# SAN FRANCISCO BAY EELGRASS INVENTORY

## October 2014



*Submitted to:*

**National Marine Fisheries Service**
777 Sonoma Avenue, Suite 325
Santa Rosa, CA 95404-6515

*Submitted by:*

**Merkel & Associates, Inc.**
5434 Ruffin Road
San Diego, CA 92123
ph. (858) 560-5465
fx. (858) 560-7779

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Eelgrass mapping is based on acoustic and aerial surveys of October 2014. Eelgrass distribution along the shoreline, and within various portions of the bay was refined using site specific survey data and diver ground truthing.

Eelgrass bed density classification is most accurate near the central portion of the range and is less accurate near the extremes of any of the defined density ranges where interpretive error may occur. Eelgrass data reflects a particular period in time and are anticipated to be a seasonally and stochastically dynamic.

Note: Charts are for planning and management purposes only. Information application is limited by survey scale and some error is expected. Information is not to be used for navigation or specific project applications.

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# 2014 SAN FRANCISCO BAY EELGRASS INVENTORY
## San Francisco Bay, California

## BACKGROUND

Eelgrass (*Zostera marina* L.) is a native plant indigenous to the soft-bottom bays and estuaries of the Northern Hemisphere. It occurs along the Pacific coast of North America from the Bering Straits down to lower Baja California. Although it is naturally restricted to a very limited amount of suitable habitat, it is the most widely distributed marine angiosperm in the Northern Hemisphere (den Hartog 1970). Because of the presence of eelgrass within protected shallow coastal waters, it has historically suffered considerable losses to degradation of water quality, dredging and filling, shading by over water structures, and changes in circulation patterns. Eelgrass abundance has declined worldwide due to increased anthropogenic effects as well as climate induced changes (Short and Wyllie-Echeverria 1996).

Eelgrass has been termed a "foundation species" due to its habitat forming characteristics that create unique biological and physical 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." It is also considered an important element of Essential Fish Habitat regulated under the Magnuson-Stevens Fishery Conservation and Management Act and has been designated as a Habitat Area of Particular Concern (HAPC) under the Act.

Until recently, very little has been known about the distribution or characteristics of eelgrass beds within San Francisco Bay; and within the past two decades, the need to establish a baseline of eelgrass (*Zostera marina*) coverage in San Francisco Bay has become apparent. While management and restoration of Bay Area marshlands has been a conservation priority, important subtidal habitats such as eelgrass have historically not received the same degree of attention. This has changed in recent years with a focused effort now being put into the San Francisco Bay Subtidal Habitat Goals Project, following the course of the earlier San Francisco Bay Area Wetlands Ecosystem Goals Project (Goals Project 1999). The San Francisco Bay Subtidal Habitat Goals Project (California State Coastal Conservancy et al. 2010) is a collaborative effort to establish a comprehensive and long-term management vision for research, restoration, and management of the subtidal habitats of San Francisco Bay. The project is an interagency partnership between the San Francisco Bay Conservation and Development Commission (BCDC), the California State Coastal Conservancy, National Marine Fisheries (NOAA), and the San Francisco Estuary Partnership. Based on present efforts to improve upon conservation, restoration, and enhancement of subtidal resources, there has been an increased need for information regarding the status, distribution, and importance of eelgrass within the San Francisco Bay ecosystem and a broader coast-wide context.

Construction activities for the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project (SFOBB Project) resulted in significant impacts to eelgrass and triggered mitigation requirements to compensate for these impacts. As a result, the California Department of Transportation (Caltrans) committed significant funding through a jointly managed effort with NOAA Fisheries to complete a Baywide Eelgrass Inventory and Resource Management Research Program (Research Program).

This effort led to many developments in the state of knowledge regarding eelgrass distribution and condition within San Francisco Bay. These included completion of a comprehensive 2003 baywide eelgrass survey (Merkel & Associates 2004), physical and ecological characterization of eelgrass habitat in San Francisco Bay (Merkel & Associates 2005), genetic characterization of eelgrass beds based on microsatellite analyses (Talbot, et al. 2004), and development of a predictive model for eelgrass distribution within San Francisco Bay (Merkel & Associates 2005). The Research Program also funded the development and testing of the regional eelgrass monitoring strategy for San Francisco Bay (Merkel & Associates 2009a).



*Dungeness crab in eelgrass bed*

A large-scale survey of the known and potential occurrence of eelgrass throughout San Francisco Bay was completed over 25 years ago (Wyllie-Echeverria and Rutten 1989); and due to the advances in acoustic survey technology over the past two and a half decades, more accurate mapping is now available for inventory of subtidal beds. The mapping work completed as a part of the 2003 survey identified just how large the data gaps were with respect to eelgrass distribution. The 2003 eelgrass survey revealed eight times the eelgrass habitat area previously known, along with a greater geographic distribution than was previously known in San Francisco Bay (Merkel & Associates 2004). In addition, the predictive model for eelgrass suggested even greater capacity for the Bay to support eelgrass may exist under good climatic conditions. As a result, additional monitoring and recurrent surveys have become a priority in supporting resource management.

Recognizing the dynamic nature of the eelgrass distribution patterns, the extensive model prediction for suitable eelgrass habitat, and a number of detections of eelgrass at widespread locations beyond previously known distribution, NOAA Fisheries determined that comprehensive baywide surveys for eelgrass should be conducted on a recurrent five year basis. As a result, a second baywide survey was conducted in 2009 (Merkel & Associates 2009b). The surveys were again completed five years later in 2014 following a long period of drought and facing a predicted El Niño event.

The 2014 the survey was conducted by Merkel & Associates under contract to NOAA Fisheries and is the subject of this current report. This survey effort was undertaken in October 2014. The format of the document, including much of the background and discussion as well as the Eelgrass Atlas map sheets (Appendix A), follows and builds upon the 2003 and 2009 eelgrass survey reports (Merkel & Associates 2004, 2009b). By adopting this format, it is anticipated that greater utility may be garnered from the presentation of the current survey results.

Differing from prior baywide surveys, the present survey implemented the use of interferometric sidescan sonar as opposed to conventional sidescan sonar. This sonar system integrates wide swath bathymetric data collection along with the acoustic backscatter of sidescan sonar. For the first time, this survey allowed for the collection of comprehensive bathymetric data within mapped eelgrass beds. The results have been an improved understanding of the vertical distribution within the Bay.

**PRIOR EELGRASS INVENTORY HISTORY**

In the late 1920s, eelgrass was reported as "an abundant species along the shores of San Francisco Bay" (Setchell 1929). As documented in the San Francisco Bay Area Wetlands Ecosystem Goals Project (1999), approximately 8,100 hectares (20,000 acres) of deep and shallow bay habitats have been lost since the 1800s as a result of bay fill and sediment deposition. Considering that almost all of the habitat losses have resulted along the shallow Bay margins, it is unlikely that eelgrass escaped impact from these historic losses. However, as a point of fact, the historic status of eelgrass in San Francisco Bay is not well known and it cannot be fully determined whether eelgrass habitat has been substantively reduced from prior levels. Because Setchell's early work did not include comprehensive maps and most of the sites referenced in 1929 remain today, it is not possible to fully determine if significant declines in eelgrass within San Francisco Bay have occurred between 1929 and present. While there is some reason to believe significant declines have occurred, even today there are many places on San Francisco Bay where eelgrass can be described as "an abundant species along the shores".

In 1987, about 60 years after Setchell's work, the first attempt to inventory eelgrass within the quarter million acre San Francisco Bay revealed only 316 acres (128 hectares) of eelgrass throughout San Francisco Bay (0.1 percent total bay bottom coverage) (Wyllie-Echeverria and Rutten 1989, Wyllie-Echeverria 1990). A decade later, sidescan sonar surveys of the San Pablo Peninsula, documented over 400 acres (162 hectares) of eelgrass (SAIC and Merkel & Associates 1997a, 1997b). The acoustic survey results from the 1997 survey, suggested either extremely dynamic conditions within the existing beds, an underestimation of eelgrass during the 1987 studies, or a combination of both factors (Thompson et al. 1997).

In 2003, a comprehensive "benchmark" eelgrass survey was undertaken using a combination of sidescan sonar and helicopter aerial investigations performed at low tide. The principal purpose of the aerial survey component was to rule out the presence of eelgrass within large areas of San Francisco Bay considered to be potentially suitable to support eelgrass based on the application of a pre-screening model. As a result, in 2003 eelgrass was mapped using sidescan sonar and diver, as well as low tide visual inspection ground truthing (Merkel & Associates 2004). This survey revealed a total of 2,628 acres (1,061 hectares) of eelgrass.

In 2009, the comprehensive benchmark survey was repeated under contract to Caltrans and survey oversight of NOAA Fisheries. This survey relied on a combination of helicopter-based aerial survey methods to map intertidal and highly detectible subtidal eelgrass coupled with sidescan sonar surveys for deeper bed mapping. The aerial survey mapping provided enhanced time and cost efficiencies; however due to the extensive presence of macroalgae that may be mistaken for eelgrass, and high epiphytic loading of eelgrass beds that make them mistakable for algal beds, the retained use of a helicopter survey platform allowed both elevated photography and low elevation inspections and truthing. Adequate overlap was used to seam the two methodologies together. At this time, it was determined that the Bay supported 3,707 acres of eelgrass (1,500 hectares) (Merkel & Associates 2009b). This represented an increase of over a thousand acres of eelgrass from the prior benchmark year survey and achieved the greatest single season eelgrass coverage.

## 2014 EELGRASS SURVEY AND ANALYSIS METHODS

### *FIELD SURVEYS*

Eelgrass surveys were conducted using acoustic survey methods in October 2014 and aerial survey methods in early November 2014. In order to manage eelgrass survey areas, San Francisco Bay was divided into one-square kilometer (247-acre) cells oriented in a Universal Transverse Mercator (UTM) coordinate grid. The study area for the program encompassed San Francisco Bay, omitting the waters of Suisun Bay. Surveys extended through waters bounded by the Carquinez Bridge in the North Bay, Dumbarton Bridge in the South Bay, and the Golden Gate Bridge. The survey area was subsequently extended upstream of the Benicia-Martinez Bridge when it was discovered that eelgrass continued along the shorelines above the Carquinez Bridge. During the 2003 surveys, widgeongrass (*Ruppia maritima*) was identified by helicopter above the Carquinez Bridge. This observation is now known to be erroneous as the vegetation above the straits and on into the Sacramento Delta is pondweed (*Stuckenia* sp.). Eelgrass was previously identified above the Carquinez Bridge in 2009 and was identified to extend above the Benicia-Martinez Bridge during the current 2014 survey. For this reason, both sidescan sonar and aerial surveys were extended well beyond the last upstream occurrence of eelgrass.

### ***Aerial Surveys***

Aerial eelgrass surveys were conducted on November 4-5, 2014. Aerial surveys were performed from a helicopter during daylight low tides. During the surveys, beds were located and photographed at both vertical and oblique angles. In addition, vertical digital video was collected. Helicopter overflights were flown at a mid-elevation between 3,000-4,200 feet (900 and 1280 meters) and at a low elevation 500 to 200 feet (60 to 150 meters). Where necessary to confirm identification, the helicopter was lowered to as little as 20 feet (6 meters) off the water surface such that clear visual inspection of plant material or other objects was possible. Low altitude inspections and on-the-water groundtruthing were critical to avoiding the erroneous mapping of large beds of the red alga, *Gracilariopsis andersonii,* as eelgrass or making the reciprocal mistake of identifying eelgrass with heavy epiphyte loading as an algal bed. Several large beds of *Gracilariopsis* were noted, particularly in Richardson Bay, at Hunters Point, Pt. Pinole, shoreward of the Emeryville Marina, and within San Leandro Bay.

A differential GPS (dGPS) was used to collect additional coordinates for on-water features that are not present or visible on orthorectified aerial imagery for San Francisco Bay. These additional points on channel markers, moorings, duck blind corners, and sunken vessels provided additional control points for registration of imagery collected during the survey flights.

Aerial survey video and vertical photographs were rectified using orthorectified shoreline imagery and on-water registration points collected during the flights. Differing from the 2003 survey, the registered high-resolution low altitude photographs were used for eelgrass mapping during the 2009 and 2014 surveys. The photographs allowed for detailed mapping of many of the shallow edges of eelgrass beds and also allowed mapping of eelgrass within highly constrained areas such as within the interior of dilapidated wharf structures. Photographs were not used for mapping when the resolution or image quality was such that it was not possible to assign density classes to mapped eelgrass. At that point, sidescan sonar was employed as the primary mapping tool, and the first sonar trackline was established within the boundary of eelgrass that could be mapped from photographic data and then extended outward past the deeper fringes of the bed.



*Cabin cruiser grounded on Berkeley Shoal eelgrass beds trying to free itself during low tide.*

The use of aerial imagery for mapping in the 2009 and 2014 surveys was of substantial benefit in two ways. First, it significantly reduced the amount of on-water survey, thus resulting in significant cost savings over a full sonagraphic survey. Second, it effectively allowed mapping of much of the shallowest portion of existing eelgrass beds thus lengthening the effective sonar survey window by reducing tidal constraints. This gain in efficiency, however, was accompanied by a reduction in the spatial accuracy of mapping in shallow environments. Less than 12 percent of the photographs and 2 percent of the video shot were used to develop registered images for mapping. This limitation was driven by video image quality and the need for true vertical photos with available registration points. In some instances, photo-registration error was as much as ±26 feet (±8 meters) horizontal compared to an estimated ±7 feet (±2 meters) error range for sonagraphic survey data. Another benefit of the aerial survey investigations was the ability to obtain an overview of eelgrass bed condition and readily apparent anthropogenic impacts to eelgrass resources during the survey.

***Acoustic Surveys***

M&A conducted nearly continuous day and night acoustic eelgrass surveys between October 13 and October 24, 2014 using low tide periods for crew changes and fueling of the survey vessel. The timing of survey work was dependent on factors such as tides, depth of the survey areas, and weather. Survey work completed in the shallowest waters was conducted at the highest tides in order to avoid submerged obstructions and maximize survey swath coverage. Windy conditions on San Francisco Bay frequently prevented work from being conducted in the late afternoon and evening, and sidescan operators often found that the calmest waters with the highest tides occurred in the middle of the night and early in the morning. As such, considerable survey work in areas of high wind exposure was conducted at night and during the early morning periods.

Sonagraphic surveys were undertaken using an interferometric sidescan sonar system. The interferometric sidescan system consisted of a dual channel hull mounted sonar operating at 468 kHz that integrates a vessel motion sensor to correct for vessel pitch, heave, and roll; a sound velocity sensor that corrects for speed of sound in water related to density differences resulting from changes in temperature and salinity; and a dual antenna differential GPS that provides submeter vessel positioning and correction for vessel yaw. Because the position of the interferometric sidescan sonar head is rigidly fixed to the vessel, the positional error is dramatically reduced from that associated with other mapping methodologies, including traditional towed sidescan sonar. Further, the system greatly reduces the complications of vegetation and other features that can foul towed sonar systems and limit survey coverage. With the survey system utilized in this effort, absolute positional error for eelgrass mapping is approximately ±1-2 meters. The relative positional error is estimated at ±0.5 meter as the GPS positional error is substantially nullified across short distances represented within sonar mosaics. The interferometric sidescan was set to 31 meters on the port and starboard channels such that the full swath was 62 meters wide.

### ***Ground-Truthing***

Acoustic records of eelgrass beds were ground-truthed by visual observation of plants on the surface as well as use of a pole camera to observe submerged plants. A cast-rake ground-truthing was also used for ground truthing.

#### *DATA INTERPRETATION AND EELGRASS MAPPING*

Digital maps of the distribution of eelgrass throughout San Francisco Bay were created from the 2014 survey data. Following completion of the surveys, sonar traces were downloaded and processed into rectified mosaic images in a GeoTiff format using Chesapeake Technologies, Inc. Sonar Wiz.

Eelgrass was mapped by manually digitizing from registered sidescan mosaics and aerial photographs using ESRI ArcGIS software. Mapping techniques and areal coverage determination made use of a mix of analytical techniques developed and employed in prior large-scale eelgrass surveys (SAIC and Merkel & Associates 1997a and b, Merkel 1988, 1992, 2003a, 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 systems (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 bottom cover categories defined by the percentage of total bottom coverage within the mapped bed. The cover classes used were 1-5 percent, 5-20 percent, 20-40 percent, and greater than 40 percent cover (Figure 1). The same reference examples for sidescan imagery have been used from 2003 through the present survey to ensure consistency in eelgrass density class interpretation over time. Digitizing of eelgrass was typically performed at a standard view scale of 1:600 in order to minimize variance in map detail and interpretation of bed cover class and aggregation of eelgrass in cover classification polygons.

Where individual plants were too far apart to be aggregated into beds, they 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 and were thus mapped at the highest bottom coverage class of >40 percent.

In addition to creating a 2014 eelgrass coverage theme, a composite theme of maximum documented eelgrass extents was created from all known spatially documented sources including the present survey, the 2009 baywide survey (Merkel & Associates 2009b), the 2003 baywide survey (Merkel & Associates 2004), and such sources as Wyllie-Echeverria and Rutten (1989), SAIC & Merkel (1997a and b), Merkel & Associates (1997, 1999, 2001, 2003b, 2008, 2009, unpublished data), and Kitting (1993, 1998). In order to present these results on a scale that would be useful to resource managers, the 2014 Eelgrass Atlas was created. Each page of this atlas presents a 9.7-square mile (25-square kilometer) section of San Francisco Bay at a scale of 1:36,000. Bathymetry is presented in feet below mean lower low water (MLLW).

