Rates of Erosion and Habitat Loss in the Elkhorn Slough

A Capstone Project
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Abstract

The Elkhorn Slough is a narrow, tidal embayment at the mouth of the Monterey Canyon in Central California. The Elkhorn Slough Estuarine Research Reserve encompasses about 1400 acres on the south and east sides of the slough. Wide ranges of habitats are represented, from grasslands and oak woodlands to saltmarsh, tidal mudflats, and open water. This diversity of habitats is home to over 400 species of invertebrates, 80 species of fish, and 260 species of birds. In 1946 the shoreline dune along the Sloughs western edge was breached to provide permanent ocean access for the Moss Landing Harbor. Since the breach of the western dune tidal currents have increased, widening and deepening the main channel of the slough. Projects to minimize the effects of increased tidal influences have been proposed but are associated with great monetary costs and ecological unknowns. Any attempts to slow the currents may have irreversible effects on the ecology.

A bathymetric survey of the slough designed to determine the degree that erosion is changing the slough channel was conducted for this project. By comparing current channel dimensions with data collected in 1993, this study shows that the Elkhorn Slough has lost $4.66x10^5 m^3$ of sediment from the main tidal channel between the mouth of the slough and Kirby Park. Channel depths increased an average of 0.52 meters with the greatest change occurring at the slough mouth and at Seal Bend with a increases of 24% and 30% respectively. The channel volume increased overall by 15% with the greatest changes at the slough mouth and Seal bend with increases of 26% and 19% respectively.

Introduction

Wetland habitats along the California coast have been greatly modified by reclamation and diking since the late 1800's. Most of California's wetlands and estuaries have been either dredged to provide safe harbors, or dried to provide agriculture and range land. Due to these activities over 90 percent of saltmarsh habitats along the California coast have been destroyed (Haltiner &Williams, 1987). This widespread loss of habitat has prompted concern for the protection and integrity of wetland habitats. The Elkhorn Slough is a shallow tidal estuarine embayment that is part of a 585 km^2 watershed at the eastern most extent of the Monterey Bay (Figure 1). The mouth of the slough is located just east of the Moss Landing Harbor with the main channel extending 10 km to the

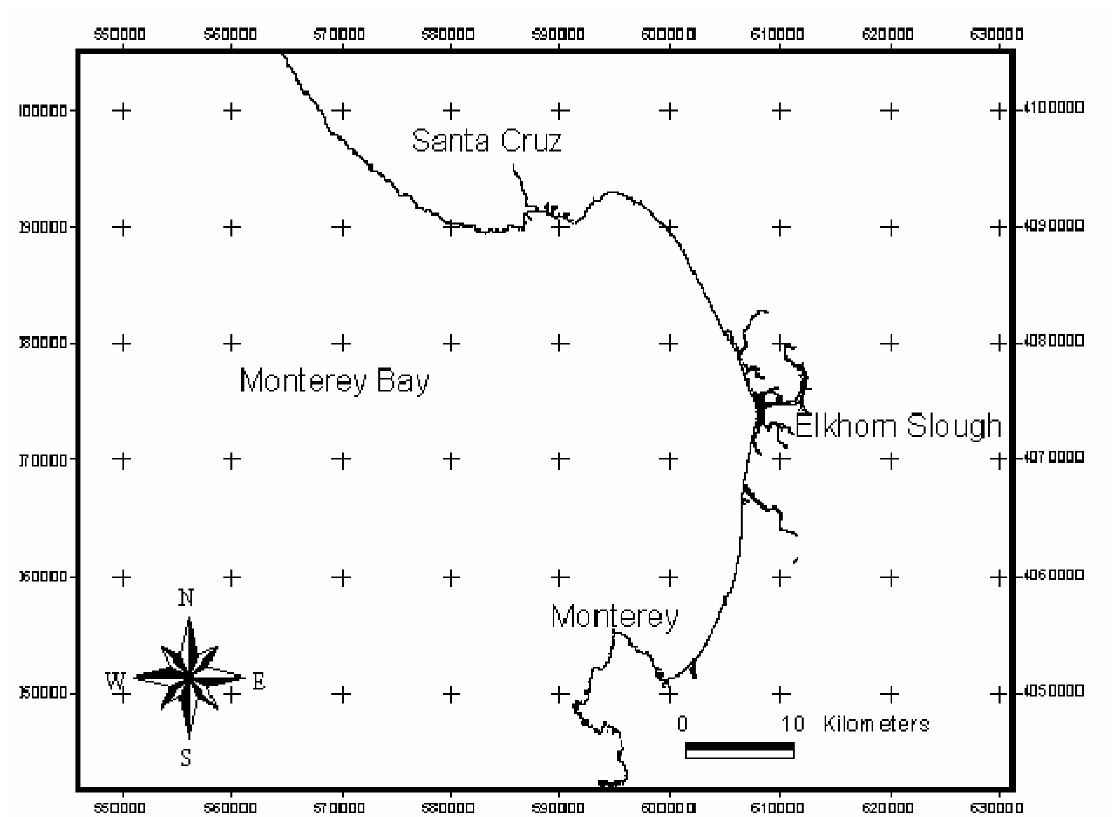


Figure 1. Site Map: Regional location of the Elkhorn Slough showing proximity to Monterey Bay in Central California.

northeast. The slough is an important part of the remaining 10 percent of California's saltmarsh habitat. The importance of the Elkhorn Slough has also been nationally reconized. The Elkhorn Slough National Estuarine Research Reserve is one of 26 National Estuarine Research Reserves established nationwide as field laboratories for scientific research and estuarine education

The Elkhorn Slough was not always as it is today. Many geologic and anthropogenic processes have shaped and continue to shape the slough to this day. Approximately two million years ago the area that is now the Elkhorn Slough was carved by a sizeable stream (Schwartz *et al*, 1986). Activity along the San Andreas and Zayante fault zones diverted this drainage in the late Pleistocene (Schwartz *et al*, 1986). At the end of the last ice age, about 15,000 years ago, sea level rose and flooded the river valley. Land adjacent to the slough eroded and filled the valley with sand and mud creating the existing mudflats and saltmarshes. Early maps of the lower slough date back as far as 1854. In the 1800's depths in the lower slough averaged approximately 1.2 m, and the width of the main channel was between 5-7 m (MacGinitie, 1935; Oliver *et al*, 1988). In those times the influence of the tides on the slough was minimal and the slough was a strongly depositional system (Philip Williams & Assoc., 1992).

In the last 150 years human infulence has helped to mold the Elkhorn Slough. Wetlands were converted into agricultural lands in the early 1800's (Smith, 1973).   Between 1876 and 1880 the Southern Pacific Railroad constructed railroad tracks that cross the slough, isolating large areas of marshland. Until 1908 the Salinas River flowed into the slough before meeting the ocean north of the Moss Landing Harbor (Figure 2). In these times the slough underwent seasonal changes as sandbars formed during the summer and deprived the slough of salt water. During the winter increased flow of fresh water into the slough would wash out the sandbar allowing saltwater and fresh water to mix, turning the slough into an estuary (MacGinitie, 1935; Gordon, 1974). In 1908 a new mouth was created for the Salinas River 6.6 km south of Moss Landing, this deprived the slough of fresh water and sediment flow (Gordon, 1977). During the early 1900's large areas of saltmarsh next to the slough were diked and drained for agriculture use.

