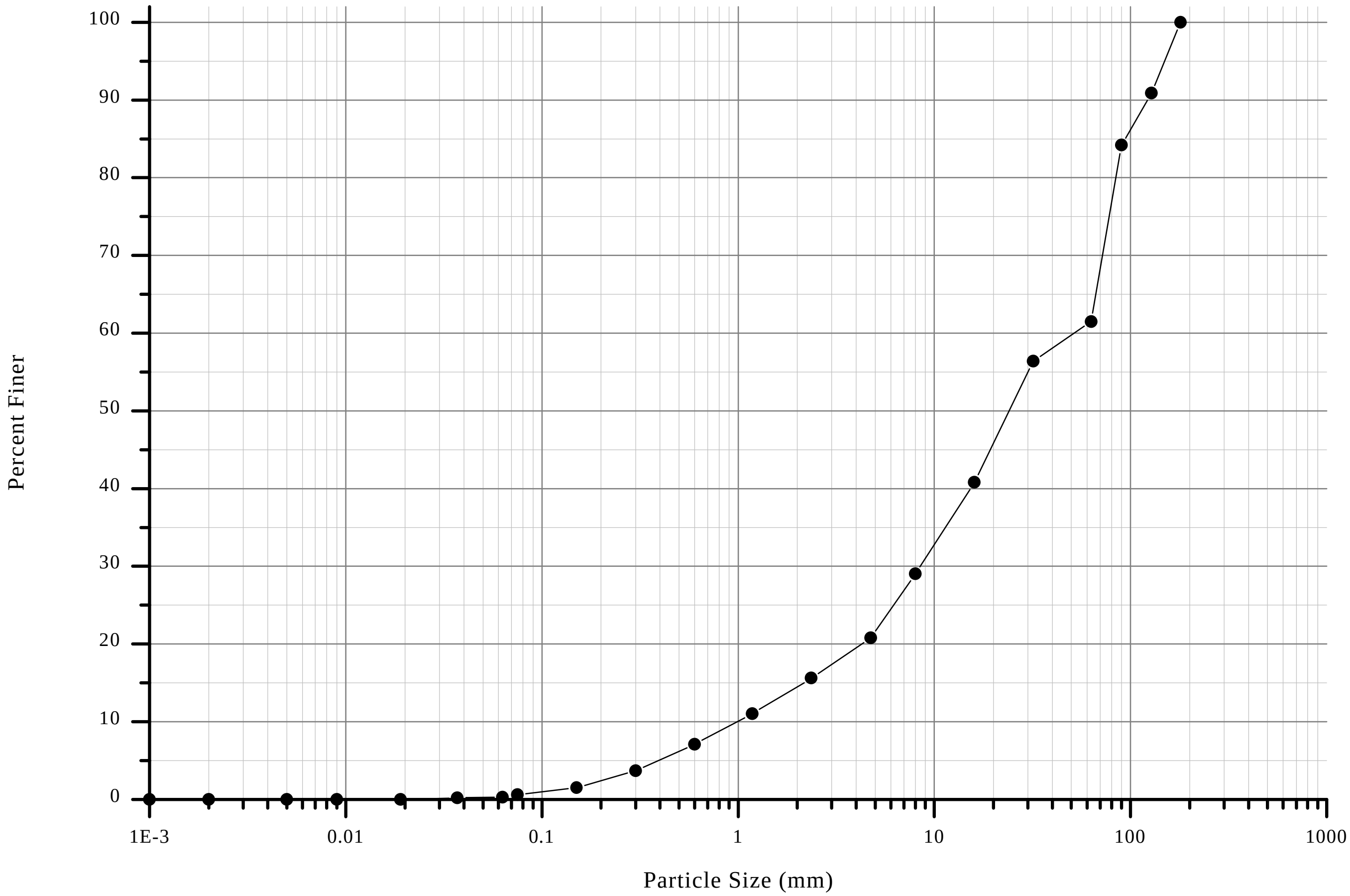


Figure C-7. Distribution plot for particle gradation for a sample near the Severson Property (DRsed-111).

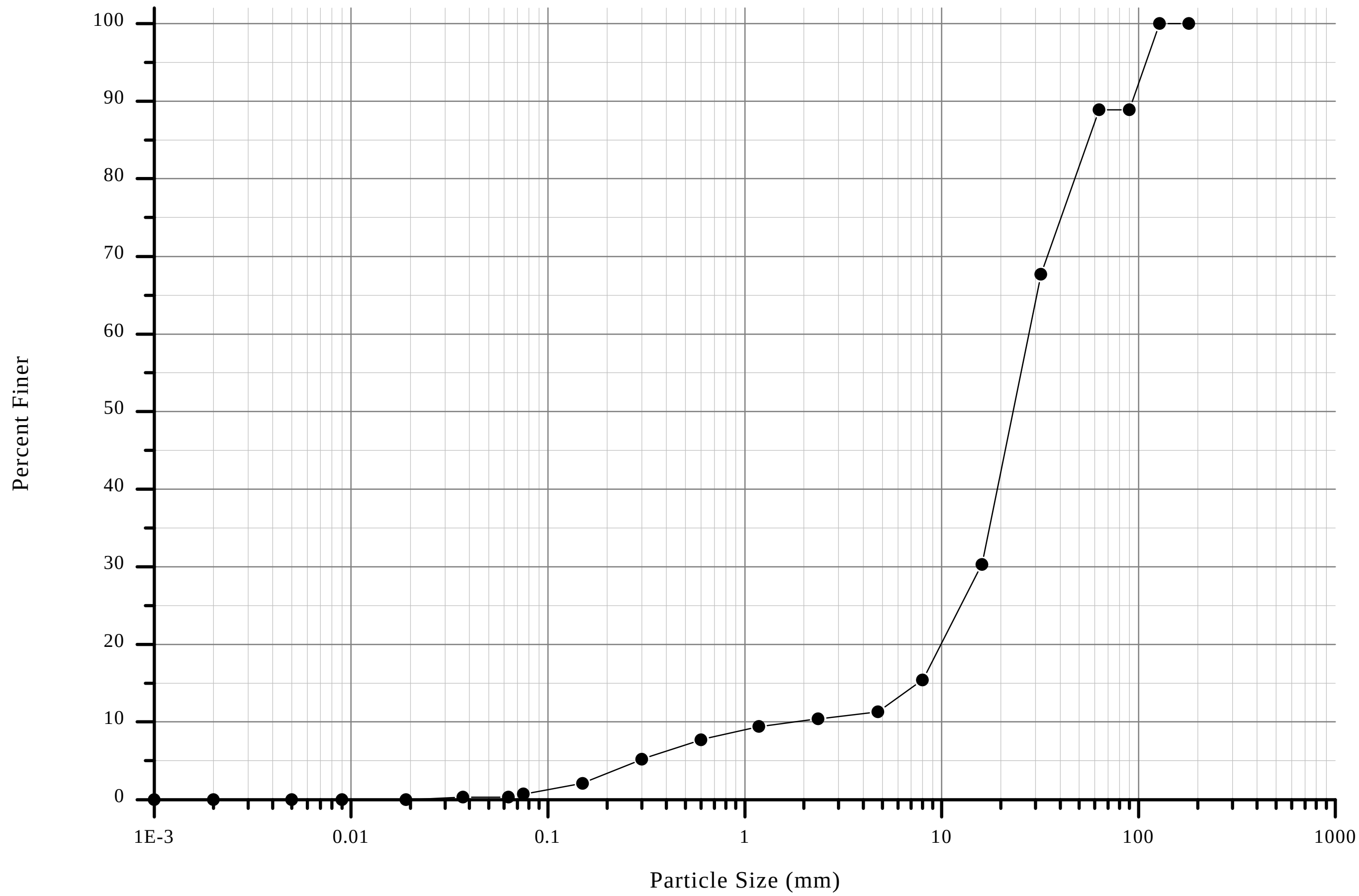


Figure C-8. Distribution plot for particle gradation for a sample near the Severson Property (DRsed-112).

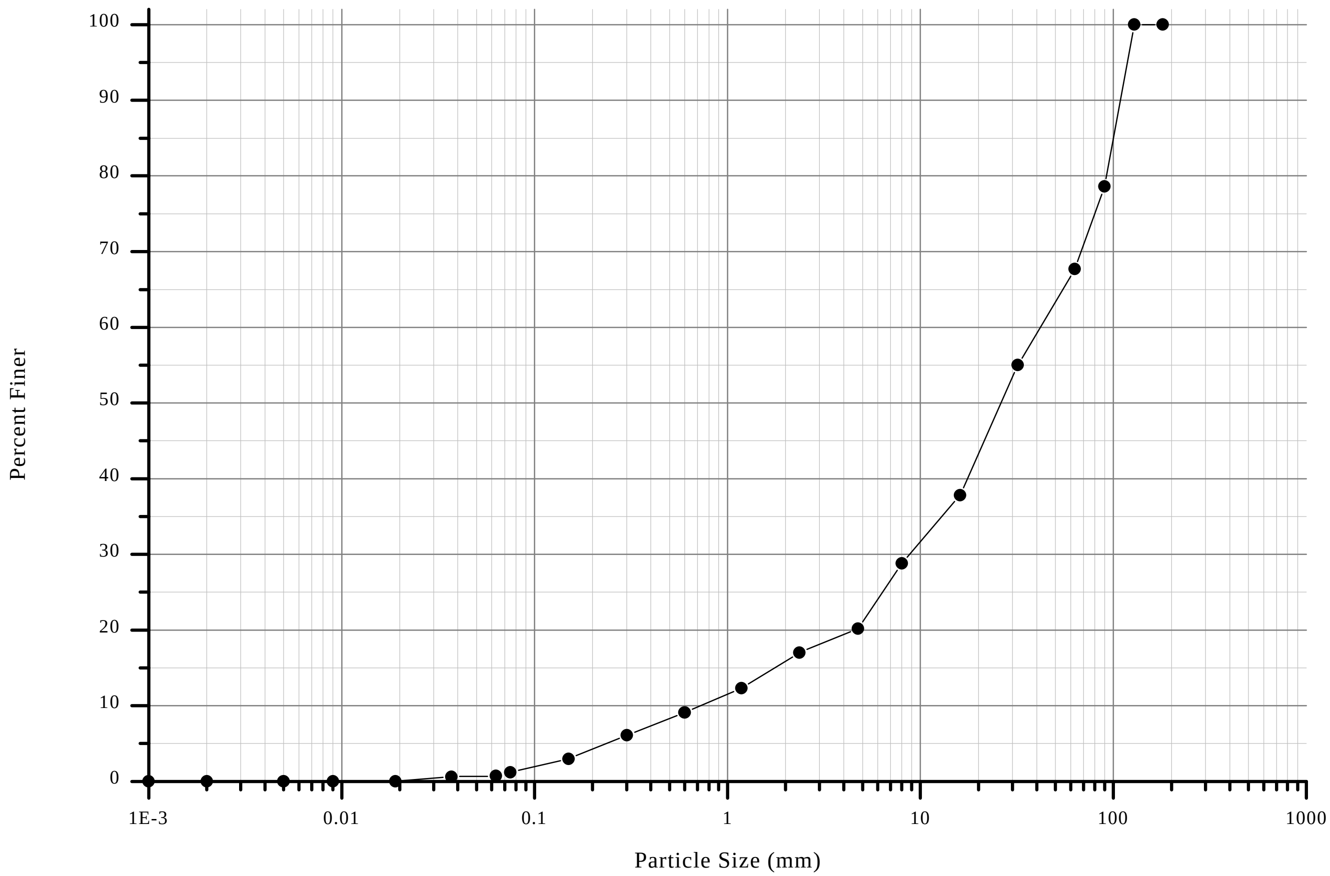


Figure C-9A. Distribution plot for particle gradation for a sample near the Clallam County Parks along Ward Road (DRsed-114).

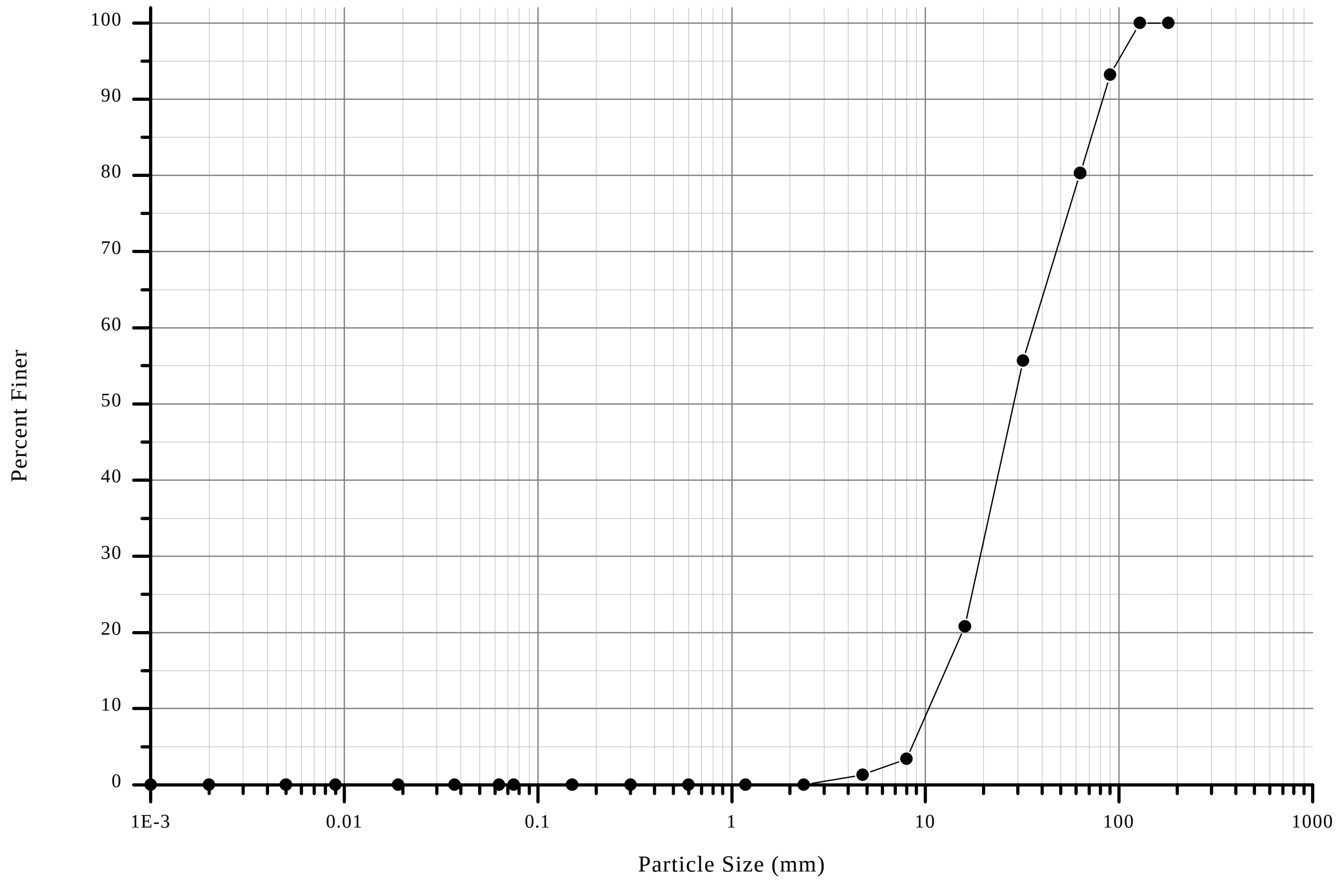


Figure C-9B. Distribution plot for particle gradation for a pavement sample near the Clallam County Parks along Ward Road (DRsed-114pv).

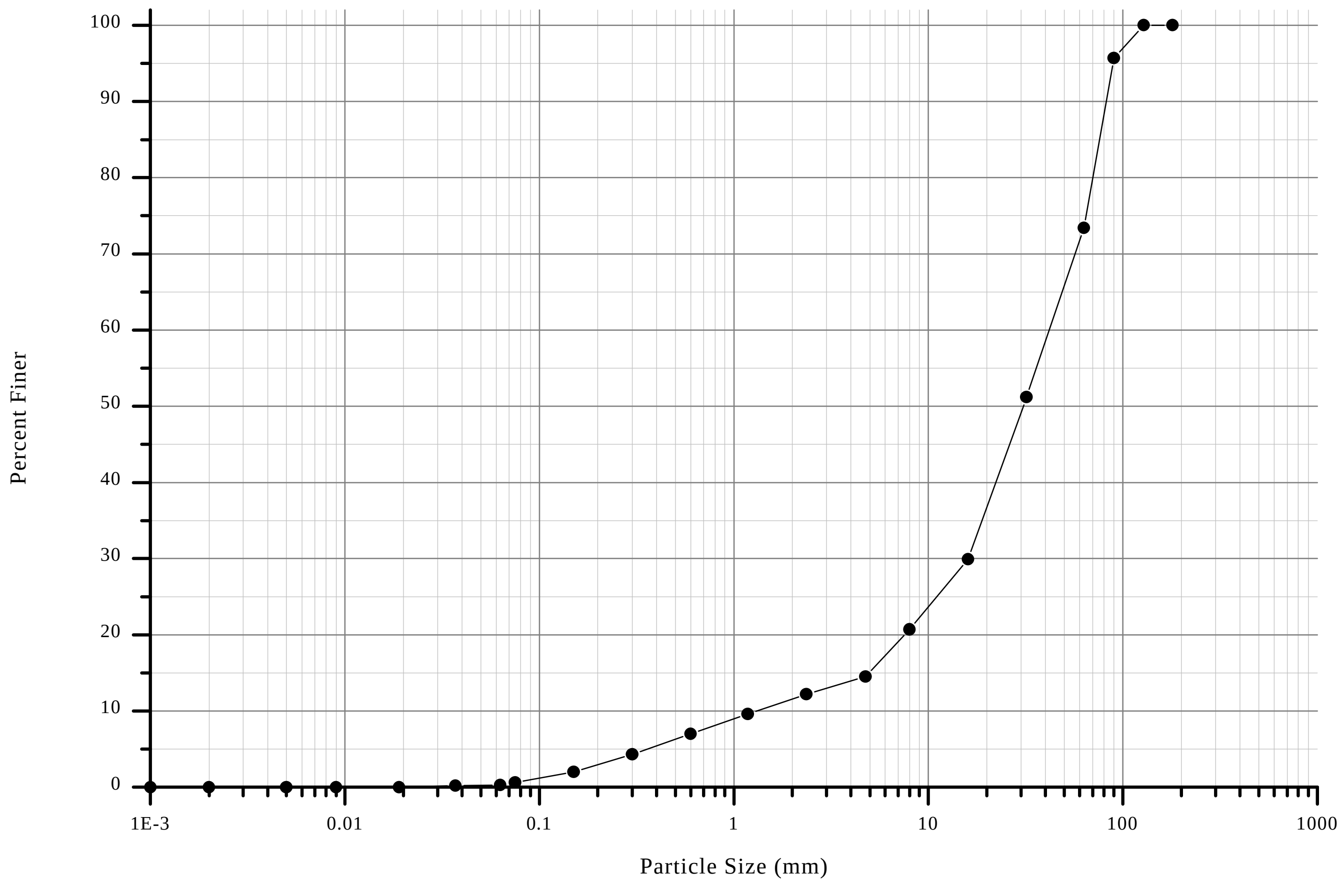


Figure C-10. Distribution plot for particle gradation for a sample near the Clallam County Parks along Ward Road (DRsed-115).

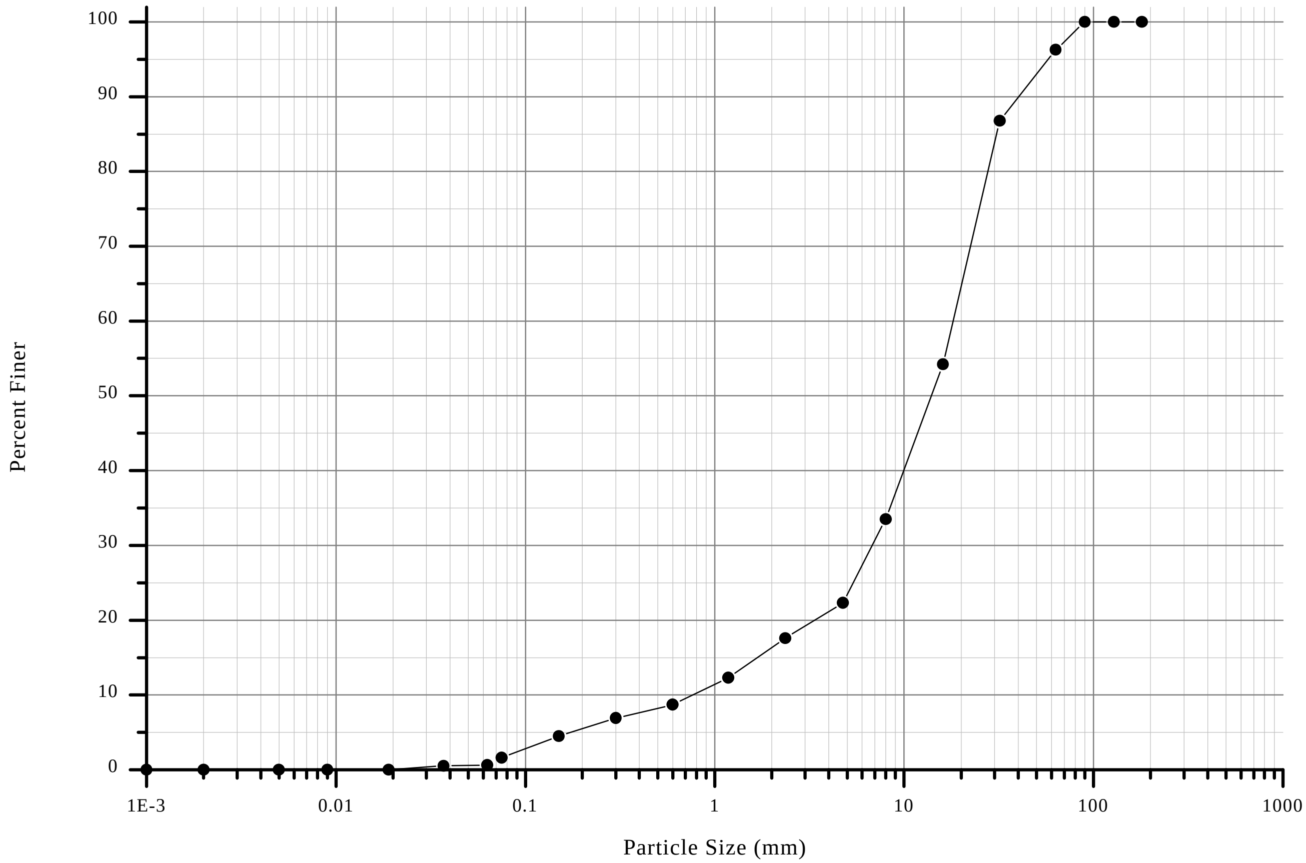


Figure C-11. Distribution plot for particle gradation for a sample near the Army Corps of Engineers and Beebe Levees (DRsed-116).

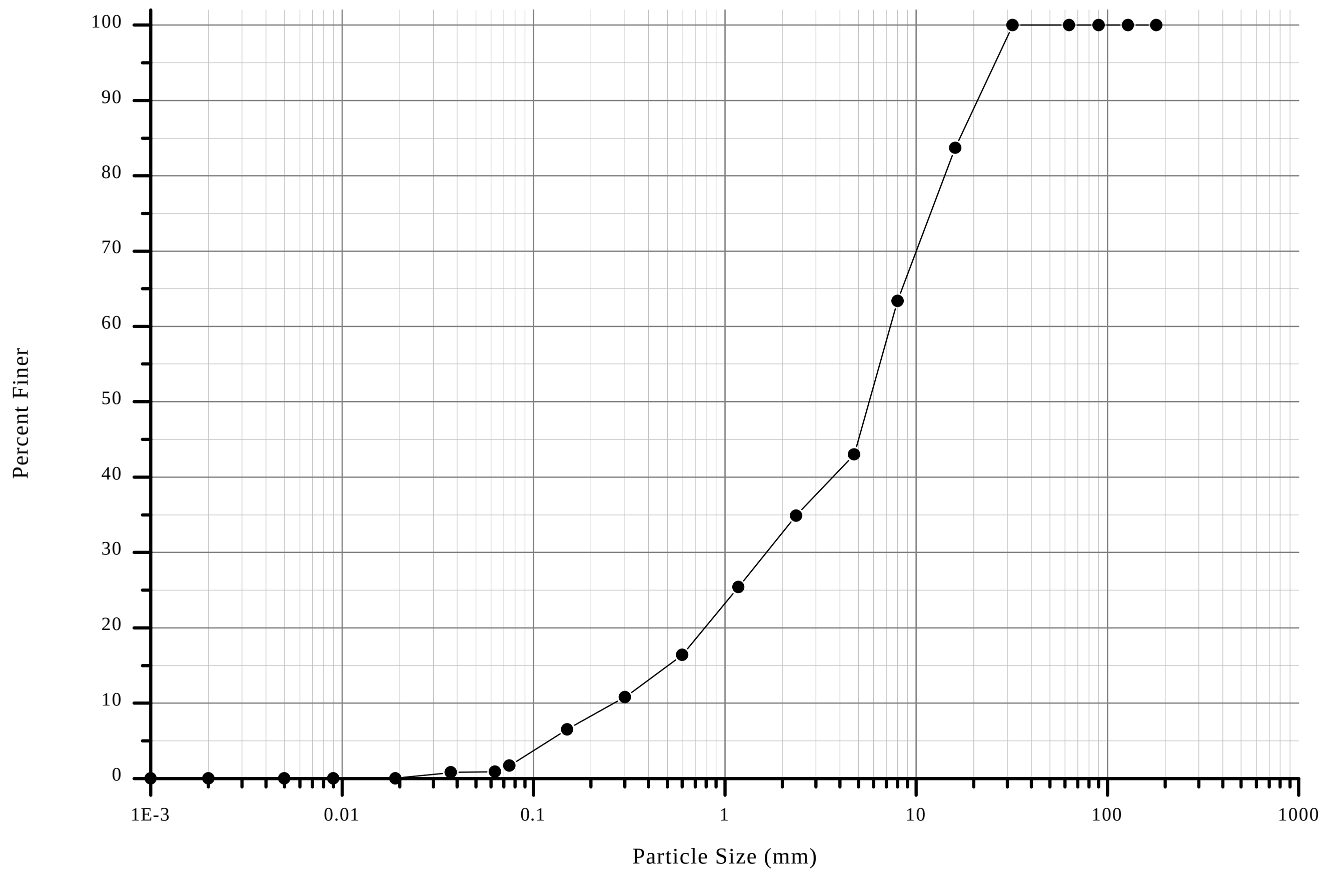


Figure C-12. Distribution plot for particle gradation for a sample near the Army Corps of Engineers and Beebe Levees (DRsed-117).

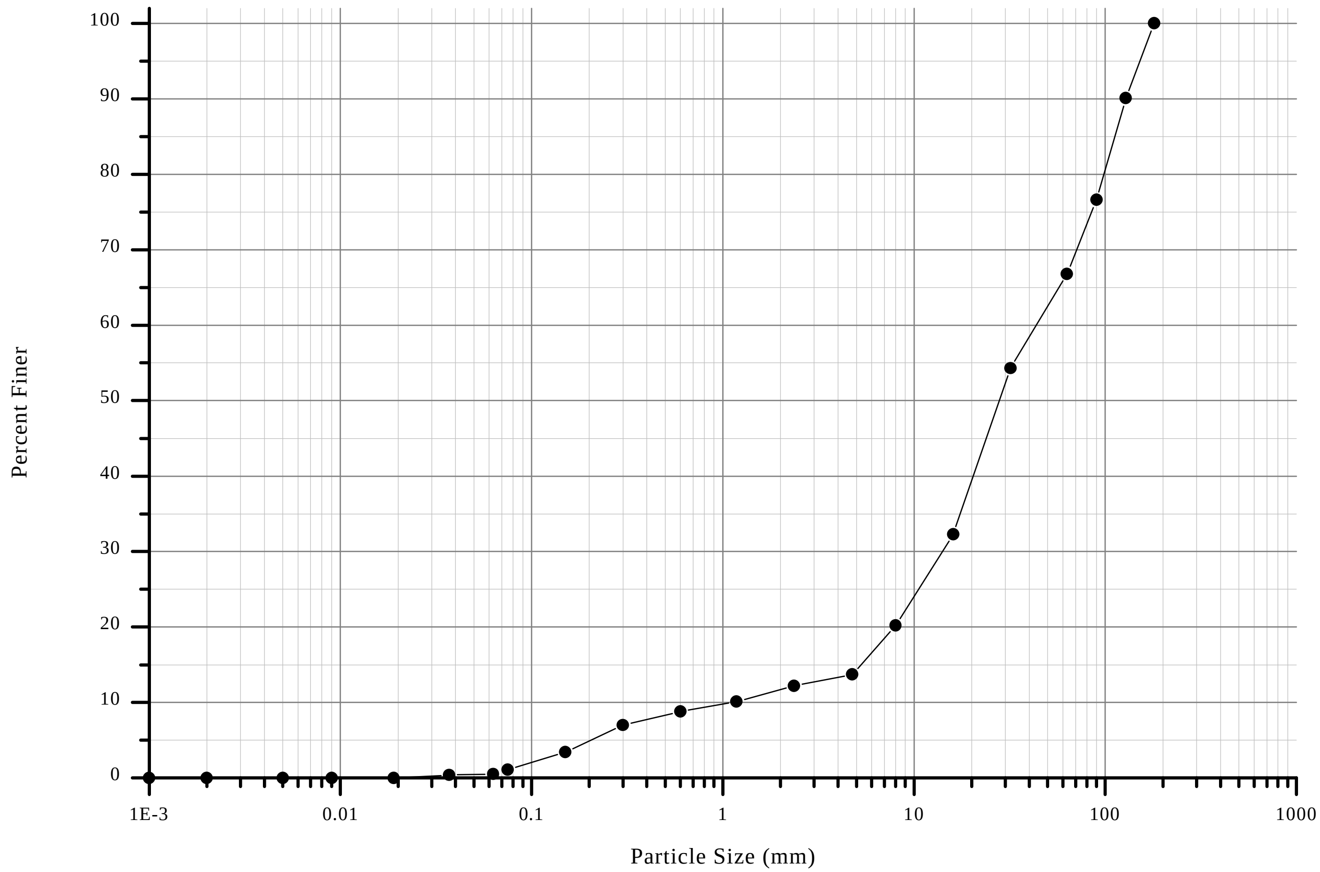


Figure C-13A. Distribution plot for particle gradation for a sample near the Army Corps of Engineers and Beebe Levees (DRsed-118).

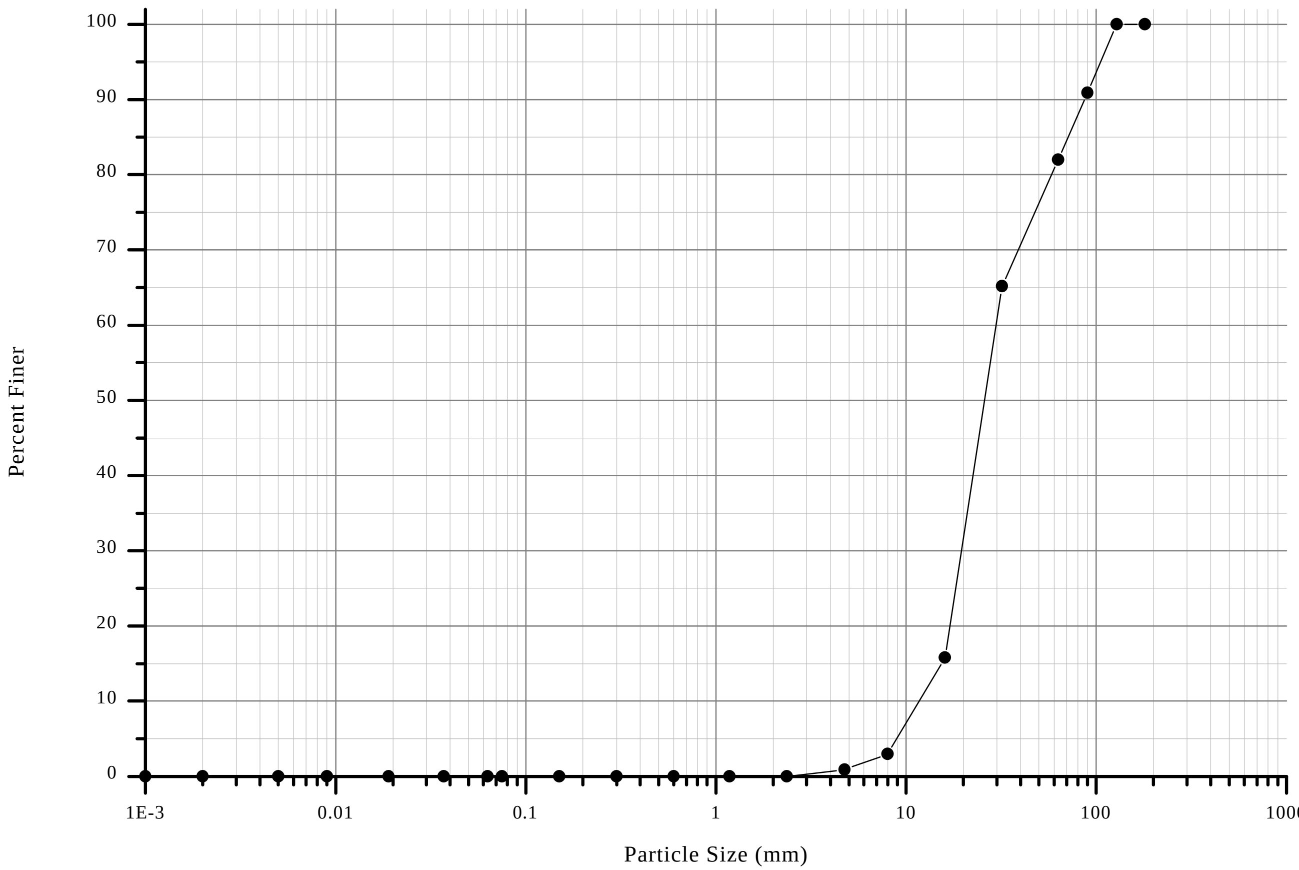


Figure C-13B. Distribution plot for particle gradation for a pavement sample near the Army Corps of Engineers and Beebe Levees (DRsed-118pv).

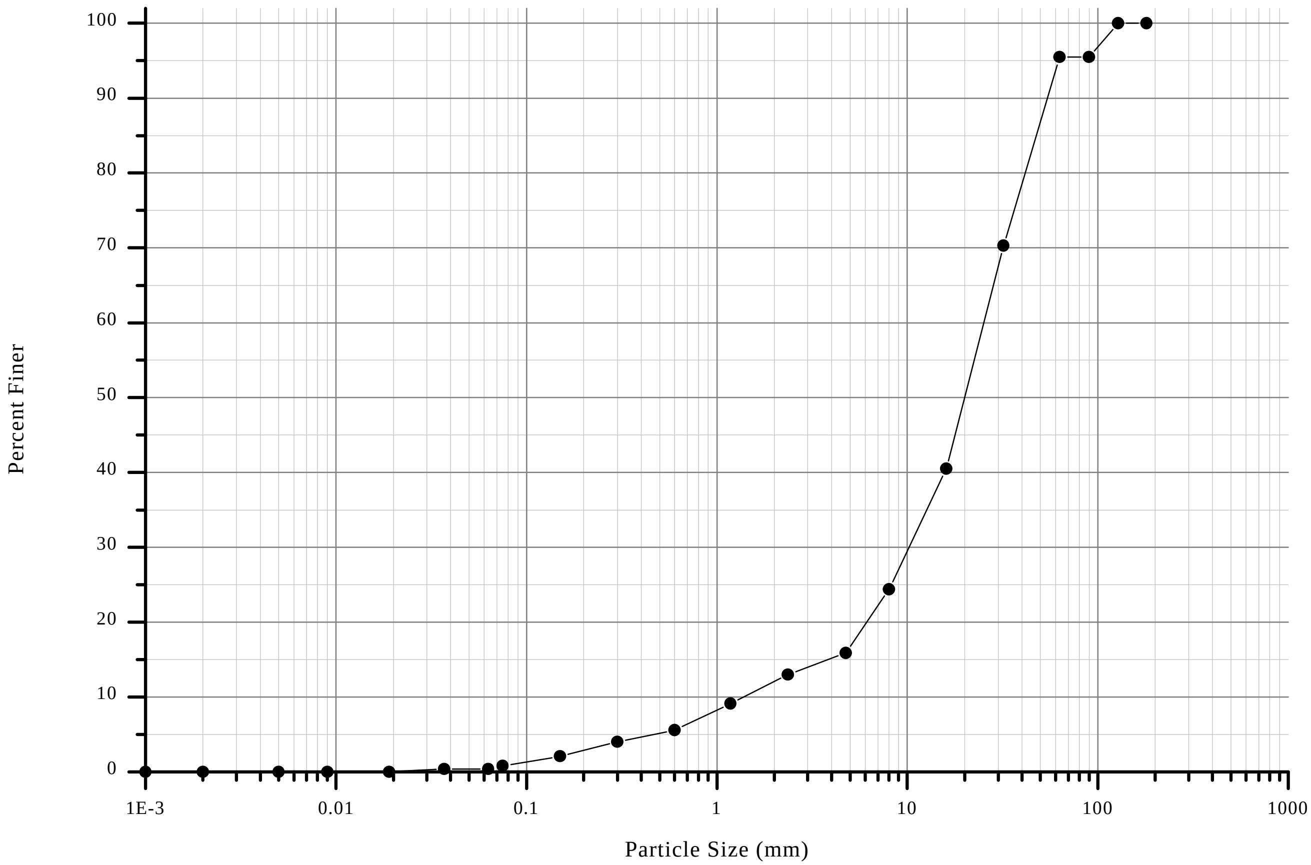


Figure C-14. Distribution plot for particle gradation for a sample near the Army Corps of Engineers and Beebe Levees (DRsed-119).