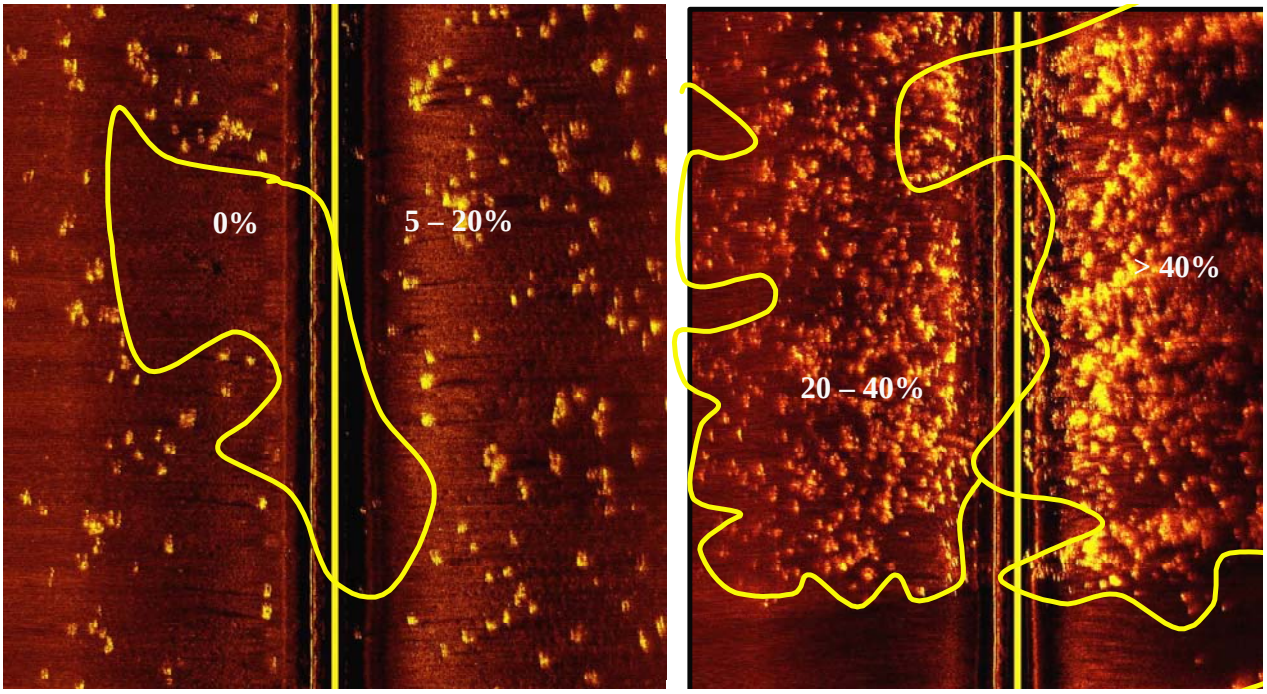


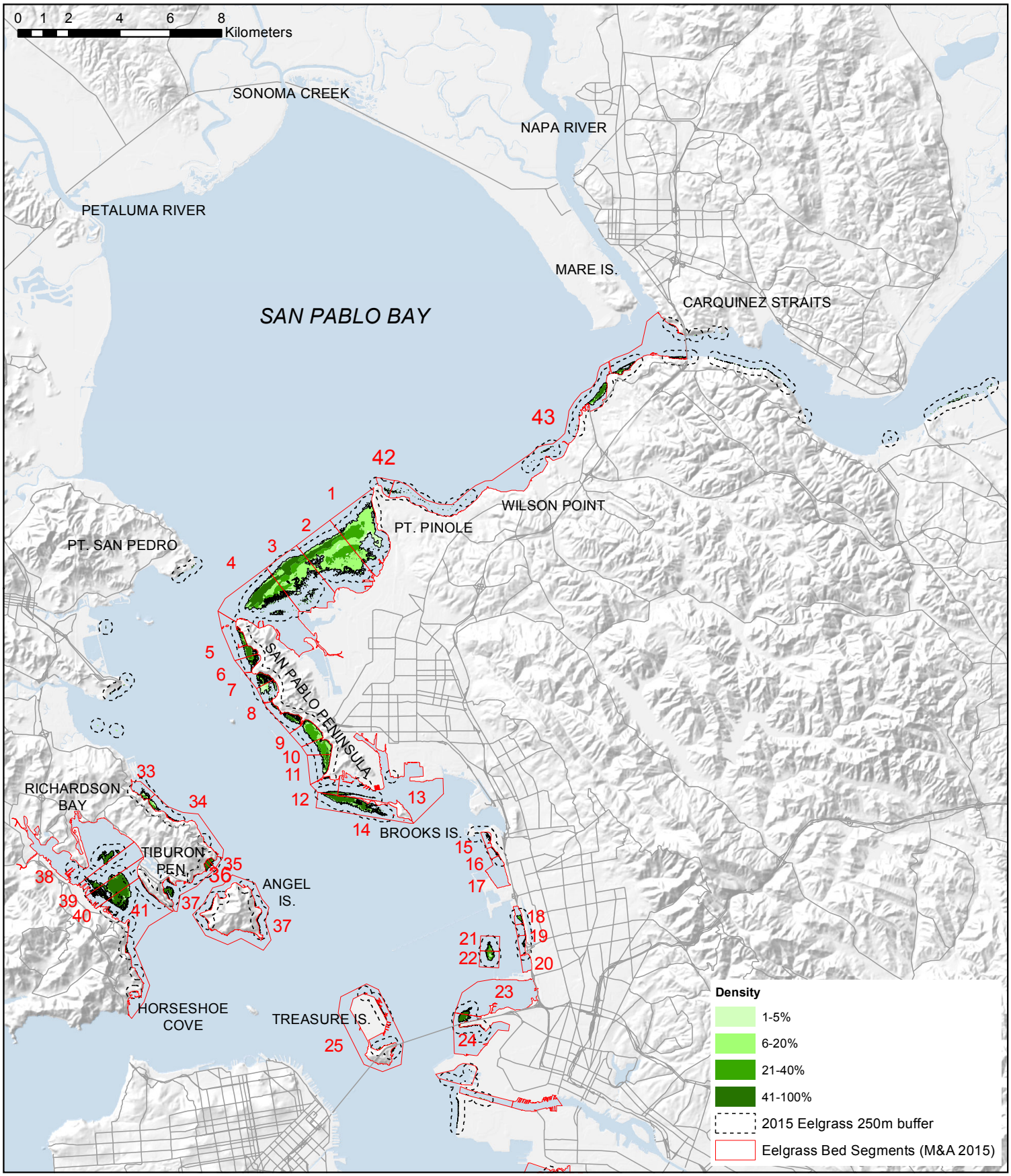

**Figure 1. Examples of Mapped Eelgrass Coverage Classes**

## SURVEY RESULTS

### *General Eelgrass Distribution*

The 2014 Baywide Eelgrass Inventory mapped 2,790 acres (1,129 hectares) of eelgrass within San Francisco Bay during October and early November 2014 (Figures 2-3, and Appendix A). In order to compare survey results between the present 2014 survey and the 2009 and 2003 surveys, it is helpful to compare eelgrass coverage within the same spatial subunits. To accomplish this, the eelgrass bed segments from the regional monitoring program (Merkel & Associates 2009a) have been adopted (Figures 2 and 3). Forty-one eelgrass bed segments exist in the present regional monitoring program, although there is potential for future addition of monitoring segments with regional expansion of eelgrass. The eelgrass not within mapping segments is scattered widely throughout San Francisco Bay. The 2003, 2009, and 2014 distribution by eelgrass bed segment is indicated in Table 1.

The overall coverage of eelgrass observed during the current survey was 24.7 percent less than the eelgrass extent mapped during the previous 2009 baywide eelgrass survey (Merkel & Associates 2009b) but 6.4 percent greater than that mapped in the 2003 surveys (Merkel & Associates 2004). The major differences observed between the 2014 survey and the prior 2009 survey are a considerable decline in eelgrass within shallow and poor circulation areas near the upper ends of coves. These areas include the shallows of inner Richardson Bay, the shoreward portions of the Point San Pablo-Point Pinole eelgrass bed, and Crown Beach. Eelgrass completely disappeared from the southern portion of San Francisco Bay between the 2009 and the 2014 surveys. One area of notable increase in eelgrass between the 2009 and 2014 benchmark surveys was an expansion of eelgrass to the east within San Pablo Bay and up into Suisun Bay above the Benicia-Martinez Bridge.

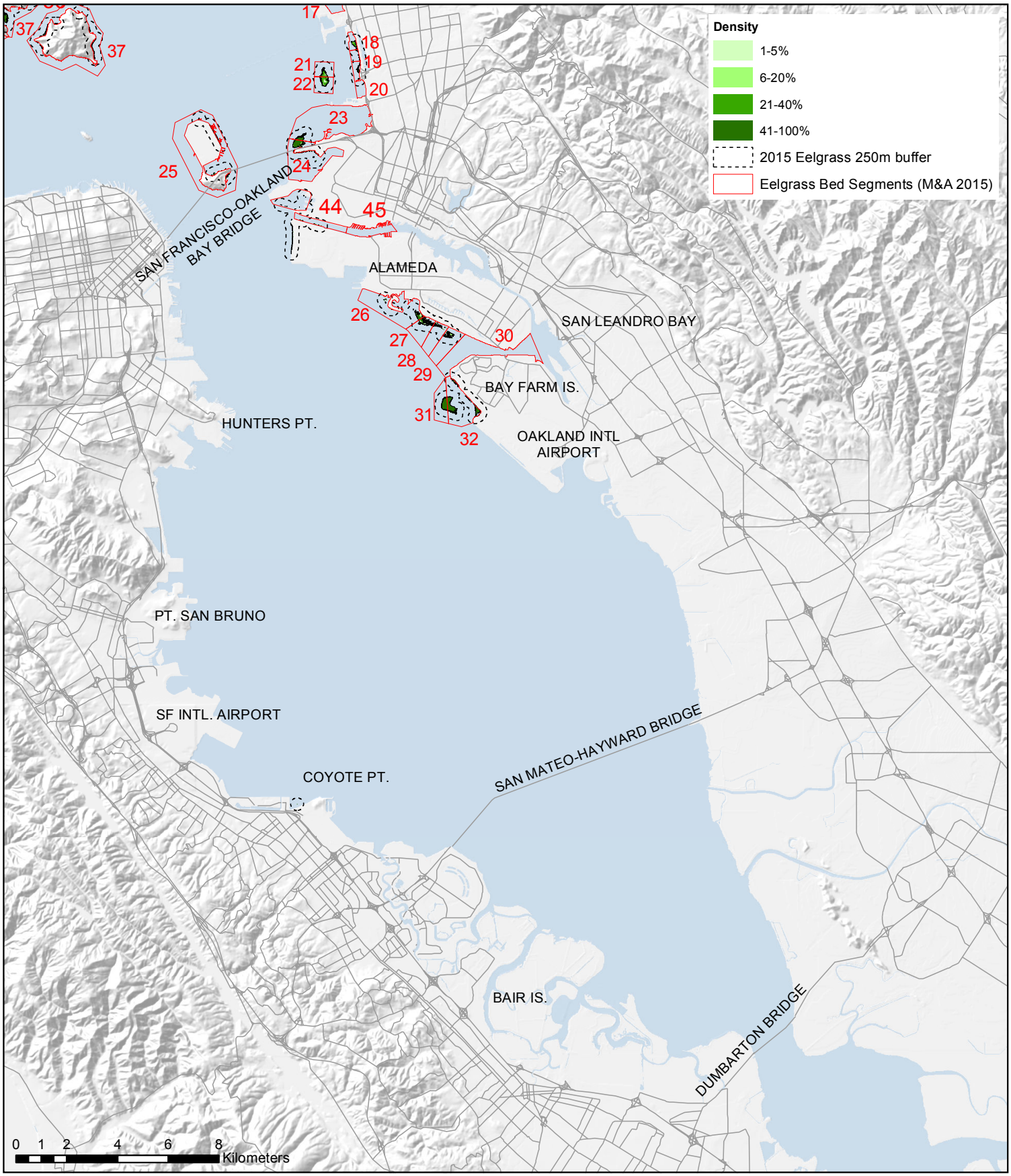



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**2014 Eelgrass Distribution**
**(North Bay and Central Bay Region)**
San Francisco Bay Eelgrass Atlas

**Figure 2**

*Merkel & Associates, Inc.*




**2014 Eelgrass Distribution (South Bay Region)**

San Francisco Bay Eelgrass Atlas

**Figure 3**

**Table 1. Location and Area of Eelgrass in San Francisco Bay (2003, 2009, and 2014 Surveys)**

| Eelgrass Segment Number | General Region | Bay Region | 2003 (acres) | 2009 (acres) | 2014 (acres) |
|---|---|---|---|---|---|
| 1 | Pt. San Pablo/Pt. Pinole | Pt. San Pablo/Pt. Pinole (East) | 345.51 | 514.11 | 393.07 |
| 2 | Pt. San Pablo/Pt. Pinole | Pt. San Pablo/Pt. Pinole (Central-East) | 419.64 | 614.49 | 528.17 |
| 3 | Pt. San Pablo/Pt. Pinole | Pt. San Pablo/Pt. Pinole (Central-West) | 316.94 | 558.23 | 360.81 |
| 4 | Pt. San Pablo/Pt. Pinole | Pt. San Pablo/Pt. Pinole (West) | 307.1 | 329.94 | 247.63 |
| 5 | Pt San Pablo | Navy Supply Depot Pt. San Pablo | 36.3 | 52.54 | 58.03 |
| 6 | Pt San Pablo | Navy Supply Depot Pt. San Pablo | 34.12 | 32.11 | 29.13 |
| 7 | Pt San Pablo | Point Molate Beach | 17.91 | 23.29 | 33.1 |
| 8 | Pt San Pablo | Point Molate Beach | 14.05 | 29.39 | 74.24 |
| 9 | Pt San Pablo | Kellers Beach North | 29 | 69.6 | 90.24 |
| 10 | Pt San Pablo | Kellers Beach South | 38.83 | 53.94 | 72.73 |
| 11 | Pt San Pablo | Kellers Beach South | 24.26 | 32.29 | 40.82 |
| 12 | Pt San Pablo | Inside Richmond Tr. Jetty | 9.51 | 10.3 | 14.57 |
| 13 | Pt San Pablo | Inside Richmond Tr. Jetty | 10.24 | 10.38 | 13.64 |
| 14 | Pt San Pablo | Outside Richmond Tr. Jetty | 68.17 | 86.79 | 125.17 |
| 15 | Emeryville / Berkeley | Albany Beach | 0.7 | 3.66 | 1.88 |
| 16 | Emeryville / Berkeley | Golden Gate Fields | 0.36 | 1.2 | 1.59 |
| 17 | Emeryville / Berkeley | Golden Gate Fields | 0.22 | 0.03 | 0.21 |
| 18 | Emeryville / Berkeley | Brickyard Cove | 5.98 | 10.02 | 7.15 |
| 19 | Emeryville / Berkeley | Berkeley Shoreline | 4.13 | 4.4 | 1.1 |
| 20 | Emeryville / Berkeley | Berkeley Shoreline | 7.6 | 11.67 | 3.76 |
| 21 | Emeryville / Berkeley | Berkeley Shoal | 11.7 | 10.48 | 12.08 |
| 22 | Emeryville / Berkeley | Berkeley Shoal | 17.03 | 18.56 | 21.49 |
| 23 | Emeryville / Berkeley | Emeryville Shoal | 9.34 | 9.69 | 11.36 |
| 24 | Emeryville / Berkeley | Emeryville Shoal | 16.8 | 19.82 | 25.45 |
| 25 | Emeryville / Berkeley | Clipper Cove/Treasure Island | 6.2 | 5.41 | 5.68 |
| 26 | Crown Beach | Crown Beach | 40.43 | 12.71 | 13.45 |
| 27 | Crown Beach | Crown Beach | 32.21 | 28.07 | 13.07 |
| 28 | Crown Beach | Crown Beach | 26.64 | 45.24 | 2.42 |
| 29 | Crown Beach | Crown Beach | 78.07 | 88.03 | 7.5 |
| 30 | Crown Beach | Crown Beach | 74.01 | 45.02 | 0 |
| 31 | Bayfarm Island | Bayfarm Island | 32.24 | 28.08 | 23.44 |
| 32 | Bayfarm Island | Bayfarm Island | 69.99 | 60.38 | 46.28 |
| 33 | Tiburon Peninsula | Paradise Cove, North | 10.18 | 7.39 | 14.15 |
| 34 | Tiburon Peninsula | Paradise Cove, South | 5.56 | 11.2 | 20.85 |
| 35 | Tiburon Peninsula | Keil Cove | 5.3 | 4.78 | 6.79 |
| 36 | Tiburon Peninsula | Keil Cove | 7.56 | 7.8 | 9.49 |
| 37 | Tiburon Peninsula | Keil Cove | 34.91 | 34.76 | 39.75 |
| 38 | Richardson Bay | Richardson Bay | 53.32 | 219.19 | 34.8 |
| 39 | Richardson Bay | Richardson Bay | 112.42 | 119.24 | 31.51 |
| 40 | Richardson Bay | Richardson Bay | 164.43 | 178.8 | 149.28 |
| 41 | Richardson Bay | Richardson Bay Entrance | 119.09 | 157.51 | 118.97 |
| 42-43 | Pt Pinole/Carquinez | Pt Pinole/Carquinez Bridge | 0.02 | 135.81 | 76.83 |
| NA | Unrepresented Beds | Pt San Quentin to Pt San Pedro | 2.17 | 0.89 | 1.98 |
| NA | Unrepresented Beds | Oakland Middle Harbor | 1.31 | 0.02 | 0.27 |
| NA | Unrepresented Beds | Oakland Inner Harbor | 0.07 | 0.37 | 0.03 |
| NA | Unrepresented Beds | Alameda Western Shoreline | 0.02 | 3.58 | 0 |
| NA | Unrepresented Beds | San Mateo to South San Francisco | 2.87 | 0.02 | 0.02 |
| NA | Unrepresented Beds | San Mateo Bridge to Dumbarton Bridge | 0.32 | 0.05 | 0 |
| NA | Unrepresented Beds | Other Eelgrass Beds | 3.29 | 5.18 | 5.97 |
| **BAYWIDE EELGRASS AREA TOTAL** | | | **2,628.08** | **3,706.50** | **2,789.96** |

### *REGIONAL EELGRASS CONDITIONS*

The majority of the eelgrass in San Francisco Bay continues to be located within two very large eelgrass beds. By far the largest eelgrass bed in San Francisco Bay is the Pt. San Pablo bed, which is located between Pt. Pinole and Pt. San Pablo in San Pablo Bay (Figure 2, Atlas Pages 20, 21, 33, and 34). This bed was approximately 1,530 acres (619 hectares) during 2014 and comprised almost 55 percent of the total eelgrass coverage in San Francisco Bay. The Pt. San Pablo eelgrass bed occurs on a shallow depositional shoal (approximately -4.1 to -0.8 feet [–1.25 to –0.25 meters] MLLW). This eelgrass bed has consistently been the largest in San Francisco Bay, comprising over 54 percent of the eelgrass mapped in 2009 (Merkel & Associates 2009), 53 percent of the eelgrass mapped in 2003 (Merkel & Associates 2004), and 39 percent of all of the eelgrass mapped during the 1987 survey (Wyllie-Echeverria and Rutten 1989).

The second largest eelgrass bed in San Francisco Bay is found in Richardson Bay, near Sausalito in Marin County (Figure 2 and Atlas Pages 6 and 14). This bed was approximately 335 acres (135 hectares) during the 2014 survey, comprising 12 percent of all eelgrass. This compares to 18 percent of all eelgrass in 2009 (Merkel & Associates 2009) and 17 percent of all eelgrass in 2003 (Merkel & Associates 2004). This comparison points to disproportionately higher eelgrass declines within Richardson Bay over the average loss of eelgrass between 2009 and 2014 surveys. Eelgrass in Richardson Bay generally occurred between -6.6 and -0.8 feet (–2.0 and –0.25 meters) MLLW during the current survey. However, the deepest eelgrass present within San Francisco Bay is found near the entrance of Richardson Bay where a very limited amount of eelgrass (>0.023 percent of the total) occurs deeper than -9.8 feet (-3.0 meters) MLLW. Much of the shallower portions of Richardson Bay that historically have supported eelgrass in 2009 did not support eelgrass during 2014.

Eelgrass is most continuous in its distribution along the eastern shoreline of the north and central portions of San Francisco Bay. Broken only by headlands and dredged channels, eelgrass extends in a nearly continuous ribbon along 15.5 miles (25 kilometers) of shoreline from east of Pt. Pinole to the outside of Richmond Training Jetty of Outer Richmond Harbor (Figure 2). The well-defined westerly facing shallow coves along the San Pablo Peninsula support extensive eelgrass beds that contribute significantly to the overall eelgrass habitat total and are generally some of the more stable eelgrass beds in San Francisco Bay. These beds are found along Kellers Beach on the Miller/Knox Regional Shoreline and in the exposed coves between Castro Point, Pt. Molate, Pt. Orient, and Pt. San Pablo.

In 2003, only a few solitary plants were recorded to the east of Pt. Pinole near Wilson Point. During the 2009 surveys, eelgrass was found to be extensive, but sparsely distributed along the southeastern shoreline of San Pablo Bay extending all the way up to the survey limits at the Carquinez Bridge and along the northeastern shoreline from the Carquinez Bridge through the California Maritime Academy and Morrow Cove up to the breakwater at the mouth of the Napa River. Eelgrass east of Pt. Pinole totaled less than >0.01 acre (0.01 hectare) in 2003 but exhibited a coverage of 135.8 acres (55.0 hectares) in 2009, although the coverage was generally at low cover density (Figure 3, Table 1). In 2014, eelgrass declined within this upper portion of San Pablo Bay to 76.8 acres (31.1 hectares) but extended eastward into Suisun Bay.

