Deer Harbor Estuary Habitat Restoration Project Orcas Island, Washington

Appendices to Environmental Assessment and Feasibility Study Report

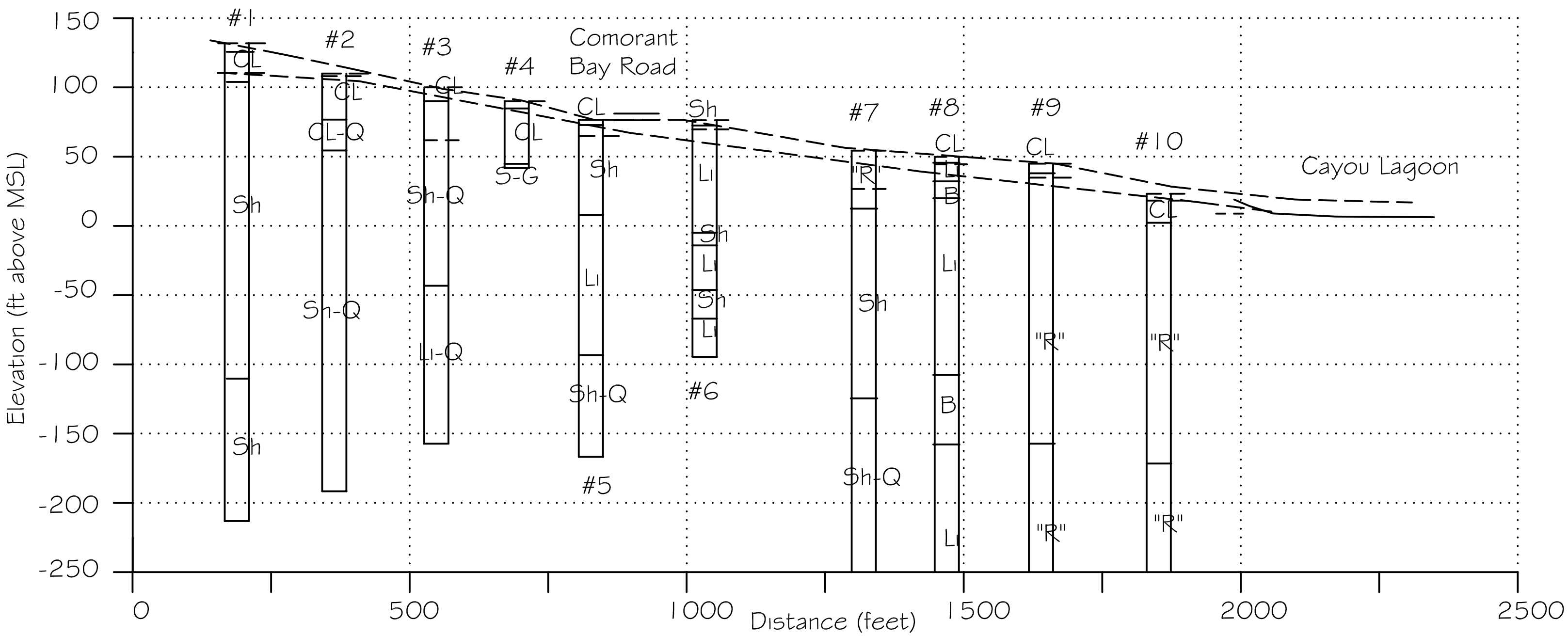
Prepared by:
Deer Harbor Restoration Project Team
Pursuant to IAC/ SRFB Grant No. 02-1577N
October 2005

Table of Appendices

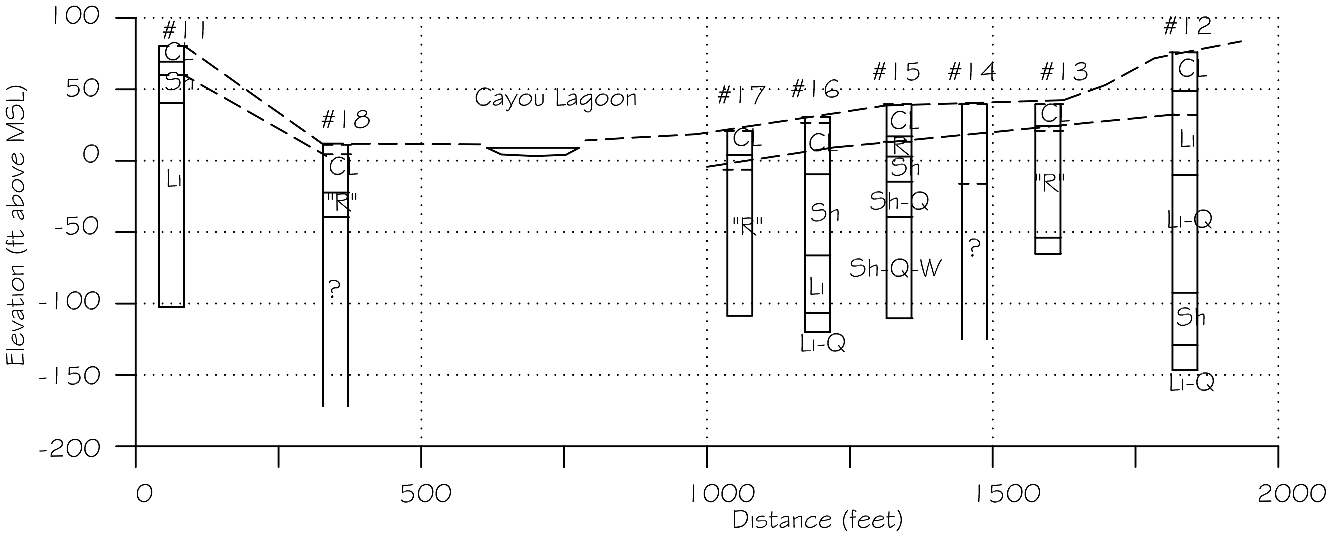
Appendix A:

Profiles of Selected Local Water Well Logs

Well Logs in SW1/4 Sec. 6: Comorant Bay Road South to Lagoon



Well Logs in NW 1/4 Sec. 7: Cross Section West to East near Mouth of Lagoon



Legend

- # = Identifying well log no.
- CL = Clays (tan, blue)
- Sh = Shales (green, black)
- Q = Quartz inclusions
- Li = Limestone
- B = Basalt
- "R" = unspecified rock
- — — = ground surface and static water level

Note rock types and elevations are as reported in drilling logs

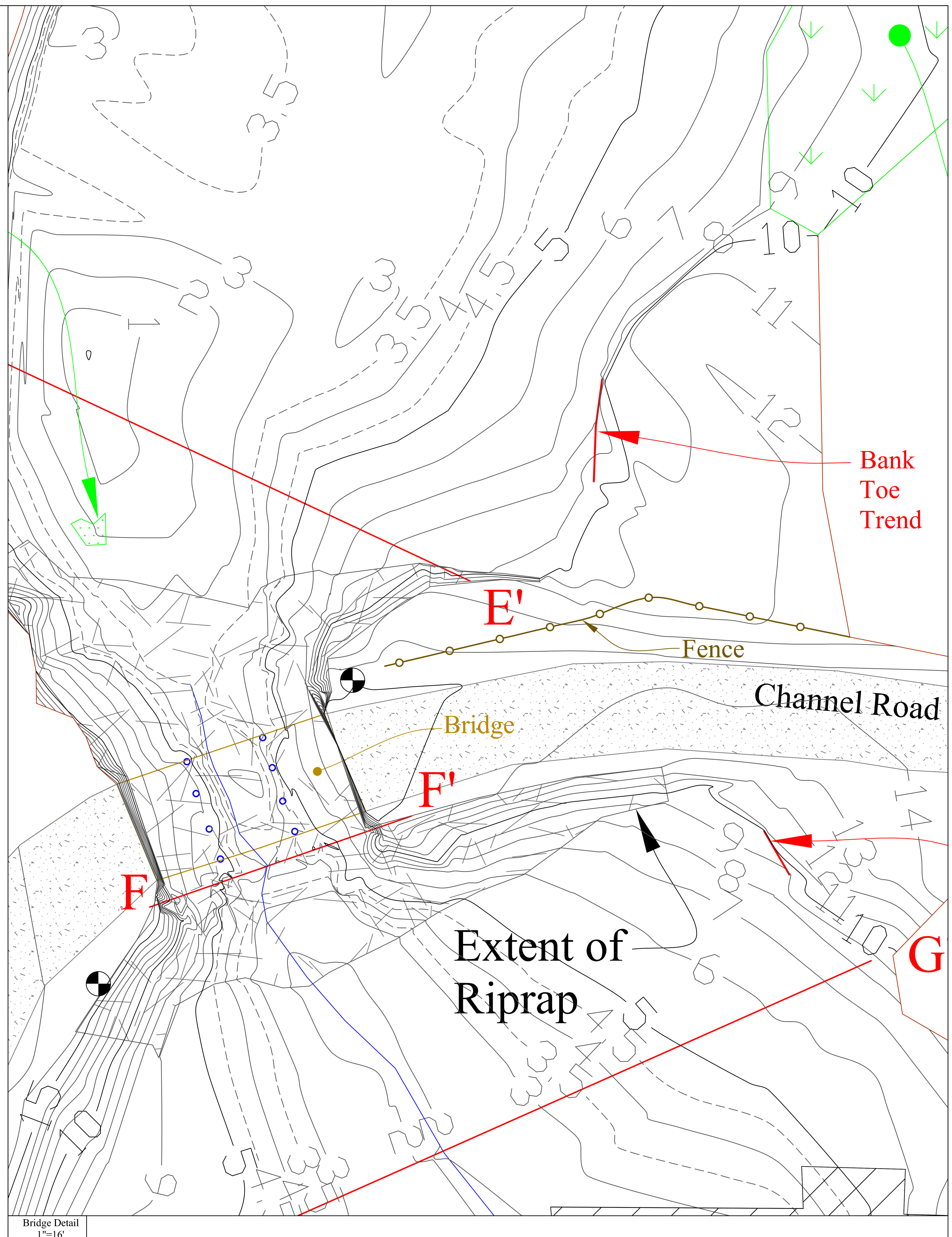
Geologic strata and elevations were summarized from drilling logs available on the Wash. Dept. of Ecology website. SJCCD does not warrant the accuracy of the data. Locations of wells are approximate and are intended for illustration purposes only.

