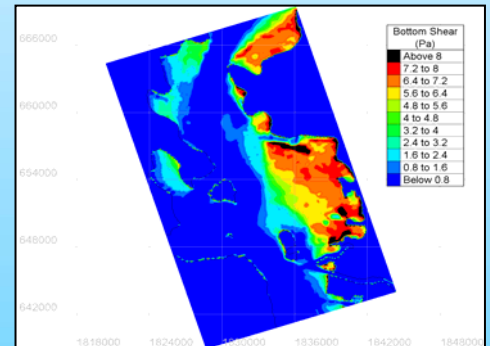


BAYWIDE EELGRASS INVENTORY OF SAN FRANCISCO BAY:

Pre-survey Screening Model and
Eelgrass Survey Report

October 2004



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by Caltrans



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with NOAA Fisheries



The Baywide Eelgrass Inventory and Habitat Management Research Program is being undertaken as a joint effort of the California Department of Transportation (Caltrans) and National Marine Fisheries Service (NOAA Fisheries). The project is fully funded by Caltrans as one element of the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project environmental mitigation. The purpose of this program is to support the advancement of eelgrass management science and policy within San Francisco Bay by providing essential information on the distribution, abundance, characteristics, and environmental controls of eelgrass within the Bay.

San Francisco – Oakland Bay Bridge East Span Seismic Safety Project

Baywide Eelgrass (*Zostera marina* L.) Inventory in San Francisco Bay: Pre-survey Screening Model and Eelgrass Survey Report



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BACKGROUND

As an element of the environmental mitigation required to compensate for impacts to eelgrass habitat from the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (East Span Project), the California Department of Transportation (Caltrans) has committed to funding a Baywide Eelgrass Inventory and Resource Management Research Program (program). Construction activities for the East Span Project will impact eelgrass habitats as a result of both the permanent bridge footprint and shading effects as well as temporary construction activities. In order to mitigate these impacts, Caltrans has been required to undertake a multi-element mitigation program that includes habitat restoration on-site and off-site as well as a commitment to fund the present \$1 million eelgrass inventory and resource management research effort. The National Marine Fisheries Service (NOAA Fisheries) identified the need to improve the understanding of eelgrass habitats and subtidal habitats within San Francisco Bay (Bay) for management purposes. As a result, the option to fund the present project as part of the mitigation program was suggested to Caltrans. Caltrans and NOAA Fisheries jointly hold the management responsibility over the inventory and research program. In addition, the NOAA Fisheries Southwest Region and the Restoration Center have provided technical guidance and assistance in data collection.

This program is intended to identify and map existing eelgrass beds and identify conditions under which eelgrass can occur throughout the Bay. In addition, the program is designed to document eelgrass resource benefits, identify current eelgrass stressors, and outline opportunities for enhancement of eelgrass communities within the Estuary. The results of the program will facilitate management of eelgrass habitat resources in the Bay by providing additional information on the status, distribution, growth limiting factors, and ecological benefits of eelgrass within this highly dynamic ecosystem.

This program will add to the resource management goals that were developed for the San Francisco Bay Area Wetlands Ecosystem Goals Project. The Goals Project (1999) was created by scientists and resource managers as a guide for restoring and improving the habitats in San Francisco Bay (for the purposes of the current report, the term “Bay” has been used to describe the entire Estuary). While the Goals Project was a major advancement in developing a cohesive strategy for sustaining diverse and healthy ecosystems in the Bay, it focused principally on “baylands” (lands within boundaries of the tides) and not subtidal marine habitats. In fact, eelgrass beds were the only subtidal habitat for which any management recommendations were made in the Goals Project. While the Goals Project provided general management goals for eelgrass, these were not developed to the extent that goals were developed for baylands. Due to a lack of well-defined goals for subtidal habitats, NOAA Fisheries along with other resource and regulatory agency partners are developing the subtidal habitat goals for the Estuary that will complement the baylands Goals Project. The present eelgrass program is anticipated to substantially support the subtidal habitat goals effort either as a critical reference, or a major component of the work.

Some of the major challenges facing the development of subtidal habitat goals for the San Francisco Estuary include the general lack of information on the extent, distribution, persistence and even the values of the Bay’s subtidal habitats over spatial and temporal scales. Absent an understanding of the habitat resources to be managed, it is not possible to effectively implement management measures that result in enhancements to the ecosystem. Although the Goals Project identified approximately 8,100 hectares (20,000 acres) of deep and shallow bay habitats that have been lost since the 1800’s as a result of bay fill and sediment deposition, the relationship of these losses to eelgrass habitat remains largely unknown.

A large-scale survey of eelgrass in San Francisco Bay was completed over 15 years ago in 1987 (Wyllie-Echeverria and Rutten 1989) and, due to the advances in survey technology over the past decade, more accurate surveys and mapping are now possible. In addition, while previous studies have addressed environmental factors such as light on the growth of eelgrass in the Estuary (Zimmerman et al 1991 and 1995), the multiple and complex environmental factors that influence eelgrass distribution are not well documented. For these reasons, a Baywide survey of eelgrass will fill in the information gap much-needed to preserve this critical biological resource.

EELGRASS INVENTORY AND PREDICTIVE HABITAT MODELING GOALS

The goals of this program element are to conduct a comprehensive baywide eelgrass survey, to classify existing beds by environmental characteristics, and to provide a model of predictive physical environmental characteristics for eelgrass in the Bay. In order to accomplish these goals, the following major tasks will be completed: 1) perform pre-survey screening of San Francisco Bay; 2) collect data on the distribution and physical parameters of existing eelgrass beds using aerial and acoustic survey techniques; 3) collect data on the genetic characteristics of the eelgrass beds; and 4) analyze and model the physical environmental characteristics governing eelgrass bed distribution throughout the Bay. This report documents the development and application of a pre-survey screening model to identify areas within which eelgrass surveys are required and the results of eelgrass surveys completed during the summer and early fall of 2003. In order to complete a predictive eelgrass model for San Francisco Bay, future work will involve applying the results of the 2003 eelgrass survey to the pre-survey screening model and classifying existing eelgrass habitats based on their environmental conditions.

EELGRASS RESOURCES

Eelgrass (*Zostera marina* L.) is the most widely distributed marine angiosperm in the Northern Hemisphere (den Hartog 1970). It is a native plant indigenous to the soft-bottom bays and estuaries of the Northern Hemisphere and occurs along the Pacific coast of North America from the Bering Straits down to lower Baja California. Eelgrass is considered to be a habitat forming species that creates unique biological environments when it occurs in the forms of submerged or intertidal aquatic beds or larger meadows. As submerged aquatic beds, eelgrass is given special status under the Clean Water Act, 1972 (as amended), Section 404(b)(1), "Guidelines for Specification of Disposal Sites for Dredged or Fill Material," Subpart E, "Potential Impacts on Special Aquatic Sites."

Eelgrass beds are important ecological communities of shallow bays and estuaries because of the multiple biological values that they provide. Eelgrass is a major source of primary production in nearshore marine systems, supplying the base of detrital-based food webs. In addition, several organisms directly graze upon it, thus contributing to the system at multiple trophic levels. For example, eelgrass is particularly important to certain waterbirds that feed directly on the plants (Susan Wainwright personal communication, Keith Merkel personal observation), as well as a number of species that make a diet of both the eelgrass plants and the epiphytic growth that occurs on the leaf tissues. Eelgrass beds are also a source of secondary production and can have up to 15% greater secondary production (Heck *et al.* 1995) and greater species richness (Orth *et al.* 1984, Zieman and Zieman 1989) than mudflats, sandflats, and marshes. They function as habitat and nursery areas for commercially and recreationally important open ocean marine fish and invertebrates, and provide critical structural environments for resident bay and estuarine species (Hoffman 1986). Eelgrass beds provide habitat for juvenile fish (Hoffman 1986), including juvenile salmon in the Pacific Northwest (Simenstad 1994). In addition to habitat and resource provisions, eelgrass also traps and removes suspended particulates, improving water clarity, tends to reduce

erosion by stabilizing the sediment (Ward *et al.* 1984), cycles nutrients, and generates oxygen during daylight hours.

Not only does eelgrass provide high intrinsic values as a habitat but also it can be an indicator of estuarine health because it responds to environmental factors by changing in distribution and abundance (Thom *et al.* 1998, Hovel 2003, Merkel 1992, 1997, 2000, 2003a and 2003b). Eelgrass is adapted to a wide range of tolerances and is capable of "averaging" exposure conditions including temperature, turbidity, seasonal light levels, sedimentation rates, etc., to result in either positive growth or a gradual decline in the resource.

There are a number of factors that can influence the distribution of eelgrass, including light regime, substrate type, water temperature, and hydrodynamics of the environment (Biebl and McRoy 1971, Backman and Barilotti 1976, Williams and McRoy 1982, Fonseca *et al.* 1983, Phillips and Backman 1983, Phillips 1984, Dennison and Alberte 1985, Marsh *et al.* 1986, Bulthuis 1987, Dennison 1987, Fonseca and Kenworthy 1987, Thom and Albright 1990, Zimmerman *et al.* 1990, 1994, Moore *et al.* 1993, Masini *et al.* 1995, Merkel 2000, 2003, Koch 2001). The availability of light constrains eelgrass at the lower depth limits (Heminga and Duarte 2000, Krause-Jensen *et al.* 2000), whereas the upper limits of eelgrass distribution are mostly constrained by wave action (Krause-Jensen *et al.* 2000) and desiccation stress at low tides (Phillips 1984). In addition, it has been demonstrated that biological controls including epiphytic growth, spatial competitors such as benthic algae, and bioturbation can also have a substantial effect on the growth and distribution of eelgrass (Merkel 1990, Sand-Jensen 1977).

Eelgrass abundance has declined worldwide over the past 20 to 30 years due to increased anthropogenic effects (Short and Wyllie-Echeverria 1996). However, it is unclear whether this trend has occurred in San Francisco Bay. In the late 1920s, eelgrass was reported as an abundant species along the shores of the Bay (Setchell 1929). In 1987, about 60 years later, a survey of the Bay revealed only 128 hectares (316 acres) (0.1 percent total bay bottom coverage) of eelgrass throughout the Bay, with much of the existing habitat exhibiting conditions of environmental stress (Wyllie-Echeverria and Rutten 1989, Wyllie-Echeverria 1990). However, most of the regions specifically identified by Setchell as supporting eelgrass continue to support eelgrass today and what was meant by "abundant" in the late 1920's remains unclear.

Notwithstanding the inability to document changes in eelgrass through recent history, there is reason to believe that existing eelgrass beds may be much reduced from its historical distribution range. Most of the documented Bay loss has occurred within the shallow bay fringes to which eelgrass is restricted. Further, watershed sediment loading from the Delta as well as bay dredging have taken their toll on eelgrass resources of the Bay. As a result of activities such as these, light attenuation throughout San Francisco Bay waters is higher than other bay and estuarine systems of California (Merkel and Associates unpublished data), which affects eelgrass growth because light availability is a major factor controlling eelgrass distribution in the Bay (Zimmerman *et al.* 1990, 1994).

Although eelgrass coverage in the Bay may be reduced from historic levels, conditions may not be as bleak as thought after the completion of the 1987 eelgrass inventory (Wyllie-Echeverria 1990, Wyllie-Echeverria and Rutten 1989). In October 1996, eelgrass surveys using sonographic techniques from Richmond Harbor to just north of Point San Pablo for two separate U.S. Army Corps of Engineers project studies were conducted (SAIC and Merkel 1997a, 1997b). In these surveys, 195.5 hectares (483 acres) of eelgrass were identified over this short stretch of shoreline alone. Additionally, subsequent surveys have identified eelgrass in numerous locations where it has not previously been known to occur, including along the Oakland and Alameda waterfronts, along portions of the Marin Peninsula, within San Leandro Bay, and at other smaller locations (Merkel

1999, 2000, 2003, and unpublished data). These data suggest either that a significant expansion of eelgrass habitat has occurred since 1987 or that improved survey techniques are allowing for greater detection and improved mapping than was possible using prior techniques. An earlier analysis of these data suggests that it is likely that both changes in eelgrass beds and improvements in survey techniques are a factor in the differences between the 1987 and 1996 surveys (Thompson *et al.* 1997).

In addition to a general paucity of eelgrass, the beds that do exist in San Francisco Bay are extremely dynamic. In repeated surveys of eelgrass beds at Point Molate, the Richmond Harbor training wall, and the Emeryville Flats, eelgrass density and abundance was noted to fluctuate significantly from year to year (Merkel 1997a, 2001). This annual variability in eelgrass appears to be related to Bay turbidity levels or even average climatic conditions within marginally suited environments. While there has not been a significant amount of rigorous monitoring of eelgrass in the Bay, at least some of the high variability appears to be related to large-scale episodic events that influence the distribution of freshwater and sediments in the Bay (Merkel 2001 and additional unpublished data). Recent studies have demonstrated that dynamism in eelgrass beds is common in many areas. For example, eelgrass above-ground biomass and shoot density can vary by as much as 500% over two years at the same site in Willapa Bay, Washington as a result of environmental fluctuations and human disturbance (Thom *et al.* 2003). In Southern California, the onsets of El Niño Southern Oscillations (ENSO) result in substantial declines in eelgrass with recovery of beds occurring under subsequent La Niña periods (Merkel 2000).

PRE-SURVEY SCREENING

San Francisco Bay consists of approximately 100,000 hectares (250,000 acres) of subtidal and intertidal habitat. The intent of the current program was to provide a complete inventory of all eelgrass resources within the Bay. Thus, the entire area of the Bay was considered and analyzed for the potential to support eelgrass habitat. In order to survey all of the Bay for eelgrass using acoustic survey techniques, over three years of fieldwork would be required along with a survey budget that vastly exceeds available resources. However, much of the area of the Bay is not suitable for eelgrass growth and by eliminating regions based on an initial analysis of suitable water depth ranges the area of potential eelgrass habitat was reduced to approximately 24,000 hectares (60,000 acres). Because the duration of work to survey this amount of area would still be prohibitively expensive and would extend through multiple seasons, an effort was made to further reduce the survey area. In order to use available resources most efficiently, a pre-survey screening model was developed for the Bay to exclude areas from survey that lack suitable conditions to support eelgrass. This model-based screening effort reduced the survey area to that area which was considered to potentially support eelgrass. The resulting survey area could be surveyed within the summer/early fall period of peak eelgrass abundance and reduced the cost of the field surveys to a manageable budget amount.

The pre-survey screening made use of existing physical data in a multiple ecological limits model in order to determine the suitable areas for eelgrass growth within the Bay. In order to capture all areas of suitable environments for eelgrass growth within the study area and avoid an inadvertent discard of potentially suitable areas, the pre-survey screening model used broadly defined limits for included physical parameters. Modeling methodology is discussed in more detail in a following section of this document.