## DISCUSSION

### *EELGRASS DYNAMICS AND POTENTIAL HABITAT*

Eelgrass coverage within San Francisco Bay is in a constant state of flux. While there appears to have been a considerable expansion of eelgrass between the 2003 and 2009 baywide surveys and great declines between 2009 and 2014, the fact is that there was at least one period of significant decline in eelgrass between 2003 and 2009 that occurred during the intervening period. This decline occurred during the winter of 2005-2006, when significant sediment loading into San Francisco Bay occurred and many eelgrass beds were buried in fine sediment up to several centimeters thick (Merkel & Associates 2008b and 2009a, and K. Merkel personal observation). In addition, during this period, salinities within the northern and central Eastbay were depressed considerably for prolonged periods lasting over a month in some areas (K. Boyer personal communication, and K. Merkel personal observation). Similarly, in a 2010 eelgrass survey conducted by kayak within the inner portions of Richardson Bay, the Richardson Bay Audubon Sanctuary demonstrated an eelgrass extent beyond that found in the 2009 surveys (Audubon Society, unpublished data). Further, high variability from year to year has also been observed in the long-term monitoring program for eelgrass at the Emeryville Shoals and Clipper Cove near the SFOBB Project (Merkel & Associates 2008a).

As a result of the high variability in eelgrass coverage within San Francisco Bay, understanding the potential for eelgrass to occur on an intermittent basis is as valuable as understanding where it occurs during any given year. To foster a development of this understanding, two actions have been taken. These include documenting the maximum extent of eelgrass known to occur within the bay, and calculating the frequency of eelgrass presence over the three comprehensive baywide surveys (2003, 2009, and 2014). A prior action was taken in 2009 to revisit and revise the baywide predictive model of potentially suitable habitat to support eelgrass. However, during this present effort, the baywide eelgrass model was not revised. This is discussed further below.

#### ***Maximum Eelgrass Extent***

In addition to the 2014 eelgrass distribution map, a separate map layer has been prepared of the maximum documented extent of eelgrass (2014 Eelgrass Atlas map sheets, Appendix A). This has been done in anticipation of future updates as additional survey data becomes available in future years. This effort was initiated with the 2003 baywide eelgrass survey; and over time, it will provide a record of recent maximum distribution patterns for eelgrass within San Francisco Bay. The maximum documented eelgrass extent is a combination of all known eelgrass surveys in San Francisco Bay where credible and accurate spatial data exist. Following completion of the 2014 baywide survey, the maximum historical extent of eelgrass was documented to be 1,823 hectares (4,504 acres).

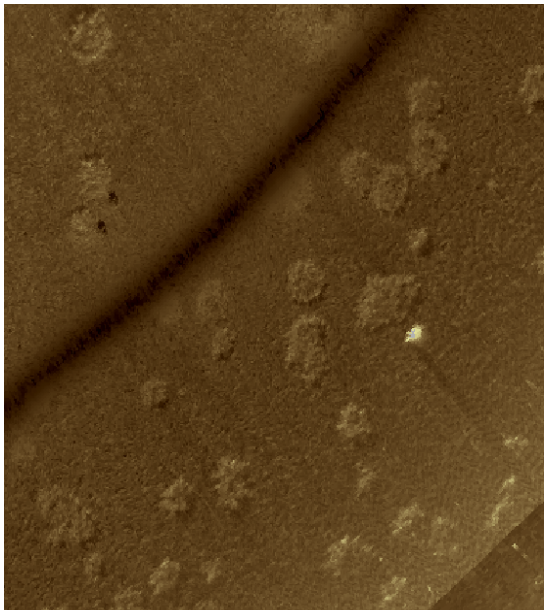
In order to present these results on a scale that would be useful to resource managers, the 2014 Eelgrass Atlas was created. Each page of this atlas presents a 9.7-square mile (25-square kilometer) section of San Francisco Bay at a scale of 1:36,000. Bathymetry is presented in feet below mean lower low water (MLLW).

### ***Eelgrass Frequency of Occurrence***

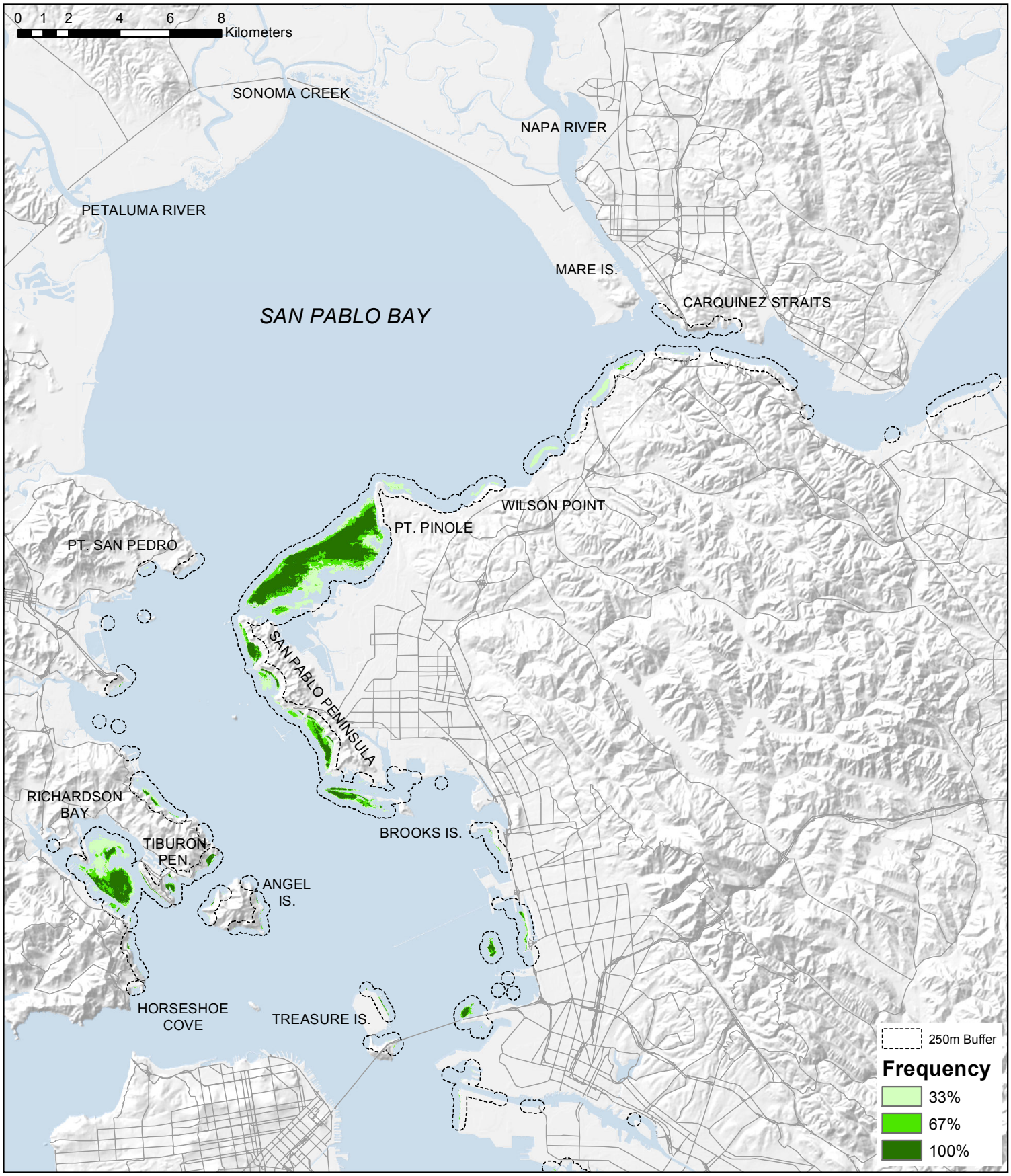
The current survey is the third comprehensive bay survey conducted since 2003. The repeated survey of the Bay using substantially similar methods and seasonal timing allows for the calculation of a frequency of eelgrass occurrence over time. The more survey periods included in this frequency analysis, the more robust the understanding of eelgrass spatial dynamics becomes. To calculate frequency of eelgrass occurrence, the eelgrass from the three survey years (2003, 2009, and 2014) were each assigned values of one, then summed and divided by three, the number of survey years. The results of this analysis were then projected as a percentage of the time that eelgrass was present during the survey periods (Figures 4a and 4b).

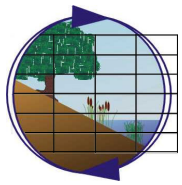
Not surprisingly, the results of the analysis demonstrate that the bay supports both persistent eelgrass beds as well as eelgrass beds that are more ephemeral in their occurrence. Typically, the core areas of eelgrass beds support persistent eelgrass, while the fringes of the beds are less persistent, dropping off in with a concentric pattern of diminishing occurrence frequency. The core areas of eelgrass range in spatial distribution from Point Pinole to Bayfarm Island; and, as with the overall bed distribution, the most persistent eelgrass beds were the Point San Pablo-Point Pinole bed and the Richardson Bay beds.

Less persistent eelgrass has been found as far north as lower Suisun Bay and as far south as offshore of Coyote Hills Regional Park, north of the Dumbarton Bridge. Notably, while the northernmost extent of eelgrass was observed to occur in 2014 in the midst of prolonged drought, the southernmost extent and nearly all of the South Bay eelgrass occurred only in 2009. In 2014, there was a near complete absence of eelgrass from the South Bay, except for a small patch at Coyote Point. The Coyote Point eelgrass is fairly interesting in that the presence of eelgrass at this location has been consistent, but the position of beds has continuously changed. In addition to small beds being observed in each of the baywide surveys, dynamic distributions of eelgrass along the shoreline north of Coyote Point Marina has been a recurrent observation over the past two decades (K. Merkel, pers. obs.) and the presence at this location was noted in the 1987 baywide investigation as well (Wyllie-Echeverria and Rutten 1989). The loss of eelgrass beds in the South Bay, while beds expanded much further to the east in the North Bay, suggests that the factors controlling eelgrass distribution in these areas may be, at least temporally, different. In the North Bay, it is speculated that the tremendous eastward expansion of eelgrass into lower Suisun Bay is related to the reduction in Delta outflow. In this area, eelgrass overlaps with the brackish water pondweed *Stuckenia* sp. Further, *Stuckenia* in this area was represented by poorly developed aboveground plants over the top of larger basal rhizome mats, suggesting that these plants were more robust in prior years. Eelgrass in this area was represented by very small plants indicative of recent seedling establishment.



*Stuckenia* rhizome mats and small eelgrass plant (bright) in lower Suisun Bay 2014.



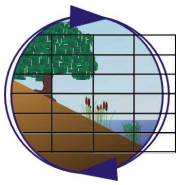



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**Eelgrass Frequency (2003, 2009, 2014)**
**North Bay and Central Bay Region**
San Francisco Bay Eelgrass Atlas

**Figure 4a**






**Eelgrass Frequency (2003, 2009, 2014)**
**South Bay Region**
San Francisco Bay Eelgrass Atlas

**Figure 4b**

As reported in the 2003 and 2009 survey reports, bathymetry for San Francisco Bay was derived from numerous survey sources that date over extended periods. In most instances, the bathymetry was collected on larger survey vessels that avoided the extreme shallows of San Francisco Bay margins. As a result, bathymetric survey data were sparse in areas that generally support eelgrass beds. To improve upon this condition, bathymetric data were supplemented during the 2003 survey and data were extrapolated to shore by using marsh vegetation and intertidal zonation features. The extrapolation methodology uses a Triangular Irregular Network (TIN) algorithm which interpolates between the assigned shoreline edges at 3 feet (0.9 meters) MLLW and the shallowest depths captured by bathymetric surveys using a straight line slope. Because the actual shore topology tends to be concave rather than linear, this extrapolation tends to generate an artificially elevated shore profile. As a result, eelgrass occurring within areas of extrapolated bathymetry would tend to be represented at artificially high elevations. In the prior 2009 eelgrass survey report, it was noted that the eelgrass represented as existing at elevations higher than +0.25 meters was almost invariably found within the upper end of well-defined coves where shallower bathymetry was an artifact of extrapolation methods used to bring existing bathymetric survey data to the shoreline edge. As a point in fact, it is unlikely that much, if any, eelgrass with San Francisco Bay extends above 0.8 to +1.1 feet (+0.25 to +0.35 meters) MLLW and eelgrass at this higher elevation is generally rare and related to perched basins located on higher mudflats or adjacent to reveted shorelines where pools are scoured at the base of the rock.

For 2003 and 2009, the 2003 extrapolated bathymetry was used to evaluate depth distribution. However, with the inclusion of bathymetric data collection concurrent with the 2014 eelgrass survey, it has been possible to determine the actual 2014 eelgrass elevation range distribution within San Francisco Bay (Figure 5). This same bathymetry was applied to eelgrass mapped in 2003 and 2009 as well, although it is not possible to know how much elevation change has occurred in these beds from 2003 to present. This new bathymetric data resulted in a narrowing of previously reported eelgrass depth distribution by lowering the upper elevation of eelgrass distribution.

This depth distribution analysis indicated that within San Francisco Bay in 2014, 98.8 percent of all eelgrass occurred within a depth range from 0 to -6.6 feet (0.0 to -2.0 meters) MLLW. An amazing 80.9 percent of all eelgrass in the Bay occurs within a one-meter depth range from -1.6 to 4.9 feet (-0.5 to -1.5 meters) MLLW. This narrow depth distribution of eelgrass is a result of the high ambient turbidity environment of the Bay, coupled with generally high wave energy. The high turbidity restricts light penetration, while higher wave energy restricts the capacity for plants to extend leaf tissue high into the water column to capture available light in shallower water. The exceptions to the shallow distribution of eelgrass include Richardson Bay and to a small extent Horseshoe Cove on the Marin Peninsula where greater availability of oceanic water exchange is available and turbidity of the water is reduced. Further, the protected embayments of these areas allow plants to extend longer leaves upward in the water column where tissues may photosynthesize for longer periods of time. Leaves of plants from Richardson Bay are commonly longer than 6.6 feet (2.0 meters) in deeper waters. Other locations with deeper eelgrass beds are on the east side of Point San Pablo, at the west end of the Oakland Inner Harbor Channel, and in Oakland Outer Harbor. In all of the inner Bay areas that support deeper eelgrass beds, the sites occur within protected or semiprotected environments with low wave exposure and are influenced by peninsulas that extend into the bay and alter tidal circulation where the eelgrass occurs at deeper limits.

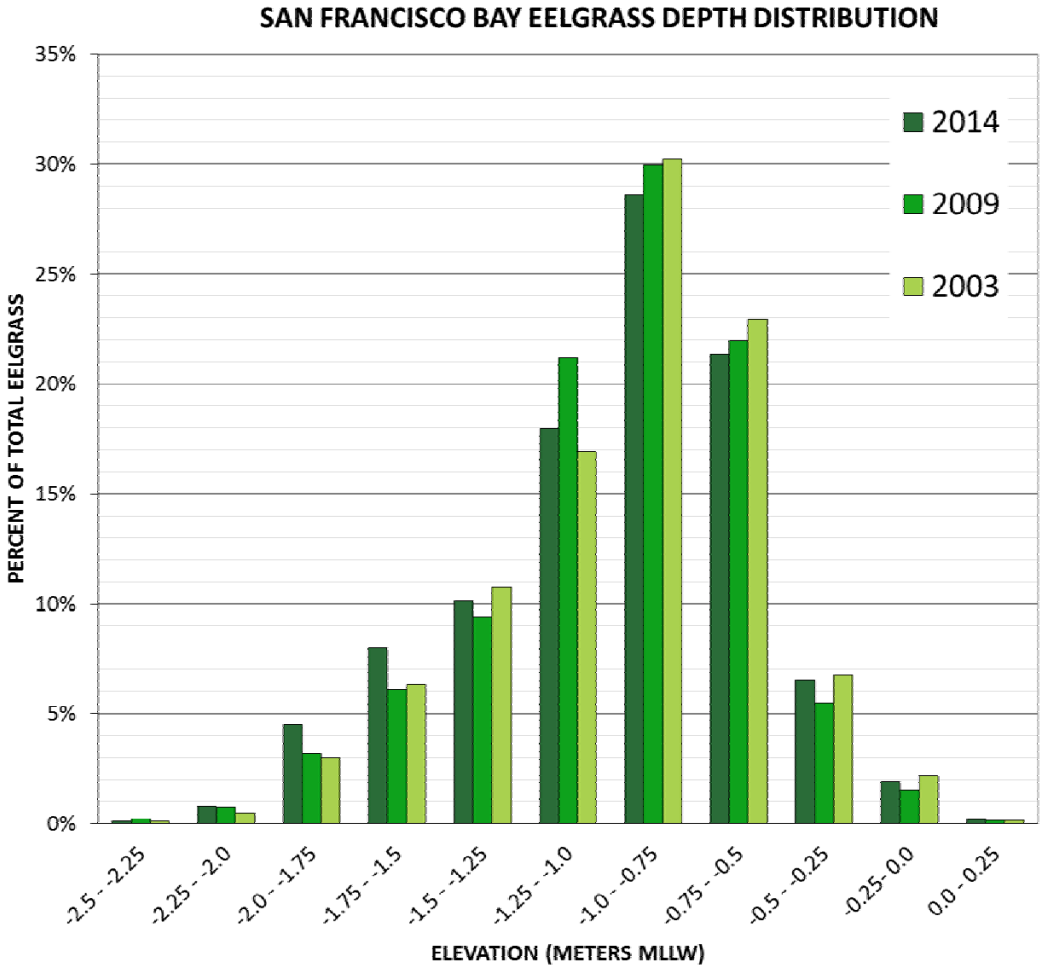



**Figure 5. Eelgrass Depth Distribution for Benchmark Baywide Survey Periods.**

### *EELGRASS PREDICTIVE MODEL*

The San Francisco Bay Ecological Limits, Viability, and Sustainability (ELVS) predictive model for eelgrass (Merkel & Associates 2005) was reviewed in consideration of the present 2014 survey results and the maximum known eelgrass distribution. Following the 2009 baywide eelgrass survey, the model was refined with revised elevation thresholds and plotted as an underlying layer in the 2009 Eelgrass Atlas map sheets, Appendix A). The 2009 revisions to the model were simplistic bathymetric range restriction modification of the 2005 ELVS model that did not rely directly on bathymetry as a suitability indicator, but rather employed the light regime developed given a multitude of physical parameters, including bathymetry (Merkel & Associates 2005). While the 2009 modifications to the ELVS model enhance the model's predictive ratio (percent eelgrass predicted/percent captured), the inclusion of an absolute limit to the bathymetric range (-2.00 meters to +0.25 meters MLLW), precludes the model capture of deeper, or shallower, environments that support eelgrass for reasons of unique physical environments or during periods of improved water clarity. It further puts considerably more emphasis on bathymetric range than would be justified by the generally limited quality of the regional bathymetric data used in the ELVS model. For this reason, it is essential to consider the true site conditions when evaluating potential eelgrass suitability and to utilize the regional mapping and modeling only as a guidance tool.