Profiles of Local Water Well Logs

San Juan County Conservation Dist., 2005

Appendix B:

Estuary Cross Sections and Sediment Monitoring Locations



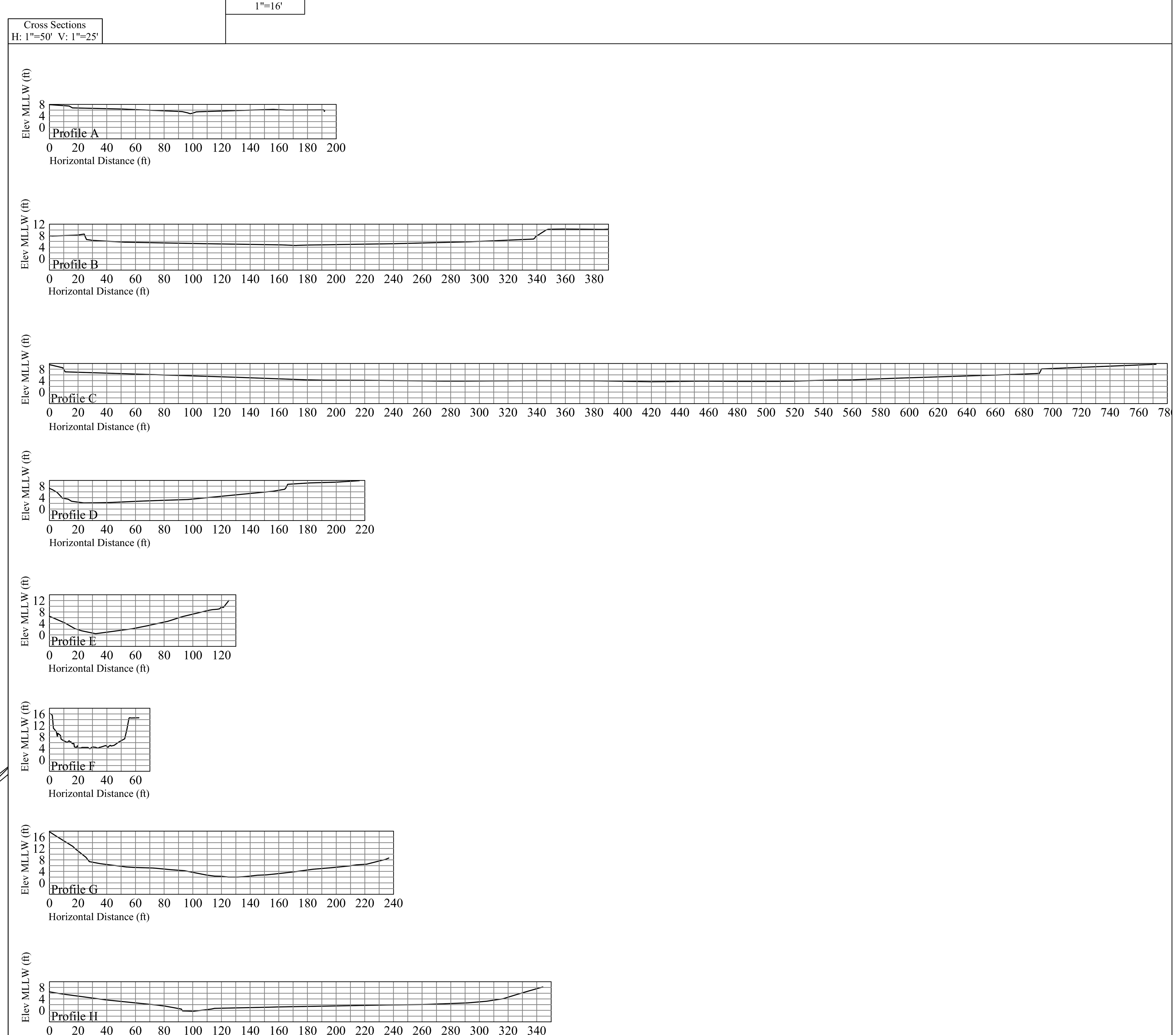


Table 4. Preliminary sedimentation and erosion data for Deer Harbor Lagoon. Positive numbers denote accretion, negative numbers denote erosion. Change and Rate "1" are from measurements made on Sept. 20, 2003 to May 7, 2004. Change and Rate "2" are from measurements made on May 7, 2004 and Sept 9, 2204.

Name	Change 1 (cm)	Rate 1 (cm/yr)	Change 2 (cm)	Rate 2 (cm/yr)	**Ave Rate (cm/yr)**
Sed Stake #1	1.6	2.6	0.0	0.0	**0.9**
Sed Stake #2	1.2	1.9	0.0	0.0	**0.6**
Sed Stake #3	0.9	1.4	0.3	0.9	**0.8**
Sed Stake #4	-0.7	-1.1	1.5	4.5	**1.6**
Sed Stake #5	-1.6	-2.6	2.1	6.2	**1.9**
Sed Stake #6	-1.0	-1.6	0.3	0.9	**-0.1**
Scour Pin #1	-1.8	-2.9	-0.3	-0.9	**-1.4**
Scour Pin #2	-3.0	-4.8	1.5	4.5	**0.4**

Sediment stakes record vertical change and are located within the lagoon. Scour pins record horizontal change and are located in the west bank north of the bridge.

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N

MLLW=0.0'

Deer Harbor Estuary - Orcas Is, WA

For: Salmon Recovery Funding Board

This map complies with National Map Accuracy Standards.

Coordinate System: WA State Plane North, NAD 83.

Elevations: Mean Lower Low Water

~Deer Harbor - base map Spring 2004 D size.dwg

Site Plan	Bridge Detail	Cross Sections
1"=100'	1"=16'	H: 1"=50' V: 1"=25'

Date Surveyed: Sept 18-20, 2003 and May 7, 2004.

Date Drawn: June 16, 2004.

Appendix C:

Sediment Core Data

Sediment Core Data

Slice log (in centimeters)

	Depth (cm)		Maximum **grain size (mm)**	Granular residue weight (grams)			Parts per million			Notes
	Begin	End		Total weight	>250µm	>250µm: total	**SO4**	**Al**	**Mg**	
	0	3								
	3	6	3.1	0.7644	0.1778	0.233	250	5	5	
	6	9								
	9	12								
	12	15	2.9	1.675	0.3579	0.214	100	5	150	Rounded pebbl
	15	18								
	18	21	3.0	1.454	0.3719	0.256	100	5	80	
	21	24	5.7	1.392	0.4187	0.301	1000	5	5	
	24	27	2.4	1.238	0.3325	0.269	50	5	80	
	27	30								*Macoma*
	30	32								*Macoma*
	32	35	1.9	1.726	0.0891	0.052	100	10	80	
	35	38								
	38	41								
	41	44								
	44	47								
	47	50	2.5	0.2437	0.1171	0.481	50-100	5	150	
	50	53								
	53	56								clam
	56	59								
	59	62	5.4	0.2752	0.2618	0.951	<50	125	80	clam
	62	64								
	64	67								
	67	70								
	70	73	5.9	0.2935	0.2640	0.899	<50	125	80	
	73	76								Rounded pebbl
	76	78								
	78	80	2.9	0.1052	0.0935	0.889	50-100	125	80	
	80	83								

Granular residue from washing of the 2.3 mL sediment samples processed in acetic and sodium acetate.

Appendix D:

Hydrologic and Hydraulic Analysis

APPENDIX D
HYDROLOGIC AND HYDRAULIC ANALYSIS
Predicted Physical Changes to Cayou Estuary Following Replacement of the Bridge

October 5, 2005

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Introduction

This memorandum is prepared to provide a description of physical changes that could occur in Cayou Estuary following bridge replacement and to quantify the expected wash-out of silt. Companion data about eelgrass, sediment, topography, fisheries, vegetation, sociology, permitting, bridge design and so on are compiled by other project team members.

Site Description

Cayou Estuary (Figure 1) is a tidal flat (as defined by Downing. 1983. "The Coast of Puget Sound") located at the head of Deer Harbor. It is partially enclosed, with a narrow opening to Deer Harbor and a small stream at its head. The sediment in the estuary is several feet thick, fine grained and muddy. Due to its small size and protected nature, there is low wave energy and little input of sediment from Deer Harbor. The intermittent stream and biological production are probably larger sources of sediment to Cayou Estuary than are marine derived sources. Similar tidal flats (presented below) are found throughout the Cascadia region at the mouths of creeks and at the heads of quiet bays.

Figure 1.

This photo is from the Ecology Shorelines website (below) and shows Cayou Estuary and its bridge looking southward into Deer Harbor during a moderately (about 5.0') high tide. A fresh water stream can be seen near the bottom of the photo. A narrow band of *Salicornia* grows around the estuary perimeter, with salt tolerant grasses beyond. Rock fill under the bridge has partially restricted water exchange, and has enhanced sediment deposition within the estuary by creating pond-like conditions.

http://apps.ecy.wa.gov/shorephotos/index.html

A bridge and associated rock fill partially restrict water flow in and out of the estuary. The bridge is old (ca. 1970) and needs to be replaced, but the replacement may promote washout of sediment from the estuary. The concern is that sediment movement could cause damage to some habitats, particularly to eelgrass beds that are located in inner Deer harbor. A recent bathymetric map by Costal Geologic Services shows the location of the eelgrass beds.

Problem Statement

A plan to replace the bridge may result in washout of mud from the estuary to Deer Harbor. Eelgrass beds in Deer Harbor could be damaged by silt. The project team seeks to compile enough data to predict the impacts of bridge replacement, and to identify basic design features for the proposed bridge such as location, span and mitigation.

The Existing Cayou Estuary Bridge

The existing timber bridge (Figures 2 and 3) is constructed with its timber footers and earthen approaches within the intertidal zone. Its span is too short by today's standards, and a rock dam constructed beneath impedes tidal exchange. Survey measurements show that water

Figure 2. This photo is looking northward into Cayou Estuary to show the rock dam under the existing bridge. Notice the ponded water in the estuary.

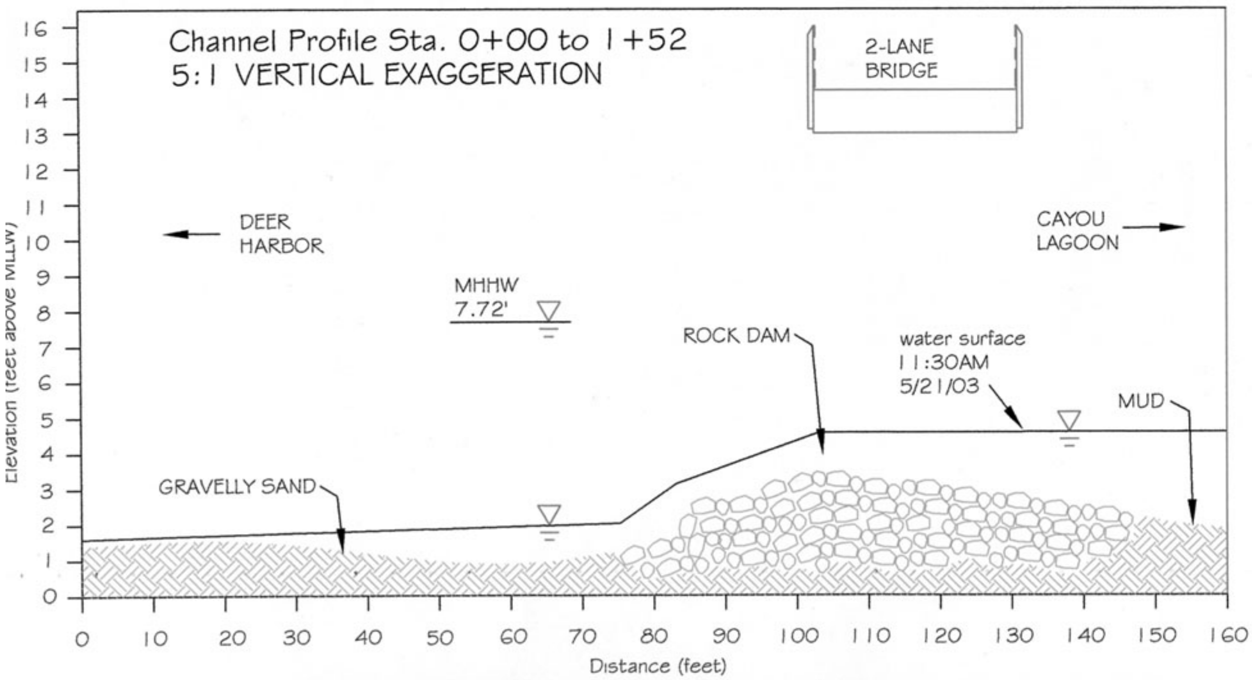


Figure 3. Survey drawing of the channel under the existing bridge (by SJCCD), showing the rock dam under the existing bridge. Notice the ponded water in the estuary. The tidal datum is only approximate.

flowing out of the estuary is blocked by the rock dam at approximately elevation 3.5' (see Figure 3) leaving ponded water in the estuary. This ponding is not a natural condition, and promotes sediment deposition within the estuary and prevents the formation of tidal channels. If the dam were to be removed, tidal channels would develop within the estuary and the eroded material would wash into Deer Harbor, as described below

Considerable beach fill is associated with the bridge approaches and footings (Figure 4).

Figure 4.