STUDY AREA

The San Francisco Bay-Delta Estuary, which includes the waters of San Francisco Bay, San Pablo Bay, Suisun Bay and the Sacramento-San Joaquin River Delta, is located in the Oregonian zoogeographical province of California (McGowan 1971, Briggs 1974) and is the largest estuarine system on the West Coast of North and South America (Figure 1). The Bay can be divided into four subregions: Suisun Bay, North Bay, Central Bay, and South Bay. The study area for the program consists of 100,000 hectares (250,000 acres) of aquatic habitat and includes the waters of the Suisun subregion of the Sacramento-San Joaquin River Delta.

According to the Goals Project (1999), eelgrass exists at the intersection of baylands and the shallow waters of the Bay. Baylands are defined as those areas that exist between Mean Lower Low Water (MLLW) and the highest observed tide and shallow Bay exists between -5.5 meters (-18 feet) MLLW and MLLW. Eelgrass spans a narrow range of intertidal and subtidal that straddles the defined boundaries of these classifications. The defined survey area did not include a restriction on the lower depth limits; however, the upper limit was restricted at mean sea level (MSL), an elevation well above the natural limit where eelgrass is restricted by desiccation stress.

ENVIRONMENTAL PARAMETERS

Although there are several environmental parameters that affect the distribution of eelgrass beds, modeling for the pre-survey screening focused on a small set of parameters. The environmental parameters that were used to construct the pre-survey screening model were bathymetry, wind/wave-generated bottom shear, current speed, and water residence time (i.e., the time it takes for water to pass through the Bay) (Table 1). While a number of additional data sources were investigated, none of these data provided sufficient detail to add constituent parameters to the model at a pre-survey screening level. Although factors such as water temperature, salinity, nutrient levels, sediment grain size, pollutant levels and biological constraints could affect the growth and abundance of eelgrass, the hydrodynamic features used in the modeling served as helpful proxies for the physiological factors that affect eelgrass growth. In addition, the hydrodynamic data were readily modeled to provide high-quality spatial data with capacity for future model extension. Bottom shear, current speed, residence time, and bathymetry directly and indirectly control the location of eelgrass beds within the Bay. These four parameters primarily affect eelgrass distribution because they influence light availability by affecting turbidity levels.

MODEL FRAMEWORK

The modeling framework used for the pre-survey screening was the Ecological Limits, Viability, and Sustainability (ELVS) model. The ELVS model is a grid-based constituent factors habitat evolution model that was originally developed by Merkel & Associates, Inc. in order to make eelgrass habitat suitability predictions from bathymetric, hydrodynamic, and atmospheric data (Merkel & Associates 2000). The model uses a series of spatially-based mathematical models based on the coincidence of environmental tolerance ranges across multiple parameters to define environmental suitability for various habitats. The data layers for the model are managed through ESRI ArcView-Model Builder™ and Spatial Analyst™.

The current application of the ELVS model utilized bathymetry, wind/wave-generated bottom shear, current speed, and fluvial influence to populate input variables. These spatially explicit themes were then used to depict the range of environmental parameters affecting eelgrass distribution throughout the Bay.

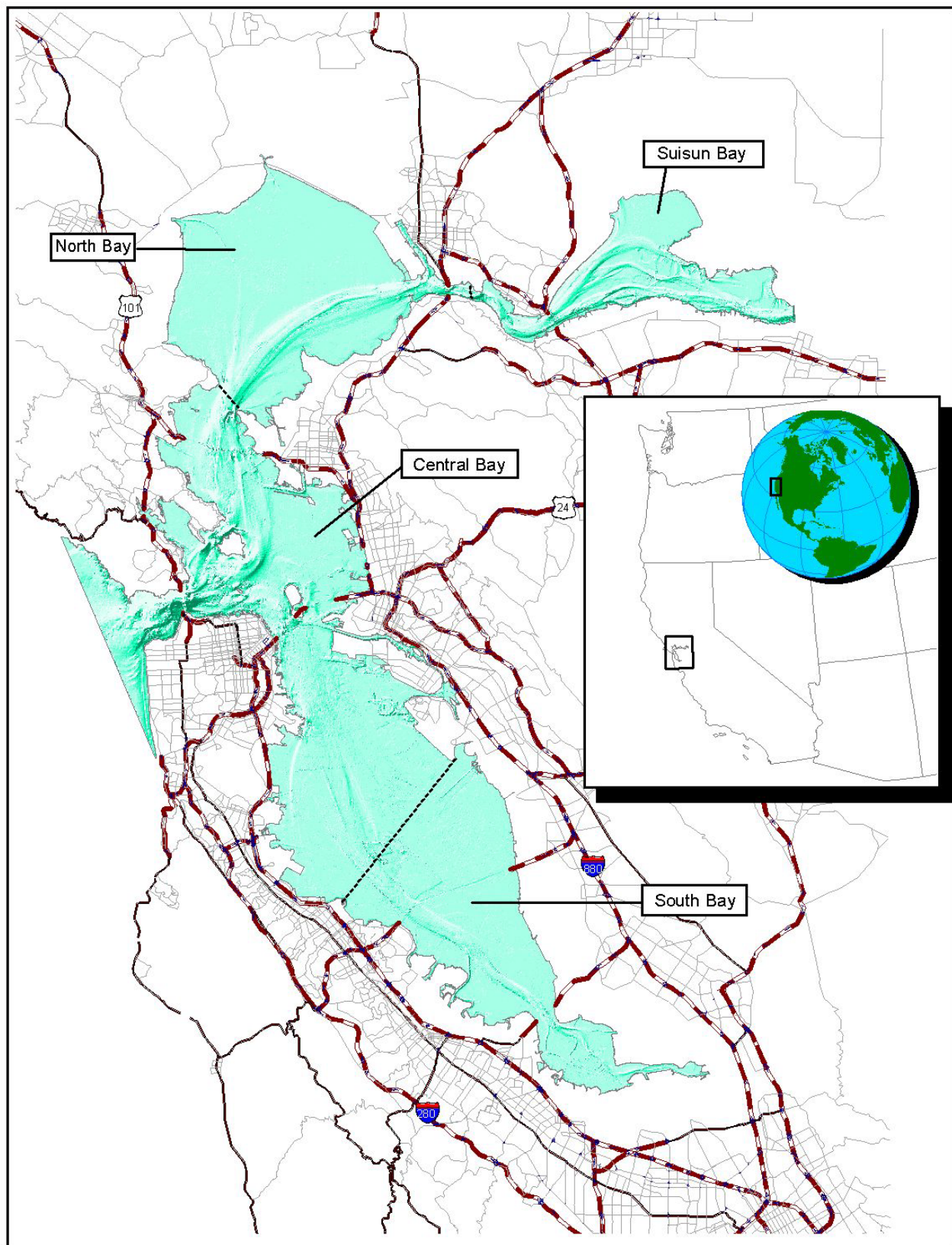


Figure 1. San Francisco Bay study area locator map showing regions adapted from the Goals Project (1999)

Table 1. Data sources and potential model parameters investigated for the pre-survey screening model

Data Type	Source	Used?
Bathymetry	NOAA (2002) Merkel & Associates (current study)	Yes
	Coast & Harbor Engineering (unpublished data)	Yes
	Port of Oakland (unpublished data)	Yes
	Merkel & Associates (current study)	Yes
30-day net current speed	Coast & Harbor Engineering (current study)	Yes
Wind/wave bottom shear	Coast & Harbor Engineering (current study)	Yes
Residence time	Coast & Harbor Engineering (current study)	Yes
Existing eelgrass beds	Merkel & Associates (1997, 1999a, 1999b, 2001, 2003)	Yes
	SAIC and Merkel & Associates (1997a, 1997b)	Yes
	NOAA/Wyllie-Echeverria and Rutten (1989)	Yes
Salinity	San Francisco Estuary Institute	No
	Conomos 1979	No

Utilizing a coarse-grained model for the pre-survey screening ensured that all known eelgrass in the Bay would occur within areas to be surveyed. Environmental tolerance limits employed under the ELVS model were broad in order to account for uncertainties in input data and uncertainties with respect to San Francisco Bay eelgrass. An advantage of the ELVS modeling process is that model outputs can be re-inserted into the model to regenerate additional outputs. After field surveys have been completed, current eelgrass distribution and ranges of occurrence across environmental parameter gradients can be incorporated into the model to tighten the predictive range of the model.

All hydrodynamic data used in the current ELVS model were derived through modeling performed by Coast & Harbor Engineering. Baywide wind-wave growth and transformation modeling was performed on three independent domains covering San Francisco Bay: South, Central and North Bay domains. The three domains were built using the same set of composite bathymetry data compiled from various sources (NOAA 1930-1999, Merkel & Associates, Inc., U.S. Army Corps of Engineers). In order to calculate wave-influenced hydrodynamics, wind data were input to an STWAVE model (Smith et al., 2001), a steady-state, 2-dimensional spectral wind-wave growth and transformation model. The STWAVE model considers a range of periods and directions in order to simulate depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, wind-wave growth, and wave-wave interaction and whitecapping (Smith et al 2001). STWAVE model output includes significant wave height, peak period, and peak direction.

MODEL PARAMETERS

Shoreline

In order to construct the framework of the ELVS model, a data layer of the shoreline of San Francisco Bay (universal transverse mercator [UTM] Zone 10 North American Datum of 1983 [NAD 83] reprojected to State Plane Zone 3) was collected from the San Francisco Bay Estuary Institute (www.sfei.org). These data were developed through the Coastal Protection & Restoration Division

(CPRD) database mapping project for the San Francisco Bay watershed and mapping project. These shoreline data were slightly modified for use in the pre-survey screening model by aligning the data with existing bathymetric contours and using recent registered aerial photographs to correct various shoreline errors.

Bathymetry

Bathymetry (bottom depth) has a direct effect on eelgrass presence because light at the bottom is affected by attenuation through the water column. In addition, bottom sediment resuspension by wave action is related to water depth. The bathymetry data layer used in the current ELVS model was a combination of data collected from NOAA (2002), Coast and Harbor Engineering (unpublished data), the Port of Oakland (unpublished data) and survey data collected by Merkel & Associates during the current survey (Figure 2). The bathymetric data were received as point data and in order to be used in the ELVS model were transformed into a triangular irregular network (TIN), which creates a continuous surface. Because the distance between the bathymetric data points varied, data were interpolated between points in order to create a regular 10-meter (33-foot) grid. The bathymetric values included in the model ranged from 5 meters (16 feet) above sea level to – 117.5 meters (385.5 feet) MLLW. Values defining the bathymetric range for eelgrass within San Francisco Bay ranged from -2.75 to 0.5 meters (-9 to 1.6 feet) MLLW.

Wind/wave Bottom Shear

Wind/wave bottom shear was included in the model because it is a measure of water movement at the sediment surface, which influences re-suspension of bottom particles and available light levels (Figure 3). In order to calculate wind-generated hydrodynamics, wind records from Alameda Naval Air Station (NAS) from 1998-2002 were evaluated. From these data average daily winds were calculated and used in wind wave modeling. A steady-state wind condition was used for wind-wave growth and transformation modeling. Wind speeds were calculated as an average of 255° to 315°, which represents 40 percent of wind measured at Alameda NAS (1945-1996). Within this data set, winds were from the West (255° to 285°) 23.8 percent of the time and from the Northwest (285° to 315°) 14.2 percent of the time. In order to correct for the differences in wind direction, bottom shear was adjusted by appropriate proportional multipliers (0.238 or 0.142) and then averaged.

Waves were developed using the Wave Parameter Generator (WPG) model. The WPG is a 2-dimensional general post-processor model (Coast & Harbor Engineering) that reads wave fields (height, period, depth, direction) as input and calculates various desired scalar and vector wave parameters. Model output is calculated using linear (Airy) wave theory in the absence of currents and includes wave bottom orbital velocity, wave bottom shear, wave bottom orbital amplitude and wave number. The values of bottom shear included in the model ranged from 0 to 5,152.25 pascals and the bottom shear considered acceptable for eelgrass growth based on existing eelgrass distribution ranged from 0 to 10 pascals.

Current Speed

Current speed influences light availability to eelgrass by affecting sediment resuspension and retention (Keith Merkel personal observation). It follows that low current speeds should keep light levels high because sediment particles are not resuspended into the water column and high current speeds keep light levels high by removing resuspendable sediments. Thirty-day net current speeds (meters/second) were used as input parameters for the ELVS model (Figure 4) where current speed was calculated as the hypotenuse of the triangle formed between the U (positive east) and V (positive north) vectors (horizontal coordinate CA State Plane NAD 83 Zone 3). The values of current speed included in the model ranged from 0 to 1.449 meters/second and the current speeds considered acceptable for eelgrass growth ranged from 0 to 0.896 meters/second.

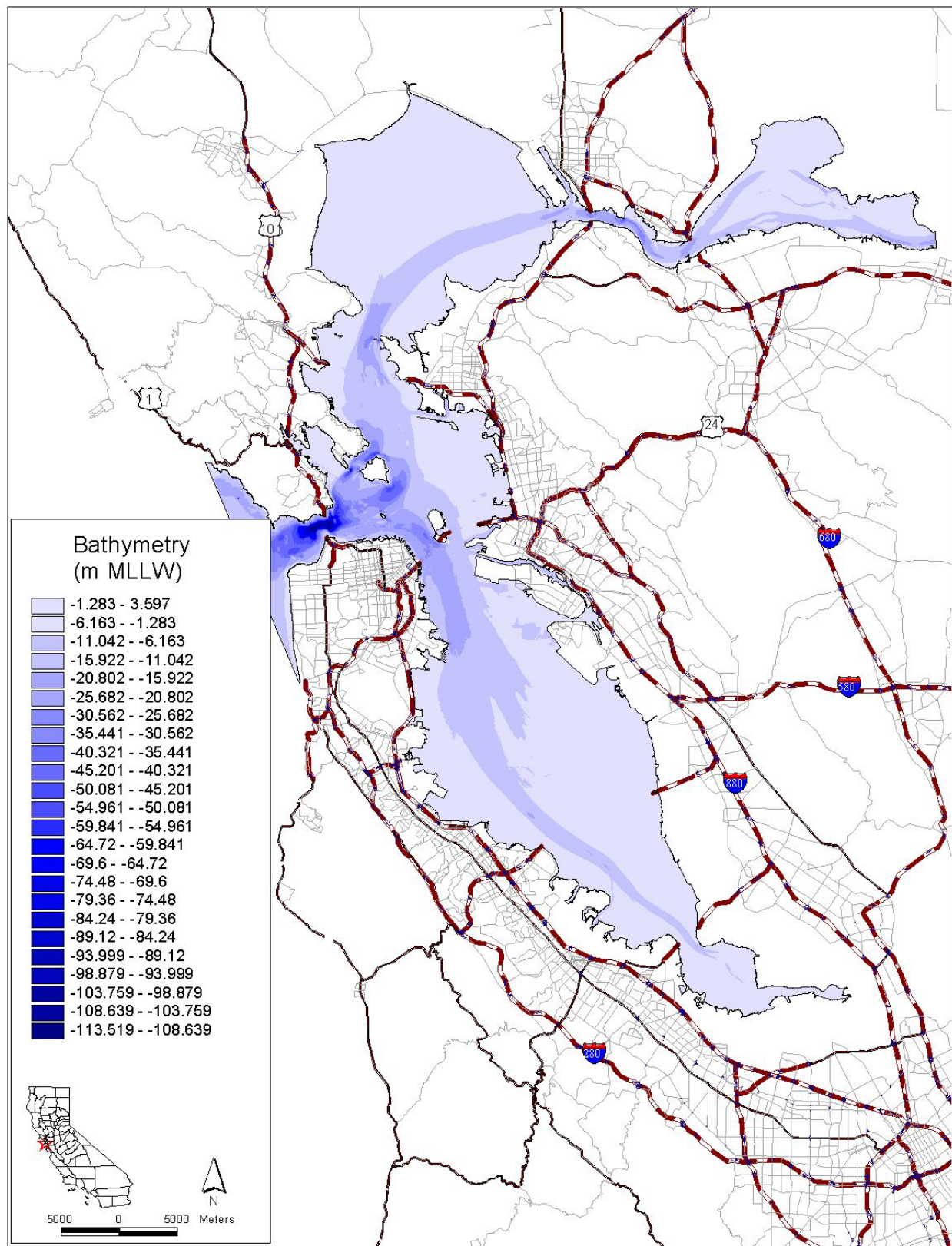


Figure 2. Bathymetry of San Francisco Bay collected from Merkel & Associates, Inc. and NOAA

