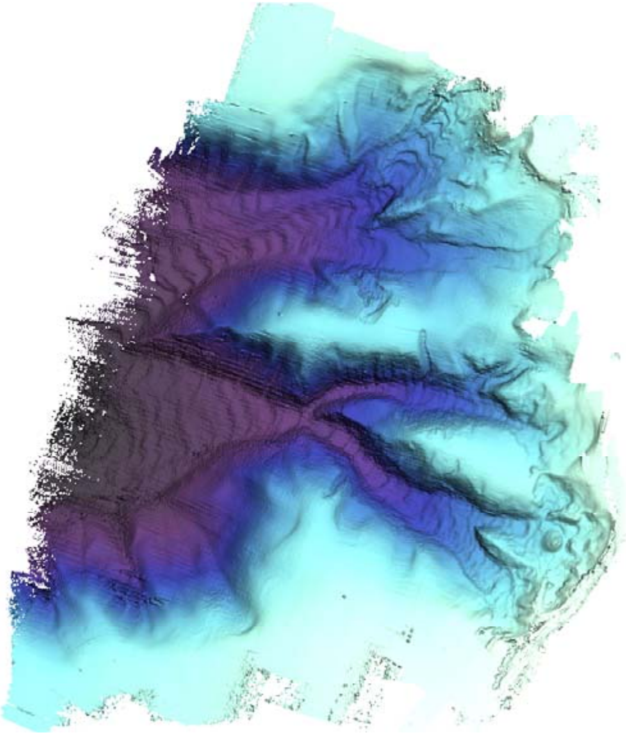
An understanding of the general geomorphology and processes occurring in the Monterey Bay Submarine Canyon



A Capstone Project
Presented to the Faculty of Earth Systems Science and Policy
In the
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At
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In Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science
By
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ESSP Faculty,

Science is the constant task of trying to understand the complexities and patterns of earth's intricate systems. A comprehension of the earth's natural processes and cycles allows scientists to synchronize anthropogenic activity with climatic activity. The Moss Landing harbor, which sits above the head of the Monterey Bay Canyon, is a prime example of the need to understand earth's cycles. Since the construction of the harbor in 1946 an eminent need for dredging of the mud and sediment that buries the harbor has existed. If the harbor was never constructed or had been fully completed to prevent the need of dredging in the harbor, the sediment would just flow into the canyon. Instead, the dredge fills the harbor creating costly problems for the Moss Landing District because it is considered toxic according to EPA standards preventing it from being dumped directly down the canyon. Many environmentalists and scientists alike believe that the dumping of toxic substances is never a solution and that other means of removal should be used on the dredge. The scientists at Moss Landing Marine Labs (MLML) and Monterey Bay Aquarium Research Institute (MBARI) believe the proximity of the canyon, the presence of colonizing benthic communities, and sediment-flushing events make the Monterey Bay a perfect candidate for dredging.

The scientists at MLML are currently working on a risk assessment plan for the harbor to determine the best method of disposal for dredge material. A detailed map displaying the bathymetry of the head of the Monterey Bay Seafloor Canyon is needed by the scientists at MLML. As part of my capstone project, I will be classifying the morphology and determining the effects of seasonal flushing events at the head of the Monterey Bay Canyon, looking for evidence of the presence of dams of sediment along the axis and determining the volume of sediment lost.

This information is intended for John Oliver at MLML, the officials of the Moss Landing Harbor, and other scientist in the Monterey Bay area interested or currently researching in the canyon. Basically there are three options; dumping the dredge into the canyon, drying it out and putting it into landfills, or detoxifying it. Filling the landfills with the toxic material is not advantageous given the cost associated and the current need to create fewer landfills. Several agencies and organizations are interested in the final outcome of the project being conducted at MLML including the EPA, California Department of Fish and Game, National Oceanographic and Atmospheric Administration, Save our Shores, and more. As of now, the EPA has the final say and with the recent 6% budget cut it may be even longer before the problem is dealt with.

I chose this project because I wanted to conduct a Capstone in the area of sea floor mapping. I had no idea the extent of the project or amazing opportunity I was given. The detailed images of the Monterey Bay Submarine Canyon created in this capstone are important to the scientific community in ways unknown to the younger scientific community raised with advanced technology. My knowledge of the Monterey Bay Submarine Canyon began with an image of its topography without an understanding of its processes as opposed to scientists who studied the processes occurring without knowing what the seafloor looked like. For the scientists who devoted a part of their lives to understanding the morphology of the canyon, the bathymetric images of the canyon were incredible and absolutely amazing.

This capstone will address my application of knowledge in the physical sciences (MLO #3) and the acquisition, display, and analysis of quantitative data (MLO #5). For

MLO #3 my general research question pertains to the seasonal fluctuations of buildup that affect the disturbance tolerant benthic community of the Monterey Bay submarine seafloor canyon. Answering this question will require a substantial amount of research and synthesizing of data in the areas of geology, mass-flushing events, submarine canyons, and sedimentation. In addition, I will be using and integrating data and results obtained from many scientist and students studying the Monterey Bay Submarine Canyon. For MLO #5 my specific research question pertains to the overall morphology of the canyon and the effects of seasonal changes. High-resolution maps, 3D models, and images will be created using technology such as Caris 8.1, ArcMap, and Fledermaus designed to aid in the assessment of the benthic communities addressed in MLO #3.

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Abstract- The head of the Monterey Submarine Canyon experiences seasonal flushing events that are hypothesized to cause large amounts of sediment settled in axis along the bottom to be moved downslope. It is believed that these dams of sediment formed along the axes of the canyon head create a habitat for a unique benthic community endemic to the sediment and debris. The magnitude of sediment transported from the head of the canyon into the deep canyon remains unknown. More information regarding the occurrence and quantitative effects of seasonal flushing events is needed to assess the risks and benefits associated with dumping dredge material into the Monterey Bay Canyon. The goals of the project proposed here are to: 1) characterize the geomorphology of the headward portion of the Monterey Submarine Canyon, 2) look for evidence consistent with the hypothesis that natural dams form before and are then lost during the winter storm season, and 3) quantify the magnitude of geomorphic changes in the canyon head between pre- and post-storm season periods. Multibeam bathymetry data was used to create pre- and post-storm, high-resolution (2-4 m horizontal posting) digital elevation models (DEMs) to detect and quantify the magnitude of these predicted sediment movement patterns. The bathymetric images of the canyon revealed detail regarding the canyon's morphology never before seen. Presence of features such as slumps and an abandoned canyon channel are evidence of active sedimentation and erosion. A large amount of sediment was moved down canyon as a result of seasonal flushing events. Both current and tidal movements dictate sediment movement in the head of the canyon.

Introduction

Currently, the Monterey Bay is the largest of the National Marine Sanctuaries (Fig. 1). It is home to one of the largest and deepest submarine canyons on the West Coast of North America. The Monterey Bay National Marine Sanctuary (MBNMS), established in 1992, protects an ecosystem that provides valuable goods and services. The purpose of such sanctuaries is to protect and preserve environments that hold special public interest so that future generations may also enjoy the unique attributes of these areas, many of which like MBNMS are still relatively close to their 'natural' condition (Eittreim, 2002). Many agencies oversee the MBNMS including the Monterey Bay Aquarium Research Institute (MBARI), National Oceanographic and Atmospheric Administration (NOAA), the Army Corps of Engineers, the Environmental Protection Agency (EPA), the California Department of Fish and Game, Moss Landing Marine Labs (MLML), Save our Shores, the Elkhorn Slough Foundation, the County of Monterey Bay, and California State University Monterey Bay (CSUMB). One goal of all these agencies and institutions is to develop a better understanding of the MBNMS environment. According to Eittreim (2002), an understanding of the region's ecosystems and how they function is fundamental to effective stewardship of the sanctuary. The need for a good description of the seafloor composition and morphology is important for building such an understanding. Information regarding the ecosystem of Monterey Bay Submarine Canyon will aid these agencies in making informed and educated decisions regarding policies and regulations designed to protect the bay.