A portion of the beach fill is visible in this picture. The bridge approaches extend out 80 feet onto the beach from one side and 20 feet on the other, filling a portion of the intertidal zone with angular quarry rock

Cayou Basin Bathymetry

Cayou Estuary is a tear-drop shaped basin of about 15.0 acres separated from Deer Harbor by a bridge, road-fill and a rock dam. The deepest part of the estuary, a small hole less than 100 feet in diameter, is located just north of the bridge is at elevation 0.0 MLLW. Coastal Geologic Services Inc. gathered survey data for the estuary (Table 1, and the attached Deer Harbor Estuary bathymetry map).

Table 1. Survey data showing the volume and area of Cayou Estuary.

Water Level *Feet, MLLW*	Volume *Cubic feet*	Area *Acres*
0	0	0.01
1	135	0.04
2	1,242	0.01
3	8,181	0.08
3.5	21,384	0.89
4	60,507	3.07
4.5	160,866	5.74
5	309,177	7.88
6	740,718	11.82
7	1,324,593	14.62
8	1,969,758	14.99
9	2,650,617	16.39
10	3,391,902	17.52

The survey data show that the 3.5 foot tall dam at the bridge causes the estuary to contain 21,384 cubic feet of water that would otherwise flow out to Deer Harbor.

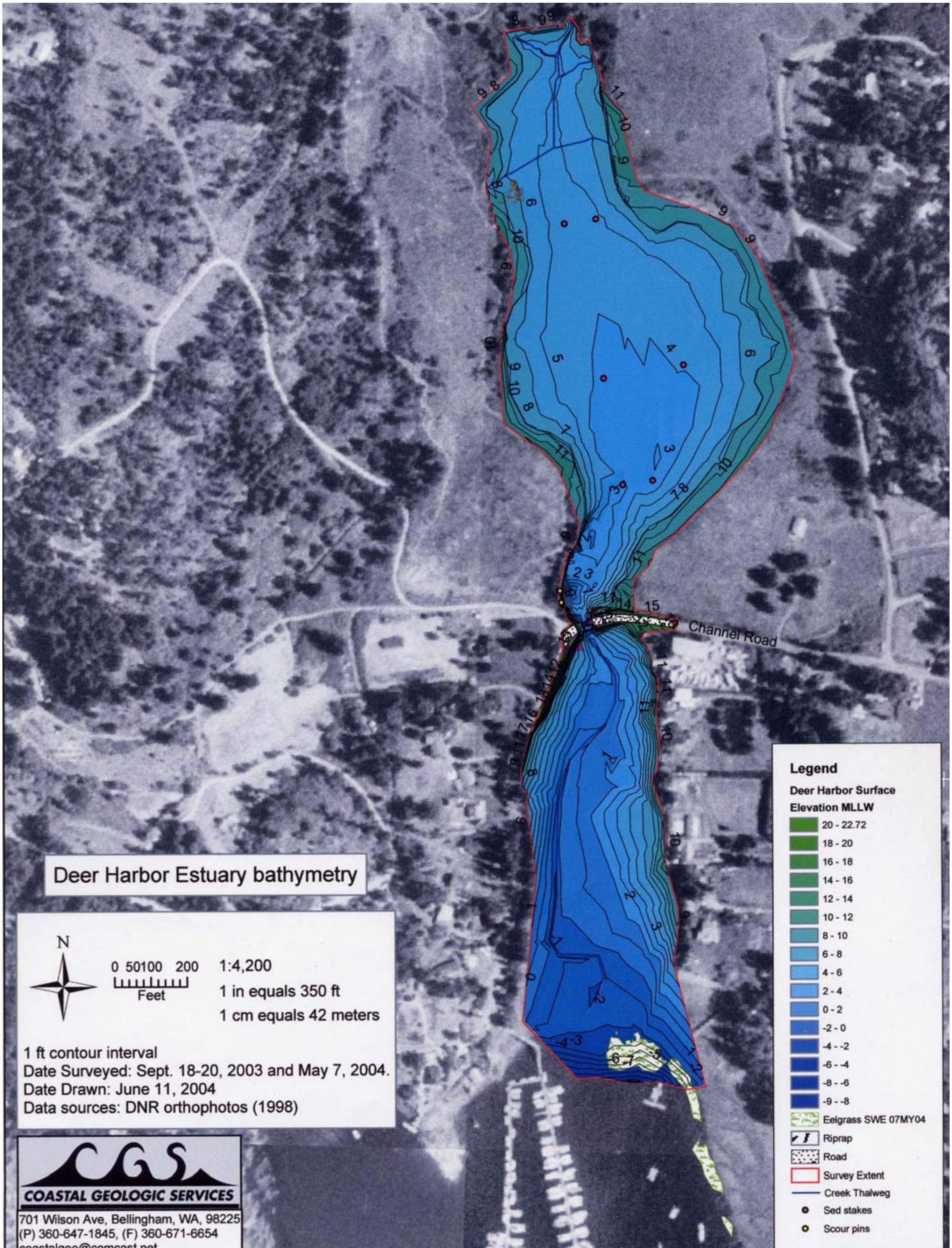
Tidal Exchange

The Friday Harbor tidal datum (Station ID 9449880) for Friday Harbor, Washington is used as the benchmark for this report (Table 2).

Table 2. Tidal data for Cayou Estuary based on the Friday Harbor gage.

	Tidal Height *Feet*
Highest Observed Water Level	11.15
Mean Higher High Water (MHHW)	7.76
Mean High Water (MHW)	7.11
Mean Tide Level (MTL)	4.70
Mean Sea Level (MSL)	4.55
Mean Low Water (MLW)	2.29
Mean Lower Low Water (MLLW)	0
Lowest Observed Water Level	-4.15

Mike Stansbury installed two water level recorders in Deer Harbor and the estuary (Figure 5). He states: "As you can see, the plots appear to track very closely until the harbor level drops below the estuary level. Once the water levels drop below about 5.0 feet, water levels in the estuary are controlled by the rock weir under the bridge. Minimum water levels in


Deer Harbor Estuary bathymetry
N
0 50100 200
Feet
1:4,200
1 in equals 350 ft
1 cm equals 42 meters
1 ft contour interval
Date Surveyed: Sept. 18-20, 2003 and May 7, 2004.
Date Drawn: June 11, 2004
Data sources: DNR orthophotos (1998)
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Channel Road
Legend
Deer Harbor Surface
Elevation MLLW
20 - 22.72
18 - 20
16 - 18
14 - 16
12 - 14
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4
0 - 2
-2 - 0
-4 - -2
-6 - -4
-8 - -6
-9 - -8
Eelgrass SWE 07MY04
Riprap
Road
Survey Extent
Creek Thalweg
Sed stakes
Scour pins

the estuary appear to be in the range of 4.4 feet although this is impacted significantly by the rate of drop in the harbor. Note also that if water levels in the harbor are going from a fairly high stage to a fairly low stage, water levels in the estuary start deviating from the harbor levels when the stage reaches about 6.0 feet..” Note that the datum used by Dr. Stansbury appears to be 1.1 feet higher than the Friday Harbor MLLW datum used by Coastal Geologic Survey.

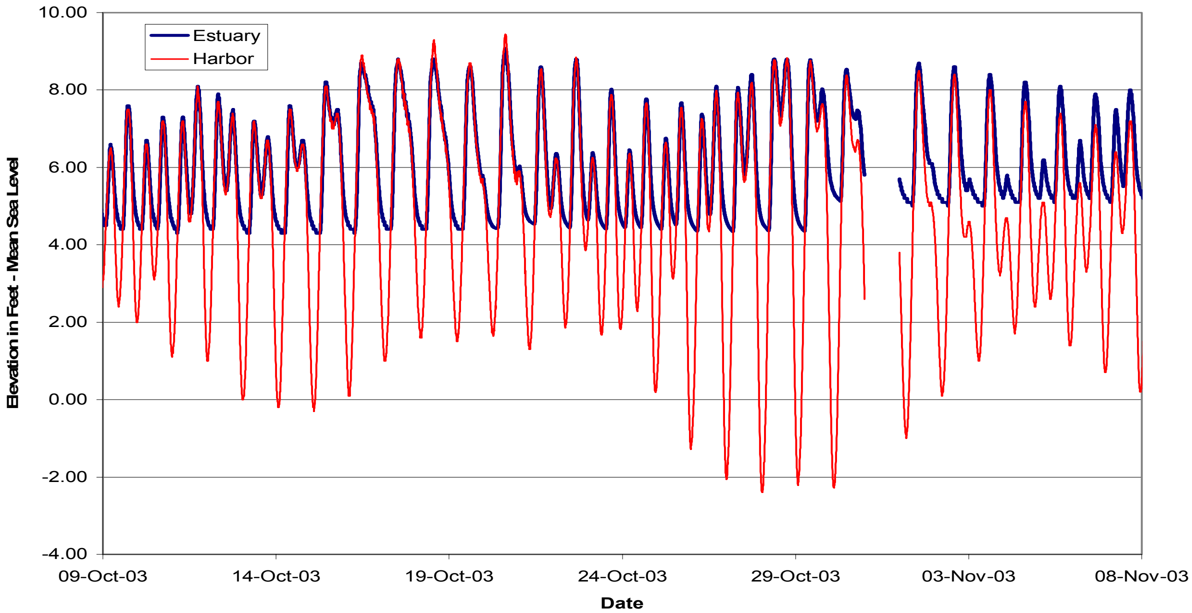

Figure 5. Water level data from Deer Harbor and Cayou Estuary during a 1 month period (by Mike Stansbury). Notice that the top of ponded water in the estuary occurs at an elevation of about 4.4’, as indicated by the lowest water level observed in the estuary. This could be corrected to level 3.5’ to make it consistent with the Friday Harbor tidal datum of Table 2, but it is suitable for the intended purpose of demonstrating the perched nature of Cayou Estuary.

For Cayou Estuary the average ebb tide, with a 4.82 foot drop from MHW to MLW, discharges 1,374,177 cubic feet of water (Table 3). After removal of the dam at the bridge, this discharge would increase to 1,392,307 cubic feet, only a 1.3 percent increase. The exchange is well over 100 percent of the mean estuary volume of 264,684 cubic feet. Based on a tidal prism calculation of mean volume divided by mean tidal discharge, the estuary water is exchanged 5.19 times per tidal exchange before dam removal, and 5.26 times per tidal exchange following dam removal. Using a time of 12.5 hours per tidal exchange, this indicates a water residence time of 2.41 hours and 2.38 hours, before and after dam removal, respectively (Table 3). Some of the water that exits Cayou Estuary will re-enter with the rising tide, so water exchange will not be quite as quick as calculated.

These calculations show that the estuary is rapidly flushed by tidal action and that the dam removal will have negligible effect on the overall degree of water exchange. The removal of the dam however will have a greater influence on sediment accumulation in the estuary because, after removal, the existing 21,384 cubic feet of impounded water (that acts as a sediment trap) will be replaced with a relatively small flowing channel that will be more able to move small sediment particles from the estuary.

Table 3. Morphometric and tidal characteristics of Cayou Estuary before and after removal of the dam at the bridge.

BEFORE DAM REMOVAL

		MHHW	MHW	MW	MLW	MLLW
Tidal Height	ft	7.76	7.11	4.70	2.29	0
Maximum Length	ft	>1800*	>1800*	1190	710	710
Maximum Depth	ft	7.76	7.11	4.70	3.50	3.50
Mean Depth	ft	2.80	2.19	0.84	0.55	0.55
Area	acre	14.90	14.66	7.24	0.89	0.89
Volume	cu ft	1,814,918	1,395,561	264,684	21,384	21,384
Water Residence Time	hr			2.41		

FOLLOWING DAM REMOVAL

		MHHW	MHW	MW	MLW	MLLW
Tidal Height	ft	7.76	7.11	4.70	2.29	0
Maximum Length	ft	>1800*	>1800*	1190	530	0
Maximum Depth	ft	7.76	7.11	4.70	2.29	0
Mean Depth	ft	2.80	2.19	0.84	2.49	0
Area	acre	14.90	14.66	7.24	0.03	0
Volume	cu ft	1,814,918	1,395,561	264,684	3254	0
Water Residence Time	hr			2.41		

*Estuary extends into Fish Trap Creek during high water.