The final 2005 eelgrass predictive model predicted 23,440 acres (9,486 hectares) of eelgrass and accurately captured 95.1 percent of the 2,622 acres (1,061 hectares) of eelgrass detected during the 2003 baywide survey (Merkel & Associates 2005). The large ratio of predicted area to eelgrass area is necessary to ensure that significant eelgrass beds are not excluded from the predicted presence of eelgrass. This model also accurately predicts 91.6 percent of the eelgrass detected during the present 2009 baywide survey and 91.2 percent of the maximum known extent of eelgrass mapped within San Francisco Bay. The substantial difference between the model capture for 2003 and the 2009 maximum extent layers was related to the substantial expansion of eelgrass eastward from Pt. Pinole between the 2003 and 2009 surveys. This expansion was observed to be even more pronounced in 2014. The eastern expansion area was omitted from the model due principally to a long-term average salinity that exists as a threshold factor resulting in clipping the model at an average surface salinity above 20 parts per thousand (ppt). However, the multiple-year drought conditions within the Sacramento-San Joaquin Delta have both resulted in an overall increase in salinity further east in San Francisco Bay and have similarly resulted in a reduction of sediment loading into San Pablo Bay (a covariant with reduced salinity). In order to improve model predictive capacity in light of the dynamic nature of the Delta inputs, the model itself would need to be modified to include dynamic fluvial inputs.

With the bathymetric range clips included in the 2009 model modification, the model predictive capacity for eelgrass was reduced by less than 2 percent; however, the area not supporting eelgrass was reduced by 26 percent from 9,530 hectares (23,550 acres) to 7,035 hectares (17,380 acres). Following the 2014 investigations, the ELVS model was not updated. This is the case because it was determined that the any meaningful update at this time is reliant upon replacement of the existing bay bathymetric data layer with an improved shallow water bathymetry data layer. A replacement of the shallow water bathymetric grid within the model would be an extremely worthwhile endeavor considering that much of the predicted eelgrass suitability occurs within areas of the bay that are based only on extrapolated bathymetric conditions rather than true bathymetry. Correction of the bathymetric layer, which is an underlying driver of model algorithms, would be expected to significantly improve model predictive capacity.

***EELGRASS EXPANSION CAPACITY***

Eelgrass habitat in San Francisco Bay fluctuates considerably over time and is known to have existed over 1,823 hectares (4,504 acres) of bay bottom at some point in the past two decades for which spatial survey data exists. This maximum known extent of eelgrass translates to approximately 1.8 percent of the bay area, which is an order of magnitude less than other large California estuarine systems (Table 2). However, due to the large size of San Francisco Bay, even the small percentage of bottom cover amounts to substantial eelgrass resources on a statewide basis.

The primary explanation for restricted eelgrass coverage in San Francisco 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 average 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 from the Delta and high resident suspended sediment loads.

**Table 2. Comparison of Maximum Documented Eelgrass in California Bays and Estuarine systems**

| System | Eelgrass (acres) | % Coverage |
|---|---|---|
| Mission Bay[1] | 1,306 | 57% |
| San Diego Bay[2] | 2,084 | 19% |
| Humboldt Bay[3] | 3,614 | 20% |
| Tomales Bay[4] | 964 | 10% |
| San Francisco Bay[5] | 4,504 | 1.8% |

[1]Merkel & Associates 2013, [2]Merkel & Associates 2014, [3]Sea Grant 2009, unpublished data, [4]National Park Service 2007, [5]Maximun known extent 1989-2014

While there still has not yet been a significant amount of rigorous monitoring of eelgrass in San Francisco 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 San Francisco Bay (Merkel 2000 and additional unpublished data). Presently, it is hypothesized that episodic high-flow fluvial events result in substantial increases in sediment loading to San Francisco Bay. This sediment becomes an additive source of resident suspended sediment that is slowly purged from San Francisco Bay by tidal exchange. During several years following heavy sediment loading, eelgrass is extirpated from areas of high sediment suspension and low sediment export. Eelgrass also likely declines along the deeper fringes of beds that survive increased turbidity, typically those further removed from direct loading or export circulation patterns. Over longer periods of benign fluvial events, such as during the present drought conditions, sediment loading is reduced, thus allowing for a recovering trend in water clarity and improvement of conditions suitable to support eelgrass. At these times, eelgrass is capable of colonizing areas of past extirpations and suitable environments. However, given the large spatial scale of San Francisco Bay, the bathymetric and hydrodynamic environments, and the limited spatial extent of eelgrass, even areas suitable to support eelgrass may go uncolonized for many years due to poor dispersal and recruitment potential.

If episodic events control eelgrass extirpation and chance recruitment events control colonization, it would suggest that considerably more suitable habitat might exist at some periods of time than is occupied by eelgrass. It would also suggest that maintaining a geographically well-distributed presence of fairly persistent eelgrass beds may be critical in the system to serve as source populations from which material may be derived for recolonization following extirpation events. It would also suggest that considerable opportunity might exist for establishing eelgrass beds in areas around San Francisco Bay, but that these beds may be subject to recurrent extirpation events through time.

This theory of San Francisco Bay eelgrass beds being in a chronic state of variable colonization and extirpation events is supported both by long-term observations of beds throughout the Bay, as well as transplant programs that have demonstrated highly variable success rates, including establishment of new persistent beds (e.g., Brickyard Cove), establishment of beds that have subsequently spread to other areas of the shoreline that did not previously support eelgrass (e.g., Marin Rod & Gun Club), and establishment of eelgrass within areas that have previously supported eelgrass (e.g., Richardson Bay). Conversely, restoration efforts have also shown early failures and failures after one or more growing seasons. These successes and failures are important to

understanding the Bay's potential to support greater amounts of eelgrass than presently exists, as well as understanding the dynamics and conditions required for colonization success.

**CONCLUSIONS**

The 2014 baywide eelgrass inventory reveals a considerable contraction of eelgrass from that observed during the 2009 baywide survey. Conditions of eelgrass in 2014 were more in line with those observed in 2003 than the expansive conditions observed in 2009.

The 2014 Eelgrass Atlas provides a snapshot of the distribution of eelgrass during a single year; and along with the maximum documented eelgrass extent, this survey alludes to the tremendously dynamic nature of eelgrass beds in San Francisco Bay. As a resource management tool, the current survey provides a third comprehensive mapping of eelgrass habitat resources in San Francisco Bay and underpins a regional eelgrass monitoring strategy based on subsampling and extrapolation that has been developed and tested (Merkel & Associates 2009a).

If the 2015-2016 water-year develops to the predicted high rainfall and runoff conditions anticipated under an El Niño year, it can be expected that eelgrass will decline from its current levels. The decline will likely be most pronounced in the North Bay, where expansions from prior survey years have been greatest.

Notwithstanding, the value of the eelgrass atlas is as a planning and large-scale resource management tool, and it is not intended to replace site specific and up-to-date surveys and analyses where potential impacts to eelgrass habitat are contemplated. Resource managers are cautioned regarding the inapplicability of the present data for completing impact assessments or site-specific evaluations. While these data provide a useful tool for planning and evaluating management needs, they are not adequate to meet the needs of specific project assessments.

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# SAN FRANCISCO BAY EELGRASS ATLAS

## October 2014



*Submitted to:*

**National Marine Fisheries Service**
777 Sonoma Avenue, Suite 325
Santa Rosa, CA 95404-6515

*Submitted by:*

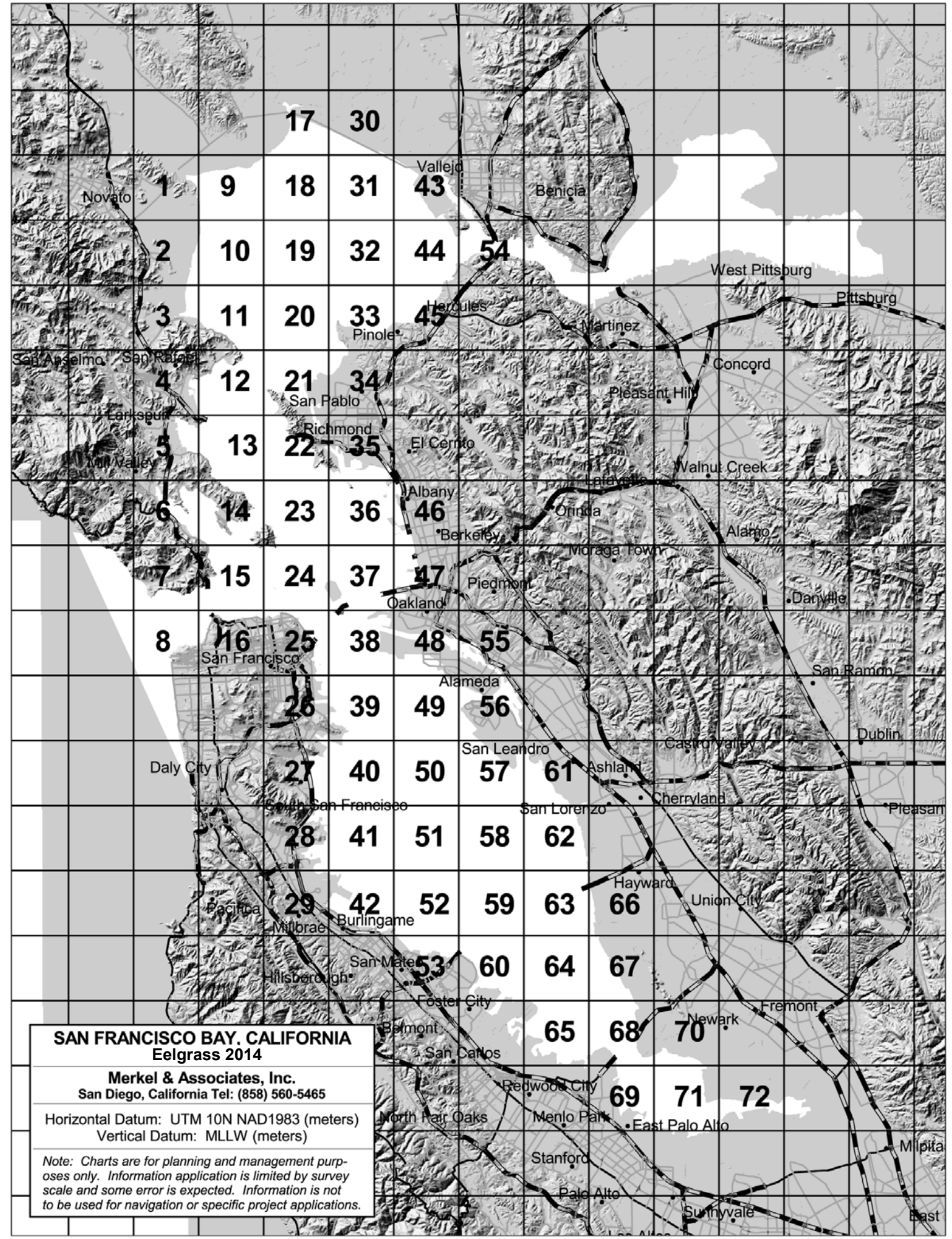
**Merkel & Associates, Inc.**
5434 Ruffin Road
San Diego, CA 92123
ph. (858) 560-5465
fx. (858) 560-7779

2015

Eelgrass mapping is based on acoustic and aerial surveys of October 2014. Eelgrass distribution along the shoreline, and within various portions of the bay was refined using site specific survey data and diver ground truthing.

Eelgrass bed density classification is most accurate near the central portion of the range and is less accurate near the extremes of any of the defined density ranges where interpretive error may occur. Eelgrass data reflects a particular period in time and are anticipated to be a seasonally and stochastically dynamic.

Note: Charts are for planning and management purposes only. Information application is limited by survey scale and some error is expected. Information is not to be used for navigation or specific project applications.

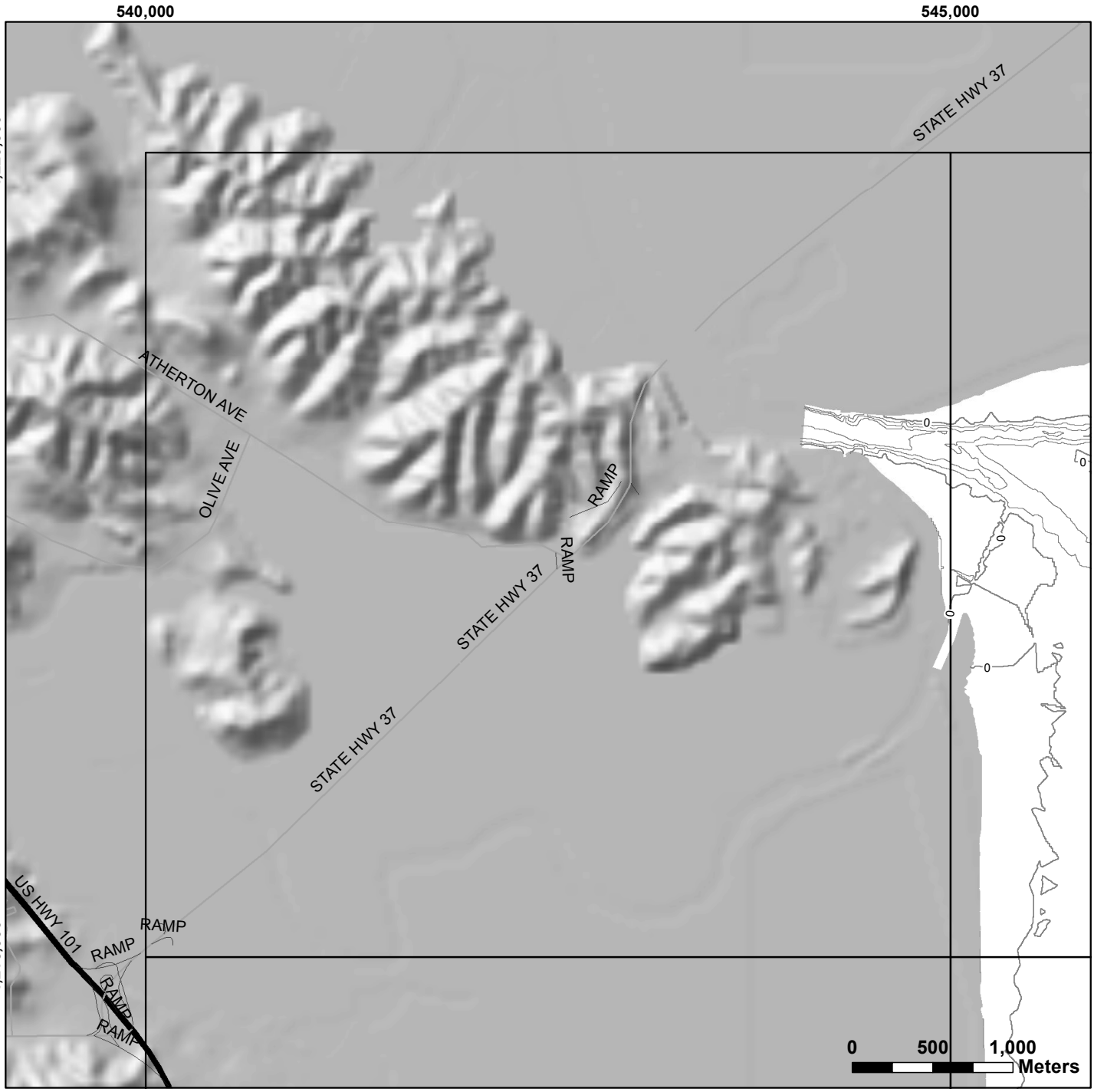



**SAN FRANCISCO BAY, CALIFORNIA**
**Eelgrass 2014**

**Merkel & Associates, Inc.**
**San Diego, California Tel: (858) 560-5465**

Horizontal Datum: UTM 10N NAD1983 (meters)
Vertical Datum: MLLW (meters)

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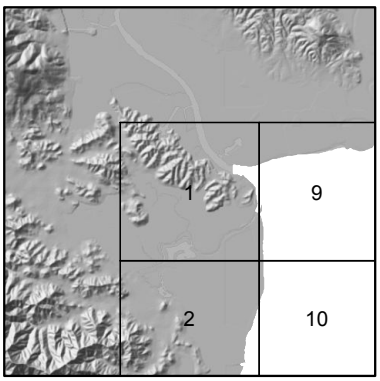

# SAN FRANCISCO BAY, CALIFORNIA
## Eelgrass 2014

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San Diego, CA - Tel: (858) 560-5465

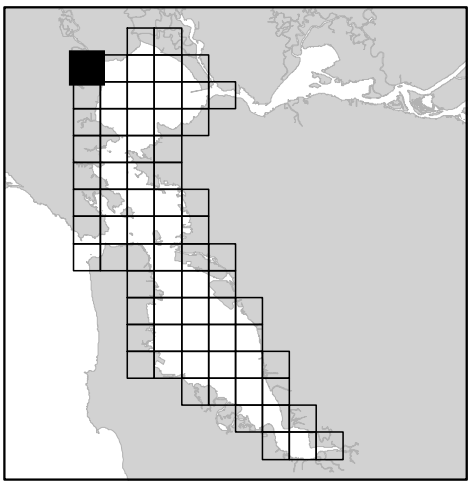
Horizontal Datum: UTM NAD83 Zone 10N (meters)
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SHEET VICINITY




SHEET LOCATOR

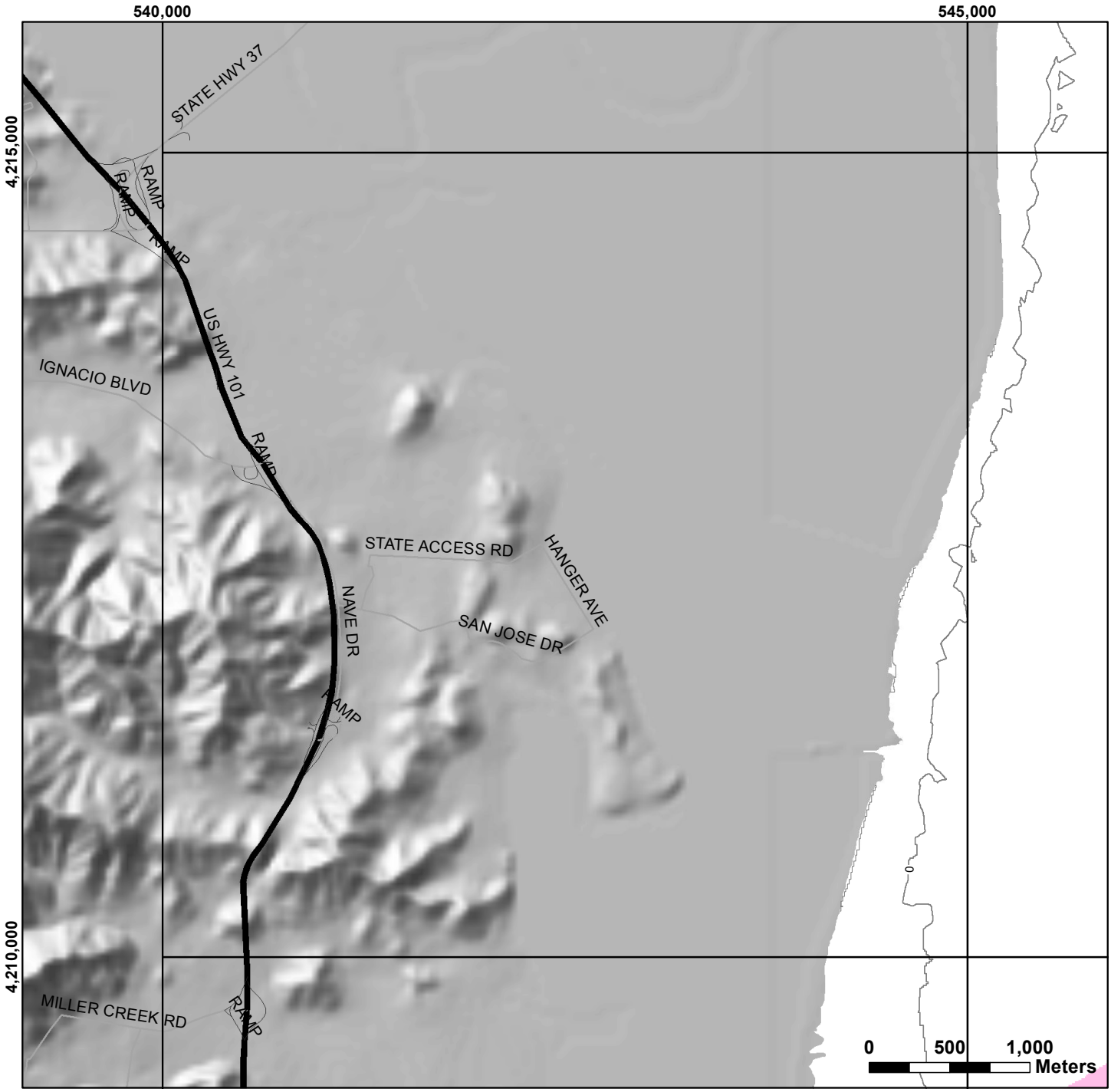


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- 21-40%
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- ELVS Predictive Model