APPENDIX O

Geomorphic Mapping of the Dungeness River Corridor

APPENDIX O.
GEOMORPHIC MAPPING OF THE DUNGENESS RIVER CORRIDOR

Appendix O: Tables

Appendix O: Figures

Reach 3:

Reach 2:

Reach 1:

Figure O-29. Active channels mapped from aerial photographs taken in 1942/43, 1965, and 2000 for Reach 1 (RM 2.6 to 0). Channels are shown on a mosaic of ortho-photographs taken in 2000. Labels beginning with R indicate localities discussed in the text and tables.

Figure O-30. Active channels, side channels, and overflow channels mapped from aerial photographs taken 1942/43 and 1965 for Reach 1. Channels are shown on a mosaic of ortho-photographs taken in 2000. Differences in the side and overflow channels may reflect their expression rather than changes in the channels.

Figure O-31. Woody debris in the active channel and side channels for Reach 1. Both large stacks of wood and single logs that are visible on aerial photographs taken in 2000 are shown.

Figure O-32. Woody debris in the active channel and side channels for Reach 1. Both large stacks of wood and single logs visible on aerial photographs taken in 1965 are shown.

Figure O-33. Active channel and the boundaries of the present, prehistoric, and geologic floodplains interpreted for Reach 1 from aerial photographs taken in 1942/43, 1965, and 2000. Boundaries are dashed where approximately located and dotted where unclear.

Figure O-34. Human-constructed features and areas of human activities in and near the active channel for Reach 1. Features were mapped from a mosaic of ortho-photographs taken in 2000.

Figure O-35. Active channel that was mapped from aerial photographs taken in 2000 for Reach 1 shown on aerial photographs taken in 1942/43. Note the similarity in the locations of the active channels in the two years.

APPENDIX O.
GEOMORPHIC MAPPING OF THE DUNGENESS RIVER CORRIDOR

Geomorphic mapping of the lower Dungeness River corridor was done to delineate channels of the river, geomorphic deposits within and adjacent to the present annually flooded channel, and man-made features and activities within the river corridor. The mapping included an attempt to discern the types and properties of the deposits related to the geomorphic surfaces and the relative ages of the channels, geomorphic surfaces, and geologic deposits. Absolute ages for some surfaces and deposits were obtained from radiocarbon dates on charcoal collected from the deposits (Appendices J and Q). The deposits in the river corridor were observed in the field at numerous locations and detailed descriptions were completed at nine localities (Appendix Q). In addition, historical changes in the river corridor, primarily created by human activities, have been incorporated into the mapping to discern, if possible, how these activities have affected the river processes.

The results of the geomorphic mapping were used to subdivide the lower Dungeness River corridor into reaches on the basis of differences in the characteristics of the river channel and associated deposits (Figure O-1; Section 8.2). The differences in the characteristics among the reaches may signal differences in the processes that are operating along the river. If processes differ along sections of the river, determining these differences and what causes them may help estimate how the river will react in the future to natural or man-induced changes to the river system. Such reactions likely vary among the reaches.

O.1. Mapping Units

Mapping units within the Dungeness River corridor consist mainly of two types: channels and alluvial deposits with their associated surfaces (Table O-1). Because changes in the channel patterns may be the best signal of changes in river processes, we concentrated our mapping and interpretation on the channels present on the 2000 ortho-photographs and on older (primarily 1942/43 and 1965) aerial photographs.

Channels

The present active, side, and overflow channels along the Dungeness River corridor were delineated using the 2000 ortho-photographs, primarily, along with some examination on the ground. Because of the dense tree cover outside of the active channel, which makes recognition of some channels on the aerial photographs difficult, some additional field mapping was used to locate the side channels and overflow channels.

The active channel includes the low-water channel, unvegetated bars, and sparsely vegetated bars (Table O-1). This is the channel that would carry water at higher flows when the most changes in the river likely occur. The sinuosity of the active channel is related to the channel slope and the sediment transported or deposited. Comparison of the sinuosity among the reaches at the three times of our aerial photographs (1942/43, 1965, and 2000) may suggest differences or changes in these channel characteristics (Section 7; Table O-2).

In addition to the active channel, side channels and overflow (flood) channels have been delineated on the 2000 ortho-photographs (Table O-1). A side channel is one that continuously carries surface water but is not part of the low-flow main channel. The side channels are usually relatively narrow, and both banks are often wooded. The side channels are at least partially concealed by the forest canopy making them difficult to discern on the aerial photographs. The side channels convey water and dissolved and suspended sediment, but little bedload (gravel). Coarser sediment is often filtered by woody debris or an open-work bar of gravel located near the upstream end of the side channel.

The overflow channels carry water and fine sediment only during the highest flood flows. They are often surrounded by low terraces that are wooded. They may be flooded annually or every few years.

Ages for the channels were estimated primarily on the basis of the expression of the channels on the aerial photographs taken in different years. The active channel and side and overflow channels were delineated on aerial photographs taken in 1942/43 and 1965, as well as those taken in 2000, in order to discern the historical changes in the Dungeness River corridor (Section 5.4). These changes include migration of the channels, erosion of banks, areas of deposition, major channel avulsions, and the growth or erosion of gravel bars. For example, in the section of Reach 3 near the Railroad Bridge, the active channel seems to have been especially unstable since 1942/43. Delineation of the portions of the banks that have eroded in this area in 1942/43, 1965, 1994, 1996, and 2000 shows the continued migration of the active channel (Figure 26). The volumes of material represented by the erosion were estimated using the Integraph software and the aerial photographs for the different years (Table O-3).

Estimation of the ages of channels that were active before the time recorded by the aerial photographs is more difficult, and has been interpreted, where possible, on the basis of geomorphic expression and vegetation type and density. Logging of parts of the floodplain means that vegetation can be used only as a tentative estimation of channel or surface age. These older channels are generally too old to be of concern for present management decisions.

Bars and Terraces

Alluvial deposits are differentiated on the basis of their geomorphic setting, the sedimentary characteristics of the deposits underlying them, and their relative ages. Alluvium is preserved in throughout the Dungeness River corridor (Table O-1). Channel alluvium, which is preserved mostly in bars, is primarily cobble and gravel in the upper part of the study reach; it is composed of sand with finer gravel near the mouth (Section 4.5; Appendix D). Limited areas of sand and silt also are present on some bars. The bars are composed mostly of sandy pebble and cobble gravel. Some include boulders. Boulders and cobbles are primarily rounded and well-rounded rock of mixed types. Deposits are poorly to moderately sorted.

The bars are subdivided first on the basis of their location within the active channel (Table O-1) and second on the basis of their vegetation type and cover. The differences in vegetation are assumed to reflect roughly the age of the bar or the frequency at which the surface is covered with water. The subdivisions are subjective and were determined by comparing bar surfaces on the aerial photographs. A gradation in vegetation type and density exists among the bars and other subdivisions are possible.

Unvegetated bars are preserved within the active channel and probably are reworked on an annual basis. These bars include abandoned channels and bar-and-swale topography. Vegetated bars are preserved in some overflow channels. The bars in the overflow channels are high enough that, although they may be covered with some flow on an annual basis, this flow is neither deep enough nor fast enough to uproot the vegetation and disturb the surface. The type and density of vegetation suggest that vegetated bars of up to three different ages exist along parts of the river corridor.

The alluvium in the terraces, where we have examined it, is composed of subrounded to well-rounded pebbles through boulders, sandy and silty sediment, or both. Where both are present, the finer sediment often overlies the gravelly alluvium. The gravelly deposits are poorly to moderately sorted and often include weak to well-defined bedding (Appendix Q). The fine-grained sediment on lower terraces in the lower portion of the river corridor appears to be primarily alluvium and is often up to 3 ft (1 m) thick (Appendix Q). The fine-grained sediment on higher terraces, especially those in the upper portion of the corridor (between RM 6.5 and RM 10.5), may be eolian (wind blown; Appendix I).

Terraces of a range of ages are preserved along all sections of the Dungeness River corridor. Higher, older terraces are more prevalent between RM 6.5 and RM 10.5; lower, younger terraces are more prevalent downstream. These terraces likely range in age from late or middle Holocene (a few hundred to a thousand years) to late Pleistocene (about 10,000 yr to about 12,000 yr).

Overbank Sediment

Fine sediment (sand, silt, and clay) is deposited when the river overtops its banks. These sediments are present in the upper parts of terrace deposits and on surfaces adjacent to the river channel (Appendix Q). These deposits have not been delineated on the maps shown in this appendix.

Woody Debris

Naturally deposited single logs or piles of logs are present within the active channel and some secondary channels. The woody debris, especially the large piles, provide salmon habitat (e.g., create pools, provide cover), are instrumental in the erosion and deposition of sediment (bars) in the active channel, and can direct flow patterns (e.g., filter large flows and sediment from side channels). Woody debris is visible on the aerial photographs, especially the ortho-photographs taken in 2000, which can be viewed stereoscopically. The woody debris that can be seen on the photographs has been mapped and its amount, location, and pattern are compared among the reaches (Section 8.1.4; Table O-4).

In addition, woody debris was mapped on the 1965 aerial photographs for most of the study reach in order to compare the locations and amounts of woody debris with those discerned from the 2000 aerial photographs. Although it appears that, in general, there was less woody debris in the active channel in 1965 than in 2000, the quality of the older photographs and the inability to view the photographs stereoscopically may account for the difference.

Floodplain Boundaries

Using the extent of active channel now and in the past (1942/43 and 1965 mainly) and the geologic units adjacent to the active channel, boundaries for the present, prehistoric, and geologic floodplains were mapped. Differences in the widths of these floodplains are shown in Table O-5). The geologic floodplain is the potential position of the floodplain over a few thousand years. The boundaries of this floodplain are features that have been in the landscape for at least that long. Such features as rock outcrops or deposits of Pleistocene terraces or glacial till. Although these deposits will erode, the rate of erosion is slow relative to human interest.

The prehistoric floodplain is the potential position of the floodplain over a few hundred years. This is where we estimate the boundaries of the active floodplain to have been just before man's arrival in the area and where the boundaries would likely still be if human activities had never been overprinted on the natural processes. In most places where the boundaries do not coincide with the boundaries of the geologic floodplain, the boundaries of the prehistoric floodplain are terrace risers that are high enough that only overbank flow overtops them. Along portions of the river, especially in Reaches 1 and 2, surfaces adjacent to the active channel rise gradually with distance from the channel. Distinct terrace risers are not present. In these sections, the approximate extent of the 1949 flood (approximately equivalent to a 100-year event) was used to estimate the boundaries of the prehistoric floodplain.

The present floodplain is the floodplain as it is now with human-built features to control flow in place. In some places the boundaries of the present floodplain coincide with the boundaries of the geologic or prehistoric floodplains (Table O-6). In other places, a levee or bridge embankment now provides a limit to the extent of flow and so provides a boundary that is different from that of the prehistoric floodplain. Table O-6 shows the amounts of the right and left banks that are now controlled by human-constructed features.

Human Features

Human features along the Dungeness River corridor that are not in thickly treed areas are readily visible on the 2000 aerial photographs, especially when viewed stereoscopically. Some of these features seem to have had little impact on the river corridor (e.g., riprap). Some appear to have changed the pattern of the active channel and amount of floodplain habitat now available (Sections 7.2 and 9; Tables O-5, O-6, and O-7).

O.2. Maps of the Dungeness River Corridor

The geomorphic mapping of the lower 10.5-miles of the Dungeness River drainage is summarized by a series of maps for each of the five reaches (Figures O-2 through O-35; Tables O-8 through O-12). These maps include the active channel in 1942/43, 1965, and 2000. For Reach 3, where the channel appears to have changed location repeatedly, the active channels were mapped on two additional years, 1994 and 1996. The 1996 photographs cover only the lower portion of Reach 5. Side channels and overflow channels were mapped on the 1942/43, 1965, and 2000 aerial photographs. Present, prehistoric, and geologic floodplain boundaries were interpreted from geomorphic information derived from the aerial photographs and field observations. Woody debris was mapped on both the 2000 ortho-photographs and the 1965 aerial photographs. Because the 1965 photographs covered only the lower portion of Reach 5, woody debris for 1965 is not shown for that reach. Human-constructed features and other human activities were delineated, where possible, on the 2000 aerial photographs. Features and activities in thickly treed areas could not be seen on the photographs. Some were added to the maps on the basis of field observations.

Table O-1. Characteristics of active, side, and overflow channels and gravel bars in each reach

Reach	River miles	Active channel pattern at high and low flows	Side channels	Overflow channels	Unvegetated bars	Vegetated bars or low terraces
Reach 5	10.5-9.0	At high flows slightly meandering; one tight meander just downstream of the Fish Hatchery	One large side channel on right referred to as Kinkade Creek		Longitudinal and point bars mostly; some mid-channel bars	Longitudinal and point bars; appear to be of two ages
Reach 4	9.0-7.0	At high flows, active channel is slightly meandering; at low flows, multiple, branching channels, but pattern less complex than in Reach 3; some sections are a single strand	One long side channel on right through lower Dungeness Meadows; side channel separated from main channel by a vegetated island	A few visible on right in the area of Dungeness Meadows; difficult to see because of human modifications to the land surface	Longitudinal, point, and mid-channel bars common	Longitudinal and point bars primarily; mid-channel bars only present at upstream and downstream ends of Dungeness Meadows levee; seem to be of one age only along levee
Reach 3	7.0-4.6	At high flows, active channel slightly meandering; at low flows, multiple (often 3), branching channels that form complex patterns	Prevalent along reach; multiple channels at a single location	Common; present nearly continuously on one or both sides; located in tree-covered surfaces	Many mid-channel and transverse bars; longitudinal and point bars also present; bars prevalent and create very complex pattern	Longitudinal, point, and mid-channel bars all prevalent; appear to be of at least three ages; very complex pattern
Reach 2	4.6-2.6	At high flows, active channel slightly meandering; at low flows, one channel or two branching channels	Present along almost entire reach; side channels located adjacent to active main channel	A few short channels within active floodplain; channels have single strand (usually) or multiple, branching strands	Longitudinal, point, and mid-channel bars all common	Mostly longitudinal and point bars; no vegetated mid-channel bars except near Olympic Highway Bridge; appear to be of at least two ages
Reach 1	2.6-0	At high flows, active channel is slightly meandering; at low flows, often a single strand, or two strands at most; channel is well defined	Some side channels present on right; most on left side have been eliminated by Beebe's levee	A few present in areas of tree-covered surfaces	Some longitudinal bars and a few point bars; no mid-channel bars	Only one vegetated bar was noted, a longitudinal bar

Table O-2. Sinuosity measurements for the active channels by reach[1]

Reach	River miles	Valley length (ft)	Meander length (ft)			Sinuosity		
			2000	1965	1942/43	2000	1965	1942/43
1	0-2.6	9,323	9,770	9,643	9,713	1.05	1.03	1.04
2	2.6-4.6	8,161	9,299	8,952	8,889	1.14	1.10	1.09
3	4.6-7.0	11,847	14,001	13,645	14,166	1.18	1.15	1.20
4	7.0-9.0	10,165	10,592	10,819	11,849	1.04	1.06	1.17
5	9.0-10.5	6,739	8,812	No photographs		1.31	--	--

[1]Measurements were made along the mid-line of the active channel using Integraph software and either ortho-photographs taken in 2000 or older photographs that were rubber-sheeted to the 2000 ortho-photographs. Active channels were interpreted on each set of photographs on the basis of geologic information.

Table O-3. Estimated volumes of sediment eroded from banks near Railroad Bridge in Reach 3[1]

Time interval	Left bank					Right bank					Total volume of material eroded from both banks (yd^3) (ft^3)	Percent of total volume	Average erosion rate (yd^3/yr)
	Area number	Area (ft^2)	Estimat-ed bank height[2] (ft)	Volume of material (yd^3) (ft^3)	Total volume of material (yd^3) (ft^3)	Area number	Area (ft^2)	Estimated bank height[2] (ft)	Volume of material (yd^3) (ft^3)	Total volume of material (yd^3) (ft^3)			
1942-1965	1	208,406	3	23,156 (625,218)	172,527 (4,658,246)	1	42,848	3	4,761 (128,544)	9,881 (266,793)	182,409 (4,925,039)	34	7,931
	2	57,491	3	6,388 (172,473)		2	46,083	3	5,120 (128,249)				
	3	**75,321**	**3**	**8,369 (225,963)**									
	4	**7,275**	**7.5**	**2,021 (54,563)**									
	5	**434,576**	**8.2**	**131,982 (3,563,523)**									
	6	5,502	3	611 (16,506)									
1965-1994	**1**	**436,820**	**3**	**48,536 (1,310,460)**	259,625 (7,009,891)	**1**	**110,179**	**3**	**12,242 (330,537)**	27,067 (730,815)	286,693 (7,740,706)	53	9,886
	2	**649,191**	**8.2**	**197,162 (5,323,366)**		2	133,426	3	14,825 (400,278)				
	3	41,296	3	4,588 (123,888)									
	4	84,059	3	9,340 (252,177)									

Table O-3. Estimated volumes of sediment eroded from banks near Railroad Bridge in Reach 3[1] (Cont.)

Time interval	Left bank					Right bank					Total volume of material eroded from both banks (yd³) (ft³)	Percent of total volume	Average erosion rate (yd³/yr)
	Area number	Area (ft²)	Estimated bank height[2] (ft)	Volume of material (yd³) (ft³)	Total volume of material (yd³) (ft³)	Area number	Area (ft²)	Estimated bank height[2] (ft)	Volume of material (yd³) (ft³)	Total volume of material (yd³) (ft³)			
1994-1996	**1**	**11,615**	**3**	**1,291 (34,845)**	13,826 (373,302)	1	82,999	3	9,222 (248,997)	9,222 (248,997)	23,048 (622,299)	4	11,524
	2	**65,441**	**3**	**7,271 (196,323)**									
	3	13,721	3	1,525 (41,183)									
	4	24,751	3	2,750 (74,253)									
	5	8,906	3	990 (26,718)									
1996-2000	1	26,255	3	2,917 (78,765)	41,665 (1,124,976)	1	29,284	3	3,254 (87,852)	6,719 (181,407)	48,384 (1,306,383)	9	12,096
	2	**2,219**	**3**	**247 (6,657)**		2	31,185	3	3,465 (93,555)				
	3	**25,184**	**3**	**2,798 (75,552)**									
	4	**22,060**	**3**	**2,451 (66,180)**									
	5	**27,951**	**8.2**	**8,489 (229,198)**									
	6	**15,598**	**8.2**	**4,737 (127,904)**									
	7	**59,239**	**8.2**	**17,991 (485,760)**									
	8	18,320	3	2,036 (54,960)									
1942-2000					487,643 (13,166,415)					52,889 (1,428,012)	540,534 (14,594,427)		

[1]Numbers shown on Figure 26 are for those areas shown on the figure only. These are the numbers shown in bold on this table. The total amounts of eroded material, in yd^3, for each time interval are as follows: 1942-1965, 142,350; 1965-1994, 257,950; 1994-1996, 8,562; 1996-2000, 36,713. The total amount of eroded material (yd^3) for these areas is 445,600. The percentages of eroded material by time interval are as follows: 1943-1965, 32%; 1965-1994, 58%; 1994-1996, 2%; 1996-2000, 8%.

[2]Bank height is measured for the bank at Severson's property (8.2 ft) and downstream of Railroad Bridge (7.5 ft). At other areas, the bank height is estimated to be 3 ft, which seems to be a average amount for the banks based on measurements using 2000 ortho-photographs and Integraph software.

Table O-4. Distribution of woody debris among the five reaches

Reach	Relative amount	Location and pattern	Number of piles readily mapped; Number of pile per mile[1]
Reach 5	Common to nearly absent	Concentrated at meander bends; nearly absent along straighter sections of reach; largest accumulations are (1) at the tight meander just downstream of the Fish Hatchery and (2) just upstream of this tight meander at the head of Kinkade Creek; some woody debris along Kinkade Creek	39; 39
Reach 4	Common; less than in Reach 3	Primarily at meanders at the upstream and downstream ends of reach; less debris upstream of about RM 8, at the upper end of the Dungeness Meadows levee; on elevated bars along the straight, middle section of the reach adjacent to the Dungeness Meadows levee	55; 22 (for entire reach) 23; 23 (adjacent to Dungeness Meadows levee) 10; 10 (just upstream of levee)
Reach 3	Prevalent	Abundant, especially at meander bends; large piles in the center of the active channel and along the sides of the channel; debris in complex pile of interconnected logs; logs appear to be of several ages; also preserved in flood-flow and abandoned channels	77; 31
Reach 2	Common	Abundant, especially at meander bends; also preserved in flood-flow and abandoned channels	16; 8
Reach 1	Very little	Very little except at meander bends; concentrated at the relatively tight meander bend at the remnant of the Pleistocene deposit on the left near RM ; small pieces stranded on elevated bars elsewhere	4; 1.6

[1]Debris piles were counted on 1998 aerial photographs and this number was divided by the number of miles in the reach. These results may vary from what is visible on the aerial photographs.
Woody debris as mapped from the 2000 and 1965 aerial photographs is shown on figures in this appendix.

Table O-5. Widths of the active channel, the present floodplain, the prehistoric floodplain (a few hundred years), and the geologic floodplain (a few thousand years)

Reach	Section/ Cross section	River mile	Width (feet)[1]				Difference between prehistoric and present floodplains	Percent of prehistoric floodplain that is present floodplain	Percent of present floodplain that is active channel	Present floodplain notes (RB, Right bank; LB, Left bank)[9]
			Active channel	Present floodplain	Prehistoric floodplain	Geologic floodplain				
1	3	0.47	92	165	>4000	>4000	≥3835	4	56	RB=ACOE Levee; LB=River's End Levee
	4	0.72	97	160	719	719	559	22	61	Just upstream of Schoolhouse Bridge; RB=ACOE Levee
	5	0.88	88	647	>2346	>2346	1699	28	14	RB=ACOE Levee and 1949 flood limit; LB=Pleistocene surface
	6	0.98	117	520	>2605	>2605	2085	20	23	RB=ACOE Levee and 1949 flood limit; LB=Pleistocene surface
	7	1.20	145	537	>2476	>2476	1939	22	27	RB=ACOE Levee and 1949 flood limit; LB=Pleistocene surface
	9	1.32	140	445	734	>2260	289	61	31	RB=ACOE Levee and 1949 flood limit; LB=Pleistocene surface
	10	1.47	180	253	1478	>3960	1225	17	71	RB=ACOE Levee and 1949 flood limit; LB= Beebe's Levee and Pleistocene surface
	11	1.65	109	220	1651	>4060	1431	13	50	RB=ACOE Levee and 1949 flood limit; LB= Beebe's Levee and Pleistocene surface
	12	1.83	91	315	>2119	>4320	1804	15	29	RB=ACOE Levee and 1949 flood limit; LB= Beebe's Levee and 1949 flood limit; Matriotti Creek valley on the left

Reach	Section/ Cross section	River mile	Width (feet)[1]				Difference between prehistoric and present floodplains	Percent of prehistoric floodplain that is present floodplain	Percent of present floodplain that is active channel	Present floodplain notes (RB, Right bank; LB, Left bank)[9]
			Active channel	Present floodplain	Prehistoric floodplain	Geologic floodplain				
1	13	1.98	129	229	1435	>4325	1206	16	56	RB=ACOE Levee and 1949 flood limit; LB= Beebe's Levee and 1949 flood limit
	14	2.13	90	393	1323	>4260	930	30	23	RB=ACOE Levee and 1949 flood limit; LB= Beebe's Levee and 1949 flood limit
	15	2.32	102	577	1277	>3030	700	45	18	RB=ACOE Levee and 1949 flood limit; LB= Beebe's Levee and 1949 flood limit
	16	2.46	115	395	1259	>3550	864	31	29	RB=ACOE Levee and 1949 flood limit; LB= Beebe's Levee and 1949 flood limit
	17	2.66	208	995	1490	>2685	495	67	21	RB=ACOE Levee; LB=1949 flood limit

Reach	Section/ Cross section	River mile	Width (feet)[1]				Difference between prehistoric and present floodplains	Percent of prehistoric floodplain that is present floodplain	Percent of present floodplain that is active channel	Present floodplain notes (RB, Right bank; LB, Left bank)[9]
			Active channel	Present floodplain	Prehistoric floodplain	Geologic floodplain				
2	18	3.00	156	723	908	>2730	185	80	22	LB=Ward Road (acts as levee) and 1949 flood limit
	19	3.21	324	941	1247	>3520	306	75	34	LB=Ward Road (acts as levee) and 1949 flood limit
	20	3.33	229	[2]840	1324	>4050	122	87	19	Downstream of Woodcock/Ward Road Bridge
	21	3.36	253	[3]663	1409	>4150	161	80	18	Upstream of Woodcock/Ward Road Bridge
	22	3.60	273	552	552	>4445	0	100	49	
	23	3.74	290	840	840	>4410	0	100	35	
	24	3.95	235	545	545	>4410	0	100	43	
	25	4.04	382	395	672	>4410	277	59	97	Just upstream of Old Olympic Highway Bridge
	26	4.13	204	887	887	>4400	0	100	23	
	27	4.27	335	887	887	>4200	0	100	38	

Reach	Section/ Cross section	River mile	Width (feet)[1]				Difference between prehistoric and present floodplains	Percent of prehistoric floodplain that is present floodplain	Percent of present floodplain that is active channel	Present floodplain notes (RB, Right bank; LB, Left bank)[9]
			Active channel	Present floodplain	Prehistoric floodplain	Geologic floodplain				
3	28	4.46	180	842	842	>4450	0	100	21	
	29	4.60	176	1145	1145	>4450	0	100	15	
	30	4.97	289	1757	1757	>4360	0	100	16	
	31	5.19	472	1304	[4]1304	>4150	0	100	36	
	32	5.38	408	1465	[5]1465	>4070	0	100	28	
	33	5.51	372	1508	1508	>4070	0	100	25	
	34	5.65	234	1226	1226	>3375	0	100	19	Just downstream of Railroad Bridge
	35	5.70	205	830	1058	>3375	228	78	25	Just upstream of Railroad Bridge; Side channel not included
	36	5.86	399	1704	1704	>1700	0	100	23	LB=Pleistocene surface
	37	6.09	284	1243	1386	>2493	143	90	23	LB=Pleistocene surface
	38	6.32	362	650	650	>2800	0	100	56	Just downstream of Highway 101 Bridge
	39	6.41	374	824	824	>2800	0	100	45	Just upstream of Highway 101 Bridge
	40	6.60	327	1032	[6]1032	>2706	0	100	32	
	41	6.75	693	1248	1248	>2600	-5	100	56	
	42	6.86	780	1570	1570	>2725	0	100	50	

Reach	Section/ Cross section	River mile	Width (feet)[1]				Difference between prehistoric and present floodplains	Percent of prehistoric floodplain that is present floodplain	Percent of present floodplain that is active channel	Present floodplain notes (RB, Right bank; LB, Left bank)[9]
			Active channel	Present floodplain	Prehistoric floodplain	Geologic floodplain				
4	43	7.17	300	1672	1949	>2638	277	86	18	
	44	7.34	610	1741	1741	>2288	0	100	35	LB=Taylor Cutoff Road (no effect on widths)
	45	7.47	336	[7]612	>2505	>3217	1893	24	55	RB=Dungeness Meadows Levee
	46	7.73	281	802	2684	2715	1882	30	35	RB=Dungeness Meadows Levee
	47	7.90	222	[8]1291	2405	2886	1114	54	17	RB=Dungeness Meadows Levee; LB=Short dike
	48	8.07	416	1558	1789	2284	231	87	27	RB=Dungeness Meadows Levee; LB=Just downstream of 1942-1943 channel
	49	8.17	282	1859	1859	>2589	0	100	15	
	50	8.44	197	288	1394	2130	1106	21	68	At power line; RB=Irrigation ditch (no effect on widths); LB=Road (acts as levee)
	51	8.65	341	611	1962	2274	1351	31	56	LB=Levee
	52	8.82	327	370	1076	1336	706	34	88	LB=Levee

Reach	Section/ Cross section	River mile	Width (feet)[1]				Difference between prehistoric and present floodplains	Percent of prehistoric floodplain that is present floodplain	Percent of present floodplain that is active channel	Present floodplain notes (RB, Right bank; LB, Left bank)[9]
			Active channel	Present floodplain	Prehistoric floodplain	Geologic floodplain				
5	53	9.07	285	1247	1247	1247	0	100	23	RB=Rock; LB=Pleistocene surface
	54	9.30	224	1102	1544	1544	442	71	20	RB=Rock; LB=Pleistocene surface
	55	9.54	224	1625	1833	1833	208	89	14	RB=Rock; LB=Pleistocene surface
	56	9.73	188	1525	1525	1525	0	100	12	RB=Rock; LB=Pleistocene surface or rock
	57	9.81	162	1273	1273	1273	0	100	13	RB=Rock; LB=Pleistocene surface or rock
	58	10.09	255	1248	1248	1248	0	100	20	RB=Rock; LB=Pleistocene surface or rock
	59	10.20	169	1390	1390	1390	0	100	12	RB=Rock; LB=Pleistocene surface or rock
	60	10.36	109	960	1051	1051	91	91	11	Just downstream of Fish Hatchery; RB=Rock; LB=Pleistocene surface or rock

Notes to accompany Table O-5:

[1]Measurements were made using Integraph software and ortho-photographs taken in 2000 on which floodplains were interpreted on the basis of geologic information.
[2]Present floodplain width is 1200 ft, if a wooded island and channel are included.
[3]Present floodplain width is 1409 ft, if a wooded island and channel are included.
[4]Prehistoric floodplain width is 2331 ft, if a wooded island and channel are included.
[5]Prehistoric floodplain width is 2105 ft, if a wooded island and channel are included.
[6]Prehistoric floodplain width could be 1255 ft, depending upon direction of measurement at a curve in the floodplain.
[7]Present floodplain width could be 1997 ft at the downstream end of the Dungeness Meadows Levee.
[8]Present floodplain width is 266 ft, if a short levee on the left bank is used as the boundary.
[9]Right bank and left bank refer to the present floodplain boundaries.

Table O-6. Controls on the boundaries of the present floodplain[1]

Control on boundaries of present floodplain	Reach 1 Downstream of Schoolhouse Bridge				Reach 1 Upstream of Schoolhouse Bridge				Reach 2			
	Right bank		Left bank		Right bank		Left bank		Right bank		Left bank	
	Length (ft)	Percent of total length	Length (ft)	Percent of total Llngth	Length (ft)	Percent of total length	Length (ft)	Percent of total length	Length (ft)	Percent of total length	Length (ft)	Percent of total length
Natural Feature Correlates with Prehistoric Floodplain Boundary	1618	36	2445	54	--	--	714	7	10,971	83	6327	60
Human Activity[2]	2702	60	1694	37	9211	97	6755	65	2170	17	4193	40
Levee	*2702*	*100*	*1694*	*100*	*9211*	*100*	*6181*	*92*	--	--	--	--
Berm	--	--	--	--	--	--	--	--	*506*	*23*	--	--
Riprap	--	--	--	--	--	--	--	--	*180*	*8*	*121*	*3*
Bridge and Abutments	--	--	--	--	--	--	--	--	*1484*	*68*	*897*	*21*
Road and Embankment	--	--	--	--	--	--	*574*	*8*	--	--	*3175*	*75*
Human Activity Indirectly	--	--	--	--	--	--	677	7	--	--	--	--
Human Activity Coincides with Geologic Boundary	--	--	--	--	275	3	--	--	--	--	--	--
Periodic Failure in Area of Human Activity	--	--	422	9	--	--	298	3	--	--	--	--
Natural Feature Coincides with Geologic Floodplain Boundary	171	4	--	--	--	--	1958	19	--	--	--	--
Natural Bank Protected by Human-Placed Logs	--	--	--	--	--	--	--	--	--	--	--	--
Human Activity with No Influence on Boundary	--	--	--	--	--	--	--	--	--	--	--	--
Total Length	4491	100	4561	100	9486	100	10,402	100	13,141	100	10,520	100

Table O-6. Controls on the boundaries of the present floodplain[1] (Continued)

Control on boundaries of present floodplain	Reach 3				Reach 4				Reach 5			
	Right bank		Left bank		Right bank		Left bank		Right bank		Left bank	
	Length (ft)	Percent of total length	Length (ft)	Percent of total length	Length (ft)	Percent of total length	Length (ft)	Percent of total length	Length (ft)	Percent of total length	Length (ft)	Percent of total length
Natural Feature Correlates with Prehistoric Floodplain Boundary	13,388	87	10,249	73	3104	26	7509	64	2558	32	--	--
Human Activity[2]	1557	10	1340	10	3751	32	3609	31	1592	20	949	12
Levee	--	--	*514*	*38*	*3751*	*100*	*3609*	*100*	*1592*	*100*	*949*	*100*
Berm	*305*	*20*	--	--	--	--	--	--	--	--	--	--
Riprap	--	--	--	--	--	--	--	--	--	--	--	--
Bridge and Abutments	*1252*	*80*	*826*	*62*	--	--	--	--	--	--	--	--
Road and Embankment	--	--	--	--	--	--	--	--	--	--	--	--
Human Activity Indirectly	--	--	--	--	702	6	--	--	--	--	--	--
Human Activity Coincides with Geologic Boundary	--	--	--	--	--	--	--	--	--	--	--	--
Periodic Failure in Area of Human Activity	--	--	--	--	--	--	--	--	--	--	--	--
Natural Feature Coincides with Geologic Floodplain Boundary	--	--	1360	10	4216	36	--	--	3438	44	6271	82
Natural Bank Protected by Human-Placed Logs	436	3	1072	8	--	--	--	--	--	--	--	--
Human Activity with No Influence on Boundary	--	--	--	--	--	--	625	5	306	4	405	5
Total Length	14,021	100	15,381	100	11,773	100	11,743	100	7894	100	7625	100

Notes to Accompany Table O-6:

[1]Identification of the present floodplain boundaries and their composition was interpreted using Integraph software and ortho-photographs taken in 2000.

[2]The portion of the boundary that is control by human activities is subdivided into the primary features controlling the boundary. The lengths and percentages of these individual features are of the general human activity category. Human features for each reach are as follows:

Reach 1	Right Bank	ACOE Levee
(downstream)	Left Bank	River's End Levee
Reach 1	Right Bank	ACOE Levee
(upstream)	Left Bank	Beebe's Levee, Road and embankment at Schoolhouse Bridge. A portion of this road fails to contain flood flows. A section of the boundary is raised above the probable prehistoric location by the height of the ACOE Levee along the right bank.
Reach 2	Right Bank	Ward Road (Burlingame) Bridge, Olympic Highway Bridge, riprap downstream of the Ward Road Bridge, and possible berms. A portion of the boundary surrounds an island.
	Left Bank	Ward Road, Olympic Highway Bridge, embankment for Ward Road Bridge (included in bridges), and possible riprap.
Reach 3	Right Bank	Railroad Bridge and associated embankment upstream of bridge, Highway 101 Bridge, and a berm. Logs have been placed on a portion of the natural bank.
	Left Bank	Railroad Bridge, Highway 101 Bridge, and a private levee. Logs have been placed on three sections of the natural bank at Severson's property.
Reach 4	Right Bank	Dungeness Meadows Levee. A portion of the boundary downstream of the Dungeness Meadows Levee is also influenced indirectly by the levee.
	Left Bank	Haller dike and short, private levees at four additional localities. Taylor Cutoff Road forms a human-supplied boundary, but does not seem to influence the location of the natural boundary.
Reach 5	Right Bank	Two private levees and a levee along the irrigation ditch. Weirs along a portion of the bank are along a terrace bank that is about 10 ft high and do not appear to influence the location of the floodplain boundary.
	Left Bank	One private levee. Riprap is along a high bank that may be composed of rock or glacial deposits. Consequently, the riprap does not appear to influence the location of the floodplain boundary.