Figure 1 MBNMS extends from Cambria to Marin.

The MBNMS encompasses some of most spectacular morphology and complex geography in the world. Within the Monterey Bay region lies an extensive submarine canyon system; the Ascension-Monterey canyon system that includes the large and active Monterey Canyon and five other major canyons. Monterey Canyon, however, is the keystone feature (Greene, 2003; Fig. 2). The Monterey Canyon is considered one of the most active submarine canyons in the world because of the amount of sediment it transports from the land to the ocean. A further understanding of the general morphology and the rates of sediment movement of the canyon are still needed. The images of the Monterey Bay Canyon provided by MBARI do not provide enough detail to allow scientist to fully understand the processes occurring in the canyon. High-resolution images (<5m) are crucial to effectively conduct scientific experiments, identify processes occurring in the canyon, and visually interpret the general morphology of the canyon.

Scientific and residential communities alike are affected by the local agricultural fields producing excess sediment, pesticides, and unused nutrients that drain into the Sanctuary that provides aesthetic value, food for consumption, and revenue from tourism. Bathymetric images collected at different time periods, pre- and post-storms, are valuable in understanding the changes in morphology and rates of sediment transport. An interpretation of the general morphology of the Monterey Bay Submarine Canyon and an understanding of how sediment moves down the canyon will aid scientists and the Moss Landing Harbor District in deciding the best method of dredge disposal (Oliver, 2002).

Formation of Monterey Bay Canyon

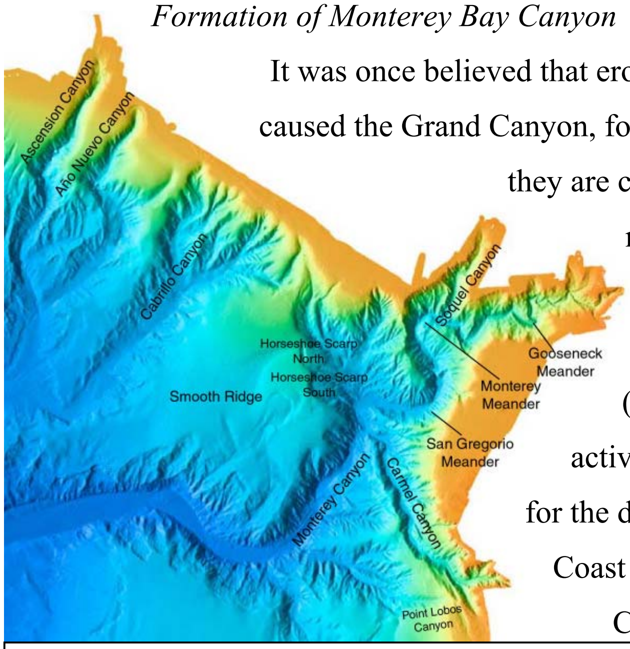

Figure 2 Bathymetric image of Ascension-Monterey Canyon System

It was once believed that eroding rivers, similar to the process that caused the Grand Canyon, formed the Monterey Bay Canyon since they are comparable in length, height, and morphology. The deep marine and terrestrial environments are in many ways morphologically comparable (Allen, 1984). However, tectonic activity associated with the bay is responsible for the deepest and largest canyon on the West Coast of North America. The Monterey Canyon is part of the Ascension-Monterey Canyon System, which includes the Ascension, Ano Nuevo, Cabrillo, Soquel, and Carmel Canyons (Fig. 2). The canyon began forming about 20-30 million years ago from fault-bounded mountain ranges that existed at the head of the canyon, which sits between the Pacific and North American Plates. Subduction of the Pacific Plate under the North American Plate created the Sierrra Nevada granite which then moved north along the San Andreas fault where it lies today on the Monterey Peninsula (Greene, 2003). The beginning of the canyon was formed by a fault extending east to west, which began eroding and formed a channel where massive amounts of sediment from the head of the bay and chunks of material from the wall flowed through the canyon as a result of tidal currents and tectonic activity. This process, created turbidity currents, which scoured the canyon seafloor and increased the magnitude of the canyon (Packard, 1997). The superficial geology and morphology of the Monterey bay shelf is a product of shoreline transgression and regression over past millennia (Eittreim et. al., 2002). As the sea level rose and fell, erosion was concentrated in the canyon. Millions of years of tectonic process and tidal action are responsible for the magnitude of the Monterey Bay Canyon (Packard 1997).

Slumping and mass wasting events in the canyon

The Monterey Canyon has been modigied over millions of years by processes such as slumping and mass wasting, which presently occur in the canyon. Mass wasting is prevalent in the MBNMS. Scars left by slumps primarily identify the occurrence of mass wasting and thin sediment flows (Greene et. al., 2002). Active fault movement and earthquakes stimulate mass wasting and sediment transport in the form of turbidity currents down submarine canyons and the continental slope (Greene et. al., 2002). Through prolonged dilution with seawater, slumps and debris flows create turbidity currents regarded as primarily responsible for submarine canyons and channeled deep-sea fans (Allen, 1986). Massive amounts of sediment, debris, and organic material consistently wash down continental slopes and shelves: the extent and impact of this mass wasting is dependent on morphology and events.

Meanders in the Canyon

The Monterey Canyon meanders several times before reaching the abyssal plain. A combination of tectonic activity, turbidity flows, and physical structure is responsible for these meanders. Paths along the faults and past the leading edge of granite outcrops provide the least resistance to turbidity current erosion forming meanders; in the Monterey Canyon, meanders appear to be formed structurally or by slumping which alter the channel path (Greene et. al., 2002). The presence of meanders signifies a decrease in the flow rate of sediment from the canyon head into the abyssal plain. Meanders in the upper canyon parallel the Monterey Bay Fault Zone that runs through the axis of the canyon (Greene, 1990). The headward portion of the canyon contains Aromas sand, Purisima Formation, fluvial deposits, marine sediment and landslide deposits (Fig. 3).

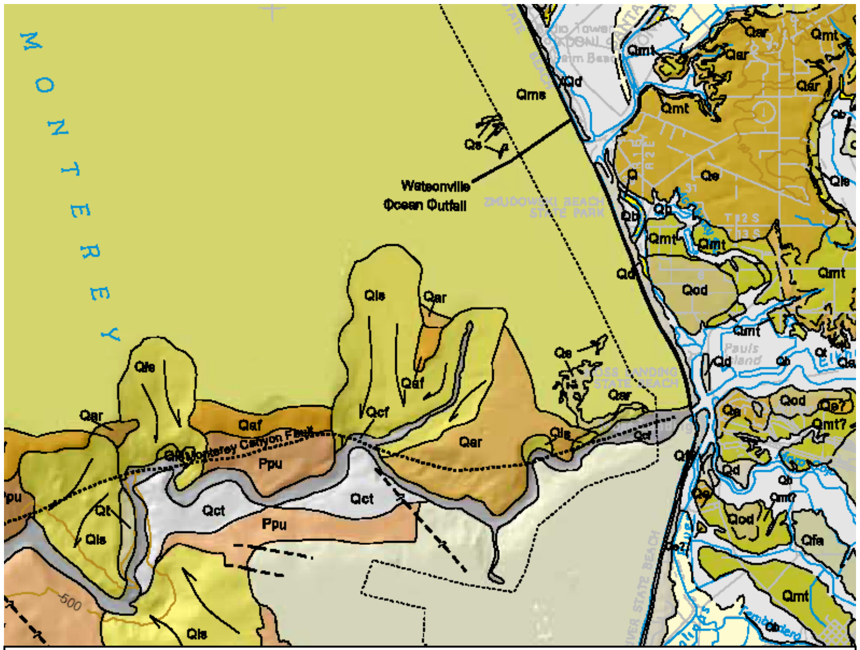

Figure 3 Geologic map of the Monterey Bay Canyon. (Greene et. al., 2000)

Current processes occurring in the canyon head

Many different tectonic and sedimentary processes are currently shaping the seafloor within the central part of the MBNMS (Greene et. al., 2002). Sediment entering at the head of the canyon is a product of active littoral cells, runoff from agricultural fields, erosion from tidal effects, and dredge material. Sediment not derived from the head of canyon that contributes to its morphology and rate of sediment movement is a product of tectonic activity, slumping, mass wasting, turbidity currents, and seasonal storm activity. Overall, the activity of the Monterey Bay Canyon is characterized by the down-canyon transport of terrestrial-derived sediment and erosion of canyon walls (Greene et. al., 2002).

