Ocean Ranch Unit, Eel River Wildlife Area
Tidal Marsh Geometry Analysis

Prepared for:

California Department of Fish and Game Northern and Marine Regions

Grantee Agreement No. A07-S6

February 2011

Prepared by:

Northern Hydrology and Engineering

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1. Introduction

The California Department of Fish and Game (DFG) Eel River Wildlife Area (ERWA) Ocean Ranch Unit (ORU), is managed to maintain, protect, enhance, and restore fish and wildlife populations and coastal wetland habitats while also providing for compatible public use. Hydraulic connectivity and drainage patterns of tidal channels and marsh plains within ORU have been severely altered by a network of levees, tide gates, and drainage ditches that have impaired estuarine aquatic and wildlife habitats. DFG intends to develop a restoration plan for the ORU to improve estuarine aquatic and wildlife habitats that may include a combination of levee breeching or removal, realignment or blockage of drainage ditches and reconnection of former tidal channels, and potential excavation of former tidal channels.

A grant was obtained from Pacific Coast Joint Venture in 2007 to collect baseline data on tidal stage throughout the ORU, and tidal channel geometries in a portion of the marsh not separated from the main slough channel by the levee system. These data are fundamental to development of conceptual restoration designs. Local tidal datums can be compared with existing ground topography to provide a first approximation of whether levee breaching alone is likely to provide enough tidal energy to scour channels and develop a tidal channel network, or if tidal channels must be mechanically excavated to provide sufficient energy to develop and maintain tidal channels. Expected evolution of tidal channel geometry or design criteria for channel excavation can be developed using relations between marsh area, tidal prism, channel width, depth and cross-sectional area (PWA 1995, 2004).

PWA (1995,2004) and Williams et al. (2002) developed design guidelines for tidal wetland creation or restoration based on measurements of hydraulic geometry in mature salt marshes in California, predominately in San Francisco Bay. Mature salt marshes with a consistent fine sediment load have ground elevations that keep pace with sea level rise and are typically near the elevation of mean higher high water (MHHW) (Atwater 1979, Williams et al. 2002). These marshes exhibit equilibrium relations between (among?) physical attributes, while young or evolving salt marshes tend toward an equilibrium state over time. Initial design guidelines were developed using all data collected at mature marshes, but were later refined to include only channels contributing marsh areas larger than 2 hectares (4.9 acres). Morphology of smaller channels likely differs due to proportionally higher friction from banks and vegetation, and bank slumping (Williams et al. 2002).

Design guidelines proposed by PWA (2004) are generalized relations based on mature marsh geomorphology from San Francisco Bay. Williams et al. (2002) reports that differences in soils, vegetation, and tidal harmonics may alter empirical relations in other regions and recommends that local hydraulic geometry relations for mature marshland be developed where anticipated marsh restoration projects occur.

Previous studies in the Humboldt Bay region investigated transferability of morphological relations reported by PWA (2004) to Humboldt Bay (JAA 2008, NHE 2009). Humboldt Bay studies included hydraulic geometry data measured at the G Street Marsh located directly east of the Arcata Wastewater Treatment Facility oxidation ponds (JAA 2008) and at Mad River Slough (MRS), located in North Humboldt Bay. Marsh plain elevations in the G Street marsh were lower than MHHW tidal datum and infrastructure (levees and a riprapped channel outlet) appeared to influence development of the channel network and marsh plain. Therefore, this marsh was not recommended as a reference for restoration design. MRS marsh plain is unimpeded by levees and elevation of the marsh plain is consistent with MHHW tidal datum, supporting designation of a mature marsh (Atwater 1979, Williams et al. 2002). Extrapolation of the PWA (2004) data set to small marsh areas (<2 ha) shows that channels measured in MRS tended to be slightly wider than predicted by the PWA (2004) relation, whereas channel thalweg depth and relations between contributing marsh area and tidal prism were consistent between PWA (2004) and MRS (JAA 2009).

1.1. Purpose and Scope

The objectives of this study are to: (1) analyze and report tidal data collected at 3 sites in the ORU; (2) provide recommendations for channel geometries for restoration design based on data collected at the reference site adjacent to the ORU and data collected in Humboldt and San Francisco Bays, and (3) provide a first approximation of areas that are likely to develop a channel network by levee breaching relative to areas that may require mechanical excavation to re-develop a channel network. Data collected in this study are in a format that can be included in a georeferenced database as other tidal wetlands in Humboldt Bay or in the North Coast Region are studied. Unless otherwise stated, data are referenced to North American Datum of 1983 (NAD83) and North American Vertical Datum of 1988 (NAVD88).

2. Study Area

ERWA Ocean Ranch Unit, is located within the Eel River estuary approximately 13 miles south of Eureka, California (Figure 2-). ORU is located within the Cannibal Island 7.5 minute USGS Quadrangle. The ORU levee system and tide gates were built in the latter 1800's and early 1900's by settlers, blocking tide waters from inundating most of the land within the ORU. Drainage ditches, fencing, roads and internal berms are present throughout the ORU, and portions of former tidal channels have been filled. Outside the levee, tidal marshes have expanded along Hawk Slough and McNulty Slough. Aerial photo sequences suggest that local erosion and widespread sedimentation occurred between 1948 and 1965, which contributed to expansion of tidal marshes near the ORU (Figure 2-2).

A levee breach occurred in 1994 that allowed tidal inundation into the ORU via McNulty Slough. Several other breaches through existing infrastructure within the ORU have occurred and at least one former road crossing is submerged at high tides. The levee surrounding a large freshwater pond was breached in 1998 and was repaired in 2006.

A reference marsh was selected to determine whether design guidelines developed in other areas would produce reasonable estimates of tidal marsh geometry in the Eel River estuary. A true reference marsh does not exist within the Eel River estuary due to extensive levee network and conversion of tidal lands in the late 1800's to early 1900's. The selected marsh provides the best approximation of a mature marsh and was selected based on its size, proximity to the restoration area (ORU), and accessibility. The reference marsh is located north of the Eel River mouth adjacent to the confluence of McNulty Slough and Hawk Slough, near the southern border of the ORU. The area is bounded to the west by beach dunes, to the north by the levee separating the ORU from the major slough channels, to the east by McNulty Slough, and to the south by Hawk Slough/North Bay. The marsh is currently accessible by the South Jetty Road, Humboldt County.

The area has evolved from a sub-tidal area with small areas of tidal flat and a vegetated peninsula in 1942 to contiguous vegetated marsh plain by the early 1980's (Figure 2-2). A substantial amount of wood accumulated at the head of the marsh between 1965 and 1981. This wood has persisted through 2009 and influenced marsh plain development. The channel network does not appear to have changed substantially in the past 30 years, with the exception of varying wood abundance near the head of the marsh. Areas shown as tidal flat and peninsula in Figure 2-2 remain slightly higher than the surrounding marsh plain and have not been dissected by any major channels as the marsh plain has evolved.