Table O-7. Human impacts on the Dungeness River corridor in each reach

Reach (Figures)	River miles	Natural features that affect river corridor (Present or Prehistoric)	Human features that impact river corridor: Human feature or activity	Human features that impact river corridor: Impact or potential impact	Human features that have little impact on river corridor
Reach 5 (Figs. O-3, O-4, O-5)	10.5-9.0	Active floodplain restricted by rock on the right and rocks and glacial deposits on the left; Kinkade Island and Kinkade Creek (side channel creating split flow around a tree-covered island); natural log jam at head of Kinkade Creek restricts sediment and flow into side channel	Levee on right bank along irrigation ditch opposite Fish Hatchery; Levees along right bank along Kinkade Island Upper end of Haller dike on left bank at the downstream end of the reach		Riprap and houses along Kinkade Creek; Riprap or logs along left and right banks; Protection of high bank along County Road
Reach 4 (Figs. O-10, O-12)	9.0-7.0	Active floodplain restricted on the right by mostly well-defined banks of Pleistocene terrace; on the left about half of the banks are well defined, half are poorly defined	Dungeness Meadows levee (~1 mi long) on right; Levee on left (Haller dike; ~0.5 mi long) Logging, especially since 1942/43	Narrows active channel and present floodplain; Decreases sinuosity; Restricts flow into side channels; Decreases riparian vegetation; Raises height of gravel bars	Short, low levees or dikes on left; Taylor Cutoff Road Gravel excavation in active channel near Dungeness Meadows levee
Reach 3 (Figs. O-17, O-19, O-20)	7.0-4.6	Unstable bed, both in plan form and vertically; multiple, low-flow channels; Active floodplain confined by well-defined to poorly defined Holocene terraces (both sides) or remnants of Pleistocene glacial deposits (left side)	Railroad Bridge, especially embankment on right just upstream of bridge	Embankment has restricted flow on right side of floodplain	Riprap and (or) anchored logs on left bank at Severson's property, along embankment at Railroad Bridge, and right bank downstream of Highway 101 Bridge
			Log jam placed at head of side channel on left	Restricts sediment and flow into side channel, which is now fed by groundwater only	
			Logging in floodplain	Changes in location of active channel; Loss of riparian habitat	
Reach 2 (Figs. O-26, O-27)	4.6-2.6	Active floodplain confined by most fairly well-defined Holocene terraces (both sides); distance between these banks is variable	Woodcock Bridge	Together cut off part of active floodplain; Decrease riparian vegetation	Riprap on right bank upstream of Woodcock Bridge Gravel excavation in active channel
			Ward Road and embankment		
			Olympic Highway Bridge	Restricts deposition vertically	
Reach 1 (Figs. O-33, O-34)	2.6-0	Active floodplain naturally confined on left by high bank of Pleistocene sediment between Matriotti Creek and Schoolhouse Bridge (RM0.9 to RM1.7); Active floodplain also naturally confined by remnants of Pleistocene deposits at Schoolhouse Bridge and Dungeness School	ACOE Levee	Restricts overbank flow and sediment deposition on right	Schoolhouse Bridge Gravel excavation in active channel
			Beebe's Levee	Restricts active floodplain and eliminates side channels on left; Reduces riparian habitat	
			River's End Levee	Restricts overbank flow and sediment deposition on left	
			All three levees together	Restrict movement and migration of active channel	

Table O-8. Present conditions and changes in channel patterns, woody debris, floodplain boundaries, and human features and activities for Reach 5 (RM 10.5-9)

Characteristic or property	Locality or feature	Condition in 2000	Change from older photograph or map
Active channel pattern and position (Figure O-2)	Flow pattern	Split flow around wooded Kinkade Island	Split flow not portrayed on 1954 USGS topographic map; split flow is present in 1965 but head of channel farther east and upstream at R5b
	Sinuosity	Relatively sinuous (1.3; Table O-2)	Less sinuous in downstream half of reach
	Meander pattern	One tight meander at upstream end of section at R5d, where meander is nearly perpendicular to valley; elsewhere meanders fairly broad; movement of meanders at R5e and R5d is restricted by high, steep bank in Pleistocene deposits	Broad meanders in downstream half of reach; meander at R5c has migrated downstream since 1954; meander at R5d has migrated upstream since 1954; result is tighter meander bends
	Bars	Point bars and mid-channel bars at meander bends; longitudinal bars in straight sections	
	Side channels	Large side channel (referred to as Kinkade Creek) on east side of Kinkade Island; head at meander bend at R5c where flow in main, active channel is nearly perpendicular to valley slope; decreased flow in main channel downstream of Kinkade Creek, along with the tight meander, results in deposition between R5c and R5d	Large side channel in position of Kinkade Creek not shown on 1954 USGS topographic map; large side channel (Kinkade Creek) is visible on 1965 and 1984 aerial photographs but its head was at R5b, east and upstream of its present location
Woody debris (Figure O-3)	Location	Primarily at meanders; nearly absent along straight sections; largest accumulation is at tight meander at R5d and just upstream at the head of Kinkade Creek at R5c; woody debris also concentrated at meander bend at R5e and at the meander bends downstream; some woody debris along Kinkade Creek	
	Impacts	Woody debris at R5c prevents main flow and bed-load sediment from entering Kinkade Creek; woody debris at R5d slows flows and enhances sediment deposition at the meander bend and immediately upstream	
Floodplain boundaries (Figure O-4)	Geologic	Left boundary is a high bank composed of Pleistocene till or outwash; right boundary is mostly rock	
	Prehistoric	Corresponds nearly everywhere along both left and right boundaries to the geologic floodplain; exception is at R5g where the right boundary is a fluvial terrace	
	Present	Corresponds nearly everywhere along both left and right boundaries to the prehistoric floodplain; exceptions are at R5a, where a levee has been built along an irrigation ditch, and at R5f, where a levee, known as the Haller dike, has been built	
Human Activities (Figure O-5)	Types	Levees along irrigation ditch at R5a-R5b and along a field at R5f (Haller dike); bank along Fish Hatchery Road at R5e is protected by riprap; riprap and weirs; houses	
	Impacts	Levee at R5f confines flood flows on left (west) side; riprap R5e slows erosion of bank along Fish Hatchery Road; however, erosion would not continue much farther to the west because of bluff of Pleistocene sediment; levee at R5a-R5b may have blocked former head of Kinkade Creek at R5b	

Table O-9. Present conditions and changes in channel patterns, woody debris, floodplain boundaries, and human features and activities for Reach 4 (RM 9 to 7)

Characteristic or property	Locality or feature	Condition in 2000	Change from older photograph or map
Active channel pattern and position (Figures O-6, O-7)	Flow pattern	Single strand active channel; low-flow channel splits around bars into multiple channels	Split flow around wooded island in 1942/43, especially at R4b, R4f, and R4i
	Sinuosity	Relatively straight (1.04; Table O-2)	More sinuous in 1942/43 (1.17); decrease in sinuosity by 1965 (1.06)
	Meander pattern	Meanders very broad at upstream and downstream ends of reach (at R4a and R4f); absent in middle portion of reach	Meanders tighter in 1942/43; meanders broader by 1965
	Bars	Mid-channel, longitudinal, and transverse bar; no point bars; tops of bars high above low-water channel; well-developed shingling of pavement rocks	More vegetation in floodplain
	Side channels	None accessible to flow at their heads	Large side channels at R4b, R4d, and R4i in 1942/43
Woody debris (Figures O-8, O-9)	Location	Primarily at meanders at upstream and downstream ends of reach (at R4a and R4f); on elevated bars, if present, along straight, middle section	Very little debris is visible on the 1965 aerial photographs; debris is primarily at meander bends and in the area near the upstream end of the Dungeness Meadows levee
	Impacts	Woody debris stranded on elevated bars in straight section requires very high flows to be moved or deposited; does not provide fish habitat (e.g., pools)	
Floodplain boundaries (Figure O-10)	Geologic	Left boundary is a high bank of Pleistocene till or outwash; right boundary is rock or high riser of Pleistocene terrace	
	Prehistoric	Left boundary either corresponds to geologic boundary or is along riser of younger terrace; exception is at upstream end near R4a, where prominent terrace riser appears to be absent; right boundary mainly corresponds to geologic boundary; at downstream end near R4i, boundary is along riser of younger terrace	
	Present	Left boundary is controlled by levees at R4a (Haller dike), at R4c (short private levees), at R4d (the elevation of the Dungeness Meadows levee), and at R4g (private levees); right boundary corresponds to the prehistoric boundary at upstream and downstream ends of reach and by Dungeness Meadows levee in middle section	Boundaries almost entirely corresponded to those of the prehistoric floodplain
Human Activities (Figures O-11, O-12)	Types	Levees along a field at R4a (Haller dike), at R4c, R4d, and R4h (along short private levees), and along Dungeness Meadows (near R4e); Taylor Cutoff Road at R4g	Dungeness Meadows levee and Haller dike not present in 1942/43; construction in Dungeness Meadows area has begun by 1965; other levees and dikes not visible

	Impacts	Levee at R4a appears to have blocked the entrance to side channel near R4b and cuts off some of the active channel and floodplain that were present in 1942/43; Dungeness Meadows levee cuts off floodplain habitat including side channels (especially at R4f), pools, and riparian vegetation; short private levees at R4c and R4h may block low areas or small channels, but do not seem to have markedly changed the active floodplain	Taylor Cutoff Road was present in 1942/43; it doesn't seem to have affected flow because it is along the riser of a high terrace

Table O-10. Present conditions and changes in channel patterns, woody debris, floodplain boundaries, and human features and activities for Reach 3 (RM 7 to 4.6)

Characteristic or property	Locality or feature	Condition in 2000	Change from older photograph or map
Active channel pattern and position (Figures O-13 through O-16, O-21)	Flow pattern	Primarily a single channel; low-water channel has multiple channels and split flow; flow across transverse bars	Split flow around wooded islands in 1942/43, especially between R3 g and R3h; lots of changes in the location and pattern of channels since 1942/43
	Sinuosity	Somewhat sinuous (1.18; Table O-2)	Sinuosity about the same in 1942/43 and in 1965 (Table O-2)
	Meander pattern	Meanders fairly broad, except just downstream of the Highway 101 Bridge (R3c and R3d) and around the Railroad Bridge (R3f and R3g)	Some meanders tighter (R3c and R3e) in 1942/43 and some broader (R3g to R3h and downstream); similar patterns in 1965, 1994, and 1996
	Bars	Point, mid-channel, longitudinal, and transverse bars	Frequent shifting in the location and pattern of bars and channels since 1942/43
	Side channels	Large one at Railroad Bridge (R3f) no longer accessible to flow; side channel downstream of Railroad Bridge near R3h; large side channel enters at R3a, but flow is from groundwater; side channel at R3b (referred to as Dawley side channel);	Large side channel at R3a appeared to carry flow in 1942/43, possibly in 1965; side channels in Railroad Bridge area in 1942/43 and in 1965; vegetated side channel downstream of Railroad Bridge near R3h did not carry flow in 1942/43
Woody debris (Figures O-17, O-18)	Location	Abundant, especially at meander bends; preserved in flood-flow and abandoned channels	Debris is visible on the 1965 aerial photographs at meander bends, especially upstream of the two bridges
	Impacts	Enough woody debris and in large enough jams that they probably create or enhance fish habitat (e.g., pools)	
Floodplain boundaries (Figure O-19)	Geologic	Except for small remnants of Pleistocene till or outwash, the left and right boundaries are not in the immediate vicinity of the present river corridor	
	Prehistoric	Left and right boundaries are mainly along well-defined terrace risers; remnants of terraces preserved on left near R3h	Because of bank erosion, the positions of the boundaries of the prehistoric floodplain, although defined by the riser of the same terrace, have shifted
	Present	Left and right boundaries mostly coincide with boundaries of the prehistoric floodplain; exceptions are small areas of fill at the two bridges and the wooded channel on the left near R3h, which may have been active in prehistoric times	Because of bank erosion, the positions of the boundaries of the present floodplain, which coincide with the boundaries of the prehistoric floodplain, have shifted
Human Activities (Figures O-20, O-21)	Types	Two bridges and embankments; riprap or logs as bank protection near R3d, R3e, R3g, and R3h; woody debris placed in active channel near R3f	Both bridges were present in 1942/43, although Highway 101 Bridge has been modified; Railroad Bridge was rebuilt after large flood in 1961; portion of floodplain was logged just before 1942/43 aerial photographs were taken
	Impacts	Bridges restrict active floodplain only slightly as both are located where banks are well-defined by terrace risers; embankment at R3g may have influenced the channel pattern and possibly the bank erosion at R3e and R3h; bank protection may slow erosion but doesn't restrict floodplain width or change flow; placed woody debris at R3e may have enhanced changes in channel pattern, erosion of banks at R3e and R3h, and has eliminated flow from side channel at R3f	Bridges do not appear to have much effect on active channel or floodplain; different position of active channel between R3e and R3h in 1942/43 before construction of embankment at R3g in the early 1960s; logging in early 1940s may have influenced location of channel and erosion of banks

Table O-11. Present conditions and changes in channel patterns, woody debris, floodplain boundaries, and human features and activities for Reach 2 (RM 4.6 to 2.6)

Characteristic or property	Locality or feature	Condition in 2000	Change from older photograph or map
Active channel pattern and position (Figures O-22, O-23, O-28)	Flow pattern	Primarily a single channel, even at low flows	
	Sinuosity	Somewhat sinuous (1.14; Table O-2)	Sinuosity about the same in 1942/43 and in 1965 (Table O-2)
	Meander pattern	Meanders fairly broad, except at the Olympic Highway Bridge (R2a) and perhaps just upstream of the Woodcock Bridge (R2c)	Meanders at the two bridges may have been broader in 1942/43 and in 1965 than they are in 2000
	Bars	Point, mid-channel, and longitudinal bars	
	Side channels	One side channel on the right side just upstream of the Olympic Highway Bridge near R2a	
Woody debris (Figures O-24, O-25)	Location	Abundant, especially at meander bends (e.g., between R2a and R2b, upstream of Woodcock Bridge, and downstream of Woodcock Bridge at Ward Road); also preserved in flood-flow and abandoned channels	Most debris that is visible on the 1965 aerial photographs is along the meander bend upstream of Olympic Highway Bridge; some debris on bars elsewhere along reach
	Impacts	Enough woody debris and in large enough jams that they probably create or enhance habitat (e.g., pools)	
Floodplain boundaries (Figure O-26)	Geologic	Except for one short section at R3e, where the boundary is along a remnant of Pleistocene till and outwash, the left and right boundaries are not in the immediate vicinity of the present river corridor	
	Prehistoric	Left and right boundaries are mainly along well-defined terrace risers upstream of Woodcock Bridge and on the right side downstream of the bridge; the left boundary downstream of Woodcock Bridge, where no definite terrace riser could be discerned, is estimated by the extent of the 1949 flood; width between the well-defined terraces varies (e.g., narrower at R2b than just upstream and downstream)	
	Present	Left and right boundaries mostly coincide with boundaries of the prehistoric floodplain; exceptions are the small areas of fill at the two bridges and the section near R3d, where Ward Road acts as a levee	
Human Activities (Figures O-27, O-28)	Types	Two bridges and embankments (Olympic Highway Bridge and Woodcock Bridge); Ward Road	Both bridges were present in 1942/43, although the Olympic Bridge has been rebuilt since that time

	Impacts	Olympic Highway Bridge at R2a restricts active floodplain width only slightly as it is located where banks are well-defined by terrace risers, however, the bridge has minimal clearance and may obstruct conveyance of woody debris and sediment at high flows; left embankment of Woodcock Bridge in conjunction with Ward Road at R2d cut off active floodplain, including side channels and riparian vegetation	Bridges do not appear to have had much effect on the location of the active channel or floodplain; however, Woodcock Bridge, along with Ward Road, cuts off the floodplain

Table O-12. Present conditions and changes in channel patterns, woody debris, floodplain boundaries, and human features and activities for Reach 1 (RM 2.6 to 0)

Characteristic or property	Locality or feature	Condition in 2000	Change from older photograph or map
Active channel pattern and position (Figures O-29, O-30, O-35)	Flow pattern	Primarily a single channel, even at low flows	Split flow around a wooded island at mouth of Matriotti Creek near R1d in 1942/43 and in 1965
	Sinuosity	Fairly straight (1.05; Table O-2)	Sinuosity about the same in 1942/43 and in 1965 (Table O-2)
	Meander pattern	Meanders fairly broad, except near R1e, where the left bank is a remnant of a Pleistocene deposit	
	Bars	Point, mid-channel, and longitudinal bars	
	Side channels	Some along right side	
Woody debris (Figures O-31, O-32)	Location	Very little except at meander bends; concentrated at relatively tight bend near R1e; small pieces stranded on elevated bars elsewhere	Very little is visible on the 1965 aerial photographs; some at meander bends and at the upstream and downstream ends of split flow between R1c and R1e
	Impacts	Woody debris on elevated bars can be moved or deposited only at largest flows; does little to create habitat (e.g., pools)	
Floodplain boundaries (Figure O-33)	Geologic	Left boundary between R1e and R1g is defined by a remnant of a Pleistocene deposit; left boundary elsewhere and all of right boundary are beyond the immediate vicinity of the present river corridor	
	Prehistoric	Left and right boundaries are estimated mainly by the limit of the 1949 flood; exceptions are the left boundary along the high bank of Pleistocene sediment and the right bank at Schoolhouse Bridge, which is defined by a remnant of a Pleistocene deposit	
	Present	Left and right boundaries are defined mostly by levees, except where they coincide with the prehistoric boundaries that are defined by natural topography; left boundary at R1f is estimated from the elevation of the ACOE levee and the embankment for Schoolhouse Bridge and culverts under Schoolhouse Road; left boundary at R1h is where high flows have periodically broken through River's End levee into a channel that was active in 1885	

Characteristic or property	Locality or feature	Condition in 2000	Change from older photograph or map
Human Activities (Figures O-34, O-35)	Types	Levees (ACOE between R1a and R1i, Beebe's between R1b and R1c, and River's End between R1g and R1i); Schoolhouse Bridge at R1g	Schoolhouse Bridge was present in 1942/43 but with a slightly different orientation; a shorter, lower levee was present in 1942/43 along part of what is now Beebe's levee; ACOE, Beebe's, and River's End levees were constructed in the 1960s
Human Activities (Cont.)	Impacts	All three levees restrict floodplain (overbank) flows and deposition of fine sediment; Beebe's levee also cuts off the active floodplain, eliminating most of the side channels, overflow channels, and riparian habitat; lower end of the ACOE levee keeps high-velocity flows out of Meadowbrook Creek; ACOE and Beebe's levees together create local constrictions in the present floodplain (which cause deposition, raise bed elevation, raise the elevation of bars, and increase sediment sizes in bars); ACOE and River's End levees together eliminate multiple, simultaneous flow paths into Dungeness Bay and create backwater near Schoolhouse Bridge; Schoolhouse Bridge is at a natural constriction and so does little to restrict floodplain width and the active channel	

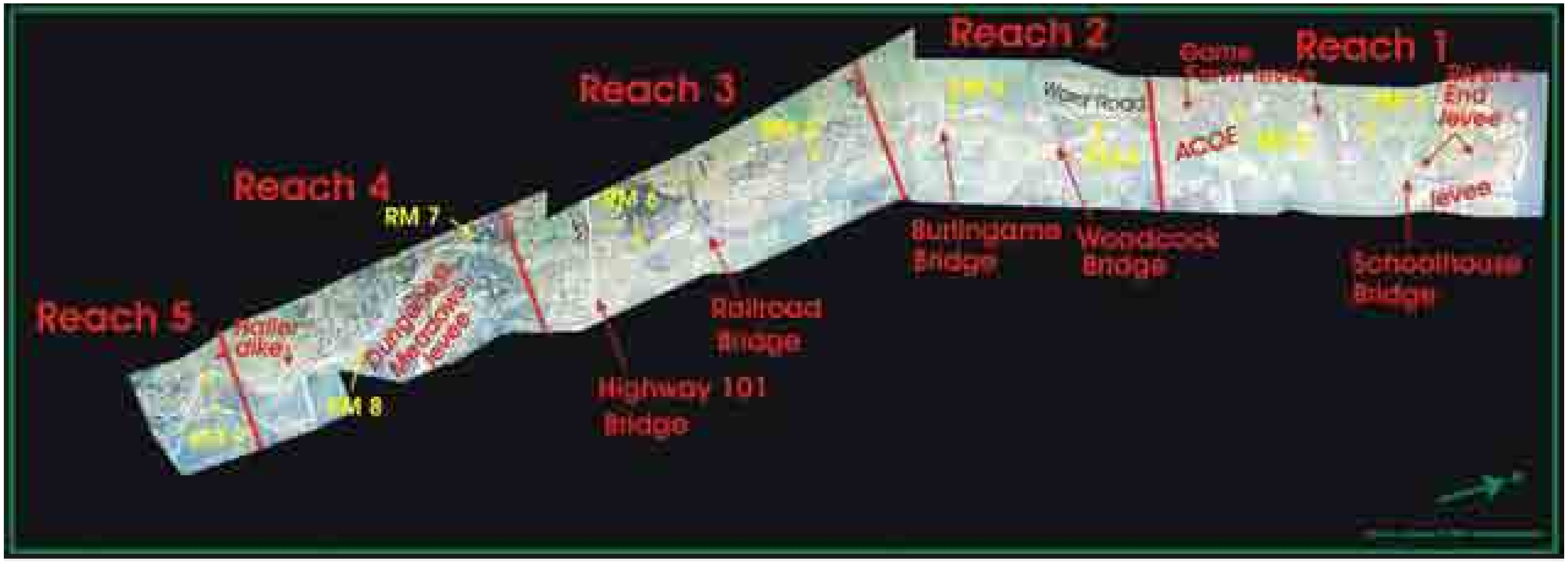


Figure O-1. The five study reaches in the lower 10.5 miles of the Dungeness River basin shown on a mosaic of ortho-photographs taken in 2000.

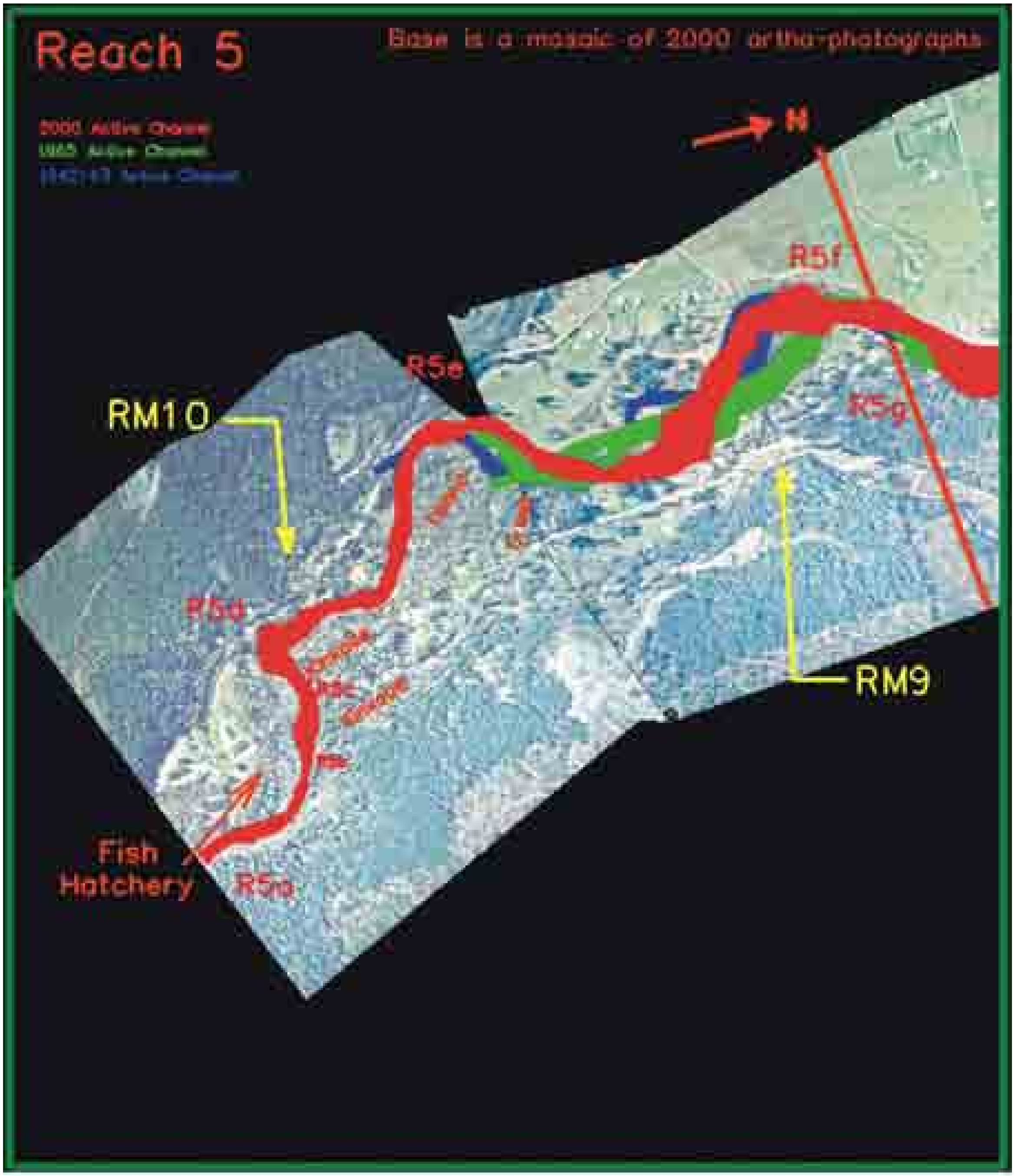


Figure O-2. Active channels mapped from aerial photographs taken in 1942/43, 1965, and 2000 for Reach 5 (RM 10.5 to 9). Channels are shown on a mosaic of ortho-photographs taken in 2000. Labels beginning with R indicate localities discussed in the text and tables.

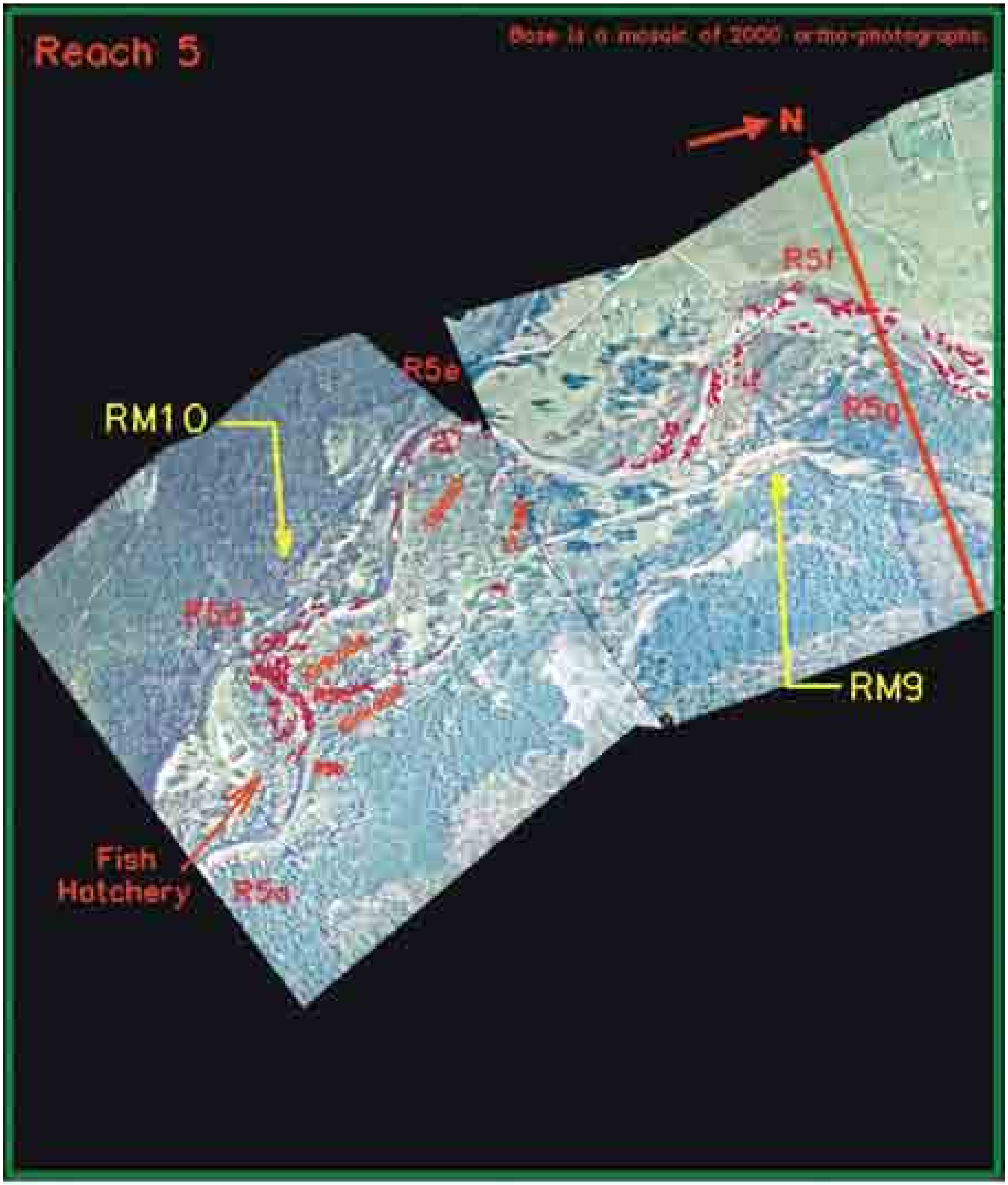


Figure O-3. Woody debris in the active channel and side channels for Reach 5. Both large stacks of wood and single logs that are visible on aerial photographs taken in 2000 are shown.

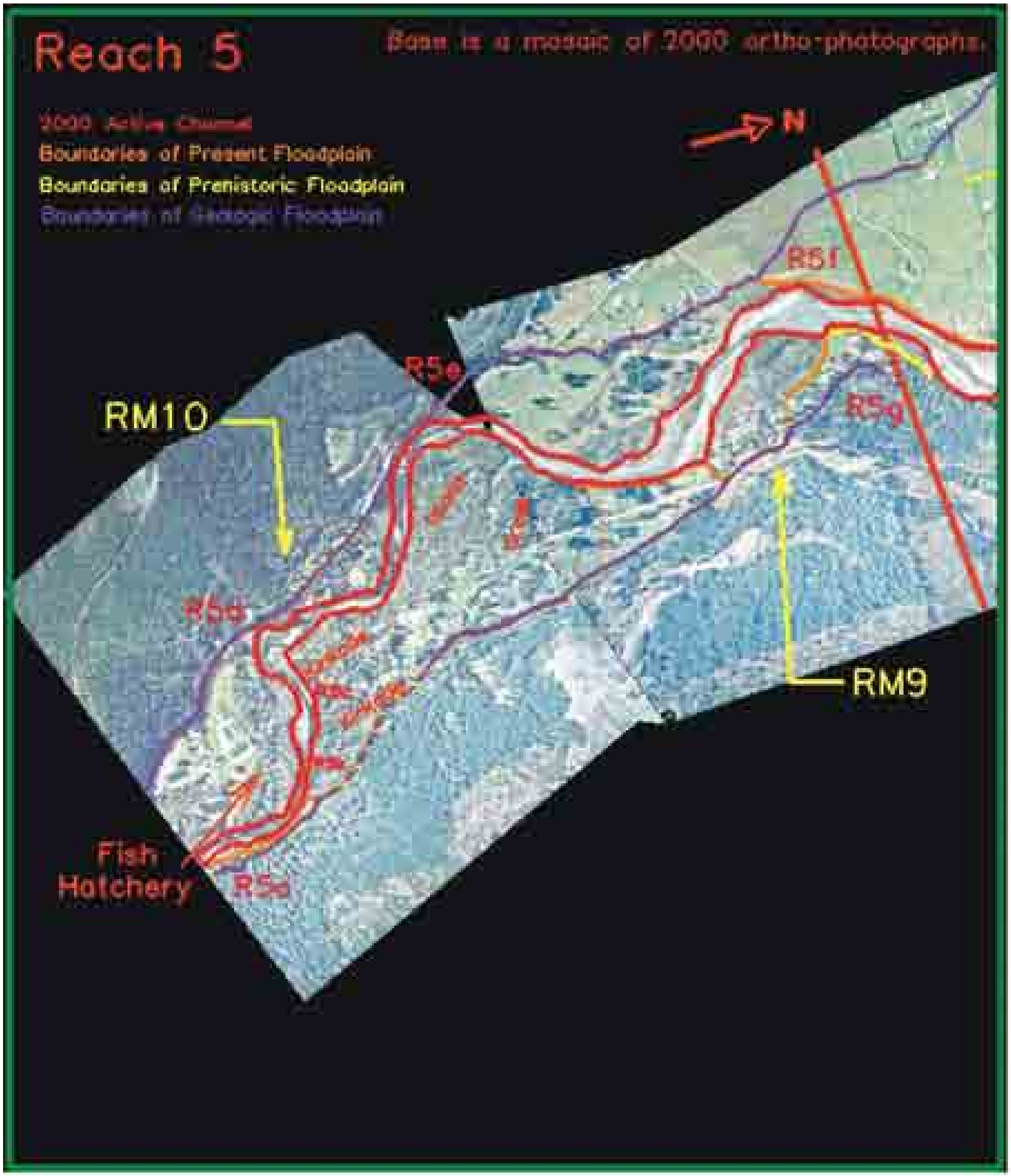


Figure O-4. Active channel and boundaries of the present, prehistoric, and geologic floodplains interpreted for Reach 5 from aerial photographs taken in 1942/43, 1965, and 2000. Boundaries are dashed where approximately located and dotted where unclear.

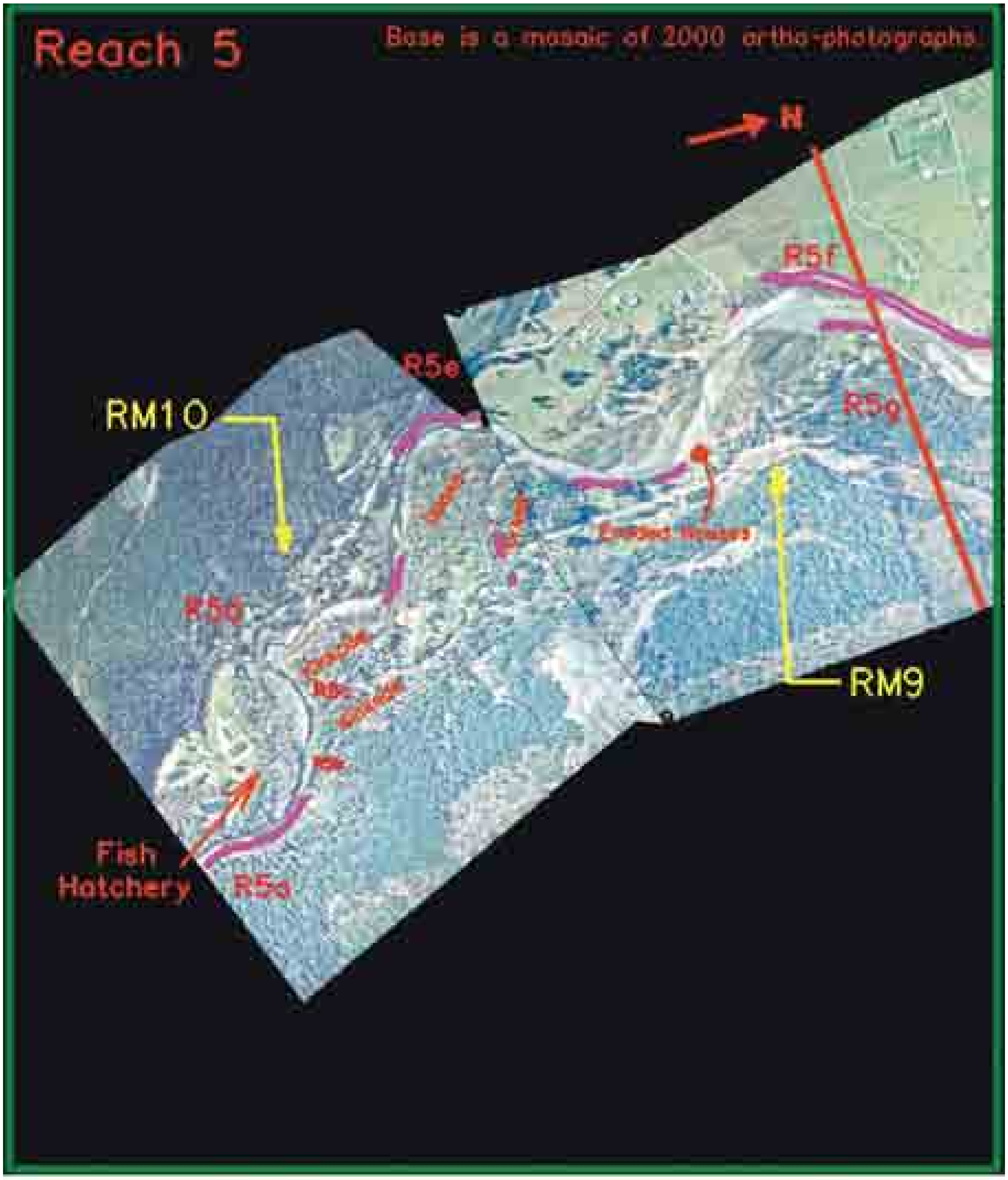


Figure O-5. Human-constructed features and areas of human activities in and near the active channel for Reach 5. Features were mapped on the ortho-photographs taken in 2000.

Figure O-6. Active channels mapped from aerial photographs taken in 1942/43, 1965, and 2000 for Reach 4 (RM 9 to 7). Channels are shown on a mosaic of ortho-photographs taken in 2000. Labels beginning with R indicate localities discussed in text and tables.