The location of a canyon head is critical to the interception of sediment transported by longshore currents (Greene et. al., 2002). The Monterey Canyon is no exception as its upper channel is filling up with sediment derived from active littoral cells, which connect to the canyon's head (Paull et. al., 2003). The huge volumes of sediment that accumulate on deep-sea fans attest to the importance of submarine canyons as major sediment transport conduits (Paull et. al., 2002). According to Paull et. al. (2003), distinct sediment lithologies occur in the canyon's flank, axial channel, and upper edge. The variable lithology of the canyon axis includes sand, pebbles, gravel, cohesive clay-casts, and plant fragments in the shallower depths. The lithologies of the flanks consist primarily of clay and are covered with a thin layer of silt and sand. The lithology of the canyon's edge consists of rocky outcrops thickly layered with sand and poorly silted clay (Paull et. al., 2003). This means that the sediment flowing through the canyon is not primarily derived from the flanks of neither the upper edge nor the sides of the canyon. Monterey Canyon is filled with a trail of high-energy deposits, similar to those found along the beaches of Monterey Bay, that extend down through the canyon from the beach and near shore sediment system (Paull et. al., 2003).

Figure 4 Image of the Monterey Bay; (A) Portion of Monterey Canyon surveyed.

The Monterey Canyon is currently in a depositional rather than an erosional phase. Ongoing erosion of the canyon walls is not currently a major sediment source (Paull et. al., 2002). Slumping of the canyon walls however is a form of erosion present in the Monterey Bay and a source of sediment within the canyon. Several factors and processes dictate the rate at which sediment flows into the abyssal plain. Meanders cause the head of the canyon to act as a reservoir of sediments waiting for a high-energy event to transport the sediment into the abyssal plain. In the depths of 100-200m, patterns of sediment and water movement are complex and often seasonally dependent (Allen, 1986). The magnitude and timing of sediment transport is dictated by the episodic nature of storm activity (Storlazzi, 2000). According to Okey (1997), during the first onshore storm of the fall/winter season large amounts of sediment along the axis may be removed from the head of the Monterey Submarine Canyon. In this scenario, flushing events are followed by accumulations of sediment and organic debris in the shallow axis. Net accumulation of this fill material increases during the calmer spring and summer until the next fall-flushing (Okey, 1997).

The benthic community at a canyon axis is very different from benthic communities where sudden flushing does not occur such as the sides and the flanks of the canyon (Okey, 1997). Okey (1997) also found that benthic communities not affected by seasonal flushing harbored more and longer-living species, larger individuals, and a less-variable population structure. Little is known about the benthic community found at the canyon axis, which is affected by sediment build-up and seasonal flushing events.

Influence of Elkhorn Slough

Almost 100 years ago, the Elkhorn Slough was connected to the ocean via the Salinas River. In 1908, the Salinas River was modified so that it ran straight into the ocean instead of meeting up with the Elkhorn Slough. Then in 1946, the entrance to the Elkhorn Slough was moved southward when the U.S. Army Corps of Engineers initiated the construction of the Moss Landing Harbor (Fig. 5). The Elkhorn Slough drains a 2,500 acre watershed, which carries excess sediment, contaminants, and mud into Moss Landing Harbor. The only way to rid the harbor of the excess sediment is by dredging it. In the 50 years since the entrance of Elkhorn Slough was modified to allow tidal action to affect the slough, it is clear that the main channel has continued to erode significantly (Brantner, 2001). The Monterey Bay Submarine Canyon starts near the mouth of the Elkhorn Slough at the center of Monterey Bay. The Slough is eroding and losing sediment at rates higher than normal due to tidal currents and increased exposure (Brantner, 2001). Erosion from the slough flows directly into the canyon adding to the sediment from the littoral cell. This non-oceanic debris and sediment flows into the canyon forming what are believed to be natural dams of sediment perpendicular to the canyon axis that undergo seasonal flushing events (Okey, 1997).

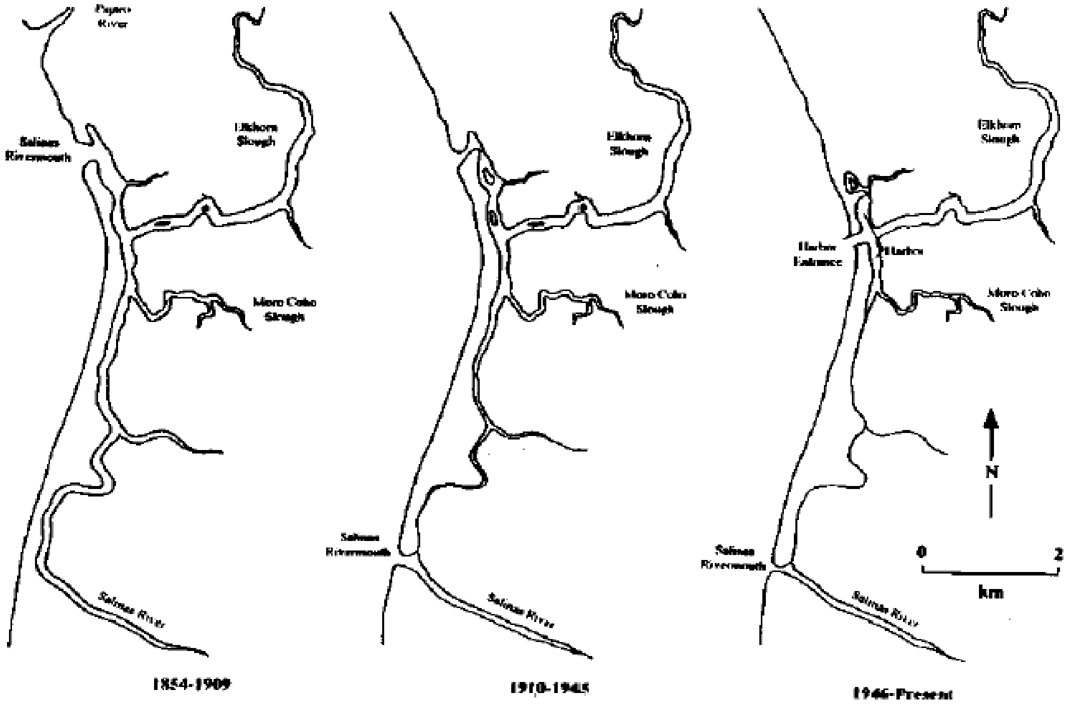

Figure 5 Historic physiographic changes to the Elkhorn Slough illustrating modifications to the flow of the Salinas River and the opening of the Moss Landing Harbor entrance (Crampton, 1994)

Dredging of DDTr rich sediments

DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane) is a pesticide that was used in agricultural fields. DDTr is the combination of DDT and its decaying products. It is transported into the ocean and down the canyon by fine sediments. A distinct trail of pesticide residue is found in the axis of Monterey Canyon (Paull et. al., 2002). A study conducted in 2002 by Paull estimated the amounts of DDTr in parts per billion (ppb) at various locations in the Monterey Bay: the coast has approximately 155 ppb, 65 ppb in the harbor, 80 ppb in dredged material, and 15 ppb off shore. DDTr contents in surface sediments changed little with water depth along the canyon axis, indicating nominal 'dilution' with newly eroded (DDTr-free) sediments from the canyon walls in recent times (Paull et. al., 2002).