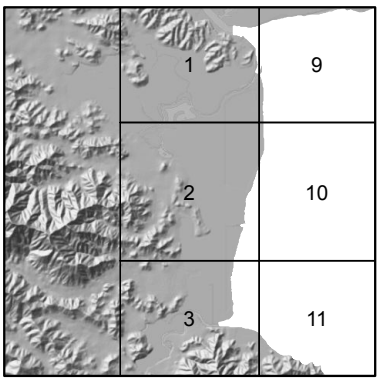

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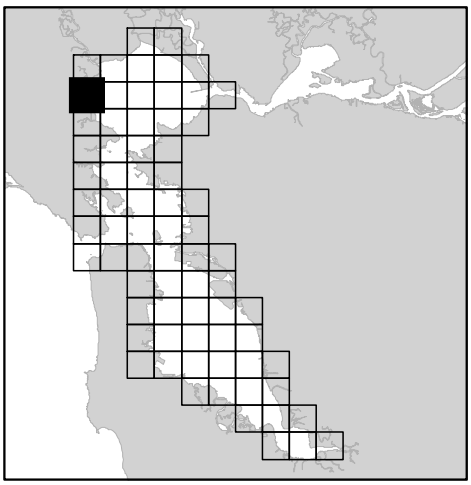
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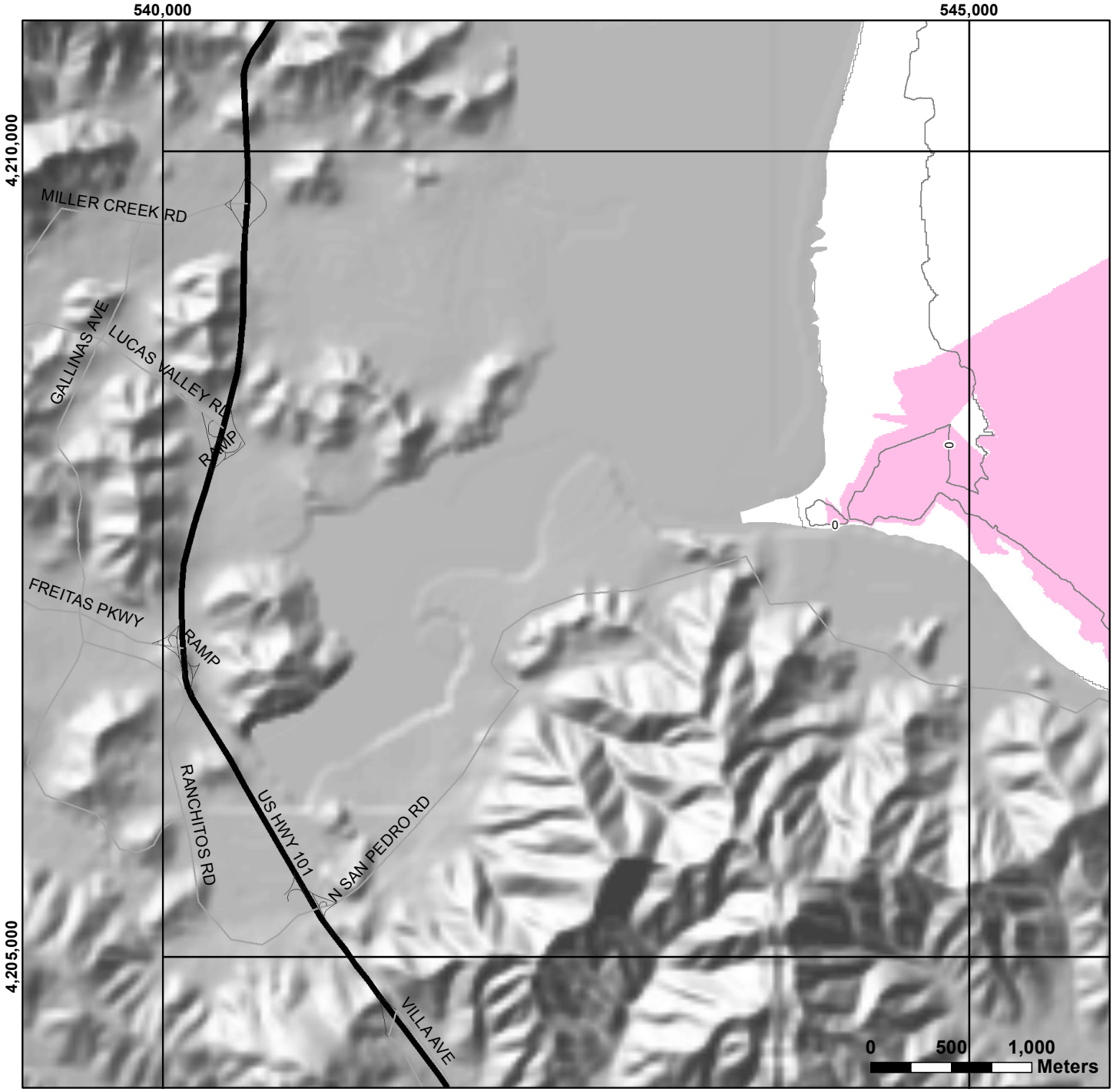


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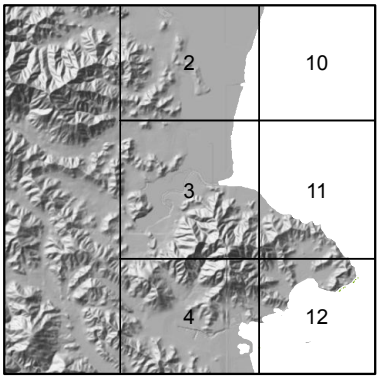

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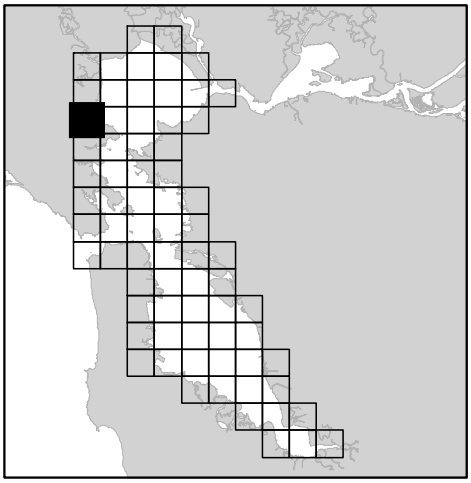
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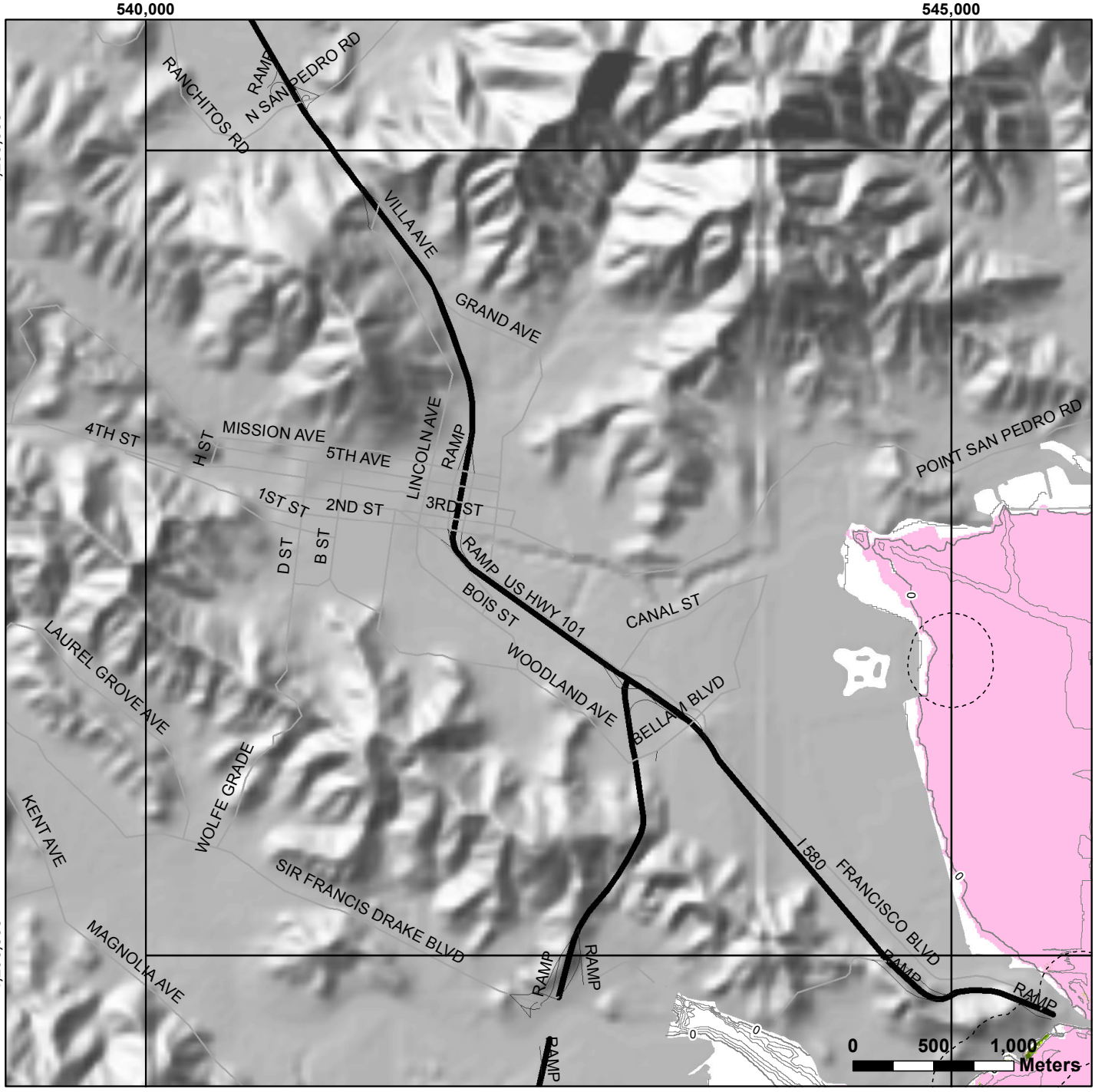


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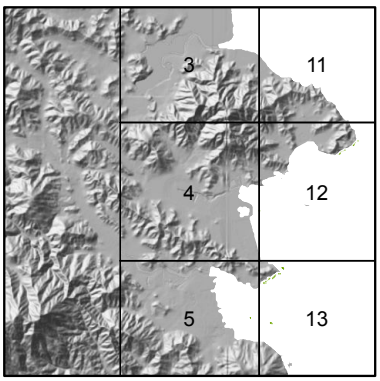

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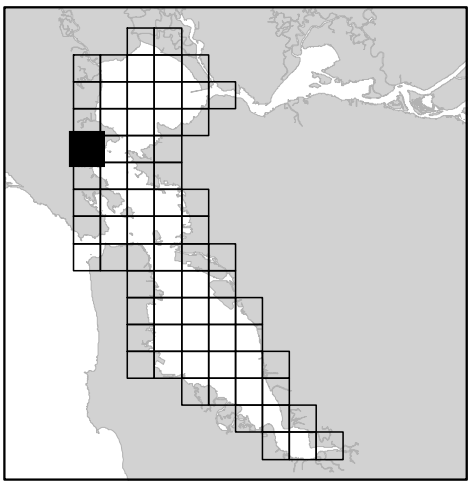

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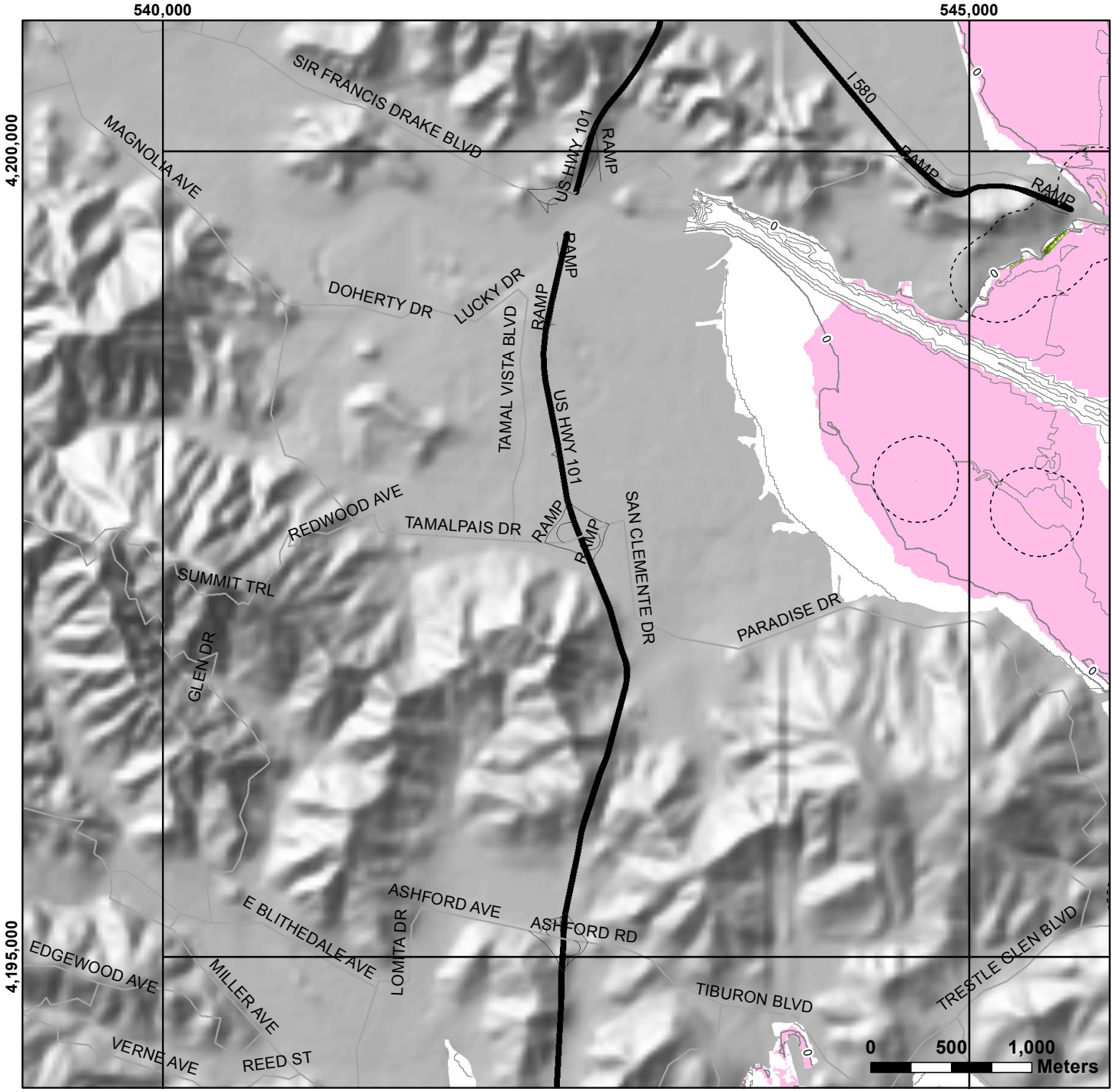


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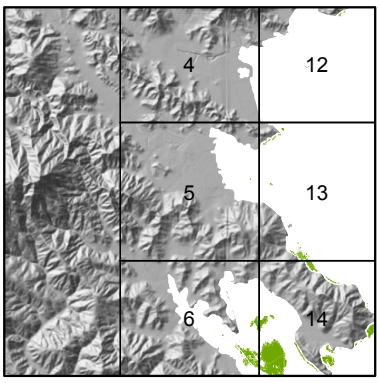

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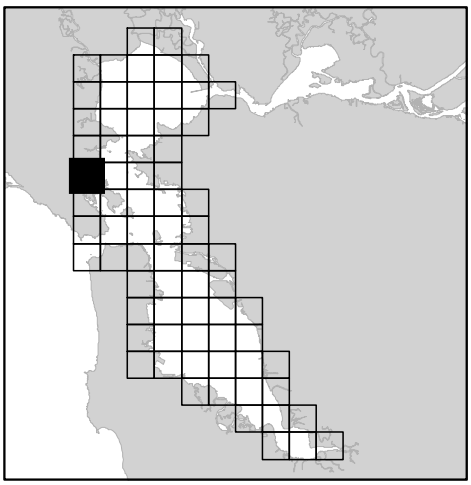

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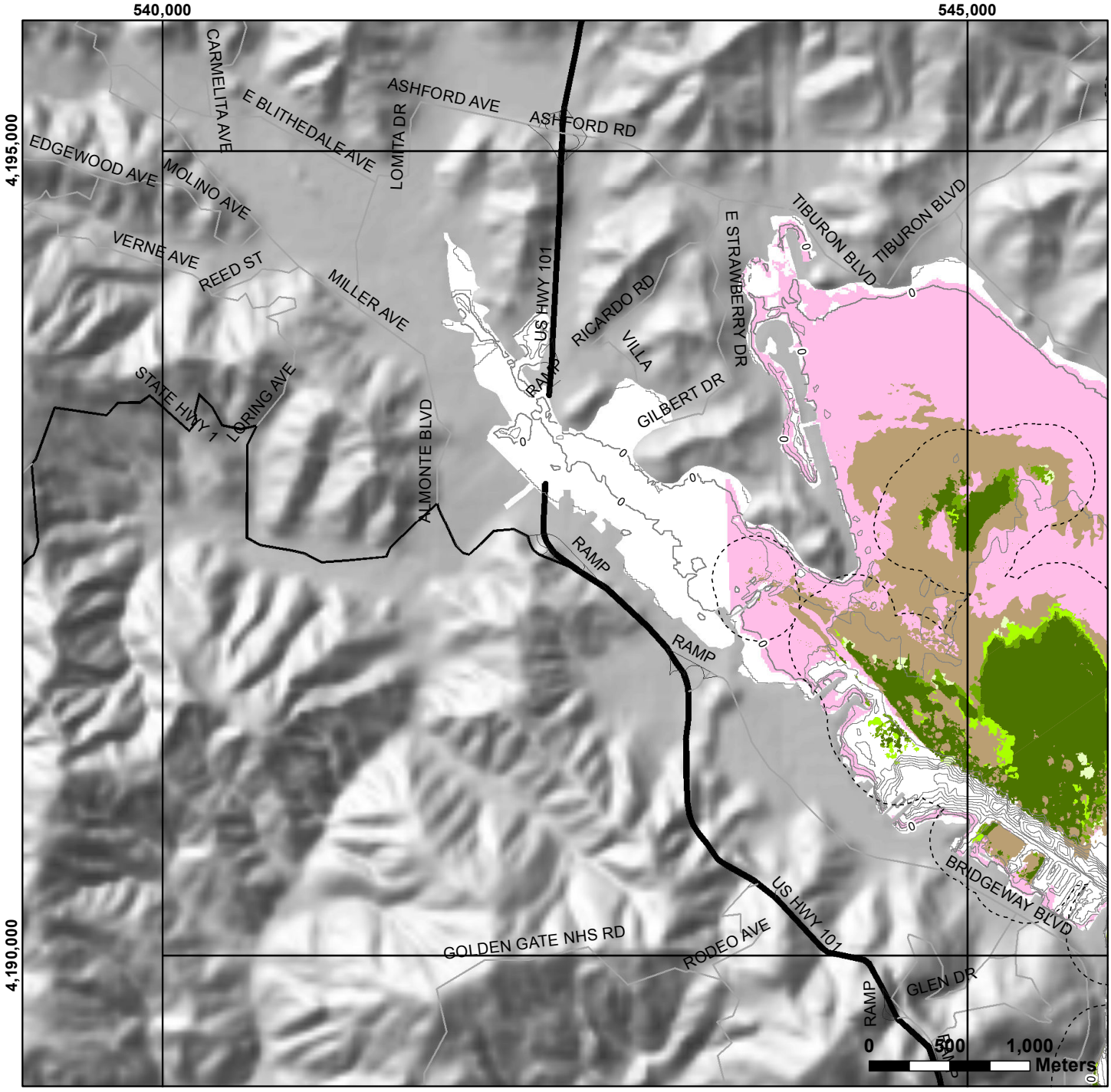