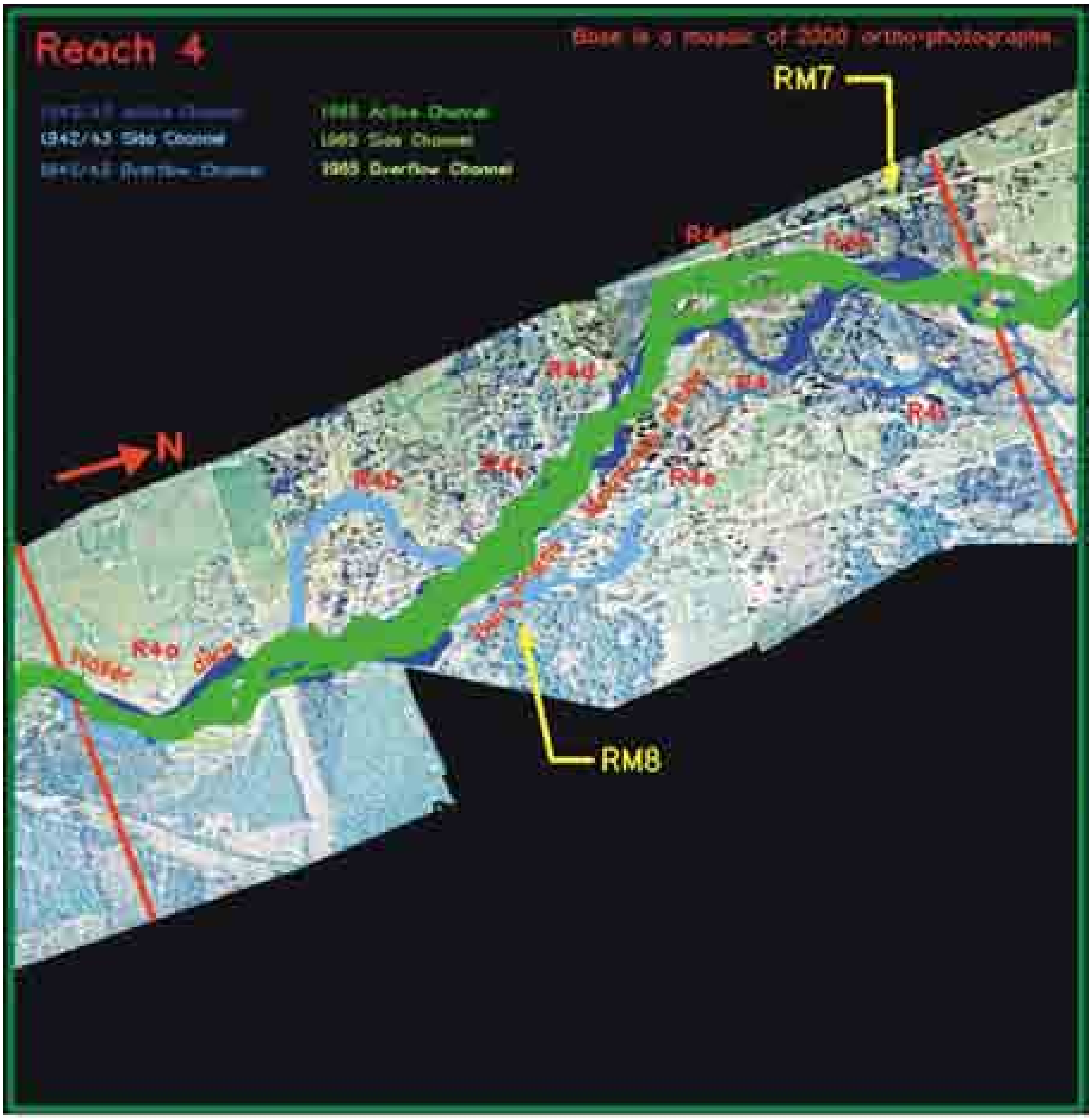


Figure O-7. Active channels, side channels, and overflow channels mapped from aerial photographs taken in 1942/43 and 1965 for Reach 4. Differences in the side and overflow channels may reflect their expression on the photographs rather than changes in the channels.

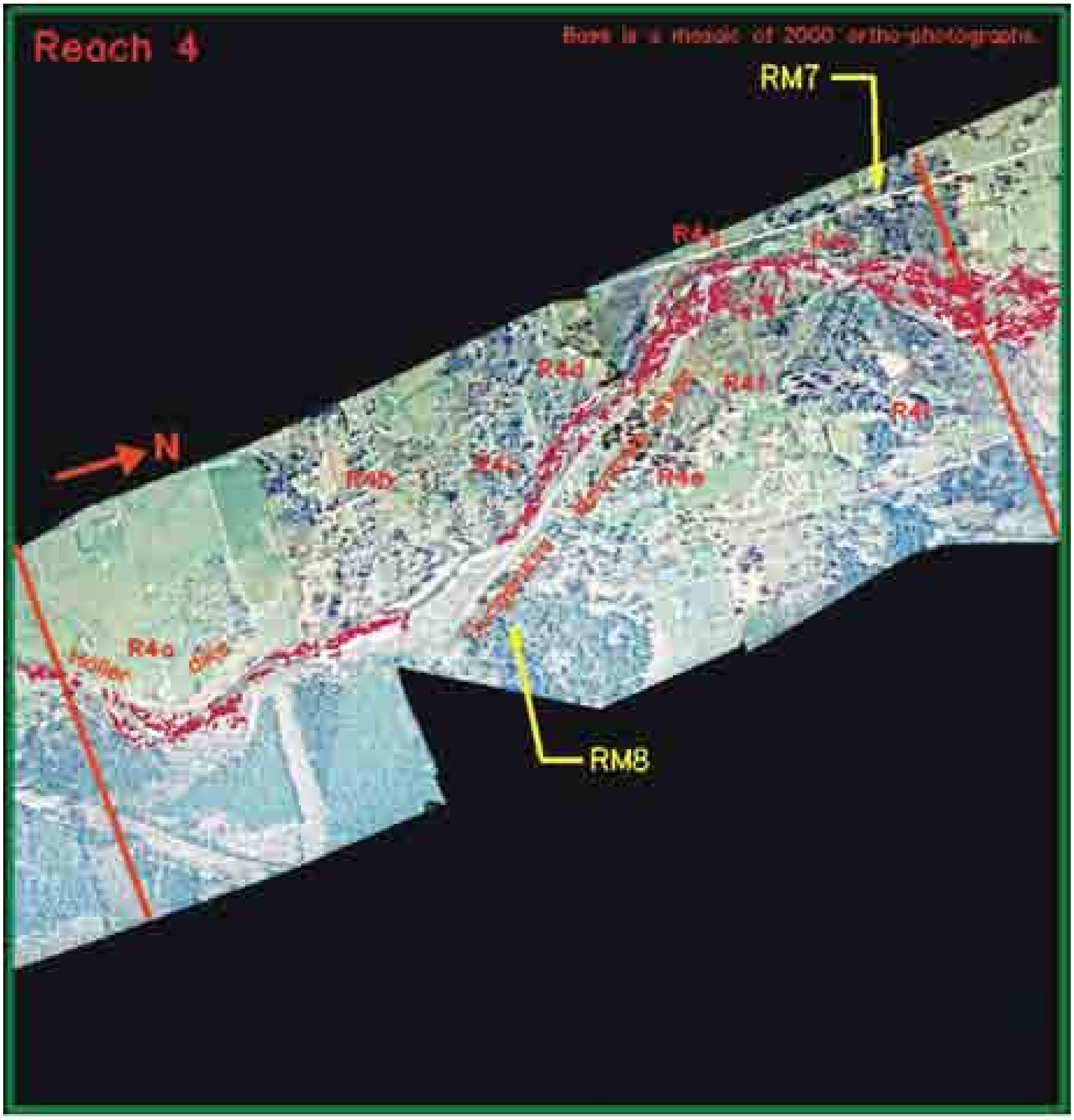


Figure O-8. Woody debris in the active channel and side channels for Reach 4. Both large stacks of wood and single logs that are visible on aerial photographs taken in 2000 are shown.

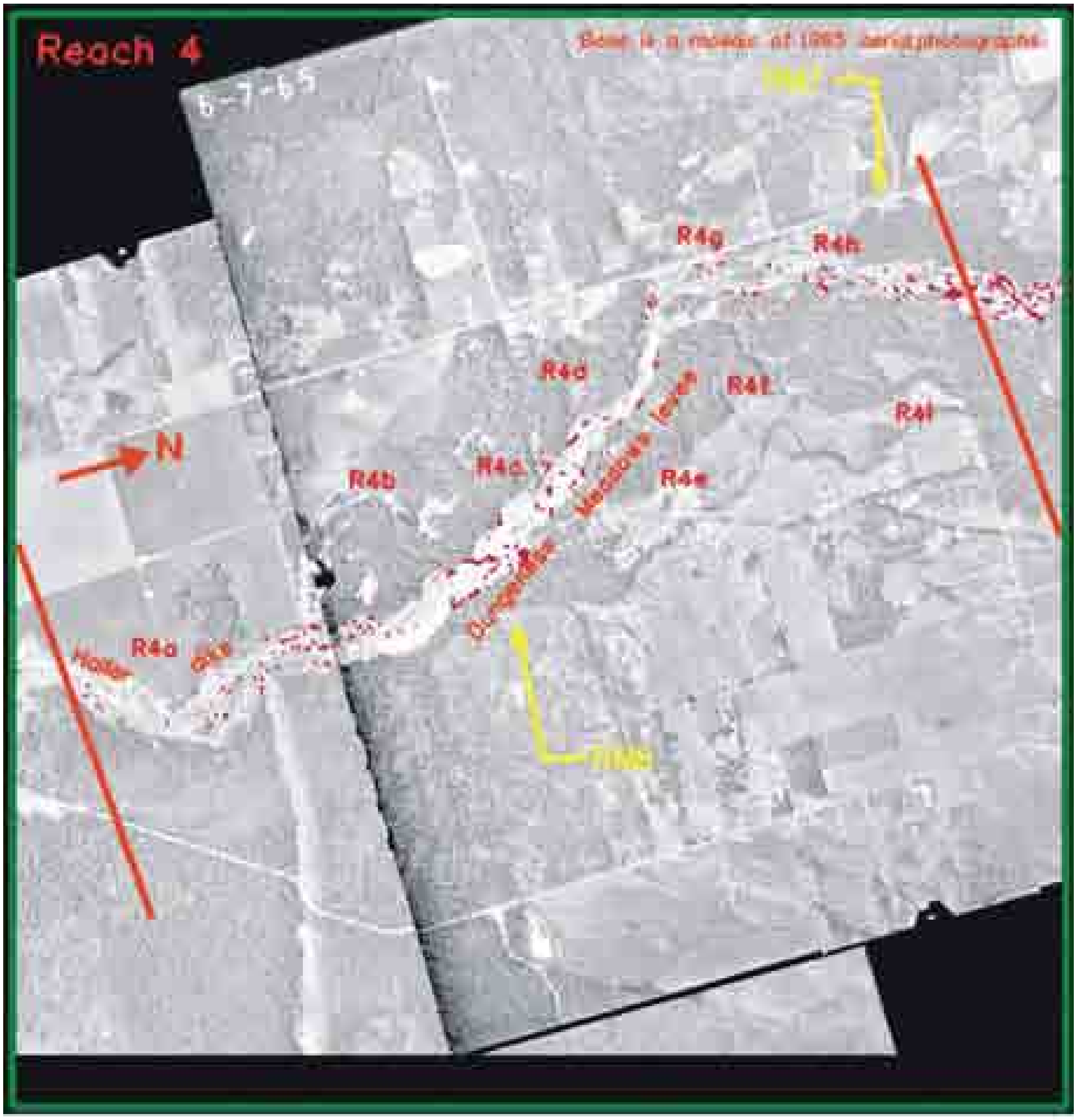


Figure O-9. Woody debris in the active channel and side channels for Reach 4. Both large stacks of wood and single logs that are visible on aerial photographs taken in 1965 are shown.

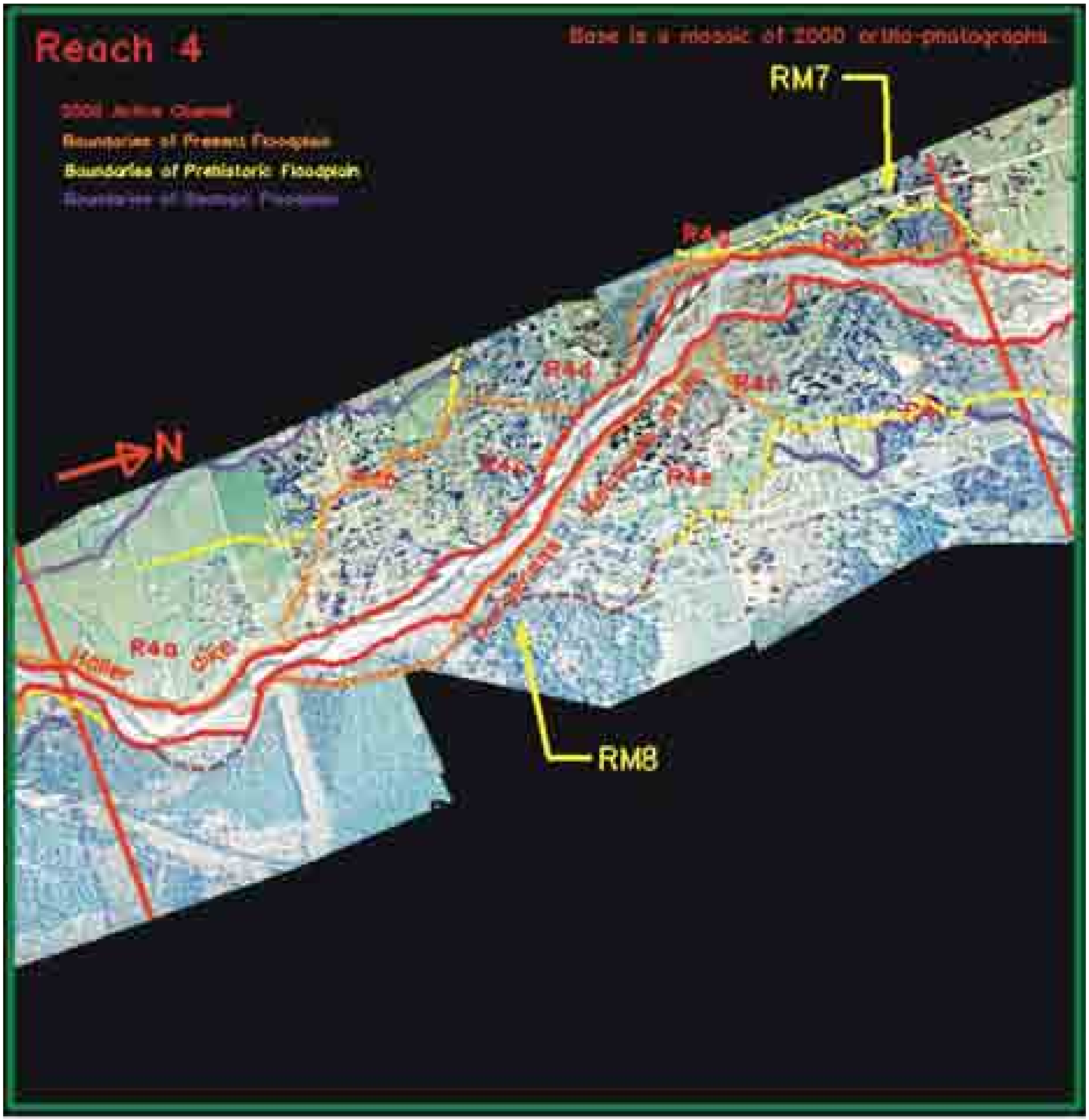


Figure O-10. Active channel and the boundaries of the present, prehistoric, and geologic floodplains interpreted for Reach 4 from aerial photographs taken in 1942/43, 1965, and 2000. Boundaries are dashed where approximately located and dotted where unclear.

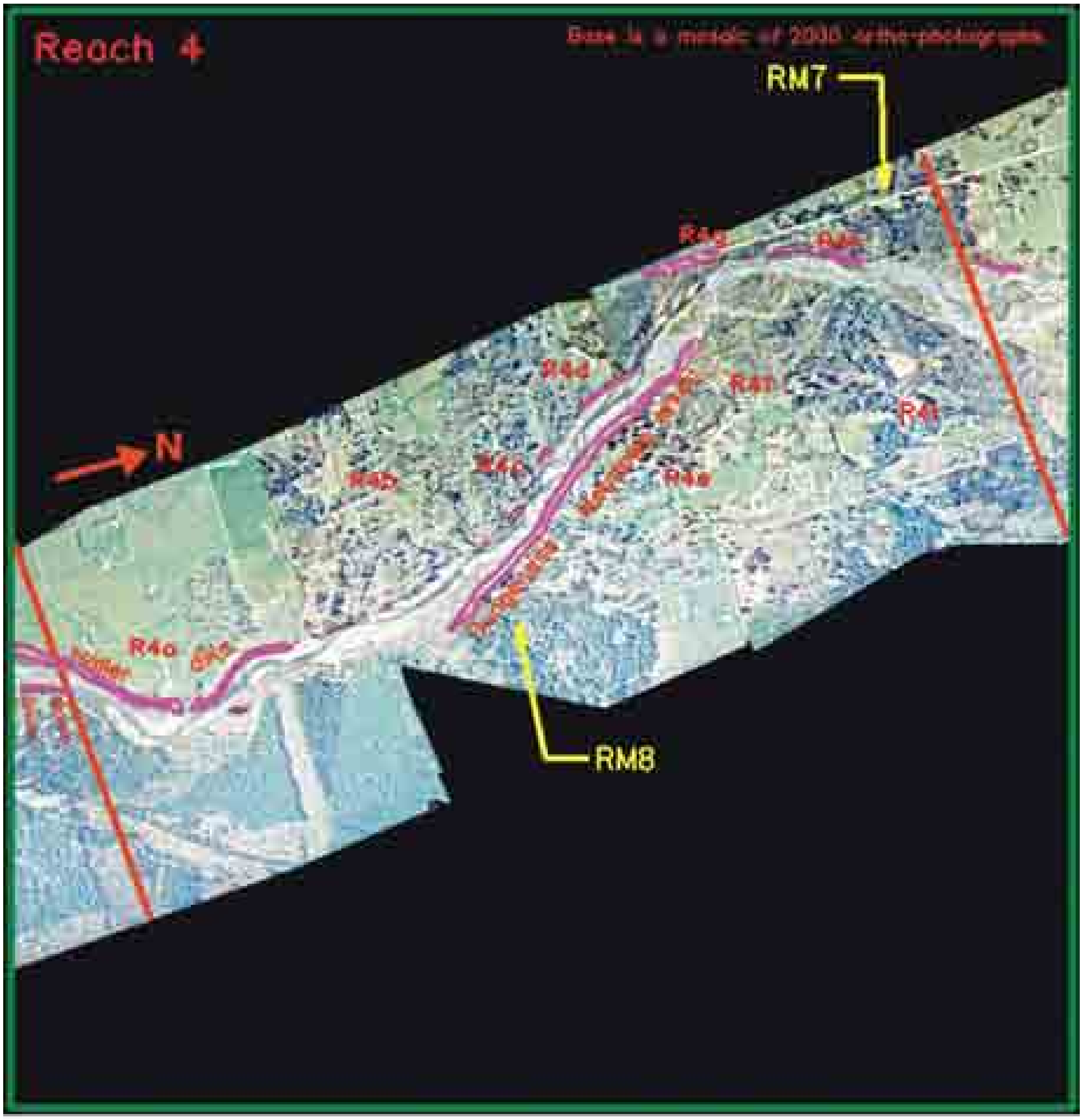


Figure O-11. Human-constructed features and areas of human activities in and near the active channel for Reach 4. Features were mapped from a mosaic of ortho-photographs taken in 2000. Irrigation out-take is near locality R4d.

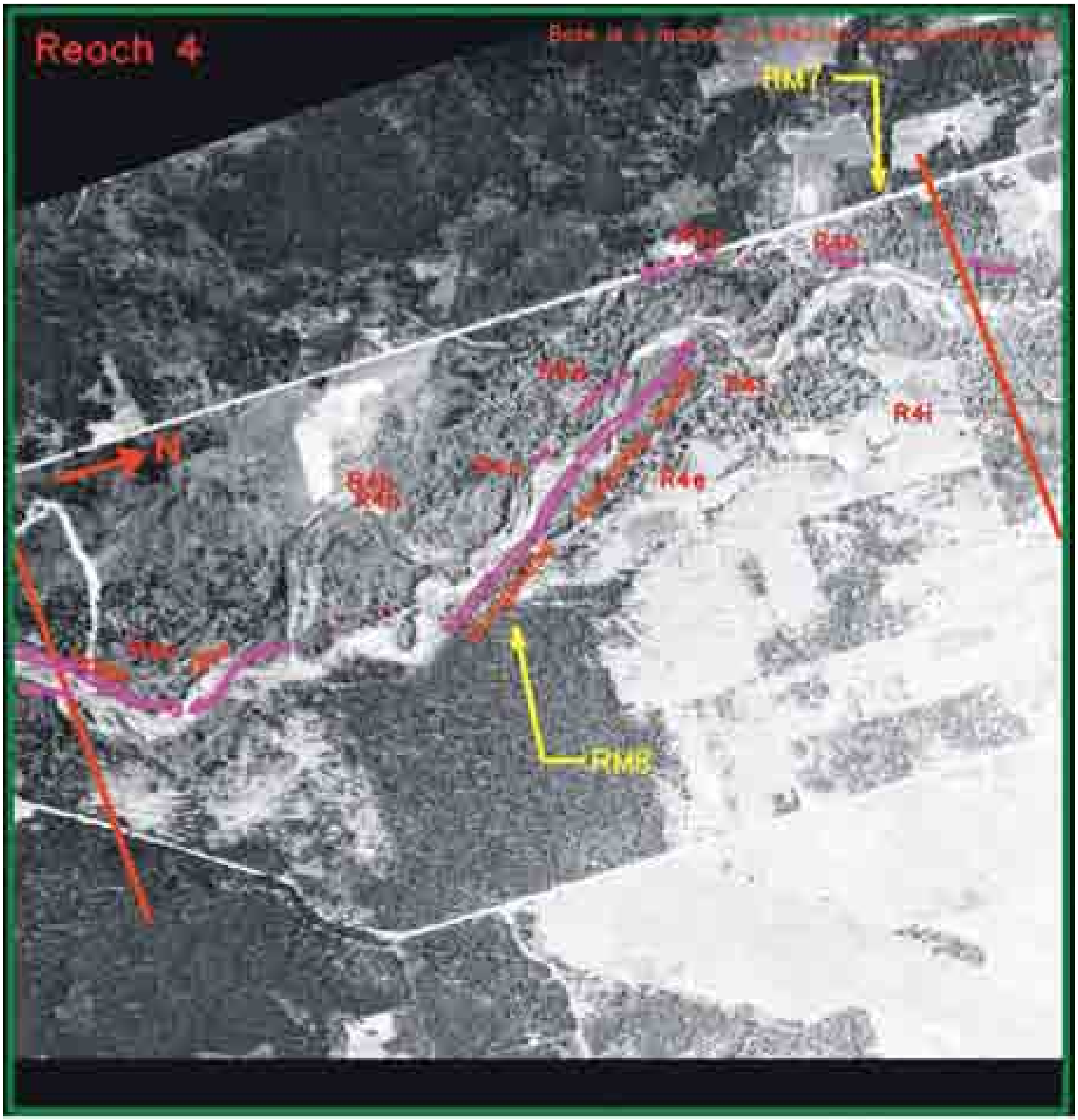


Figure O-12. Locations of the primary levees and some of the other human modifications that were present in 2000 in Reach 4 and shown on aerial photographs taken in 1942/43.

Figure O-13. Active channels mapped from aerial photographs taken in 1942/43, 1965, and 2000 for Reach 3 (RM 7 to 4.6). Channels are shown on a mosaic of ortho-photographs taken in 2000. Labels beginning with R indicate localities discussed in the text and tables

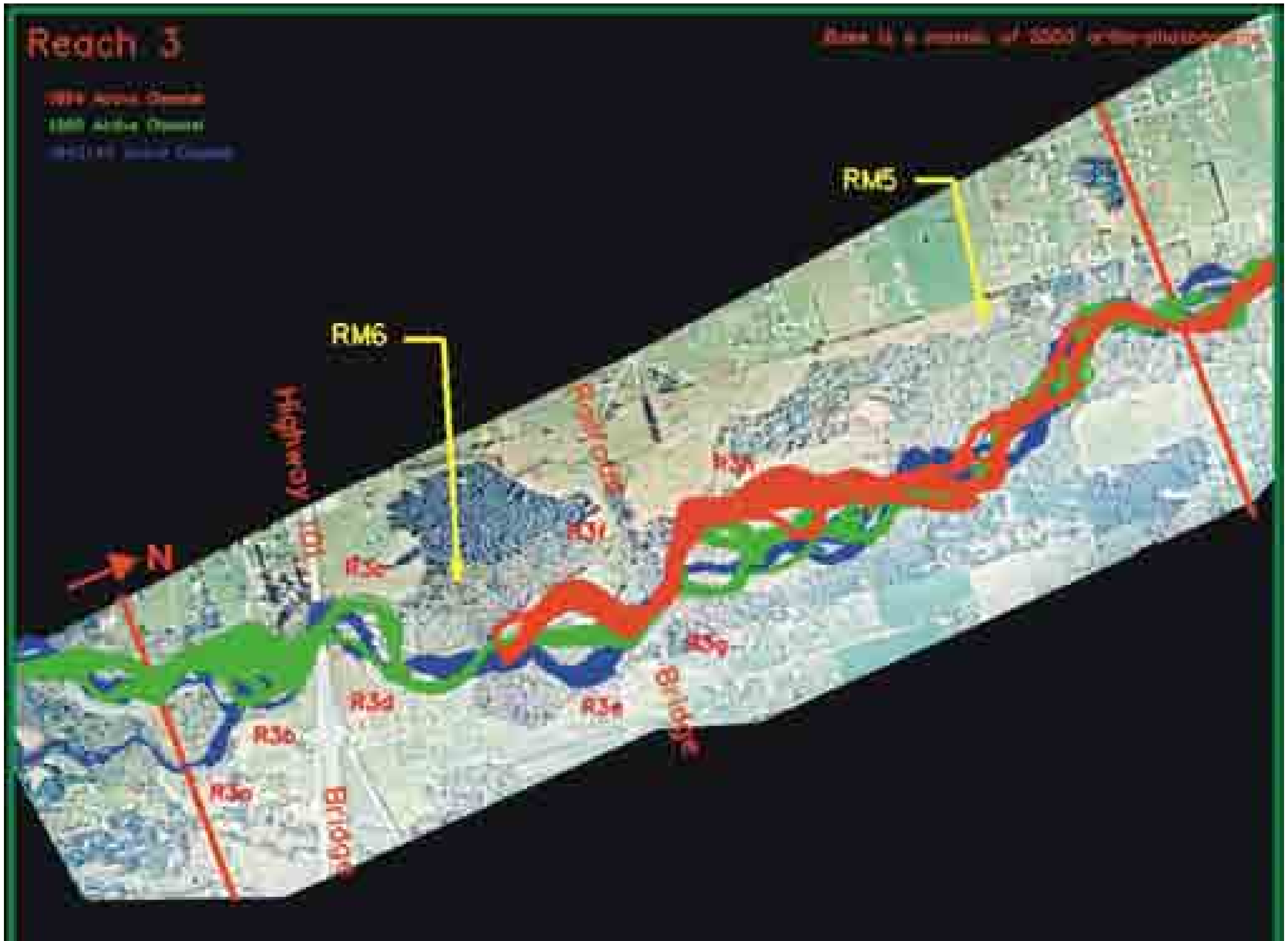


Figure O-14. Active channels mapped from aerial photographs taken in 1942/43, 1965, and 1994 for Reach 3 (RM 7 to 4.6). Channels are shown on a mosaic of ortho-photographs taken in 2000. The 1994 photographs cover the lower part of the reach only.

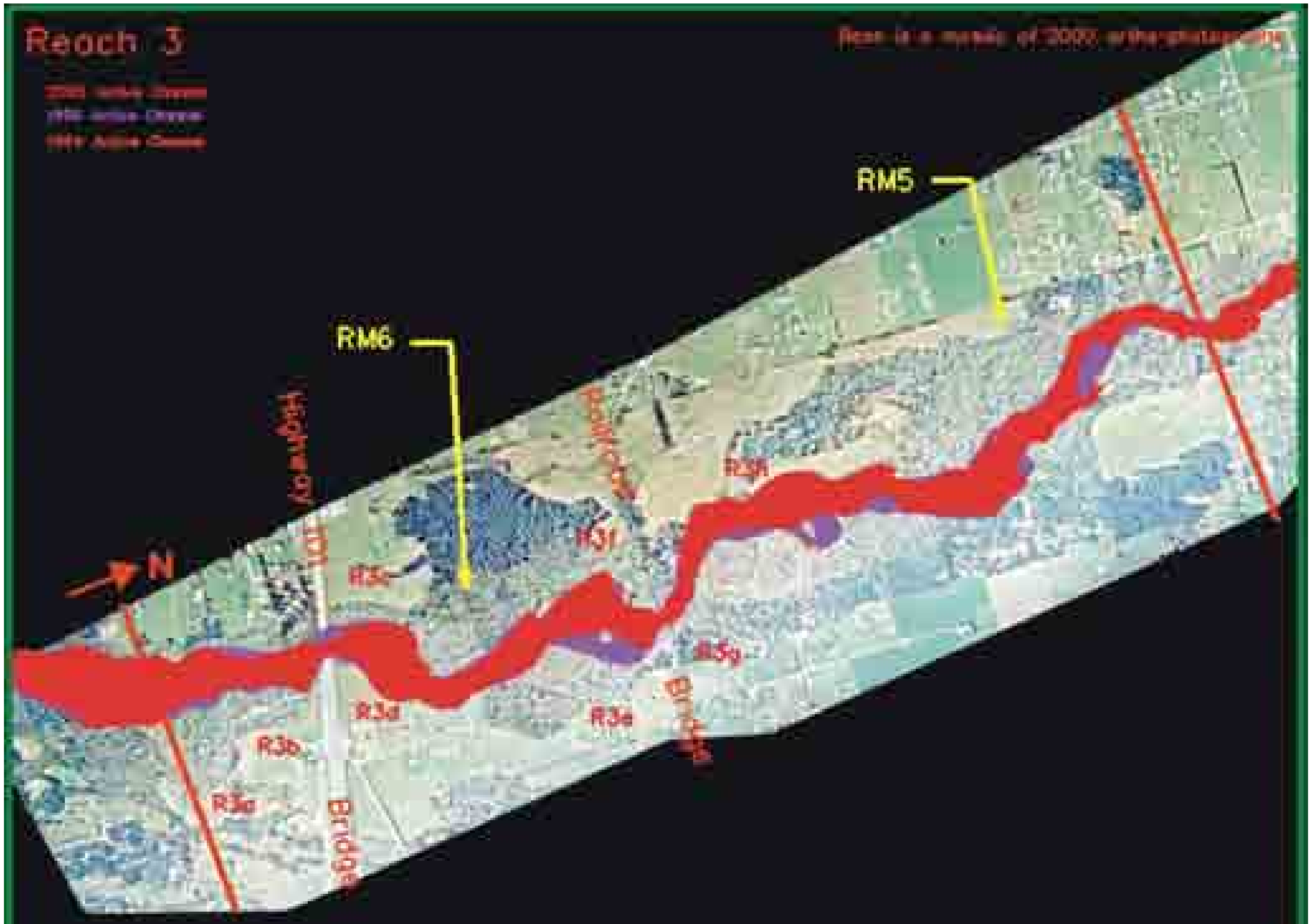


Figure O-15. Active channels mapped from aerial photographs taken in 1994, 1996, and 2000 for Reach 3 (RM 7 to 4.6). Channels are shown on a mosaic of ortho-photographs taken in 2000. The 1994 photographs cover the lower part of the reach only.

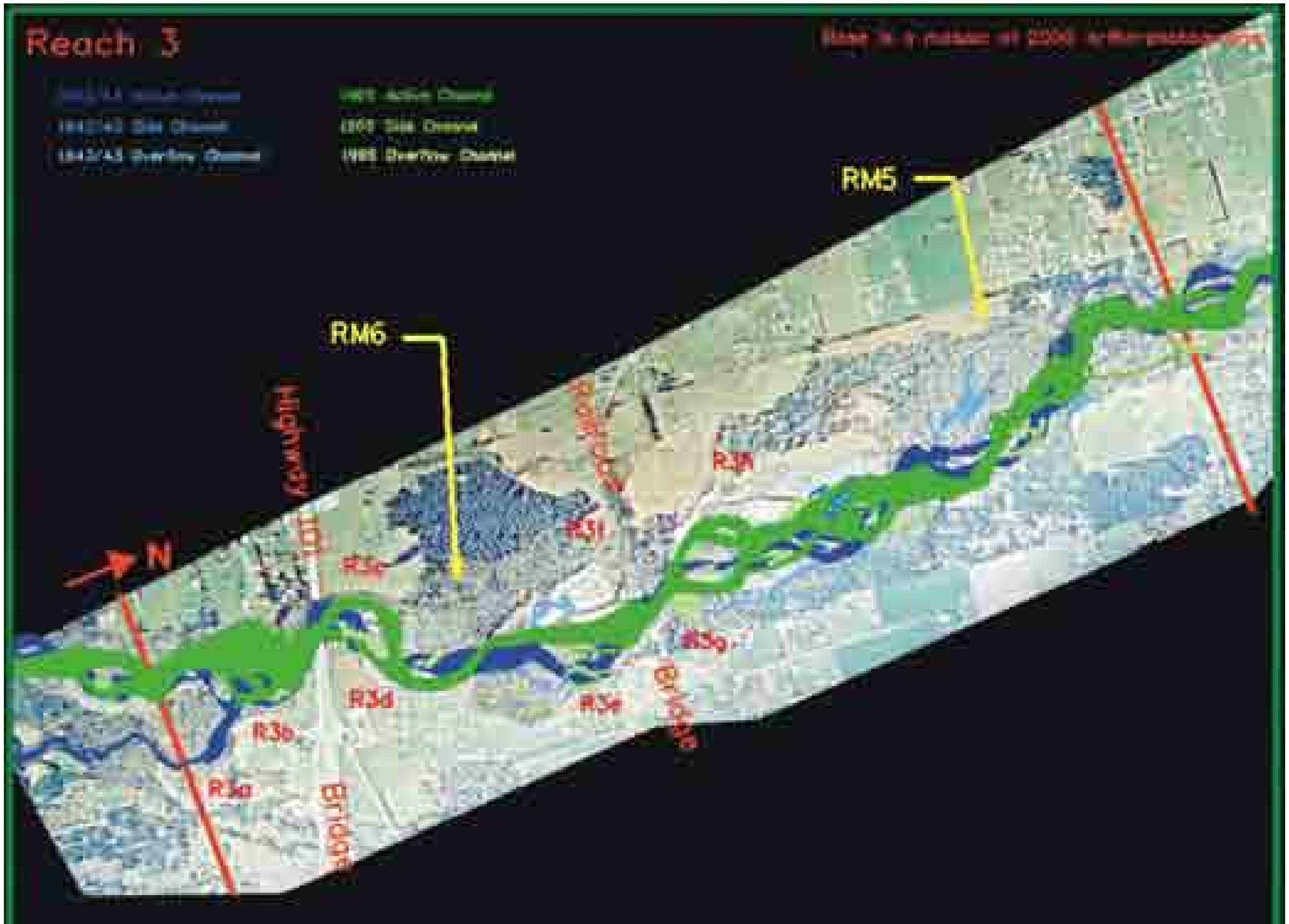


Figure O-16. Active channels, side channels, and overflow channels mapped from aerial photographs taken in 1942/43 and 1965 for Reach 3. Channels are shown on a mosaic of ortho-photographs taken in 2000. Differences in the side and overflow channels may reflect their expression on the photographs rather than changes in the channels.

Figure O-17. Woody debris in the active channel and side channels in Reach 3. Both large stacks of wood and single logs that are visible on aerial photographs taken in 2000 are shown.

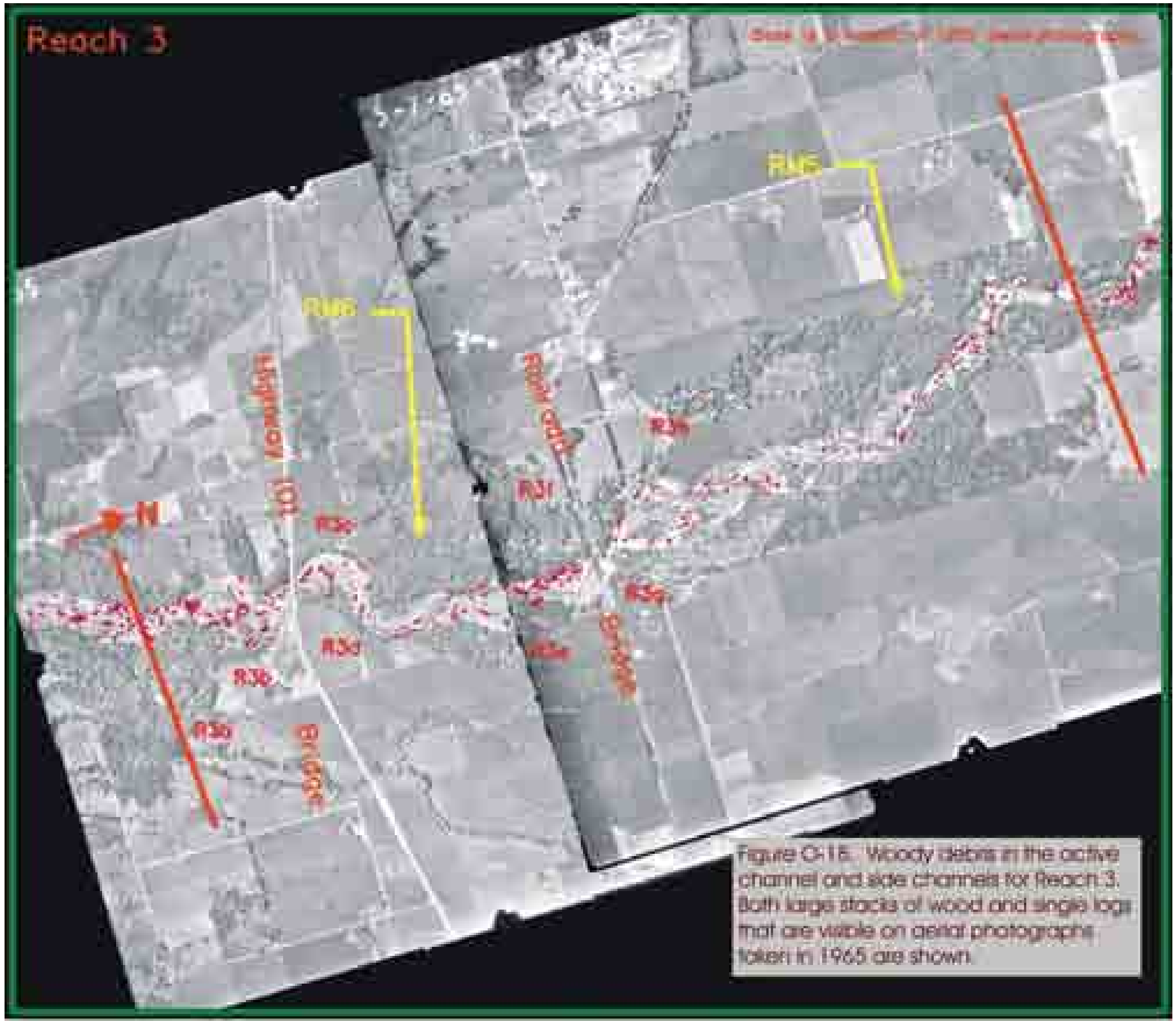


Figure O-18. Woody debris in the active channel and side channels for Reach 3. Both large stacks of wood and single logs that are visible on aerial photographs taken in 1965 are shown.