Freshwater Inflows: Fishtrap Creek Base Flow and Storm Flow and Seepage

Fishtrap Creek is an intermittent stream that flows into Cayou Estuary, Orcas Island, WA, draining an area of 736 acres (Figure 6). It is dry roughly from May through November and there is some speculation that the flows are less than historically occurred. Salmon are not now known to use the stream, but a rock fish trap is an indication of previous use by salmon. Wahington Trout and Russel Barsh have mapped culverts, seepage areas and other features of the creek (contained in other appendices). A large constructed reservoir upstream may be influencing flows.

Flows during a two-month period during winter 2004 ranged from 0.08 cfs to 0.79 cfs (Figure 7).

Peak flows calculated by SEA, Inc. using StormShed software indicate that the 2-year recurrence interval peak flow is 17.6 cfs and the 100 year recurrence interval peak flow is 89.2 cfs (Table 4). Rainfall depths, CN values and time to concentration F coefficients were obtained from the Washington Department of Ecology Stormwater Management Manual (1990). In accord with the Ecology Manual, residential areas were assumed to be 15% impervious. Soils data was obtained from the San Juan County Soil Survey (SCS, 1962). Drainage basin sizes, slopes and lengths were determined from the USGS topographic map (Figure 6).

The following input data were used:

- Rainfall
  Water Quality storm = 1.0 in
  2 yr - 24 hr = 1.5 in
  10 yr - 24 hr = 2.4 in
  100 yr - 24 hr = 3.5 in

- Soils
  Forest, Meadow and Residential areas = type C
  Marsh = type D
  Gravel roads = type D

- CN factors
  Second Growth Forest = 76
  Meadow = 86
  Marsh = 92
  Residential Yards = 86
  Residential Impervious = 98
  Gravel Road = 91
  Paved Road = 98
  Estuary = 100

- Contributing Areas
  Second Growth Forest = 505.8 ac
  Meadow = 144.1 ac
  Marsh = 8.7 ac
  Residential Yards = 45.9 ac
  Residential Impervious = 8.1 ac
  Gravel Road = 3.7 ac
  Paved Road = 4.0 ac
  Estuary = 15.7 ac

- Time to Concentration Distance and Slope
  Forest sheet flow = 200 ft, 4.95%
  Forest channel = 5300 ft, 4.95%
  Streambed = 5450 ft, 2.2%
  Road surface = 10 ft, 2.0%

- Time to Concentration F coefficients
  Forest sheet flow = 0.8
  Forest channel = 5
  Streambed =
  Roadside ditches = 20

Based on that input data, hydrologic results are summarized in Table 4.

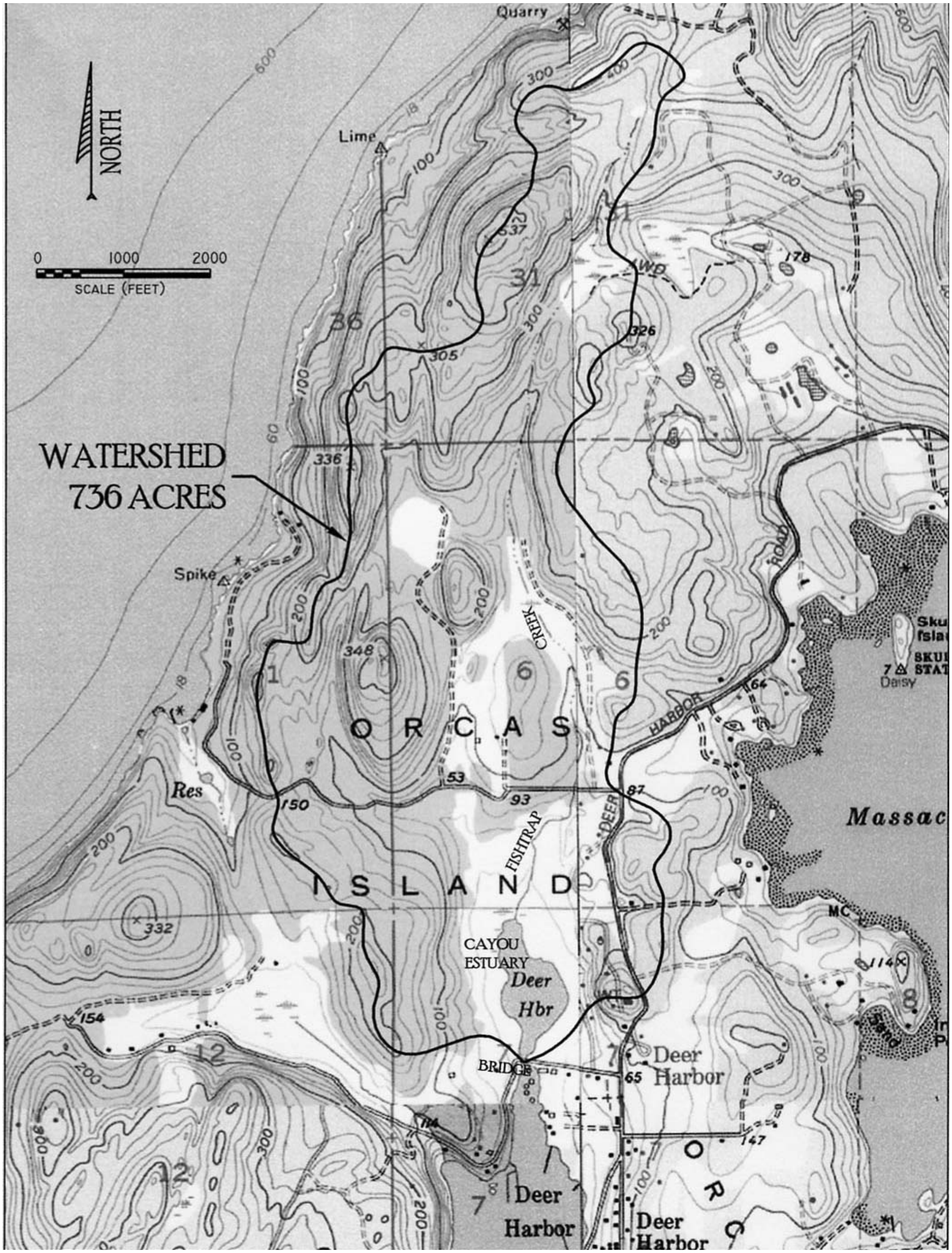

Figure 6. Cayou Estuary watershed and Fishtrap Creek.

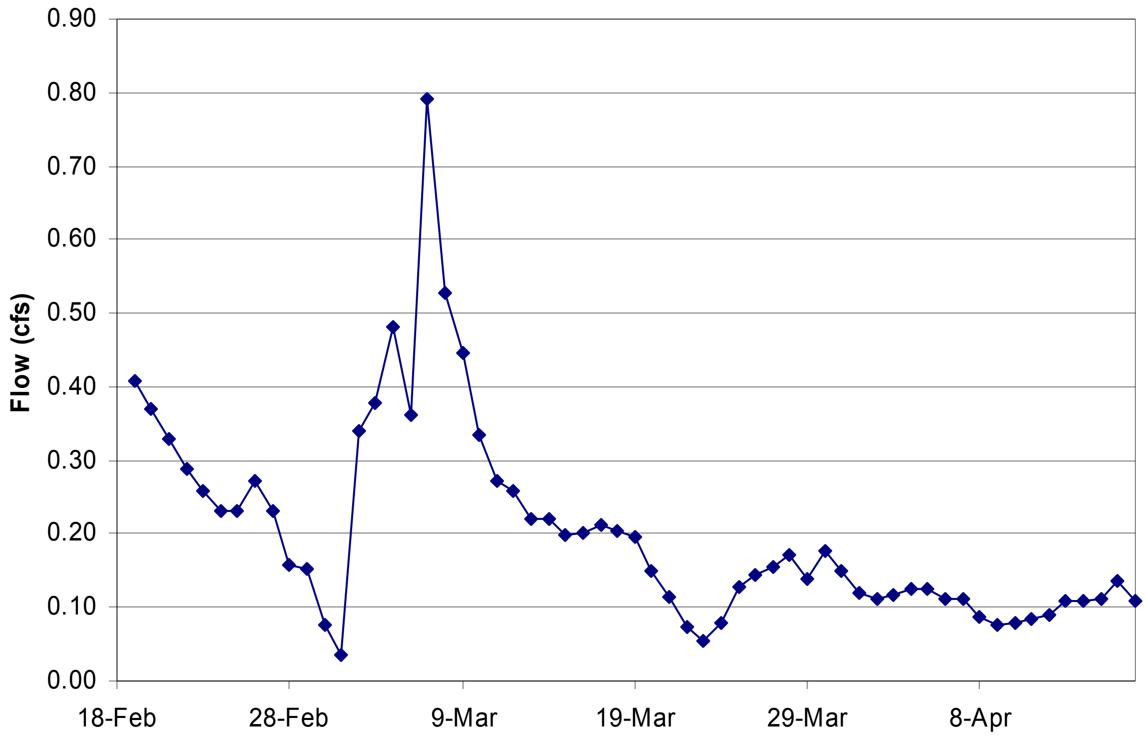

Figure 7. Flow in Fishtrap Creek during part of the winter 2004, as provided by Devine Tarell and Assocaites, Inc. Notice that flows get very low, to less than 0.1 cfs during this period.

Table 4. Runoff peak rate and volume to the mouth of Cayou Estuary:

Storm Recurrence	Peak Flow	Storm Volume
Water Quality Storm	6.5 cfs	10 ac-ft
2 yr - 24 hr	17.6 cfs	33 ac-ft
10 yr - 24 hr	46.6 cfs	96 ac-ft
100 yr - 24 hr	89.2 cfs	191 ac-ft

Freshwater seepage enters the estuary, with flows obvious during low tide, even in summer (Figure 8).

Perhaps storage in the farm ponds and infiltration of stored water into the water table accounts for the very low flow data that was measured by Devine Tarbell in winter 2004. We do know that powerful flows do sometimes occur as indicated by the sizeable head-cut in the Creek (Figure 9). That head cut could be explained by 100-year recurrence interval flows such as likely occurred in 1997 and 1990, but could also happen if sudden large releases occurred from farm ponds.

Figure 8. Seepage into Cayou Estuary is most obvious along the eastern shore, as seen here during July 2003. *Salicornia* is visible to the left to indicate elevation. Russell Barsh found that the water in this area had lower salinity than seawater, confirming that the seepage has measurable influence on Cayou Estuary hydrodynamics, and is comprised at least in part of freshwater, not just seawater seepage from the intertidal range. The green seaweed (possibly *Ulva)* may be associated with the fresh water.

Erosion in Fishtrap Creek

It is easy to see that significant erosion has occurred in Fishtrap Creek and in the Cayou Estuary. Two areas of recent scour were observed, including Fishtrap Creek downcutting (Figure 9) and along the west bank of the estuary just upstream of the bridge (visible near the center, behind the bridge in Figure 2). The creek and bank erosion combined with biological detritus are believed to be the major sources of sediment to the estuary.

As an approximation based on field measurement with a tape measure as described in Figure 9, the Fishtrap Creek erosion is estimated:

(120 yd long) x (2 yd deep) x (7 yd wide) = 3360 cubic yards of silt loam
= 2570 cu m

The eroded material is gravelly sandy silt and is believed to primarily accumulate within the estuary due to the influence of the dam and the quiescent waters of the estuary.

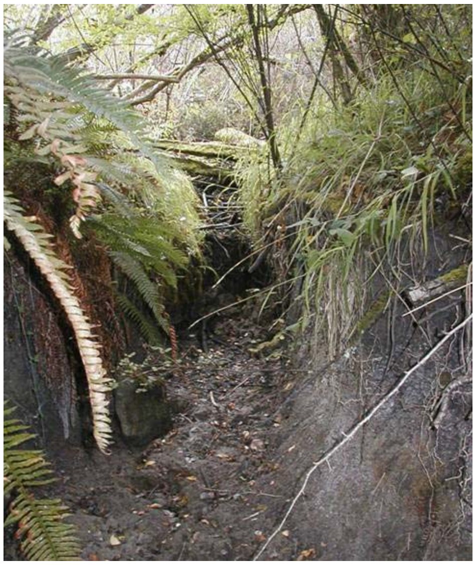

Figure 9.