There is currently a growing debate over the dredging of Moss Landing, an artificial harbor that was never completed. In the past, excess sediment and debris were disposed of near the canyon head eventually settling in the deep sea. Based on EPA standards, some of the dredge spoils are contaminated beyond acceptable levels therefore preventing them from being dumped into the ocean. Also, the Sanctuary has regulations against the disposal of dredge via the ocean. According to conversations with Linda Horning, the Harbormaster for Moss Landing Harbor, the district is required to conduct extensive and costly testing for contaminants. Permits for ocean disposal of dredged materials that do not meet EPA and Regional Water Quality Control Board standards are not issued. Permits are issued based on the findings of consultants and agencies. Contaminated dredged material can only be removed if the District has an upland handling and disposal site. Unfortunately, the costs of upland disposal are sometimes double or triple the costs of dredging (Oliver, 2002). During a dredging episode following the '95 and '98 floods, there were unacceptable levels of contaminants in some of the dredged material. The District was given permission to use its own property to spread the material for drying and truck it to a waste management site provided that the drying site was turned into a native species habitat once the projected reached completion (Horning, 2003).

In the past 2 years, the Harbor was dredged once, commencing March 6 and ending March 13, 2003 (Hall, 2003). 12,380 cubic meters of material were dredged from the harbor (Hall, 2003). The dredge disposal site is located approximately 15 meters offshore near the end of the MLML ocean pier, south of the harbor jetties. Local scientists believe that the close proximity of the deep canyon, in addition to the seasonal flushing events it experiences, make it a candidate for the disposal of dredge material into the canyon (Oliver, 2001). The scientists at MLML are currently working on a risk assessment plan requiring the collection of benthic samples from different points around the canyon head to determine the possibility of harmful ecological effects of dredge dumping in the canyon. Oliver believes that the dredge material settles in the head of the Monterey Bay Seafloor Canyon and is "flushed" and dispersed down the canyon into deeper water during the first winter storm. The Moss Landing Harbor is acting as a holding site for toxic sediment that was originally headed toward the deep-sea canyon. By synchronizing anthropogenic activity with nature's cycle, we can provide the least amount of disturbance on the Monterey Bay Submarine Canyon and the benthic community inhabiting it.

Project Purpose

Full coverage of the seafloor with acoustic imagery opens up new possibilities of understanding benthic processes on a small scale (Eittreim et. al., 2001). The purpose of my project was to identify the overall change in the morphology of the head of Monterey Bay Submarine Canyon from 10m to 300m in depth between pre- and post-winter storm activity. My specific goals were to find evidence of sediment "dams" forming across the canyon axis and to quantify how the morphology of the canyon changes following the first storms of winter, which are believed to trigger flushing events and removal of the hypothesized dams. My hypothesis is that there will be a net loss or down slope movement of sediments along the canyon axis between the pre- and post-winter storm conditions.

By determining how much sediment is transported from the canyon head into the deep canyon via seasonal flushing events, questions pertaining to the ecosystem of the canyon can be answered with increased certainty by the scientific community. These questions include: What are the positive and negative effects of using the canyon to dispose of dredge material? Is there a benthic community endemic to the buildup of sediment and debris? What are the effects of sediment accumulation and flushing on this benthic community? What is the best solution for disposing of dredge spoils from Moss Landing Harbor?

A team of professors and graduate students at Moss Landing Marine Labs are currently studying the ecology of benthic communities associated with sediment buildup and seasonal flushing events in an attempt to answer these questions. The bathymetric images that they have are not detailed enough. They were in need of more detailed map to merger with existing maps of the canyon. A detailed high-resolution map will be created using multibeam bathymetry. The maps and models generated by this capstone project will be essential in their efforts to find a solution for Moss Landing Harbor's dredging issues. Detailed maps can also be used to monitor changes that occur in the sanctuary in the future; changes that may be both man-induced and natural (Eittreim, 2001).

General Approach

Bathymetric data of the headward portion (< 300 m in depth) of the Monterey Bay Submarine Canyon was collected on three separate occasions and processed to produce a snapshot of the canyon in unprecedented detail on two separate occasions. Bathymetric data is recorded as x,y,z (latitude, longitude, depth) data points that can be used to generate depth contours and digital elevation models (DEM's) to determine volumes of deposition/erosion, wavelength/height of dams of sediment in the canyon, and the presence of hypothesized morphological features.

Methods

Data Collection

Before data were collected, a series of planned lined files, which guide the R/V during the survey, were created in Hypack. Hypack is a PC based software developed by Coastal Oceanographics, Inc designed for planning, conducting, editing, and publishing hydrographic surveys. These files were used to calculate survey time estimates. The areas mapped in 2002 and 2003 were executed using the same line files.

A DGPD (differential global positioning device), which positions the vessel for multibeam surveys was provided by Trimble 4700 GPS (global positioning system) with differential corrections was provided by Trimble ProBeacon receiver for 2002 surveys. Since the vessel is affected by roll, pitch, heave, heading, tide, and surge, a more precise form of GPS was needed, hence the DGDP. The DGPD uses two receivers, one stationary and another revolving around it, to reduce timing errors to differentially correct for errors inherent in the system. Surveys in 2003 used Trimble 5700 RTK (Real Time Kinematic) for global positioning. To account for motion changes associated with data collection aboard a vessel, pitch, heave, heading, and roll data were recorded using a TSS HDMS heading and motion sensor with a +/_ 0.02 degrees of precision to improve the accuracy of the data.

The head of the Monterey Bay Canyon was mapped aboard the trailerable R/V MacGinitie, the CSUMB research training vessel designed for surveying shallow water habitats, with an overall length of 32 ft. and a hull length of 27 ft. The upper part of the canyon head was first mapped by the SFML on the 29 of June 2000. The head of the canyon, starting from Moss Landing Harbor and extending to 300m was mapped September 30, 2002. Most recently, on the 25 and 26 of March 2003, the same area of the canyon from the September 30 survey was mapped. The dates of collection occurred during the seasons of summer, fall, and spring. The conditions of data collection for 2002 and 2003 were relatively calm with flat seas and low winds.

The hull-mounted Reson 8101 mulitbeam sonar collects bathymetric data measuring the distance from the seafloor to sea level by emitting acoustic beams with 150 degrees of coverage. Dense coverage is achieved utilizing up to 3,000 soundings per second for a swath of up to 7.4 times the water depth. The 8101 has a maximum depth range of 300 meters. The time required for the signals to travel from the transducer to the bottom and back to the receiver is converted into depths based on estimations of speed of sound through the water column, which can be affected by fluctuations in factors such as temperature and salinity. The AML SV+ sound velocity profiler, an instrument that measures variations through the water column, was deployed for later adjustment of depth soundings. All raw data was logged using a Triton-Elics International Isis Sonar data acquisition system, with real-time bathymetry digital telegraphic model (DTM) generation. Survey data collected on the ship was burned onto a CD for post-processing in the lab.