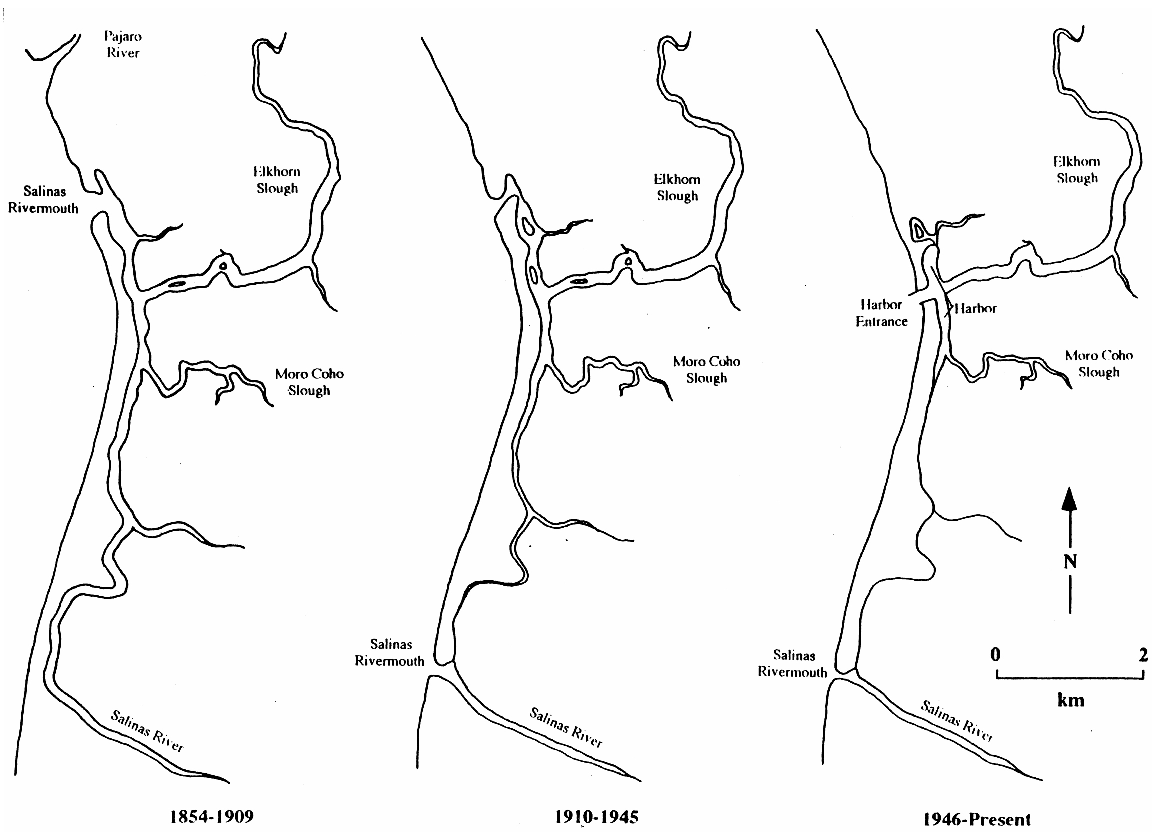


Figure 2. Historic physiographic changes to the Elkhorn Slough showing modifications to the flow of the Salinas River and the opening of the Moss Landing Harbor entrance (Crampton 1994).

In 1946 the U.S. Army Corps of Engineers initiated the construction of the Moss Landing Harbor. In order to provide the harbor with permanent ocean access the coastal dunes at the current mouth of the slough were breached (Figure 2). Two rubble jetties were constructed at the new harbor mouth in 1947 (Gordon, 1977). By breaching the dunes to create the new harbor entrance the Army Corps of Engineers initiated the most significant physical change to the slough system. Before the opening of the harbor entrance the slough had been shoaling for some 8000 years (Schwartz *et al*, 1986). In 1946 the slough changed from a depositional tidally restricted lagoon to a fully tidal estuarine embayment (Crampton, 1994).

Between 1946 and 1983 the increased tidal currents eroded the main channel and tidal creeks. In an effort to reclaim saltmarsh habitat several dikes and levees were opened between 1983 and 1989 (Table 1). In total 4.3 square kilometers were flooded, increasing the surface area of the slough by 48%, and increasing the tidal volume by 43% (Malzone and Kvitek, 1994). The tidal volume may have been further increased during the Loma Prieta earthquake in 1989. The earthquake may have caused settling in the mudflats of the slough (Malzone and Kvitek, 1994). This increase in tidal volume causes more water to travel in and out of the slough with every tide and has accelerated the erosion rates.

Tidal currents drive tidal erosion. Currents are related to the tidal volume and the cross-sectional area this volume has to travel through. High tidal volume forced through a narrow channel will cause high currents and erosion. Erosion will continue until the tidal channel is large enough to accommodate the tidal volume. Increasing the tidal volume will increase tidal currents and erosion until equlibrium is reached.

Table 1. Recent additions to the Elkhorn Slough contributing to increases in water volume (Malzone and Kvitek, 1994).

		Surface Area of Saltwater Habitat		**Tidal Volume**	
Location	Date of Saltwater Incursion	Surface Area (km^2)	% of Total Slough System	Volume (m^3)	% of Total Slough System
Bloom/Porter Marsh	1989	1	11	21,880	1
North Marsh	1985	0.6	7	52,622	1
Parson's Slough/South Marsh	1984	1.8	20	1,633,240	30
Dolan Marsh	1986	0.3	3	131,400	2
Salt Ponds	1984-1988	0.6	11	507,820	9
Total		**4.3**	**48**	**2,346,962**	**43**
Elkhorn Slough and Adjacent Tributaries		9.1	100	5,552,920	100

At the time of the harbor construction the U.S. Army Corps of Engineers planned to limit tidal influence in the slough by constructing water-flow control gates at the Highway One Bridge. This action was never taken and erosion began with the opening of the mouth in

1946. In 1991 the U.S. Army Corps of Engineers hired Philip Williams & Associates to evaluate the scour problem and suggest possible solutions. Solutions included the construction of a sill at the mouth of the slough to reduce tidal flow and scour. The feasibility study associated with this solution suggested costs close to $1,000,000 (Malzone and Kvitek, 1994). Due to the high costs of such a project no action has been taken to this date. The challenge now is to decide what action is necessary and how our decisions will affect the fate of the slough. Possible actions range from doing nothing to making another major hydrologic modification to the slough. Any modification comes with serious implications and unknown ramifications to the existing slough system.

Due to the high costs and ecological uncertainties with any action to minimize tidal activity the critical question is how close is the slough to reaching equilibrium? One method to approach this question is to determine if the rate of channel erosion is slowing. The purpose of this project is to determine if and where the main tidal channel of the Elkhorn Slough is eroding. To achieve this objective I conducted a bathymetric survey on April 17, 2001 and compared the results with those of Malzone and Kvitek in 1993 (Figure 3).

This project is a combined a bathymetric survey and Geographic Information Systems (GIS) analysis to provide insight about the erosive processes currently affecting the slough. This project will also provide baseline data for future multibeam surveys. This information will be provided to the Elkhorn Slough Foundation to assist in future policy decisions that may protect the slough's tidal channels, mudflats, and marshes, which provide habitat for a variety of plants and animals, including several vanishing species.