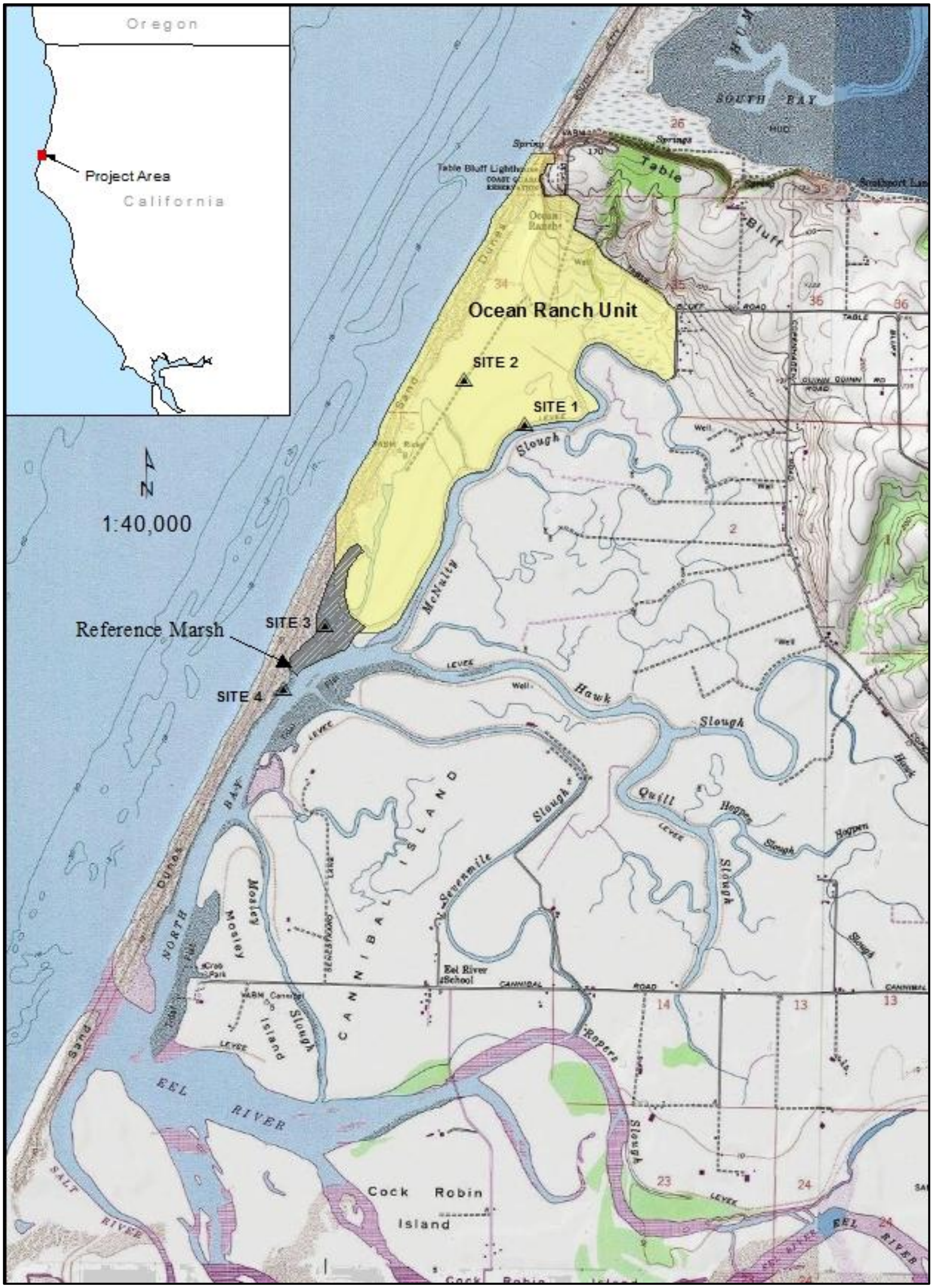

Figure 2-1. ORU project site and water level stations.

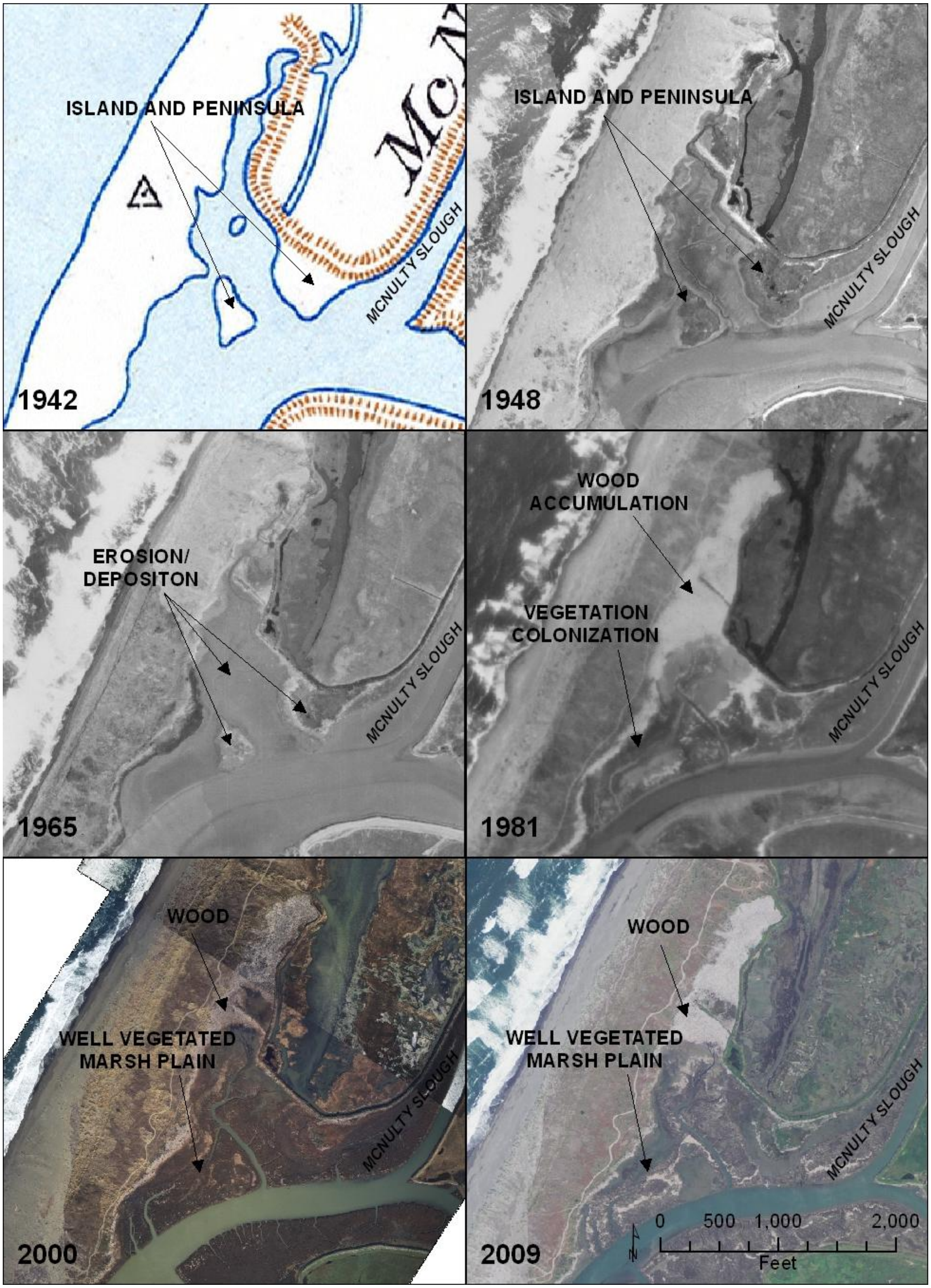

Figure 2-2. Evolution of reference marsh from 1942-2009.

3. Tidal Datums (Task 1A)

Tidal datums at the project site were estimated from water level data measured at 6-minute intervals with Global Water and Solinst 3001 level loggers. Four stations were established throughout the project area (Figure 2-): Site 1 was located on McNulty Slough on the south east side of the ORU adjacent to the levee delineating the ORU; Site 2 was located within the ORU, in the tidal marsh area recently reintroduced to tidal action when the levee breached; Site 3 was located interior to the reference site near the southern edge of the ORU, approximately 750 feet upstream from Hawk Slough; and Site 4 was located approximately 1,600 feet south of Site 3, in Hawk Slough.

Data were collected for 21 months at Site 1, 15 months at Site 2, 6 months at Site 3, and 3 months at Site 4. Measured tidal data was translated to tidal elevation and was reduced to equivalent 19-year tidal datums through a mathematical comparison with the closest control station at NOAA Station ID 9418767 (North Spit) using the NOAA direct method computational technique (NOAA 2003). Low water tidal datums (mean lower water (MLW) and mean lower low water (MLLW)) are not reported for Sites 1, 2 and 3. The data logger at Site 1 was installed near the bank rather than in the center of the channel to avoid boat traffic and commonly dried during the lower low tide. A downstream control at Site 2 controlled low water elevations. The channel at Site 3 drains completely as the channel bed elevation is near MLW in Hawk Slough.

Benchmarks (T-posts) were installed near each station and occupied using a Real Time Kinematic (RTK) Global Positioning System (GPS). GPS data were processed with the Online Positioning User Service (OPUS) to compute a National Spatial Reference System (NSRS) coordinate. Coordinates are provided in Table 3-1, and site photos of benchmark (BM) and station locations are provided in Figure 3-1 to Figure 3-7.

Table 3-1. Site and benchmark locations (NAD 83 California State Plane Zone I, Feet, Vertical datum NAVD88).

