US Army Corps
of Engineers ®
Portland District

Crims Island
Section 536 Habitat Restoration Project
Lower Columbia River and Estuary

APPENDIX F

HYDRAULIC AND HYDROLOGIC EVALUATION

Project Partners:

U.S. Army Corps of Engineers
U.S. Fish and Wildlife Service
Bonneville Power Administration
U.S. Geological Survey
Columbia Land Trust

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Lower Columbia River
Ecosystem Restoration 536

Crims Island

Hydraulic and Hydrologic Evaluation

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Table of Contents

1.0 INTRODUCTION:

Crims Island presents an opportunity to create a freshwater intertidal marsh in the Lower Columbia River Basin. The purpose of this report is to document the technical data and considerations leading the to proposed Crims Island intertidal marsh design. This document presents technical data supporting the development and design of 91 acres of intertidal marsh including an associated tidal channel system. The report is organized to provide the reader with information leading to logical conclusions concerning each design element. A hydrologic analysis of the Lower Columbia River focusing on tidal range is included along with suspended sediment data collected in the vicinity of the Island. Reference marshes are selected to provide analog data and direct the design of the Crims Island marsh. A plan form including channel system, entrance locations and marsh plain elevation is presented. A design methodology for channel cross-section sizing is established and verified for the project. Finally, designs for channel cross- section construction are presented.

2.0 HYDROLOGY:

Crims Island is located at river miles 54.0 to 56.5 on the Lower Columbia River, upstream of the saline estuary, but still subject to tidal action. The United States Army Corps of Engineers (USACE) Northwest Division produced combined probability flood profiles for the lower Columbia River (June 1, 1994) based on the unsteady flow model results. Table 2.0-1 shows the flood frequency elevations at the upstream and downstream ends of Crims Island.

Location	Water Surface Elevations for given Flood Frequency feet NGVD (feet NAVD88)				
	2 yr	10 yr	50 yr	100 yr	500 yr
River Mile 54.0, Downstream End of Crims Island	10.2	12.1	13.7	14.3	16.1
	(13.4)	(15.3)	(16.9)	(17.5)	(19.3)
River Mile 56.5, Upstream End of Crims Island	10.4	12.6	14.3	15.0	16.9
	(13.6)	(15.8)	(17.5)	(18.2)	(20.1)

Table 2.0-1. Columbia River Combined Probability Flood Elevations. (Source = USACE CENPP-PE-HY)

Flood frequency flows above the tidal zone at the Dalles Dam (river mile 191.5) are given in table 2.0-2. Several large rivers join the Columbia River below The Dalles Dam, including the Willamette, Lewis and Cowlitz. Their contribution to flow is not included in the table. Regulated discharge flow frequency values are taken from a USACE analysis dated June 1987.

Maximum Annual Daily Regulated Discharge for given Frequency x1000 cfs				
2 yr	10 yr	50 yr	100 yr	500 yr
360	515	635	680	800

Table 2.0-2. Columbia River Regulated Flood Frequency Flows at The Dalles Dam (RM 191.5).

An analysis of USGS station 14246900, Columbia River at Beaver Army Terminal, located at river mile 53.8, was performed to gain understanding of the tidal effects at Crims Island. This station has been recording instantaneous stage data at 15-minute intervals since February 1991. Review of the Columbia River flood profiles (CENPP-PE-HY) show that the difference in water surface between Beaver Army Terminal and Crims Island is 0.2 ft at 2-year flood frequency flows. During extreme conditions, low river flow and high tides, negative flows are observed in the Columbia River at Beaver Army Terminal. Therefore, a constant shift cannot be applied to the observed stage data. Stages at Crims Island will be considered as equivalent to Beaver Army Terminal for this study.

Mean values over the period of record for each Julian day are calculated for maximum, minimum and mean stages. Monthly and annual means are calculated from each of these daily values (figure 2.0-3). The average daily tidal range at river mile 53.8 is 5.1 ft. There is also a seasonal effect in terms of mean water elevations. This variation ranges from a low monthly mean of 4.6 ft in September to a high monthly mean of 6.7 ft in February.

The Columbia River in the vicinity of Crims Island has mixed semidiurnal tides. This means that there is a large inequality in either the high or low water heights with the two flood periods and two ebb periods occurring each tidal day. This phenomenon is described in the terminology, *higher high water*, the higher of the two high waters of any tidal day, and conversely *lower low water*, the lower of the two low waters. Achieving proper use of this terminology requires the use of the lunar day in the stage-frequency analysis. Solar days have been used for this analysis, as little accuracy is lost at a gain of using commonly available software and data formats. More importantly, this departure allows for the capture of seasonal flow effects in stage.

A strict analysis of tidal mean conditions would also require 19 years (a Metonic cycle) of data in lieu of 13 years available at Beaver Army Terminal. A correction to the data will not be applied as additional factors of regulated seasonal flows and distance upstream from the ocean make the refinement unreasonable. The terms *annual mean of daily maximum* and *annual mean of daily minimum* will be used in lieu of the *mean higher high water* (MHHW) and *mean lower low water* (MLLW) respectively for this study.

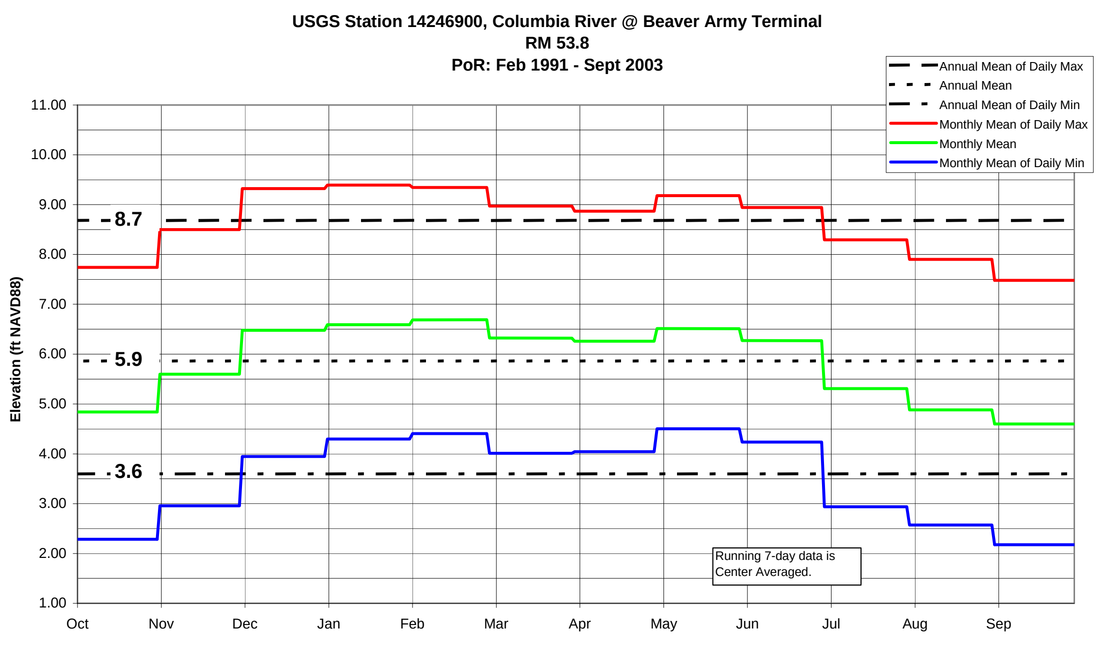


Figure 2.0-3: Stage-Frequency at Columbia River Mile 53.8

Stage analysis (figure 2.0-3) shows characteristics typical of the regulated lower Columbia River with two distinct periods of higher water. A winter period caused by rainstorms in the lower Columbia basin and a late spring period caused by snowmelt from the upper Columbia basin.

While river stages at Crims Island are related primarily to oceanographic phenomena, they are also related to flow in the Columbia River with typical seasonal effects present.

3.0 COLUMBIA RIVER SUSPENDED SEDIMENT:

The USGS has analyzed 158 grab samples taken from the Lower Columbia River at Beaver Army Terminal for suspended sediment concentration since 1990. A plot of these values is shown in figure 3.0-1. An average concentration of 32 mg/l is calculated for all data. The large spike occurring in the winter of water year 1996 corresponds with flooding experienced in the lower tributaries (Willamette, Cowlitz, Lewis, Sandy, etc. Rivers).

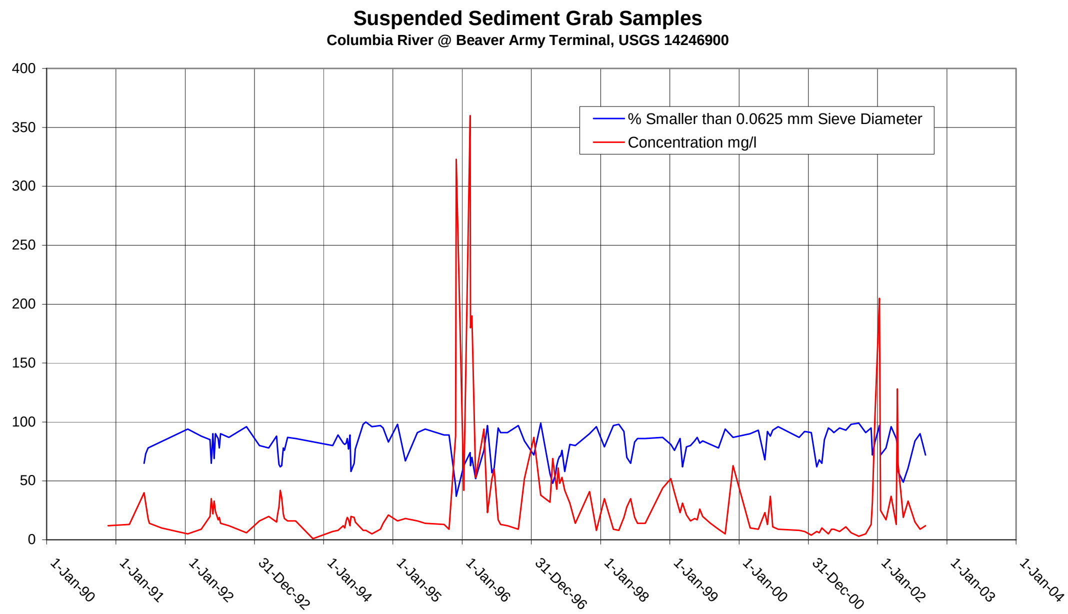


Figure 3.0-1: Suspended Sediment Concentrations at River Mile 53.8.