Data Processing

All bathymetric data was processed in the Seafloor Mapping Lab using Caris Hips hydrographic data cleaning software designed for the management and analysis of bathymetric spatial data. Raw data files (.xtf) which contain x,y,z, data, vessel heading, and motion data were imported into the processing software and corrected for the difference in position of the GPS antennae and the sonar head using a vessel configuration file (VCF). The sound velocity profile files were imported into Caris and applied toward x,y,z data. Tide files created from a computer-simulated program predicting tide values were imported into Caris and also applied toward x,y,z data to negate tidal cycle effects. The data were then filtered, merged, cleaned, and examined to insure rejection of false data points and "noise".

To ensure quality assurance and quality control (QAQC), x,y,z data from Caris was imported into Fledermaus, an interactive 3D visualization system that can be used for swath bathymetric editing and exporting grids for use in ArcView. Once data was QAQC'd, 3m resolution grey scale and color tiff images of the Monterey Bay Submarine Canyon survey area were exported from Caris. Based on size, 3 m resolution x,y,z text files could be directly exported from Caris or exported as ASCII raster grid files from Fledermaus. The resolution of 3 meters was used because it offered the best resolution with the least amount of missing data or “holes”.

Data Analysis

To interpret the general morphology of the Monterey Submarine Canyon and the presence of “dams” of sediment down the axis, three-meter resolution raster files and georeferenced tiff files of data collected in 2002 and 2003 were imported into ArcMap 8.1, and used to create a detailed map and images of the head of the canyon. The morphology was also analyzed using images of the canyon generated in Fledermaus. A map identifying morphological features present in the canyon was produced in ArcMap.

To determine sediment erosion and deposition in the Monterey Bay Canyon, I compared the pre-storm 2002 and post-storm 2003 raster images in ArcMap. A raster image is a mosaic of pixels, each with an associated depth (or elevation) value. The spatial analysis function in ArcMap contains a raster calculator that subtracts one raster image from another, pixel by pixel. The 2002 raster image of the canyon was subtracted from the 2003 raster image. Positive values represent a gain in sediment or deposition, and negative values represent a loss in sediment or erosion. I then exported the attribute table containing the change in elevation in meters and the number of pixels with the associated change to determine the volume of deposition and sediment in the canyon.

During the post-storm survey, the data was collected over a two-day period. Each day the headward portion of the canyon to depths of approximately 120 meters was mapped providing a glimpse into the patterns of sediment movement over a 1-day interval. Two raster images, one for data collected on March 25 and another on March 26 were imported into ArcMap. An image containing the shape of the dunes on March 25 was superimposed over the image of the canyon collected on March 26 to determine the direction and trends of shift in sediment in the axis.

Results

General Morphology

The bathymetric images of the Monterey Bay Submarine Canyon provide detailed information regarding its morphology that has never been seen before (Fig. 6 and 7). Features such as slumps and thin sediment flows are identifiable (Fig. 8). The axis of the canyon is lined with sediment dunes. According to Smith (2003), the Monterey Canyon Fault is well expressed.

General processes occurring in the axis

Mass wasting caused by the relatively new slumps on the west side of the canyon buries the dunes downslope. The presence of an abandoned axial channel suggests recent canyon incision and channel straightening perhaps from gradient increase or faulting (Smith, 2003).

Projecting a sun angle from the northeast on an image creates a shadow, which illuminates a bimodal or unidirectional current. The dunes are uni-directional in the channel and bi-directional in the headward portion of the canyon. Dunes with a long back and steep face, found through the trunk of the canyon, are the results of uni-directional current flowing down the axis of the canyon.

Seasonal changes in morphology

An analysis of the change in volume was achieved by interpolating grids from data collected in 2002 and 2003. Sediment erosion is highest along the sides of the channel, in narrow areas, and along bends. Movement of dune crests and troughs can see alternating deposition and erosion in dune fields. A raster image created by subtraction values shows the negative values (orange through purple), which represent erosion, and the positive values (yellow through green), which represent deposition. Deposition is most concentrated in the head outside the Moss Landing Harbor (Fig. 9). There was significantly more sediment eroded for the canyon than deposited as a result of seasonal flushing events. The amount of sediment eroded from the headward portion of canyon surveyed is approximately 1,876,806 cubic meters and the amount of sediment deposited is approximately 436,626 cubic meters.

Short Term Tidal Changes in Morphology

In a 24 hour period, the dunes in the upper canyon were observed migrating up-canyon while the dunes in the lower canyon were observed migrating down-canyon (Fig. 10). The rounded dunes in the upper right and left canyon head indicate a bimodal flow, alternating between ebb and flow (Smith, 2003).

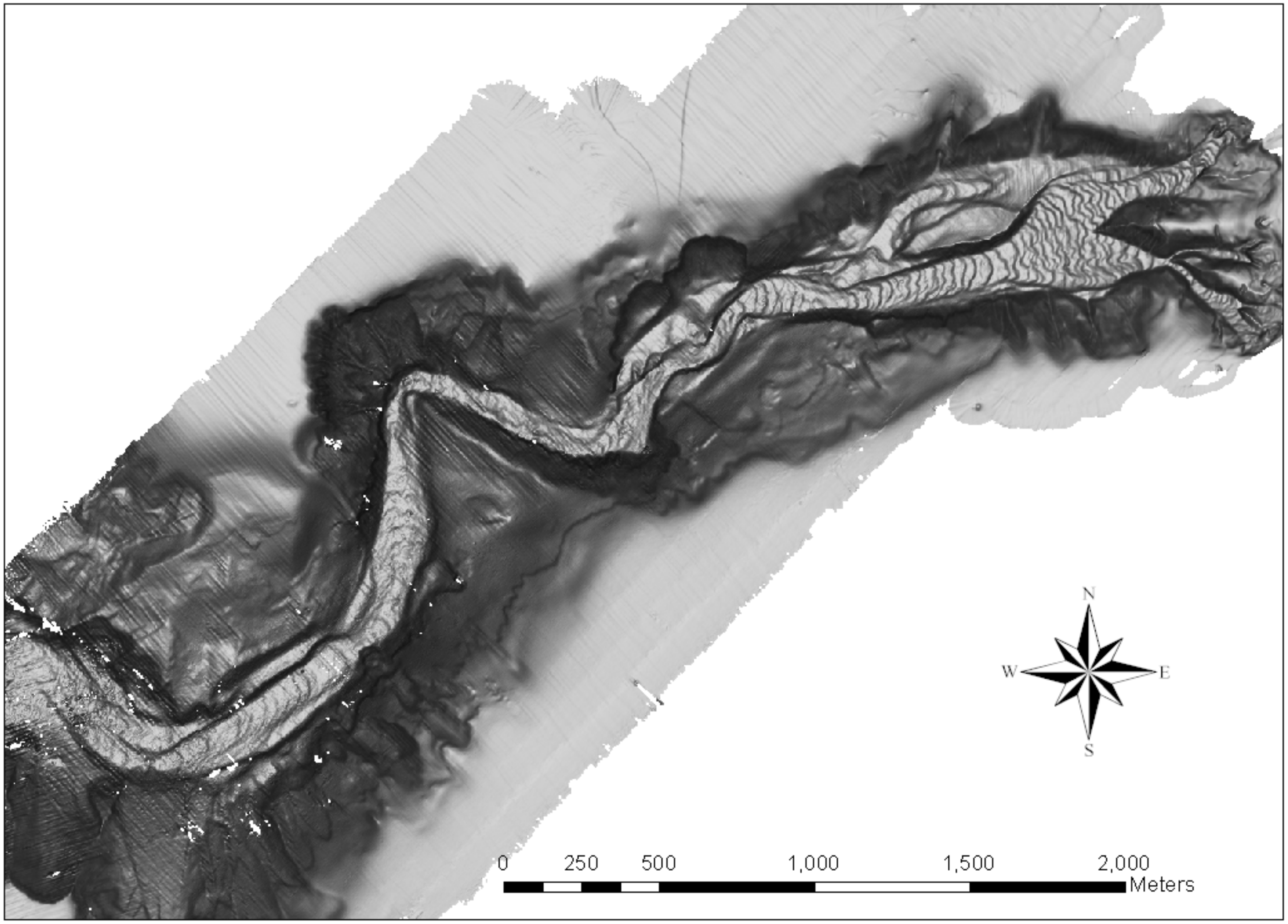

Figure 6 Monterey Bay Submarine Canyon collected in September of 2002. Image is in 3-meter resolution.