Site or BM	Northing	Easting	Elevation
Site 1 Station	5930259.6	2138948.0	NA
Site 1 BM1	2138966.5	5930275.5	12.27
Site 1 BM2	2138972.6	5930341.8	12.92
Site 2 Station	5928823.6	2140013.1	NA
Site 2 BM1	2140339.8	5929029.5	6.69
Site 2 BM2	2140106.8	5928879.0	6.38
Site 3 Station	5925510.5	2134270.5	NA
Site 3 & 4 BM1	2134447.9	5925257.9	9.45
Site 3 & 4 BM2	2134267.4	5925206.7	9.95
Site 3 & 4 BM3	2134257.3	5925489.5	6.69
Site 4	5924516.5	2132802.3	NA

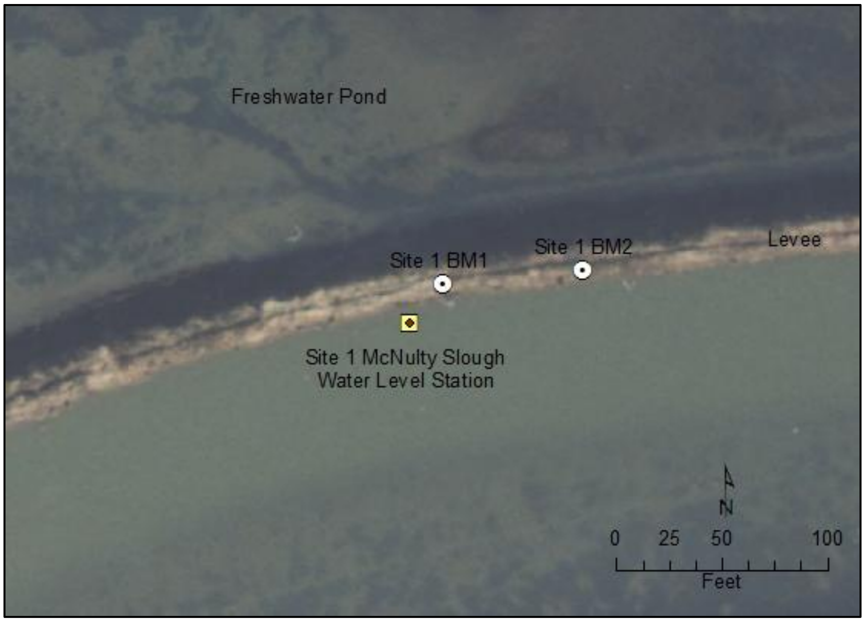

Figure 3-1. Site 1 McNulty plan view.

Figure 3-2. Site 1 McNulty water level station location photo. Photo date: May 13, 2008.

Figure 3-3. Site 2 Interior Breach plan view.

Figure 3-4. Site 2 Interior Breach water level station location photo. Photo Date: 2007.

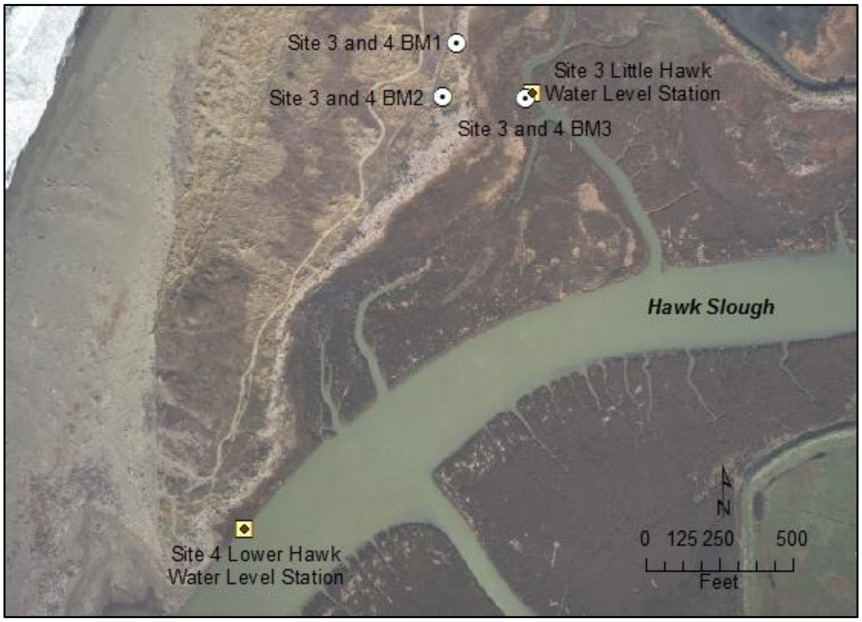

Figure 3-5. Site 3 Little Hawk and Site 4 Lower Hawk plan view.

Figure 3-6. Site 3 Little Hawk water level station location photo. Photo Date: March 30, 2008.

Figure 3-7. Site 4 Lower Hawk water level station. Photo date: May 13, 2008.

MHHW and MHW increases with distance from the ocean around the ORU (Table 3-2). MHHW was highest interior to the ORU at Site 3. However, this amplification may not be representative of water levels throughout the ORU. Circulation patterns are complex within the ORU and existing water levels may vary significantly. Restoration actions may increase or decrease water levels depending on the location of breaches, width and depth tidal channels, distance from the main slough channel and size of the contributing marsh, etc.

Mean Lower Low Water in Hawk Slough is approximately 0.7 feet higher than North Spit and Mean Low Water is 0.5 feet higher than North Spit. These higher datums may be a result of a combination of base level control at the outlet of the bar built estuary and freshwater flows from the Eel River. An elevated base level may result in channels shallower than channels with lower base levels.

Tidal datums reported in Table 3-2 were used in Task 1B to develop relations between tidal prism and channel geometry and in Task 2 to delineate areas likely to develop a tidal channel network by levee breaching, versus areas likely to require mechanical excavation to restore a functional channel network.

Table 3-2. ORU and North Spit tidal datums, ORU datums corrected to North Spit (NOAA Station 9418767).

Datum (feet, NAVD88)	North Spit (9418767)	Site 1 McNulty	Site 2 Interior Breach	Site 3 Little Hawk	Site 4 Lower Hawk
Mean Higher High Water (MHHW)	6.53	6.93	7.27	6.49	6.39
Mean High Water (MHW)	5.82	6.19	6.56	5.78	5.72
Mean Low Water (MLW)	0.93	NA	NA	NA	1.45
Mean Lower Low Water (MLLW)	-0.33	NA	NA	NA	0.41

4. Tidal Marsh Geometry (Task 1B)

Expected evolution of tidal channel geometry or design criteria for channel excavation can be developed using relations between marsh area, tidal prism, channel width, depth and cross-sectional area (PWA 1995, 2004). Given that differences in soils, vegetation, and tidal harmonics may alter empirical relations developed in other regions (Williams 2002), empirical relations developed for MRS (JAA 2008) and San Francisco Bay (PWA 2004) were used to predict channel dimensions for the reference marsh to determine whether they are likely to produce reasonable estimates of channel geometry in the ORU.

Predictive capability was assessed using two measures. The first was the percent difference between measured and predicted values for tidal prism based on measured marsh area, channel top width, channel depth and channel cross-sectional area based on estimated tidal prism. The second was the root mean square error (RMSE) statistic. RMSE is reported for the best fit power function through the measured data, providing a baseline for error due to variability within measured data. RMSE was computed for the reference marsh data set based on relations developed in Humboldt and San Francisco Bays and compared to the RMSE for the best-fit power function. The RMSE statistics, based on the San Francisco Bay and MRS relations, provided an overall measure of predictive error.

Three channels were selected in the ORU reference marsh. The largest channel is a third order channel and the three largest branches are included in the development of the geometric relations. These channels are similar in size to the channels in the San Francisco Bay data sets. Smaller channels are both first order channels and drain directly to Hawk Slough and are similar in size to those in the MRS data set. The required physical attributes for each channel were measured directly or estimated using methods recommended by PWA (1995) and Williams et al. (2002). These parameters include marsh area, marsh elevation, channel width, channel depth, cross-sectional area and potential diurnal tidal prism. Tidal datum for the reference area is computed based on measured water level data at Site 3 (Table 3-2).

Channel geometry was surveyed with an Auto-Level (cross-sections CHC 1, 2, and 3, See Figure 4-1) and a Trimble R8 GPS system. Monuments were installed at the auto-level cross sections and were surveyed with the GPS system in order to spatially reference the cross-sections.

Contributing marsh area was defined as the area of the marsh that drains to a particular cross-section and was computed for each of the selected cross-sections (Figure 4-1). The contributing marsh area included channels, standing water or tidal marsh vegetation. Outside edge of the marsh plain roughly followed the 5 foot MSL contour (8.37 feet NAVD88). Delineation of internal contributing area boundaries were mapped from aerial photos (Humboldt Coast Aerial Photography 2000 and NAIP 2009) and ground surveys.

Potential diurnal tidal prism was used as a surrogate for channel forming flow in hydraulic geometry relations (Williams et al. 2002). Potential diurnal tidal prism was defined as the volume of water in a marsh system between the tidal datums MHHW and MLLW. Methods for tidal prism calculation were modified from those described by Williams et al. (2002) and PWA (2004). Minor modifications to their approach include: (1) cross-sections were surveyed and cross-sectional area was computed directly from survey data rather than assuming a cross-sectional shape; (2) marsh areas were delineated with surveyed topography in addition to aerial photographs; (3) channels drained completely at low tide, therefore, the channel bed elevation was substituted for MLLW. Channel geometry and extents were surveyed and channel lengths were measured from National Agricultural Imagery Program ortho-rectified aerial photos (NAIP 2009).