4.0 SOILS:

The National Resource Conservation Service (NRCS) provides publicly available soil survey products containing basic information about soils in a region. These products include delineation of soil types through mapping as well as basic physical and engineering properties. The NRCS classifies the Crims Island project area soils as deep, very poorly drained soil on concave, low flood plains of the Columbia River. The soil is formed in silty alluvium derived from mixed sources. The surface layer is typically mottled, dark grayish brown silt loam to very dark gray silt loam about 8 to 10 inches thick. The substratum to a depth of 60 inches or more is mottled, gray silt loam with thin lenses of peat or muck. The soil characteristics of the project area as well as reference marshes on Gull Island and Tronson Island are shown in table 4.0-1.

	Depth	USDA Testure	Percent Passing Sieve Number				Liquid	Plastic	Clay	Permeability
	(in.)		4	10	40	200	Limit	Index	%	(In/Hr)
Project Area										
LOCODA	0-10	Slit Loam	100	100	95-100	75-90	20-35	5-10	15-22	0.6-2
	10-60	Stratified Silt Loam to Silty Clay Loam Silty Clay Loam	100	100	95-100	75-95	25-40	5-15	18-35	0.2-0.6
WAUNA	0-8	Silt Loam	100	100	95-100	75-90	20-35	5-10	15-22	0.6-2
	8-26	Silt Loam Silty Clay Loam	100	100	95-100	75-95	25-40	5-15	18-35	0.2-0.6
	26-60	Stratified Sandy Loam to Silt Loam Silt Loam	100	100	90-100	70-80	25-35	NP-10	10-20	0.2-2
Gull Island Reference Marsh										
UDIPSAMMENTS	0-4	Fine Sand Loamy Snad Coarse Sand Sand	100	100	50-75	5-30	0-10	NP	0-5	6-100
	4-60	Sand Fine Sand Coarse Sand	100	100	50-70	5-25	0-10	NP	0-3	6-100
Tronson Island Reference Marsh										
COQUILLE	0-6	Silt Loam	100	100	95-100	75-90	30-35	NP-5	20-27	0.6-2
	6-30	Silt Loam Silty Clay Loam	100	100	95-100	75-95	35-40	5-10	20-35	0.2-0.6
	30-60	Silt Loam Silty Clay Loam Silty Clay Loam	100	100	95-100	80-95	45-55	15-20	25-65	0.06-0.2
CLATSOP	0-6	Muck	---	---	---	---	---	NP	---	0.6-2
	6-24	Silt Loam Silty Clay Loam	100	100	90-100	85-95	30-40	10-15	20-35	0.6-2
	24-60	Silt Loam Silty Clay Loam	100	100	95-100	85-95	45-55	15-25	20-35	0.06-2

Table 4.0-1: Soil Properties (NRCS)

5.0 GULL ISLAND REFERENCE MARSH:

The reference marsh for marsh plain design elevations is located on Gull Island, near the western (downstream) end of Crims Island. This marsh is close to the project area with driving river stages considered equivalent between the two areas. USACE personnel performed a survey of the Gull Island reference marsh in September of 2003 in order to assess the mature marsh plain elevations.

The downstream boundary of the reference marsh on Gull Island is a channel off of the Columbia River that separates Crims Island from Gull Island. This channel is subtidal and large compared to the largest channel in the reference marsh. The downstream interface between this channel and the reference marsh is a gently sloping unvegetated mudflat. The highest elevations in this mudflat are 6.0-6.5 ft (NAVD88). This mudflat yields to a vegetated marsh plain at elevations 7.2-8.0 ft in a narrow zone of steeper grade. A single channel passes through this lower marsh plain and then bifurcates into two distinct zones.

One branch of the bifurcated channel connects the downstream water source to an interior quasi-mudflat (lightly vegetated, very soft soils similar to non-vegetated mudflat). This channel bisects the interior mudflat and is distinguishable throughout the length of the mudflat. This interior quasi-mudflat exists at an elevation of 6.5-7.0 ft. This interior mudflat yields to vegetated marsh plain on either side.

The second branch of the bifurcated main channel bisects a vegetated marsh plain. The steep banks of the channel yield to marsh plain at elevation 7.5-8.0 ft. This channel can be follow to the upstream boundary of the reference marsh. The marsh plain on either side of this channel is the highest non-forested lands in the intertidal area and has the highest elevation at 9.5 ft.

The upstream boundary of the reference marsh is the main stem of the Columbia River. This interface is vertically cut and eroding with slump-blocks sloughing into the Columbia River. This is in contrast to the downstream interface where a large mudflat and delta have formed. Review of historical aerial photos reveal that the upstream interface has been receding for the past 30 years while the downstream mudflat and delta has expanded.

Elevation of the reference marsh plain corresponds well with the stage-frequency analysis of Beaver Army Terminal USGS station 14246900 (figure 2.0-3). The monthly mean of daily maximum stage for the period of record varies from a low of 7.5 ft in September to a high of 9.4 ft in December. This is the same range of elevations seen in the vegetated marsh plain in the reference marsh. This relationship between daily maximum stage elevations and marsh plain elevations follows marsh development theory (Callaway, 2001) and will serve as a design elevation range for excavations in the project area.

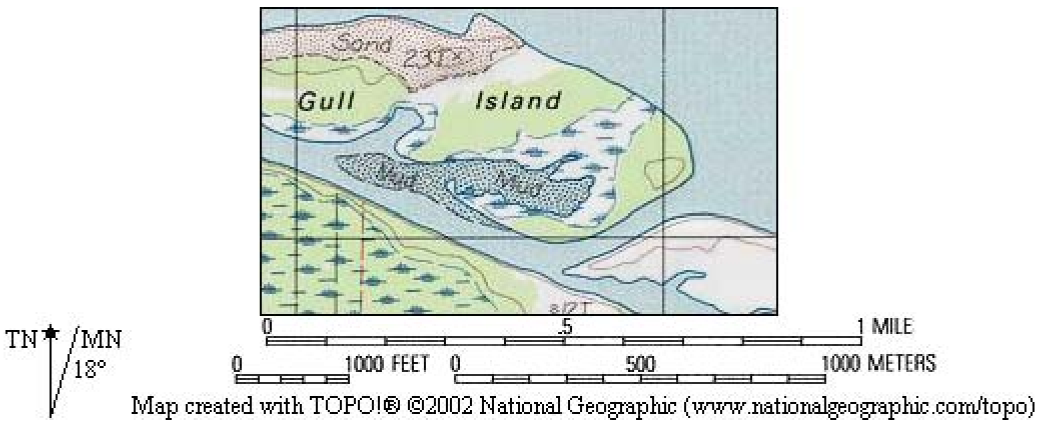


Figure 5.0-1: Topographic Map of Gull Island Reference Marsh

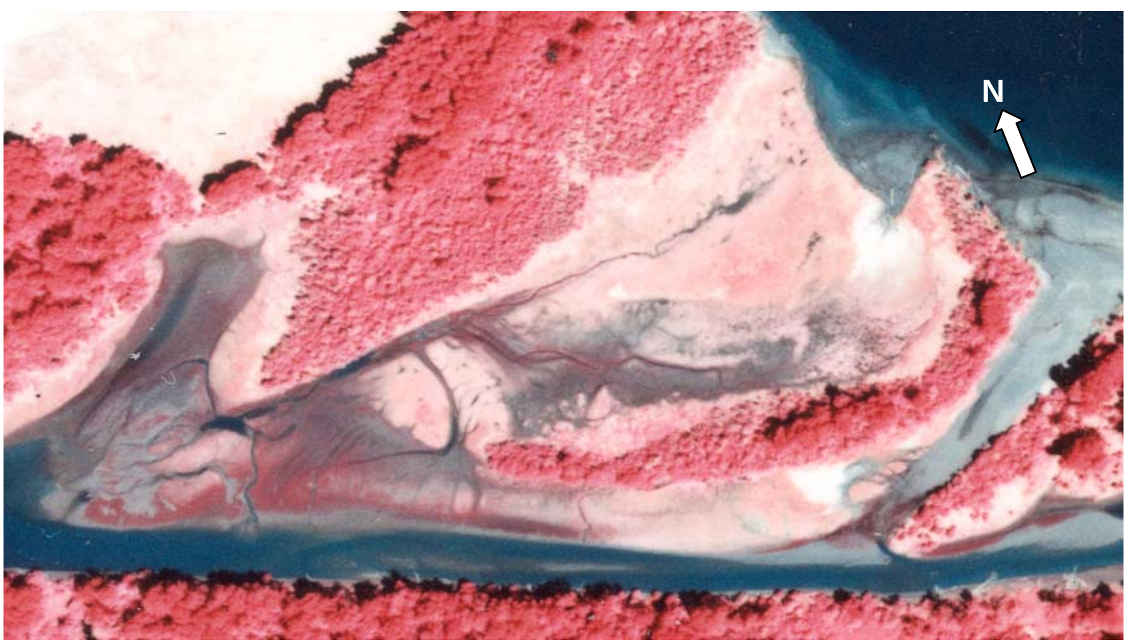


Figure 5.0-2: Aerial Photo of Gull Island Reference Marsh (USACE 2001).

The NRCS classifies the Gull Island marsh soils as *Udipsamments*, nearly level. This unit is characterized as very deep, excessively drained soils formed in sandy dredge material. Permeability is rapid to very rapid. The Gull Island udipsamments differ significantly from the Crims Island project site soils, which are described as deep, poorly drained with moderately slow permeability. The presence of significantly more fines and a plastic limit at the project site has implications on sediment transport and channel development. While the Gull Island reference marsh can provide valuable information concerning mature marsh plain elevations, the need for an analog for the channel system remains.

6.0 TRONSON ISLAND REFERENCE MARSH:

Tronson Island, located at Columbia River mile 30, provides an additional analog for the wetland channel system. Several factors make this particular reference site appealing:

- The soil types on Tronson Island are similar to those found in the project area (Table 4.0-1.)
- The inland intertidal marsh is supplied water from two main channels, one downstream and one mid island, similar to the channel system proposed on Crims Island.
- The two main wetland channels on Tronson Island are connected to a side slough and not the main stem of the Columbia River.
- The marsh area on Tronson Island is the roughly equivalent to the project area on Crims Island.

Tronson Island characteristics will be used to guide final Crims Island project construction.