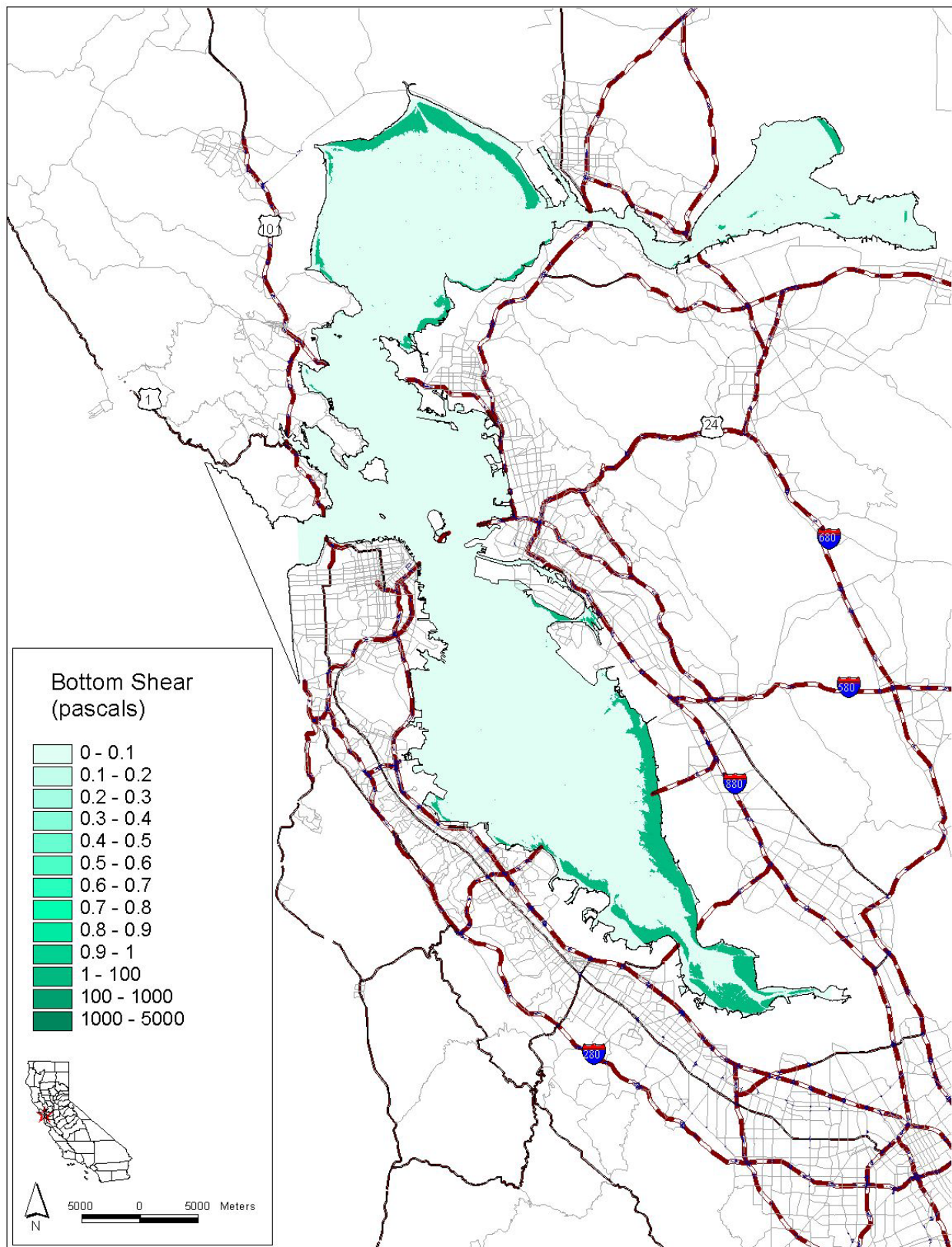


Figure 3. Predicted wind/wave bottom shear in San Francisco Bay.

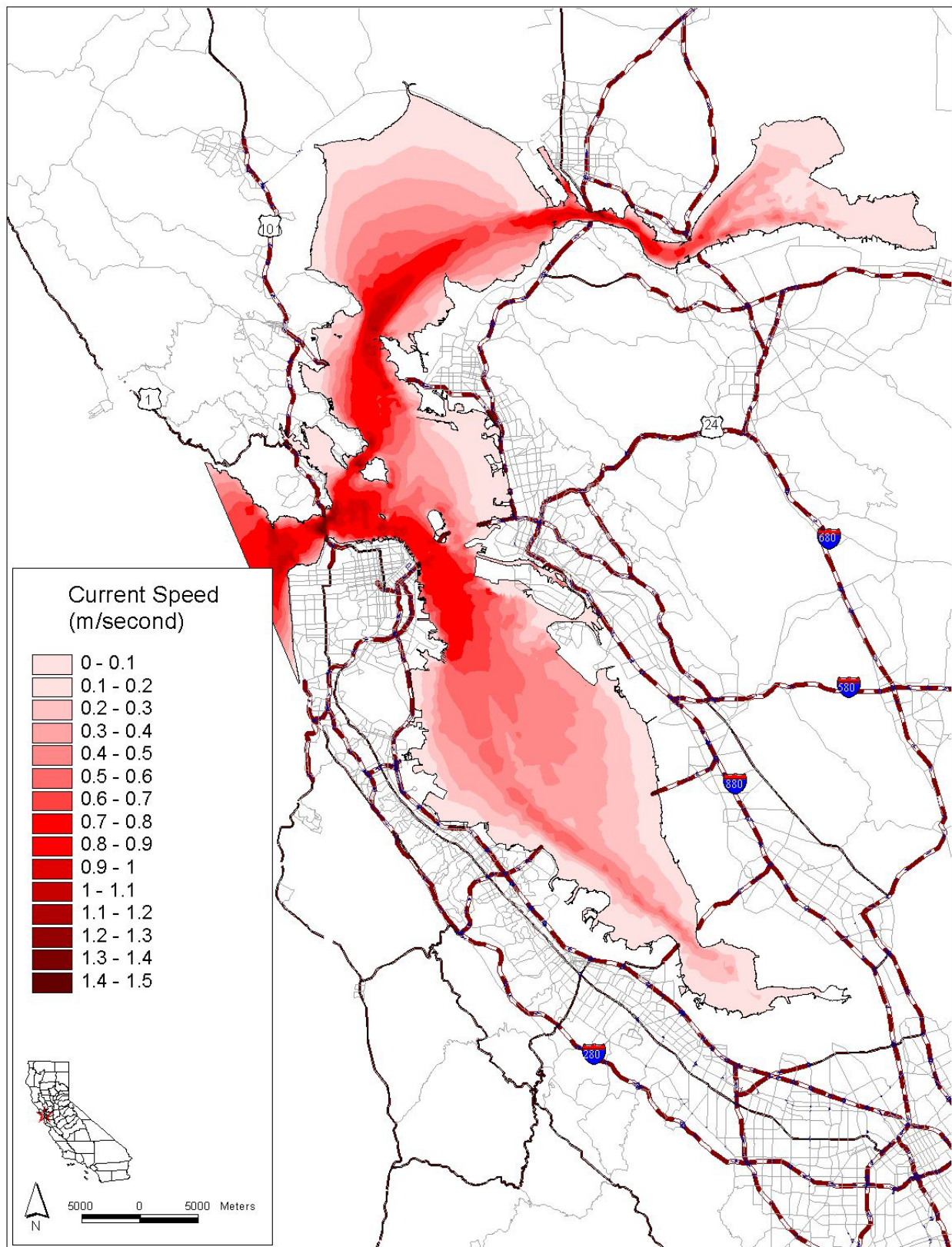


Figure 4. Predicted 30-day net current speed in San Francisco Bay.

Fluvial Influence

Streams and rivers provide for net import of suspendable sediments to the Bay and provide a significant load of suspended sediment to the water column. The concentration of suspended particles that originated from a freshwater source was not known for pre-survey screening modeling; however, an equilibrium concentration gradient was developed throughout the Bay by setting the concentration of river flows equal to one and the concentration of the Pacific Ocean equal to zero and allowing circulation models to run to a state of equilibrium (Figure 5). There were only three freshwater sources used in the fluvial influence model: the Sacramento River, the Napa River, and Coyote Creek and flow data for these rivers were obtained from the U.S. Geological Survey (<http://nwis.waterdata.usgs.gov/ca/nwis/annual>). After achieving equilibrium, the concentration of suspended sediment in each grid cell of the model was calculated and regions of the Bay were assigned a value of fluvial influence.

RUNNING THE MODEL

In order to process the raw bathymetry, current speed, bottom shear, and fluvial influence data each of these parameters was processed into a TIN and then a grid yielding a continuous queriable surface of 10-meter (33-foot) grid cells using ESRI's ArcView 3.x-Spatial Analyst™ extension. Every cell within the resulting grid had a value, which was the product of the input parameters.

Existing Eelgrass Beds

Adjustments to the model were made to ensure good predictive capacity relative to known conditions by calibrating it against the known distribution of eelgrass throughout the Bay. The most conservative tolerance limits for eelgrass were employed in the ELVS model in order to ensure that all eelgrass present in the Bay was included within proposed survey areas. In order to ascertain the values of each environmental parameter that characterized eelgrass beds throughout the Bay, a map of existing eelgrass beds was used as a base layer of the model (Figure 6). This map of the distribution of known existing eelgrass beds throughout the Bay was compiled from SAIC and Merkel & Associates (1997a and 1997b), Merkel & Associates (1999a), and NOAA (Wyllie-Echeverria and Rutten 1989). Hydrodynamic parameters were overlaid onto the eelgrass map in order to calculate the values of the parameters that occurred within known eelgrass beds. These values provided boundaries for determining where eelgrass was expected to occur (Figures 9, 10, 11, and 12).

Parameter Suitability Index

In order to combine the different units of bathymetry, current speed, bottom shear, and fluvial influence, these parameters were combined into submodels (Figure 7). However, before these parameters were combined, values outside the acceptable range of eelgrass occurrence were removed. Bottom shear and current speed were combined to form a submodel termed "turbidity" and bathymetry and fluvial influence were combined to form "residence time". Parameter normalization of the submodels was accomplished by calculating a Parameter Suitability Index (PSI). The PSI was calculated by breaking each parameter into 64 equal range classes (the maximum available in ArcView-Spatial Analyst™) and then calculating the percent of known eelgrass captured by each class. For example, if a range class captured 23% of existing eelgrass, the PSI for this class was 0.23 and the sum of all PSI in each parameter was 1.0. The PSI submodels, along with bathymetry, were overlaid on a map of known eelgrass beds in order to calculate the probability of eelgrass occurrence within a cell of known environmental conditions.

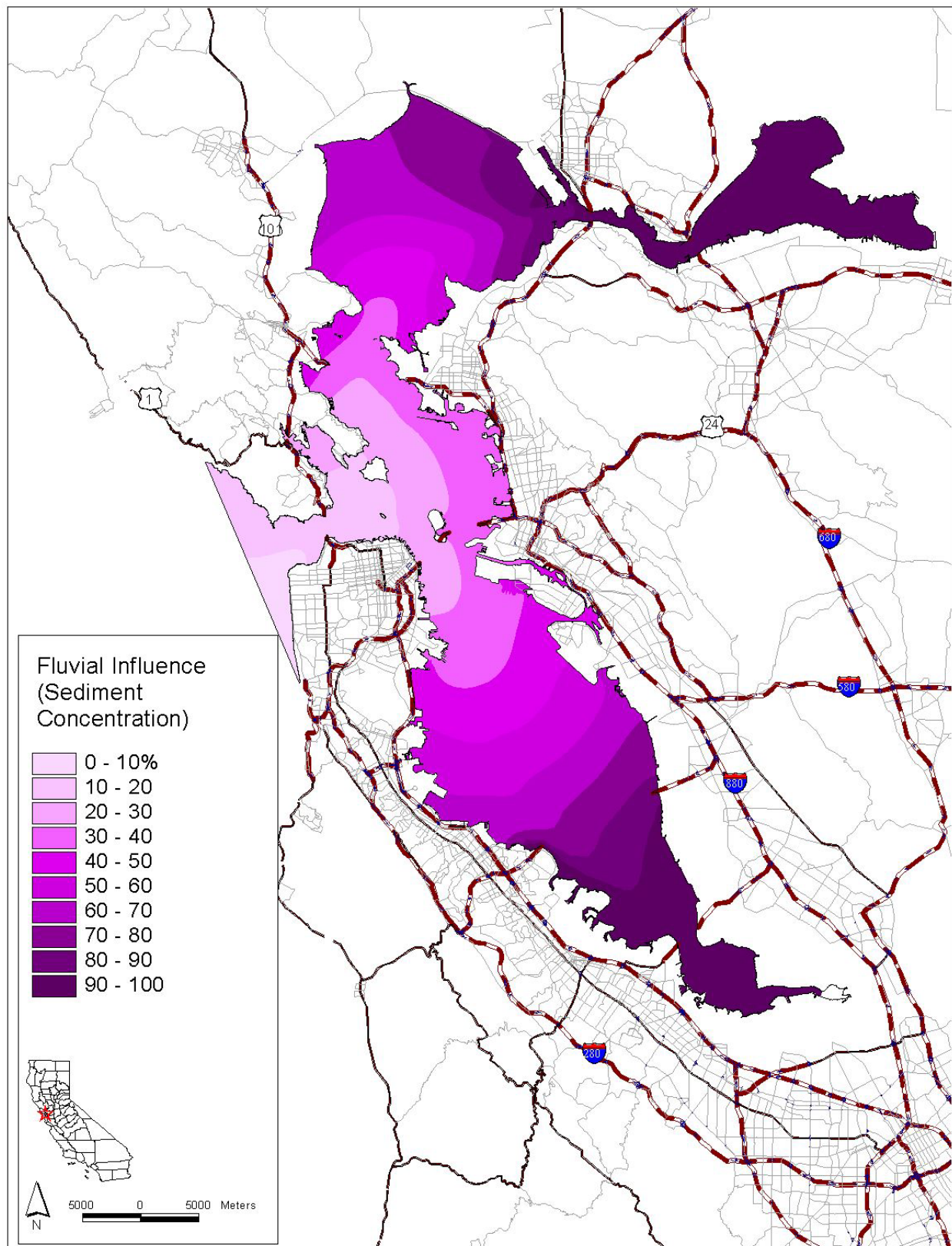


Figure 5. Predicted relative fluvial influence (sediment concentration) in San Francisco Bay.