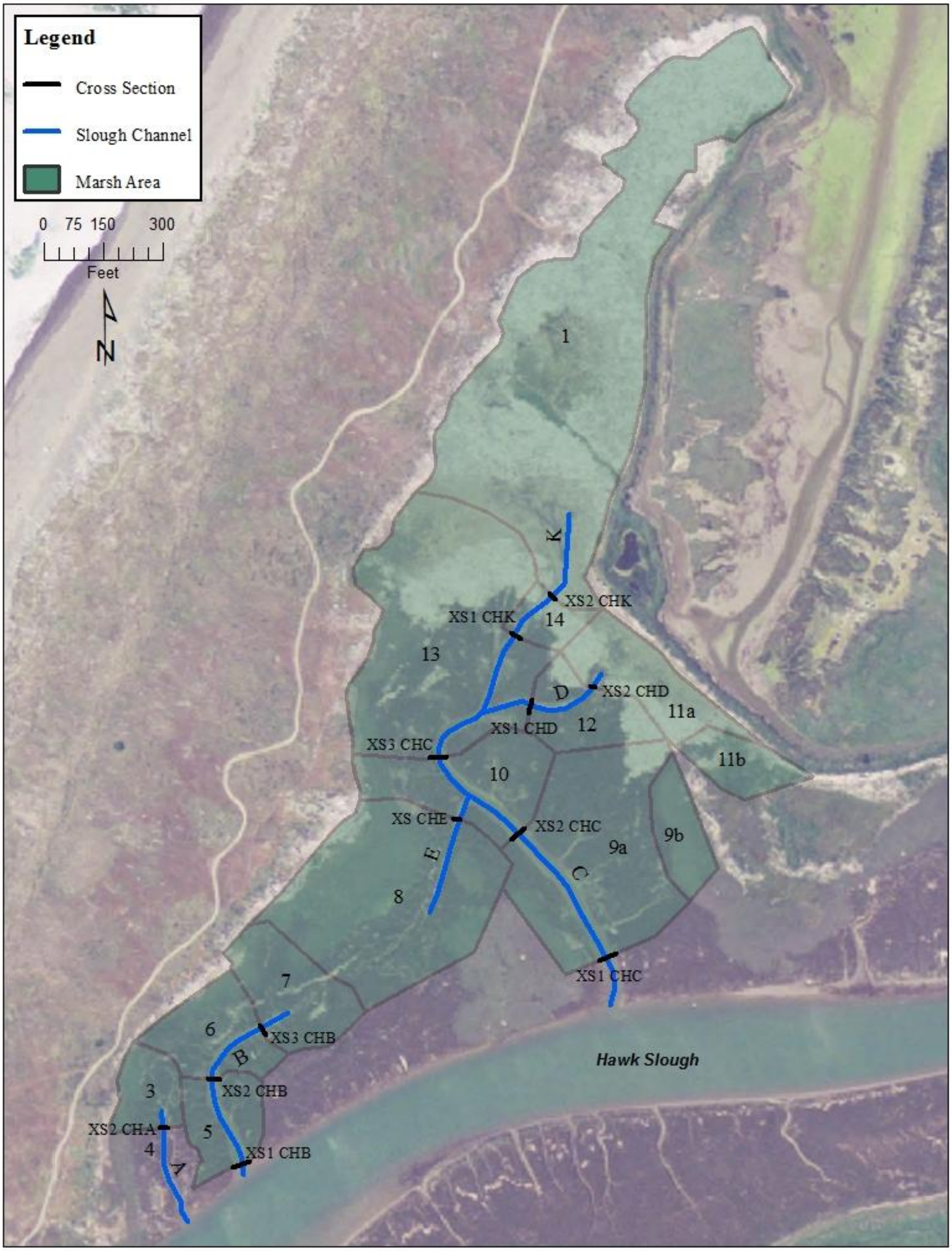

Figure 4-1 Reference marsh slough channels and surveyed cross sections included in hydraulic geometry analysis.

The tidal prism was calculated as the sum of the volume water in the channel and marsh plain upstream of a given cross-section. Volume of water in the channel was calculated by multiplying the cross-section area and channel length using the average end method. Marsh plain volume was computed as the product of contributing marsh area and depth above the marsh plain at MHHW. Average marsh plain elevation was computed from ground surveys for 4 areas (Table 4-1): (1) mudflat: area occupied by dense large woody debris at the head of the largest channel; (2) peninsula: shown as a distinct feature on historical aerial photographs and topographical maps; (3) island: shown as a distinct feature on historical aerial photographs and topographical maps; and (4) vegetated marsh surface: covers the majority of the marsh plain. The peninsula and vegetated island ground surface are above MHHW and, thus do not contribute any volume to the tidal prism. Vegetated marsh surface and mudflat are below MHHW and contribute a significant volume to the tidal prism estimates. Average vegetated marsh surface elevation was calculated to be 0.5 feet below MHHW, within the range of reported mature salt marsh around San Francisco Bay (Atwater 1979, Williams et al. 2002). The mudflat type marsh plain was calculated to be 1.1 feet below MHHW, which is about the recommended design elevation required for channel networks to develop (1 foot below MHHW) (PWA, 2004). Notably, the mud type marsh plain occurs at the distal end of the largest channel and contributes to five of the analyzed cross sections (see “Marsh Area 1” in Figure 4-1). This low area in the distal portion of the marsh plain may result in a higher tidal prism due to a higher storage area on the marsh plain. Channels through the proximal, more mature area of the marsh may have slightly larger cross-sectional areas due to more tidal energy as water is conveyed into the low area, while channels developing within the low area are likely to be smaller.

Table 4-1. Average elevations of ORU reference marsh.

Marsh Plain Type	Average Marsh Elevation (feet, NAVD88)	MHHW Site 3 (feet, NAVD88)
Mud	5.4	6.5
Vegetated	6.0	
Peninsula	7.0	
Island	6.8	

4.1. Results and Discussion

Relations between contributing marsh area and potential diurnal tidal prism, and potential diurnal tidal prism and channel top width, channel depth and cross-section area were developed based on physical measurements of tidal channels in the ORU reference marsh. Contributing areas of five of the channel cross-sections in the reference marsh are similar in size to those in the William et al. (2002) study and seven cross-sections have contributing areas similar in size to those measured in MRS, Humboldt Bay.

4.1.1. Tidal Prism

The tidal prism measured in ERWA is within the range of tidal prisms measured in San Francisco Bay and MRS marshes; however, there is a tendency for the tidal prisms in ERWA to be in the upper range of data collected (Figure 4-2). Higher tidal prism for a given marsh area estimated at the ERWA was likely due to larger volume of water on the marsh plain caused by the lower ground elevations relative to MHHW. Based on the lower overall RMSE, the San Francisco Bay relation is a better predictor of tidal prism for the reference marsh than the MRS relation (Table 4-2). The RMSE using the San Francisco Bay relation as a predictor of tidal prism is about twice as large as the best fit line through the ORU reference marsh data and the MRS predictor has an RMSE about three times larger.

Table 4-2. Measured and predicted potential diurnal tidal prism.

Reference Marsh			San Francisco Bay		MRS	
Cross-Section	Contributing marsh Area	Potential diurnal tidal Prism	Potential diurnal tidal prism	Percent difference (%)	Potential diurnal tidal prism	Percent difference (%)
(CODE)	(ACRES)	(AC-FEET)	(AC-FEET)	(%)	(AC-FEET)	(%)
XS2 CHA	0.73	0.33	0.18	-46%	0.21	-38%
XS2 CHD	1.43	0.61	0.39	-35%	0.40	-35%
XS3 CHB	1.51	0.67	0.42	-37%	0.42	-38%
XS2 CHB	2.82	1.46	0.88	-40%	0.77	-47%
XS1 CHD	3.32	1.20	1.06	-12%	0.90	-25%
XS1 CHB	3.85	2.33	1.26	-46%	1.03	-56%
XS CHE	4.74	2.11	1.60	-24%	1.27	-40%
XS2 CHK	10.02	10.87	3.86	-65%	2.62	-76%
XS1 CHK	10.53	11.22	4.08	-64%	2.75	-76%
XS3 CHC	19.58	15.76	8.44	-46%	5.02	-68%
XS2 CHC	26.26	19.66	11.90	-39%	6.66	-66%
XS1 CHC	31.19	22.96	14.55	-37%	7.88	-66%
Overall RMSE		**2.3**	**4.9**		**7.4**	
RMSE (<4.9 ac)		**0.36**	**0.52**		**0.66**	
RMSE (>4.9 ac)		**3.5**	**7.5**		**11.4**	