Fishtrap creek is significantly downcut for a distance of about 120 yards, with an average depth of 2 yards and width of 7 yards. This picture shows the headwall at the upstream extent of the cut. Speculation is that the creek's baseflows are significantly less than historically occurred, but storm flow is intense enough to cause the downcutting seen here.

Other Similar Tidal Flats
The Reference Reach Approach to Estimating Future Scour

The most similar case of removing a dam at the mouth of an estuary is Dogfish Creek at Liberty Bay in Poulsbo, Kitsap County (Figures 10, 11 and 12). An undersized culvert was replaced with a new bridge during 2003. As a result, a new stream channel has carved itself into the soft marine mud in the vicinity. The main difference between Cayou Estuary and Dogfish is that Dogfish Creek is a much larger creek than Fishtrap Creek, and so the size of any newly carved channel is expected to be less at Cayou Estuary.

Figure 10.

This photo is from the Ecology Shorelines website and shows Dogfish Creek and its bridge looking southward into Liberty Bay, Poulsbo during a low tide. The bridge was recently replaced and downcutting and erosion of marine mud occurred.

Figures 11 and 12. Liberty Bay at Dogfish Creek, Poulsbo, Kitsap County. Top: Looking upstream from new 2003 bridge during 2005. Bottom: Looking downstream. The new bridge replaced a slightly perched culvert, and a stream downcut about 2 feet in 6 months as can be seen in the top photo. Note *Salicornia* to left of lower photo for elevation.

Other similar areas are shown in Figures 13 through 17. These pictures show the general shape of drainage channels across tidal flats. Note that the typical situation is with meandering channels within the intertidal range. It is my belief that removal of the rock dam at Cayou Estuary bridge would allow the development of a meandering channel within Cayou Estuary.

Figure 13. Big Beef Creek and Miller Bay. Ecology photos.

Figure 14. Thorndyke Bay, 2 views. Ecology photos.

Figure 15. Stavis Bay and Tarboo Bay. Ecology photos.

Another location that is quite similar to Cayou Estuary is Appletree Cove in Kingston (Figures 16 and 17). The Appletree Cove watershed is 486 acres, a bit smaller than that of Cayou Estuary, but it receives more rainfall. I suspect that the overall flows are very similar to Cayou Estuary, but the main difference is that the outlet goes through a culvert that does not appear to block the outflow nearly as much as does the bridge at Cayou Estuary. Thus, Appletree Cove and its small tributary creek, Carpenter Creek, might be reasonable case studies for the expected future condition in Cayou if the dam was removed.

Figure 16. Appletree Cove and Carpenter Creek. I believe that this picture is representative of future conditions in the southern half of Cayou Estuary following bridge removal. This channel is 40 feet across with a maximum depth of 3.5 feet and an average depth of 2.1 feet.

Figure 17. Appletree Cove and Carpenter Creek. I believe that this picture is representative of future conditions in the northern half of Cayou Estuary, where combined freshwater and tidal flow volumes are small, following bridge removal. Note *Salicornia* to left of lower photo for elevation. This channel is 14 feet across with a maximum depth of 1.2 feet and an average depth of 0.5 feet.

Literature Review on the Morphometry of Salt Marsh Tidal Channels
The Numerical Approach to Estimating Future Scour

The degree to which site conditions such as substrate, slope and flow influence channel geometry and spacing has been summarized by Zeff (1999. “Salt March Tidal Channel Morphometry: Applications for Wetland Creation and Restoration”, in Restoration Ecology, 7:2, p. 205-211). She differentiates between “through-flowing channels” such as the one that originates at Fish Trap Creek and continues through Cayou Estuary to Deer Harbor, and “dead-end channels” that branch off of the main through-flowing channel. Further the channels are characterized as first order when they have no other channels branching away, second order when it has branching channel, third order when the branches have branches, and so on up to fifth order channels.

The data appears to be quite variable, except that sinuosity was found to have a narrow range of values from 1.4 to 1.8 (where sinuosity is the actual channel length divided by that of the straight path). Mid-order channels were found to be most sinuous and higher and lower order channels somewhat less sinuous. Width to depth ratios were quite variable, ranging from 5 to 34, with a single outlier at 129. In general, muddier soils had smaller width to depth ratios than did sandier soils.

Sediment Grain Size Data

Sediment samples (Table 5) have been collected in the mud of the estuary and from the outlet channel that flows from the bridge down into Deer Harbor. The estuary mud samples provide an indication of the type of material that will erode following dam removal, and the channel samples are indicative of the bed material that will remain on the bed of the newly formed channels in the estuary.

Table 5. Sediment samples of Cayou Estuary and its outlet channel (in mm).

SAMPLE	D100	D90	D50	D20	D10	MATERIAL
Estuary, surface	19	.209	.177	.106	.025	Silty SAND
Estuary, 20 cm	19	.348	.267	.136	.035	Silty SAND
Channel #1	53.3	22.9	10.2	5.1	5.1	Coarse GRAVEL
Channel #2	78.7	53.6	19.1	10.2	7.6	Coarse GRAVEL
Channel #3	182.9	63.8	30.5	15.2	9.9	Coarse GRAVEL
Channel #4	68.6	46.2	20.3	10.2	7.6	Coarse GRAVEL
Channel #5	76.2	55.9	20.3	12.2	7.6	Coarse GRAVEL

The two estuary samples were found to be comprised of 20.2 and 23.6 percent fines (silts and clays), with the remaining material fine sand and coarser. This percentage of material might remain suspended in tidal exchange water long enough to be swept well out into Deer Harbor. The remaining portion of the material would be transported by saltation (bedload) except during the highest of flows.

Estimate of Erosion from Cayou Estuary into Deer Harbor

For the purpose of this estimate of new channel formation, I make the following assumptions as justified by the explanations above:

- the rock dam is removed and the affected substrate is smoothed to feather into the surrounding contours,

- the fine-grained, erodable substrate within the estuary is deep enough (over 3 feet deep) so that the depth of scour is not limited by a gravelly layer located just beneath the surface (and the sediment is assumed not to be especially cohesive, such as peat for example, which is fibrous and not very erodable),

- a creek channel will cut its way from the bridge toward the mouth of the creek along an even slope,

- the depth of the cut will be controlled by the existing channel just downstream of the bridge, which is at elevation 2.0 feet and the elevation at the top of the estuary which is at elevation 5.0 feet, with an even slope in between.

- I have reviewed Coastal Geologic Services' drawing of the historic channels in Cayou Lagoon from 1977 (presented elsewhere) to estimate the overall density of new channels. The anticipated future channels are drawn to follow existing low spots and to connect to Fishtrap Creek and to the area of seepage (that is know to exist even during summertime) along the estuary's eastern shore, and

- I anticipate that the size of the channels will be as found in Appletree Cove as presented in Figures 16 and 17. I postulate that the speed of washout shall be on the order of two years as found in Dogfish Creek at Liberty Bay. Thus, Appletree Cove is used as a reference reach for channel morphometry, and Dogfish Creek is used as the reference area with respect to timing.

Existing bathymetry is shown on Figure 18 and proposed channel conditions on Figure 19. A total of 3090 feet of anticipated channels are drawn. These have a sinuosity of 1.4 and are segregated into two size classes:

1. The third order and a small portion of the second order channels are anticipated to have a 40 foot average width and average depth of 2.1 feet. 900 feet of this size channel is anticipated.

2. The first order and most of the second order channels are anticipated to have an average with of 14 feet and average depth of 0.5 feet. 2190 feet of this size channel is anticipated.

But less cut will occur than these average dimensions because the Bay already has traces of a channel through it as determined by the topographic mapping. The total channel length from the bridge to Fishtrap Creek is 1920 feet, and the slope is 0.156 percent. Regularly spaced cross-sections were taken to determine the total cut anticipated. These resulted in an expected

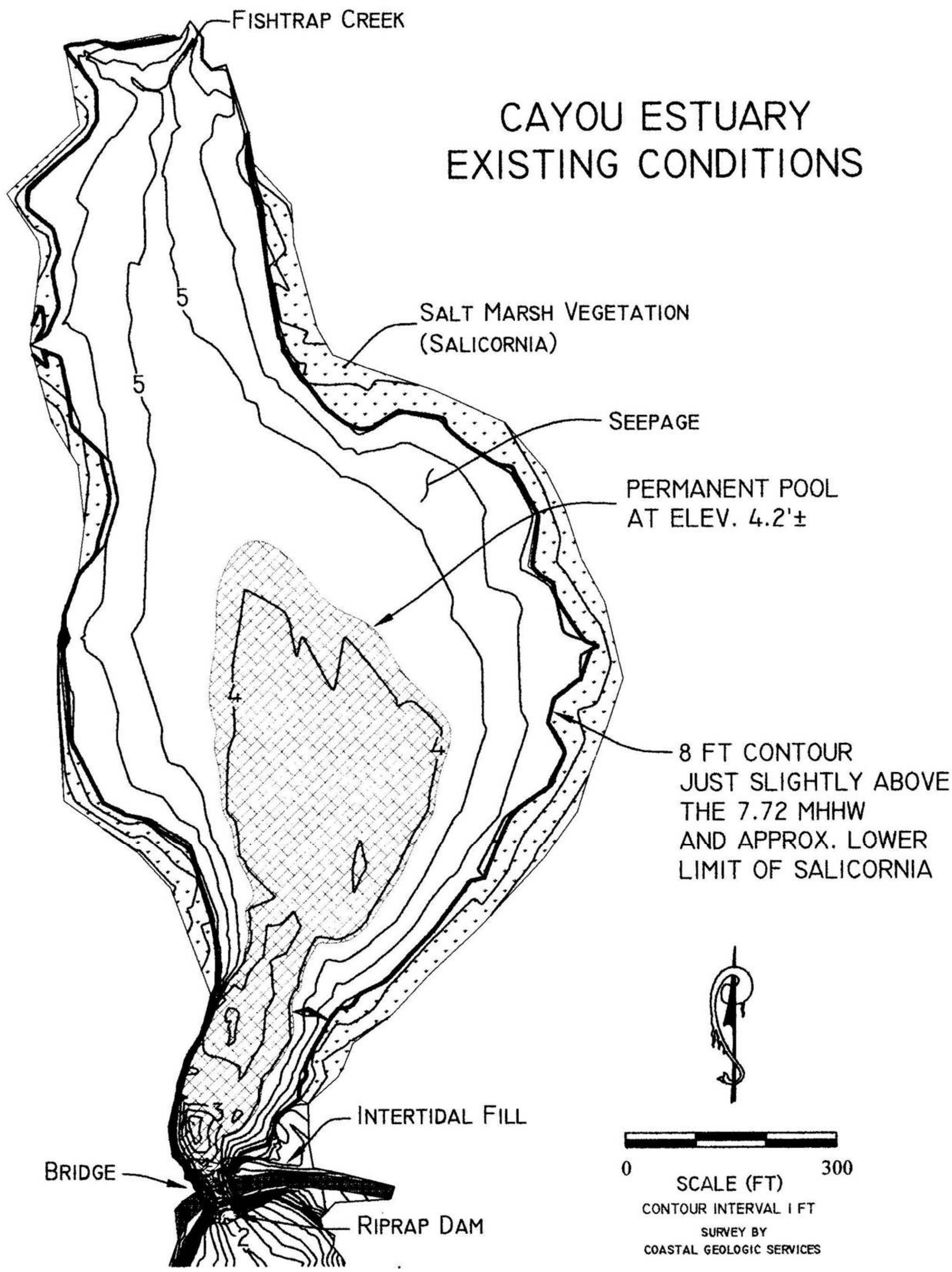

Figure 18. Existing conditions in Cayou Estuary.