Figure O-19. Active channel and the boundaries of the present, prehistoric, and geologic floodplains interpreted for Reach 3 from aerial photographs taken in 1942/43, 1965, and 2000. Boundaries are dashed where approximately located and dotted where unclear.

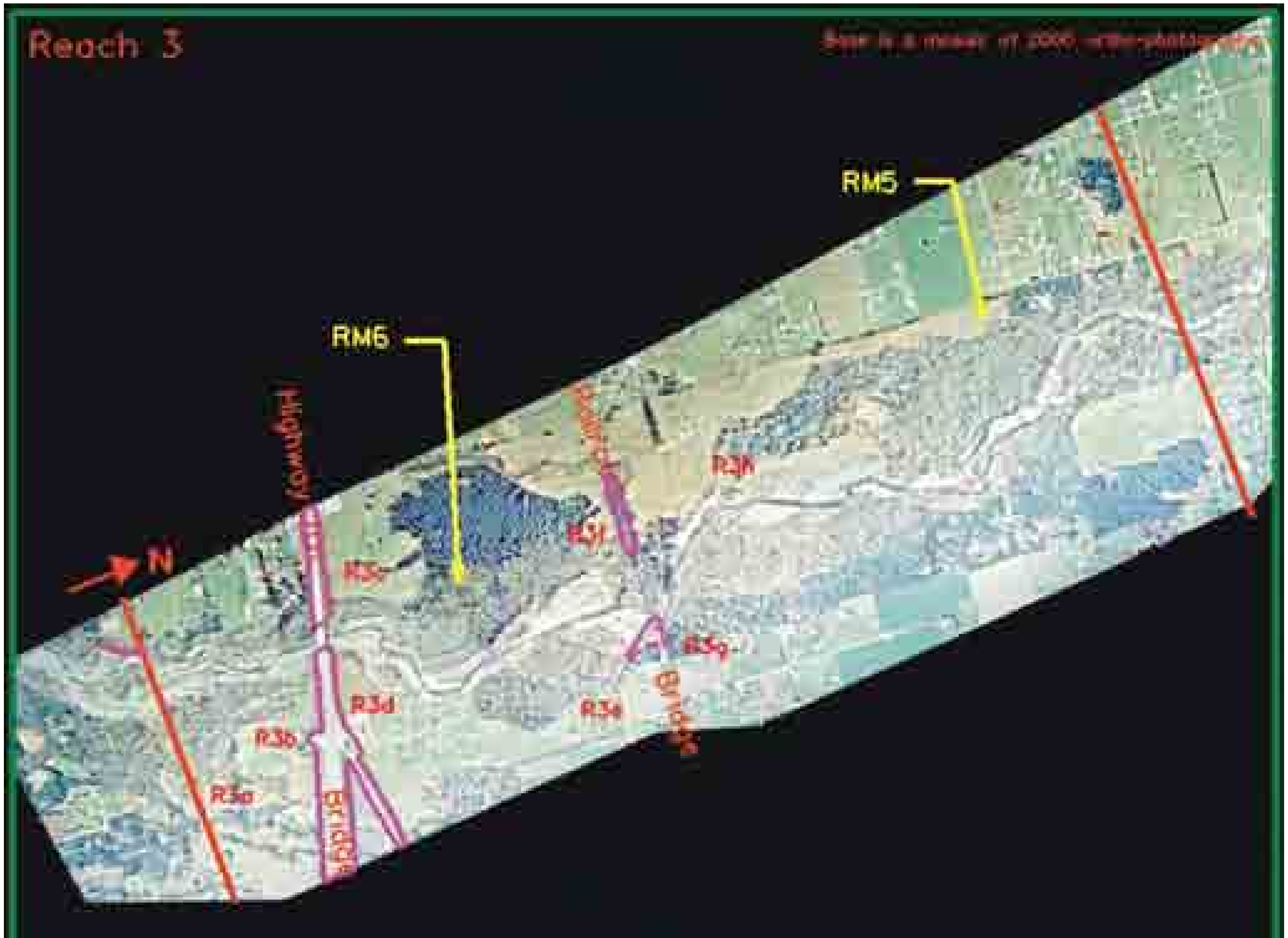


Figure O-20. Human-constructed features and areas of human activities in and near the active channel for Reach 3. Features were mapped from a mosaic of ortho-photographs taken in 2000.

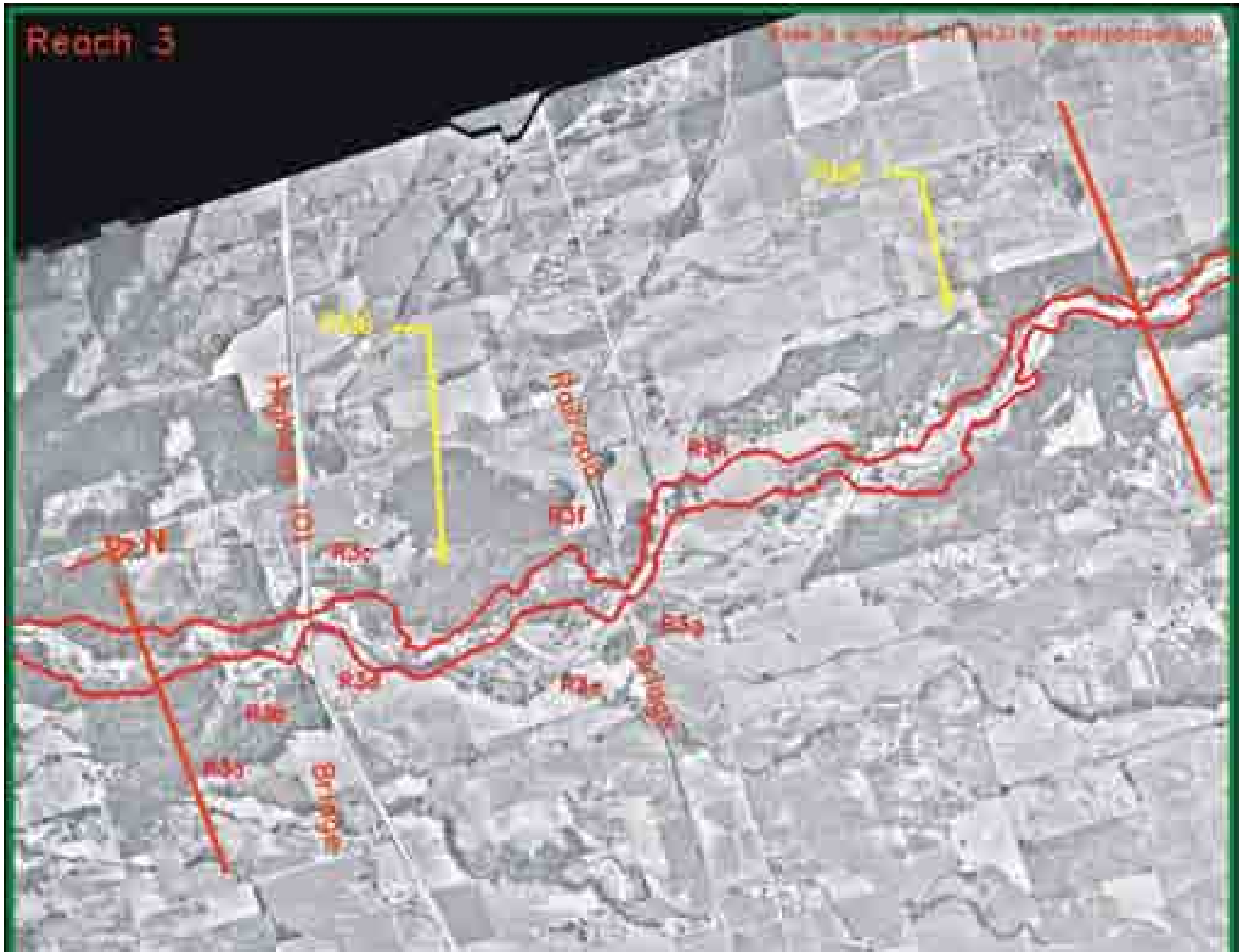


Figure O-21. Active channel that was mapped from aerial photographs taken in 2000 for Reach 3 and shown on aerial photographs taken in 1942/43. Note the changes in the location of the channel between the two years, especially immediately upstream and downstream of Railroad Bridge.

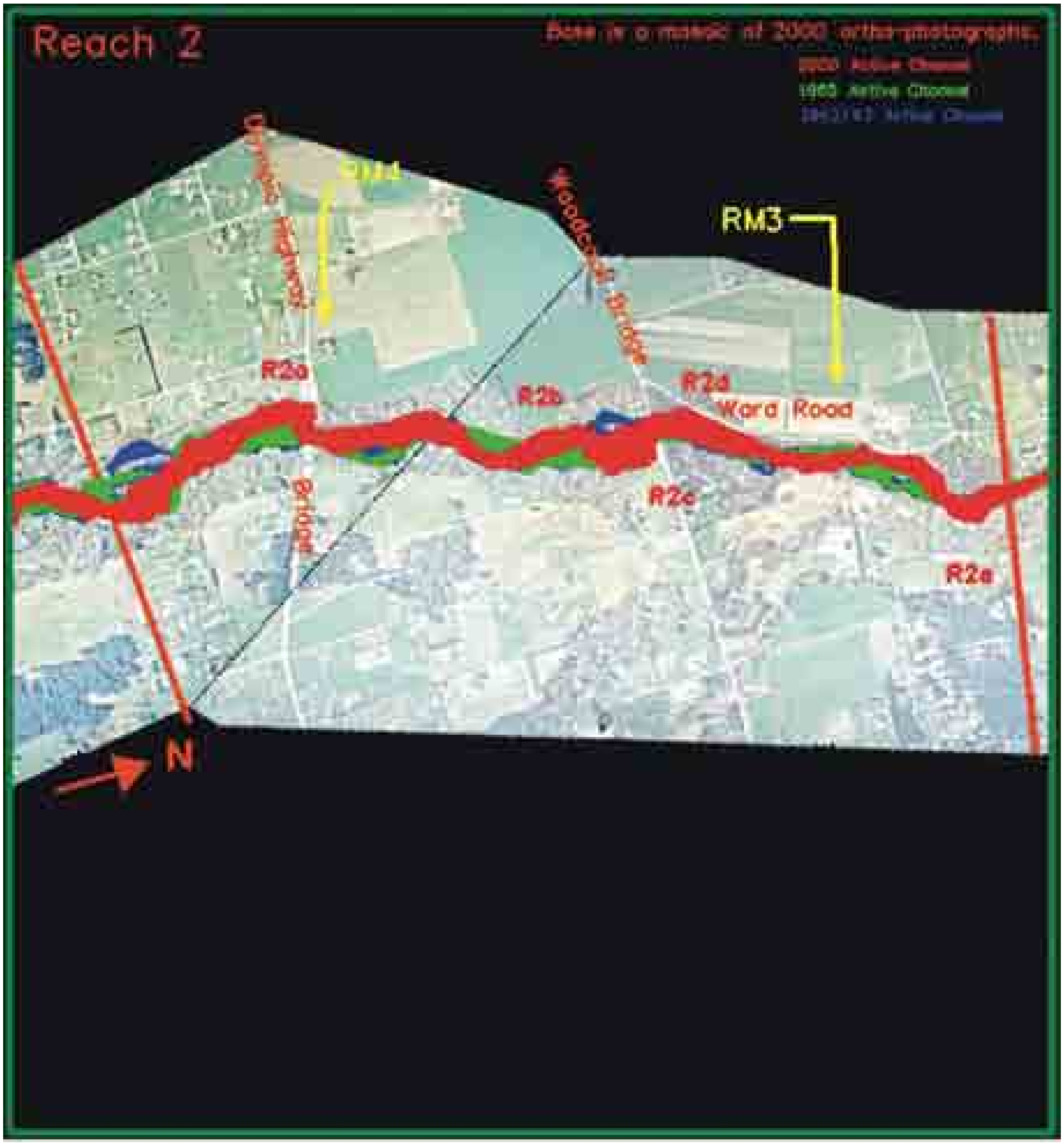


Figure O-22. Active channels mapped from aerial photographs taken in 1942/43, 1965, and 2000 for Reach 2 (RM 4.6 to 2.6). Channels are shown on a mosaic of ortho-photographs taken in 2000. Labels beginning with R indicate localities discussed in the text and tables.

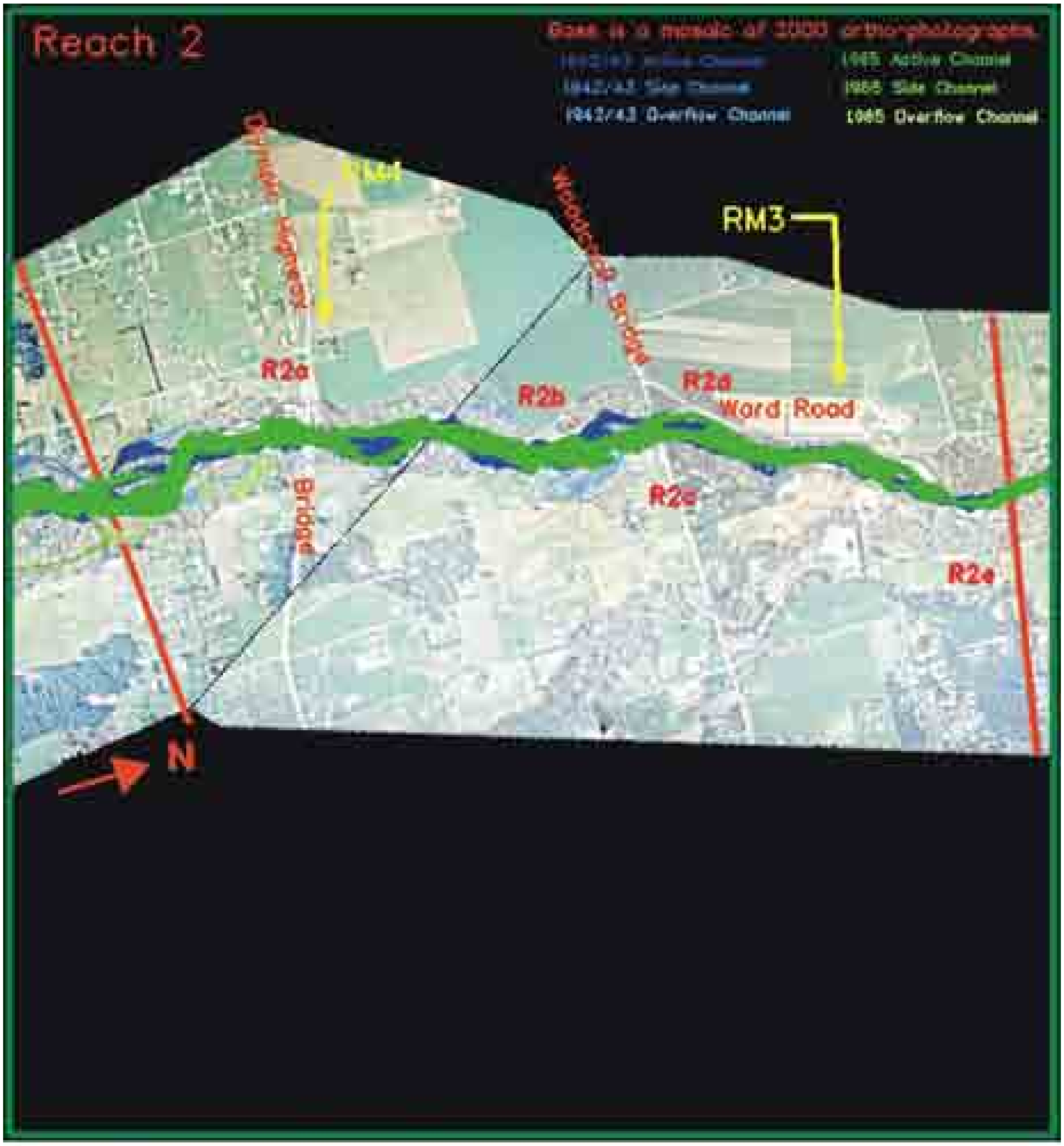


Figure O-23. Active channels, side channels, and overflow channels mapped from aerial photographs taken 1942/43 and 1965 for Reach 2. Channels are shown on a mosaic of ortho-photographs taken in 2000. Differences in the side and overflow channels may reflect their expression on the photographs rather than changes in the channels.

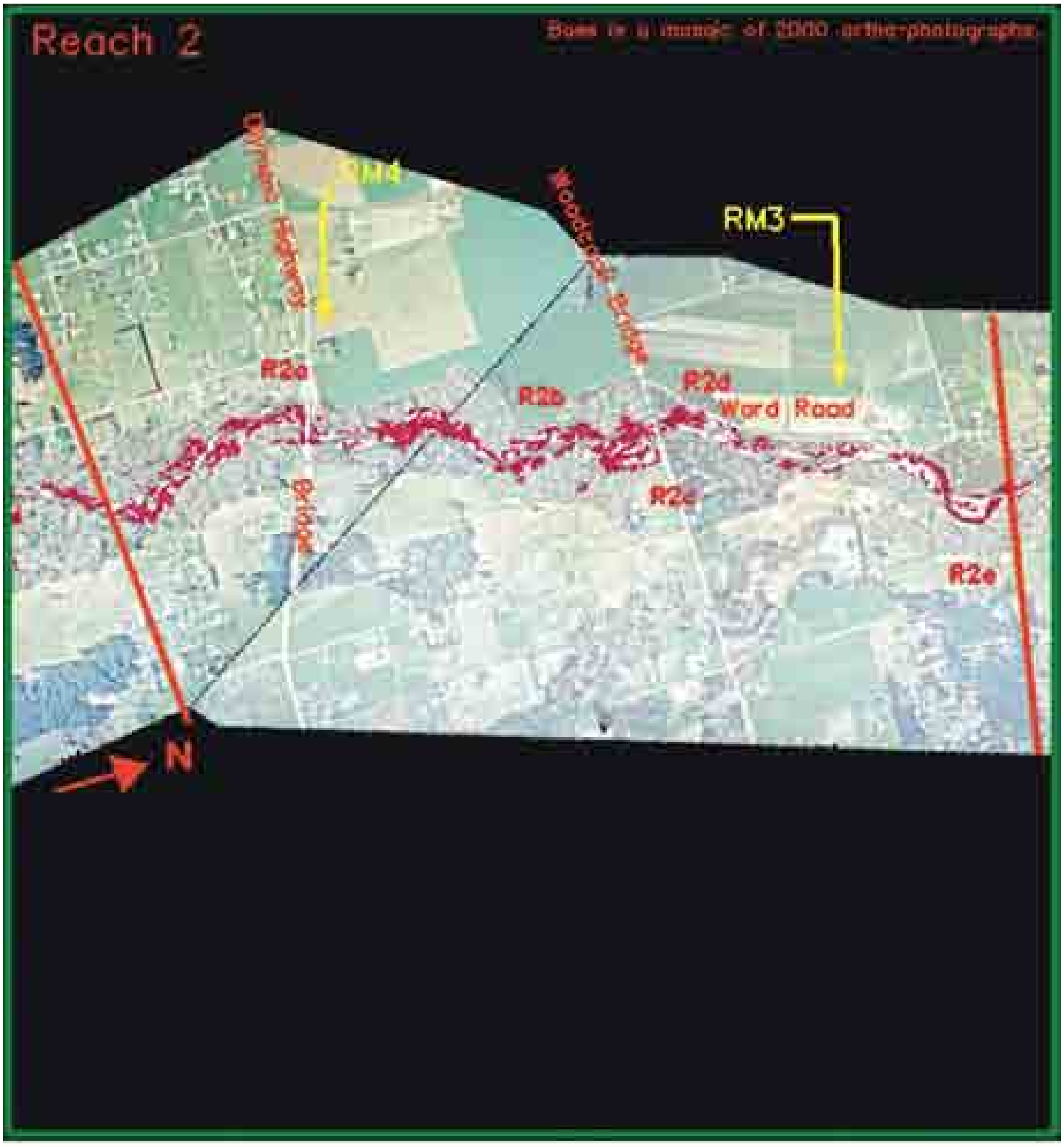


Figure O-24. Woody debris in the active channel and side channels for Reach 2. Both large stacks of wood and single logs that are visible on aerial photographs taken in 2000 are shown.

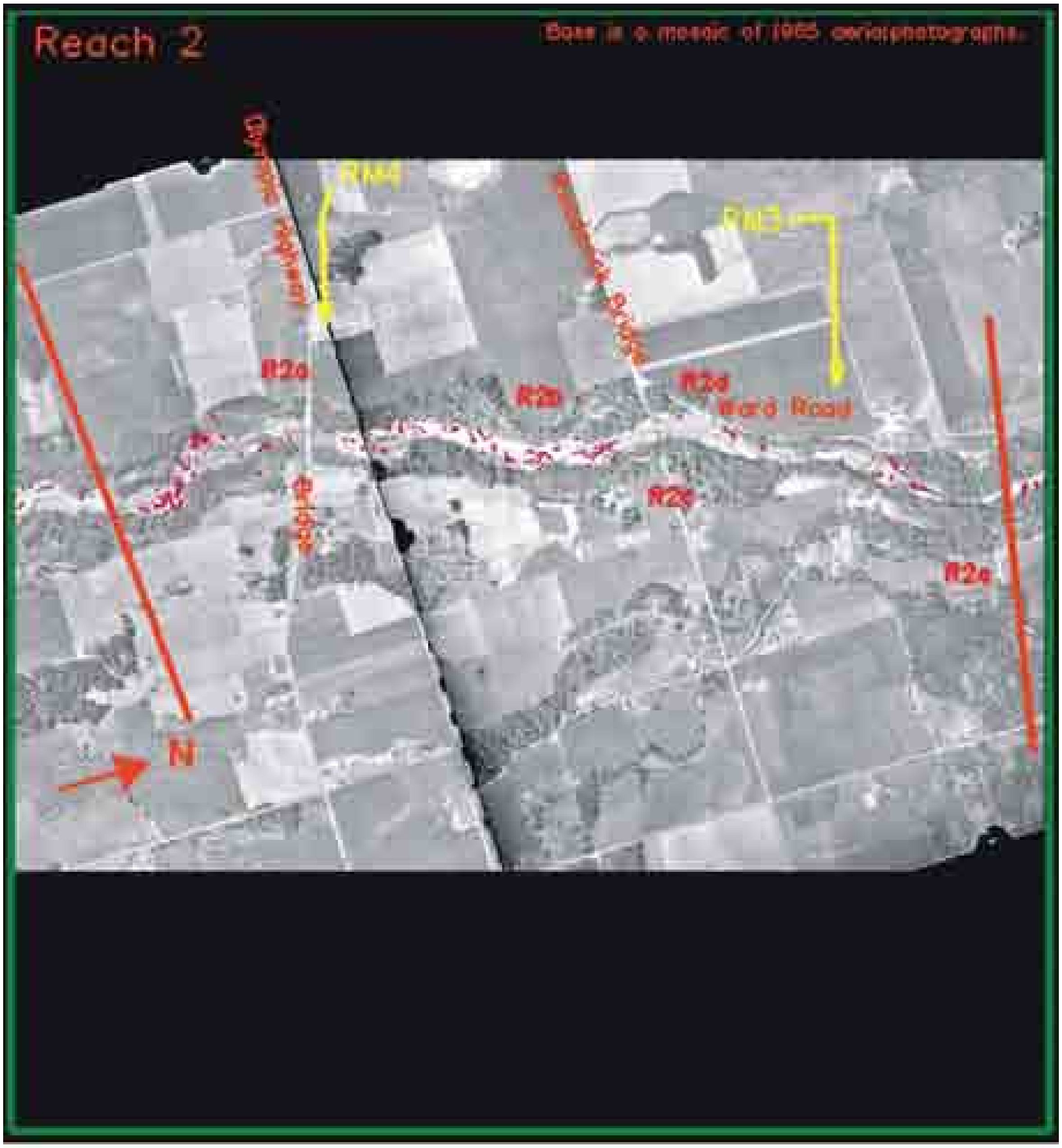


Figure O-25. Woody debris in the active channel and side channels for Reach 3. Both large stacks of wood and single logs that are visible on aerial photographs taken in 1965 area shown.

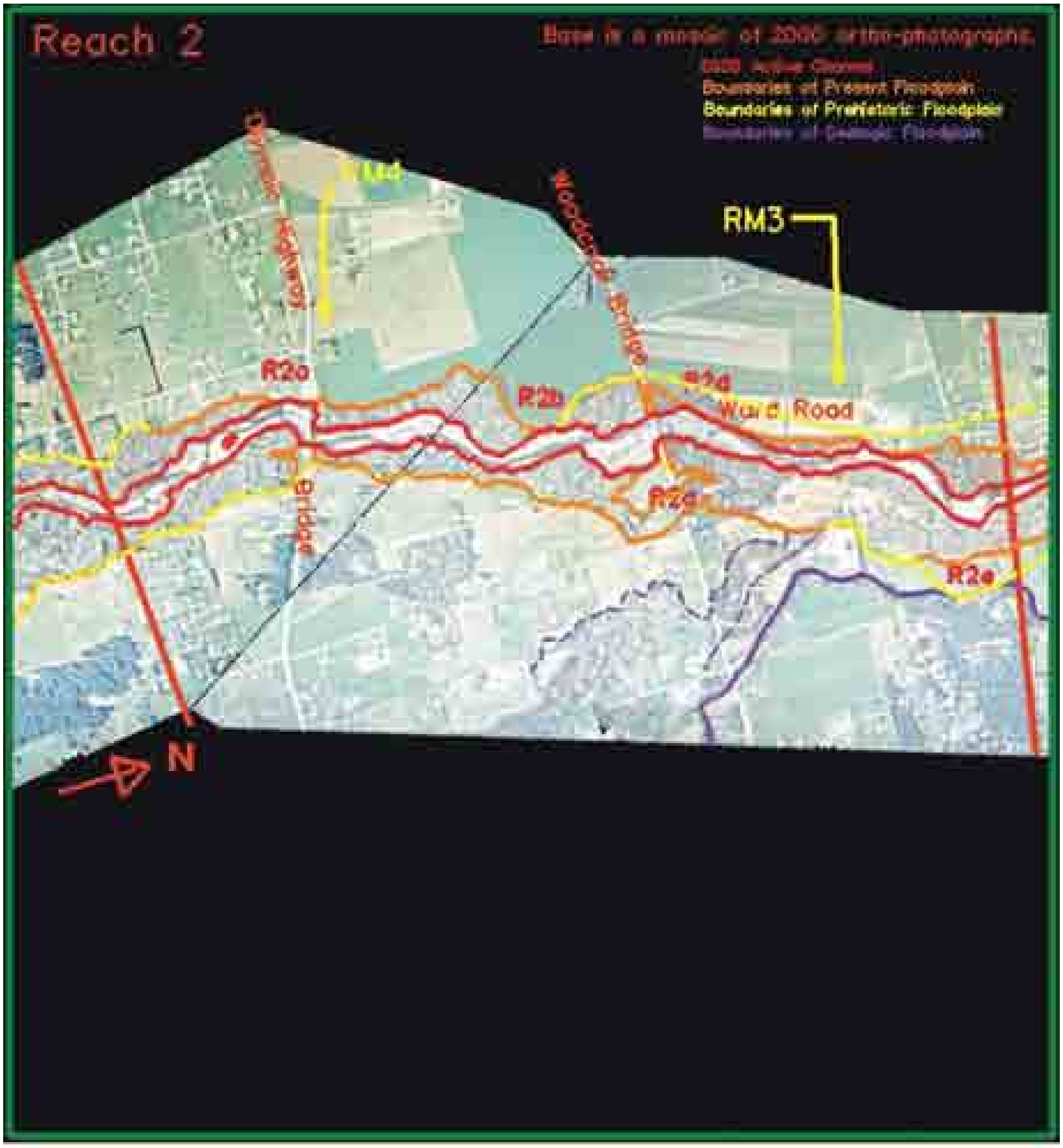


Figure O-26. Active channel and the boundaries of the present, prehistoric, and geologic floodplains interpreted for Reach 2 from aerial photographs taken in 1942/43, 1965, and 2000. Boundaries are dashed where approximately located and dotted where unclear.

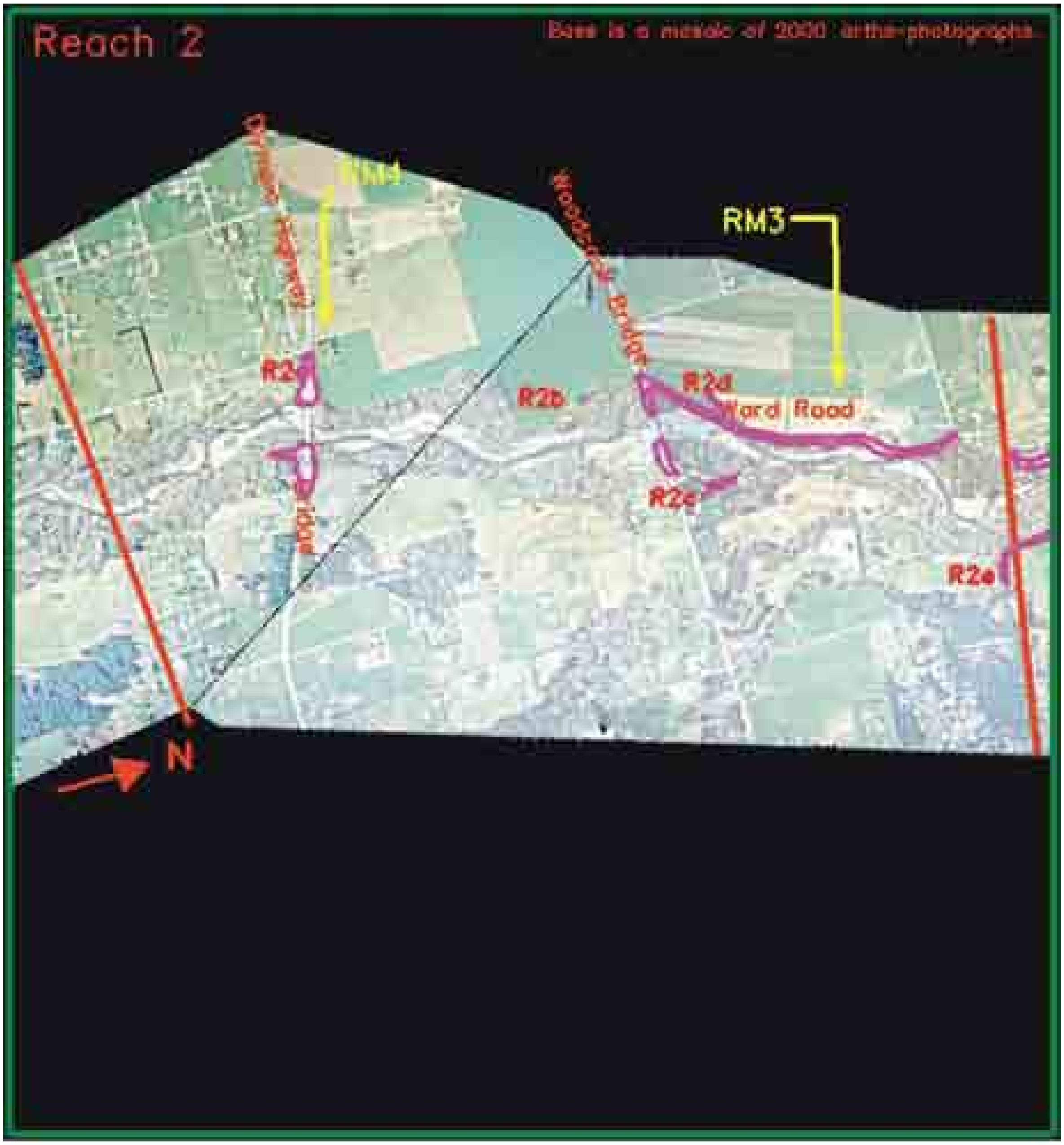


Figure O-27. Human-constructed features and areas of human activities in and near the active channel for Reach 2. Features were mapped from a mosaic of ortho-photographs taken in 2000.

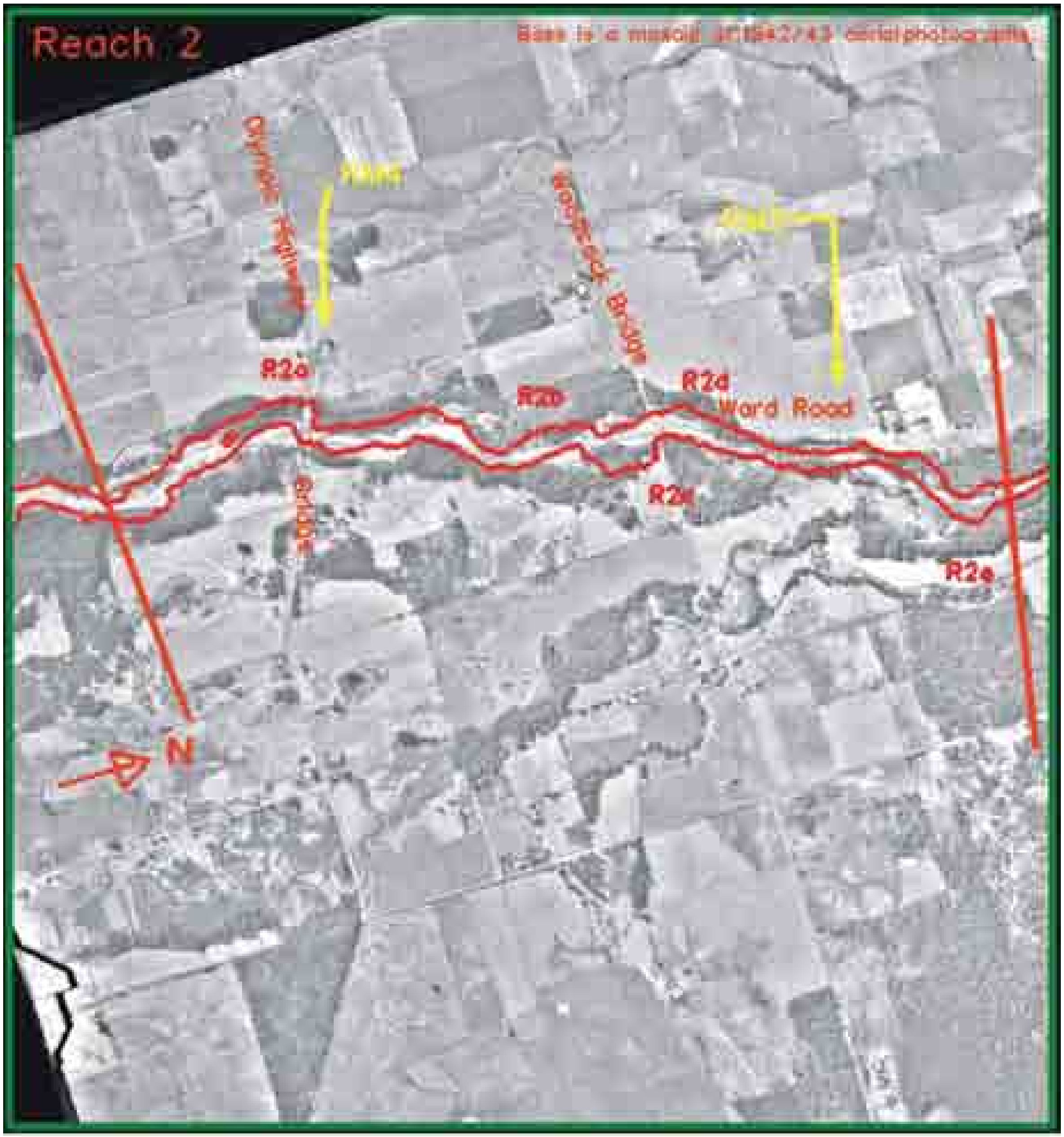


Figure O-28. Active channel that was mapped from aerial photographs taken in 2000 for Reach 2 and shown on aerial photographs taken in 1942/43.