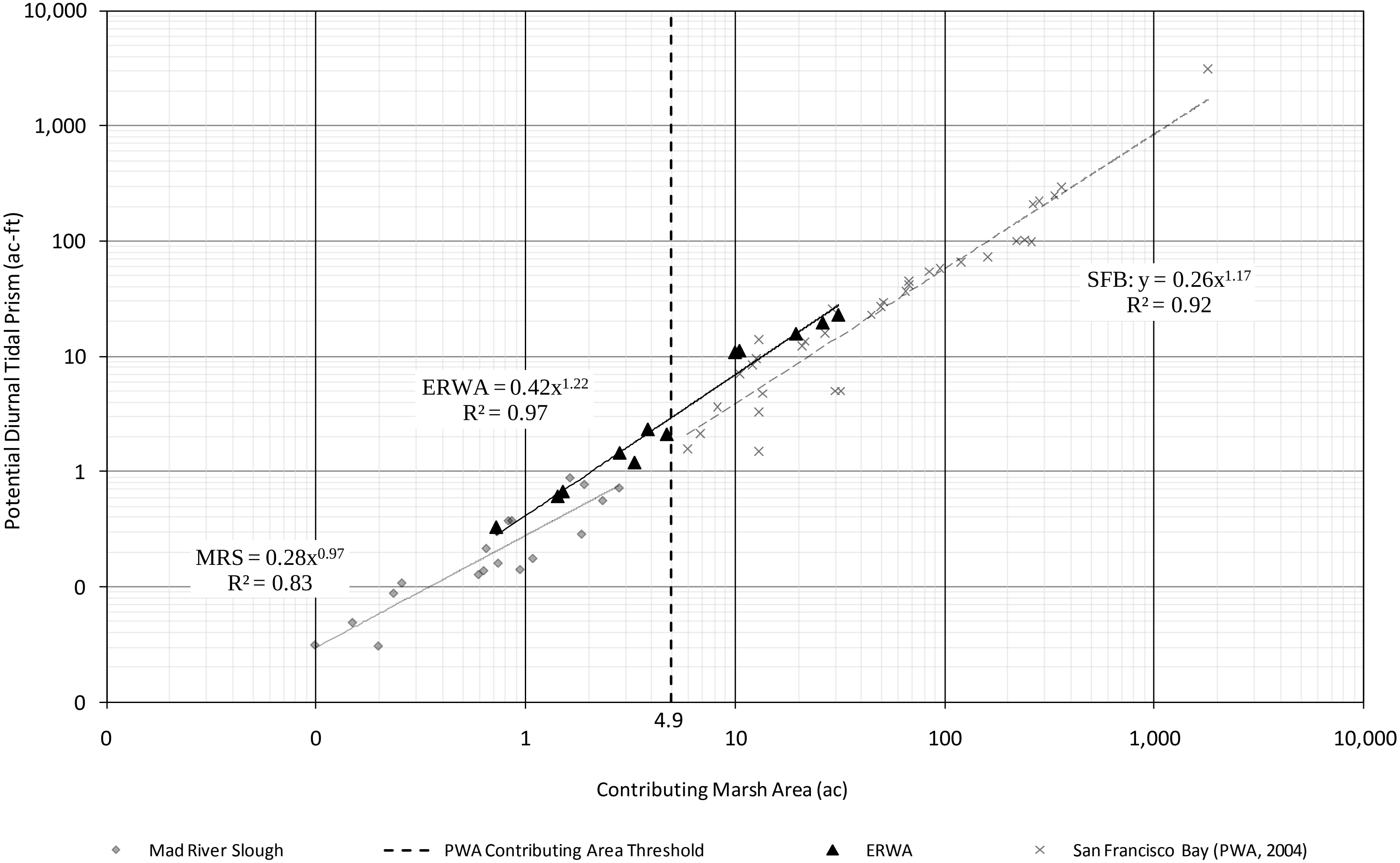

Figure 4-2. Relations between contributing marsh area and potential diurnal tidal prism at reference marsh and Humboldt and San Francisco Bays.

4.1.2. Channel Depth below MHHW

Channel depths in the ORU reference marsh tend to be shallower, more variable, and increase with tidal prism at a lower rate than those measured in MRS and San Francisco Bay (Figure 4-3). The tendency toward shallower channels may be controlled by base level at the outlet of the bar built estuary as indicated by higher MLW and MLLW tidal datums at Lower Hawk Slough (Site 4, Table 3-2). The MRS relation is a slightly better predictor for channels with smaller marsh areas (<5 acres) and San Francisco Bay is a slightly better predictor for channels with larger marsh areas. San Francisco Bay and MRS models produce similar RMSE and are about twice as large as the best fit line (Table 4-3). Channel K drains the area that remains a mudflat at the head of the main slough channel and is significantly shallower than other channels within the reference marsh. Development of this channel may be lagging behind the remainder of the marsh plain due to significant wood accumulation that has limited vegetation growth and trapping of fine sediment to build the marsh plain.

Table 4-3. Measured and predicted channel depths.

Reference Marsh			San Francisco		MRS	
Cross-Section	**Potential diurnal tidal prism**	**Measured depth below MHHW**	**Predicted depth below MHHW**	**Percent difference (%)**	**Measured depth below MHHW**	**Percent difference (%)**
(CODE)	**(AC-FEET)**	**(FT)**	**(FT)**	**(%)**	**(FT)**	**(%)**
XS2 CHA	0.33	3.5	3.7	6%	3.6	3%
XS2 CHD	0.61	2.4	4.1	68%	4.0	65%
XS3 CHB	0.67	3.4	4.2	24%	4.1	22%
XS2 CHB	1.46	3.7	4.8	29%	4.7	28%
XS1 CHD	1.20	3.0	4.6	52%	4.6	50%
XS1 CHB	2.33	4.8	5.2	9%	5.2	8%
XS CHE	2.11	3.7	5.1	39%	5.1	39%
XS2 CHK	10.87	2.6	6.8	163%	6.9	168%
XS1 CHK	11.22	3.1	6.8	121%	7.0	126%
XS3 CHC	15.76	4.9	7.3	48%	7.4	52%
XS2 CHC	19.66	5.3	7.5	44%	7.7	48%
XS1 CHC	22.96	6.0	7.8	30%	8.0	33%
Overall RMSE		**0.9**	**2.1**		**2.2**	
RMSE (<4.9 ac)		**0.58**	**1.2**		**1.1**	
RMSE (>4.9 ac)		**1.2**	**3.0**		**3.2**	