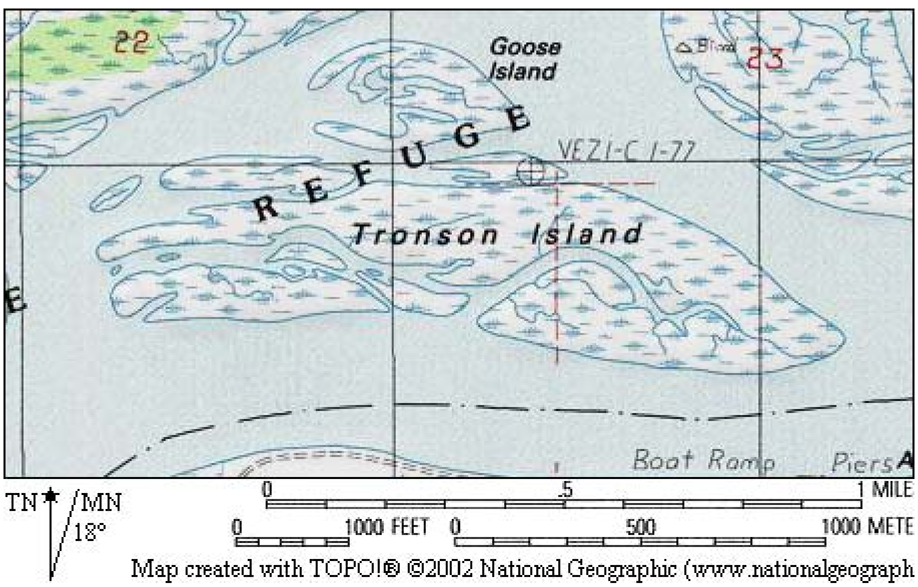


Figure 6.0-1: Topographic Map of Tronson Island Reference Marsh

Figure 6.0-2: Aerial Photo of Tronson Island Reference Marsh (USACE 2001).

7.0 MARSH PLAIN DESIGN ELEVATIONS:

The Gull Island reference marsh provides design elevations for the project area. Mudflats at elevations lower than 6.5 ft NAVD88. A transitions zone between mudflat and marsh plain is at elevations of 6.5 to 7.5 ft and vegetated marsh plain between elevations 7.5 and 9.5 ft. Applying a consistent 2.0 cut to the project area indicated in plate 1 results in a marsh plain at the desired elevation range while maintaining the existing microtopography of the site. A topographic map of the upstream portion of the project area with the 2.0 excavations is shown in figure 7.0-1. The predominant elevations are between 7.0 and 8.5 feet. An interior quasi-mudflat, similar to the one seen in Gull Island with elevations between 6.5 and 7.0, is present above cross section E.

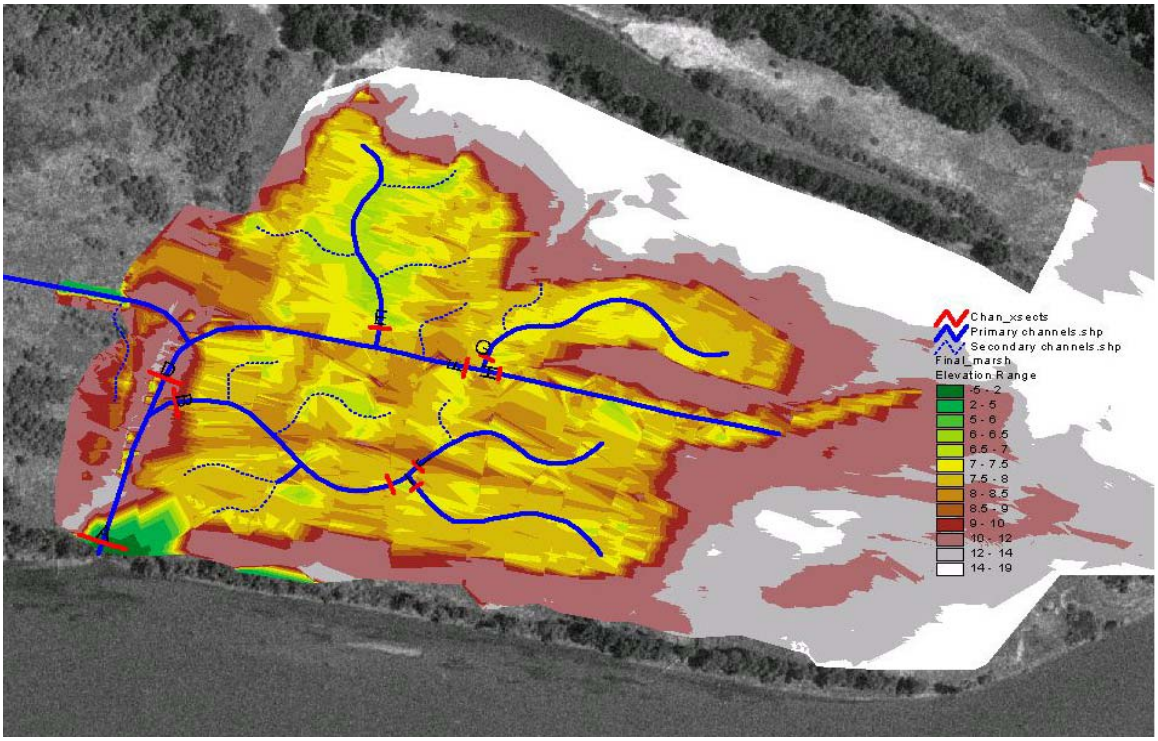


Figure 7.0-1: Design Marsh Elevation at Upstream Portion of Project Area.

Elevation data is only available for the upstream portion of the project area. The desired design elevations remain the same for the downstream portion of the project area, but the appropriate cut to achieve those elevations is dependent on the existing elevations.

8.0 CHANNEL SYSTEM PLAN FORM:

Excavation of the marsh plain allows for a more frequent and longer duration tidal inundation. Excavation also allows space for a larger volume of water to enter and exit marsh during each tidal cycle. Tidal channels accommodate this transfer of water and dissipate energy. The size and shape of the channel network is dependant on several factors including hydrodynamics, substrate, and vegetation and is necessarily unique to each channel system.

The existing project site inundates during high tides in the winter and spring months. Despite this inundation, a channel system has not developed far beyond the man made T-Channel. This is likely due to several factors, most importantly that the marsh plain is too high. The marsh plain is currently at an elevation well above the MHHW elevation of 8.7 ft NAVD88. With a high marsh plain, bed shear stress will be insufficient to create new channels (Coats et al. 1995). Figure 8.0-1 shows the project area and the existing man made T-Channel from a 2001 aerial photo.

Applying a consistent excavation depth to the proposed marsh results in a restored site that retains small-scale features, such as pannes and other topographic variability, and provides complexity to the natural site. The goal of this channel system design is to connect these vegetated marsh plains and the mudflats to Bradbury Slough in a way that mimics nature within the bounds of constructability. Plan form of the channel system is subjective and many variations would satisfy the goals equally well.

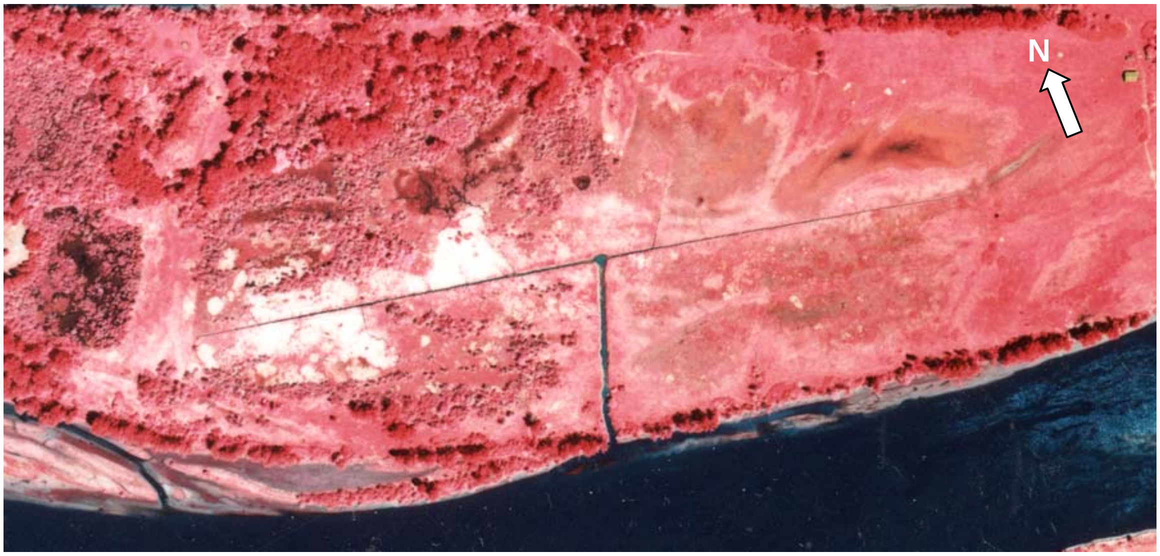


Figure 8.0-1: Project Area from 2001 Aerial Photo

Using Tronson Island as an analog for the Crims Island project area, a channel system is developed utilizing a mid marsh and a downstream entrance channel. The existing T-Channel is utilized to the extent possible due to the scale and extent of the existing system. For Crims Island, the marsh area upstream (east) of the T-Channel will be considered the marsh area associated with the mid marsh entrance with an area of 59 acres. The area downstream (west) of the channel is the marsh area for the downstream entrance with an area of 32 acres. Coats et al. (1995) relate marsh area to channel order for several San Francisco Bay marshes. The data indicates that the upstream entrance channel should be a 4^{th} or 5^{th} order channel while the downstream entrance is a 3^{rd} order channel. A forth order and a third system was designed for the upstream and downstream portions of the project area respectively.

Petstrong (1965) relates the relationship between junction angle and order of entering and receiving steams. Junction angles increase for first and second order channels as the difference between the orders of the tributary and mainstream increase. The junction angle approaches 90 degrees as the difference between orders or tributary and receiving channels increase. This relationship can be observed at the reference Marsh on Tronson Island, Figure 6.0-2, and will be utilized in the channel system

Only the larger order channels will be excavated to full capacity during construction. By creating full capacity in the larger tidal channel during the construction process, sufficient volumes of tidal water will be immediately available to improve water quality, tidal circulation and habitat. Smaller channels, further upstream from the entrance, will be excavated as pilot channels. The smallest first order channels will be allowed to form naturally. This approach will promote development of the complex channel system and help to control any potential negative effects of mass erosion during channel formation.