Methods

<u>Data Collection</u>

Using CSUMB's research vessel, the MacGinitie, a high resolution bathymetic map of the Elkhorn Slough was created with a Triton Elics International Isis sonar system and

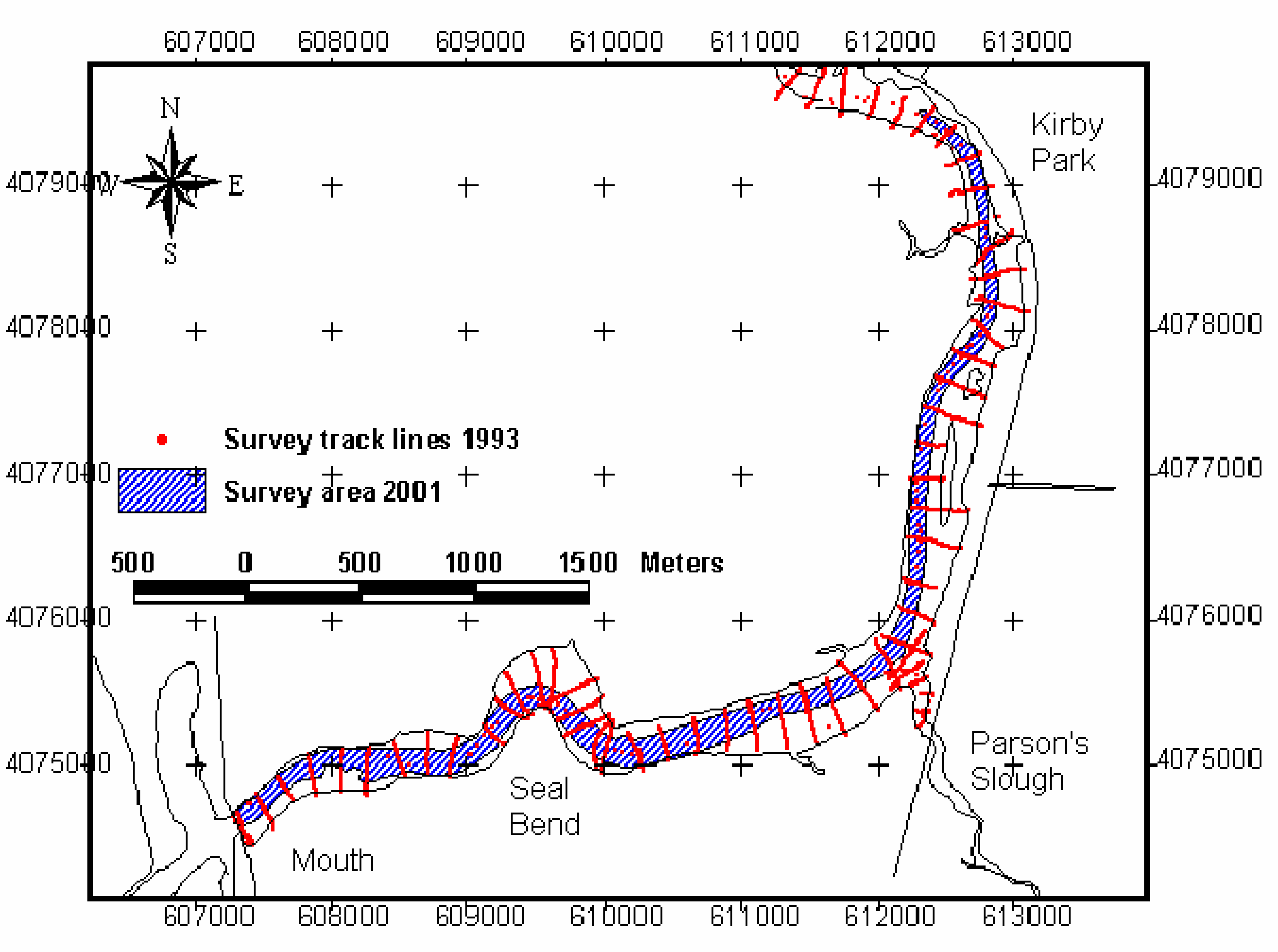


Figure 3. Elkhorn Slough showing bathymetric survey tracklines from November/December 1993 and area surveyed on April 17, 2001.

Hypack Navigation software from Coastal Oceanographics, Incorporated. Bathymetic soundings were collected using a Reson 8101 multibeam echosounder. For every acoustical sounding a UTM position was generated using a Trimble 4700 Global Positioning System (GPS) operating in Real Time Kinematic(RTK) mode, which gives horizontal positional accuracy within 10cm. To facilitate RTK GPS a base station was erected at benchmark ELK1 located on the overlook near the Elkhorn Slough visitor's center. A TSS-Position and Orientation System for Marine Vessels (POS MV) was used to correct soundings for boat movement (heave, pitch, roll, and yaw). An Applied Microsystems Limited (AML) SV+ sound velocity profiler was used to adjust for sound refraction due to density variations in density in the water column.

Data Processing

All data was processed using Caris Hydrographic Information Processing System (Hips). Hips was used to first examine navigation data to check for any errors. Then Hips was used to correct for boat motion, sound velocity through the water column, and to correct for changes in tidal height that occurred during surveying. Published tidal data from the Elkhorn Slough Railroad Bridge was used due to its location near the middle of the survey area. All data was then filtered to remove bad data points, merged, and reexamined. Caris GIS was then used to create an x,y,z data set of the bathymetry of the slough.

To determine rates of subtidal sediment loss the x,y,z data were imported into ArcView GIS software, where cross-sections of the slough were created to match cross-sections from the 1993 survey (Figure 4) by Malzone (1999). Cross-sections were named to match cross-sections used in the 1993 survey, CS 1 is located just east of the Highway 1 bridge and CS 4 is at Kirby Park. The 2001 survey area was divided into lower slough (0 to 3000m from the slough mouth) and middle slough (3000m to 7000m) for comparison with the 1993 data set. X,y,z data was also used to create the thalwag (channel center line) profile. Interactive Visualization Systems' Fledermaus software was used to create high resolution grids of the x,y,z data from 1993 and 2001. These grids were imported into ArcView for analysis.

Results

Cross-sectional Changes

Current bathymetric and historical bathymetric conditions of the Elkhorn Slough are shown in Figure 5, the locations of these cross-sections are shown in Figure 4. These cross-sections clearly show that the slough is continuing to erode. Cross-sectional areas in the lower slough (CS 1 to CS 2) increased by 20% between 1993 and 2001. The