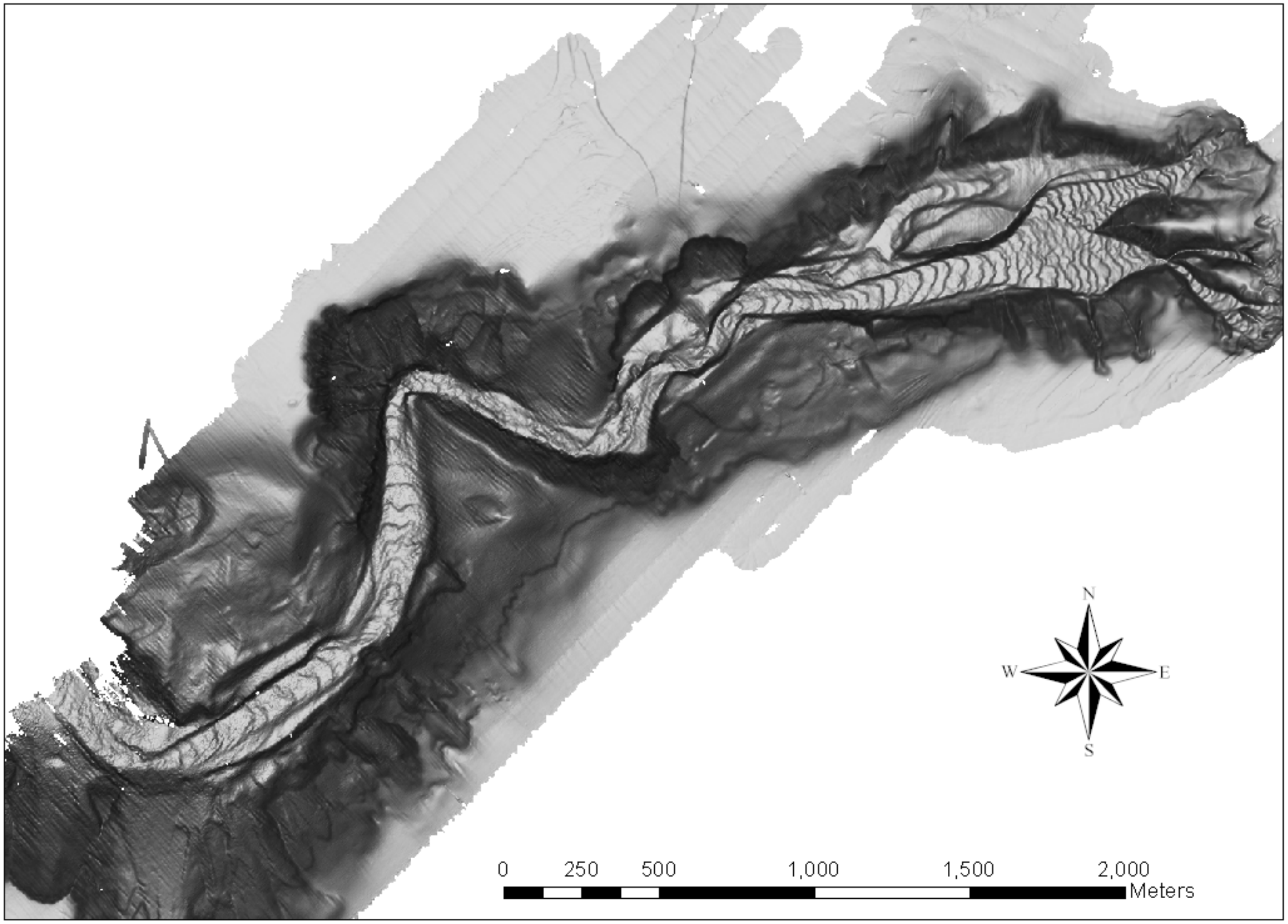

Figure 7 Monterey Bay Submarine Canyon collected in March of 2003. Image is in 3-meter resolution.

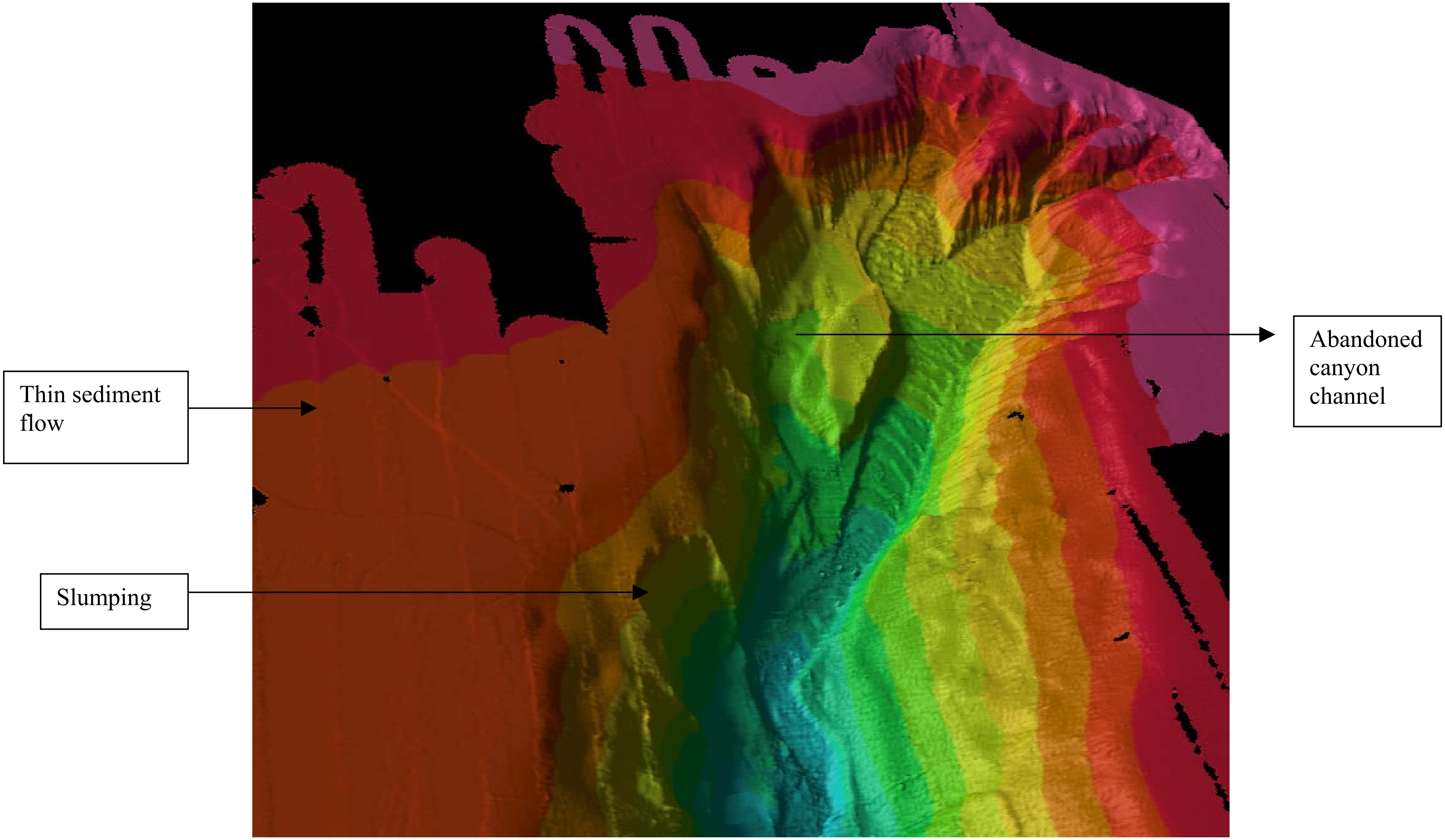

Figure 8 Monterey Bay Submarine Canyon collected in March of 2003. Image is in 3-meter resolution.