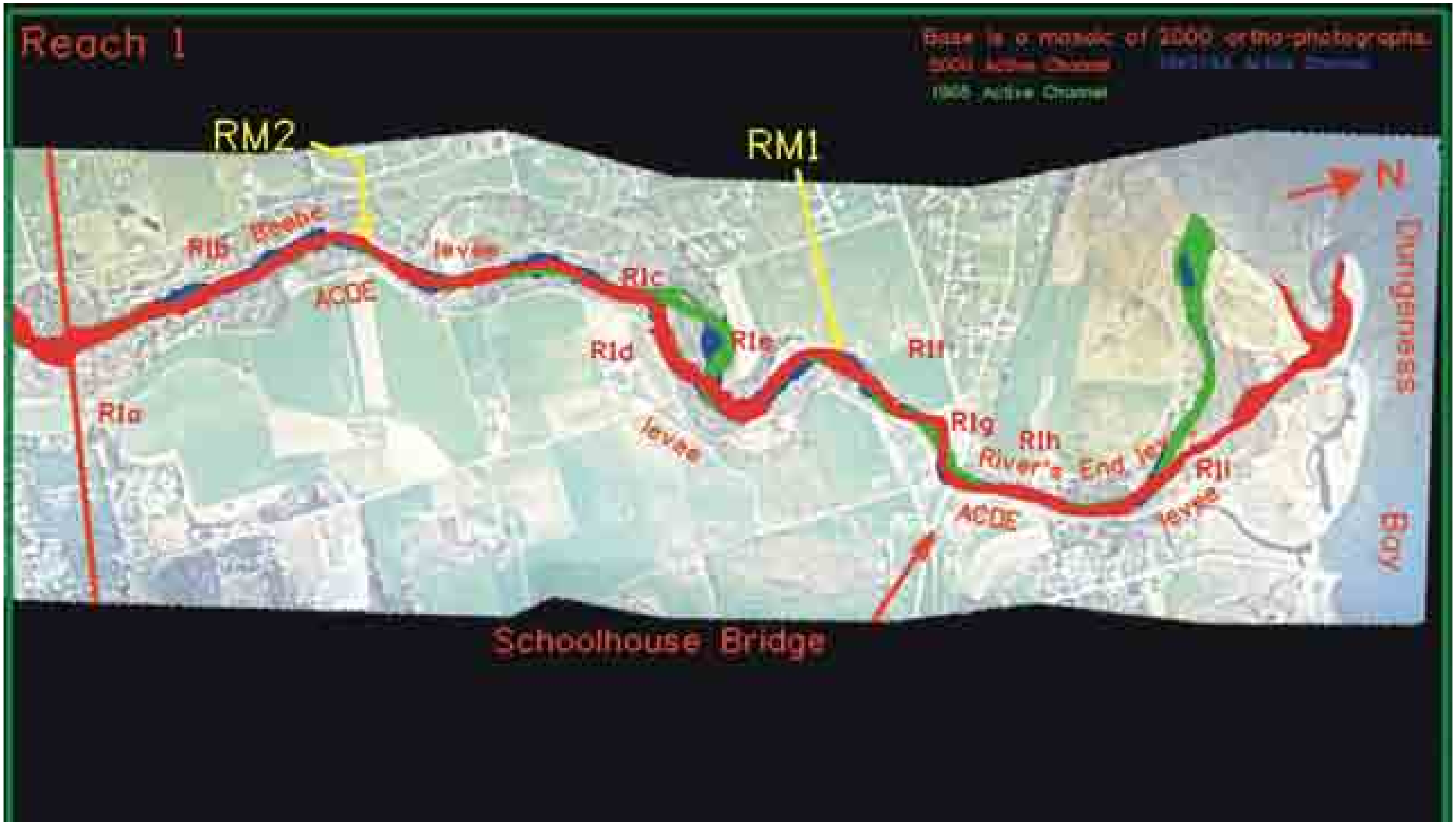


Figure O-29. Active channels mapped from aerial photographs taken in 1942/43, 1965, and 2000 for Reach 1 (RM 2.6 to 0). Channels are shown on a mosaic of ortho-photographs taken in 2000. Labels beginning with R indicate localities discussed in the text and tables.

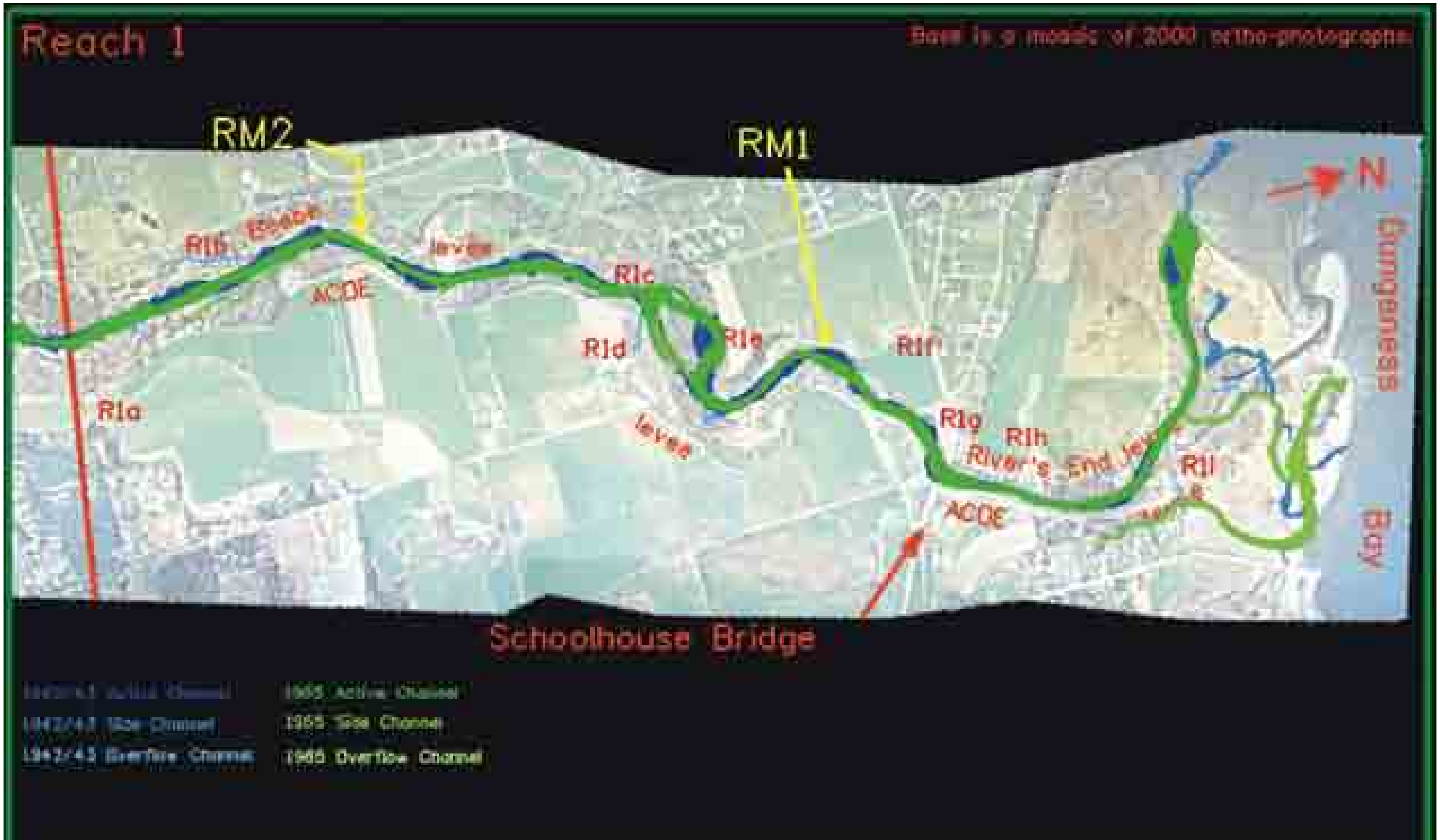


Figure O-30. Active channels, side channels, and overflow channels mapped from aerial photographs taken in 1942/43 and 1965 for Reach 1. Channels are shown on a mosaic of ortho-photographs taken in 2000. Differences in side and overflow channels may reflect their expression on the photographs rather than changes in the channels.

Figure O-31. Woody debris in the active channel and side channels for Reach 1. Both large stacks of wood and single logs that are visible on aerial photographs taken in 200 are shown.

Figure O-32. Woody debris in the active channel and side channels for Reach 1. Both large stacks of wood and single logs that are visible on aerial photographs taken in 1965 are shown. Debris is shown on a mosaic of aerial photographs taken in 1965.

Figure O-33. Active channel and the boundaries of the present, prehistoric, and geologic floodplains interpreted for Reach 1 from aerial photographs taken in 1942/43, 1965, and 2000. Boundaries are dashed where approximately located and dotted where unclear. Beebe levee is the same as the Olympic Game Farm levee.

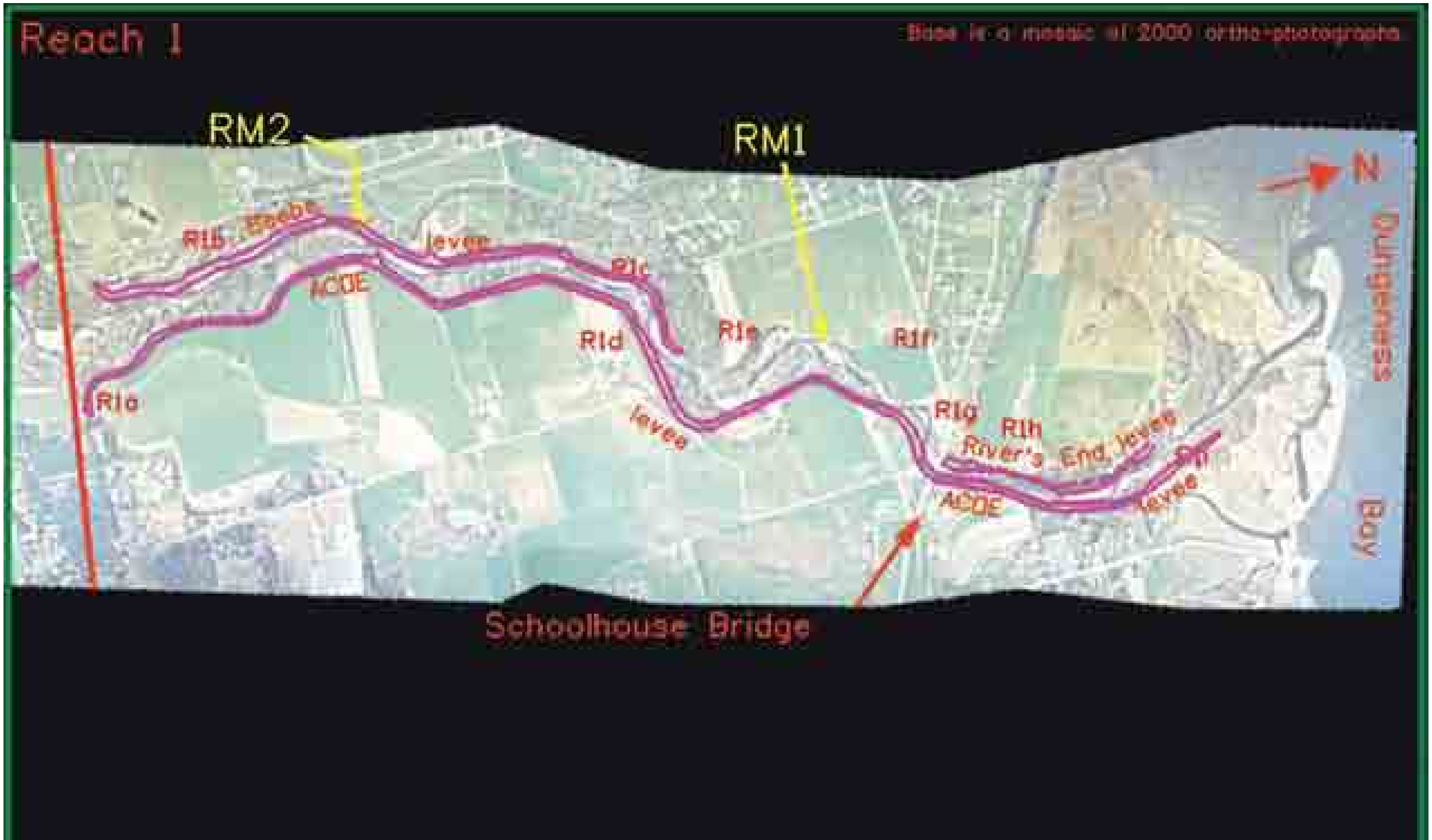


Figure O-34. Human-constructed features and areas of human activities in and near the active channel for Reach 1. Features were mapped from a mosaic of ortho-photographs taken in 2000.

Figure O-35. Active channel that was mapped from aerial photographs taken in 2000 for Reach 1 and shown on aerial photographs taken in 1942/43. Note the similarity in the locations of the active channels in the two years.

APPENDIX Q
STRATIGRAPHY OF TERRACES ADJACENT TO THE DUNGENESS RIVER

Q.1. Introduction

The surfaces adjacent to the present active channel and the deposits underlying these surfaces preserve the recent geologic history of the Dungeness River corridor. The surfaces and underlying deposits were examined to determine the characteristics of the of the deposits, their extent and thickness, and their ages using radiocarbon dates and soil development. The primary goal of these studies was to determine the locations of the active channel of the Dungeness River through time, during the last few tens of thousands to a few thousand years, if possible. Secondly, we wanted to get an estimate of the ages of the surfaces (terraces) adjacent to the river. In trying to fulfill these two objectives, we found abundant charcoal within overbank deposits, which allowed us to estimate rates of deposition for the floodplain deposits. The charcoal was often concentrated in beds and associated with reddened sediment. We interpreted these layers to be the result of forest fires or burns within the watershed. The radiocarbon dates obtained from charcoal from these layers allows us to estimate the ages of these forest fires.

Q.2. Methods

During field reconnaissance as part of our study, we examined in accessible exposures of the sediments below surfaces adjacent to the active channel of the Dungeness River. Most of these were vertical exposures created by lateral cutting by the river. Stratigraphy and soils were described in detail in four natural exposures (DRsoil-1, DRsoil-2, DRsoil-7, and DRstrat-1; Table Q-1; Figure Q-1). Descriptions were done in hand-dug pits at two localities (DRsoil-2 and DRsoil-4; Table Q-1) and in backhoe excavations at three localities (DRsoil-3, DRsoil-5, and DRsoil-6). Localities DRsoil-3 and DRsoil-5 were selected because the backhoe pits had been dug by the landowners for other uses.

After completing detailed descriptions, in which the characteristics and thicknesses of the sediments were noted, we collected charcoal, where available, from units that we thought would provide the most information about the age of channel deposits, overbank deposits, or burn layers. If individual pieces of charcoal were not observable in a unit that we thought was important stratigraphically or if the charcoal was very small and broadly disseminated throughout a unit, we collected a bulk sample of the sediment from which charcoal could be extracted in a laboratory (Table Q-2; Appendix K). The charcoal samples were cleaned and subdivided by species (Appendix K). For these sub-samples, the ones that we thought would provided the most stratigraphic information were sent to Beta Analytic, Inc. for radiocarbon dating (Table Q-2; Appendix J).

In order to determine the stability of the surfaces, soils developed in the sediments were noted and described (Appendix I). We concentrated on soils that are related to the present surfaces, although buried soils, if present, also were described.

Q.3. Characteristics of the Deposits and Stratigraphic Interpretation

At most of the localities where we examined them, the sediments below surfaces adjacent to the Dungeness River consist of fine-grained alluvium over gravelly alluvium. We interpret the fine-grained alluvium (primarily silt and sand) as overbank deposits that were deposited by the river at times of large floods. We interpret the gravelly alluvium (primarily cobbles, pebbles, and sand) as channel deposits of the Dungeness River. The overbank deposits vary in thickness from about 50 cm (20 in) to about 200 cm (80 in) (Figure Q-2). Some eolian (wind-blown) silt may be present in the upper portions of some of the sediments, especially in the upstream section of our study reach.

At two localities (DRstrat-1 and DRsoil-5; Figure Q-1), fine-grained alluvium directly overlies fine-grained, unsorted sediment that we interpret to be glacial deposits. These two localities are near the Schoolhouse Bridge on surfaces that are elevated above the surrounding surfaces that are adjacent to the Dungeness River. The overbank alluvium at these two localities is about 75 to 100 cm (30 to 40 in) thick (Figure Q-2).

The stratigraphy at individual localities is discussed briefly in the following sections in order of downstream to upstream (Figure Q-1).

Locality DRstrat-1 at RM 0.7

This natural exposure is on the left bank of the Dungeness River about 150 m (495 ft) upstream of Schoolhouse Bridge (Figure Q-1). The total height of the exposure is about 3 m (10 ft; Figure Q-3). The Dungeness River flows along the base of the exposure.

The lower 15 to 35 cm (6-14 in) of the exposure is very compact silt that includes scattered pebbles. The unit breaks into blocks and has contorted bedding. We interpret this sediment as a glaciomarine deposit that may be correlative with the transitional unit of the youngest (Vashon stade) glaciation that is described by Dethier and others (1995). The upper contact of this unit is erosional and slopes to the west (Figure Q-3).

Charcoal collected from a depth of 98 cm (39 in; Sample DRsoil-1-0) and within the glaciomarine sediment yielded a date of 1570 to 1410 cal yr BP. If this sediment is glacial, then its age should be at least 12,000 years (Section 2.1). Because the radiocarbon date is so much younger than indicated by the stratigraphy, we suspect that the charcoal is a root that is markedly younger than the surrounding sediment.

The upper 75 to 90 cm (30 to 35 in) of the exposure is weakly bedded, somewhat compact, fine-grained sediment (mostly silt) that we interpret as overbank deposits. Within this unit are two to four layers that consist of charcoal and reddened sediment. The most continuous of these layers are shown on Figure Q-3. The lowest (Burn 1) is just above the unconformity between the overbank sediments and the glaciomarine deposits between 65 and 90 cm (26-36 in) in depth. The upper layer (Burn 2) is between about 40 and 45 cm (16-18 in) in depth. Charcoal was collected from both of these layers. The date from Burn 1 is between1410 and 1280 cal yr BP;

the dates from Burn 2 are 520 to 430 cal yr BP and 380 to 320 cal yr BP (Figure Q-3; Appendix J).

The uppermost unit in the exposure is a dark gray, loose silty sand that is 5 to 15 cm (2-6 in) thick (Figure Q-3). Because of its looseness, color, and unconformable, abrupt contact with the unit below, we interpret this uppermost unit to be overbank sediment that has been deposited since the Corps of Engineers (ACOE) levee was built in 1963.

Locality DRsoil-5 at RM 0.7

Locality DRsoil-5 is on the same surface as the Dungeness Schoolhouse and is about 157 m (514 ft) east of the schoolhouse. The sediments in the upper 100 to 150 cm (39-59 in) of this surface were exposed in a utility trench that was dug by the landowner for a new residence. We examined the sediments along the trench and made descriptions of them in several places (Figure Q-4). In addition, we described the soil development at one location within the trench at DRsoil-5A (Appendix I).

At the highest part of the surface, we interpret the lower 30 to 50 cm (12-20 in) of the exposure to be glaciomarine deposits, correlative to those exposed in the lower part of the exposure at Locality DRstrat-1. This compact, mostly silty unit includes a few percent pebbles that are most granitic. The presence of the pebbles and their lithology suggest that this unit was deposited in a glaciomarine environment (Dethier and others, 1995). Charcoal collected from the upper part of this sediment, between depths of 95 and 102 cm (37-40 in; Sample DRsoil-5A-1) did not yield an interpretable date (Appendix J).

Above the glaciomarine deposits the sediment is primarily sand that is loose to hard. A soil has developed within the sediment that is slightly browner, more compact, and blocky than the original sand (Appendix I). The soil seems to be developed only on the highest part of the surface.

Downslope and to the north, the sediment is primarily gray, loose sand to depths between about 60 and 110 cm (24-43 in; Figure Q-4). Charcoal collected from the sand at two locations within the trench, at DRsoil-5B (Sample DRsoil-5B-1) and DRsoil-5C (Sample DRsoil-5C-1) yielded dates of 4240 to 3960 cal yr BP and 1820 to 1580 cal yr BP (Figure Q-4; Appendix J). We interpret this sandy unit to be either overbank deposits or beach deposits.

In the north part of the trench, the gray, loose sand overlies units that are either mostly silty or that include alternating beds of sand and silt (Figure Q-4). These deposits are on the lower edge of the surface and are likely overbank deposits that lap onto the glaciomarine sediments.

Locality DRsoil-3 at RM 1.6

This locality is on a surface on the east side of the Dungeness River just east of the ACOE levee and about 100 m (326 ft; Figure Q-1). The exposure was in a shallow (about 80 cm (30 in) deep) trench that was dug by the landowner along the edge of a plowed field in order to drain water from the field. All the exposed sediment was moist or wet. Water was present in the bottom of the trench.

The sediment exposed is fine and very fine sandy silt (Figure Q-5). We interpret this sediment to be fine-grained alluvium that has been deposited by overbank flows of the Dungeness River. Because the sediment is alternately and repeatedly wet and dry, the sediment is mottled blue-gray and red-brown. Large pieces of charcoal are present near the bottom of the trench between depths of 52 and 60 cm (about 23 in) (Figure Q-5). Dates on this charcoal range between 295 and 665 cal yr BP (Figure Q-5; Appendix J).

Locality DRsoil-6 at RM 2.5

Sediments and soil development were described in a backhoe pit on a cultivated surface about 2.5 m (7.5 ft) above the Dungeness River, about 162 m (530 ft) east of the river, and upstream of the ACOE levee (Figure Q-1). The sediments include three main units that are separated by unconformities (Figure Q-6).

The lower 30 to 50 cm (12-20 in) of the pit is loose, gravelly sand that includes rocks up to about 50 mm in diameter. This gravelly alluvium (3C3 horizon of soil) is probably channel deposits of the Dungeness River and is now 130 to 145 cm (51-57 in) below the ground surface (Figure Q-6). The upper part of this unit has been eroded and the contact slopes to the west.

Loose sand about 50 cm (20 in) thick overlies the gravelly alluvium (Figure Q-6). The sand is primarily overbank sediment. However, a lens of gravelly sand near the base of this unit suggests that the lower part was deposited near the edge of the channel. A bulk sediment sample collected between depths of 110 and 120 cm (43-47 in; Sample DRsoil-6-1), near the base of the sand, yielded radiocarbon dates of 1170 and 970 cal yr BP (Figure Q-6; Appendix J). This would be a minimum age for the position of the active channel at this location. The upper part of this unit has been eroded and the contact slopes to the west.

The sediment above the loose sand includes alternating sand and silt beds that are 6 to 13 cm (2 to 5 in) thick (Figure Q-6; C1 horizon of soil). The alternating beds and the finer grain size of this sediment relative to the underlying sand suggest that the active channel of the Dungeness River has moved farther from this locality so that only lower velocity overbank flows reached the locality during this time. A soil that includes browner colors than the underlying sediment and weak clay films that indicate movement of clay within the sediment (Figure Q-6; Appendix I). Charcoal collected from a silt bed in the lower part of the upper sediment between depths of 57 to 60 cm (22 to 24 in; Sample DRsoil-6-3) yielded radiocarbon dates of 680 to 630 cal yr BP and 600 to 560 cal yr BP (Figure Q-6; Appendix J). Charcoal sampled from the upper part of this unit at a depth of 29 to 30 cm (11 to 12 in; Sample DRsoil-6-8) yield a radiocarbon dates of $\leq$430 cal yr BP. This is likely a minimum age for the sediment because the shallow depth of the charcoal and its position at the base of the Btj horizon of the soil, where roots and bioturbation are likely.

Locality DRstrat-2 at RM 4.5

This natural exposure nearly 2.1 m (7 ft) high is along a present overflow channel on the left (west) side of the Dungeness River (Figure Q-1). The surface is about 2.7 m (9 ft) above the active channel of the river. The sediment is in two main units of different textures and origin that are separated by an erosional unconformity (Figure Q-7).

The lower 50 to 60 cm (20-24 in) of the exposure is weakly bedded, loose, sandy gravel that was deposited in the active channel of the Dungeness River, when the main channel was at this locality (Figure Q-7).

The sediment above the gravelly alluvium consists of alternating beds of sand and silt (Figure Q-7). Individual beds are 5 to 30 cm (2-12 in) thick. The entire package of sediment is between 180 and 185 cm (71-73 in) thick. The lowest silt-rich bed contains about 10% pebbles and scattered charcoal. The presence of the gravel suggests a transitional unit between the active channel and the finer overbank deposits above. A bulk sample collected from this unit yielded charcoal that dated between 4430 and 4240 cal yr BP (Figure Q-7; Appendix J).

Above the transitional unit, some of the silty beds are reddish orange and include charcoal. In contrast, the sandy beds, and some silty beds, are gray. At least four of the reddish, charcoal-rich beds are nearly continuous along the exposure. Because of their color and common charcoal, we interpret these beds to represent periods when forest fires occurred at the site or in a large part of the drainage. The sediment was either burned in place or the sediment and charcoal were eroded from elsewhere in the drainage and redeposited at this locality during high (flood) flows that overtopped the surface.

Charcoal from the lowest reddened layer (Burn 1 between 143 and 153 cm (56-60 in) depth) yielded a radiocarbon date of 4430 to 4240 cal yr BP (Sample DRstrat-2-5; Figure Q-7; Appendix J). Charcoal from the two successively younger reddened layers (Burn 2 between 113 and 117 cm (44-46 in; Sample DRstrat-2-6) depth and Burn 3 between 81 and 88 cm (32-35 in; Sample DRstrat-2-7) depth yielded radiocarbon dates of 3830 to 3600 cal yr BP and 1560 to 1400 cal yr BP (Figure Q-7; Appendix J). These dates suggest 400 to 800 yr between Burn 1 and Burn 2 and 2,000 to 4,000 yr between Burn 2 and Burn 3. A bulk sediment sample collected from the uppermost layer of reddened sediment (Burn 4 between 24 and 57 cm depth; Sample DRstrat-2-8) yielded a radiocarbon date of 2330 and 2100 cal yr BP (Figure Q-7; Appendix J). Because this date is older than the one from Burn 3, which is lower and, thus, should be older than Burn 4, either (1) the charcoal dated in Burn 4 has been eroded from an older burn and was redeposited at this locality, or (2) the date from Burn 3 is too young because it has been contaminated with younger organic material, such as roots.

The upper 24 cm (9 in) of this exposure consists of loose, gray sand in which a soil has not yet developed.

Locality DRsoil-1 at RM 5.1

This 2.5-m-high (8.2-ft-high) natural exposure on the left side of the present active channel of the Dungeness River includes two main depositional units: sandy gravel below silty sand (Figure Q-8). The lower about 100 cm (40 in) of the exposure loose sandy gravel that was deposited when the active channel of the Dungeness River was is this location.

The silty sand that overlies the gravelly alluvium is about 145 cm (57 in) thick. The lowest 46 cm (18 in) includes some gravel (<10% of the unit) and may represent a transitional unit when the surface still received fairly deep flows that could transport at least some gravel. The overlying sediment is sandy and becomes siltier near the ground surface. The increasing silt could be from a fining of the overbank sediment, the addition of eolian sediment after the surface was abandoned by the river, or both.

Reddened sediment and common charcoal suggest several burn layers within the overbank deposits. These layer are present at depths of 128 to 143 cm (50 to 56 in; Burn 1) and 119 to 125 cm (46 to 49 in; Burn 2) in the lower part of the unit and between depths of 44 to 46 cm (17 to 18 in), 34 to 36 cm (13 to 14 in), and 24 to 27 cm (9 to 11 in) (Figure Q-8). The upper three, thin layers are grouped together as Burn 3. Charcoal collected from the lowest two burn layers (1 and 2) that are just above the gravelly channel deposits yielded dates between 2690 and 1970 cal yr BP for the lower layer (Burn 1; Sample DRsoil-1-2) and between 2465 and 2125 cal yr BP for the upper layer (Burn 2; Sample DRsoil-1-3; Figure Q-8; Appendix J). A sample collected between the two burn layer yielded a date of 2330 to 2465 cal yr BP (Sample DRsoil-1-1).

Locality DRsoil-2 at RM 5.5

The sediments and soil at this locality were described in a hand-dug pit on a terrace about 207 m (674 ft) west of the Dungeness River and about 655 m (2150 ft) south-southwest of DRsoil-1 (Figure Q-1). The surface is about 4 m (13.5 ft) above the present active channel and is probably correlative with the surface at Locality DRsoil-1. The sediment at Locality DRsoil-2 consists of two primary units: channel deposits overlain by overbank deposits. The channel deposits consist of a weakly bedded, coarse sand about 27 cm (11 in) thick that is overlain by a gravelly coarse sand that is 7 to 14 cm (3 to 5 in) thick (Figure Q-9). Charcoal from a bulk sediment sample (Sample DRsoil-2-2) collected from the coarse sand yielded a radiocarbon date between 2700 to 2350 cal yr BP (Figure Q-9; Appendix J).

The upper 46 cm (18 in) of the sediment is silty fine sand that we interpret to be overbank deposits. A weak soil that consists of an Ap (plow) horizon and an A horizon is developed in this sediment (Figure Q-9; Appendix I). A bulk sediment sample was collected between depths of 15 to 36 cm (6 to 14 in; Sample DRsoil-2-1). Charcoal from this sample yielded a radiocarbon date of $\leq$295 cal yr BP (Figure Q-9; Appendix J).

Locality DRsoil-7 at RM 5.6

This exposure is about 144 m (472 ft) downstream from the Railroad Bridge on the left side of the present active channel of the Dungeness River (Figure Q-1). The surface is about 1 m (3.3 ft) above the active channel. At least three distinct sedimentary units are present in this exposure (Figure Q-10).

The lowermost 30 cm (12 in) of the exposure consists of well-bedded, sandy, pebble-cobble gravel and one sand bed that is about 3 cm thick (4C4 horizon of soil; Figure Q-10). Because spoil covers much of the lower part of the exposure only a small portion of this unit is visible. The unit appears to be cross bedded. The upper contact of the unit is an angular unconformity.

The overlying unit is a coarse sandy, cobble-boulder gravel and is about 56 cm (22 in) thick (3C3 horizon of soil; Figure Q-10). The unit is weakly bedded with lenses of gravel and sand. This unit contains more gravel and coarser gravel than the unit below.

The next unit consists of a medium sand that interfingers with a cobbly gravel. The unit is about 44 cm thick (18 in; 2C2 horizon of soil). Charcoal from a bulk sediment sample collected between depths of 139 to 149 cm (55 to 59 in; Sample DRsoil-7-2), near the base of the sand, yielded a radiocarbon date of 1320 to 1240 cal yr BP (Figure Q-10; Appendix J). The upper contact of this unit is an erosional unconformity.

The units discussed above are interpreted to be channel deposits. The variability of the texture of the sediments is likely the result of the position of the active channel at this locality over time.

Above this package of channel deposits are alternating beds of sand and silt (C1 horizon of soil), which are overbank deposits that were deposited once the active channel moved to a different location. Most of the unit is sandy; the silt beds are irregular and lens shaped (Figure Q-10). A very weak soil is developed in the upper 33 cm (13 in) of this unit (Figure Q-10; Appendix I). Reddened sediment and charcoal that suggest forest fires at this locality or deposition during or shortly after forest fires occur at depth of 95 to 100 cm (37 to 39 in), 39 to 49 cm (15 to 19 in), 44 to 46 cm (17 to 18 in), 34 to 36 cm (13 to 14 in), and 24 to 27 cm (9 to 11 in). Charcoal collected at 96.5 cm (39 in; Sample DRsoil-7-4), from the lowest of these burn layers (Burn 1), yielded a radiocarbon date of 550 to 500 cal yr BP (Figure Q-10; Appendix J). Charcoal from a bulk sediment sample collected between depths of 39 to 49 cm (15 to 19 in; Sample DRsoil-7-6), from a higher burn layer (Burn 2) yielded a radiocarbon date of 500 to 290 cal yr BP (Figure Q-10; Appendix J).

Locality DRsoil-4 at RM 9.5

This hand-dug pit was located on a terrace about 310 m (1010 ft) west of the Dungeness River and about 19 m (62 ft) above the active channel (Figure Q-1). The surface is about 9 m (30 ft) above the adjacent terrace. The sediment exposed consists mainly of gravelly alluvium (Figure Q-11). Fine sand and silt in the upper 21 cm (8 in) may be overbank sediment, eolian additions after the surface was abandoned by the river, or both. A soil developed in the sediment includes a 2Bt horizon that appears to be at least 60 cm (24 in) thick (Figure Q-11; Appendix I). The height of this terrace above the present level of the Dungeness River and the strong development of the soil suggest that this terrace is at least a few thousand years old. Because the surface looks as if it grades into glacial till just upstream, it is likely that the gravel in this terrace is outwash that was deposited near the end of the last glaciation 10,000 to 12,000 year ago. Charcoal collected from about 50 cm (20 in) depth yielded ages between 2300 and 1725 cal yr BP (Samples DRsoil-4-3 and 4-3a). These ages seem to be too young based on the stratigraphic relationships and soil development.

Q.4. Ages of Channel and Overbank Deposits

An attempt was made to estimate the age of the channel deposits at each locality (Figure Q-12). Because charcoal is rarely preserved in gravelly alluvium, the dates were obtained from the lower part of the finer overbank deposits that overlie the gravelly channel deposits. Because of this, most of the ages shown on Figure Q-12 are minimum ages for the time when the active channel of the Dungeness River was at each of these localities. The exceptions are Locality DRsoil-2, where the date is from sand that underlies gravelly channel deposits and would be a maximum age for the channel deposits, and Locality DRsoil-7, where the date is from a sand that interfingers with the upper part of the gravelly channel deposits.

On the basis of single dates from the few scattered localities in our study, it is difficult to draw conclusions about channel age. In addition, the dates at several of the localities encompass a wide age range. However, the dates that we do have seem to indicate that the channel deposits, which are buried by about 125 to 200 cm (49-79 in) of overbank sediment, are at least 1,000 years old and could be as old as 2,000 or 3,000 years.

In Reach 3, dates for the gravelly alluvium were obtained at three localities. The gravelly alluvium at Locality DRsoil-1 is at a depth of about 145 cm (57 in); dates from overbank sediment just above the gravel range between about 2,000 and 2,500 cal yr BP. The gravelly alluvium below the surface at DRsoil-2, which is about 10 m (30 ft) higher than the surface at DRsoil-1 and about 550 m (1,800 ft) upstream, is at a depth of about 50 cm (20 in). The age obtained just above the gravelly alluvium is about 2,500 cal yr BP. Thus, the gravelly alluvium at these two localities could be contemporaneous. At Locality DRsoil-7, which is east of Locality DRsoil-2 and adjacent to the present channel of the Dungeness River, the gravelly alluvium is at a depth of about 150 cm (59 in). The date on charcoal collected from just above the gravel is about 1,300 to 1,200 cal yr BP. Although the elevation at Locality DRsoil-7 is similar to that at Locality DRsoil-2 (60 m; 200 ft), the gravelly alluvium at Locality DRsoil-7 appears to be about 1,000 years younger and suggests that the gravelly alluvium at Locality DRsoil-7 is inset into the gravelly alluvium at Locality DRsoil-2.

In Reach 2, dates for the gravelly alluvium were obtained at two localities. At Locality DRsoil-6, which is at an elevation of about 11 m (36 ft), the gravelly alluvium is at a depth of about 127 cm. A date from just above the gravelly alluvium is about 1,000 to 1,500 cal yr BP. This is similar to the date from the gravelly alluvium at Locality DRsoil-7 in Reach 3. At Locality DRstrat-2, below a surface that is 3 m above the Dungeness River and adjacent to an overflow channel, is the oldest date that we obtained for gravelly alluvium. The elevation of the top of the surface is about 41 m (135 ft). The gravelly alluvium is at a depth of about 180 to 200 cm (71-79 in). The date obtained on charcoal just above the gravelly alluvium is about 4,300 cal yr BP.

In Reach 1, only one date was obtained. At Locality DRsoil-3, a date of 300 to 600 cal yr BP was obtained on charcoal collected from overbank sediment at a depth of about 60 cm (24 in). Because of the shallow water table at this locality, the exposure could not be made deeper. Gravelly alluvium was not present at this locality and the depth to the gravelly alluvium, if it is present at this locality, is not known. Thus, this date is a very minimum for any gravelly alluvium that might be below the overbank sediment at this site.

Q.5. Surface Ages

A comparison of dates obtained from within about 50 cm (20 in) of the surfaces where the stratigraphy was described give an estimate of the maximum ages of these surfaces (Figure Q-13). At these shallow depths, contamination of charcoal samples with young organic matter (e.g., roots) can yield dates that are markedly younger than the surrounding sediments that we are trying to date. By selecting one piece of charcoal that has been cleaned and identified (Appendix K), we have minimized this factor. However, the dates, at best, are rough estimates of surface age. The dates from the upper portions of the overbank sediment range between 200 and 600 cal yr BP.