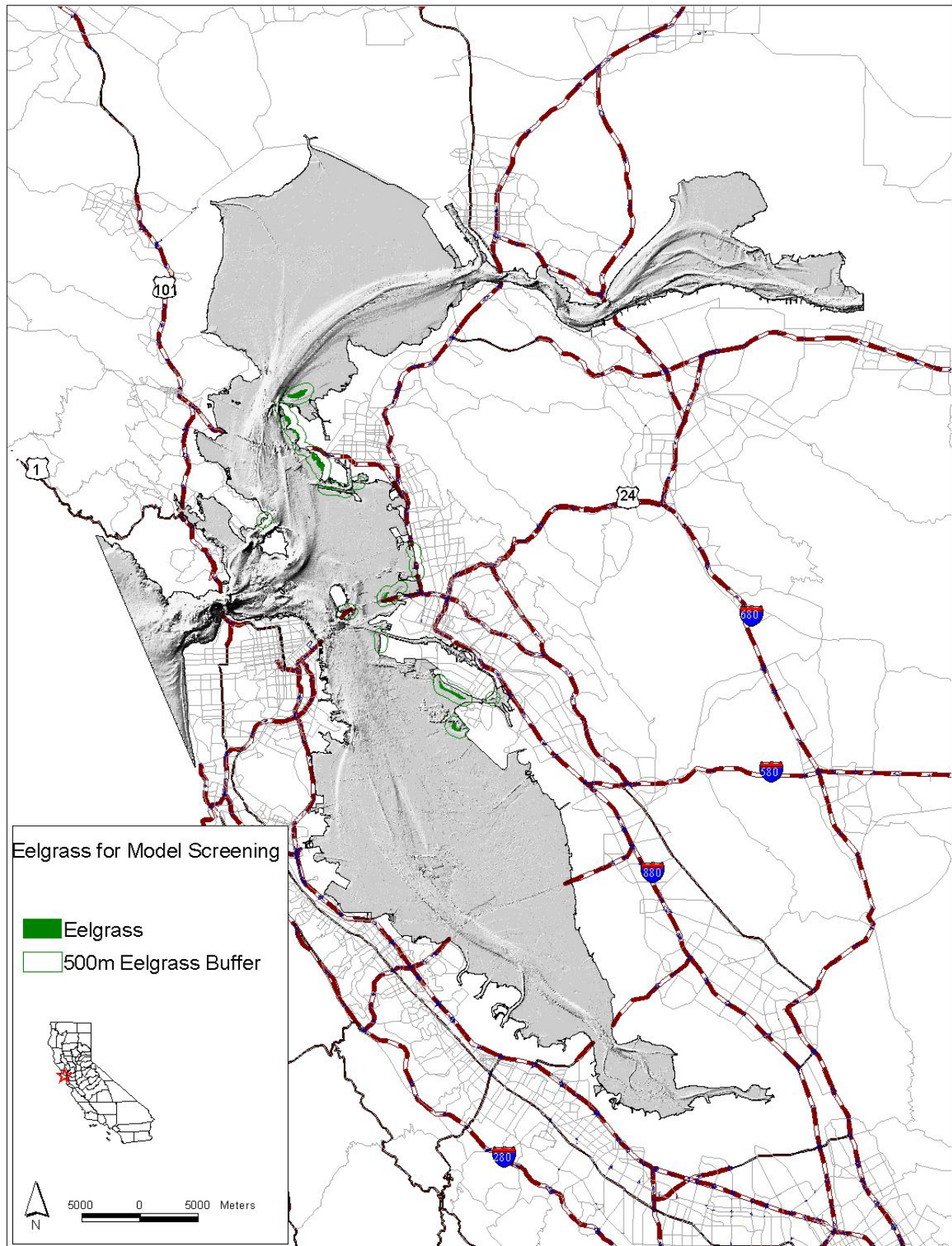


Figure 6. Known existing eelgrass distribution in San Francisco Bay prior to 2003 survey

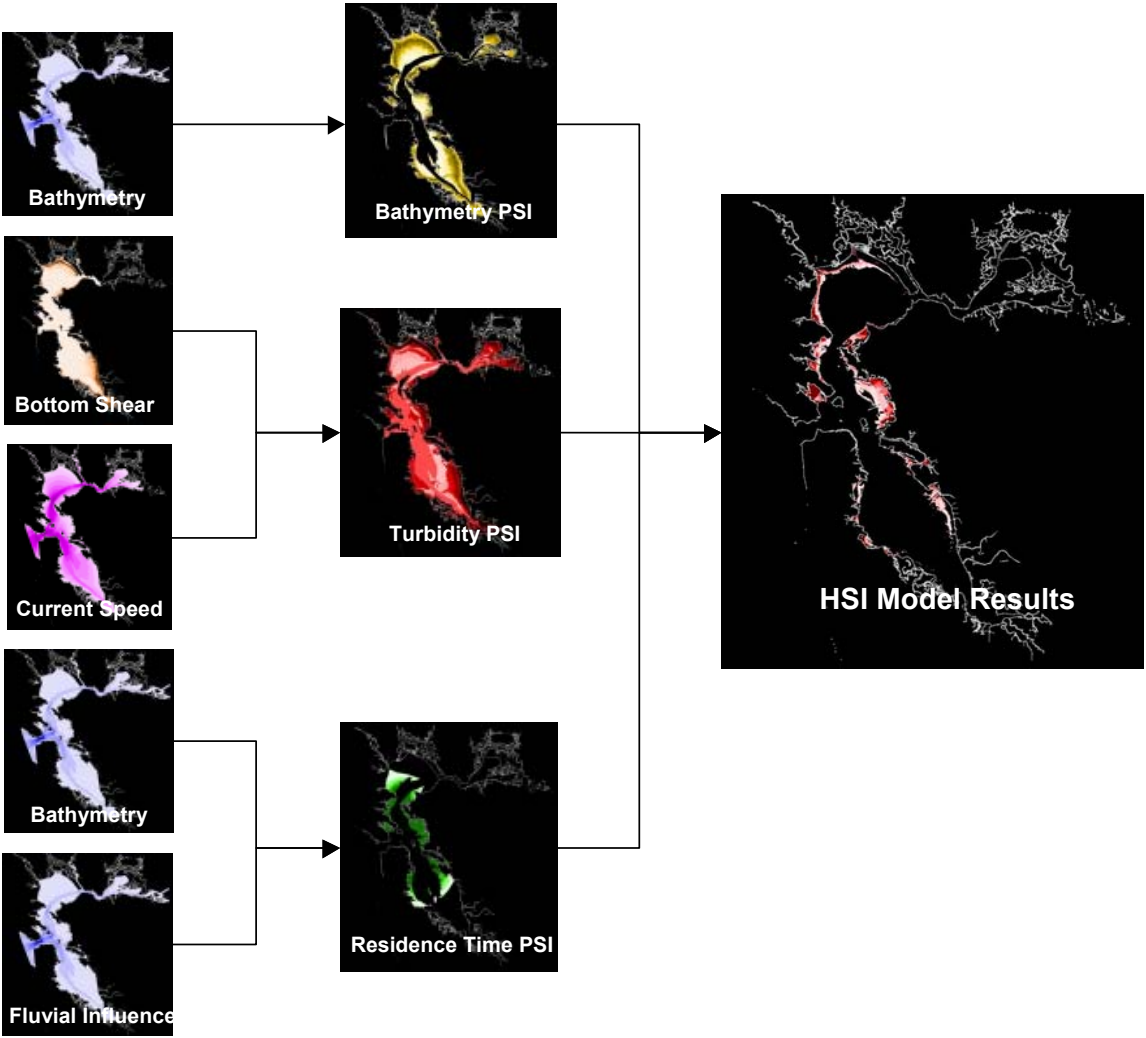


Figure 7. Schematic representation of Ecological Limits, Viability, and Sustainability (ELVS) model assembly.

Habitat Suitability Index

The probability of eelgrass occurrence within a cell in the pre-survey screening model was calculated as the Habitat Suitability Index (HSI). The HSI is the product of the PSI for bathymetry, turbidity, and residence time and represents the suitability of each grid cell for supporting eelgrass growth. There were 62 possible values of HSI, ranging from least suitable to most suitable to support eelgrass habitat and the combination of all HSI classes resulted in the total potential eelgrass habitat within the Bay. The values of HSI were the final results of the pre-survey screening model (Figures 8a, 8b, and 8c).

PRE-SURVEY SCREENING RESULTS

The pre-survey screening model identified approximately 13,585 hectares (33,569 acres) of potential habitat within San Francisco Bay (Figures 8a, 8b, and 8c). The results of the pre-survey screening were used to guide efficient field survey strategies and prioritize survey areas and grid cells with highest the HSI were identified as the highest priority areas for the eelgrass survey. Within the total potential habitat area, 694 hectares (1,716 acres) occurred within the highest HSI category.

Results of the pre-survey screening model provided insight into the expected characteristics of bathymetry, current speed, bottom shear, and fluvial influence within eelgrass beds in the Bay. For example, the greatest percentage of predicted eelgrass (about 25%) occurred at approximately -0.5 meters (-1.6 feet) MLLW and there was also a small peak of abundance (about 8%) at -1.0 meter (3.3 feet) MLLW (Figure 9). This range of eelgrass depth distribution is similar to that observed experimentally at turbid and clear sites, respectively (Zimmerman *et al* 1995). The deepest depth at which eelgrass was predicted was -5.4 meters (-17.7 feet) MLLW and the shallowest was 0.3 meters (1 foot) MLLW. There were two peaks in predicted eelgrass abundance in relation to current speed, one occurred at approximately 0.15 meters/second and another at 0.39 meters/second (Figure 10). This relationship predicts that eelgrass will exist in either high-current areas where the water clarity is maintained by transport of suspended particles or low-current environments where sediment resuspension is minimal. Within San Francisco Bay, eelgrass beds at Bayfarm Island and in Clipper Cove typify these current extremes. Predicted eelgrass occurrence had a negative relationship with bottom shear and the majority of eelgrass was predicted to occur in areas with 0.25 pascals of shear or less, the lowest bottom shear category (Figure 11). The predicted levels of fluvial influence tended to be lower in eelgrass beds than the baywide conditions (Figure 12). Most eelgrass was predicted to occur between 15 and 55% suspended fluvial sediment, whereas the baywide range was between 5 and 95%. Eelgrass is more likely to occur in areas with less fluvial influence, which is also likely to correspond to higher water clarity.

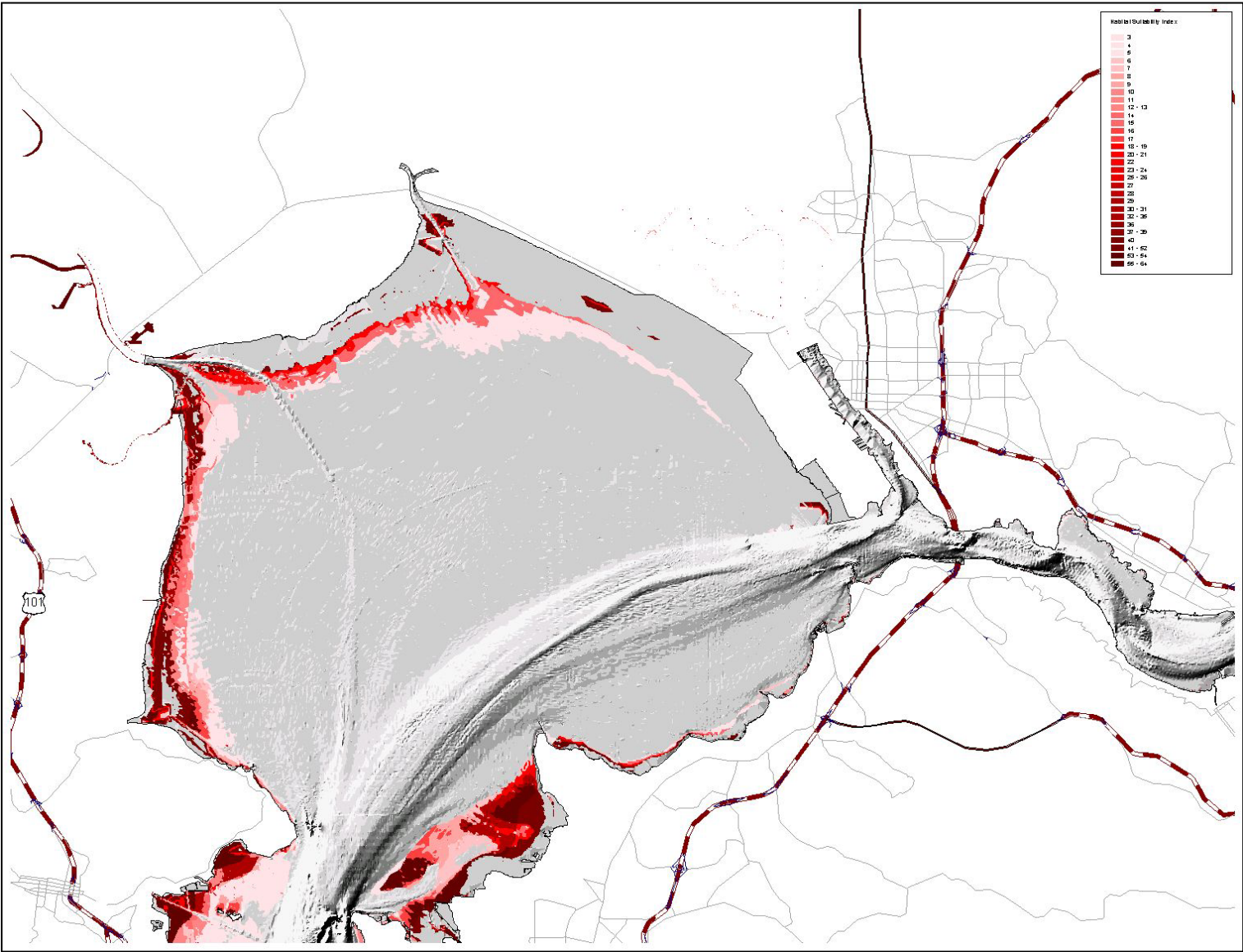


Figure 8a. Predicted suitable eelgrass distribution in north San Francisco Bay resulting from the Ecological Limits, Viability, and Sustainability (ELVS) model.