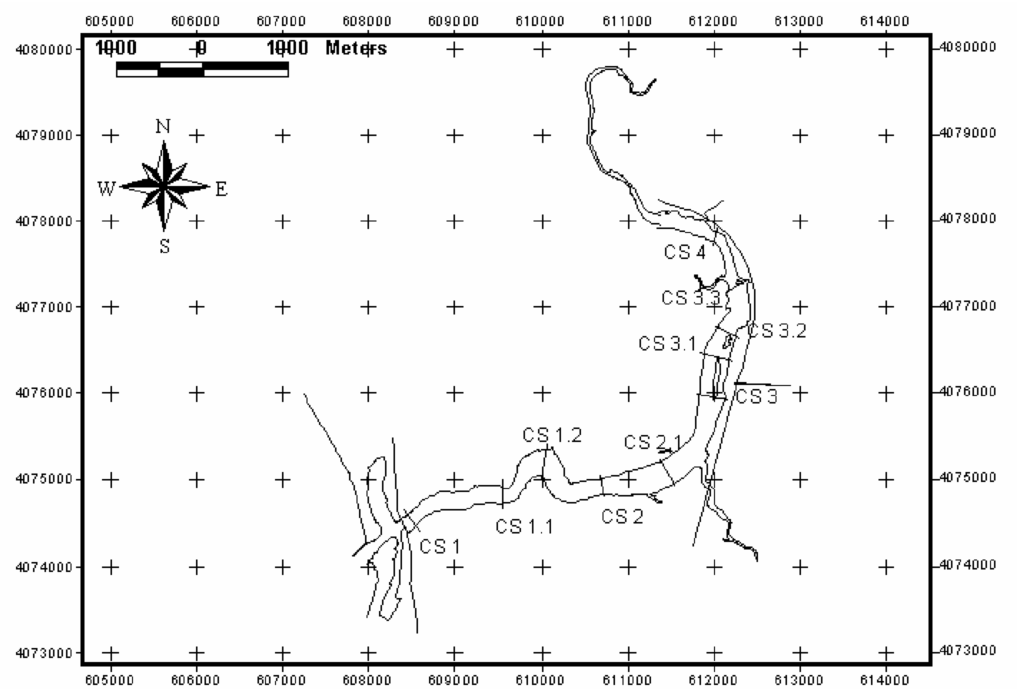


Figure 4. Elkhorn Slough showing location of cross-section comparisons of the 1993 and 2001 bathymetry.

middle slough (CS2.1 to CS 4) showed much less change in cross-sectional area, increasing by four percent. The greatest changes occurred at the slough mouth (CS 1) and at Seal Bend (CS 1.2) where areas increased 29% and 19% respectively. Only one cross-section showed a decrease in channel area, CS 3.2 decreased by 4% over the last eight years (Figure 6).

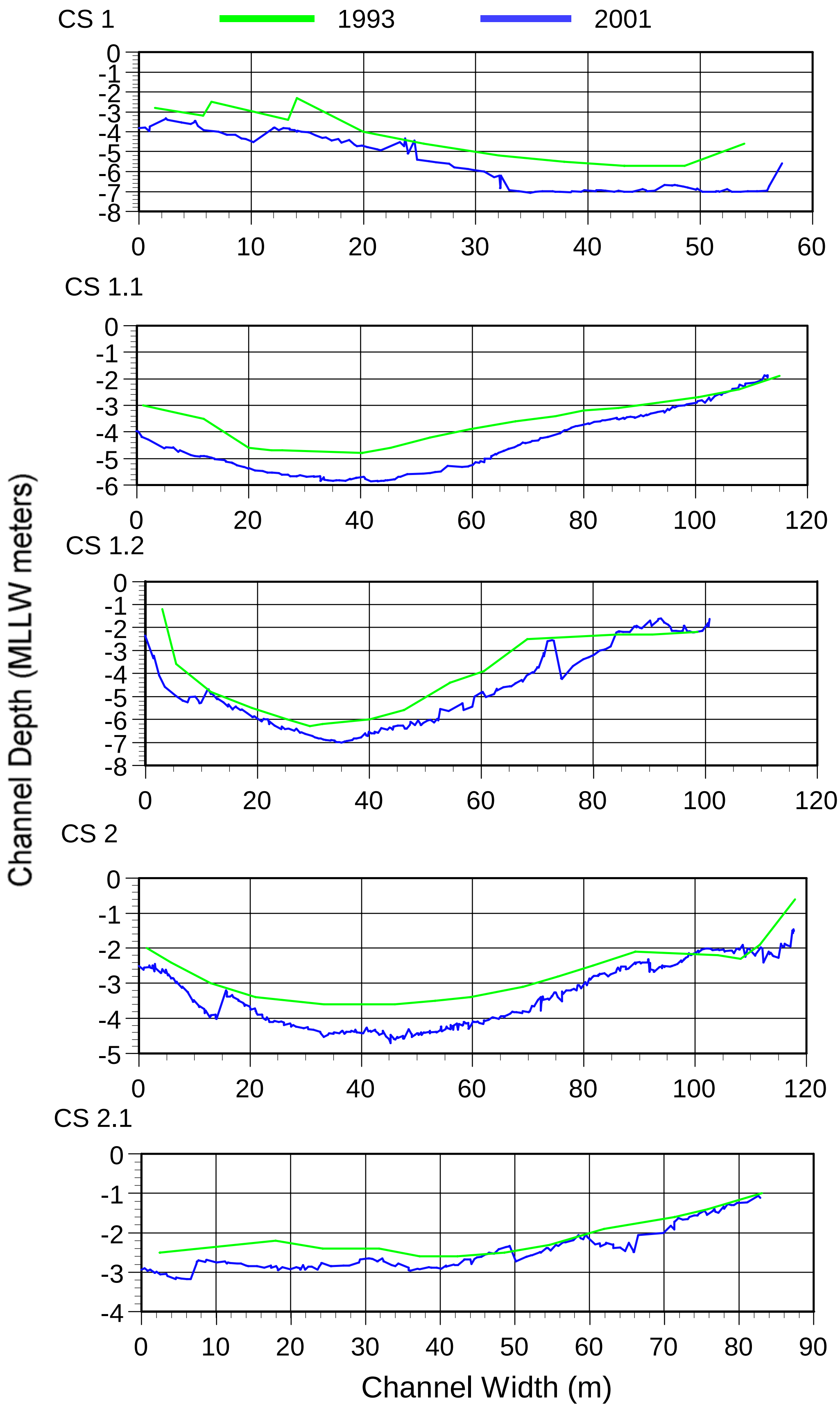


Figure 5. Comparison of 1993 (Malzone, 1999)and 2001cross channel profiles at ten locations along the length of the Elkhorn Slough. Cross-section locations shown in Fig. 4.