Low drainage density (length of tidal channel / area) is a common problem at restoration sites (Callaway 2001). Variation of drainage densities in mature marshes ranges between 0.005 and 0.045 ft/ft^2 (Coats et al. 1995, Pestrong 1965). The drainage density calculated for the upstream portion of Tronson Island using the 2001 aerial photo (6.0-2) is 0.011 ft/ft^2 including all channels. This calculation may be underestimated due to constraints seeing smaller 1^{st} order channels from the aerial photo. The design proposed for the project area on Crims Island and shown in figure 8.0-2 has a total drainage density of 0.004 ft/ft^2.

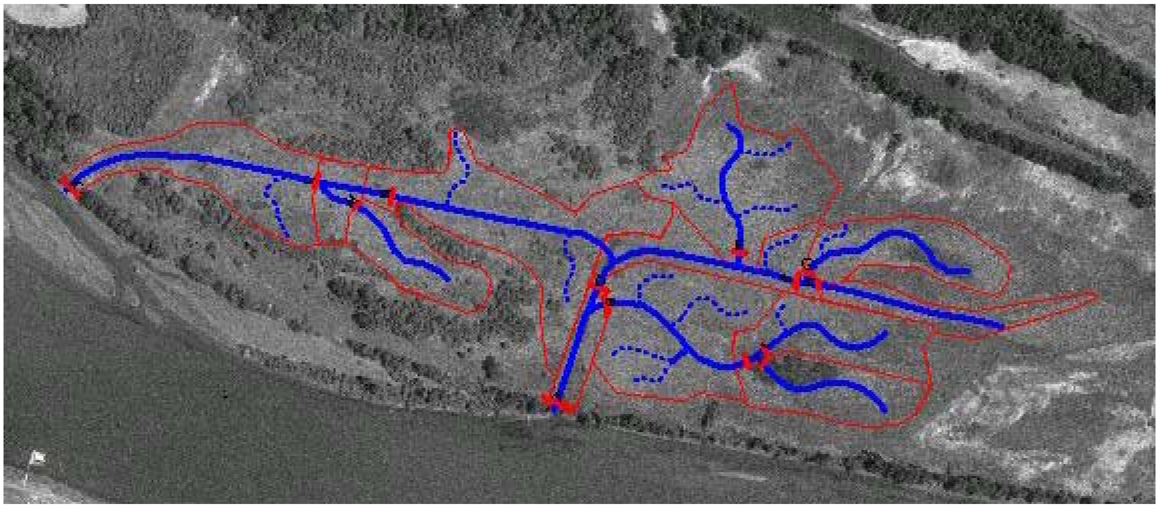


Figure 8.0-2: Primary and Secondary Channels with "Watershed" Area Delineations at Crims Island Project Area

9.0 CHANNEL SIZING:

Literature research on the topic of hydrology and hydraulic geometry of intertidal marshes yields a body of work on west coast marshes by Philip Williams & Associates, Ltd. *Design Guidelines for Tidal Channels in Coastal Wetlands* (1995) and follow up document *Hydraulic Geometry: A Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects* (2002) provide a design methodology as well as case studies of three youthful channel systems in San Francisco Bay.

The data set used to develop the design methodology consisted of San Francisco Bay coastal marshes ranging in size from 2 to 5,700 ha. San Francisco Bay has mixed semidiurnal tides with the average diurnal tide ranging between 4.9 and 9.8 ft. Crims Island falls within this data set with a total marsh area of 216 ha. The tidal effects seen at Crims Island are also mixed semidiurnal with an average tidal range within the study group range at 5.1 ft.

Williams et al. (2002) present two sets of equilibrium hydraulic geometry relationships. One set of relationships is based on contributing "watershed" area and the other is based on diurnal tidal prism. The channel dimensions related are channel depth related to MHHW, channel top width and cross sectional area. Contributing "watershed" area is defined as the area extending to the tidal drainage divides. Diurnal tidal prism is the volume of water between MHHW and MLLW. Calculations have been made using both sets of relationships at 10 cross sections in the upstream portion of the proposed marsh (existing T-Channel and area to the east). Topographic data is available for the upstream portion making tidal prism calculations possible. No topographic data is available at the downstream portion, so calculations won't be included.

9.1 TIDAL PRISM CHANNEL DESIGN METHOD:

Development of the diurnal tidal prism volume for each cross section utilized the topographic data developed for the marsh plain elevation design (figure 7.0-1.) A triangulated irregular network (TIN) of this data was created with ArcView 3.3. The existing T-Channel was cut from the TIN to produce a channel-less marsh plain. Elevation volume curves were calculated using HEC-GeoRAS 3.1 (COE 2002) for 10 “watersheds” corresponding to the contributing areas associated with cross sections shown on plate 1. The volume of water contained between the annual mean of daily maximum and annual mean of daily minimum elevations (surrogates for MHHW and MLLW discussed in the hydrology section) or diurnal tidal prism was calculated for each “watershed.” The three equations presented by Williams et at. (2002) to determine channel dimensions from diurnal tidal prism are presented below:

$$\text{Maximum Channel Depth below MHHW (m)} = 0.388\ x^{0.176}$$

$$\text{Channel Top Width (m)} = 0.147\ x^{0.461}$$

$$\text{Cross-Sectional Area (m}^2\text{)} = 0.0284\ x^{0.649}$$

where x = diurnal tidal prism (m^3)

The diurnal tidal prism calculation includes the water volume in the channels as well as the volume over the marsh plain, so an iterative method was used to size the channel. Starting with a channel-less volume, channel geometry was calculated at each cross section. The volume of the channel was calculated and added to the original volume. This was repeated for two iterations. Results from the diurnal tidal prism relationships are presented in table 9.1-1.

Tidal Prism		Maximum Channel Depth Below Elevation 8.7 NAVD88			Channel Top Width at Elevation 8.7 NAVD88		Cross-Sectional Area	
Cross-section	m^3	(m)	(ft)	Elevation NAVD88 (ft)	(m)	(ft)	(m^2)	(ft^2)
A	105999	3.0	9.8	-1.1	30	100	52	558
B	39195	2.5	8.2	0.5	19	63	27	293
C	19076	2.2	7.2	1.5	14	45	17	183
D	56635	2.7	8.7	0.0	23	75	35	371
E	40894	2.5	8.2	0.5	20	64	28	301
F	20058	2.2	7.3	1.4	14	46	18	189
G	10837	2.0	6.5	2.2	11	35	12	127
H	5217	1.8	5.7	3.0	8	25	7	79
I	9093	1.9	6.3	2.4	10	32	11	113
J	9030	1.9	6.3	2.4	10	32	10	113

Table 9.1-1: Diurnal Tidal Prism Relationship Results

9.2 WATERSHED AREA CHANNEL DESIGN METHOD:

Contributing “watershed” area is defined as the area extending to the tidal drainage divides. Easily referenced divides do not exit at the outer boundary of the proposed marsh area. An area boundary was selected at the 10 ft elevation contour taken from topographic data. This boundary location was selected, as marsh excavation will occur at areas lower than the 10-foot elevation to create the new intertidal marsh. The boundary of the area inundated at the annual mean of daily maximum elevation of 8.7 ft NAVD88 will necessarily be in the same range as the existing 10 ft contour. Areas were calculated using ArcView 3.3. The three equations presented by Williams et at. (2002) to determine channel dimensions from “watershed” area are presented below:

$$\text{Maximum Channel Depth below MHHW (m)} = 1.31\,x^{0.202}$$

$$\text{Channel Top Width (m)} = 3.44\,x^{0.552}$$

$$\text{Cross-Sectional Area } (m^2) = 2.40\,x^{0.772}$$

where x = "watershed" area (hectares)

Results from the "watershed" area relationships are presented in table 9.2-1.

"Watershed" Area		Max Channel Depth Below Elevation 8.7 NAVD88			Channel Top Width at Elevation 8.7 NAVD88		Cross-Sectional Area	
Cross-section	Hectares	(m)	(ft)	Elevation NAVD88 (ft)	(m)	(ft)	(m^2)	(ft^2)
A	144.6	3.6	11.7	-3.0	54	176	112	1201
B	65.8	3.1	10.0	-1.3	35	114	61	654
C	34.3	2.7	8.8	-0.1	24	79	37	395
D	72.6	3.1	10.2	-1.5	37	120	66	706
E	30.8	2.6	8.6	0.1	23	75	34	364
F	28.3	2.6	8.4	0.3	22	71	32	341
G	17.1	2.3	7.6	1.1	17	54	22	232
H	10.4	2.1	6.9	1.8	13	41	15	157
I	16.1	2.3	7.5	1.2	16	52	20	220
J	18.3	2.4	7.7	1.0	17	56	23	243

Table 9.2-1: "Watershed" Area Relationship Results

The "watershed" area calculations predict significantly larger equilibrium channels. On average, the channels are 2.7 times larger in terms of cross sectional area. While delineation of the marsh area is subjective, the diurnal tidal prism can be calculated with some certainty making diurnal tidal prism a more rational hydraulic parameter. Ultimately, this discrepancy in channel sizing warrants further investigation for this project and for future use in the Lower Columbia River.

9.3 MODELING:

An unsteady state one-dimensional HEC-RAS (COE 2002) model was developed for the upstream entrance channel to verify sizing of the channel. Average velocities are calculated in the channel for a series of conditions and compared to established maximum permissible velocities in similar substrates. As the soils in the proposed marsh area are cohesive, the common equations for incipient motion do not apply. Without extensive laboratory testing to determine the engineering properties of the soil beyond those reported by the NRCS, the available equations and procedures for calculation of the maximum permissible velocities in cohesive soils can not be solved with any certainty. The accepted approach is to utilize the maximum permissible velocities proposed by Fortier and Scoby (1926) and the ASCE (1977).

Maximum permissible velocity proposed by Fortier and Scoby for a silt loam substrate carrying clear water is 2.00 ft/sec (Simons et al. 1977). The American Society of Civil Engineers' Sedimentation Engineering handbook (1977) recommends an allowable velocity of ranging from 1.5 to 2.0 ft/sec in diversions with silty loam to silty clay loam channels barren of vegetation. A design velocity of 2.0 ft/sec will be used in sizing the entrance channel and evaluating the design method recognizing that the velocity frequency relationship in a tidally influenced channel differs from that of a canal or diversion.