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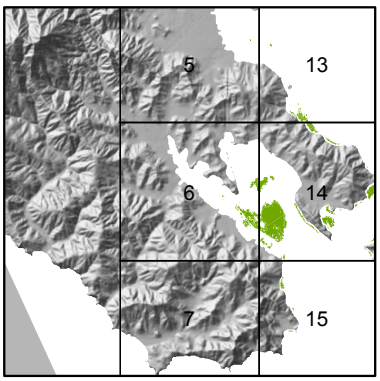

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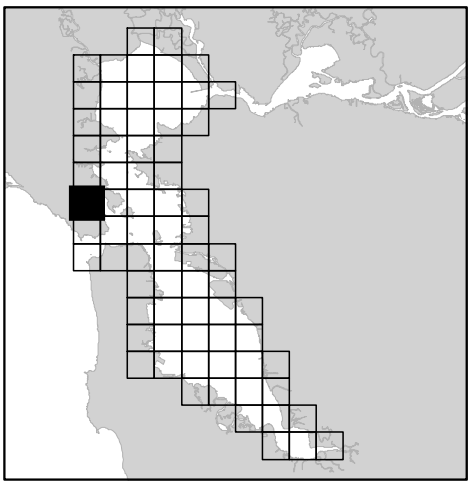

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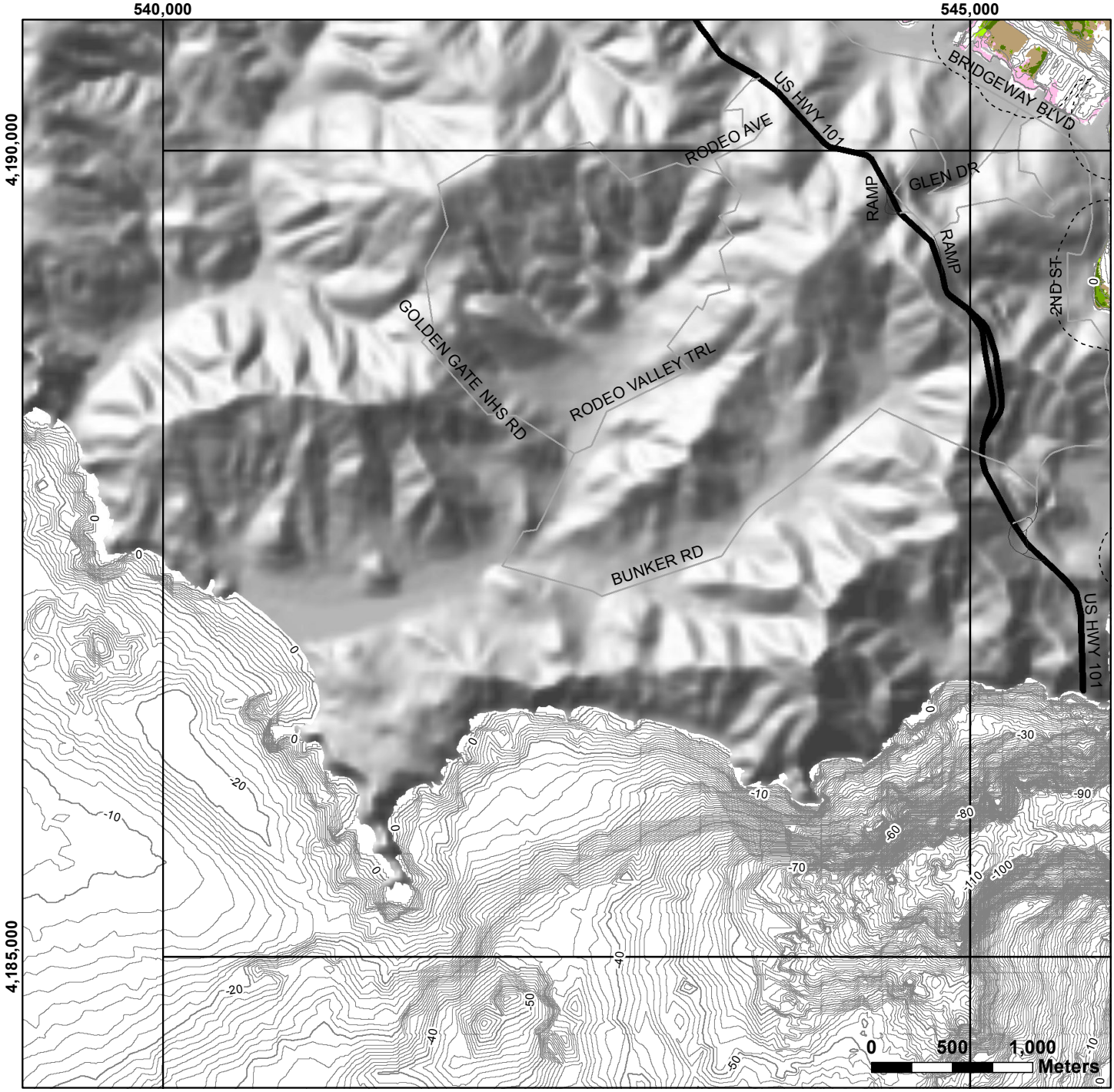


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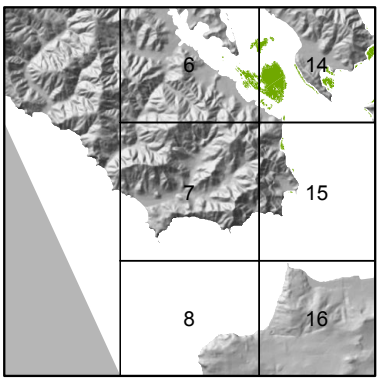

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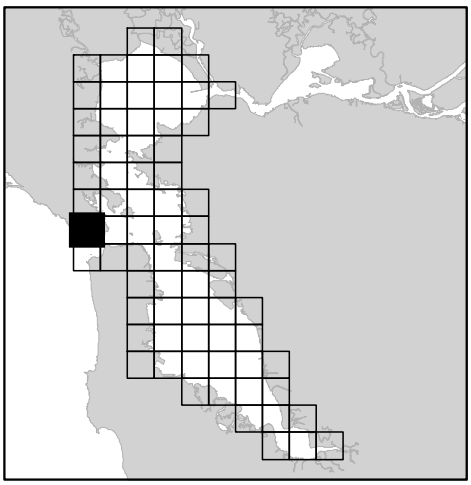
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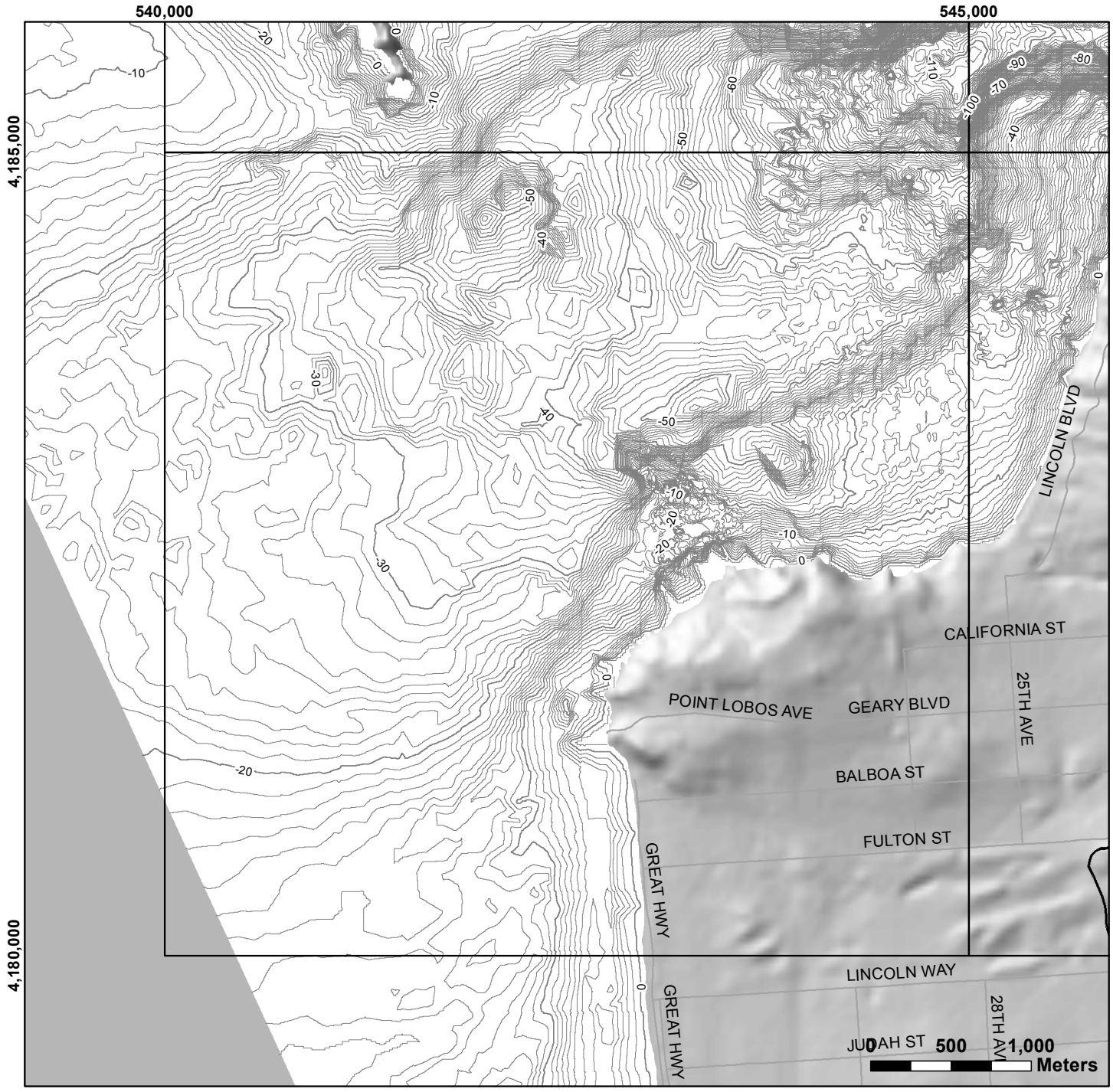


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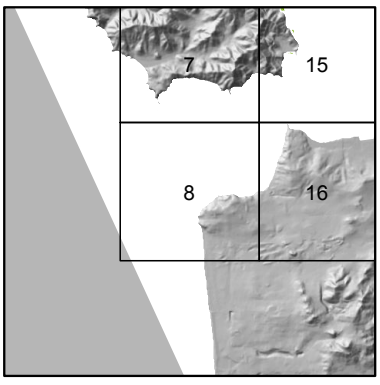

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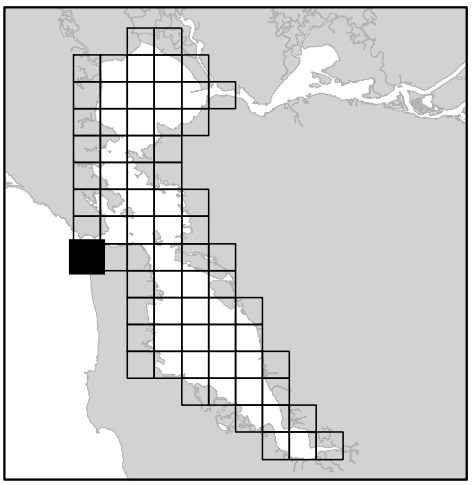
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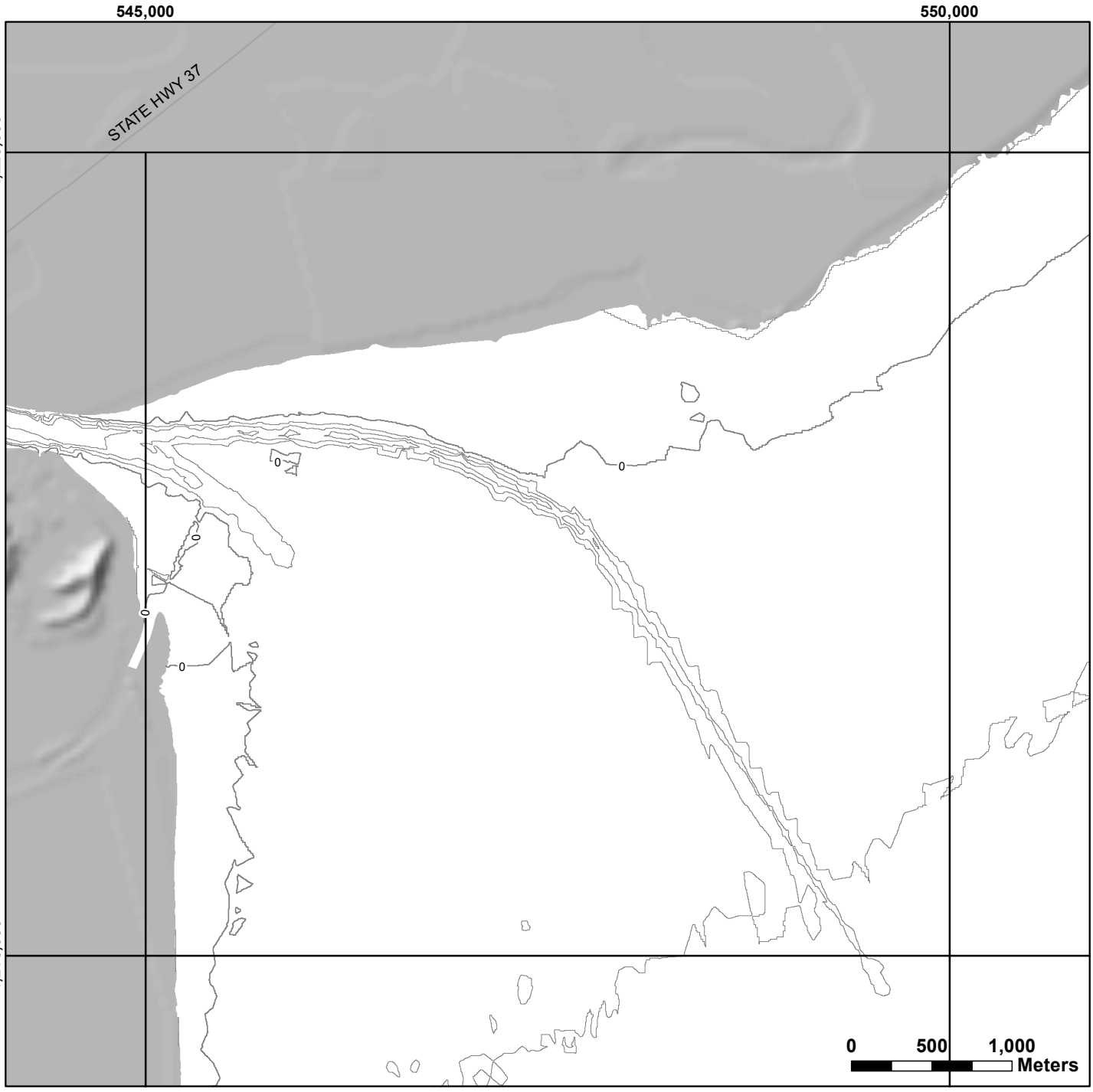


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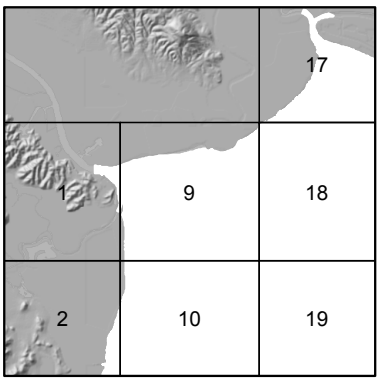