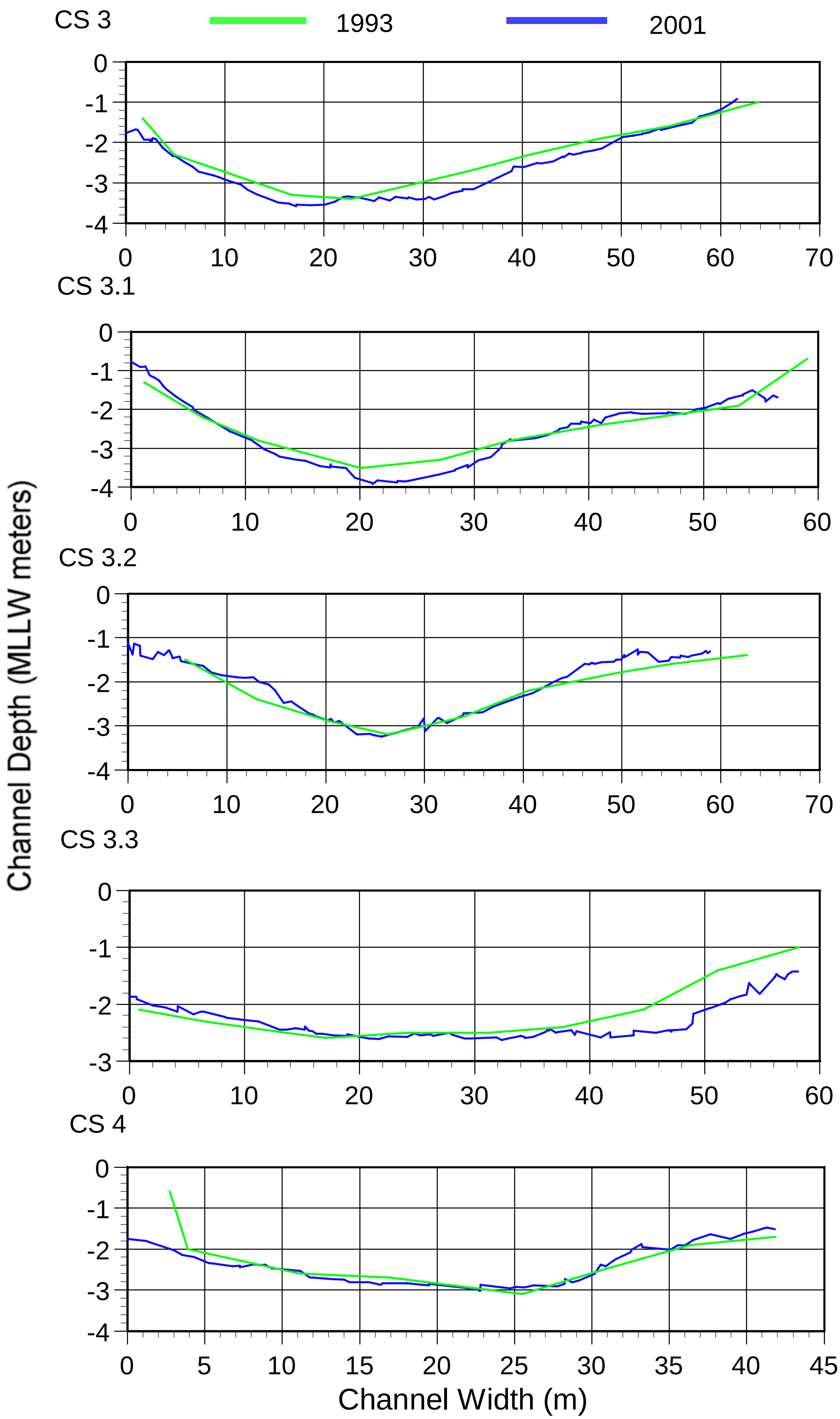
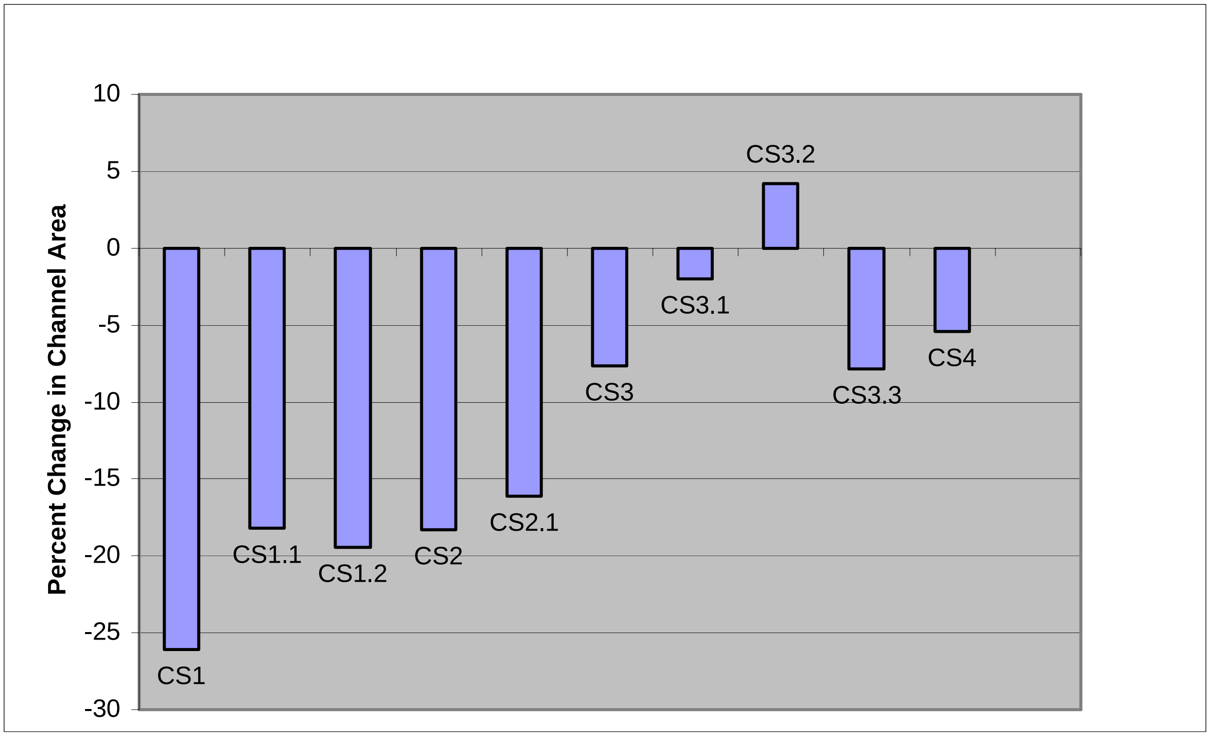


Figure 5 cont. Comparison of 1993 (Malzone, 1999)and 2001cross channel profiles at ten locations along the length of the Elkhorn Slough. Cross-section locations shown in Fig. 4.

a)



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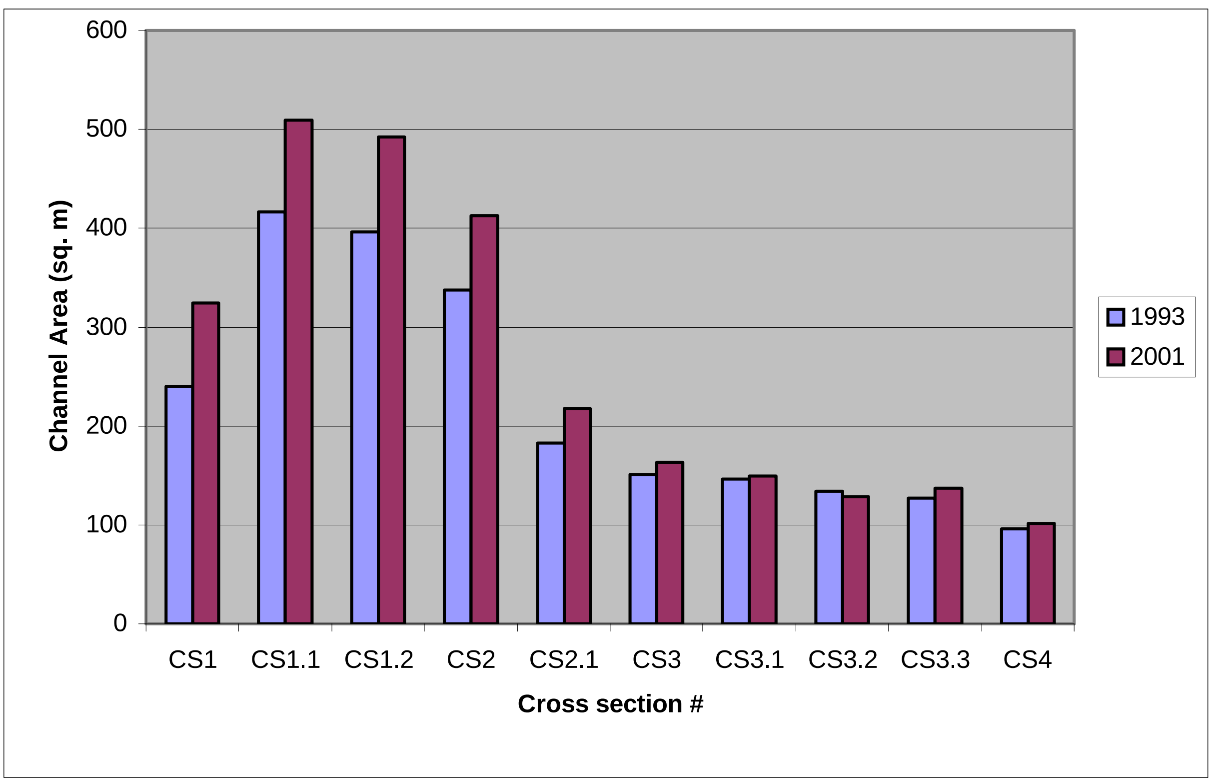