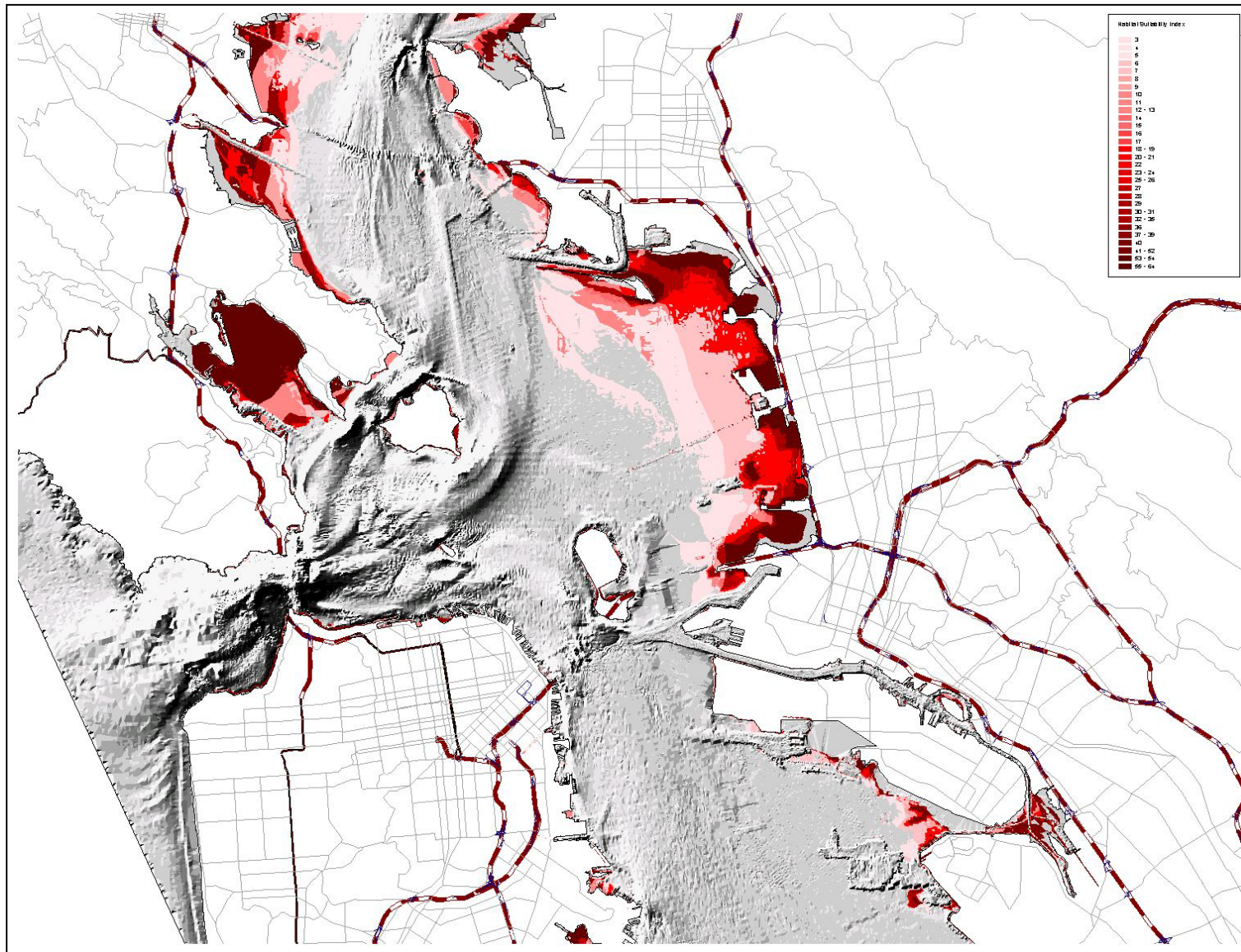


Figure 8b. Predicted suitable eelgrass distribution in central San Francisco Bay resulting from the Ecological Limits, Viability, and Sustainability (ELVS) model.

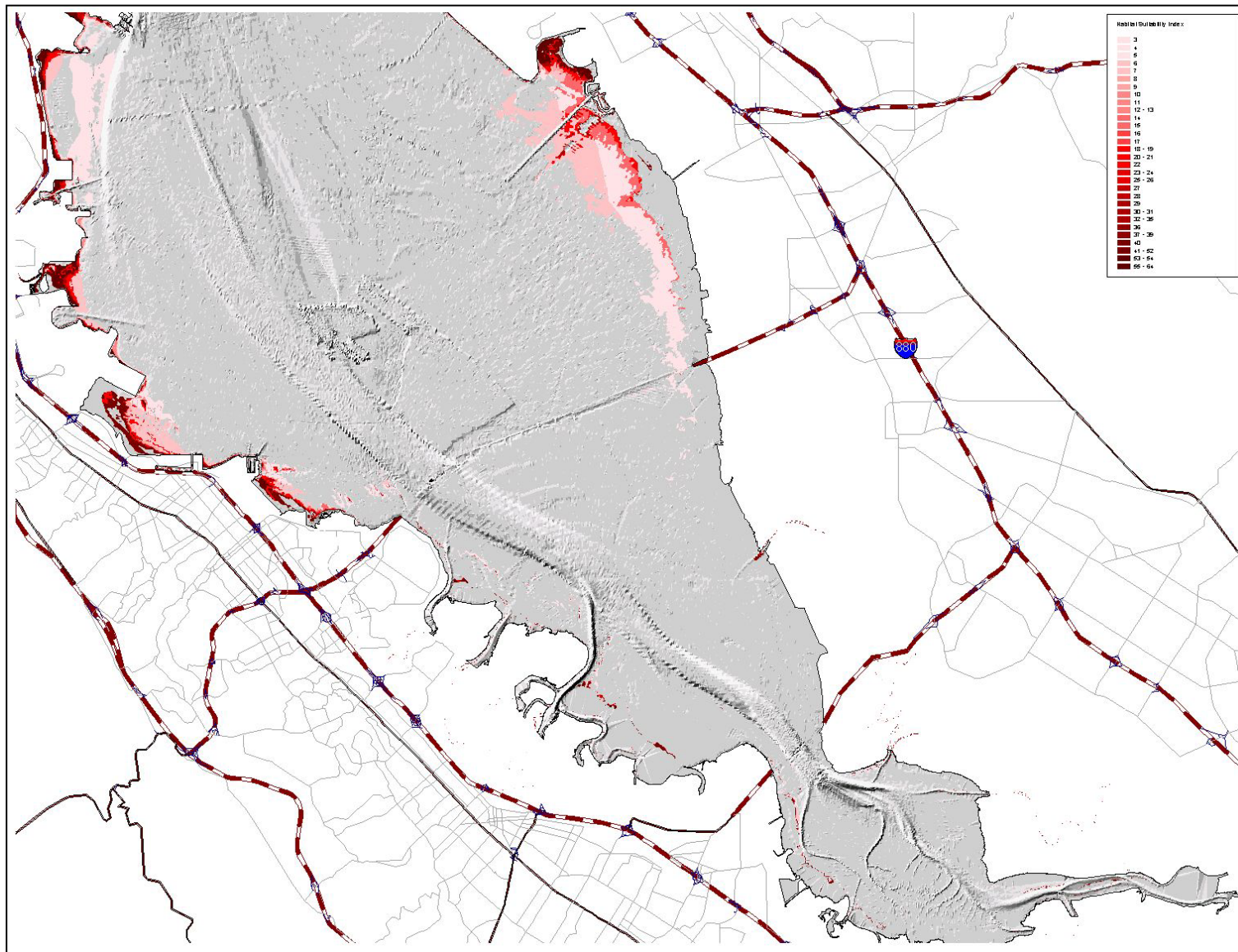


Figure 8c. Predicted suitable eelgrass distribution in south San Francisco Bay resulting from the Ecological Limits, Viability, and Sustainability (ELVS) model.

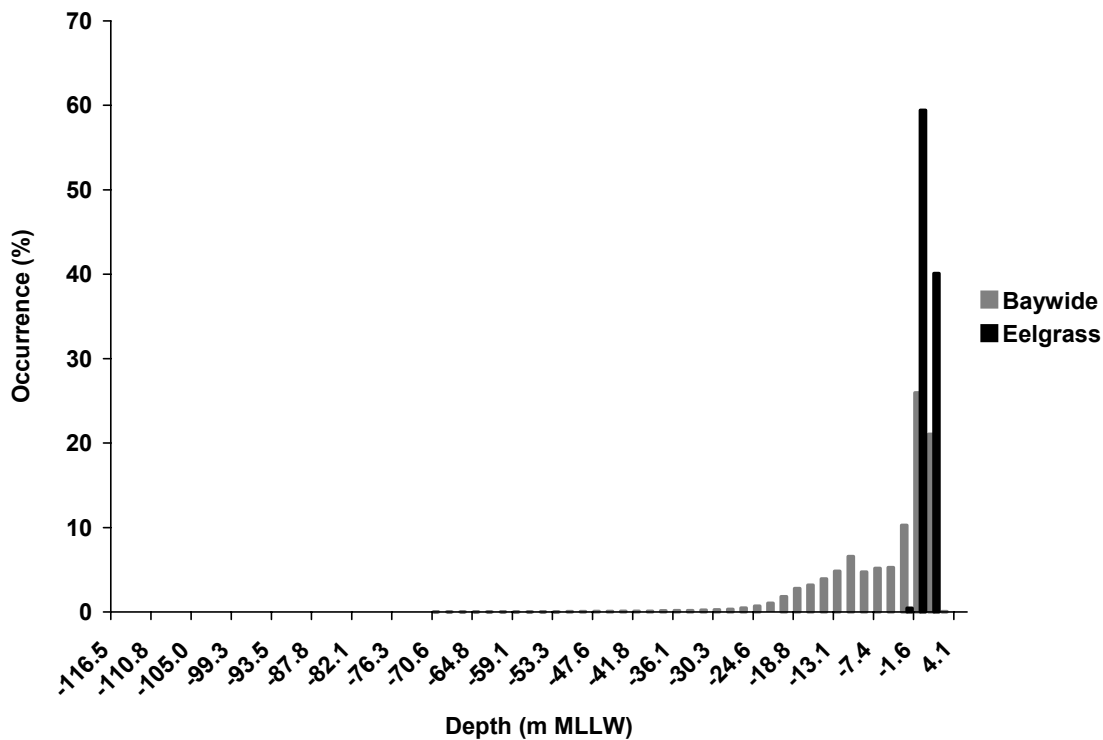


Figure 9. Predicted bathymetry within eelgrass beds and throughout San Francisco Bay.

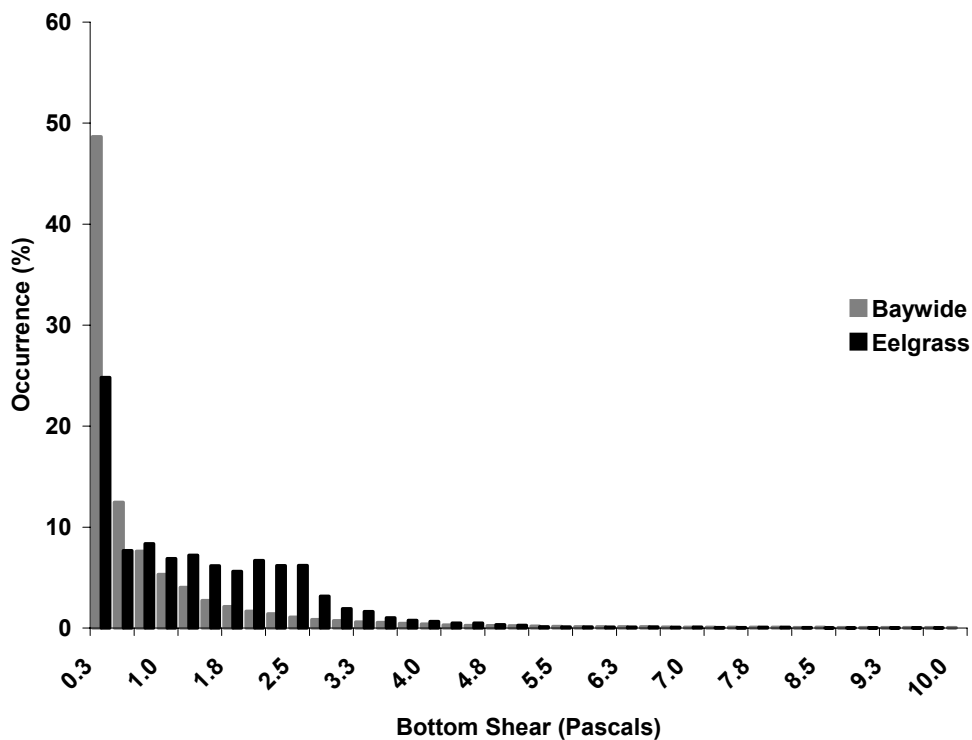


Figure 10. Predicted bottom shear within eelgrass beds and throughout San Francisco Bay

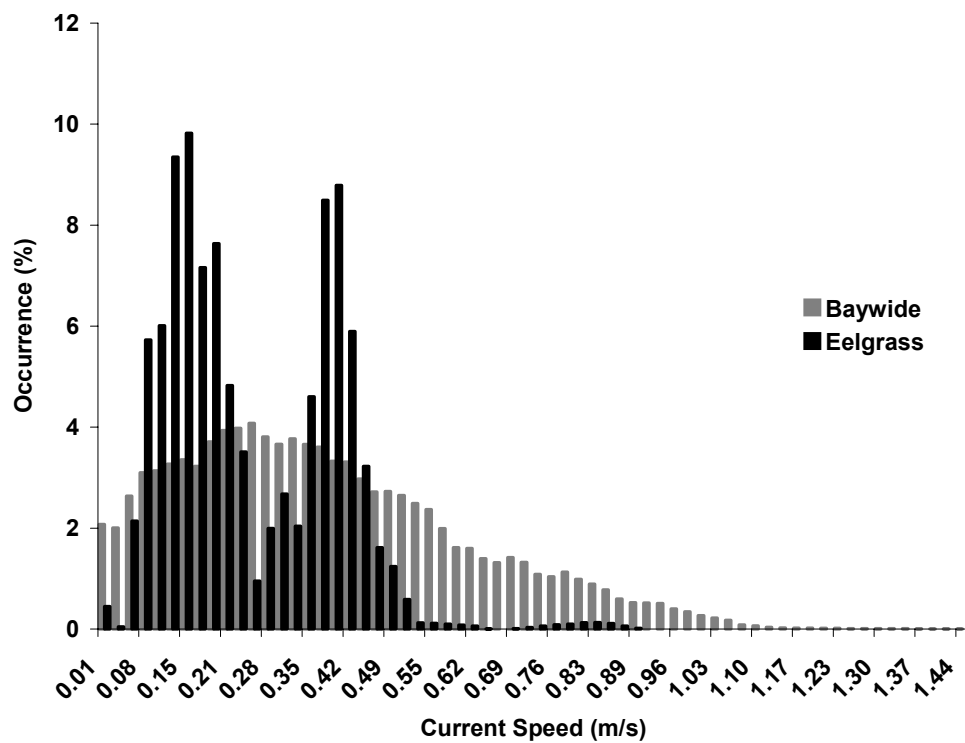


Figure 11. Predicted current speeds within eelgrass beds and throughout San Francisco Bay