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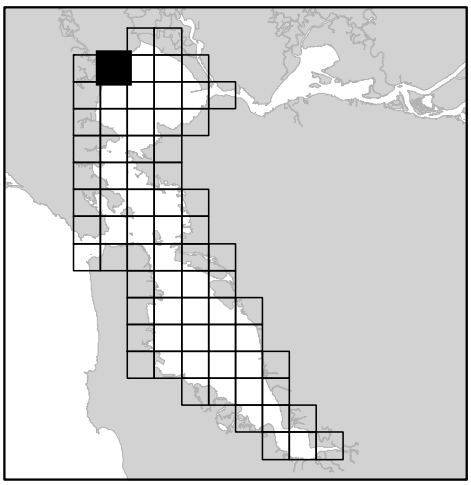
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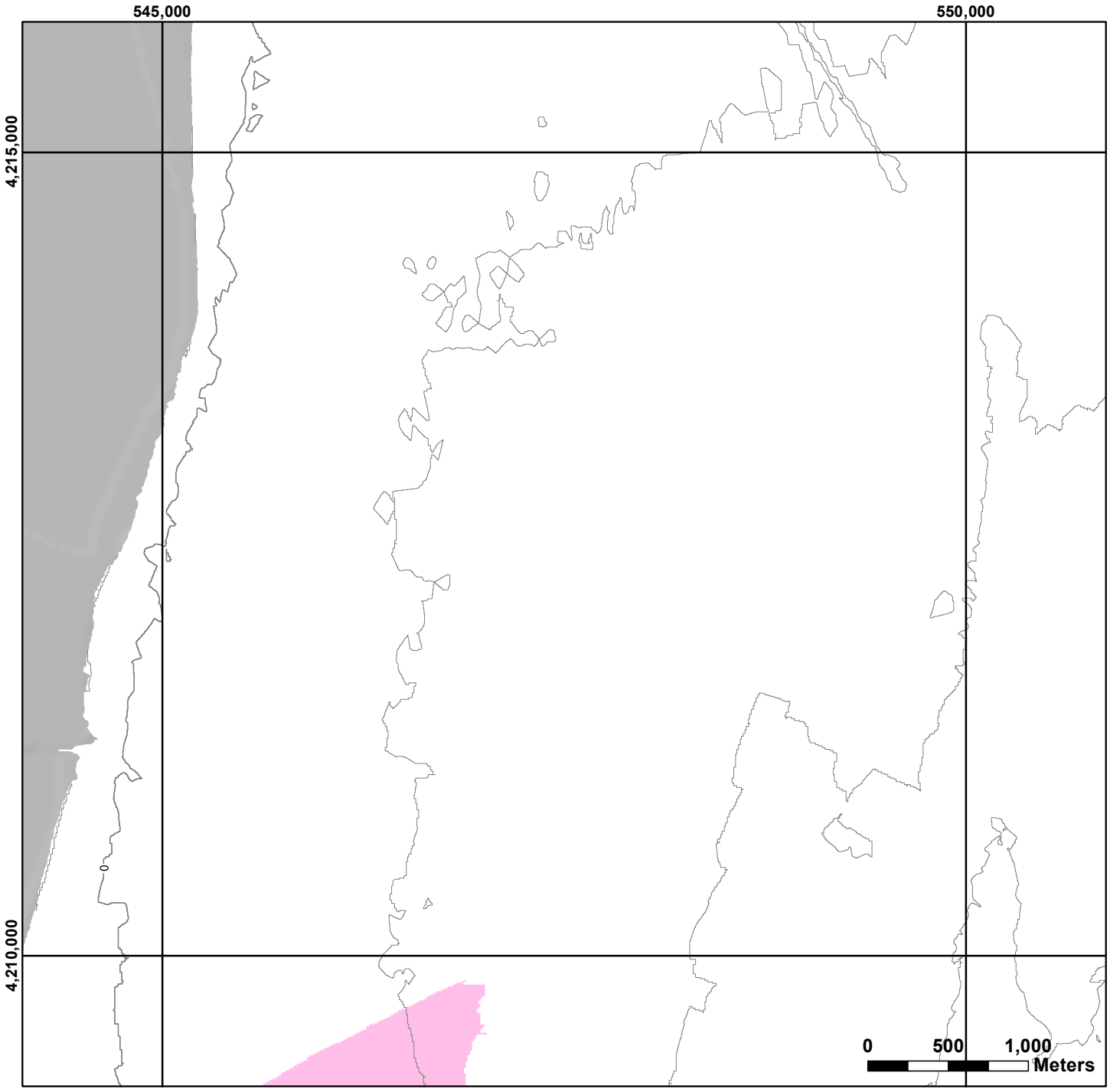

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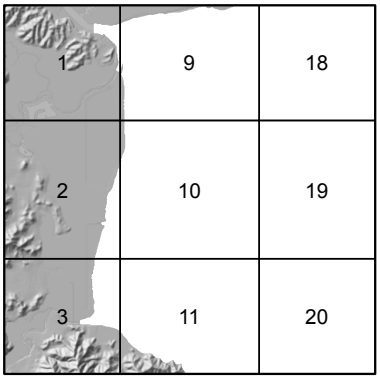

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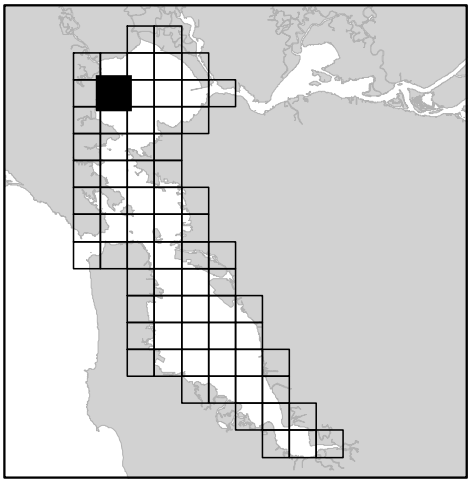
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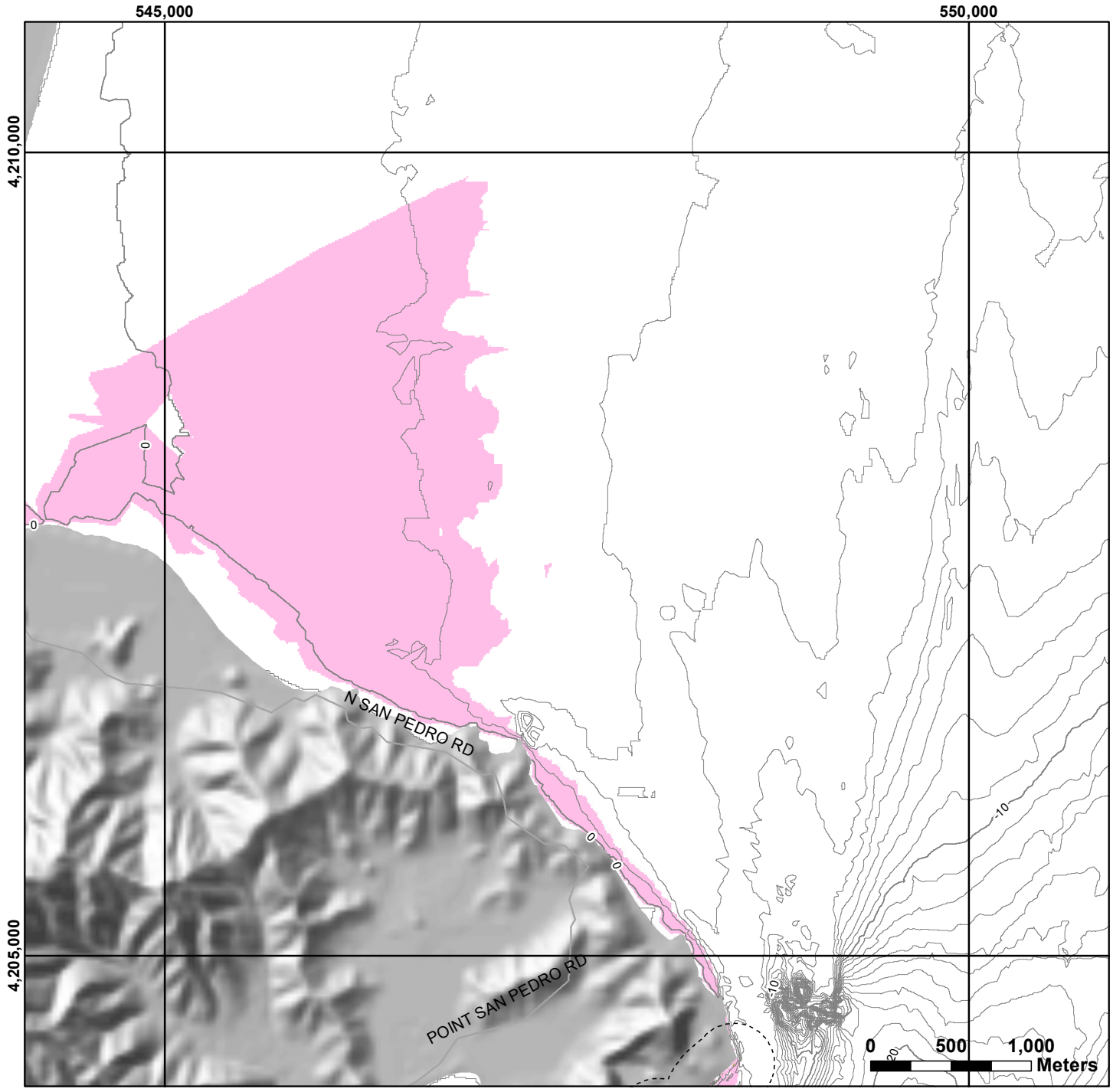


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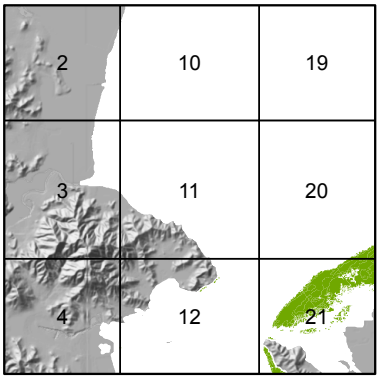

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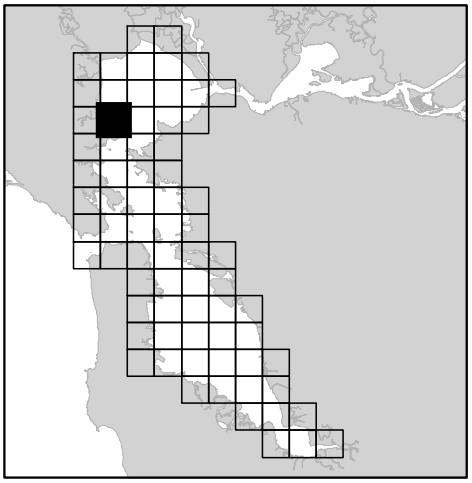
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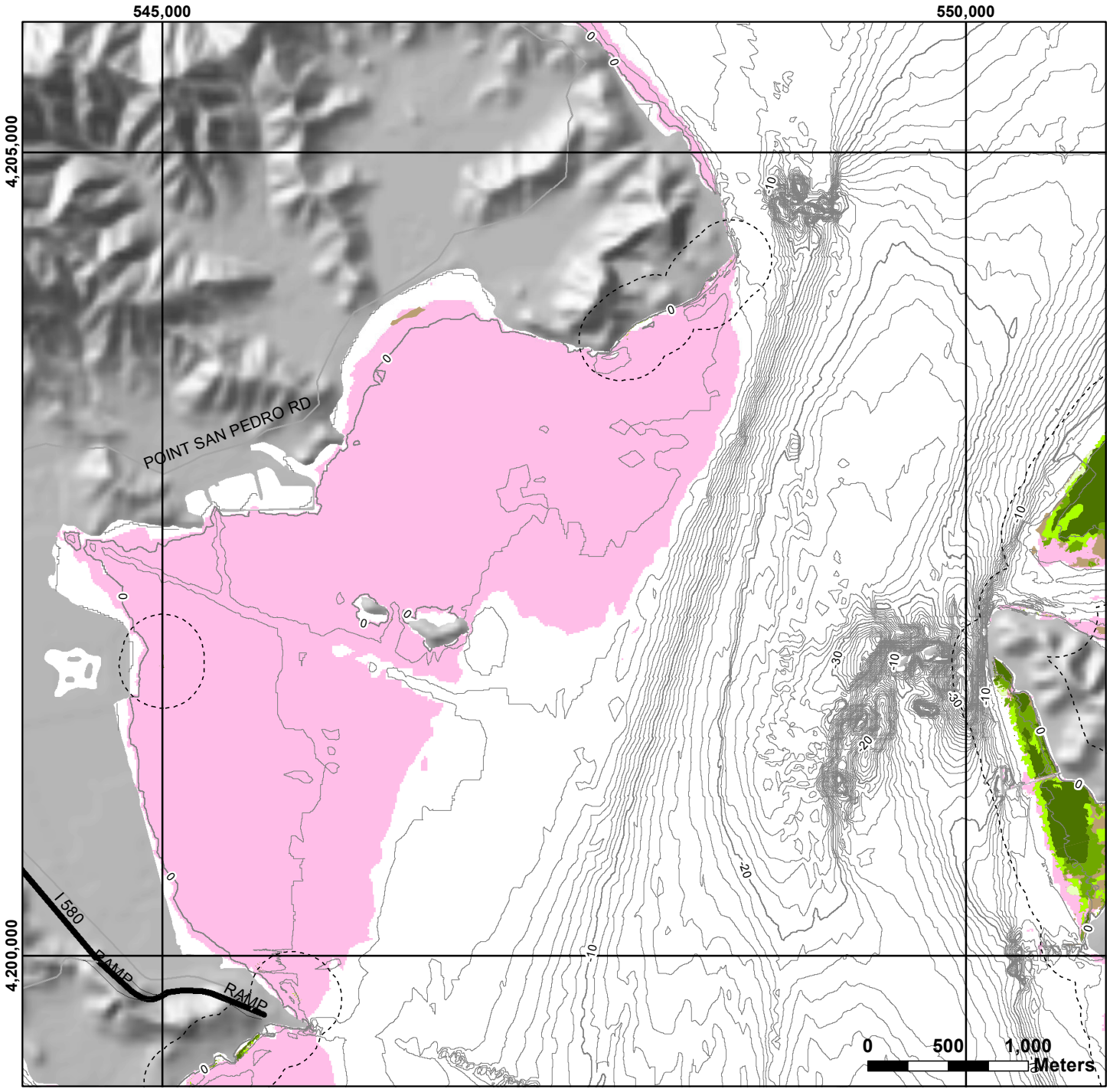

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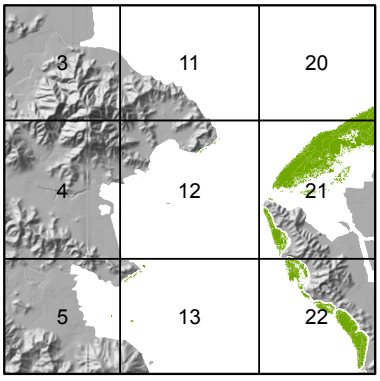

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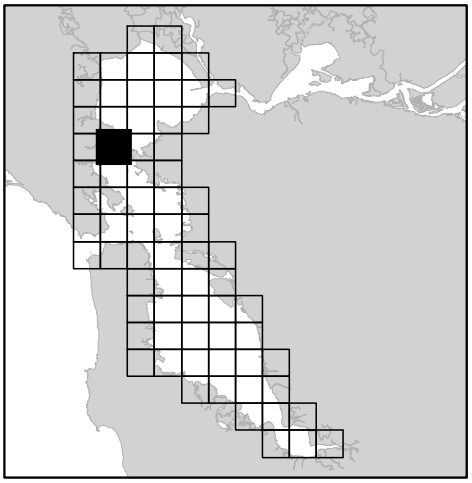
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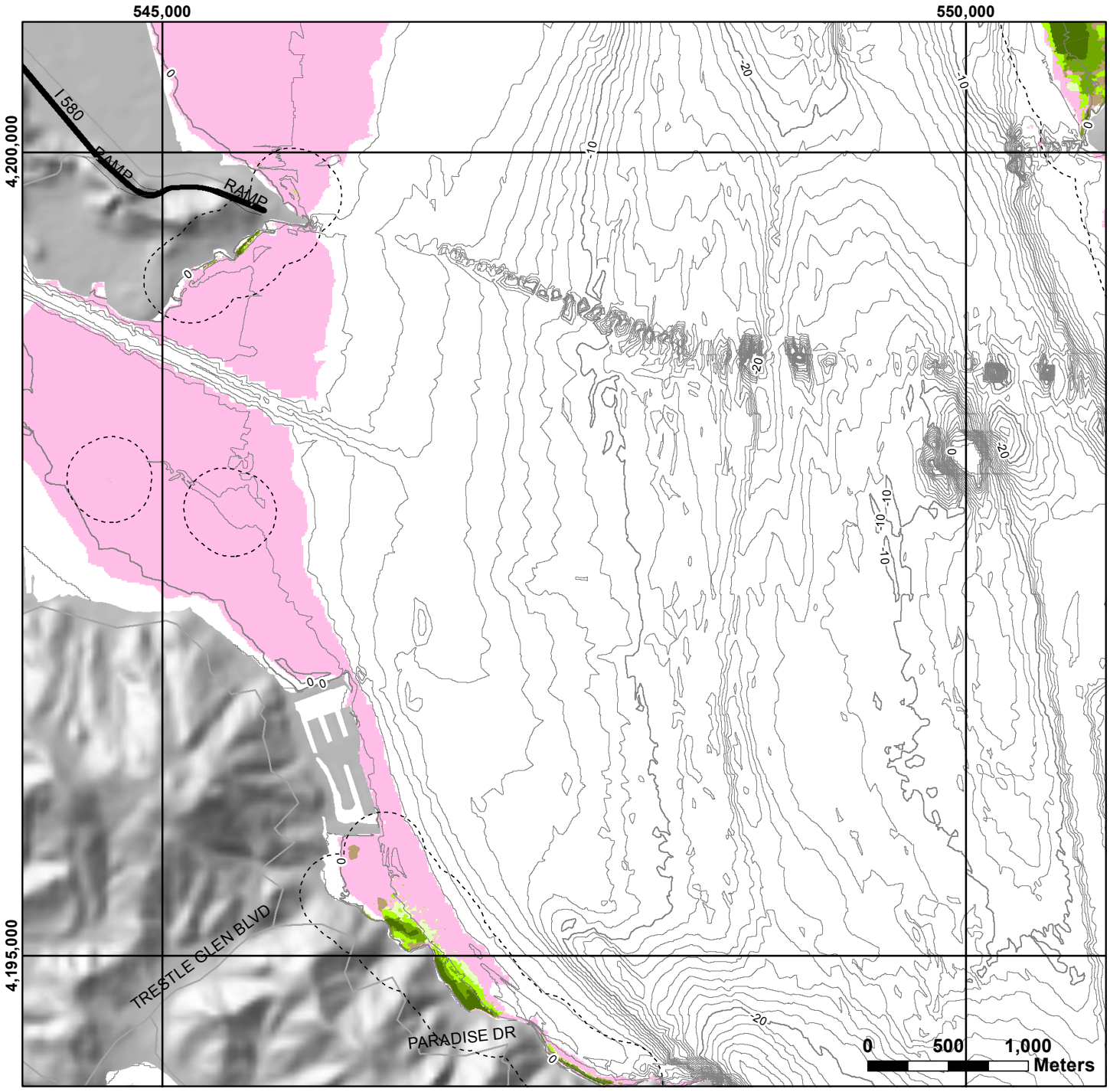


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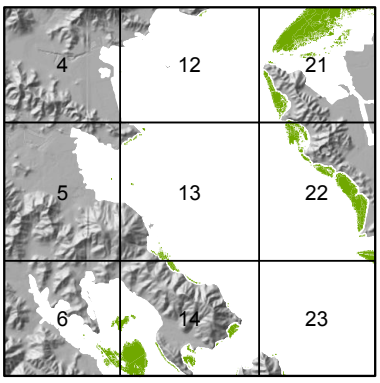