Channel designs from both "watershed" area and diurnal tidal prism relationships, as well as the existing condition, were analyzed using the HEC-RAS model. The model geometry consists of a 450 ft long channel connected to a storage area representing the marsh plain. Sizing of the channel matches the calculations for cross section "A" from the "watershed" area and tidal prism sections. The elevation-volume curve associated with the storage area was calculated using HEC-GeoRAS (COE 2002) outputs along with results from the channel calculation and was specific to each model. Overbank areas at the channel entrance were cut from the topographic TIN and incorporated into the model. Three months of 15-minute stage data, October 1994 through December 1994, from the USGS gaging station 14246900-Columbia River @ Beaver Army Terminal were used to drive the downstream end of the channel (Bradbury Slough). This set of data was selected because monthly mean of daily maximums and monthly mean of daily minimums in November are most similar to the annual means. October and December are relatively lower and higher respectively. This selection gives a large range of stages and tides surrounding the mean conditions. The data set characteristics are shown in table 9.3-1 relative to those of the period of record (POR).

	Elevation (ft NAVD88)			
	October-94	November-94	December-94	POR (Feb-91 to Sep-03)
Mean of Daily Maximum	7.5	8.6	9.6	8.7
Mean	4.9	5.7	6.6	5.9
Mean of Daily Minimum	2.8	2.8	3.9	3.6

Table 9.3-1: Characteristics of Input Stage Data

Graphs of mean channel velocity data from the watershed area, tidal prism and existing condition runs are presented in appendix A. A summary of 8212 data points generated from each run is shown in table 9.3-2.

	Existing T-Channel	Watershed Area Design	Diurnal Tidal Prism Design
Maximum Absolute Channel Velocity (ft/sec)	5.0	1.7	2.7
1.0% of Data Exceeds an Absolute Channel Velocity (ft/sec) of:	3.4	0.8	1.7
% of Data where Absolute Chanel Velocities Exceed 2.0 ft/sec:	4.1%	NA	0.3%

Table 9.3-2: Summary Statistics From Varying Channel Designs (Manning's n for channel = 0.025, overbank = 0.030)

The modeling results indicate that velocities in the existing channel exceed 2.0 ft/sec, 4.1% of the modeling period with a maximum velocity of 5 ft/sec. The existing T-Channel entrance is known to be eroding since the removal of the plug at the entrance adding strength to the selection of a maximum permissible design velocity of 2 ft/sec.

1% of the "watershed" area design results show data exceeding 0.8 ft/sec. This indicates that the design significantly oversized the channel. The maximum allowable velocity was never achieved.

The diurnal tidal prism design shows a maximum velocity of 2.7 ft/sec with 1% of data exceeding 1.7 ft/sec. 0.3% of the data exceeds a velocity of 2.0 ft/sec. This channel design approaches the design velocity and exceeds it only in extreme conditions in this data set. A sensitivity analysis to the roughness coefficient, Manning's n, was performed on the tidal prism design using coefficients expected to bound the actual conditions. The entrance channel shows little sensitivity to the roughness coefficient. This is expected with low channel velocities. Graphs of the results are located in appendix A. A summary of the data is shown in table 9.3-3.

	Channel n = 0.020 Overbank n =0.025	Channel n = 0.025 Overbank n =0.030	Channel n = 0.030 Overbank n =0.035
Maximum Absolute Channel Velocity (ft/sec)	2.9	2.7	2.6
1.0% of Data Exceeds an Absolute Channel Velocity (ft/sec) of:	1.7	1.7	1.7
% of Data where Absolute Chanel Velocities Exceed 2.0 ft/sec:	0.4	0.0	0.3

Table 9.3-3: Summary Statistics from Sensitivity Analysis, Diurnal Tidal Prism Design.

The diurnal tidal prism is a rational hydraulic parameter to use in an empirically based design methodology. The resultant channel design proves itself under the scrutiny of hydraulic modeling at the entrance channel. This methodology will be used for sizing all tidal channels where topographic data exists. The downstream portion of the project area (west of the existing T-Channel entrance) lacks topographic data. In order to produce a channel design, a relationship between diurnal tidal prism and "watershed" area for Crims Island will be established.

9.4 WATERSHED AREA VS. DIURNAL TIDAL PRISM ON CRIMS ISLAND:

A relationship between diurnal tidal prism and "watershed" area specific to the design at Crims Island is shown in figure 9.4-1. The highest outlier in the data set is associated with cross section "E", 30.8 hectares and 41,116 m^3 tidal prism. This "watershed" contains an area in the project site that is currently low. After excavation, this part of the marsh plain will have elevations as low as 6.5 ft NAVD88. This low zone (similar to the southern qasi mud flat in the Gull Island reference marsh) drives the tidal prism volume up relative to the "watershed" area resulting in the outlier. Variability similar to this is seen in the "watershed" to "watershed" elevations at the Gull Island reference marsh. Although this variability expresses itself in the area to tidal volume relationship, a general relationship with high correlation coefficient, $r^2 = 0.92$, exists.

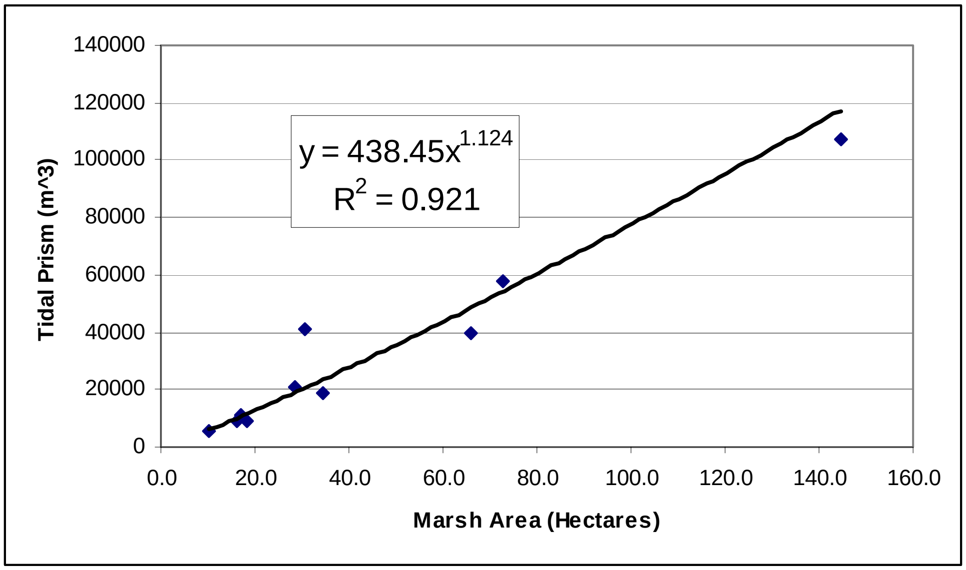


Figure 9.4-1: Marsh "Watershed" Area vs. Tidal Prism for Crims Island.

Substituting the relationship developed in figure 9.4-1 into the tidal prism equations presented in section 9.1 establishes a channel design methodology utilizing "watershed" areas on Crims Island. Table 9.4-2 shows channel cross section geometry for cross sections in the downstream portion of the project area using this substitution.

"Watershed" Area		Max Channel Depth Below Elevation 8.7 NAVD 88			Channel Top Width at Elevation 8.7 NAVD88		Cross-Sectional Area	
	Hectares	(m)	(ft)	Elevation NAVD88 (ft)	(m)	(ft)	(m^2)	(ft^2)
K	80.0	2.7	8.8	-0.1	24	77	36	387
L	55.7	2.5	8.2	0.5	19	64	28	297
M	12.5	1.9	6.1	2.6	9	29	9	100
N	37.5	2.3	7.6	1.1	16	52	21	223

Table 9.4-2: Cross Section Geometry for Down Stream Portion of Project Area.

10.0 CROSS SECTION SHAPE:

Channel cross sections seen at Crims (picture 10.0-1) Island show steep, near vertical, vegetated slopes in the upper channel wall. The lower wall and channel base are low angle, unvegetated marsh soils. A parabolic channel shape is generally exhibited. This form cannot be directly duplicated during channel construction without vegetation present to strengthen the soils in the upper section. A reasonable compromise is to construct a trapezoidal or v-shaped channel with side slopes of 3:1 to 6:1 (horizontal: vertical). Natural channel scour and sedimentation will adjust the channel side slopes to some new equilibrium. The equilibrium side slopes will increase as vegetation becomes established (Coats et al., 1995).

Field observations indicated that the unvegetated channel slopes are stable at side slopes as steep as 2:1, picture 10.0-1. However, through discussions with USACE Seattle District personnel concerning intertidal wetland development projects in their District, lowering side slopes to extent practicable was recommended. This recommendation resulted from experience with projects where steep banks quickly eroded and slumped into the channel. This erosion is believed to be caused by a permeable lens in the soils through which water moved into the channel weakening the soils in the channel banks. A maximum side slope of 4:1 will be used in the Crims Island design. This slope is less than stable slopes observed in the field and within the recommended range of 3:1 to 6:1.

Picture 10.0-1: Existing Entrance Channel Looking Toward Bradbury Slough.

Maintaining all of the channel geometry factors (bottom elevation, channel top with, cross sectional area and side slope) becomes impossible with the smaller channels. Sloping all channel banks to a maximum of 4:1 while maintaining channel depth forces all but the 6 largest channel cross sections into v-shapes in lieu of trapezoids. In order to maintain slope stability and the draining ability inherent with calculated bottom elevation, the cross sectional area along with top width is allowed to exceed the design calculation.

11.0 FINAL:

The final channel sizes developed utilizing techniques and considerations discussed in this report are shown in table 11.0-1.

Cross Section	Top Width at Elevation 8.7 ft ft	Bottom Width ft	Bottom Elevation NAVD88 (ft)	Side Slope Horizontal to 1 Vertical	Cross Sectional Area ft^2
A	100	14	-1.1	4.4	561
B	69	3	0.5	4	295
C	58	0	1.5	4	208
D	78	8	-0.1	4	378
E	70	4	0.4	4	302
F	58	0	1.4	4	214
G	52	0	2.1	4	172
H	46	0	2.9	4	134
I	51	0	2.4	4	161
J	51	0	2.4	4	161
K	79	8	-0.1	4	387
L	69	3	0.5	4	297
M	49	0	2.6	4	150
N	61	0	1.1	4	231

Table 11.0-1: Final Cross Section Design.