In Reach 3, two dates were obtained (Figure Q-13). At Locality DRsoil-7, a date of 300 to 500 cal yr BP was obtained from a sample collected between depths of 40 to 50 cm (16-20 in). At Locality Drsoil-2, where the top of the surface is about the same elevation as the top of the surface at Locality DRsoil-7, charcoal collected between depths of 15 and 36 cm (6-14 in) yielded a date of ≤295 cal yr BP, suggesting that the surface is “modern”.

In Reach 2, charcoal collected at about 30 cm (12 in) at Locality DRsoil-6 yielded a date of 200 to 300 cal yr BP. At Locality DRstrat-2, which is nearly 30 m (100 ft) higher and about 2.5 km (1.5 mi) upstream, charcoal collected from 24 to 57 cm (9-22 in) depth yielded a date of about 2,000 cal yr BP. Because charcoal collected from a depth of about 92 cm (36 in) at this locality yielded a date of about 1,500 cal yr BP, it is not clear if the surface at Locality DRstrat-2 is really as old as about 2,000 years, or if the charcoal was eroded from an older deposit and redeposited at this site.

In Reach 1, charcoal was collected near the surface at three localities. At Locality DRsoil-3, charcoal collected at a depth of about 60 cm (24 in) from overbank sediment yielded a date of 300 to 600 cal yr BP. At Localities DRstrat-1 and DRsoil-5, overbank sand or, perhaps, beach sand overlies glaciomarine sediment. A date of about 300 to 400 cal yr BP was obtained from the overbank sediment at a depth of about 40 cm (16 in) at Locality DRstrat-1. Charcoal at a similar depth (35 to 40 cm; 14 to 16 in) at Locality DRsoil-5, on the opposite side of the Dungeness River, yielded a date of about 4,000 cal yr BP. Charcoal that was collected at a depth of 70 to 80 cm (28-32 in) from a site north of the 4,000-year date but on the same surface yielded a date of about 1,600 cal yr BP. The older date is from near the top of the surface, and the younger date is from slightly lower down the slope. However, it is not clear at this time if the 4,000-year date represents the age of the surface at this locality.

Q.6. Rates of Overbank Deposition

Using the ages discussed in the previous sections and others obtained on charcoal at other depths within the overbank deposits, we estimated average rates of overbank deposition (Table Q-3). These average rates range between about 0.05 and 0.1 cm/yr (0.02 to 0.04 in/yr) for the time intervals represented by the dates (Table Q-3). The rates are for various time intervals during the last 1,000 to 2,000 years at most localities. The rates extend to about 4,000 years at Locality DRstrat-2.

Q.7. Burns Preserved within the Overbank Deposits

Layers of reddened sediment that often include common charcoal are interpreted by us to be the result of forest fires in the drainage basin. Charcoal and burned sediment would have eroded relatively quickly after a fire that destroyed vegetation and would have been deposited in distinct layers or beds downstream (Section 2.5). The historical record of large fires in the Dungeness River basin suggests that such a fire occurred about every 200 years. Because we thought that the reddened sediment and charcoal-rich beds represented fires, we looked to see if the ages from these beds could reveal additional information about the fire history in the basin (Table Q-4).

The youngest burn layers at the three localities they were dated (DRsoil-7 in Reach 3, DRsoil-6 in Reach 2, and DRstrat-1 in Reach 1) range between 300 to 600 cal yr BP (Table Q-4; Figure Q-14). These layers are found at depths between 35 and 50 cm (14-20 in) within overbank sediment. Large, stand-replacing fires in the Dungeness River drainage basin have been recognized at AD1308, 1508, and 1701 (Section 2.5). All of these fires could be represented by our youngest dated burn layers.

The highest burn layer present at Locality DRstrat-2 is at a depth of 25 to 55 cm (10-22 in). Charcoal from this layer yielded a date of about 2,200 cal yr BP, which is markedly older than the dates on young burn layers at the other three localities. Two burn layers at depths between 120 and 135 cm (47-53 in) at Locality DRsoil-1 dated at about 2,000 and 2,500 cal yr BP and could be correlative with the 25-to-55-cm-deep burn layer at Locality DRstrat-2. At Locality DRstrat-2, three other burn layers are preserved (Table Q-4; Figure Q-7).

Dated burn layers can be subdivided into five very rough age ranges: 300-500, 1400-1550, 2000-2500, 3500, and 4000 to 4500 cal yr BP (Table Q-4). Although these ranges are broad and are represented by only a few dates, they suggest that large areas of the Dungeness River drainage basin burned periodically during the last few thousand years. More study is needed to reconstruct the long-term history of fires in the drainage basin.

Q.8. References

Dethier, D.P.; Pessl, Fred, Jr.,; Keuler, R.F.; Balzarini, M.A.; and Pevear, D.R., 1995, Late Wisconsinan glaciomarine deposition and isostatic rebound, northern Puget Lowland, Washington: Geological Society of America Bulletin, v. 107, no. 11, p. 1288-1303.

Table Q-1. Locations of description and sample sites

Locality	Reach; River mile	Location								Elevation (ft; m)	Aerial photograph	Date described and sampled
		Description	USGS 1:24,000-scale quadrangle	From topographic map			Survey coordinates					
				Town-ship	Range	Section	Latitude (N)	Longitude (W)	Error (± ft)			
DRsoil-1	3 5.1	Vertical exposure in left (west) bank of active channel of Dungeness River on Severson's property; surface about 2.5 m (8 ft) above active channel	Carlsborg	T.30N.	R.4W.	NE1/4, SE1/4, 14	48º05'28.36"	123º09"04.69"	22	165; 50	Dungeness River 1998 #3-5	9/12/98
DRsoil-2	3 5.5	Hand-dug pit on surface 206 m (674 ft) west of and 4 m (13.5 ft) above the active channel of the Dungeness River on Severson's property; about 655 m (2149 ft) south-southwest of DRsoil-1	Carlsborg	T.30N.	R.4W.	NE1/4, NE1/4, 23	48º05'10.74"	123º09"07.82"	26	198; 60	Dungeness River 1998 #3-5	9/13/98
DRsoil-3	1 1.6	Backhoe trench on surface 99.5 m (326 ft) east of and 0.4 m (1.4 ft) above active channel of Dungeness River on Brown's property	Dungeness	T.31N.	R.4W.	NE1/4, SW1/4, 36	48º08'10.02"	123º08"20.27"	24	25; 8	Dungeness River 1998 #2-5	9/13/98
DRsoil-4	4 9.5	Hand-dug pit on surface 308 m (1010 ft) west of and 19 m (62 ft) above the active channel of the Dungeness River along Fish Hatchery Road; 9 m (30 ft) above the adjacent terrace	Carlsborg	T.29N.	R.4W.	NE1/4, NE1/4, 2	48º02'25.89"	123º09"09.96"	22	444; 135	Dungeness River 1998 #3-14	9/16/98
DRsoil-5	1 0.7	Backhoe trench about 157 m (514 ft) east-southeast of Dungeness School; about 240 m (785 ft) east of and 4.5 m (14.5 ft) above the active channel of the Dungeness River	Dungeness	T.31N.	R.4W.	NE1/4, SE1/4, 36	48º08'31.52"	123º07"36.87"	17	19; 6	Dungeness River 2000 #2-10	7/12/00

Table Q-1. Locations of description and sample sites (Cont.)

Locality	Reach; River mile	Location								Elevation (ft; m)	Aerial photograph	Date described and sampled
		Description	USGS 1:24,000-scale quadrangle	From topographic map			Survey coordinates					
				Town-ship	Range	Section	Latitude (N)	Longitude (W)	Error (± ft)			
DRsoil-6	2 2.5	Backhoe pit on surface 162 m (530 ft) east of and 2.3 m (7.5 ft) above the active channel of the Dungeness River on Moore's property; 0.8 m (2.7 ft) above the adjacent terrace	Carlsborg	T.30N.	R.4W.	West-central, 1	48º07'22.31"	123º08"25.87"	22	35; 11	Dungeness River 2000 #2-5	7/14/00
DRsoil-7	3 5.6	Vertical exposure in left (west) bank of active channel of Dungeness River about 144 m (472 ft) downstream of Railroad Bridge; surface about 1 m (3.5 ft) above active channel	Carlsborg	T.30N.	R.4W.	NE1/4, NE1/4, 23	48º05'10.59"	123º08"59.45"	24	200; 61	Dungeness River 2000 #3-4	7/16/00
DRstrat-1	1 0.8	Vertical exposure in left (west) bank of active channel of Dungeness River about 151 m (494 ft) upstream of Schoolhouse Bridge; about 42 m (138 ft) south of Schoolhouse Road; surface about 3 m (9.5 ft) above active channel	Dungeness	T.31N.	R.4W.	NW1/4, NE1/4, 36	48º08'37.65"	123º07"50.33"	22?	15; 5	Dungeness River 2000 #2-10	7/11/00
DRstrat-2	2 4.5	Vertical exposure in left (west) bank of overflow channel of Dungeness River on North Olympic Land Trust property; surface about 2.7 m (9 ft) above active channel; about 2 m (7 ft) above the adjacent terrace	Carlsborg	T.30N.	R.4W.	NW1/4, NE1/4, 14	48º05'59.10"	123º09"19.88"	22?	135; 40	Dungeness River 2000 #3-6	7/15/00 7/17/00

Locations are shown on Figure Q-1.

Table Q-2. Description and stratigraphic information for samples collected for radiocarbon dating

Sample number; River mile	**Type of material for radiocarbon dating**	**Depth (cm)**	**Sediment properties**					**Depositional environment**	**Associated reddened sediment (Burn layer)**	**Stratigraphic position and relationship to other samples**
			Grain size	**Compactness or hardness**	**>2-mm material**	**Color**	**Bedding**			
DRstrat-1-4; RM 0.7	Detrital charcoal	39	Silt	Somewhat compact	None?	10YR 6/1 (d) for sediment; 5YR 6/6 (d) for burn layer	Weakly bedded to massive	Floodplain (overbank)	Near top of lower burn layer (BURN 2), which is about 30 cm above the glaciomarine sediments	
DRstrat-1-3; RM 0.7	*Detrital charcoal*	*43*	*Silt*	*Somewhat compact*	*None?*	*10YR 6/1 (d) for sediment; 5YR 6/6 (d) for burn layer*	*Weakly bedded to massive*	*Floodplain (overbank deposits)*	*Near top of lower burn layer (BURN 2), which is about 30 cm above the glaciomarine sediments*	*About 7 cm above the glaciomarine sediments; may be in same burn layer as sample DRstrat-1-4*
DRstrat-1-1; RM 0.7	*Detrital charcoal*	*73*	*Silt*	*Somewhat compact*	*None?*	*10YR 6/1 (d) for sediment; 5YR 6/6 (d) for burn layer*	*Weakly bedded to massive*	*Floodplain (overbank)*	*Near base of burn layer (BURN 1), which is just above the glaciomarine sediments*	*Just above the glaciomarine sediments in floodplain alluvium; in the same burn layer as sample DRstrat-1-2*
DRstrat-1-2; RM 0.7	Detrital charcoal	78	Silt	Somewhat compact	None?	10YR 6/1 (d) for sediment; 5YR 6/6 (d) for burn layer	Weakly bedded to massive	Floodplain (overbank)	Near base of burn layer (BURN 1), which is just above the glaciomarine sediments; burn layer and top of glaciomarine sediments slope to the west	About 7 cm above the glaciomarine sediments in floodplain alluvium; in the same burn layer as DRstrat-1-1
DRstrat-1-0; RM 0.7	Detrital charcoal	98	Silt with scattered gravel (mostly pebbles)	Very compact	10%	10YR 7/2 (d); includes rust-colored mottles	Massive or contorted bedding; breaks into blocks; "jointed"	Glaciomarine	None; about 25 cm below BURN 1	Near the base of the exposure

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRstrat-2-8; RM4.5	Bulk sediment sample	24-57	Silt and sand beds; silt beds predominate	Loose	None	Reddish orange	Bedded; alternating beds of silt and sand	Floodplain (overbank)	Red hue and scattered charcoal fragments suggest a layer of burned sediment (BURN 4)	Loose, gray sand 24 cm thick overlies unit; slightly hard silt with sand about 24 cm thick underlies unit
DRstrat-2-3; RM 4.5 (Collected during initial description; not shown on Figure Q-7)	*Detrital charcoal*	*60*	*Sand*		*None*		*Massive*	*Floodplain (overbank)*	*Sample from top of burned sediment*	*From 124 cm above gravelly alluvium; stratigraphically above (80-88 cm above) samples DRstrat-2-1 and DRstrat-2-2; sediment below is light-colored, compact silt*
DRstrat-2-7; RM 4.5	Detrital charcoal	88	Silt	Slightly hard	None		Bedded; alternating beds of silt and sand	Floodplain (overbank)	Charcoal from base of reddened sediment (burn layer; BURN 3), which is at the base of the sand/silt unit	Sample taken in an irregularly shaped area of roots, but in the area between the roots; collected 4 m north of Drstrat-2-8 and DRstrat-2-6
DRstrat-2-1; RM 4.5 (Collected during initial description; not shown on Figure Q-7)	*Detrital charcoal*	*105*	*Sand*	*Slightly hard*	*None*		*Massive*	*Floodplain (overbank)*	*From base of sloping burn layer 36-44 cm above gravelly alluvium; possibly BURN 1 of 7/17/00; correlation based on height above the gravelly alluvium*	*From 36-44 cm above gravelly alluvium; charcoal is in layer about 4 cm thick; loose sand above; probably from same unit as DRstrat-2-2*
DRstrat-2-6; RM 4.5	Detrital charcoal	114	Silt	Hard	None	Light tan; reddish cast	Massive	Floodplain (overbank)	Reddish hue and scattered charcoal suggest a burn layer (BURN 2); this layer is not as continuous along the exposure as are the other burn layers here	Sample from silt bed 6 cm thick within gray sand, which is above and below the silt bed

Sample number; River mile	**Type of material for radiocarbon dating**	**Depth (cm)**	**Sediment properties**					**Depositional environment**	**Associated reddened sediment (Burn layer)**	**Stratigraphic position and relationship to other samples**
			Grain size	**Compactness or hardness**	**>2-mm material**	**Color**	**Bedding**			
DRstrat-2-2; RM 4.5 (Collected during initial description; not shown on Figure Q-7)	*Detrital charcoal*	*135*	*Sand*	*Hard*	*None*		*Massive*	*Floodplain (overbank)*	*Charcoal from top of burn layer 3-4 cm thick; possibly BURN 1 of 7/17/00 collected at this locality; correlation based on height above the gravelly alluvium*	*From 37 cm above gravelly alluvium; charcoal in layer about 2 cm thick; from top of consolidated sand that overlies gravelly alluvium; loose sand above; upper contact with loose sand is abrupt; probably from same unit as DRstrat-2-1*
DRstrat-2-5; RM 4.5	Detrital charcoal	143-145	Silt	Slightly hard?	None	Tan; reddish-orange cast	Massive	Floodplain (overbank)	Reddish hue and scattered charcoal suggest a burn layer (BURN 1at 143-153 cm depth); sample from upper 2 cm of this layer	In burn layer, with slightly hard silty sand 9 cm thick above and silt containing 10% SR and R pebbles below
DRstrat-2-4; RM 4.5	Organic-rich sediment with detrital charcoal	158-182	Silt with some gravel in channels near base	Slightly hard?	10%; mostly SR and R pebbles	Tan	Massive; lenses of gravel near base	Floodplain (overbank)	Bulk sediment sample from silt 5 to 29 cm below BURN 1; charcoal visible but difficult to sample separately	Gravelly alluvium below at 82 cm depth; silt with reddened hue and charcoal fragments (BURN 1) is about 5 cm above
DRsoil-1-4; RM 5.1	*Bulk sediment sample*	*63-79*	*Sandy loam*	*Hard*	*0*	*2.5Y 7/3 (d)*	*Massive*	*Floodplain (overbank)*	*None*	
DRsoil-1-3; RM 5.1	Detrital charcoal	108-133	Silty loam; C4 horizon of soil	Very hard	<10	2.5Y 7/3 (d)	Massive	Floodplain (overbank)	From burn layers between 119-125 cm (Burn 2) and 128-143 cm (Burn 1)	
DRsoil-1-1; RM 5.1	Detrital charcoal	116-119	Silty loam; C4 horizon of soil	Very hard	<10	2.5Y 7/3 (d)	Massive	Floodplain (overbank)	None	From just above burn layer between 119-125 cm (Burn 2)

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-1-2; RM 5.1	Detrital charcoal	128-134	Silty loam; C4 horizon of soil	Very hard	<10	2.5Y 7/3 (d)	Massive	Floodplain (overbank)	From burn layer between 128-143 cm (Burn 1)	From base of floodplain deposits; about 2 cm above the top of the gravelly alluvium
DRsoil-1-5; RM 5.1	*Detrital charcoal*	*186-191*	*Gravelly sand; 2C5 horizon of soil*	*Loose*	*75*	*2.5Y 7/3 (d)*	*None*	*Fluvial channel*	*None*	*From 41-46 cm below top of gravelly alluvium*
DRsoil-2-1; RM 5.5	Bulk sediment sample	15-36	Loam; A horizon of soil	Slightly hard	<10	10YR 5/3 (d)	None	Floodplain (overbank)	None	From upper part of floodplain deposits
DRsoil-2-2; RM 5.5	Bulk sediment sample	53-80	Loamy sand; 3C4 horizon of soil	Soft	0	2.5Y 6/3 (d)	Weakly bedded with alternating lenses of silt and clay	Floodplain (overbank)	None	From sandy unit below a gravelly unit that is probably a fluvial channel deposit; floodplain deposit below fluvial-channel deposit
DRsoil-3-1; RM 1.6	*Bulk sediment sample*	*4-10*	*Sandy loam; Cg1 horizon of soil*	*Slightly hard*	*0*	*2.5Y 5/2 (d)*	*None*	*Floodplain (overbank)*	*None*	*From near top of floodplain deposits*
DRsoil-3-5; RM 1.6	*Detrital charcoal*	*52*	*Sandy loam; Cg2 horizon of soil*		*<5*	*2.5Y 4/2 (m)*	*None*	*Floodplain (overbank)*	*None*	
DRsoil-3-2; RM 1.6	Detrital charcoal	58	Clayey silt; Cg3 horizon of soil		<5	Blue-gray and red-brown mottles	Weakly bedded with alternating sandy and silty lenses	Floodplain (overbank)	None	From lowest part of exposure

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-3-4; RM 1.6	*Detrital charcoal*	*59*	*Clayey silt; Cg3 horizon of soil*		*<5*	*Blue-gray and red-brown mottles*	*Weakly bedded with alternating sandy and silty lenses*	*Floodplain (overbank)*	*None*	*From lowest part of exposure*
DRsoil-3-3; RM 1.6	Detrital charcoal	60	Clayey silt; Cg3 horizon of soil		<5	Blue-gray and red-brown mottles	Weakly bedded with alternating sandy and silty lenses	Floodplain (overbank)	None	From lowest part of exposure
DRsoil-4-1; RM 9.5	*Detrital charcoal*	*35*	*Gravelly sandy loam; 2Bt horizon of soil*	*Slightly hard*	*75*	*10YR 5/3 (d)*	*None*	*Fluvial channel*	*None*	*From upper part of gravelly alluvium*
DRsoil-4-2; RM 9.5	*Detrital charcoal*	*35*	*Gravelly sandy loam; 2Bt horizon of soil*	*Slightly hard*	*75*	*10YR 5/3 (d)*	*None*	*Fluvial channel*	*None*	*From upper part of gravelly alluvium*
DRsoil-4-3; RM 9.5	Detrital charcoal	48	Gravelly sandy loam; 2Bt horizon of soil	Slightly hard	75	10YR 5/3 (d)	None	Fluvial channel	None	From upper part of gravelly alluvium
DRsoil4-3a; RM 9.5	Detrital charcoal	46-49	Gravelly sandy loam	Slightly hard	75	10YR 5/3 (d)	None	Fluvial channel	None	From upper part of gravelly alluvium

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-5A-3; RM 0.7	*Organic-rich charcoal with detrital charcoal*	*29-33*	*Sandy loam containing medium sand; B2 horizon of soil*	*Slightly hard*	*<10%*	*10YR 7/1 (d)*	*Massive*	*Floodplain or beach*	*None*	*Sample from upper part of the fluvial or beach sand deposit; 44-48 cm above the glaciomarine sediment at about 77 cm depth from northeast wall of trench*
DRsoil-5A-2; RM 0.7	*Bulk sediment sample*	*61-75*	*Loamy sand containing medium and coarse sand; includes cobble-size blocks of glacial sediment; C1 horizon of soil*	*Soft*	*<10%*	*2.5Y 6/2 (d)*	*Weakly bedded; may contain clay lamellae at base of unit*	*Floodplain or beach*	*None*	*Sample from lower part of fluvial or beach sand deposit; 2-16 cm above the glaciomarine sediment at about 77 cm depth; from northeast wall of trench*
DRsoil-5A-1; RM 0.7	Organic-rich charcoal with detrital charcoal	95-102	Alternating layers of coarse sand and silt-rich lenses; 2C2 horizon of soil	Hard to slightly hard	1-2%; up to 50 mm diameter; mostly pebbles (granitic)	10YR 6/6 (d) for sand beds; 10YR 7/4 (d) for silt-rich beds	Bedded; alternating beds of coarse sand and silt	Glaciomarine	None	From northeast wall of trench
DRsoil-5B-3; RM 0.7 (6 m northwest of DRsoil-5A)	*Detrital charcoal*	*28-36*	*Sand (PM1 of DRsoil-5A)*	*Loose*	*None*	*Gray*	*Massive*	*Floodplain or beach sand*	*Sample from base of a reddened layer about 2 mm thick (BURN 2?)*	*From west wall of trench opposite DRsoil-5B-2; from 18 cm below the Ap horizon; from 11 cm above the glaciomarine sediment*

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-5B-1; RM 0.7 (6 m northwest of DRsoil-5A)	Detrital charcoal	36-39	Sand (PM1 of DRsoil-5A)	Loose	None	Gray		Floodplain or beach sand	None; top of charcoal is ~13 cm below a layer of reddened sediment (burn layer), which is 25 cm southeast of the charcoal sample	From east wall of trench; top of charcoal is 11 cm below Ap horizon and ~52 cm above the glaciomarine sediment
DRsoil-5B-2; RM 0.7 (1.5 m southeast of DRsoil-5B-1)	*Detrital charcoal (Buried root or stump?)*	*47-57*	*Sand (PM1 of DRsoil-5A)*	*Loose*	*None*	*Gray*		*Floodplain or beach sand*	*From just below a layer of reddened sediment (burn layer)*	*From east wall of trench; opposite DRsoil-5B-3; from 19 cm below Ap horizon and 12 cm above glaciomarine sediment*
DRsoil-5C-1; RM 0.7 (4.7 m north of DRsoil-5B)	Detrital charcoal	70-82	Sand (PM1 of DRsoil-5A)	Loose	None	Gray		Floodplain or beach sand	None	From 59-71 cm below the Ap horizon; immediately above glaciomarine sediment, which is predominantly silt with a few sand layers
DRsoil-5D-1; RM 0.7 (4.3 m north of DRsoil-5C)	*Bulk sediment sample*	*113-135*	*Mostly medium sand with some beds of silty sand*		*None*		*Finely bedded*	*Glaciomarine*	*None*	*From top of the sand immediately below the unit of alternating beds of coarse sand and silty sand (83-113 cm); 30 cm below top of glaciomarine sediment*
DRsoil-5D-2; RM 0.7	*Detrital charcoal*	*112*	*Alternating beds of coarse sand and silty sand*		*None*		*Bedded; alternating beds of coarse sand and silty sand*	*Glaciomarine*	*None*	*From base of the alternating coarse sand and silty beds; immediately above the unit of mostly medium sand at DRsoil-5D-1*

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-5E-1; RM 0.7 (9.5 m north of DRsoil-5D)	*Detrital charcoal*	*81-87*	*Silty bed in a unit of alternating beds of sand and silt*		*None*		*Bedded; alternating beds of silt and sand*	*Glaciomarine*	*None*	*From 25-31 cm above silt-rich glaciomarine sediments; 18-24 cm below the top of glaciomarine sediments with alternating beds of silt and sand*
DRsoil-5F-1; RM 0.7 (2.6 m north of DRsoil-5E)	*Detrital charcoal*	*122*	*Silt*	*Hard*	*1-2%; mostly pebbles*	*10YR 7/4 (d)*	*Massive*	*Glaciomarine*	*None*	*From 10 cm below the top of the glaciomarine sediments*
DRsoil-5G-2; RM 0.7	*Peat layer or a root*	*94*	*From base of silty layer in unit of alternating beds of sand and silt*		*None*			*Glaciomarine*	*None*	*From 23-24 cm above DRsoil-5G-1; from top of unit of alternating beds of sand and silt; loose, weakly bedded sand above*
DRsoil-5G-1; RM 0.7	*Peat layer*	*117-118*	*Sandy bed in unit of alternating beds of sand and silt*		*None*			*Glaciomarine*	*None*	*From 23-24 cm below DRsoil-5G-2; within unit of alternating beds of sand and silt*
DRsoil-6-10; RM 2.5	Bulk sediment sample	7-33	Loam with very fine sand; Btj horizon of soil	Slightly hard	None	10YR 5/2 (d)	None	Floodplain (overbank)	None	From just below Ap horizon; from north wall of pit

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-6-9; RM 2.5	*Bulk sediment sample*	*33-77*	*Alternating beds of sand and silt; medium and fine sand; small amount of coarse sand; C1 horizon of soil*	*Loose and soft*	*None*	*10YR 5/1 (d) and 2.5Y 5/2 (d)*	*None*	*Floodplain (overbank)*	*None; charcoal visible throughout unit*	*From north wall of pit*
DRsoil-6-8; RM 2.5	Detrital charcoal	29-30	Loam with very fine sand; Btj horizon of soil	Slightly hard	None	10YR 5/2 (d)	None	Floodplain (overbank)	From a layer with coarse-sand-size clasts of reddened silt (burned, eroded, and redeposited)	From north wall of pit; from sand bed
DRsoil-6-7; RM 2.5	*Detrital charcoal*	*29-30*	*Loam with very fine sand; Btj horizon of soil*	*Slightly hard*	*None*	*10YR 5/2 (d)*	*None*	*Floodplain (overbank)*	*From a layer with coarse-sand-size clasts of reddened silt (burned, eroded, and redeposited)*	*From south wall of pit; from sand bed*
DRsoil-6-6; RM 2.5	*Detrital charcoal*	*51-53*	*Silt bed in unit of alternating silt and sand beds; C1 horizon of soil*	*Soft*	*None*	*10YR 5/2 (d)*	*Bedded; alternating beds of silt and sand*	*Floodplain (overbank)*	*None; burn layers about 1 cm thick are present in the upper 4 cm of the sand/silt unit (to a depth of 39 cm); these layers are 12-14 cm above this charcoal sample*	*From south wall of pit; from silt bed at a depth between 43 and 53 cm*
DRsoil-6-5; RM 2.5	*Detrital charcoal*	*76*	*Silt bed in unit of alternating silt and sand beds; C1 horizon of soil*	*Soft*	*None*	*2.5Y 5/2 (d)*	*Bedded; alternating beds of silt and sand*	*Floodplain (overbank)*	*None*	*From north wall of pit; from same bed as sample DRsoil-6-4 in south wall; silt bed at a depth between 74 and 78 cm*

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-6-4; RM 2.5	*Detrital charcoal*	*66*	*Silt bed in unit of alternating silt and sand beds; C1 horizon of soil*	*Soft*	*None*	*10YR 5/2 (d)*	*Bedded; alternating beds of silt and sand*	*Floodplain (overbank)*	*None*	*From south wall of pit; from same bed as sample DRsoil-6-5 in north wall; from silt bed at a depth between 63 and 73 cm*
DRsoil-6-3; RM 2.5	Detrital charcoal	57-60	Silt bed in unit of alternating silt and sand beds; C1 horizon of soil	Soft	None	10YR 5/2 (d)	Bedded; alternating beds of silt and sand	Floodplain (overbank)	None	From south wall of pit; from silt bed at a depth between 57 and 60 cm
DRsoil-6-2; RM 2.5	*Organic-rich sediment with detrital charcoal*	*68-81*	*Very fine and fine sand; 2C2 horizon of soil*	*Loose*	*None*	*2.5Y 5/2 (d)*	*Massive*	*Floodplain (overbank)*	*None*	*From upper part of massive sand; upper contact of sand is at 72 cm depth*
DRsoil-6-1; RM 2.5	Bulk sediment sample	110-120	Fine and medium sand; 2C2 horizon of soil	Loose	None	2.5Y 4/2 (d)	Massive	Floodplain (overbank)	None	From lower part of massive sand; immediately above gravel with 50% of sediment larger than 2 mm; gravel has abrupt, wavy boundary between depths 127 and 145 cm with the pebbly coarse sand
DRsoil-7-6; RM 5.6	Bulk sediment sample	39-49	Silt bed in unit of alternating beds of silt and sand; C1 horizon of soil	Hard to slightly hard	None	2.5Y 6/3 (d)	Bedded; alternating beds of sand and silt	Floodplain (overbank)	From an area with granule-size pieces of reddened (baked) sediment (redeposited burned sediment); charcoal visible but difficult to sample individually	From upper part of unit with alternating silt and sand beds and lenses

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-7-5; RM 5.6	*Bulk sediment sample*	*51-70*	*Sand bed in unit of alternating beds of silt and sand; C1 horizon of soil*	*Soft*	*None*	*2.5Y 6/2 (d)*	*Bedded; alternating beds of sand and silt*	*Floodplain (overbank)*	*None*	*From sand bed just below the silt bed where sample DRsoil-7-6 was collected*
DRsoil-7-4; RM 5.6	Detrital charcoal	96.5	Silt bed in unit of alternating beds of silt and sand; C1 horizon of soil	Hard to slightly hard	None	2.5Y 6/3 (d)	Bedded; alternating beds of sand and silt	Floodplain (overbank)	Charcoal in lens of reddened silt	Salts on the face of the exposure along the silt beds; from same bed as sample DRsoil-7-3
DRsoil-7-3; RM 5.6	*Detrital charcoal*	*98*	*Silt bed with very fine sand in unit of alternating beds of silt and sand; C1 horizon of soil*	*Hard to slightly hard*	*None*	*2.5Y 6/3 (d)*	*Bedded; alternating beds of sand and silt*	*Floodplain (overbank)*	*Charcoal in lens of reddened silt*	*Salts on the face of the exposure along the silt beds; from same bed as sample DRsoil-7-4*
DRsoil-7-2; RM 5.6	Bulk sediment sample	139-149	Sandy loam to loamy sand with medium sand; 2C2 horizon of soil	Loose to soft	None	2.5Y 5/2 (d)	Weakly bedded; alternating beds of silt and sand; grades into overlying C horizon	Floodplain (overbank)	None	From base of sand; just above cobbly, bouldery gravel (fluvial channel deposits)

Sample number; River mile	Type of material for radiocarbon dating	Depth (cm)	Sediment properties					Depositional environment	Associated reddened sediment (Burn layer)	Stratigraphic position and relationship to other samples
			Grain size	Compactness or hardness	>2-mm material	Color	Bedding			
DRsoil-7-1; RM 5.6	*Bulk sediment sample*	*208-211*	*Pebbly, cobbly gravel with coarse and very coarse sand; 4C4 horizon of soil*	*Loose*	*25-50%; some beds with 75%; R and SR pebbles and small cobbles; 10% larger cobbles*	*10YR 5/1 (d)*	*Bedded*	*Fluvial channel*	*None*	*Bedded gravelly alluvium between depths of 205 cm and the base of the exposure at 230 cm depth*

Notes for Table Q-2:

Multiple samples were taken from each sample locality shown in this table. The individual samples were cleaned, separated and examined for charcoal by Paleo Research Laboratory (Appendix K). Individual pieces of charcoal were identified to species and weighed by Paleo Research Laboratory (Appendix K). From the individual pieces of charcoal that resulted, a single sample was selected and submitted to Beta Analytic, Inc. for radiocarbon dating (Appendix J).

The samples shown in regular font are those from which at least one subsample was submitted to Beta Analytic, Inc. for radiocarbon dating. The samples shown in italics were not submitted from radiocarbon dating because of stratigraphic importance and budgetary constraints.

Abbreviations for rock shape are as follows: R, rounded; SR, subrounded.

Table Q-3. Estimated rates of deposition of fine-grained alluvium (overbank deposits) on surfaces adjacent to the Dungeness River

Locality; River mile	Sample number	Depth (cm; in)	Radiocarbon date (cal yr BP)	Average rate of deposition (cm/yr; in/yr)
DRstrat-1 (RM0.7)	DRstrat-1-4	39; 15	520-430; 380-320	0.08-0.12; 0.03-0.05
	DRstrat-1-2	78; 31	1410-1280	0.06; 0.02
DRsoil-5 (RM0.7)	DRsoil-5B-1	36-39;14-15	4240-3960	0.01; 0.004
	DRsoil-5C-1	70-82; 28-32	1820-1580	0.04-0.05; 0.02
DRsoil-3 (RM1.6)	DRsoil-3-2	58; 23	665-505	0.09-0.11; 0.04
	DRsoil-3-3	60; 24	525-295	0.11-0.20; 0.04-0.08
DRsoil-6 (RM2.5)	DRsoil-6-10	7-33; 3-13	300-220	0.02-0.15; 0.01-0.06
	DRsoil-6-8	29-30; 11-12	≤430	>0.07; >0.03
	DRsoil-6-3	57-60; 22-24	680-630; 600-560	0.08-0.11; 0.03-0.04
	DRsoil-6-1	110-120; 43-47	1170-970	0.09-0.12; 0.04-0.05
DRstrat-2 (RM4.5)	DRstrat-2-8	24-57; 9-22	2330-2100	0.01-0.03; 0.004-0.01
	DRstrat-2-7	92; 36	1560-1400	0.06-0.07; 0.02-0.03
	DRstrat-2-6	114; 45	3830-3600	0.03; 0.01
	DRstrat-2-5	143-145; 56-57	4430-4240	0.03; 0.01
	DRstrat-2-4	158; 182	4430-4230	0.04; 0.02
DRsoil-1 (RM5.1)	DRsoil-1-3	108-133; 43-52	2330-2125	0.05-0.06; 0.02
	DRsoil-1-1	116-119; 46-47	2465-2330	0.05; 0.02
	DRsoil-1-2	128-134; 50-53	2305-2240; 2180-1970	0.06-0.07; 0.02-0.03
DRsoil-2 (RM5.5)	DRsoil-2-1	15-36; 6-14	≤295	>(0.05-0.12); >(0.02-0.05)
	DRsoil-2-2	53-80; 21-32	2700-2645; 2490-2350	0.02-0.03; 0.01
DRsoil-7 (RM5.6)	DRsoil-7-6	39-49; 15-19	500-290	0.08-0.17; 0.03-0.07
	DRsoil-7-4	47; 19	550-500	0.09; 0.04

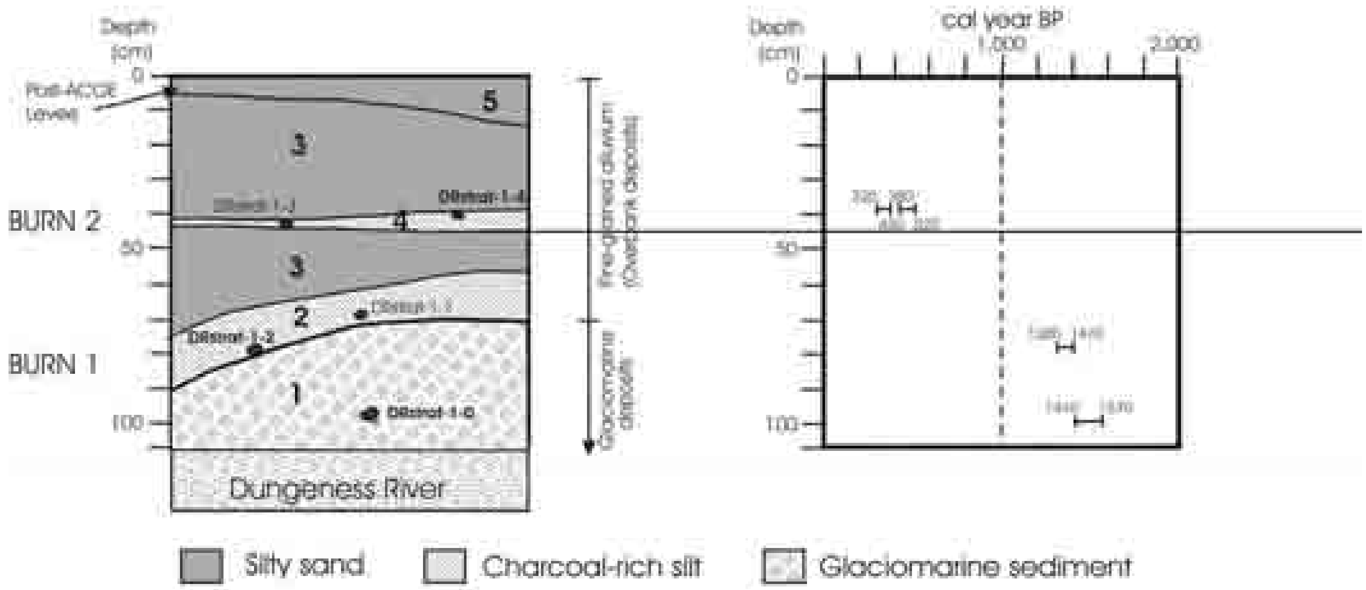
Table Q-4. Radiocarbon dates obtained from burn layers (Listed from youngest to oldest)

Age range (cal yr BP)	**Depth of burn layer (cm; in)**	**Characteristics**	**Charcoal sample number**	**Locality**			
				Burn layer at locality	**Number**	**River mile**	**Elevation (m; ft)**
500-290	39-49; 15-19	Youngest burn layer at site; in discontinuous, silt-rich layer; 50-75 cm above gravelly alluvium	DRsoil-7-6TH	Burn 2	DRsoil-7	5.6	61; 200
520-430; 380-320	41-43;	Youngest burn layer at site; in nearly continuous reddened layer in silt; 20-40 cm above glaciomarine sediment	DRstrat-1-4TS	Burn 2	DRstrat-1	0.7	6; 19
≤430	29-30	Lens-shaped concentration of coarse-sand-size clasts of reddened silt along with charcoal	DRsoil-6-8TH		DRsoil-6	2.5	11; 36
550-500	95-105;	Oldest burn layer at site; in discontinuous, silt-rich layer;	DRsoil-7-4BAc	Burn 1	DRsoil-7	5.6	61; 200
1560-1400	81-88;	Third burn layer above gravelly alluvium at depth 180 to 200 cm; discontinuous layer; in area of reddened sediment	DRstrat-2-7COBv	Burn 3	DRstrat-2	4.5	41; 135
2330-2125	119-125	Upper part of second burn layer at site; about 25 cm above top of gravelly alluvium; in silty bed	DRsoil-1-3PS	Burn 2b	DRsoil-1	5.1	50; 165
2330-2100	24-57;	Youngest burn layer at site; within unit of alternating silt and sand beds; fourth burn layer above gravelly alluvium at depth of 180 to 200 cm	DRstrat-2-8PS	Burn 4	DRstrat-2	4.5	41; 135
2465-2330	116-119	Lower part of second burn layer at site; about 10 cm above top of gravelly alluvium; in silty bed	DRsoil-1-1PS	Burn 2a	DRsoil-1	5.1	50; 165
2690-2065; 2305-1970	128-143	Oldest burn layer at site; about 2 cm above the top of the gravelly alluvium; in silty bed	DRsoil-1-2TS	Burn 1	DRsoil-1	5.1	50; 165
3830-3600	113-119	Second burn above the gravelly alluvium at depth of 180 to 200 cm; in silt bed	DRstrat-2-6COv	Burn 2	DRstrat-2	4.5	41; 135
4430-4240	143-150	Oldest burn layer at site; about 30 to 50 cm above top of gravelly alluvium; in silt bed	DRstrat-2-5PS	Burn 1	DRstrat-2	4.5	41; 135

Figure Q-1. Location map of the northern portion of the study reach showing localities where stratigraphic and soil descriptions were done. Locality DRsoil-4 is along Fish Hatchery Road upstream of the area shown.