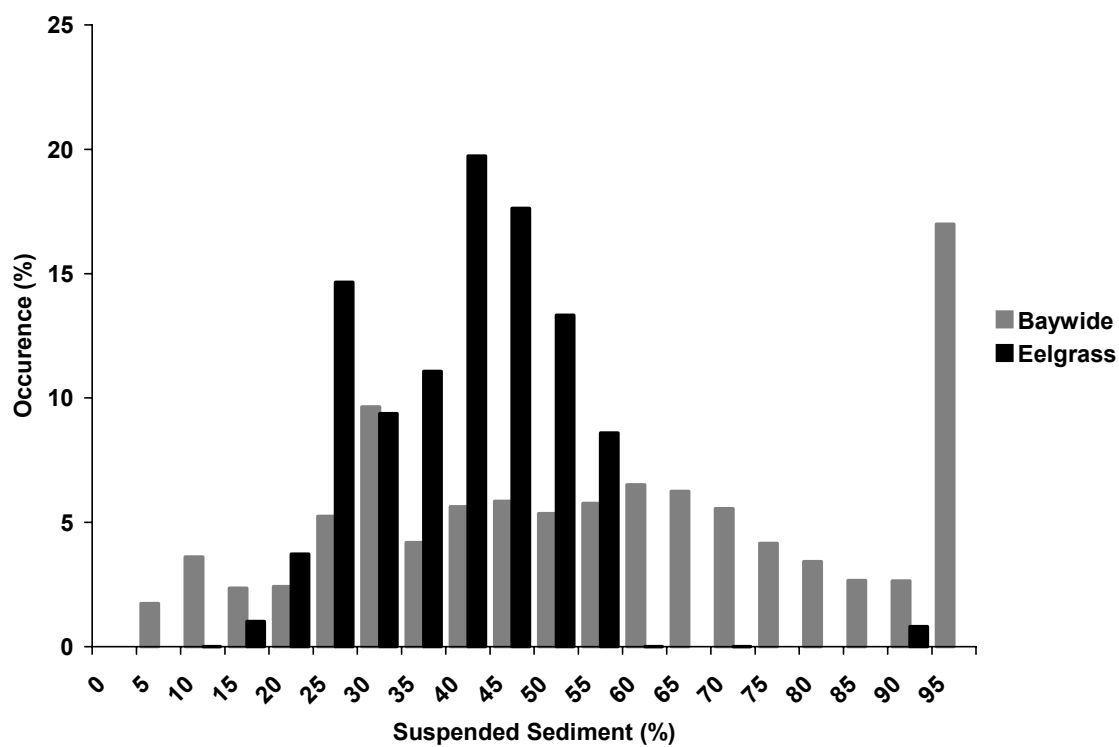


Figure 12. Predicted fluvial influence within eelgrass beds and throughout San Francisco Bay

SURVEY METHODS

EELGRASS

Eelgrass surveys were conducted from June to October 2003 using both acoustic and aerial survey methods. In order to manage eelgrass survey areas, the Bay was divided into one-square kilometer (247-acre) cells oriented in a UTM coordinate grid.

Acoustic Surveys

Merkel & Associates conducted sixty-five days of acoustic eelgrass surveys between June 4 and October 12, 2003. The timing of survey work was dependent on factors such as tides, depth of the survey areas, and weather. Survey work was conducted at high tides whenever possible in order to avoid submerged obstructions and to survey as close to shore as possible. Windy conditions on the Bay frequently prevented work from being conducted in the late afternoon and evening and side-scan operators often found that the calmest waters with the highest tides occurred in the middle of the night. As a result, much of the work was conducted during night-time hours when calmer water provided for better acoustic signal.

Survey techniques utilized a combination of aerial surveys, side-scan sonar, single-beam sonar, and diver ground-truthing to search for eelgrass beds. In-water surveys were conducted aboard the 7.3-meter (24-foot) R/V Merkel Johnson-150 and made use of side-scan and single beam sonar with the integration of a differential global positioning system (dGPS). Side-scan data were collected using a Marine Sonics side-scan sonar operating at 600 kHz. The side-scan towfish was positioned approximately 0.5 to 2.0 meters (1.6 to 6.6 feet) below the water surface, depending on the amount of water between the surface and the Bay bottom. To obtain good coverage and resolution, the side-scan was configured to provide a display range of 20 meters (66 feet) per channel (port and starboard). Transects were spaced 38 meters (125 feet) apart, which for a trackline overlap of one meter (3.3 feet) between parallel tracklines.

The dGPS receiver (Leica MX400) utilized the U.S. Coast Guard FM correction beacon and collected navigation and positioning data for the surveys. Navigational fixes were collected every second during data collection. Vessel position was maintained along predetermined transect lines using an on-board, real-time GPS display. Side-scan and fathometer data were collected and analyzed digitally using Marine Sonics Sea-Scan PC side-scan data collection software and Oceanic Imaging Consultants GeoDAS analysis software. The horizontal system resolution was approximately ± 2.0 meters (± 6.5 feet) as a combined error of the navigation system and side-scan equipment. All data were collected in decimal degrees latitude and longitude using NAD 83 in meters and subsequently converted and plotted on a coordinate grid using UTM coordinates in meters (NAD 27).

Aerial Surveys

Aerial eelgrass surveys were conducted on June 3, 16, and 17, 2003 and October 23, 2003. Aerial surveys were performed from a helicopter during daylight low tides and eelgrass was mapped using visual surveys, photography, and dGPS to mark coordinates of existing eelgrass beds. The outlines of eelgrass beds that were mapped during the aerial surveys aided in planning in-water surveys and also provided a large-scale perspective of eelgrass abundance and distribution. These surveys were primarily used to exclude large areas of intertidal mudflats from the requirements of in-water acoustic surveys by confirming the absence of eelgrass in these areas.

Helicopter overflights were typically flown between 150 and 60 meters (500 and 200 feet), but surveys occasionally were conducted as high as 1,500 meters (5,000 feet) to photograph large beds and were flown as low as 6 meters (20 feet) in order to distinguish eelgrass from widgeon grass (*Ruppia maritima*) in Suisun Bay. Three days of aerial surveys were completed before the in-water surveys were initiated to eliminate large areas of the Bay from the in-water eelgrass surveys and to review and document navigation hazards in the shallow waters surveyed at high tides.

Diver Ground-truthing

Acoustic records of eelgrass beds were ground-truthed by SCUBA divers who confirmed the presence of eelgrass in mapped beds. Diver ground-truthing was conducted at Bayfarm Island, Emeryville Flats, Crown Beach, Oakland Middle Harbor, Clipper Cove, Richmond Training Wall, Pt. Molate, Pt. San Pablo, Pt. San Quentin, Angel Island, Keil Cove, Coyote Point, and Richardson Bay (Figure 13).

BATHYMETRY

Bathymetric data were collected using a Furuno FCV-600L single-beam fathometer operating at a frequency of 200 kHz with the 15% beam width. The echo-sounder was mounted on the stern of the vessel and the transducer was located approximately 0.15 meters (0.5 feet) below the water surface. Fathometer data were recorded with the side-scan data and stored with time and xyz coordinate data.

SURVEY DATA INTERPRETATION AND EELGRASS MAPPING

Digital maps of the distribution of eelgrass throughout the Bay were created from the 2003 side-scan survey data. Following completion of the surveys, sonar traces were downloaded, processed, and geographically registered using ArcView Version 3.2a[®]. All plots were generated based on California State Plane Zone 3 (NAD 83). Two themes were created in the ArcView program – eelgrass habitat from the 2003 survey, and a “maximum documented eelgrass extents” layer that combined data from all spatially documented sources including such sources as Wyllie-Echeverria and Rutten (1989), SAIC & Merkel (1997a and b), Merkel & Associates (1997, 1999, 2001, 2003b, unpublished data), and Kitting (1993, 1998). In order to present these results on a scale that would be useful to resource managers, the San Francisco Bay Eelgrass Atlas was created (Merkel and Associates for Caltrans and NOAA Fisheries 2004). Each page of this atlas presents a 25-square kilometer (9.7-square mile) section of the Bay at a scale of 1:36,000. Bathymetry is presented in feet below MLLW.

Mapping techniques and areal coverage determination made use of a mix of analytical techniques (SAIC and Merkel & Associates 1997a and 1997b, Merkel 1988, 1992, 2003a and 2003b, U.S. Navy SWDIV 1994, 2000). Eelgrass beds in San Francisco Bay generally consist of clustered patches of eelgrass as opposed to continuous carpets, such as those observed in most other west coast bays and estuaries (Keith Merkel personal observation). For the purpose of this survey, a given eelgrass bed included many clustered eelgrass patches and the edges were determined by locating the greatest extent of the eelgrass patches within the survey area. Within the boundaries of the bed, eelgrass was subdivided into four cover categories defined by the percentage of total bottom coverage within the mapped bed. The cover classes used were less than 5%, 5%-20%, 20%-40%, and greater than 40% cover (Figure 14). Where individual plants were too far apart to be aggregated into beds, the individual plants were considered to define the boundaries of discrete beds. These patches, like many of the patches that occurred within the beds, were typically comprised of single plants with only a few turions.

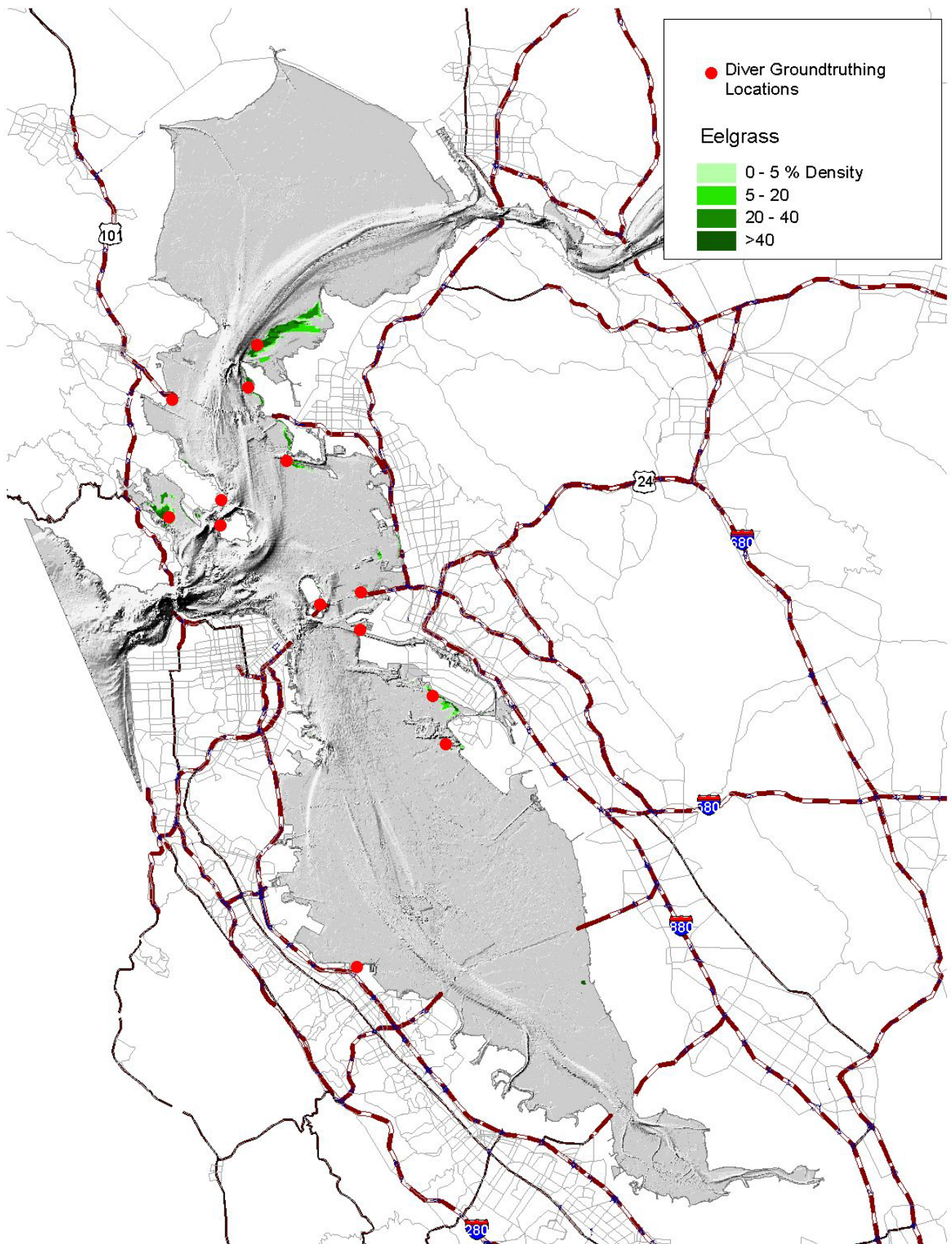


Figure 13. Location of diver ground-truthing points throughout San Francisco Bay.