Figure 6. a) Figure showing percent change in channel area from 1993 to 2001 for surveyed cross-sections. b) Figure showing channel area for cross-sections from 1993 and 2001. Graph shows increase in area for all cross-sections except for CS 3.2.

The cross-sectional data was also used to examine changes in channel depth. The maximum depths in the lower slough increased by an average of 1.1 (±0.27) meters per cross- section (0.14m/yr). The greatest change occurred at CS 1 just east of the Highway 1 Bridge where the channel deepened 1.4 meters or 0.17m/yr (Figure 7). In the middle slough erosion continues to deepen the channel increasing the depth by an average of 0.2 (±0.20) meters per cross-section (0.03m/yr). On average the maximum channel depth increased by an average of 12% for all cross-sections over the last eight years.

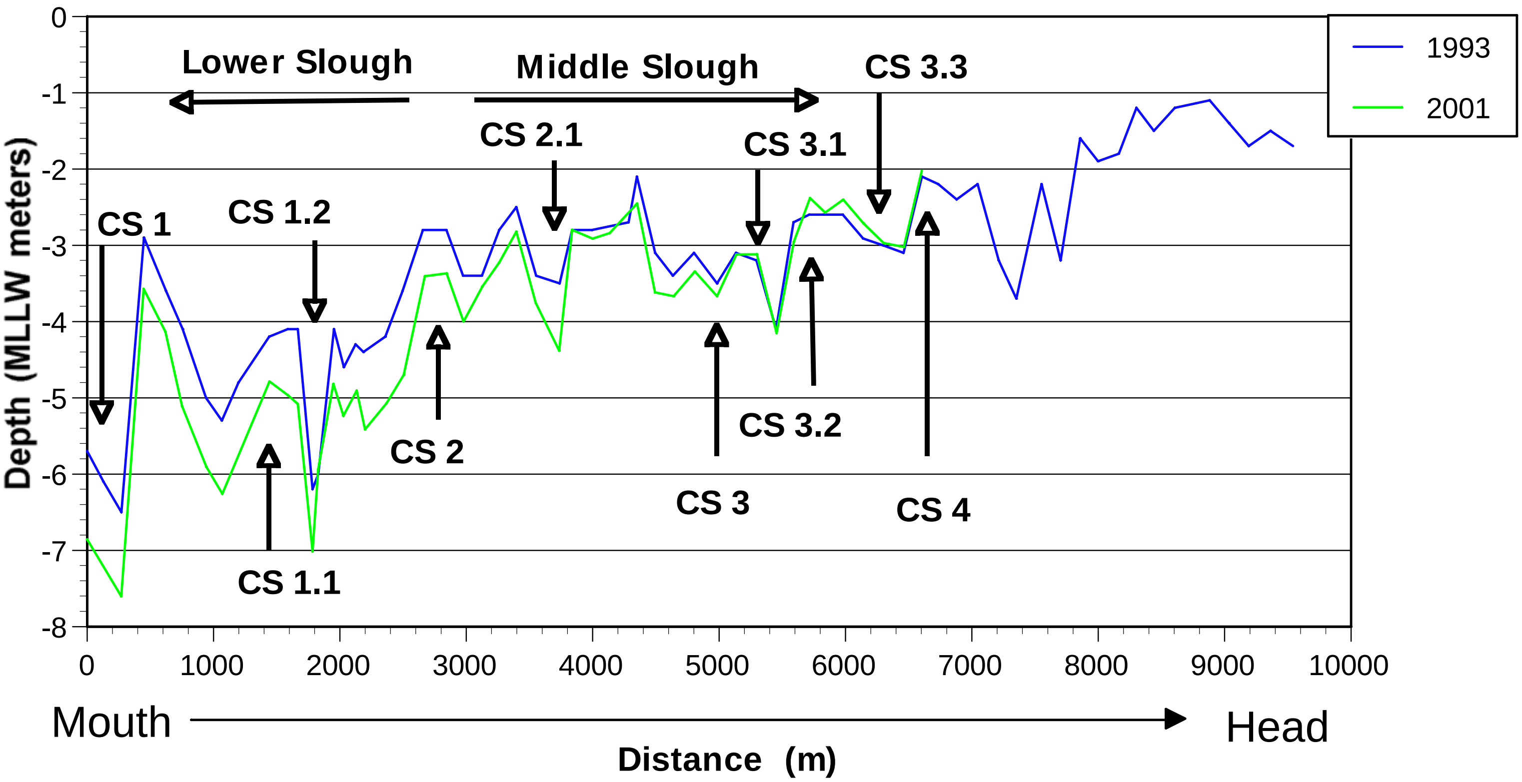

Figure 7. Elkhorn Slough main channel center line depth profile showing depth changes as you move up the slough from the mouth. Lines represent depths surveyed in 1993 (green) and 2001 (blue).

Overall Bathymetry

By interpolating grids of the entire 2001 and 1993 survey areas, analysis of the change in slough volume was determined. Between 1993 and 2001 the Elkhorn Slough lost 4.66×10^5 cubic meters of sediment from the 5.95×10^5 square meters surveyed in 2001. This translates into an average depth increase of 0.78m (0.10m/yr) for the lower and middle slough. The change in the slough was determined by creating grids from each of the two surveys. These grids were then subtracted from each other resulting in a new grid showing the change in the slough since 1993 (Figure 8). This new grid shows which areas in the slough are eroding and which areas are depositional. Looking at the