Cross Sections will be either trapezoidal or v shaped depending on bottom width. The side slope indicated in table 11.0-1 will be extended to the excavated ground elevation. This elevation may be higher or lower than 8.7 ft NAVD88. A typical cross section is shown in figure 11.0-2.

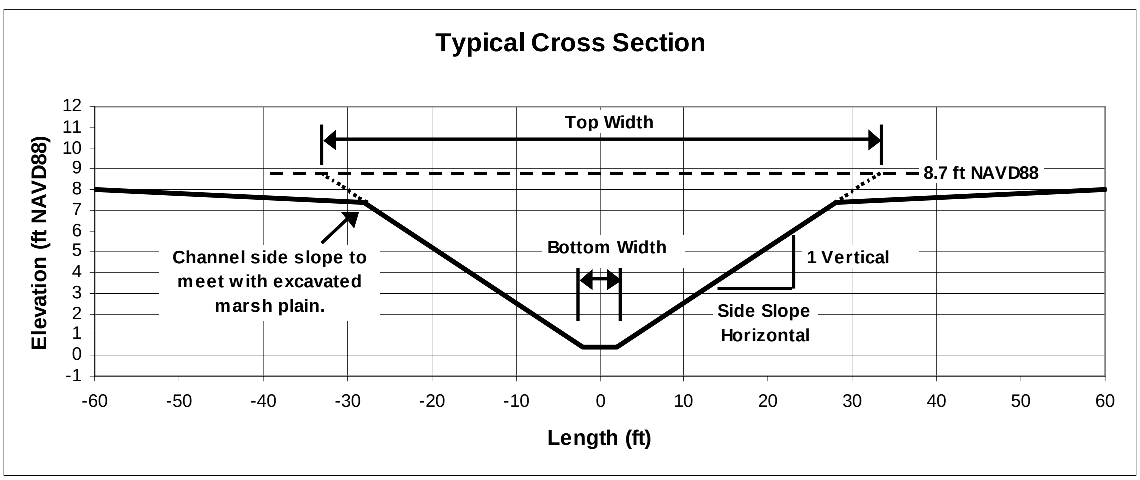


Figure 11.0-2: Typical Cross Section.

Plate 1 depicts the channel system plan form along with designation of the primary and secondary channels. Plate 1 also depicts the tidal marsh project area where a 2 ft excavation will create the new marsh plain. Cross section designs are calculated at stream junctions and downstream locations for the primary channels only. The distal end of each of the channels as well as the secondary channels will be v-shaped with 4:1 side slopes. For secondary channels, the channel cross section will be constant along the length of the channel. The channel bottom will generally be 3 ft below the marsh plain elevation and sloped to the channel system to ensure drainage during ebb tide

Primary channels will have the same v-shaped channel cross section with bottom elevation 3 ft below the marsh plain at the distal ends, but will taper along their length to meet the cross section geometry specified in Table 11.0-1. The channel will slope toward the downstream connection to ensure drainage during ebb tides.

References:

Callaway, J.C. 2001. Hydrology and Substrate. Pages 89-117 in J.B. Zedler, ed. Handbook for Restoring Tidal Wetlands. CRC Press, New York.

Coats, R.N., P.B. Williams, C.K. Cuffe, J.B. Zedler, D. Reed, S.M. Waltry, and J.S. Noller. 1995. Design Guidelines for Tidal Channels in Coastal Wetlands. Philip Williams & Associates, Ltd., San Francisco, CA, USA.

American Society of Civil Engineers. 1975. Sedimentation Engineering. Headquarters of the Society, New York.

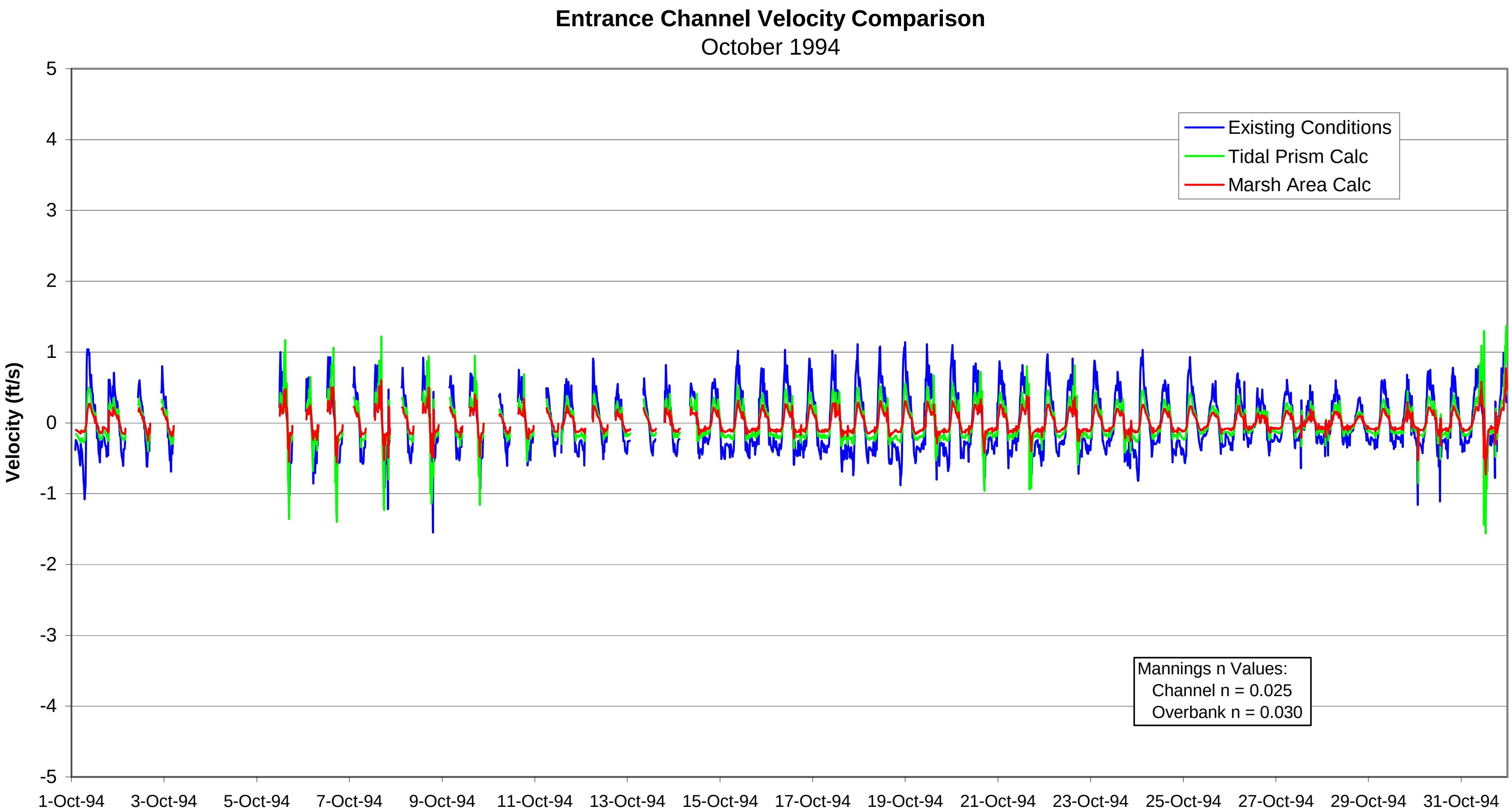
Pestrong, R.P. 1965. The Development of Drainage Patterns of Tidal Marshes. Geological Sciences Publications X(2), Stanford.

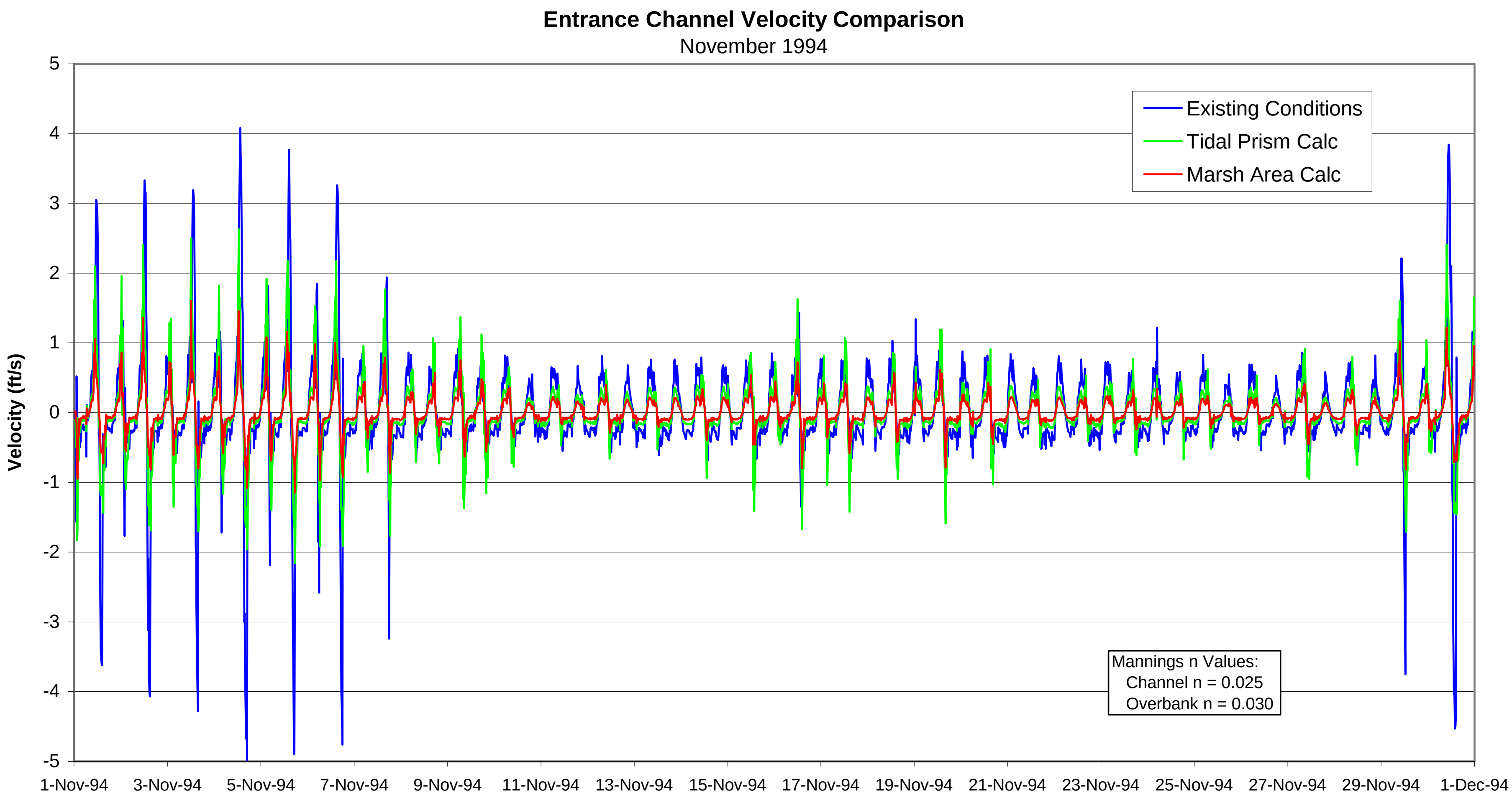
Simons, D.B. and Senturk, F. 1976. Sediment Transport Technology. Water Resources Publications, Fort Collins, CO, USA.