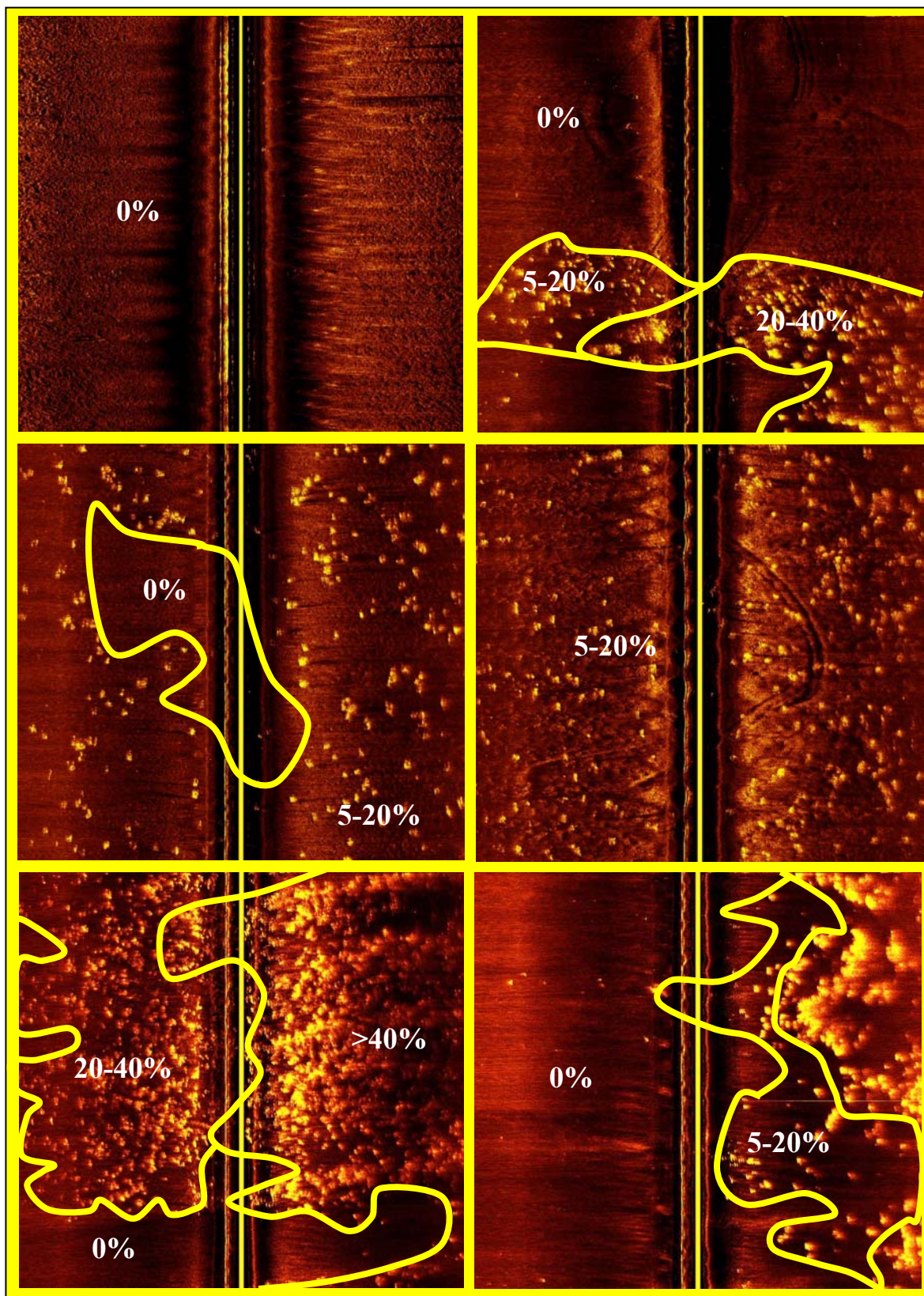


Figure 14. Categories of eelgrass percent coverage for map creation protocol

SURVEY RESULTS

CURRENT EELGRASS DISTRIBUTION

The Baywide Eelgrass Inventory mapped 1,165.7 hectares (2,880.5 acres) of eelgrass within San Francisco Bay during the summer of 2003 (Figures 15a 15b, and 15c). The coverage of eelgrass observed during the current survey was approximately 900% greater than the 128 hectares (316 acres) mapped during the previous baywide eelgrass survey (Wyllie-Echeverria and Rutten 1989). This major increase in eelgrass coverage is attributed at least in part to an increase in eelgrass coverage and in part to recent advances in mapping technology. In order to compare mapping technologies between the two surveys, it is helpful to compare eelgrass coverage between the same beds. Twenty-two eelgrass beds were mapped in 1987, and all of these were located and mapped during the current survey (Table 2). In addition to those beds mapped in 1987, eight major beds (e.g., Emeryville Flats) and several smaller eelgrass patches and individual plants were mapped during the current survey. The total coverage of the major beds (Table 2) was 1,129.2 hectares (2,790.3 acres) and the coverage of additional small eelgrass patches was 36.5 hectares (90.2 acres). Both the increased coverage of the major beds and the addition of the smaller patches contributed to the increased coverage during the 2003 survey.

The majority of the eelgrass in the Bay was located on the east shoreline between Point Pinole and Bayfarm Island (Table 2). A few solitary plants were recorded north of Point Pinole near Wilson Point and several individual plants and two small patches were observed south of the San Mateo Bridge along the Alameda shoreline. On the west shoreline, eelgrass was mapped from Point San Quentin in Marin County to Coyote Point south of the San Francisco Airport, but eelgrass was primarily located along the Marin County shoreline. On the western shoreline, the range of eelgrass distribution during the current survey was similar to the 1987 survey.

By far the largest eelgrass bed in the Bay is the Point San Pablo bed, which was located between Point Pinole and Point San Pablo north of the Richmond-San Rafael Bridge (Figure 15a, Merkel and Associates for Caltrans and NOAA Fisheries 2004, sheets 21 and 34). This bed was approximately 608.9 hectares (1,504.5 acres), which was 52.2% of the eelgrass coverage in the entire Bay. The Point San Pablo eelgrass bed occurs on a shallow shoal (approximately -1.5 to -0.5 meters [-4.9 to -1.6 feet] MLLW). The Point San Pablo eelgrass bed was also mapped as the largest bed in the Bay during the 1987 survey, although it was mapped as an order of magnitude smaller than during the current surveys (Wyllie-Echeverria and Rutten 1986).

The second largest eelgrass bed in the Bay was found in Richardson Bay near Sausalito in Marin County (Figure 15b, Merkel and Associates for Caltrans and NOAA Fisheries 2004, sheets 6 and 14). This bed was approximately 176.7 hectares (436.7 acres), the densest part of which was located among the boat moorings and near the marinas on the western side of the Bay. Eelgrass in Richardson Bay occurred between -3.0 and -0.5 meters (-9.8 and -1.6 feet) MLLW.

Table 2. Location and acreage of major eelgrass beds in San Francisco Bay during the 1989 (Wyllie-Echeverria and Rutten) and current 2003 surveys.

LOCATION	1987		2003		ATLAS PAGE
	(ha.)	(ac.)	(ha.)	(ac.)	
San Pablo Bay	50.2	124	608.9	1,504.5	21, 34
Point Orient	1.2	3	0.9	2.3	21
Naval Supply Depot	4.9	12	31.2	77.0	21
Point Molate Beach	10.5	26	13	32.0	22
Toll Plaza West	0.2	0.5	0	0.0	22
Toll Plaza East	0.2	0.5	1	2.5	22
Point Richmond, North	2.8	7	9.7	24.0	22
Point Richmond, South	1.6	4	26.5	65.6	22
Richmond Breakwater, North	7.3	18	7.7	19.0	22, 35
Richmond Breakwater, South	2.8	7	35	86.3	23, 36
Brickyard Cove	-	-	7.2	17.7	22
Emeryville (breakwater)	5.3	13	11.6	28.7	47
Emeryville Flats	-	-	8.7	21.6	37
Yerba Buena Island	-	-	0.7	1.7	37
Treasure Island	-	-	2.1	5.1	37
Alameda	22.3	55	109	269.9	49, 56
Bayfarm, North	0.8	2	1.8	4.4	49, 56
Bayfarm, South	1.6	4	51.8	127.9	49, 56
Coyote Point	0.4	1	0.2	0.6	42
Richardson Bay	5.3	13	176.7	436.7	6, 14
Angel Island West	1.2	3	0.6	1.6	14
Angel Island South	-	-	0.3	0.7	15, 24
Angel Island East	-	-	1.1	2.8	23
Belvedere Cove	2.0	5	8.8	21.8	14
Point Tiburon	0.4	1	0.1	0.2	14
Keil Cove	4.0	10	8.3	20.4	14
Paradise Cove, North	1.6	4	5.3	13.0	13
Paradise Cove, South	1.2	3	0.1	0.2	14
Pt. San Quentin	-	-	0.2	0.5	13
Pt. San Pedro	-	-	0.6	1.6	12
Minor Beds and Patches	-	-	36.5	90.2	various
TOTAL	127.9	316	1,165.7	2,880.5	