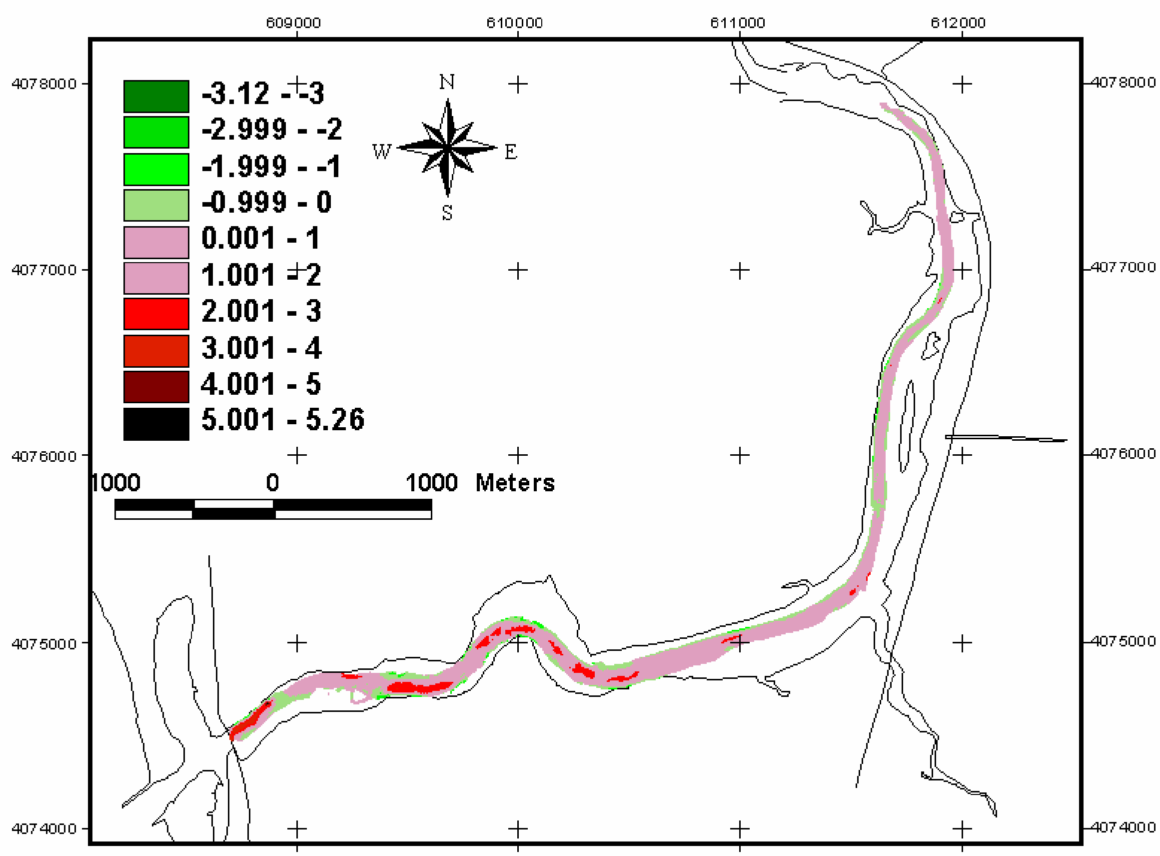

Figure 8. Elkhorn Slough showing change in depth between 1993 and 2001. Positive (red) values show an increase in slough depth and negative (green) values show a decrease in depth.

difference layer it is clear that much of the slough is still eroding, but there are also some areas that are depositional. Most of the deposition is occurring along the edges of the tidal channel, but there is a large area of deposition just east of the slough mouth that crosses the entire channel.

Discussion

Even though it has been over 50 years since the entrance of the Elkhorn Slough was modified to allow tidal action to affect the slough it is clear that the main channel has eroded significantly since 1993.

The main channel continues to grow as the slough loses sediment with each tidal cycle. Cross-sectional data shows that the main channel in the lower slough increased in area by 20% while the middle slough saw only a 4% increase in cross-sectional area. The lower slough saw the highest erosion at the mouth (CS 1) and in Seal Bend (CS 1.2) where moving water is constricted as it moves around the bend. Cross-sectional areas in the middle slough continue to grow but at a much slower rate. This difference in erosional rates may be due to the middle slough being upstream of Parson's Slough, which accounts for 30% of the Elkhorn Slough's tidal volume.

Since the opening of the Moss Landing Harbor in 1947 tidal scour has resulted in the main channel deepening at the mouth of the Elkhorn Slough from 1.5m to over 7m (Philip Williams and Associates, 1992). Since 1993 the channel mouth has increased in maximum depth by over 1.5m or 24%. Cross-sectional data shows that the maximum depth of the slough deepened on average by 0.52m or 12%.

Overall the Elkhorn Slough has lost $4.66x10^5 m^3$ from the 2001 survey area. This suggests an estimate rate of erosion of $5.88x10^4 m^3/yr$. This is lower than the $8x10^4 m^3/yr$ estimated by Malzone (1999), suggesting a decrease in the rate of erosion but due to differences in survey design and survey area this may not be the case. Malzone (1999) conducted a survey of the entire slough system including the upper slough and the mudflats that border the channel. The rate of erosion presented here is an estimate of sediment loss from the main channel between the slough mouth and Kirby Park, the total loss of sediment from the entire slough system could possibly be much different than $5.88x10^4 m^3/yr$.

While the trend for the Elkhorn Slough is mostly erosive, some areas show deposition since 1993. Deposition is occurring along the edges of the channel and across the channel about 800 meters east of the slough mouth. This depositional area is supporting newly emerged seagrass beds that trap sediment and prevent it from leaving the slough (Silberstein pers com).

The disparity in quality and resolution of the data sets limit comparisons of this survey with earlier surveys. The 1993 survey was conducted using a single beam echosounder collecting a single sounding every meter along cross-sections of the slough (Figure 3) (Malzone, 1999). The current high resolution survey was conducted using a multibeam echosounder collecting 101 soundings per ping over a 150 degree swath at greater than 20 pings per second while traveling up and down the channel of the slough at an average of 5kts. This new technology allows for the creation of much denser data sets; the current survey data density is on the order of one sounding for every quarter meter. Due to this difference in sounding densities, this project focused primarily on comparisons of the 1993 cross-section data with their corresponding 2001 multibeam soundings. In addition to cross-sectional comparisons, overall slough bathymetry for 1993 and 2001 was compared using computer interpolated models derived from the sounding data for each year. Cross-sectional comparisons yield results with high confidence levels because they are based upon actual sounding data and not on computer interpolated surfaces. Never the less the overall bathymetry comparisons are useful and are the only means of comparing the overall changes in the Elkhorn Slough's main channel. Future studies will yield greater confidence when making overall bathymetry comparisons of new multibeam sounding data sets with the 2001 data set collected for this project.

Conclusions

The introduction of tidal action to the Elkhorn Slough in 1946 began a process of erosion that has transformed the slough. The 1993-2001 comparison suggests that the slough is still actively eroding along the center channel though there is some evidence of deposition along the edges and isolated shallow areas of the channel. These depositional shallow areas are supporting newly emerged seagrass beds (Silberstein pers com). However because eight years have passed since the last survey, it is difficult to determine if there has been any change in the erosion rates in the Elkhorn Slough. In the future, using the 2001 high resolution data collected for this project as a base map, it will be possible to accurately monitor the rate of erosive change on a yearly basis, and there by track the sloughs progress towards equilibrium.

Acknowledgements

I would like to thank and express my sincerest appreciation to the many people that devoted their time and effort in helping complete this project. I would like to specifically thank Rikk Kvitek, Pat Iampietro, and Kate Thomas for their patience and support.