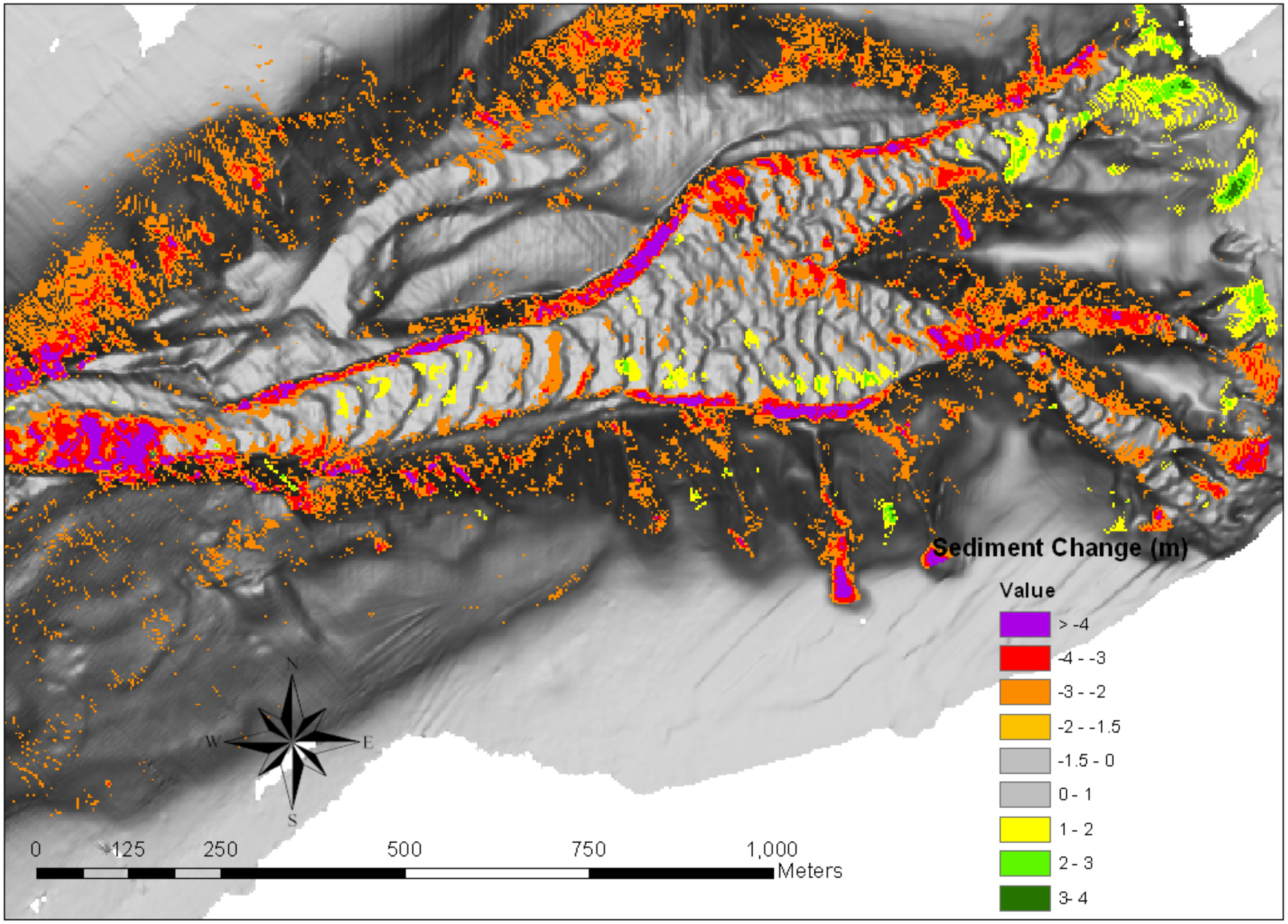

Figure 9 Image of the Monterey Bay Submarine Canyon illustrating change in sediment from September 2002 to March 2003.

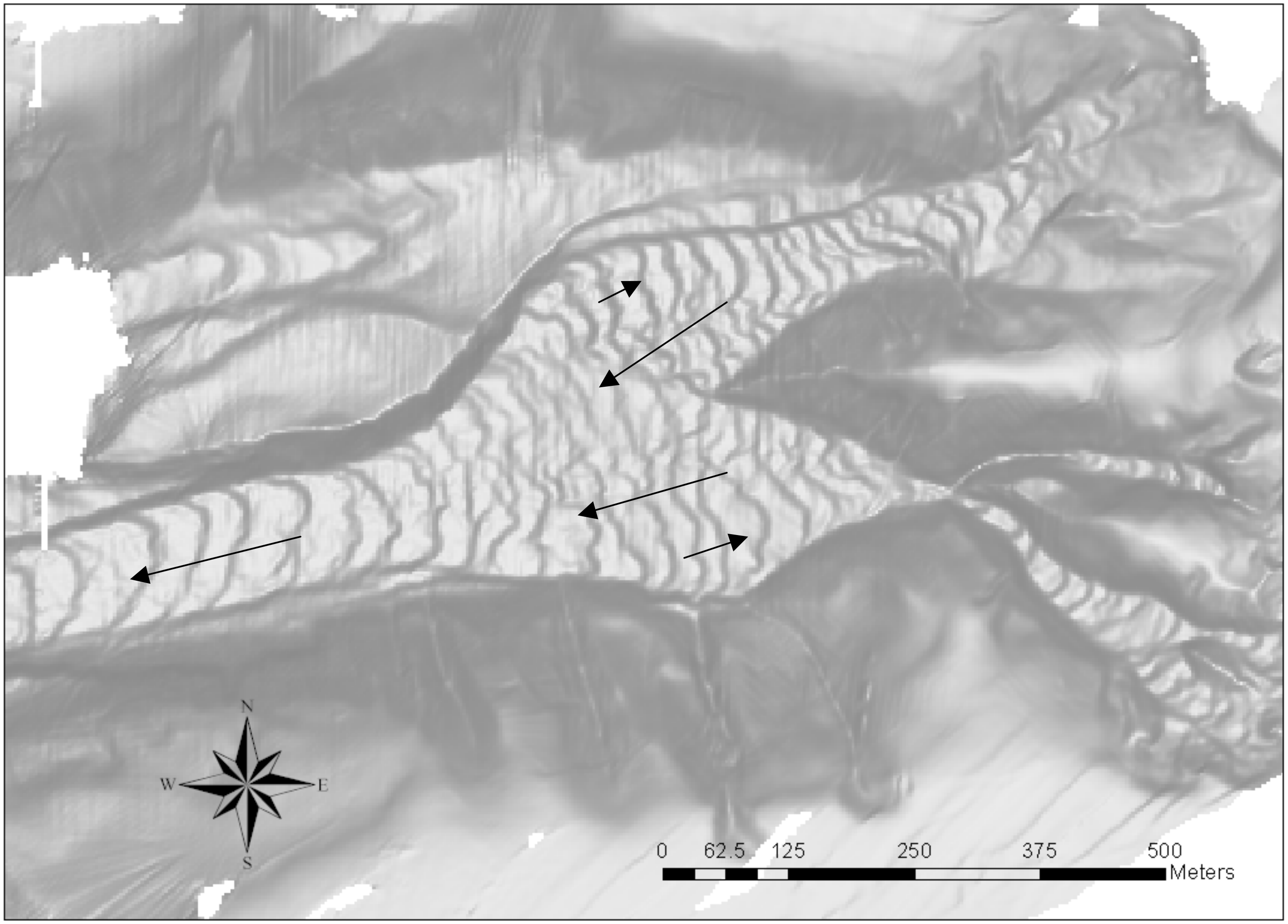

Figure 10 Image of the Monterey Bay Submarine Canyon illustration the direction of sediment change over a one day period.