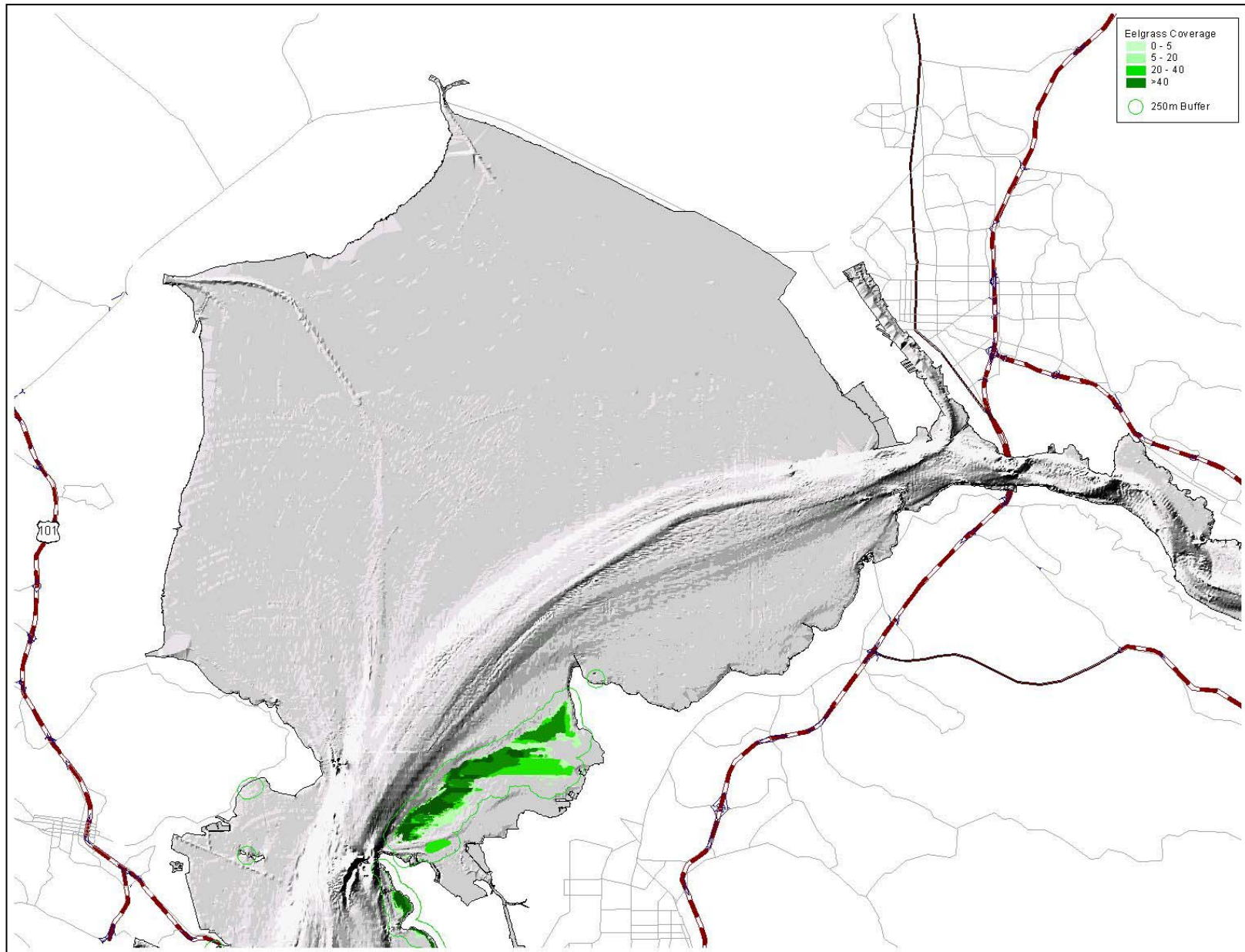


Figure 15a. Northern San Francisco Bay eelgrass distribution

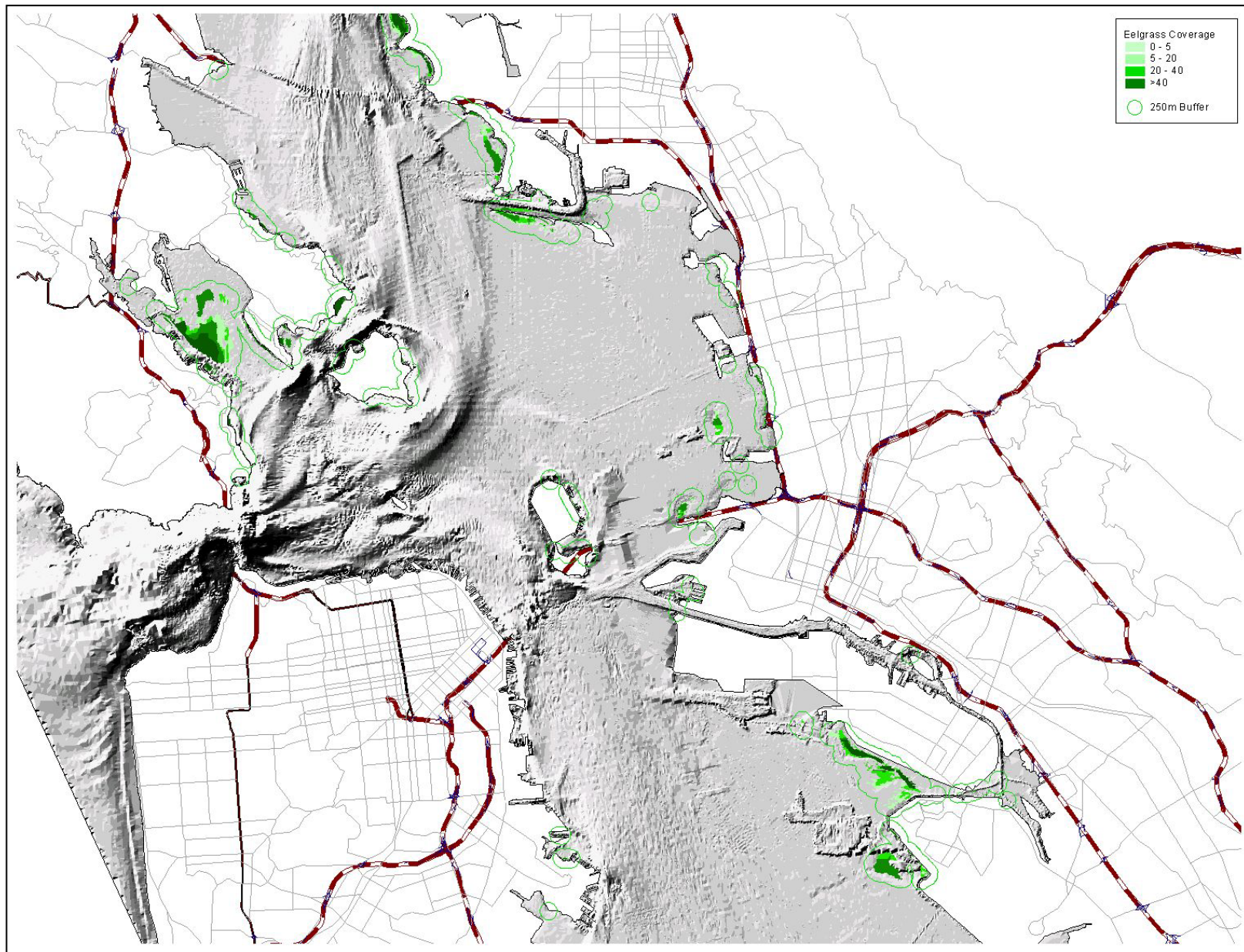


Figure 15b. Central San Francisco Bay eelgrass distribution

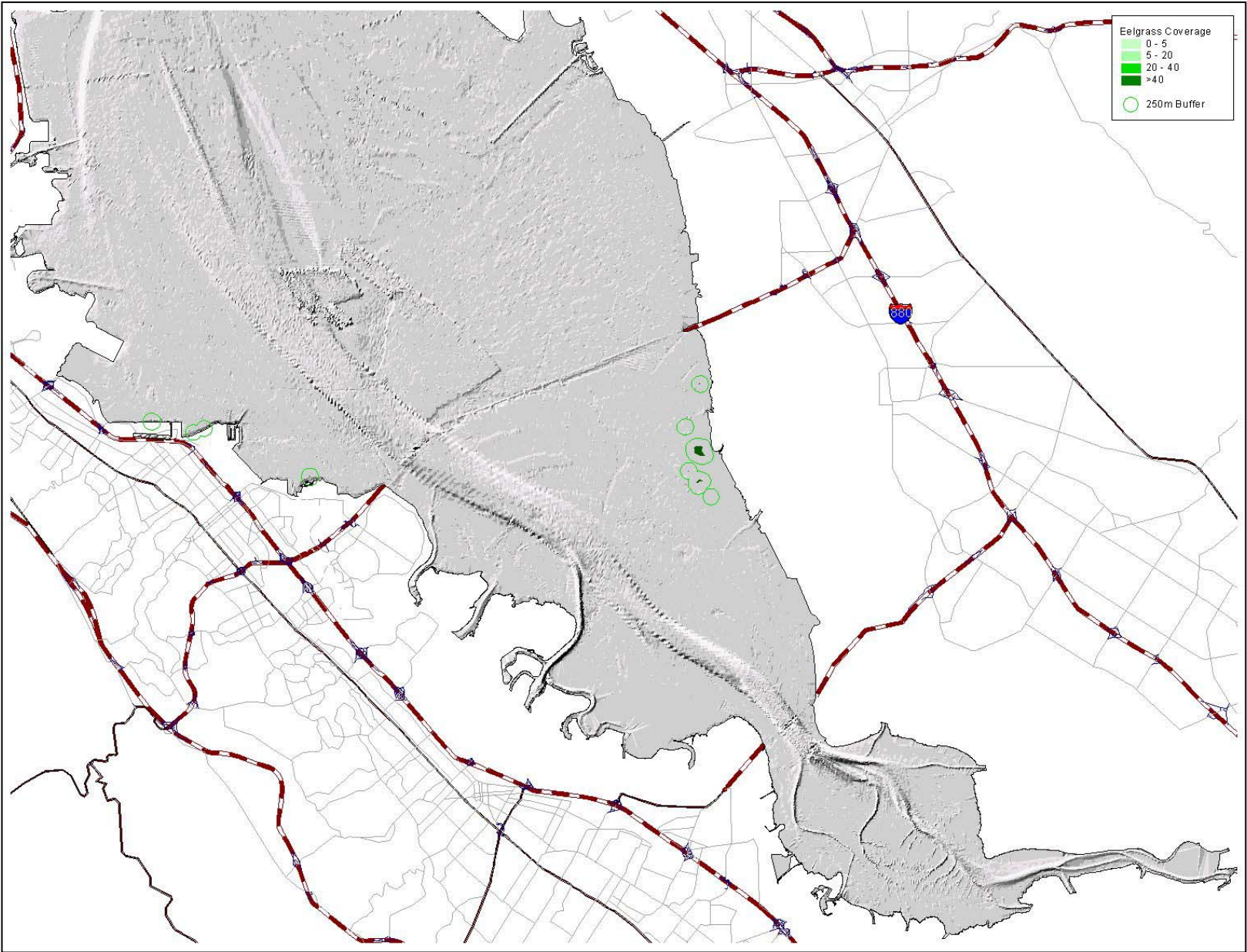


Figure 15c. Southern San Francisco Bay eelgrass distribution
San Francisco-Oakland Bay Bridge East Span Seismic Safety Project

HISTORICAL DISTRIBUTION RANGE

Eelgrass coverage within San Francisco Bay is in a constant state of flux. Thus, understanding the potential eelgrass habitat areas in addition to the beds that were mapped during the 2003 survey is crucial to determining the extent and distribution of areas within the Bay that are potentially suited to supporting eelgrass under various conditions. While it is not possible to exclude many shallow areas of the Bay as unsuited to support eelgrass, many areas that did not support eelgrass during the present survey have been previously documented to support eelgrass. For this reason a map layer has been prepared of the maximum documented extent of eelgrass (Merkel and Associates for Caltrans and NOAA Fisheries 2004). This has been done in anticipation of future updates as additional survey data becomes available in future years. The maximum documented eelgrass extent is a combination of all known eelgrass surveys in the Bay where credible and accurate spatial data exist. At the time this map was produced, the maximum historical extent of eelgrass was documented to be 1,392.4 hectares (3,440.6 acres).

BATHYMETRY

Bathymetry for the Bay has been derived from numerous survey sources that date over extended periods (NOAA 2002, Coast and Harbor Engineering unpublished data, the Port of Oakland unpublished data, Merkel & Associates current survey). In most instances, the bathymetry has been collected on larger survey vessels that have avoided the extreme shallows of the Bay margins. As a result, bathymetric survey data are sparse in the shallowest areas that support eelgrass beds. To improve upon this condition, bathymetric data from the present survey has been used to supplement prior survey data and provide a more accurate bathymetry range for eelgrass.

Using the bathymetric data, it has been possible to determine the elevation range distribution of eelgrass within the Bay (Figure 16). The depth distribution of eelgrass is extremely narrow and is indicative of the turbid nature of the Bay. A full 98.8% of eelgrass mapped during the 2003 surveys occurred within a depth range from -1.77 to 0.40 meters (-5.8 to 1.3 feet) MLLW. Perhaps even more remarkable is the fact that 94.0% of all mapped eelgrass occurred within a 1.6-meter (5.2-foot) range between -1.6 and 0.0 meters (-5.2 and 0.0 feet) MLLW, which is similar to the range observed for clear and turbid sites, respectively (Zimmerman *et al* 1995).

REGIONAL COMPARISON

Existing eelgrass beds cover approximately 1% of San Francisco Bay, which is at least an order of magnitude less than other large California estuarine systems (Table 3). However, due to the large size of the Bay, even a minor proportional representation amounts to substantial eelgrass resources on a statewide basis and the importance of this resource should not be undervalued in resource management decisions. While San Francisco Bay eelgrass resources accounted for only a small portion of the total Bay habitat area, the eelgrass beds of the Bay rank second only to Humboldt Bay in gross eelgrass area. Further, given the highly dynamic nature of San Francisco Bay eelgrass beds and the extensive areas of the Bay that are considered to be marginal for eelgrass, only minor variations in physical environmental parameters such as river flows, sediment loads, or sea level could significantly alter the extent of eelgrass coverage.

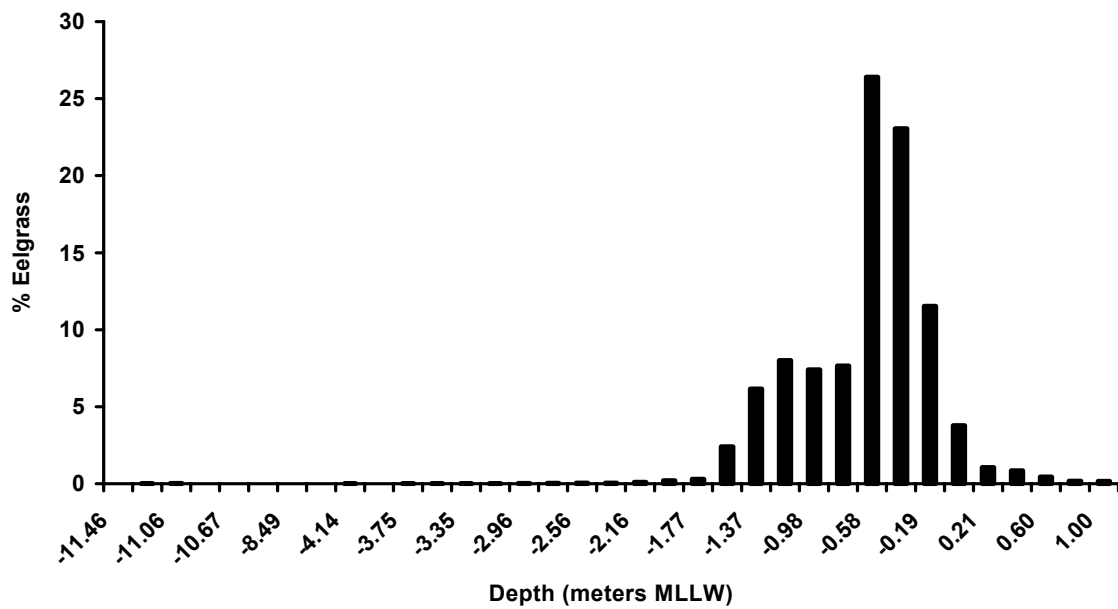


Figure 16. Depth distribution of eelgrass within mapped beds in San Francisco Bay

Table 3. Comparison of eelgrass coverage in estuarine systems on the West Coast of North America.

System	Eelgrass Coverage (acres)	Percent Coverage
Mission Bay ¹	1,210	54%
San Diego Bay ²	1,626	14%
Humboldt Bay ³	4,821	10%
Tomales Bay ⁴	965	13%
San Francisco Bay	2,881	1%

¹Merkel & Associates 2003²U.S. Navy 2000³McBride et al., unpublished data⁴Spratt as reported in Wyllie-Echeverria 1990

The most likely factor limiting eelgrass coverage in the Bay is the low-light levels available to eelgrass in the North and South Bay regions. More than 4.5 million cubic meters (6 million cubic yards) of sediment enter the Estuary per year from approximately 20 major freshwater streams and rivers (Goals Project 1999). In addition to the sources of sedimentation from freshwater flows, there is additional suspended sediment resulting from tidal currents and wind-driven waves. The Central Bay region has the clearest water, followed by the South Bay and North Bay, and lastly Suisun Bay. The Suisun and North Bay regions are by far the most turbid of any area in the Estuary due to freshwater input of the Delta. In addition to presence of a substantial amount of sedimentation in the Bay, the sediment is also retained within the regions of the Estuary that are far from the mouth of the Bay where it is constantly put into or kept in suspension by chronic wind-waves.

Although the North Bay region is likely the most turbid area of the Bay, the majority of eelgrass technically occurs in this region because of the Point San Pablo eelgrass bed. The Point San Pablo eelgrass bed is unique in the North Bay because it is well flushed by the clearer waters of the deep channel around Point San Pablo.

FUTURE WORK

The completion of the 2003 eelgrass inventory provides considerable insight into the extent and distribution of eelgrass within San Francisco Bay. However, it is as much a beginning as an endpoint to understanding this resource within the Bay. Research has already been undertaken to understand the similarities and differences between San Francisco Bay and other areas where more extensive work has been performed. Presently, additional resource characterization is underway as elements of the current study. This work is outlined below.

CLASSIFY EELGRASS BEDS

Data collected during the field surveys will be used to provide a description of the environmental characteristics that typify eelgrass beds within the Bay. Environmental descriptions of eelgrass beds will include water temperature, light availability, and sediment grain size. In addition, the genetic relationships of eelgrass from sampled beds will be analyzed using genetic markers, specifically microsatellite loci, to characterize perennial versus annual beds and levels of genetic variation. These data will be integrated into the final analysis of distribution and dynamics of eelgrass populations within San Francisco Bay.

It is recognized that a one-time survey will not adequately capture the high degree of variability exhibited in eelgrass coverage within the Bay over the course of a year or many years. As a result, all analyses are limited to the description of static conditions at the time of the survey. However, as part of the current program, a refined eelgrass model that incorporates the eelgrass maps for the

current survey and data on environmental parameters will be published, which will provide a prediction of the maximum extent of suitable eelgrass habitat within the Bay.

REFINE PREDICTIVE EELGRASS MODEL

During the 2003 field surveys, 8.6% of the area that was identified by the pre-survey screening model as being suitable for eelgrass actually supported eelgrass and examining the maximum documented extents, as much as 10.2% of this area was found to presently support or have supported eelgrass in the past. While the proportion of occupied habitat derived from the screening model is quite high, the model has also captured considerable area that was not occupied in 2003 and has not been documented to support eelgrass. For example, a large crescent of habitat was predicted to be suitable to support eelgrass in the shallow regions of San Pablo Bay (Figure 12a), but the current survey revealed no eelgrass in these portions of San Pablo Bay. In addition, the model predicted eelgrass along the Alameda shoreline south of the Oakland International Airport and this area was also found to be without eelgrass during the 2003 surveys. These two areas where eelgrass was erroneously predicted by the model have some common environmental conditions. Both areas support shallow mud-bottoms subject to high wave energies, but low circulation relative to other regions of the Bay. The pre-survey screening model predicted significantly more eelgrass than was mapped during 2003 partly because it was constructed using few niche defining parameters over which broad tolerance ranges were used to ensure that the model captured all possible eelgrass habitats; the goal was to ensure no eelgrass would be missed during the comprehensive inventory effort.

Although the pre-survey screening model predicted eelgrass in several areas where it did not occur during the 2003 survey, a more refined predictive eelgrass model is being developed to provide a more narrowly defined predictor of habitat suitability for eelgrass throughout the Bay. Due to the dynamic nature of eelgrass coverage in the Bay, a robust predictive model of suitable eelgrass habitat, in addition to the mapped extent of eelgrass, will provide resource managers better capabilities to detect and track changes in eelgrass resources within the Bay. Potential eelgrass habitat may not currently support eelgrass due to environmental conditions or intermittent local extirpations. However, these areas may support eelgrass under different prevailing environmental regimes, which can fluctuate annually and interannually.

In order to create a refined model that will be predictive of eelgrass habitat in the Bay, the pre-survey screening model is being refined with data gathered during the 2003 surveys. The updated eelgrass distribution and more accurate bathymetry will allow for more accurate characterization of environmental parameters within eelgrass beds, allowing for a more exact model. Subsequent ELVS model runs will be conducted in order to identify the stability of suitable site conditions and areas that may support eelgrass under moderately altered environmental conditions.

CONCLUSIONS

The Baywide Eelgrass Inventory and Resource management Program will provide a unique tool for developing NOAA's subtidal habitat goals for San Francisco Bay. When the predictive eelgrass model is refined and analyzed in conjunction with the results of the 2003 eelgrass survey, resource managers will be able to create an appropriate long-term sampling program that will adequately characterize seasonal and annual variability within the various eelgrass populations. This information will provide a baseline of current eelgrass distribution, potential habitats and ecological knowledge that will enable realistic and quantified goals to be set for eelgrass management.

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APPENDIX A: PHOTOS OF SAN FRANCISCO BAY EELGRASS



Southern End of Point San Pablo Eelgrass Bed, between Point San Pablo and Point Pinole, Contra Costa County



Eelgrass at Point Molate, Contra Costa County



Eelgrass at Keil Cove, Tiburon, Marin County



Eelgrass in Richardson Bay near Sausalito, Marin County



Eelgrass in Richardson Bay near Sausalito, Marin County



Low Tide Eelgrass at Emeryville Shoal, Oakland, Alameda County



Solitary Patch of Eelgrass South of San Mateo Bridge along the Alameda County Shoreline