US Army Corps of Engineers. 2002. HEC-GeoRAS, An Extension for Support of HEC-RAS using ArcView, User's Manual, Version 3.1, October 2002, Hydrologic Engineering Center; Davis, California.

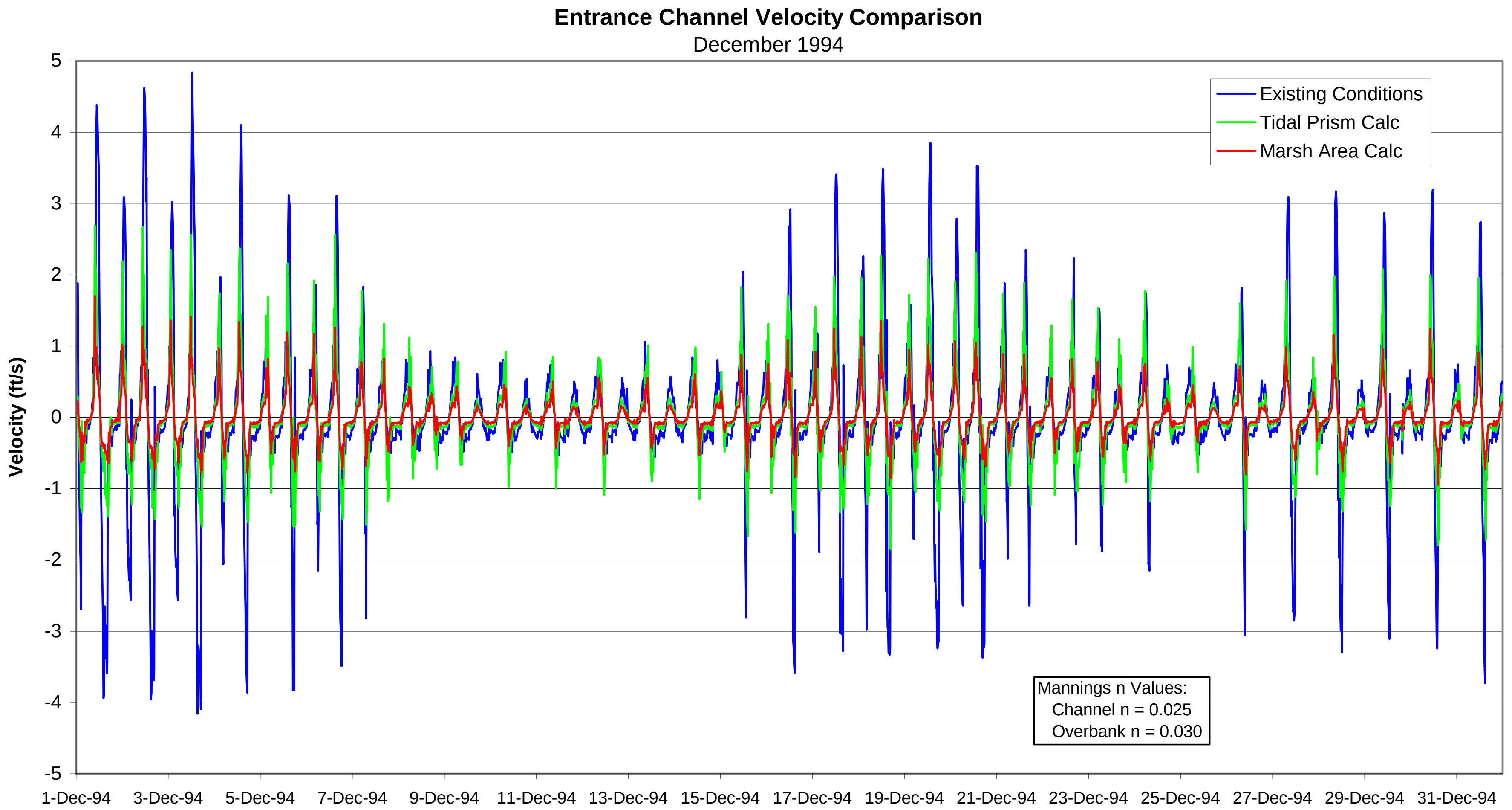
US Army Corps of Engineers, 2002. HEC-RAS, River Analysis System, User's Manual, Version 3.1, November 2002, Hydrologic Engineering Center; Davis, California.

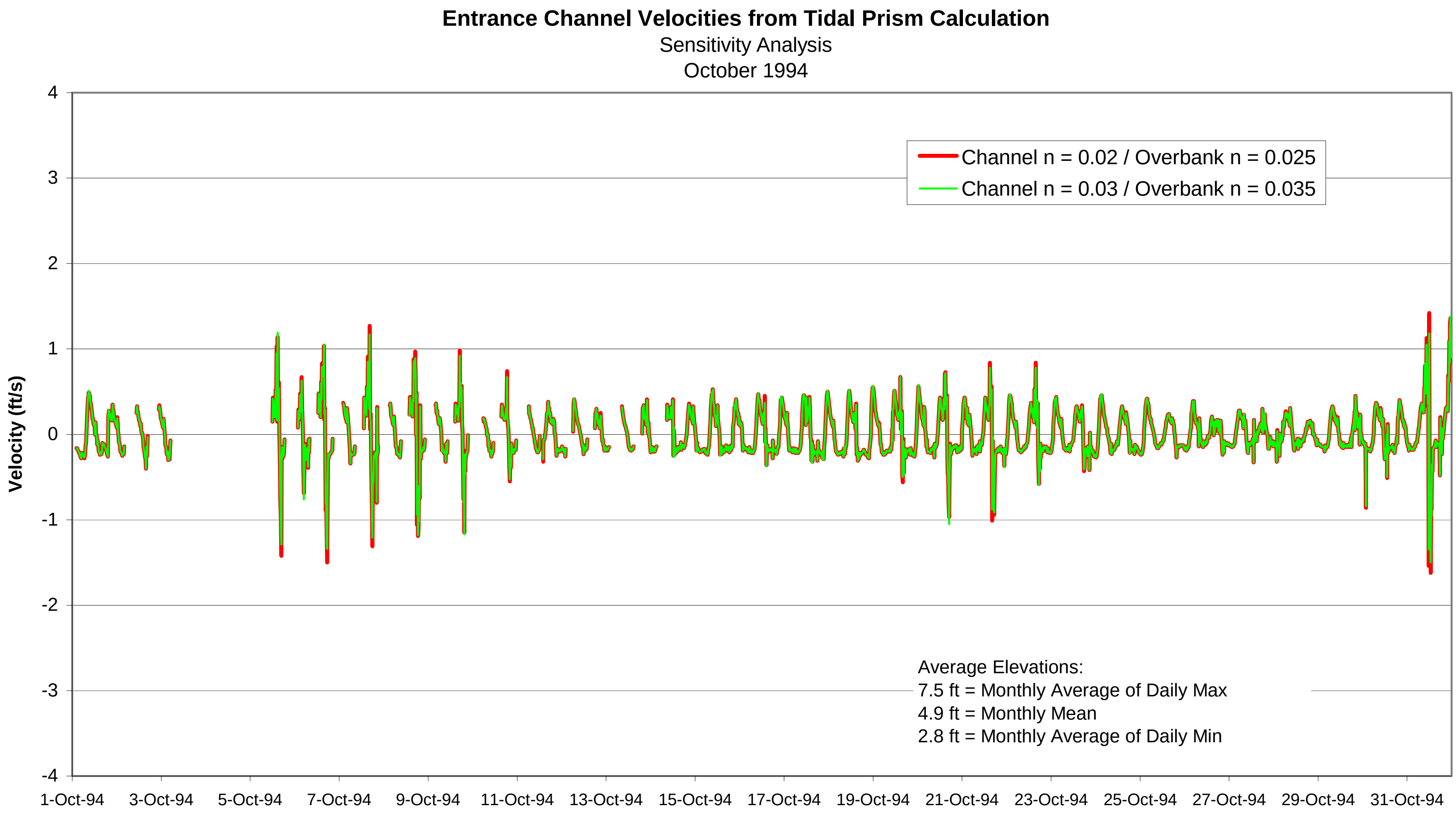
Williams, P.B., M.K. Orr, and N.J.Garrity. 2002. Hydraulic Geometry: A Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects. Restoration Ecology Vol. 10 No. 3, pp. 577-590.