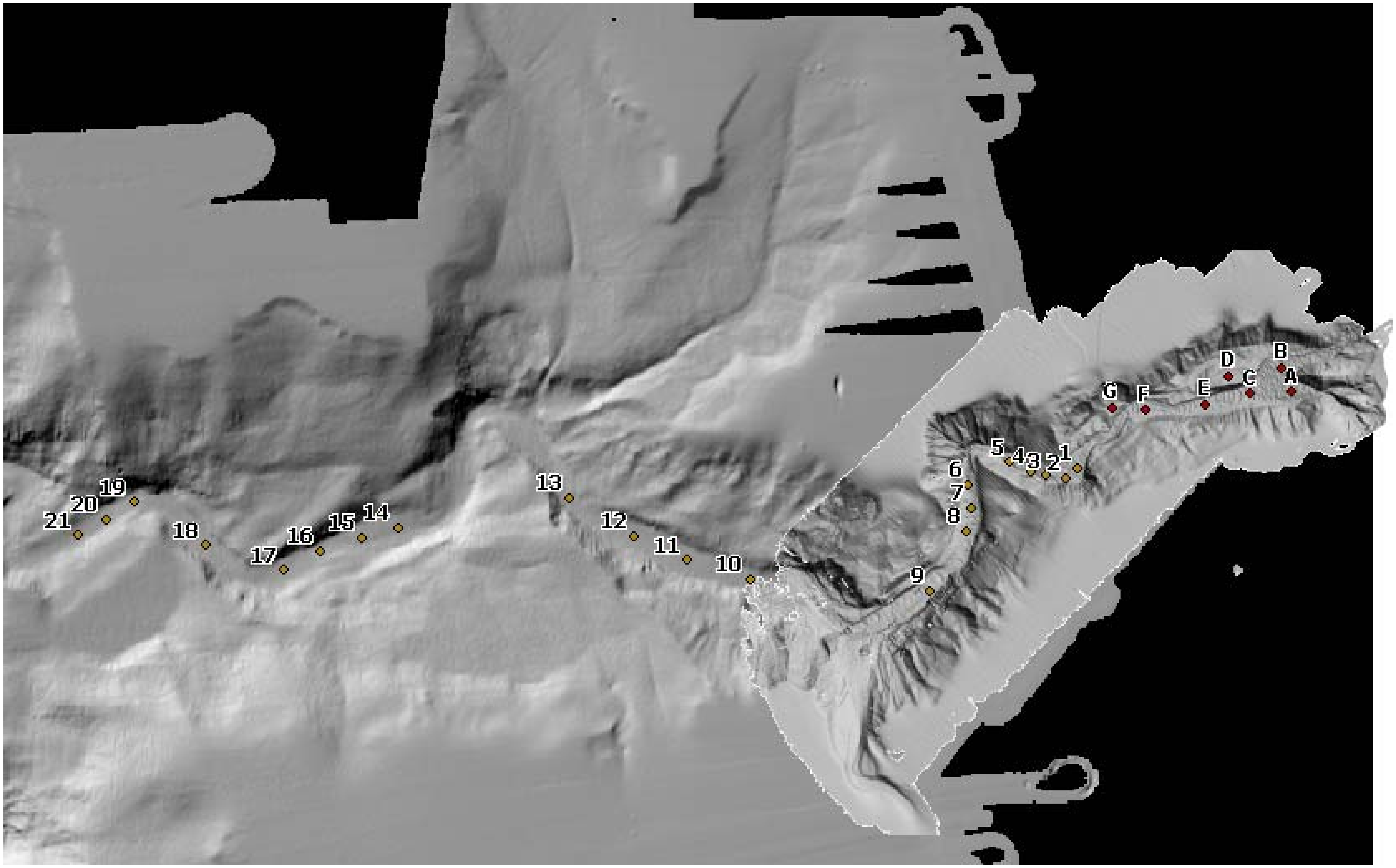

Figure 11 2003 high-resolution image of Monterey Bay Canyon merged with existing bathmetric data by MLML students. Numbers and letters signify stations for benthic sampling along the canyon.

Discussion

The Monterey Canyon experienced a large amount of sediment loss in the axis during the seasonal flushing events. The net trend is a downward movement of sediment. The Moss Landing Harbor was dredged March 6 -13 of 2003, which explains the large amount of sediment deposited at the head of the canyon. The amount of material dredged from the harbor is less than one percent of the calculated amount of sediment lost between September and March.

The morphology of the Monterey Canyon is similar to that of a terrestrial canyon, with an active axis and structure similar to a river canyon system. It appears as though the thin sediment flow is a result of slumping. (Fig. 8)

There are many interpretations of the general morphology of the headward region of the Monterey Bay Submarine Canyon that remain unidentified in this project. Interpreting the morphology beyond keystone features is beyond the scope of this project. Time was another limiting factor in this project.

The images produced for this project are of immeasurable value to the scientific community. This data have many uses. The students as Moss Landing merged the data I collected with existing bathymetric data to aid their benthic invertebrate project. (Fig. 11) The scientists at MBARI already possess the images created in this capstone and are using them to infer sediment movement in the canyon. Before this capstone, the presence of dams of sediment forming perpendicular to the canyon's axis was a hypothesis. Images clearly illustrate the presence of sediment dunes along the axis of the canyon, which are different from dams. The sediment does not flow over the dunes; instead the sediment flows across the flat dunes and over the edge.

The abandoned channel is an indicator of an increased gradient due to increased amounts of sediment in the canyon. If this increase in sediment were proven to be detrimental to the benthic community, which can create a chain reaction in the food chain, the issue of sediment movement would need serious attention. Policies and practices designed to decrease the amount of sediment entering Elkhorn Slough and the Moss Landing Harbor would have to be implemented.

Conclusion

The images produced in this capstone are aiding the scientist at Moss Landing Marine Labs in determining the risk assessment of dredging the harbor. The risk assessment combines research regarding benthic communities and sediment movement in the axis of the Monterey Bay Canyon. The hypothesis for the research regarding benthic communities is that ‘toxic’ dredge, when dumped into the canyon will dilute to concentrations not harmful to benthic communities. The large amount of sediment moved from the canyon during seasonal flushing events means that dredging events could be timed with high-activity events to reduce its impact on the environment. The ‘toxic’ sediment would flow straight into the canyon if the harbor was never constructed.

Since the Elkhorn Slough is eroding and transporting sediment into the Moss Landing Harbor, there is a need for regulation within the slough (Bratner). Tidal erosion and sedimentation within the slough can be decreased by various hydrodynamic engineering solutions which includes building a sill under Highway 1 or constructing shoals, dikes, or channels to slow water movement. Enhancing vegetation and controlling introduced burrowing isopods can decrease rates of erosion. Theses are potential solutions with high costs that will be covered by the taxpayers. The EPA is currently providing grants for watershed management and wetland restoration in the Salinas Valley. This will not solve the dredging problem but it will decrease the amount of contaminants and excess material settling in the harbor (Crampton).

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