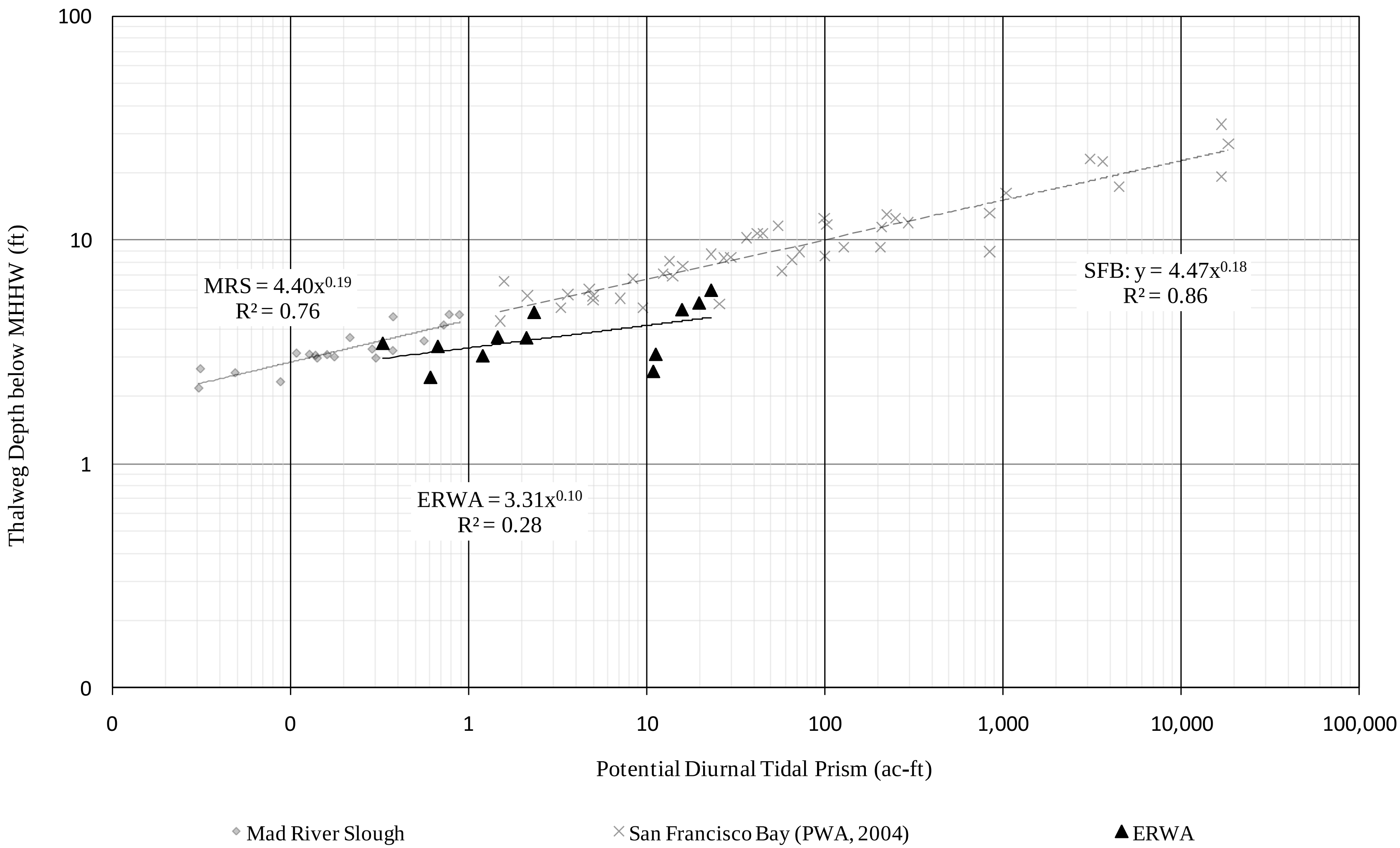

Figure 4-3. Relations between thalweg depth and potential diurnal tidal prism at ORU and Humboldt and San Francisco Bays.

4.1.3. Channel Top Width

Channel top widths measured in the ORU reference marsh are within the range of top widths measured in San Francisco Bay and MRS marshes (Figure 4-4). Top widths of channels with contributing areas less than 4 acres tend to be wider than predicted from relations developed from San Francisco Bay and MRS marshes, and narrower for contributing areas greater than 4 acres, with the exception of the two cross-sections with the largest contributing areas, which were predicted well by both San Francisco Bay and MRS relations (% error < 20%) (Table 4-4). The channel top width in the reference marsh appears to increase with tidal prism at a lower rate than measured in San Francisco Bay and MRS marshes. Overall, San Francisco Bay and MRS models produce similar errors (RMSE = 12.7 and 11.4 feet, respectively) to the best fit line through the measured data (RMSE = 10.9 feet) (Table 4-4).

Table 4-4. Measured and predicted channel top width.

Reference Marsh			San Francisco Bay		MRS	
Cross-Section	**Potential diurnal tidal prism**	**Measured top width**	**Predicted top width**	**Percent difference (%)**	**Predicted top width**	**Percent difference (%)**
(CODE)	**(AC-FEET)**	**(FT)**	**(FT)**	**(%)**	**(FT)**	**(%)**
XS2 CHA	0.33	20.3	7.7	-62%	11.4	-44%
XS2 CHD	0.61	12.2	10.2	-16%	14.2	17%
XS3 CHB	0.67	27.3	10.6	-61%	14.7	-46%
XS2 CHB	1.46	31.7	15.2	-52%	19.5	-39%
XS1 CHD	1.20	15.0	13.9	-7%	18.2	21%
XS1 CHB	2.33	45.5	18.9	-59%	23.1	-49%
XS CHE	2.11	17.8	18.0	1%	22.3	25%
XS2 CHK	10.87	22.2	38.4	73%	40.2	81%
XS1 CHK	11.22	30.1	39.0	29%	40.6	35%
XS3 CHC	15.76	36.0	45.5	26%	45.9	27%
XS2 CHC	19.66	50.2	50.4	0%	49.7	-1%
XS1 CHC	22.96	62.8	54.2	-14%	52.6	-16%
Overall RMSE		**10.9**	**12.7**		**11.4**	
RMSE (<4.9 ac)		**9.9**	**14.3**		**11.5**	
RMSE (>4.9 ac)		**12.1**	**10.1**		**11.3**	

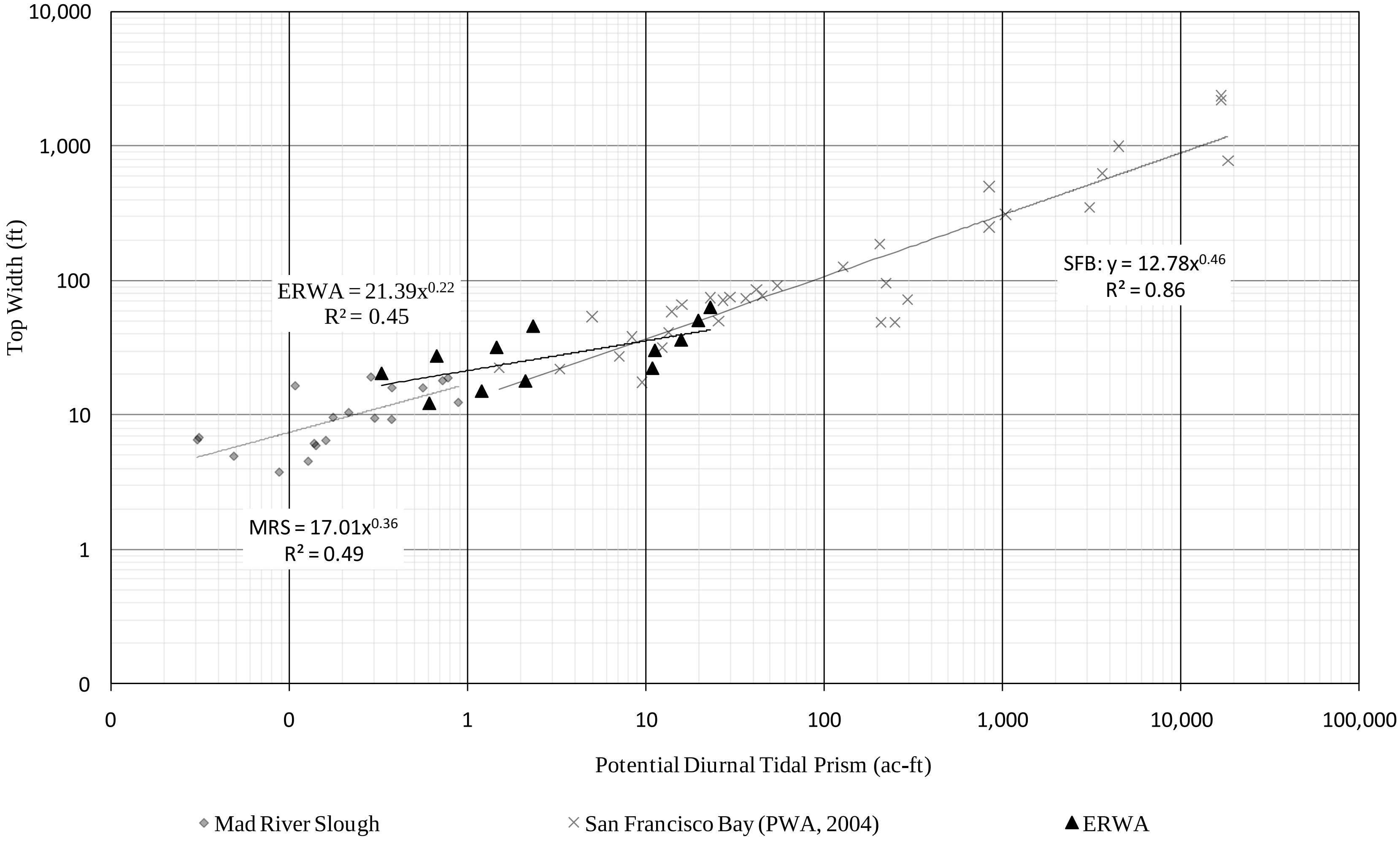

Figure 4-4. Relations between potential diurnal tidal prism and channel top width at ORU and Humboldt and San Francisco Bays.