Entrance Channel Velocity Comparison
October 1994
Velocity (ft/s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
1-Oct-94
3-Oct-94
5-Oct-94
7-Oct-94
9-Oct-94
11-Oct-94
13-Oct-94
15-Oct-94
17-Oct-94
19-Oct-94
21-Oct-94
23-Oct-94
25-Oct-94
27-Oct-94
29-Oct-94
31-Oct-94
Existing Conditions
Tidal Prism Calc
Marsh Area Calc
Mannings n Values:
Channel n = 0.025
Overbank n = 0.030



Entrance Channel Velocity Comparison
November 1994
Velocity (ft/s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
1-Nov-94
3-Nov-94
5-Nov-94
7-Nov-94
9-Nov-94
11-Nov-94
13-Nov-94
15-Nov-94
17-Nov-94
19-Nov-94
21-Nov-94
23-Nov-94
25-Nov-94
27-Nov-94
29-Nov-94
1-Dec-94
Existing Conditions
Tidal Prism Calc
Marsh Area Calc
Mannings n Values:
Channel n = 0.025
Overbank n = 0.030


Entrance Channel Velocity Comparison
December 1994
Velocity (ft/s)
5
4
3
2
1
0
-1
-2
-3
-4
-5
1-Dec-94
3-Dec-94
5-Dec-94
7-Dec-94
9-Dec-94
11-Dec-94
13-Dec-94
15-Dec-94
17-Dec-94
19-Dec-94
21-Dec-94
23-Dec-94
25-Dec-94
27-Dec-94
29-Dec-94
31-Dec-94
Existing Conditions
Tidal Prism Calc
Marsh Area Calc
Mannings n Values:
Channel n = 0.025
Overbank n = 0.030



Entrance Channel Velocities from Tidal Prism Calculation
Sensitivity Analysis
October 1994
Velocity (ft/s)
4
3
2
1
0
-1
-2
-3
-4
Channel n = 0.02 / Overbank n = 0.025
Channel n = 0.03 / Overbank n = 0.035
Average Elevations:
7.5 ft = Monthly Average of Daily Max
4.9 ft = Monthly Mean
2.8 ft = Monthly Average of Daily Min
1-Oct-94
3-Oct-94
5-Oct-94
7-Oct-94
9-Oct-94
11-Oct-94
13-Oct-94
15-Oct-94
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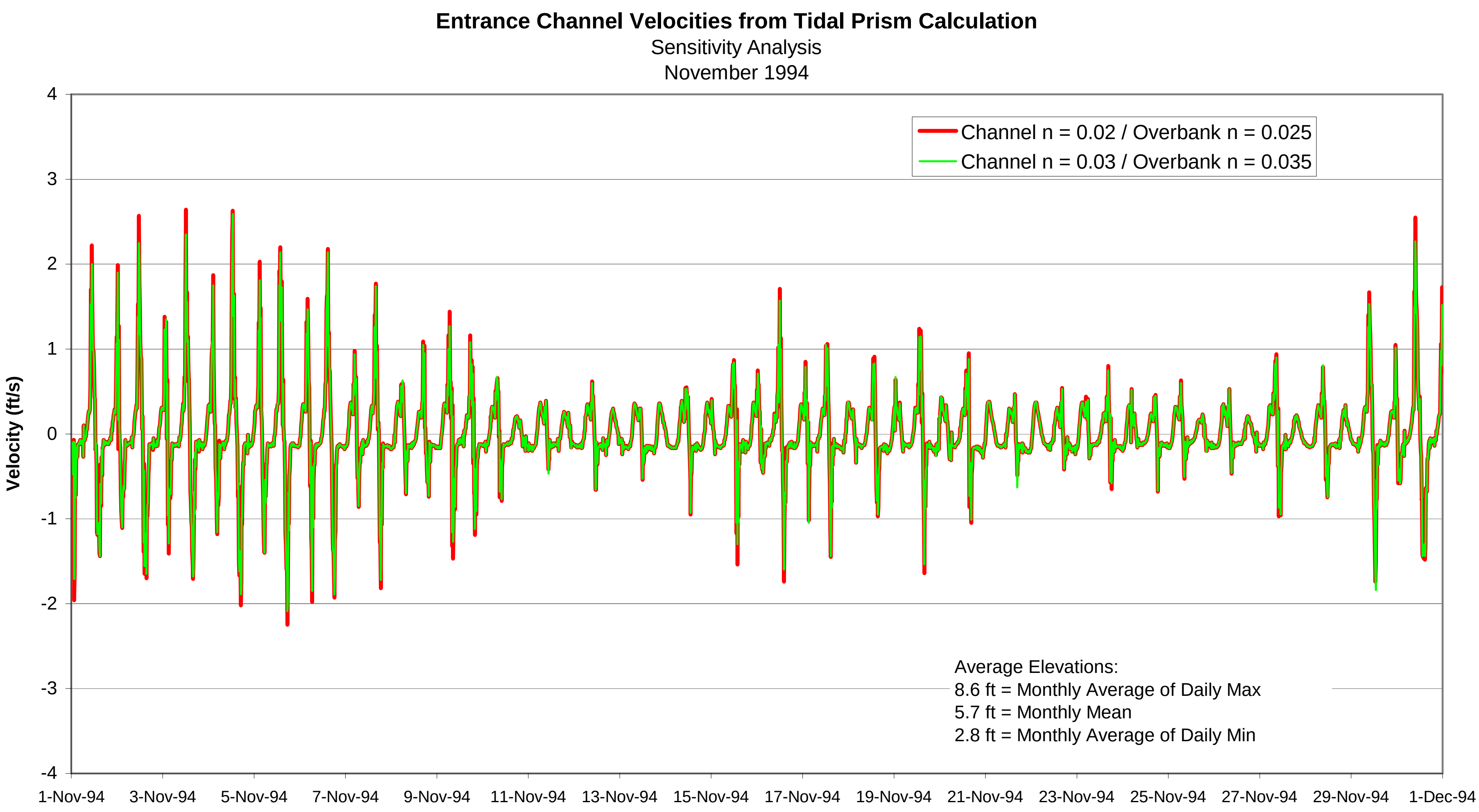
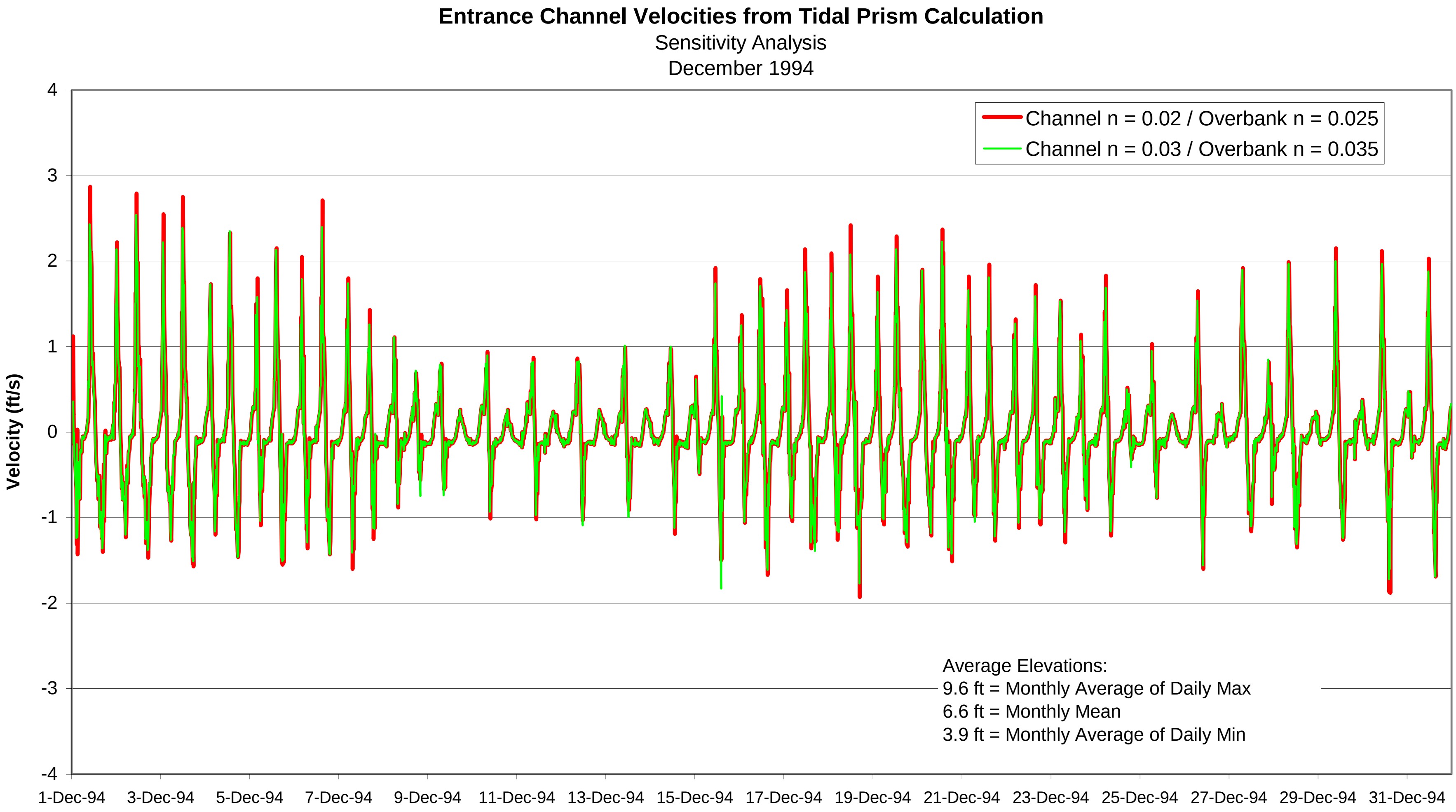
29-Oct-94
31-Oct-94


Entrance Channel Velocities from Tidal Prism Calculation
Sensitivity Analysis
November 1994
Channel n = 0.02 / Overbank n = 0.025
Channel n = 0.03 / Overbank n = 0.035
Velocity (ft/s)
4
3
2
1
0
-1
-2
-3
-4
1-Nov-94
3-Nov-94
5-Nov-94
7-Nov-94
9-Nov-94
11-Nov-94
13-Nov-94
15-Nov-94
17-Nov-94
19-Nov-94
21-Nov-94
23-Nov-94
25-Nov-94
27-Nov-94
29-Nov-94
1-Dec-94
Average Elevations:
8.6 ft = Monthly Average of Daily Max
5.7 ft = Monthly Mean
2.8 ft = Monthly Average of Daily Min



Entrance Channel Velocities from Tidal Prism Calculation
Sensitivity Analysis
December 1994
Velocity (ft/s)
4
3
2
1
0
-1
-2
-3
-4
Channel n = 0.02 / Overbank n = 0.025
Channel n = 0.03 / Overbank n = 0.035
Average Elevations:
9.6 ft = Monthly Average of Daily Max
6.6 ft = Monthly Mean
3.9 ft = Monthly Average of Daily Min
1-Dec-94
3-Dec-94
5-Dec-94
7-Dec-94
9-Dec-94
11-Dec-94
13-Dec-94
15-Dec-94
17-Dec-94
19-Dec-94
21-Dec-94
23-Dec-94
25-Dec-94
27-Dec-94
29-Dec-94
31-Dec-94