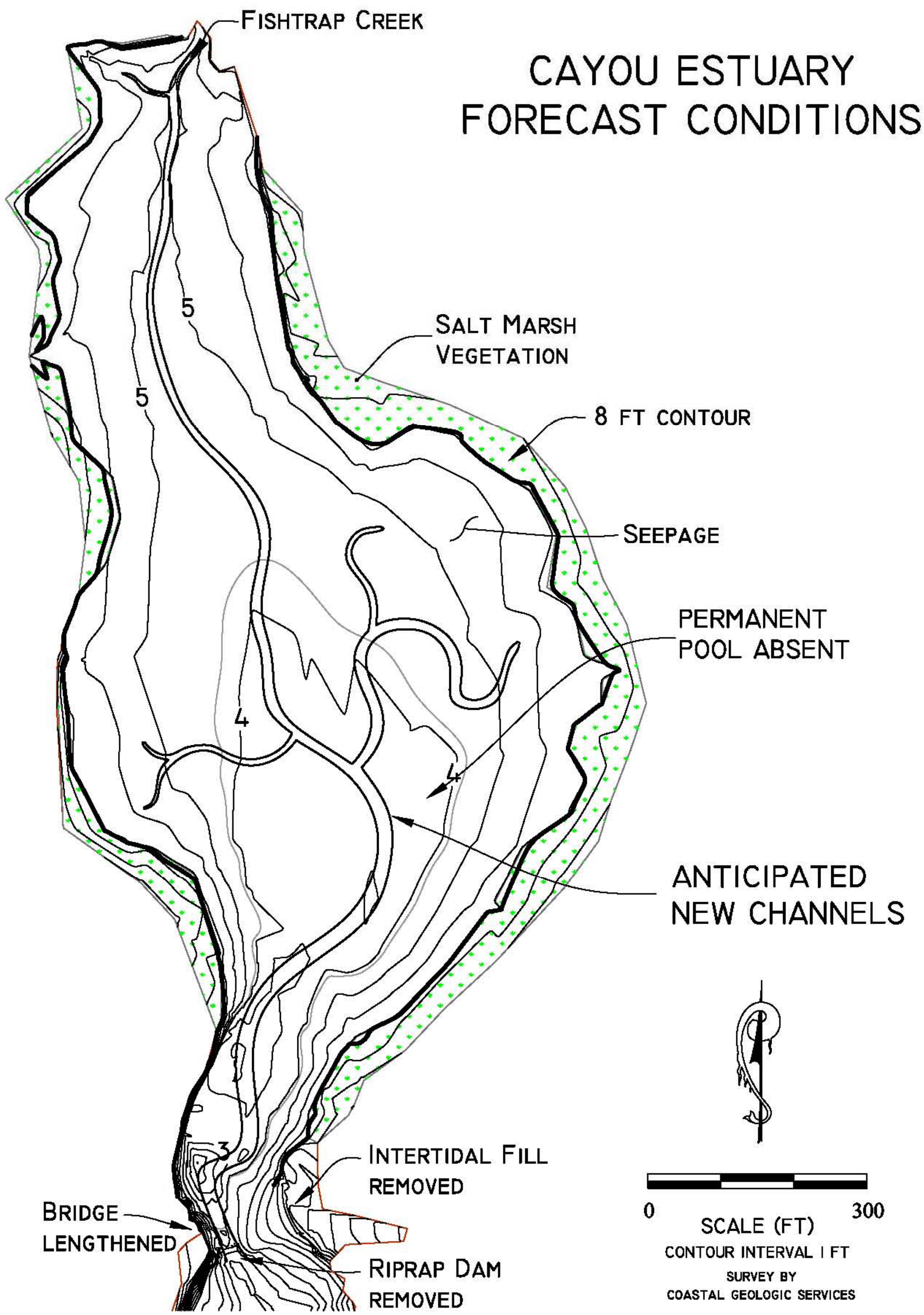

Figure 19. Anticipated conditions in Cayou Estuary.

average cut of 0.95 feet for the 40-foot wide channels and 0.22 feet for the 14-foot wide channels. Therefore the expected amount of erosion is:

(0.95 ft deep) x (40 ft wide) x (900 ft long) + (0.22 ft deep) x (14 ft wide) x (2190 ft long)

= 40,945 cu ft = **1516 cu yd** = 1159 cubic meters

Of this, 23 percent (349 cu m) is silt-sized and could be transported as suspended load and 77 percent (1168 cu m) is sand sized or larger and could be transported as bedload.

Based on the Dogfish Creek experience (Figures 11 and 12), it is likely that most of this material would wash out in a year or two. The washout would begin to occur immediately following dam removal. Episodic adjustments are anticipated during especially wet and stormy periods such as typically occur during late fall and early winter. Once these adjustments have occurred, the estuary channels will become stable. Indeed, the literature reports that channels like these may be fixed in one position for centuries.

It is important to recognize the mechanism of washout is by scour that will occur during outgoing tides when the flow is confined within the channel with a high enough velocity to transport solids. At higher tidal levels the cross-sectional area of the out flowing stream would be larger and velocity will be sufficiently low that scour will not occur. High creek flow would add to scour.

Deposition of this eroded material outside of the estuary is controlled by the same process. Namely, during low tide, the out flowing water will have the necessary velocity to transport bedload particles via the channel. The typical deposition pattern for channels of this sort is to deposit material to either side of the channel. This is our expectation. The eroded material will be deposited to either side of the outlet channel. We know the lowest extent of the outlet channel (about 1100 feet south of the bridge), thus we know that that is as far as the stream has power to transport sandy solids. At this location the water is so deep and with such a large cross-sectional area, that even during the lowest tides scour does not occur. We pick this point to be the seaward extent of transport of the coarse solids (the 77 percent that are coarser than silt) from Cayou Estuary (Figure 20).

There is one additional consideration for these solids. Wave action will redistribute these solids. So the expected pattern of deposition is along the channel, but also spread out by the energy of wind waves. This expected deposition area is shown on Figure 20.

The existing hole upstream of the bridge is expected to be filled as shown on Figure 20. Combined, these two deposition areas (Figure 20) are 168,805 square feet in area, as drawn. If 77 percent of the 1516 cubic yards of sediment were deposited in this area, the average depth of accumulation would be 0.19 feet thick.

The fine grained solids, the silts that make up 23 percent of the total erodable material, will be transported from the estuary as suspended load. These particles stay entrained in the water column as a function of turbidity and have potential to transport thousands of feet.

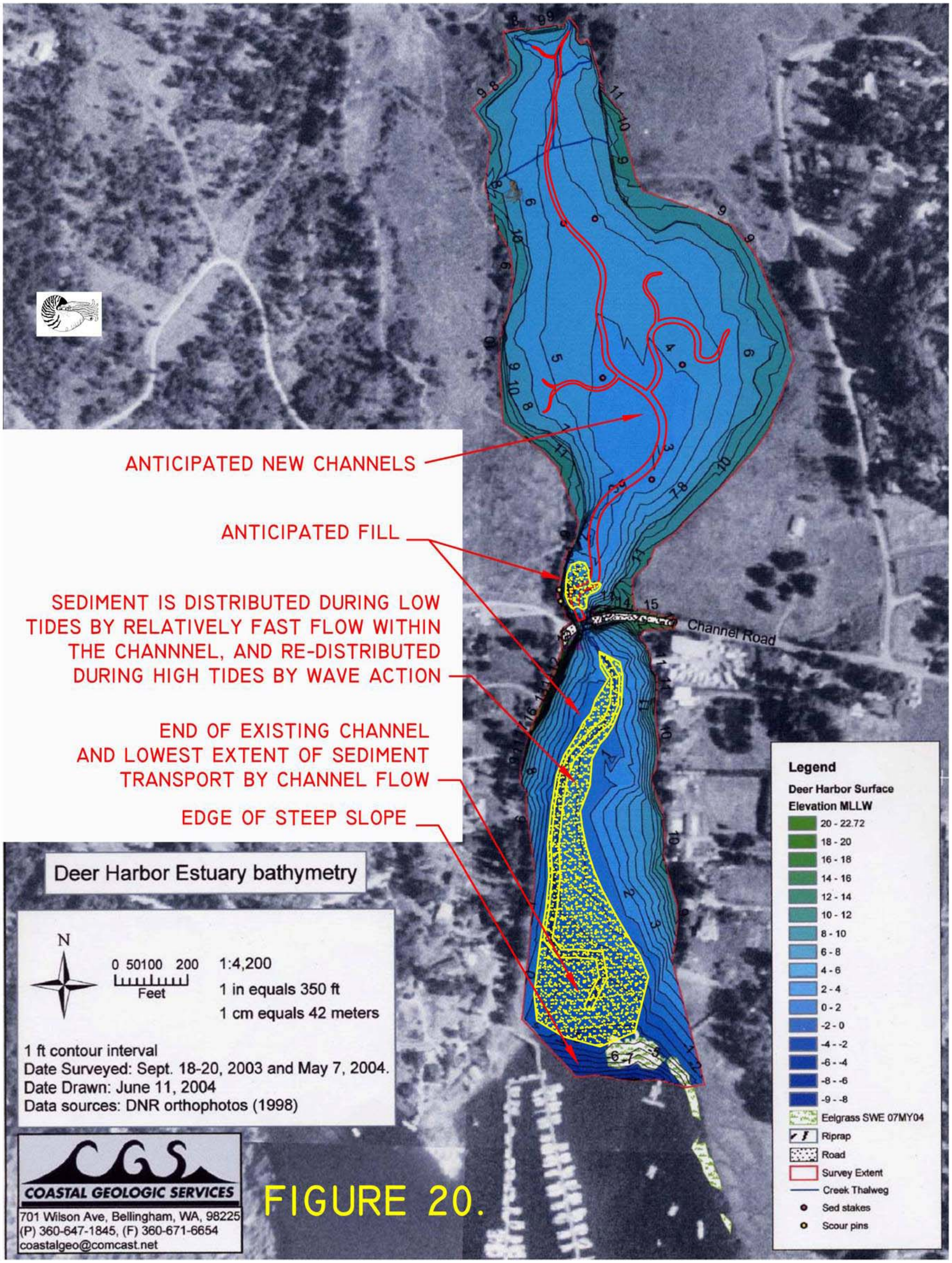
ANTICIPATED NEW CHANNELS
ANTICIPATED FILL
SEDIMENT IS DISTRIBUTED DURING LOW TIDES BY RELATIVELY FAST FLOW WITHIN THE CHANNNEL, AND RE-DISTRIBUTED DURING HIGH TIDES BY WAVE ACTION
END OF EXISTING CHANNEL AND LOWEST EXTENT OF SEDIMENT TRANSPORT BY CHANNEL FLOW
EDGE OF STEEP SLOPE
Channel Road
Deer Harbor Estuary bathymetry
N
0 50100 200
Feet
1:4,200
1 in equals 350 ft
1 cm equals 42 meters
1 ft contour interval
Date Surveyed: Sept. 18-20, 2003 and May 7, 2004.
Date Drawn: June 11, 2004
Data sources: DNR orthophotos (1998)
CGS
COASTAL GEOLOGIC SERVICES
701 Wilson Ave, Bellingham, WA, 98225
(P) 360-647-1845, (F) 360-671-6654
coastalgeo@comcast.net
Legend
Deer Harbor Surface Elevation MLLW
20 - 22.72
18 - 20
16 - 18
14 - 16
12 - 14
10 - 12
8 - 10
6 - 8
4 - 6
2 - 4
0 - 2
-2 - 0
-4 - -2
-6 - -4
-8 - -6
-9 - -8
Eelgrass SWE 07MY04
Riprap
Road
Survey Extent
Creek Thalweg
Sed stakes
Scour pins

FIGURE 20.

The net effect will be the creation of new sandy gravel channels within the Cayou Estuary. The existing pool behind the dam will be lost, and replaced by a fully exposed (at low tide) mudflat with a sinuous channel. The new channels will provide a different type of habitat than the previous mudflat, for example, supporting oysters.

Conclusions and Expectations

- It is clear that the rock dam under the existing bridge is 3.5 feet tall and blocks the outflow of water from the estuary. This blockage promotes sediment accumulation within the estuary and prevents formation of tidal channels that would otherwise occur.