4.1.4. Cross-Section Area below MHHW

The channel cross-section areas measured in the reference marsh are generally within the range of cross-section areas measured in San Francisco Bay and MRS marshes (Table 4-5 and Figure 4-5). Similar to the trend in top width, cross-section areas of channels with contributing areas less than 4 acres tend to be larger than predicted for relations developed from San Francisco Bay and MRS marshes, and smaller for contributing areas greater than 4 acres (Table 4-5). Cross-section areas of channel K are poorly predicted due to both a narrower top width and shallower depth than predicted. The cross-section with the largest contributing area (XS 1 CHC) was predicted well by both San Francisco Bay and MRS relations. Channel cross-section area in the reference marsh appears to increase with tidal prism at a lower rate than cross-sections measured in San Francisco Bay and MRS marshes. Overall, San Francisco and MRS models produce similar errors (RMSE = 58.5 and 61 square feet, respectively) to the best fit line through the measured data (RMSE = 45.3 feet) (Table 4-5).

Table 4-5. Measured and predicted channel cross-section area.

Reference Marsh			**San Francisco Bay**		**MRS**	
Cross-Section	**Potential diurnal tidal prism**	**Measured cross-section area**	**Predicted cross-section area**	**Percent difference (%)**	**Predicted cross-section area**	**Percent difference (%)**
(CODE)	**(AC-FEET)**	**(FT)**	**(FT)**	**(%)**	**(FT)**	**(%)**
XS2 CHA	0.33	56.1	15.1	-73%	30.3	-46%
XS2 CHD	0.61	24.9	22.5	-10%	41.0	65%
XS3 CHB	0.67	66.0	23.9	-64%	43.0	-35%
XS2 CHB	1.46	102.0	39.5	-61%	62.8	-38%
XS1 CHD	1.20	36.6	34.9	-5%	57.1	56%
XS1 CHB	2.33	169.2	53.7	-68%	79.1	-53%
XS CHE	2.11	44.5	50.4	13%	75.3	69%
XS2 CHK	10.87	50.4	145.8	189%	168.2	234%
XS1 CHK	11.22	81.8	148.9	82%	170.8	109%
XS3 CHC	15.76	124.2	185.5	49%	201.7	62%
XS2 CHC	19.66	167.7	214.2	28%	224.8	34%
XS1 CHC	22.96	208.8	236.9	13%	242.6	16%
Over all RMSE		**45.3**	**58.5**		**61.0**	
RMSE (<4.9 ac)		**43.7**	**54.4**		**42.2**	
RMSE (>4.9 ac)		**47.5**	**63.8**		**80.2**	

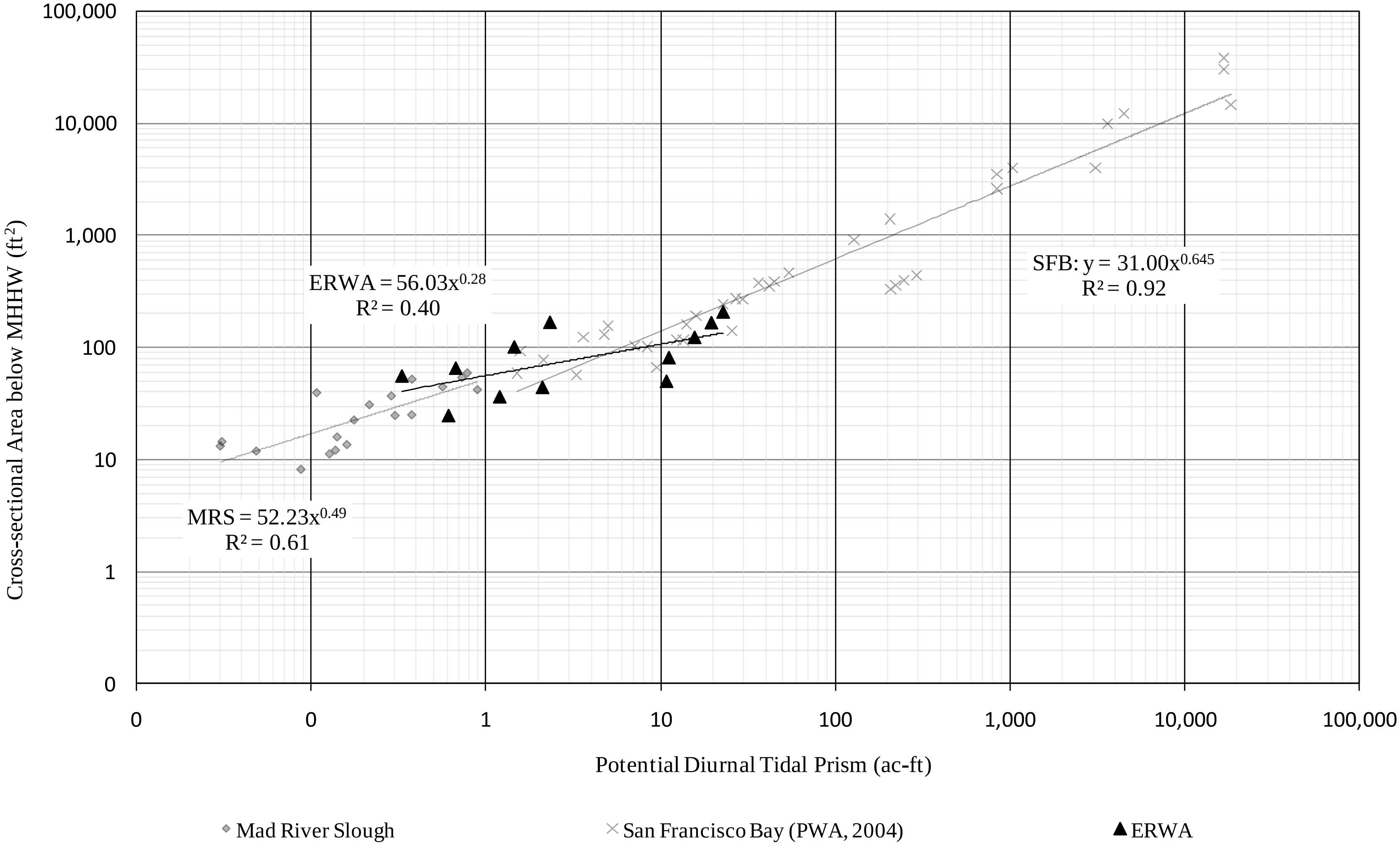

Figure 4-5. Relations between potential diurnal tidal prism and channel cross-sectional area below MHHW at ORU and Humboldt and San Francisco Bay.

4.2. Conclusions/Recommendations

Tidal datums were computed from water level measurements at four sites within and adjacent to the ORU. Water level measurements indicate that tidal amplification occurs with distance from the ocean along Hawk Slough and McNulty Slough and within the ORU. MHHW tidal datum was highest at the Interior Breach (Site 2, 7.3 feet NAVD88) and lowest at Lower Hawk Slough (Site 4, 6.4 feet NAVD88).

The marsh plain at Site 3 (Little Hawk/ORU reference area) was measured to determine whether hydraulic geometry relations developed in San Francisco Bay and/or MRS could provide reasonable estimates of channel geometry for restoration in the Eel River estuary. The reference site is the largest tidal marsh near the ORU that has an unrestricted connection to the main slough channels bounding the ORU. The reference area had evolved from a combination of open water and tidal flat in 1965 to a well vegetated contiguous marsh plain with ground elevations within 0.5 feet of MHHW, indicating the marsh plain is approaching equilibrium.

Based on our findings, we recommend using the San Francisco Bay relations (PWA 2004) for estimating tidal prism, channel top width, and cross-section area for marsh areas greater than 4.9 acres, and MRS relations for marsh areas less than 4.9 acres for channel designs rather than using sites specific relations measured within the ORU for the following reasons:

1. Measured data generally fall within the range of channel geometries measured in San Francisco Bay and MRS marshes.
2. The reference marsh has indicators that it may still be evolving and channel geometries may not be “mature.” These include: (a) low marsh plain elevations relative to both older marsh surfaces identified on historic photos and to MHHW, and (b) significant areas of mudflat that exist near the head of the largest slough channel. Extrapolation of the site specific relations may lead to large errors if extrapolated beyond the measured data.
3. MRS, Humboldt Bay was generally a better predictor of channel dimensions for marsh areas less than 4.9 acres than the extrapolated San Francisco Bay relation.
4. San Francisco Bay relations were generally better predictors of channel dimensions for marsh areas greater than 4.9 acres than the extrapolated MRS relations.

Channel depths may be shallower in the Eel River estuary due to potential base level control at the outlet of the bar built estuary, and freshwater flows in the Eel River, than predicted by either the San Francisco Bay relation or the MRS Humboldt Bay relation. Design channels should grade to either McNulty Slough or Hawk Slough and should not exceed channel depths predicted by the San Francisco Bay or MRS relations. Design channel cross-section area may need to be adjusted accordingly.