Figure Q-2. Thickness of fine-grained alluvium (overbank deposits) on surfaces adjacent to the Dungeness River

Locality DRstrat-1



Unit Descriptions

Unit 5: Sand and silty sand; loose; dark gray; 10YR 4/2 (d)
Unit 4: Burn 2; reddened silt; 5YR 6/6 (d); charcoal common
Unit 3: Silt; slightly compact; 10YR 6/1 (d); weakly bedded to massive
Unit 2: Burn 1; reddened silt; 5YR 6/6 (d); charcoal common
Unit 1: Silt with scattered pebbles composing 10% of deposit; very compact; 10R7/2 (d); bedded; in places bedding is contorted; breaks into blocks.

Figure Q-3. Stratigraphic description and radiocarbon dates at Locality DRstrat-1, located on the left (west) side of the Dungeness River near RM 0.7. This locality in Reach 1 is at the Schoolhouse Bridge and just south of the highway embankment on the west side of the bridge.

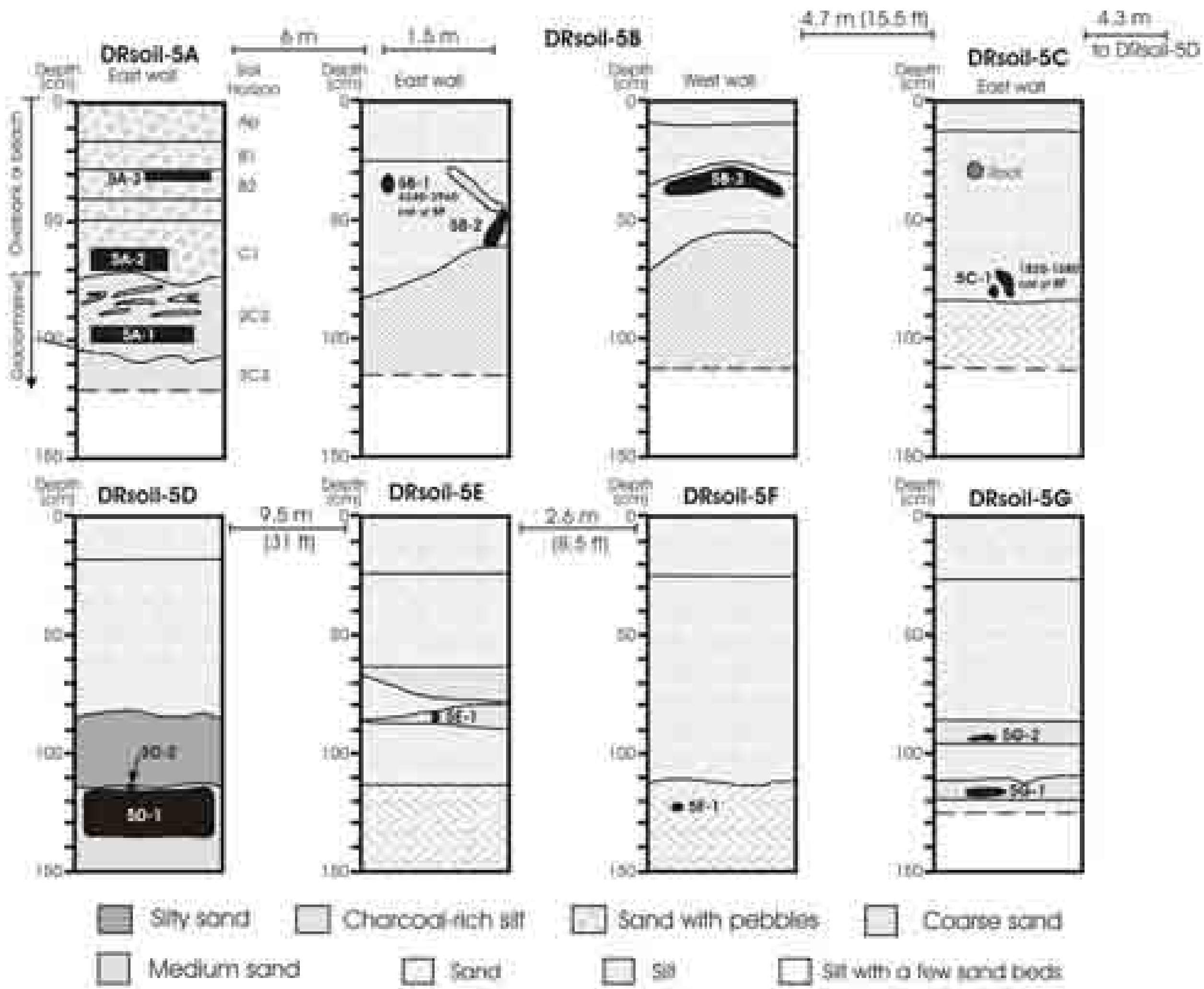


Figure Q-4. Stratigraphic and soil description at Locality DRsoil-5, located in a trench on the east side of the Dungeness River near RM 0.7. This locality in Reach 1 is about 0.13 km (400 ft) east-southeast of the Dungeness Schoolhouse. Radiocarbon dates are given in Appendix J. Descriptions of the soil horizons and depositional units are in Appendix I.

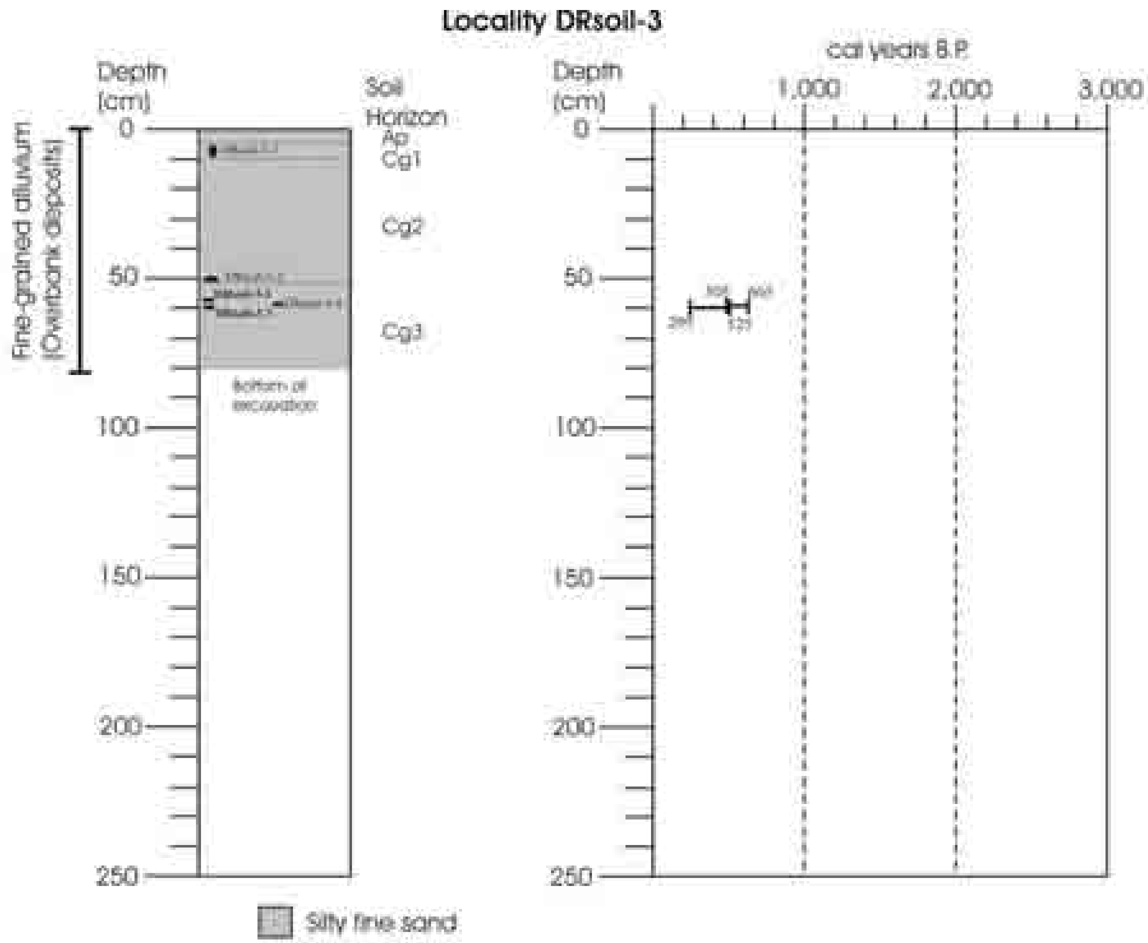


Figure Q-5. Stratigraphic and soil descriptions at Locality DRsoil-3, located on the east side of the Dungeness River near RM 1.6. This locality is in Reach 1, which is bounded by the ACOE levee on the east and the Game Farm levee on the west. Radiocarbon dates are shown on the right (Appendix J). Descriptions of the soil horizons and depositional units are in Appendix I. All of the C horizons have prominent mottles of blue gray and brown. The material was wet, and water filled the base of the shallow trench where this soil profile was described.

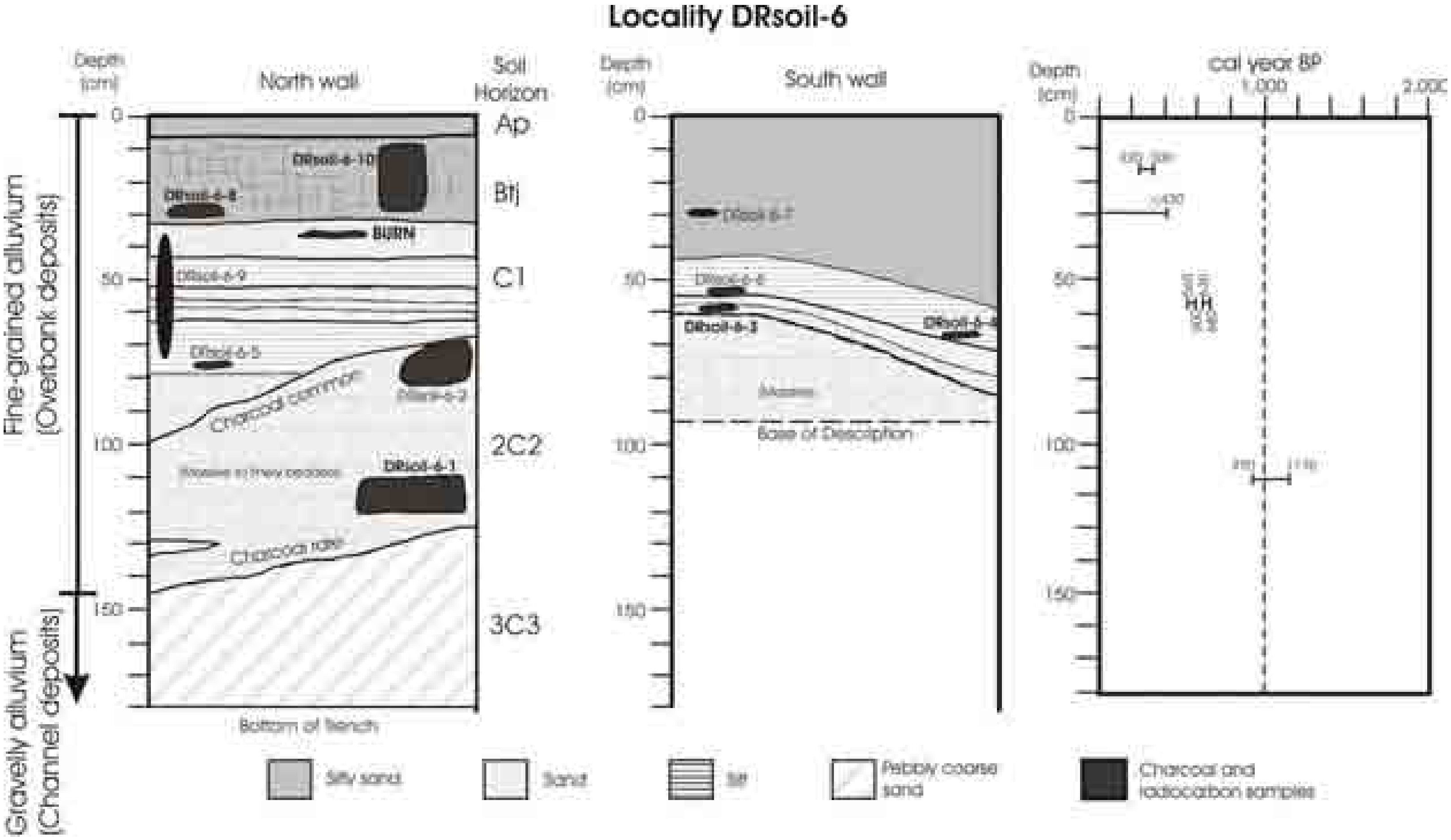
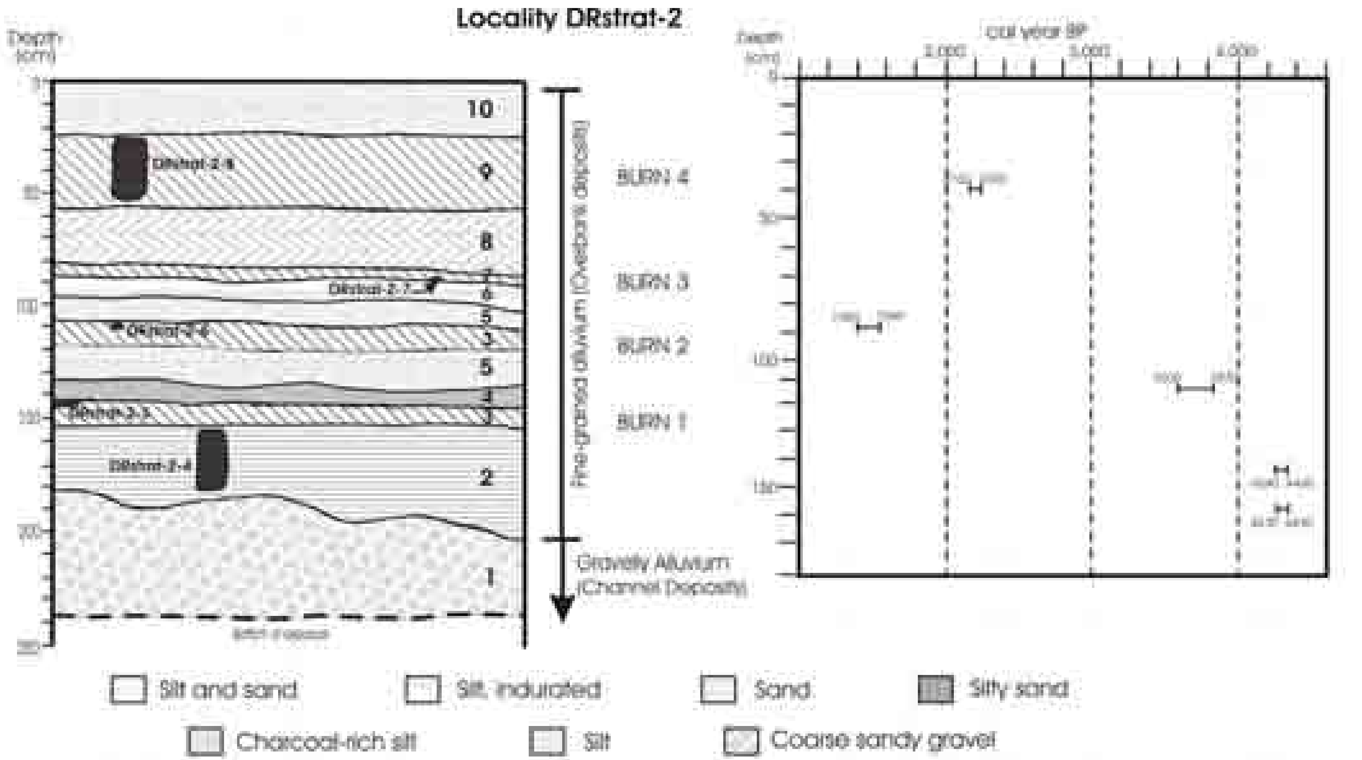


Figure Q-6. Stratigraphic and soil descriptions at Locality DRsoil-6, located on a terrace on the east side of the Dungeness River near RM 4.5 (Figure Q-1). This locality is in Reach 2. Radiocarbon dates are shown on the right (Appendix J). Descriptions of soil horizons and depositional units are in Appendix I.



Unit Descriptions

Unit 10: Sand; loose; dark gray; 10YR 4/2 (d); numerous roots; lens of light-tan silt near top

Unit 9: Silt and sand with scattered charcoal; loose; 5YR 6/6 (d); common roots

Unit 8: Silt and sand; alternating beds; sand beds slightly indurated; silt beds indurated; beds 8 to 25 cm thick

Unit 7: Silt; indurated; reddened; charcoal common

Unit 6: Silt; indurated.

Unit 5: Sand; loose; gray

Unit 4: Silty sand; slightly indurated; inversely graded

Unit 3: Silt with common charcoal; loose; reddened

Unit 2: Silt; 10% pebbles; subrounded and rounded; common charcoal

Unit 1: Coarse sandy gravel; ≥75% gravel; all sizes; subrounded and rounded; compact; weakly bedded

Figure Q-7. Stratigraphic description and radiocarbon dates at Locality DRstrat-2, located on the left (west) side of the Dungeness River near RM 4.5. This locality in Reach 2 is at the Olympic Land Trust property just east of Grandview Road and upstream of the Olympic Highway Bridge. Charcoal samples DRstrat-1, DRstrat-2, and DRstrat-3 were collected during a preliminary description are not shown.

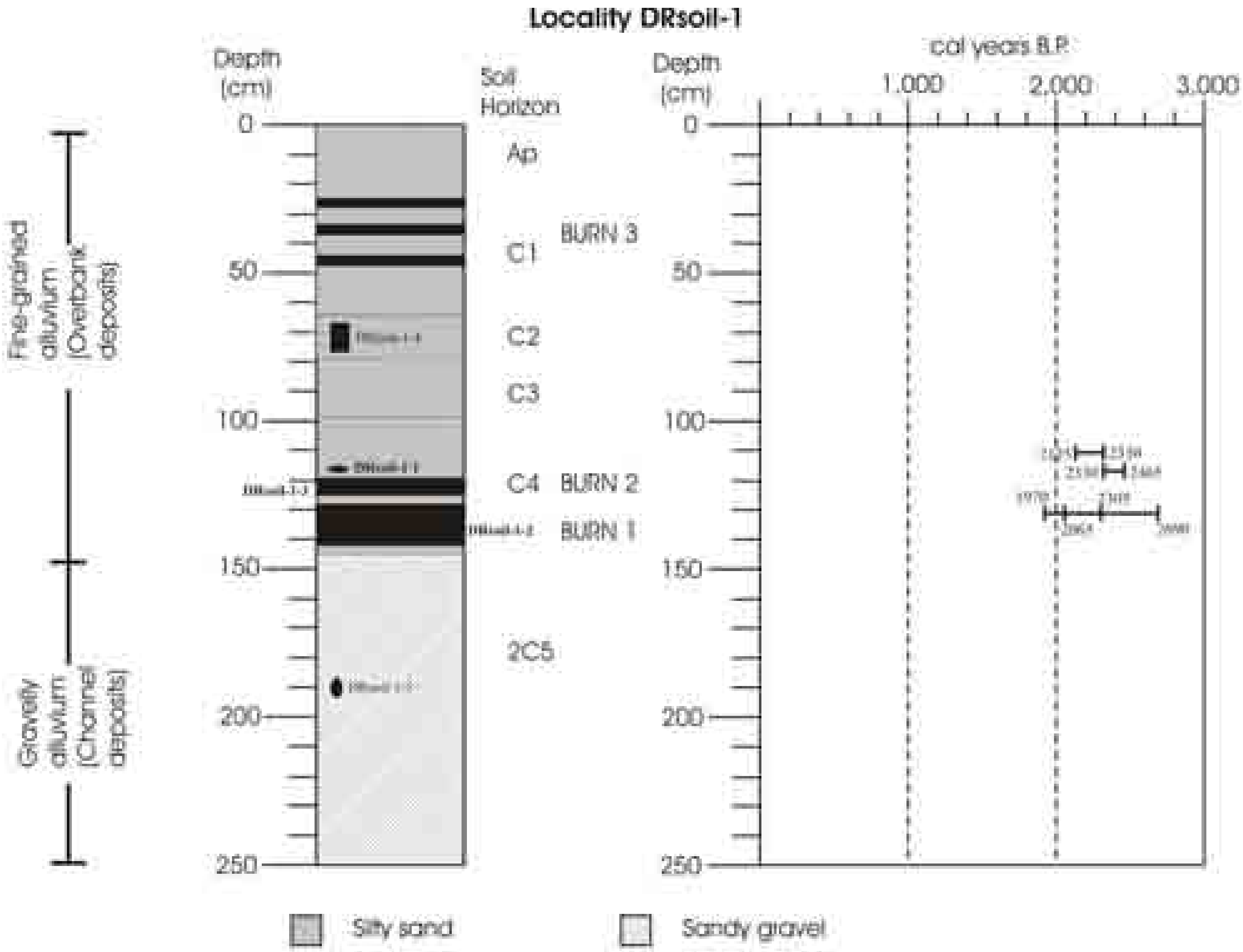


Figure Q-8. Stratigraphic and soil descriptions at Locality DRsoil-1, located on a terrace on the west side of the Dungeness River near RM 5. This locality is in Reach 3. Radiocarbon dates are shown on the right (Appendix J). Descriptions of the soil horizons and depositional units are in Appendix I. Spoil (man-made pile of sandy sediment) 68 cm thick overlies this profile.

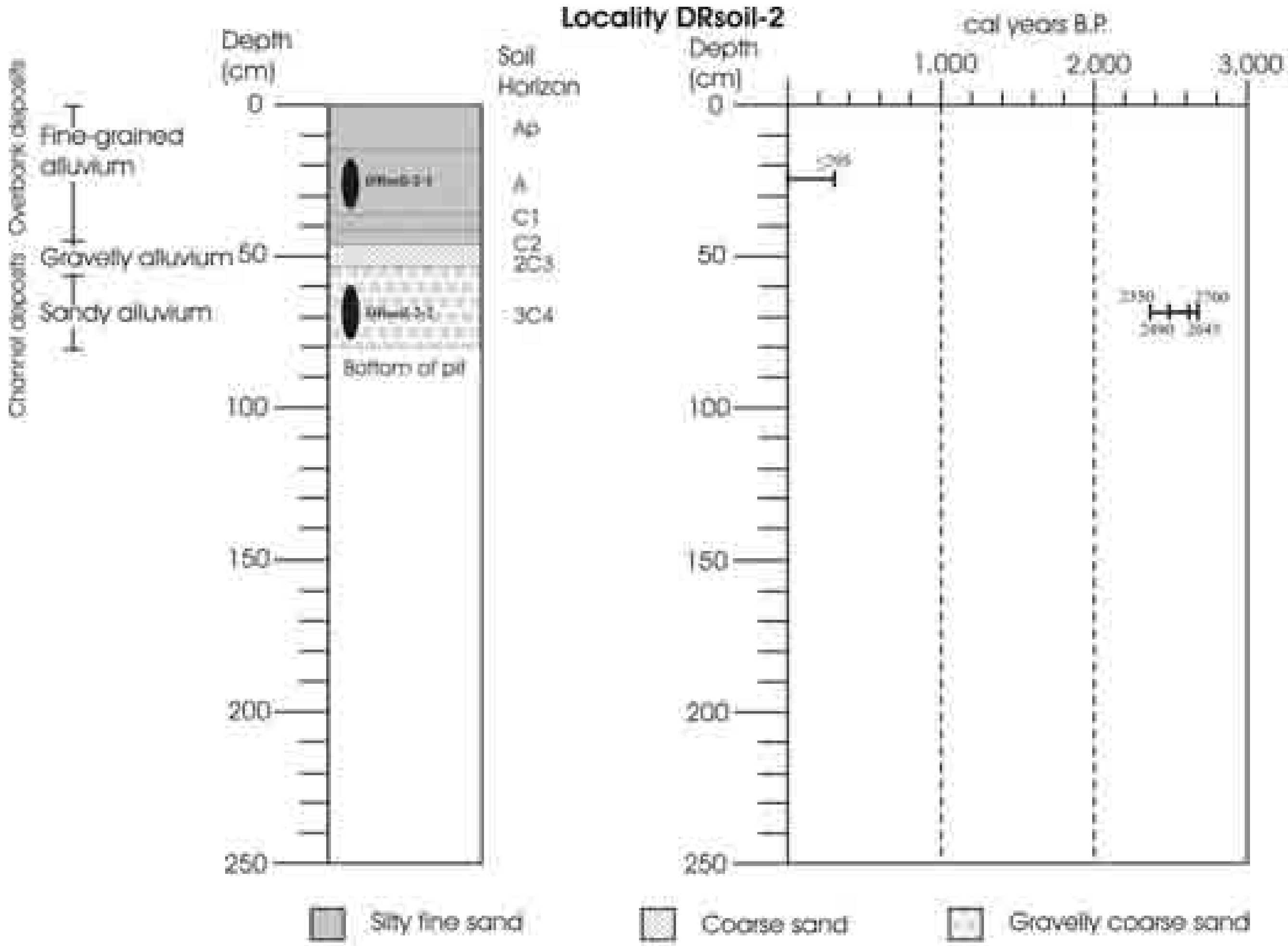


Figure Q-9. Stratigraphic and soil descriptions at Locality DRsoil-2, located on a terrace on the west side of the Dungeness River near RM 5.5. This locality is in the Reach 3. Radiocarbon dates are shown on the right (Appendix J). Descriptions of the soil horizons and depositional units are in Appendix I. Radiocarbon dates are on charcoal extracted from bulk sediment samples from the horizons indicated.

Locality DRsoil-7

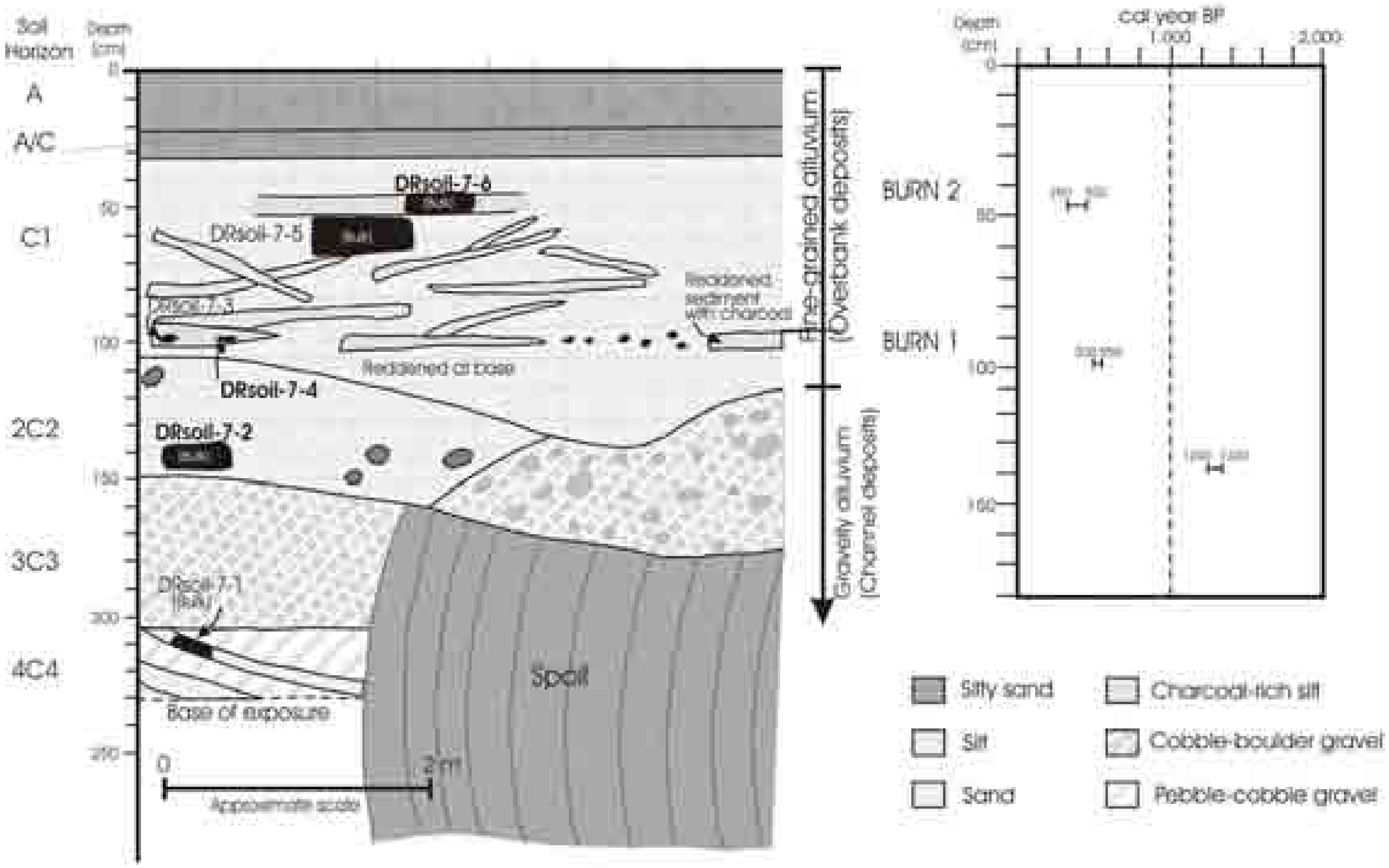


Figure Q-10. Stratigraphic and soil descriptions at Locality DRsoil-7, located on a terrace on the west side of the Dungeness River about 90 m (300 ft) downstream of Railroad Bridge near RM 5.6. This locality is in Reach 3. Radiocarbon dates are shown on the right (Appendix J). Descriptions of the soil horizons and depositional units are in Appendix I.

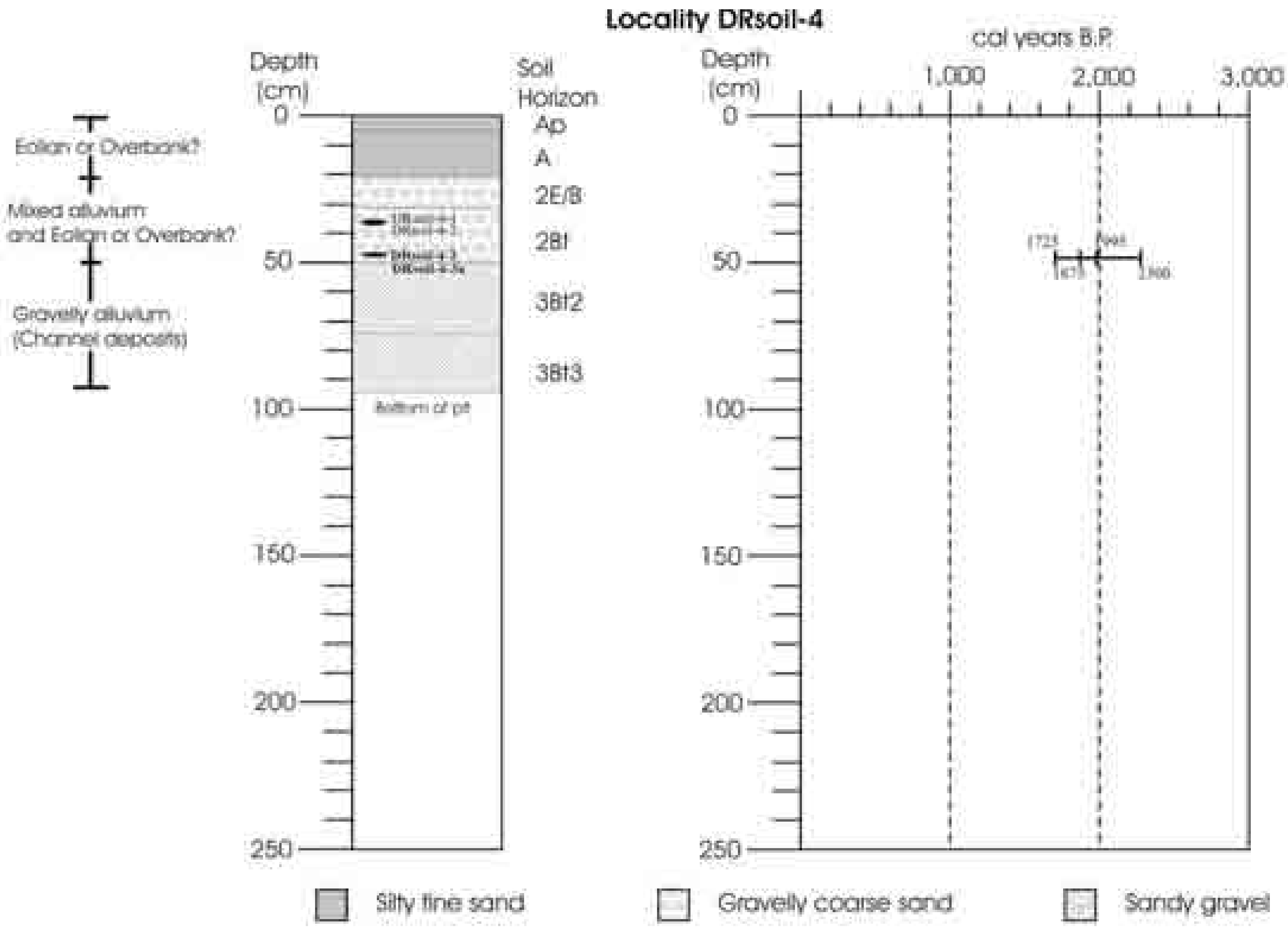


Figure Q-11. Stratigraphic and soil descriptions at Locality DRsoil-4; located on a terrace on the west side of the Dungeness River near RM 9.5(Figure 38). This locality is in Reach 5. Radiocarbon dates are shown on the right (Appendix J). Descriptions of the soil horizons and depositional units are in Appendix I. Radiocarbon dates are on two charcoal samples from the same horizon. The results overlap as shown and are minimum ages for this late Pleistocene terrace.

Figure Q-12. Minimum age estimates (in cal years BP) for the gravelly alluvium (channel deposits) at each locality. Ages are on charcoal collected from overbank sediments just above the gravelly alluvium for all sites except DRsoil-2 and DRsoil-7. At these two sites, the dated charcoal is from sand that interfingers with gravelly alluvium and so is from the channel deposits.

Figure Q-13. Estimated ages (in cal years BP) of surfaces adjacent to the Dungeness River. Ages are on charcoal collected within 50 cm (20 in) of the ground surface from overbank deposits.

Figure Q-14. Dates obtained on charcoal collected from the uppermost burn layers at the localities shown. Young burn layers either were not present or were not dated at the other localities.