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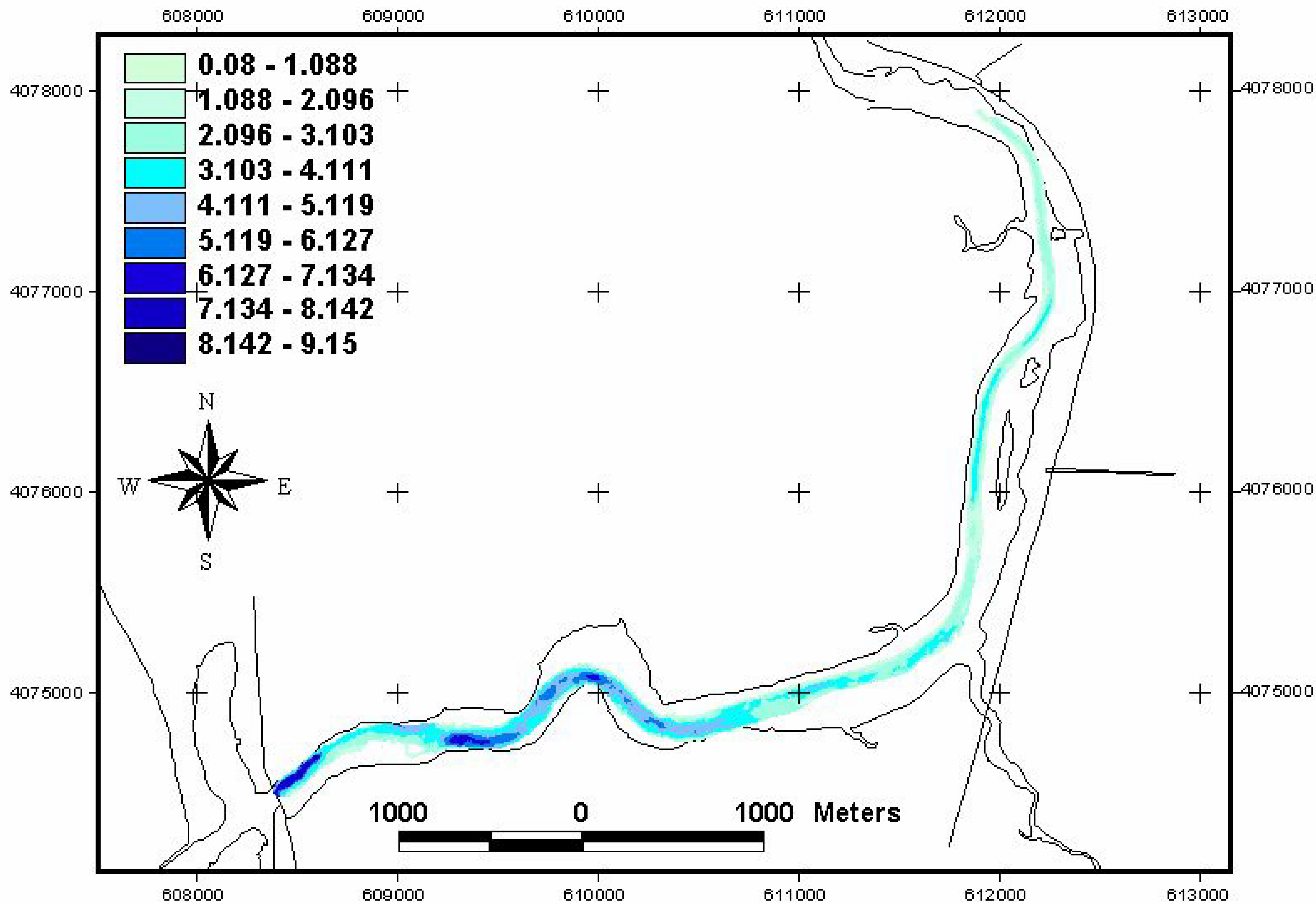
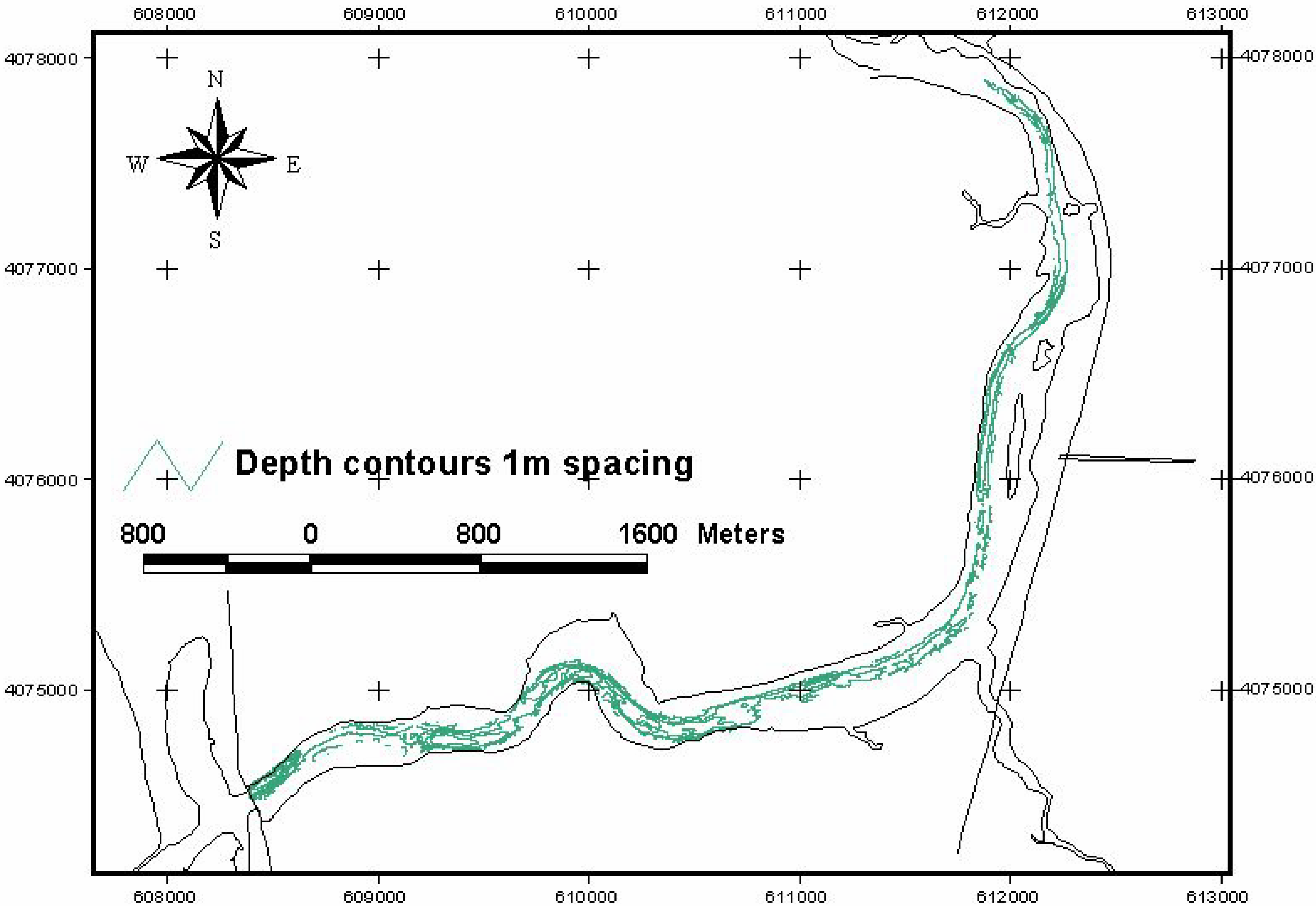


Figure 9. Elkhorn Slough showing bathymetric depths surveyed April 17, 2001. All depths are in meters below MLLW.



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