Relations from the reference marsh may be used to design channels that are approaching equilibrium. Appropriate areas to apply ORU reference marsh relations are areas that have ground elevations less than one foot below MHHW and have contributing areas less than 31 acres. The rate of the ORU reference marsh evolution is unknown. The rate of the ORU marsh evolution may be tracked by conducting additional topographic surveys and measuring marsh plain accretion with sediment elevation tables.

5. Ocean Ranch Unit Delineation (Task 2)

ORU is delineated into four categories based on actions required to create a channel network through a vegetated marsh plain. **These categories are not intended to be design recommendations and are first order approximations of actions required to reestablish channel network and vegetated marsh plain in the ORU**. Some low areas within desirable existing channel networks should not be filled, whereas others are within drainage ditches that may be filled. Similarly, areas that are currently high (potential uplands) provide topographic complexity desirable to maintain as targeted wildlife habitats. Polygons associated with each category are rough approximations of extents and show the largest possible area that may be suitable for recovery of channel network within a vegetated marsh plain based on tidal datums measured around the project site and ground elevations.

Areas within the ORU likely to develop a tidal channel network by levee breaching alone and areas that are likely to require mechanical excavation or fill to restore a functional channel network can be approximated by comparing ground elevations to the tidal datum MHHW, or the expected elevations of the equilibrium/mature marsh plain (PWA 2004). In order for a channel network to develop, bed shear stresses must be sufficiently high to erode and incise into the marsh plain. A rule of thumb provided by PWA (1995) is that ground elevations must be 1-1.5 feet below MHHW or the expected elevation of the mature marsh. Building and maintenance of the marsh plain also requires a sufficient sediment supply to keep pace with sea level rise. Sediment supply should be considered when choosing locations and number of levee breaches. Ground elevations lower than approximately 1.5 feet are not likely to support vegetation and will remain mudflat until sufficient elevations are reached from sediment accretion.

Ground elevations were estimated based on 5-foot contours and point elevations spaced approximately 400 feet apart from a survey conducted on March 25, 1968 prepared by Clair A. Hill & Associates for the Corps of Engineers (Figure 5-1). Humboldt Coast Aerial Photography (2000) photos were used to interpolate between data points and contours.

MHHW tidal datum in the two major slough channels (Hawk Slough and McNulty Slough) surrounding the Ocean Ranch Unit varies from 6.39 feet at the oceanward site (Site 4 Lower Hawk Slough) and increases to 6.86 feet in McNulty Slough. Within the Ocean Ranch Unit, the MHHW tidal datum is approximately 7.27 feet (Site 2 Interior Breach) (Table 3-2). For the purposes of marsh plain delineation for a given restoration action (levee breaching alone or levee breaching in conjunction with mechanical excavation), we assume the best estimate of a mature marsh plain elevation in the ORU is equal to MHHW.

Categories are (Figure 5-2):

1. **Fill**: Ground elevations are more than 1.5 feet below MHHW at Site 4 (< 4.9 feet NAVD88; <1.5 feet MSL). These areas are found within active channels, drainage ditches, and ponded areas and are not likely to support salt marsh vegetation because water depths are too high.
2. **No Excavation or Fill**: Ground elevations are 1-1.5 feet below one or more MHHW estimates at least one the four monitoring sites (4.9-6.3 feet NAVD88; 1.5-2.9 feet MSL). These areas may not require excavation or fill to re-establish a channel network and support salt marsh vegetation.
3. **Excavation of Channel Network**: Ground elevations are higher than 1 foot below MHHW at Site 2 and low enough to support tidal marsh vegetation (6.3-8.4 feet NAVD88; 2.9-5.0 feet MSL). These areas may require channel excavation to re-establish a channel network.
4. **Excavation of Channel Network and Marsh Plain**: Ground elevations are greater than 8.4 feet NAVD88 (5 feet MSL). These areas may be too high to support marsh plain vegetation or a channel network based on surveys in the ORU reference marsh.

Delineation is based on a coarse topographic data set collected in 1968 and existing tidal datums. Areas shown as ‘No excavation or fill’ span a 1.5 foot elevation range due to the range of existing tidal datums around the project site (0.9 feet). The type and location of levee breaching, and modification of the interior channel network will alter MHHW tidal datum within the ORU, thus, the extent of the polygon. The design MHHW datum can be estimated by modeling the proposed project. Once this datum is established, the final elevation range that will support no excavation or fill will be 0.5 feet and the ‘No excavation or fill required’ polygon will shrink substantially and surrounding polygons will expand. These polygons are a first order approximation and may be used to develop conceptual restoration designs. A new topographic data set (LIDAR) may be collected in the near future by an OPC/NOAA collaborative project, which could be used to refine these polygons. Alternatively, DFG may consider detailed ground surveying in specific areas of interest.

Figure 5-1. Sample of topographic map with 5-foot contours and spot elevations spaced approximately 400 feet apart.

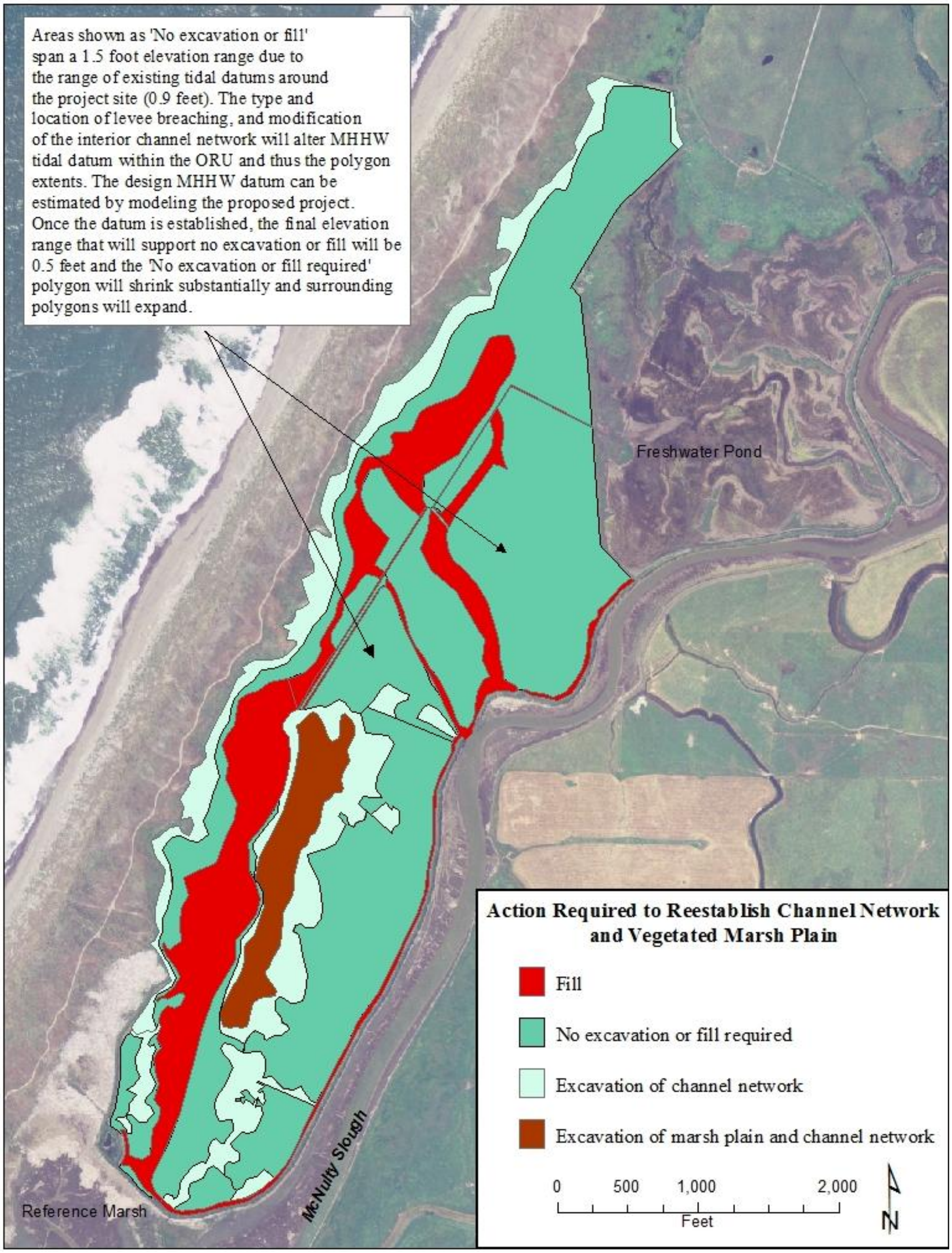

Figure 5-2. Delineation of ORU based on tidal datums and ground elevations (need to locate date surveyed) .

6. References

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