- Removal of the dam would result in the formation of new tidal channels. Approximately 1516 cubic feet of silty sand may wash out of the estuary following dam removal.

- Most of this washout is expected to occur within a 2 year period. A stable channel is anticipated after that time.

- The newly formed channels will have sandy gravel beds and should support oyster and foot-traffic.

- Most of the sediment washed from the estuary is expected to accumulate within 1100 feet of the bridge at an average thickness of about 0.19 feet.

Appendix E:

Deer Harbor
Eelgrass Assessment

Deer Harbor Bridge/ Restoration Design

Zostera marina (eelgrass) Component

S. Wyllie-Echeverria[1], R.E. Wyllie-Echeverria[2] and V. R. Wyllie-Echeverria[3]

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[3]Friday Harbor Laboratories, University of Washington, Friday Harbor, Washington 98250 USA

Objectives

1) Survey the extant *Zostera marina* (eelgrass) patches within the study area.
2) Develop and implement an experimental design to determine the relationship between submarine light (i.e., Photosynthetically Active Radiation (PAR)) within the study area.
3) Based the findings of objective #2, provide direction toward the selection of bridge replacement options.

Methods

Z. marina survey

During maximum low water (approximately -1 m (-3.3 ft) MLLW) on 7 May 2004, we located and mapped extant *Z. marina* populations within the study area (Fig 1.2).

Submarine Light Sampling

<u>Permanent Stations</u>

We established two permanent stations within the study area and one in a control site within Picnic Cove on the southern side of Shaw Island (Figure XX and Figure YY). Picnic Cove is a permanent reference station for the Washington State Department of Natural Resources, Submerged Vegetation Monitoring Program (Berry et al. 2003). Yearly estimates of *Z. marina* bottom cover are calculated and indicate that the population at this site has remained relatively stable since 2000. At each permanent station vertical transects were sampled within 2 hrs of solar noon using a spherical 4π sensor (Zimmerman et el. 1991; Carruthers et al. 2001). Sampling began on 2 July 2003 and continued until 19 April 2004 and sampling events occurred in each season (Table WW). Attenuation coefficients (the relationship between available PAR (wavelengths 400-700 nm) and depth) were calculated for each date at the each station in Microsoft Excel (Zimmerman et al. 1991; Carruthers et al. 2001). Statistical comparisons were made using the student t-test ($\alpha = 0.05$) in Microsoft Excel.

Figure XX. Permanent submarine light sampling stations located within Deer Harbor and Picnic Cove.

Table WW. Sampling of permanent stations occurred on the dates listed below.

Date	Date
16 Jul 03	1 Dec 03
22 Jul 03	8 Dec 03
5 Aug 03	17 Dec 03
19 Aug 03	9 Feb 04
9 Sep 03	10 Mar 04
29 Sep 03	17 Mar 04
27 Oct 03	23 Mar 04
17 Nov 03	29 Mar 04

24 Nov 03	19 Apr 04

Grid Sampling

On 26 January 2004 and 28 April 2004, we sampled randomly selected stations with a grid pattern in the study area. These dates were chosen to compare a month of high flow (January) with a month of moderate flow (April) into the estuary from the from the surrounding watershed. The most northerly *Z. marina* patch in the estuary and adjacent deep and shallow water habitats were contained within grid boundaries (Figure XX.). GPS coordinates within each grid cell were calculated in ArcView by Coastal Geological Services, Inc. Following this, twenty-nine individual grid cells were randomly selected in three strata; shallow water stations without *Z. marina* (6 stations), shallow water stations within the extant *Z. marina* patch (10 stations) and deep water stations outside the zone of observed *Z. marina* presence (13 stations). Vertical transects were sampled within 2 hrs of solar noon at each station using a spherical 4π sensor and attenuation coefficients were calculated in Microsoft Excel (Zimmerman et el. 1991; Carruthers et al. 2001). Statistical comparisons were made using the student *t*-test (α = 0.05) in Microsoft Excel.

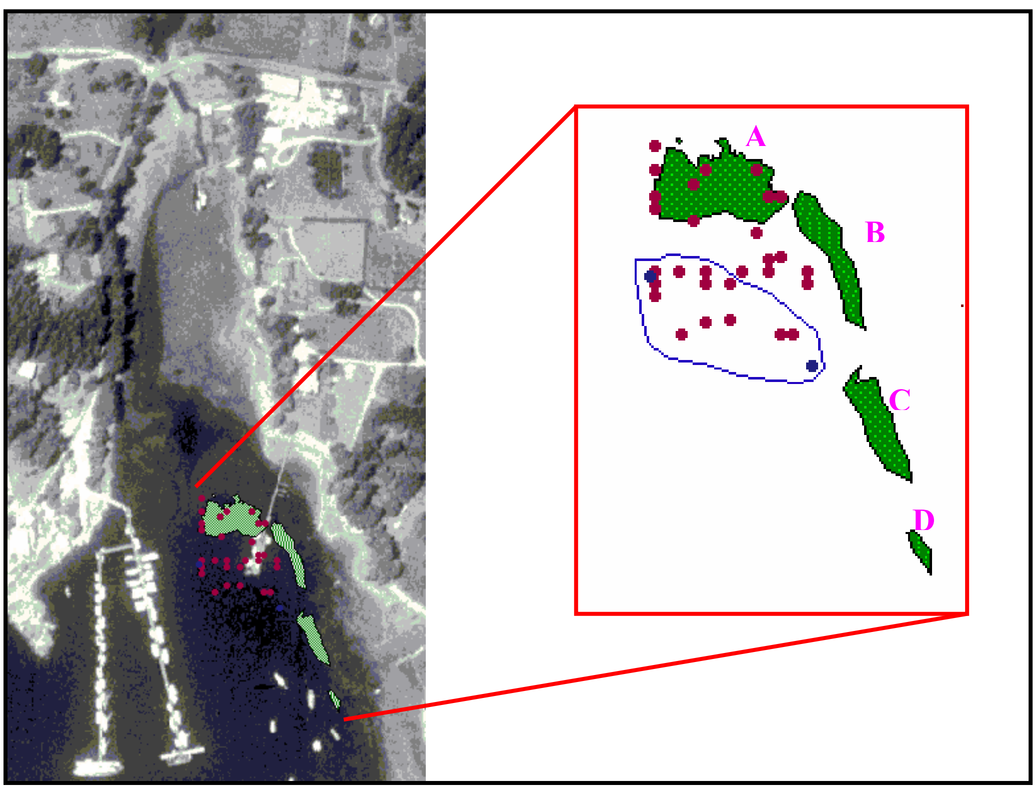

Figure YY. Permanent submarine light sampling stations and randomly selected stations sampled in January and April are marked in the inset. Permanent stations are marked in blue; randomly selected stations in red. The blue polygon encircling stations indicates deeper water locations. Individual *Z. marina* patches are identified as A, B, C and D.

Results

Z. marina survey

Four discontinuous patches of *Z. marina* were present on the eastern side of the study area in May 2004 (Figure YY). The size of individual patches is listed in Table YY.

Table YY. Area estimates for each of the four patches within the study site.

Patch	Size
A	0.28 ac (0.12 ha)
B	0. 12 ac (0.05 ha)
C	0.11 ac (0.04 ha)
D	0.02 ac (0.01 ha)
Totals	0.53 ac (0.21 ha)

Submarine Light Sampling

Permanent Stations

While there was a slight variation between available PAR between Deer Harbor Station 1 and Deer Harbor Station 2 over the course of the sampling period, this difference was not significant (α= 0.05) (Table XX). However the difference between available PAR at both Deer Harbor Stations and Picnic Cove, during the sampling period, was significantly different (α = 0.05) with Picnic Cove values being higher indicating less available PAR (Table XX). Seasonal differences between the three stations were not significantly different (α = 0.05) except during the winter when the higher values at Picnic Cove were significantly different (α= 0.05) than at Deer Harbor Station 2.

Table ZZ. Attenuation coefficients are listed for each sampling period at each station.

Date	Deer Harbor 1	Deer Harbor 2	Picnic Cove
16 Jul 03	0.37	0.30	0.41
22 Jul 03	0.36	0.50	0.70
5 Aug 03	0.31	0.29	0.39
19 Aug 03	0.36	0.34	0.28
9 Sep 03	0.36	0.33	0.44
29 Sep 03	0.27	0.22	0.97
27 Oct 03	0.18	0.22	0.16
17 Nov 03	0.35	0.29	0.32
24 Nov 03	0.23	0.20	0.55
1 Dec 03	0.17	0.14	0.34
8 Dec 03	0.18	0.20	0.52
17 Dec 03	0.31	0.17	0.28
9 Feb 04	0.20	0.23	0.58
10 Mar 04	0.24	0.29	0.56

17 Mar 04	0.20	0.23	0.30
23 Mar 04	0.30	0.25	0.15
29 Mar 04	0.25	0.26	0.34
19 Apr 04	0.38	0.21	0.29

<u>Grid Sampling</u>

Aggregate attenuation coefficients for January were significantly ($\alpha = 0.05$) lower (more available submarine PAR) than April. Values were also consistently lower ($\alpha = 0.05$) in all three strata ((1) shallow: no *Z. marina*; (2) deep: no *Z. marina* and (3) *Z. marina* patch) in January compared to April. There was no significant difference ($\alpha = 0.05$) between the three strata in January; however in April while values for shallow stations without *Z. marina* and stations with *Z. marina* present were not different ($\alpha = 0.05$), values for both these strata were lower than the deep stratum ($\alpha = 0.05$).

Table ZZ. Differences in attenuation coefficients observed between months and strata within the study site.

Comparison	Difference
Aggregate January to April	Lower in January ($\alpha = 0.05$)
January Strata	No Difference
April Strata 1 and 3	No Difference
April Strata 1 and 3 to April Stratum 2	Lower in Strata 1 and 3 ($\alpha = 0.05$)

Findings

1) There are four relatively small, discontinuous patches on the eastern side of the study (Figure XX) ranging in size from 0.28 acres (0.12 ha) to 0.02 acres 0.01 ha).

2) From the July 2003 to April 2004 attenuation coefficients were lower within the study area than the reference site (Picnic Cove). Because lower coefficient values indicate more available submarine light and the reference site supports a relatively stable population of *Z. marina*, we can postulate that, during this time frame, submarine light was probably not a limiting factor for *Z. marina* within the study site.

3) In 2004 more submarine light was available on 26 January than on 28 April within the study area.

4) On 28 April, 2004 more submarine light was available in shallow stations with or without *Z. marina* than in deeper stations.

5) On 26 January and 28 April 2004, submarine light was equally available in shallow stations with or without *Z. marina*.

Recommendations

1) Based on this pilot study, activities that increase sediment loading in early spring should be avoided.

2) Before bridge construction begins and continuing for a year after construction has ended submarine light should be continuously monitored to determine the potential influence of impounded sediment released from Cayou Valley Lagoon on the submarine light environment in Deer Harbor.

3) This pilot study indicates that the submarine light environment may not limit *Z. marina* patch expansion in Deer Harbor. Because the distribution of *Z. marina* and other seagrasses can be influenced by a suite of natural and anthropogenic disturbance vectors acting singly or in concert (Short and Wyllie-Echeverria 1996), and *Z. marina* restoration sites may be needed following construction, a more detailed environmental assessment is needed within the study site.

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Appendix F:

Deer Harbor
Fish Utilization Study

Appendix F: Deer Harbor Estuary Fish Utilization Study

T. Wyllie-Echeverria, R.E. Wyllie-Echeverria and V. R. Wyllie-Echeverria

Conclusions and Recommendations

Juvenile salmonids were sampled from Deer Harbor and inside the lagoon. Sampling data are presented in the following tables and figures.

If the elevation under the bridge is deepened, the opening widened and the current velocity reduced, it is likely that more pelagic fish would move between Deer Harbor and Cayou Lagoon. This would include surf smelt, shiner perch, herring, and juvenile salmon. It is likely that the species typically found in the harber (see data table) would increase their use of the lagoon after construction. If the proposed restoration activities are not implemented and the lagoon substrate continues to be mud, the species complex in the lagoon would continue to be dominated by sculpins.

Construction of the proposed restoration activities should be done during the fall and winter months in order not to disrupt the population of fish observed in this sampling study.

Deer Harbor Fish Sampling 2003-2004- Summary table of species and numbers of fish sampled by date

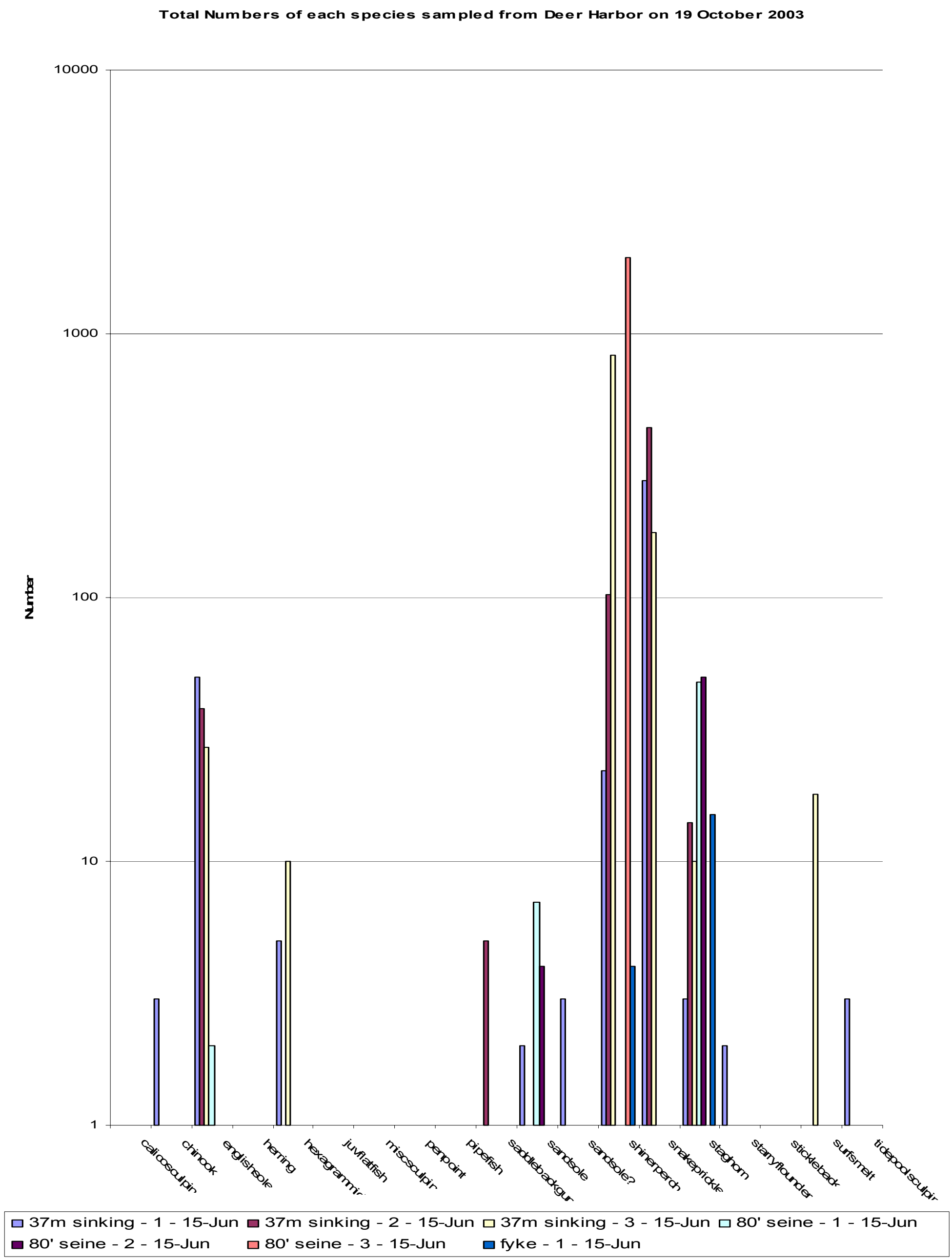
Sum of totalcatch	net	set	date															
	37m sinking						Total	80' seine						Total	fyke		Total	Grand Total
	1	1 Total	2	2 Total	3	3 Total		1	1 Total	2	2 Total	3	3 Total		1	1 Total		
fish	6/15/04		6/15/04		6/15/04			6/15/04		6/15/04		6/15/04			6/15/04			
calicosculpin								1	1					1				1
chinook	3	3					3											3
englishsole	50	50	38	38	27	27	115	2	2	1	1			3				118
herring	1	1			1	1	2											2
hexagrammid	5	5			10	10	15			1	1			1				16
juvflatfish			1	1			1											1
miscsculpin								1	1					1				1
penpoint	1	1					1											1
pipefish	1	1					1								1	1	1	2
saddlebackgun			5	5	1	1	6											6
sandsole	2	2					2	7	7	4	4			11				13
sandsole?	3	3					3											3
shinerperch	22	22	103	103	833	833	958					1942	1942	1942	4	4	4	2904
snakeprickle	278	278	442	442	177	177	897											897
staghorn	3	3	14	14	10	10	27	48	48	50	50	1	1	99	15	15	15	141
starryflounder	2	2					2											2
stickleback															1	1	1	1
surfsmelt					18	18	18											18
tidepoolsculpin	3	3	1	1			4											4
Grand Total	374	374	604	604	1077	1077	2055	59	59	56	56	1943	1943	2058	21	21	21	4134

Deer Harbor Fish Sampling 2003-2004- Summary table of species and numbers of fish sampled by date - 37 M seine

Sum of totalcatch	net / set / date										
	37m sinking						Total	fyke		Total	Grand Total
	1	1 Total	2	2 Total	3	3 Total		1	1 Total		
fish	10/19/2003		10/19/2003		10/19/2003			10/19/2003			
buffalosculpin	4	4	3	3			7				7
cresentgunnel	19	19	21	21			40				40
englishsole	16	16	6	6	2	2	24				24
greengreenling	1	1			1	1	2				2
herring								3	3	3	3
hexagrammid	6	6					6				6
lumpsucker	1	1					1				1
penpoint	1	1	3	3			4				4
pipefish	4	4					4				4
rainbowperch	1	1					1				1
saddlebackgun			10	10			10				10
shinerperch	63	63	1	1	27	27	91	3	3	3	94
snakeprickle	1	1					1	1	1	1	2
sole	2	2					2				2
staghorn	12	12	2	2	4	4	18	2	2	2	20
starryflounder	6	6					6				6
stickleback	1	1					1	21	21	21	22
surfsmelt								2	2	2	2
tidepoolsculpin	15	15	2	2	8	8	25				25
Grand Total	153	153	48	48	42	42	243	32	32	32	275

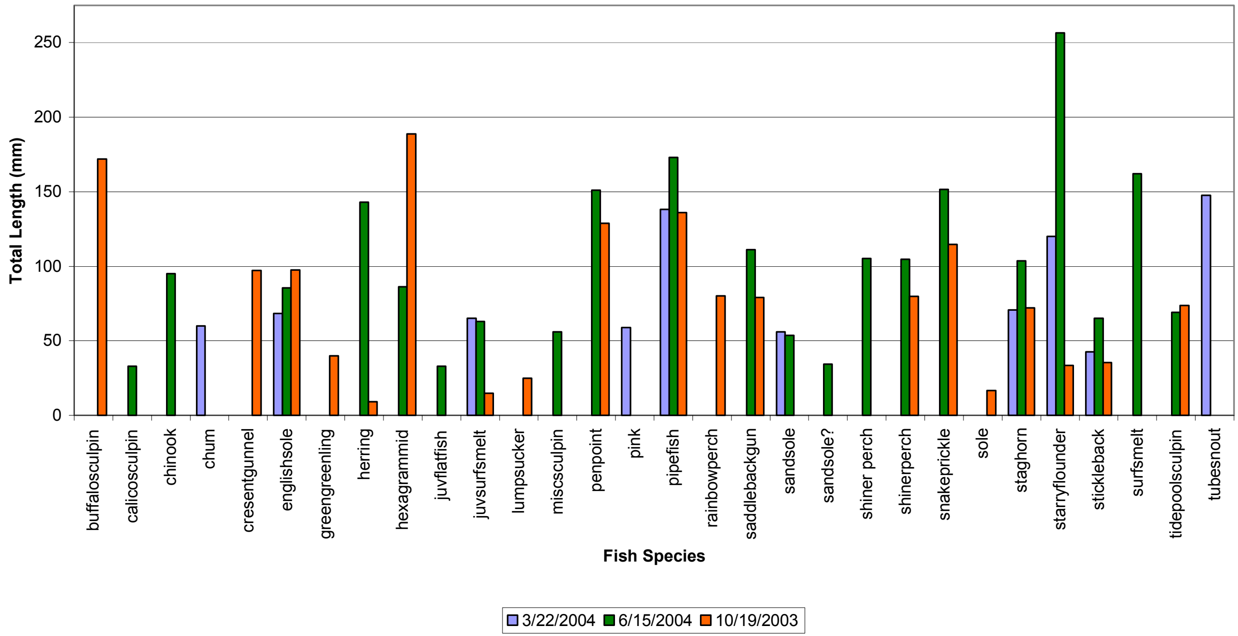
Deer Harbor Fish Sampling 2003-2004- Summary table of species and numbers of fish sampled by date - 37 M seine

Sum of totalcatch	net	set	date									
	37m sinking						Total	fyke		Total	Grand Total
	1	1 Total	2	2 Total	3	3 Total		2	2 Total		
fish	22-Mar-04		22-Mar-04		22-Mar-04			22-Mar-04			
0								0	0	0	0
englishsole	2	2	3	3			5				5
juvsurfsmelt					1	1	1				1
pink					1	1	1				1
pipefish	7	7			1	1	8				8
sandsole	1	1					1				1
staghorn	7	7	44	44	21	21	72				72
starryflounder	1	1	1	1	2	2	4				4
stickleback	1	1	9	9	1	1	11				11
tubesnout	2	2					2				2
Grand Total	21	21	57	57	27	27	105	0	0	0	105



Total Numbers of each species sampled from Deer Harbor on 19 October 2003
10000
1000
100
10
1
Number
calicosculpin
chinook
englishsole
herring
juvflatfish
miscsculpin
penpoint
pipefish
sandsole
sandsole?
shinerperch
staghorn
starryflounder
surfsmelt
37m sinking - 1 - 15-Jun
37m sinking - 2 - 15-Jun
37m sinking - 3 - 15-Jun
80' seine - 1 - 15-Jun
80' seine - 2 - 15-Jun
80' seine - 3 - 15-Jun
fyke - 1 - 15-Jun

Average Total Length for each Species by month sampled at Deer Harbor, Orcas Island 2003-2004



Average total lenghts for all species caught at Deer Harbor during 2003-2004.

Average of totallength	date			
fish	3/22/2004	6/15/2004	10/19/2003	Total Average Length
buffalosculpin			172	172
calicosculpin		33		33
chinook		95		95
chum	60			60
cresentgunnel			97	97
englishsole	68	85	98	88
greengreenling			40	40
herring		143	9	63
hexagrammid		86	189	125
juvflatfish		33		33
juvsurfsmelt	65	63	15	39
lumpsucker			25	25
miscsculpin		56		56
penpoint		151	129	133
pink	59			59
pipefish	138	173	136	143
rainbowperch			80	80
saddlebackgun		111	79	94
sandsole	56	54		54
sandsole?		34		34
shiner perch		105		105
shinerperch		105	80	98
snakeprickle		152	115	150
sole			17	17
staghorn	71	104	72	87
starryflounder	120	257	34	100
stickleback	43	65	35	39
surfsmelt		162		162
tidepoolsculpin		69	74	73
tubesnout	148			148
Total Average Length	77	110	82	97