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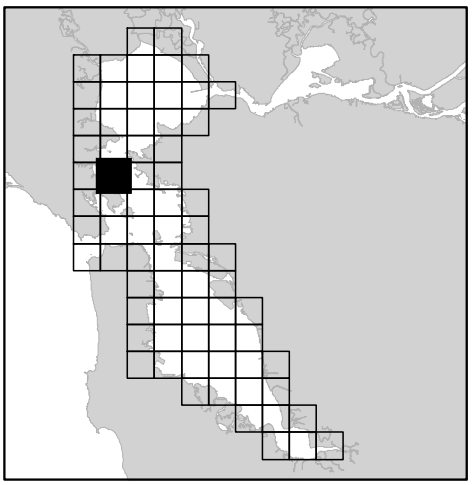
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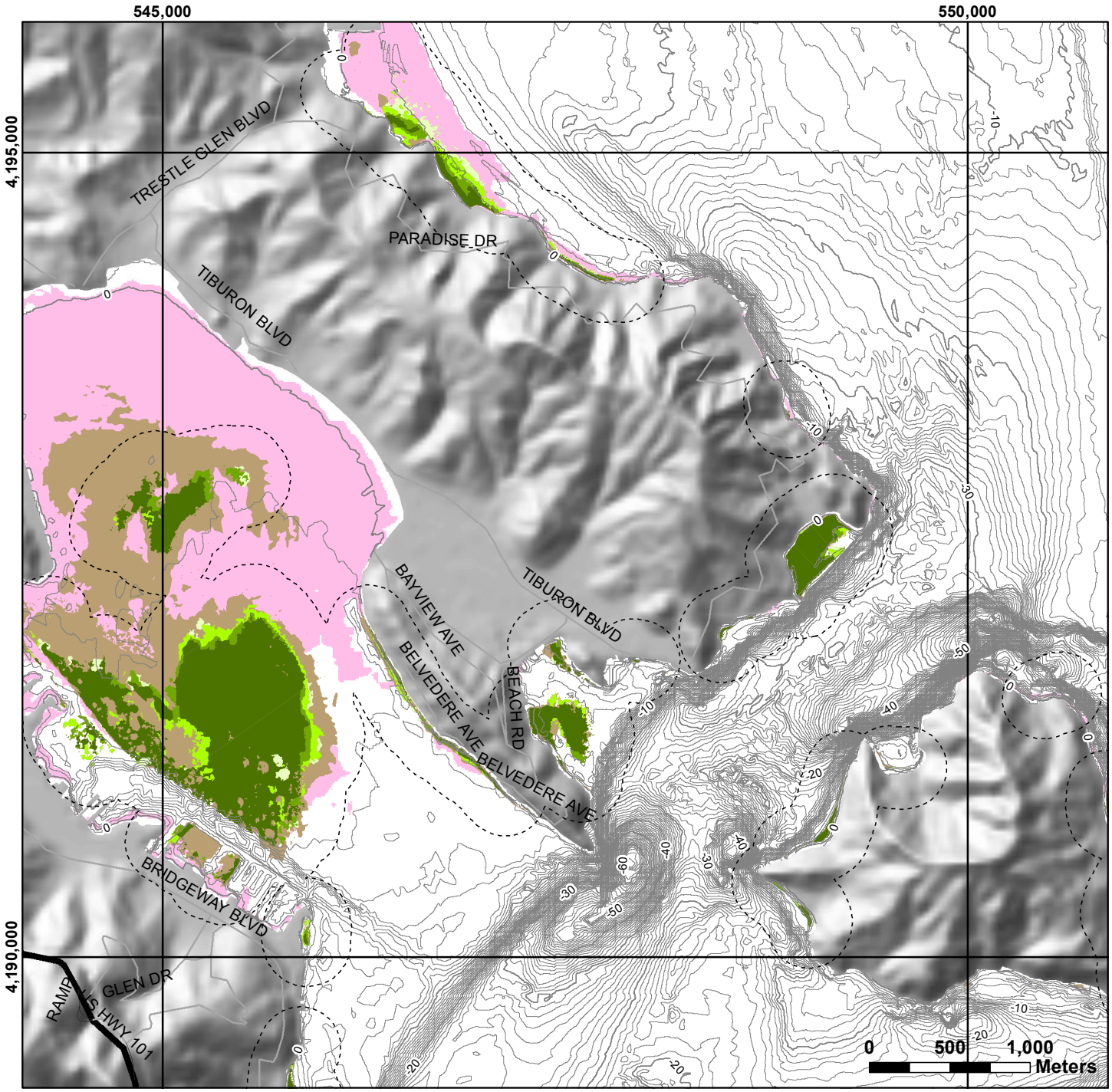


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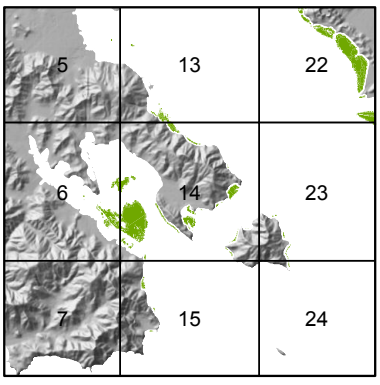

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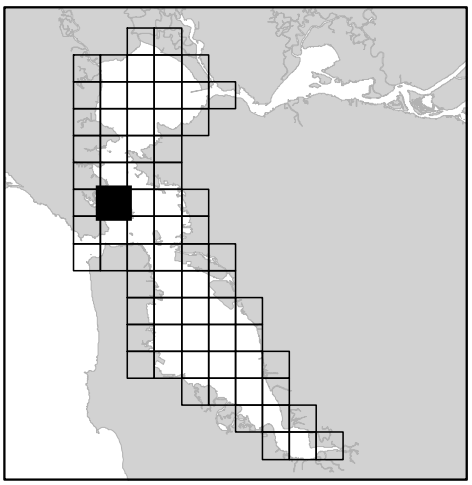
Horizontal Datum: UTM NAD83 Zone 10N (meters)
Vertical Datum: MLLW (meters)

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SHEET VICINITY




SHEET LOCATOR

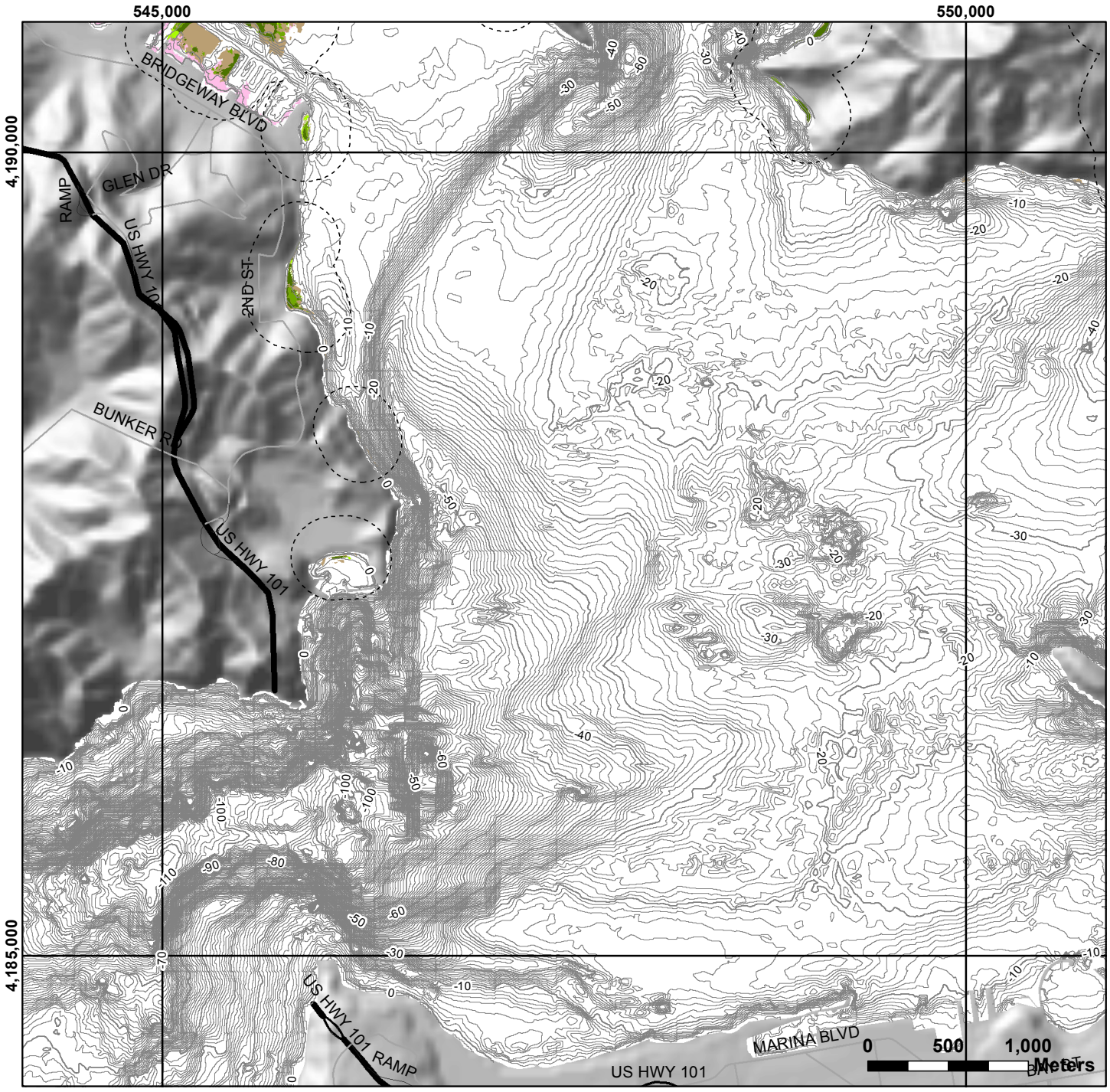


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- 41-100%

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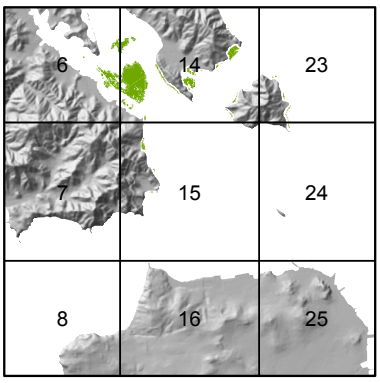

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## Eelgrass 2014

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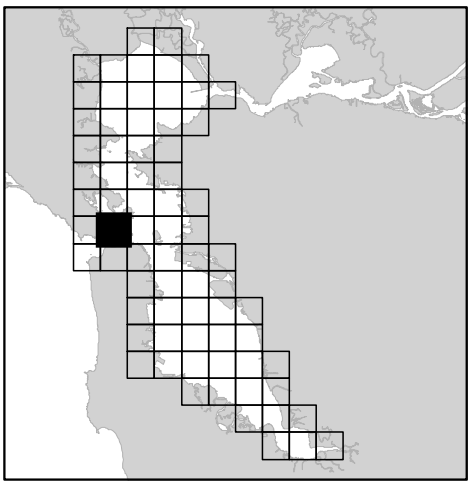
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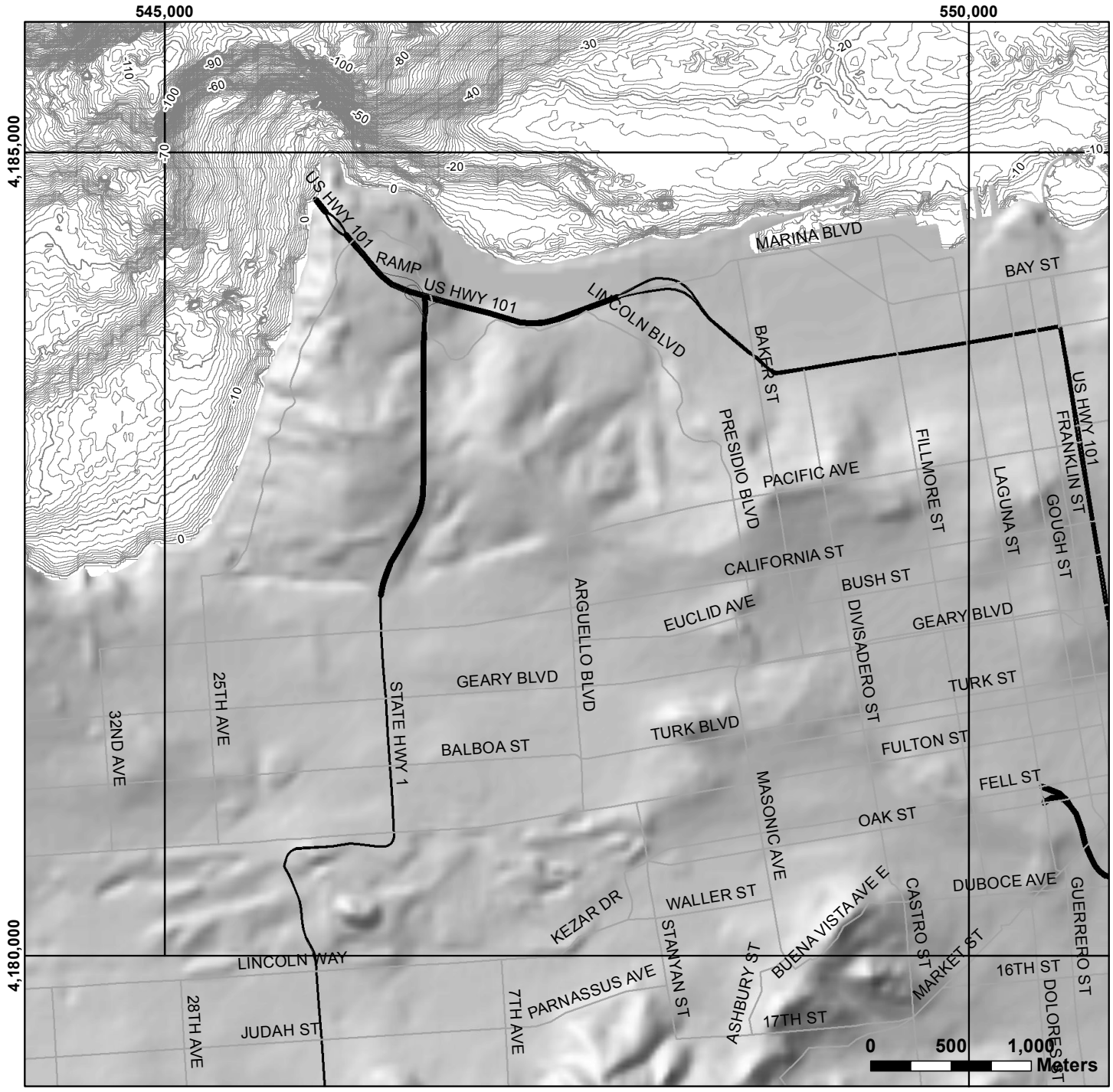


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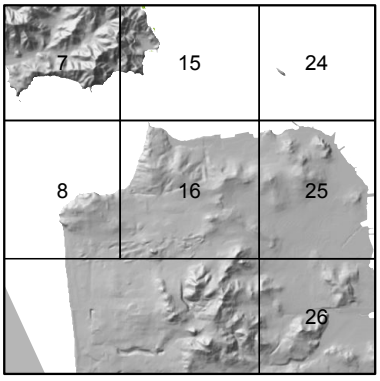

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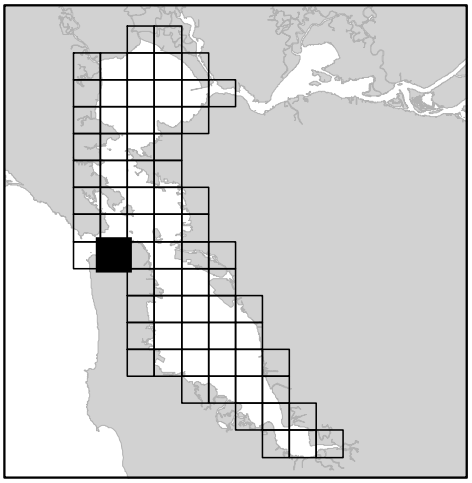

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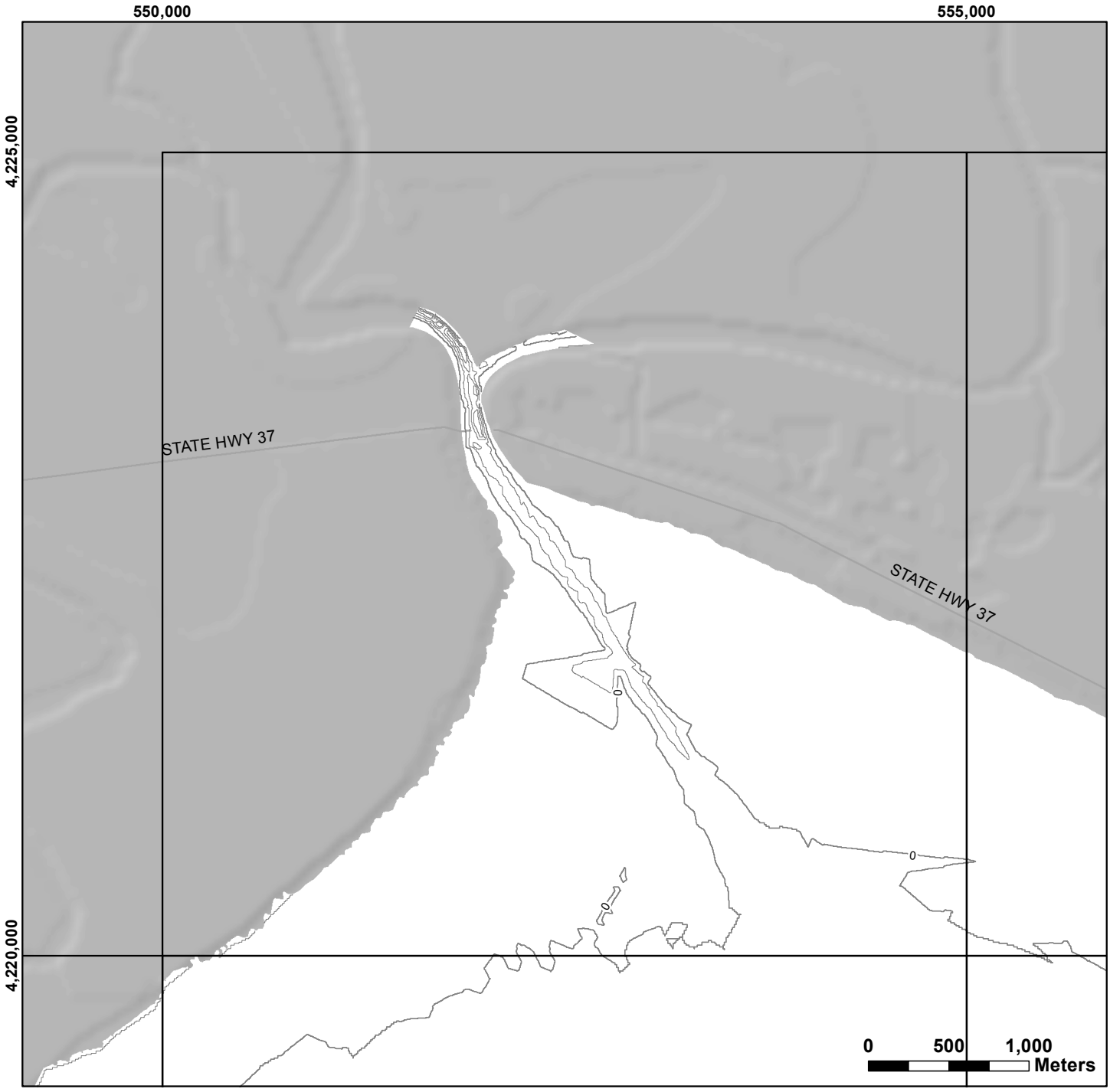


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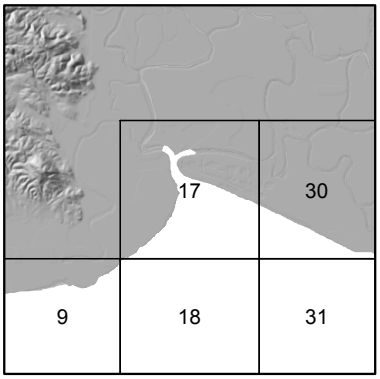

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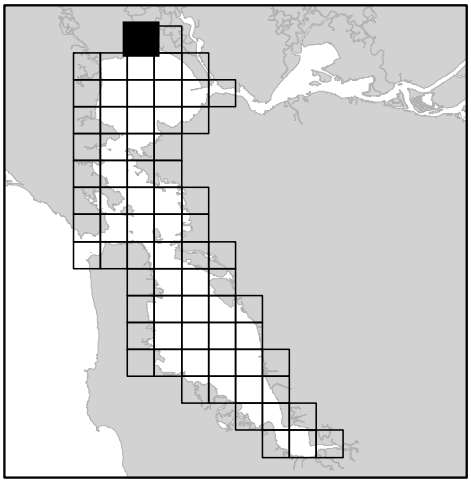
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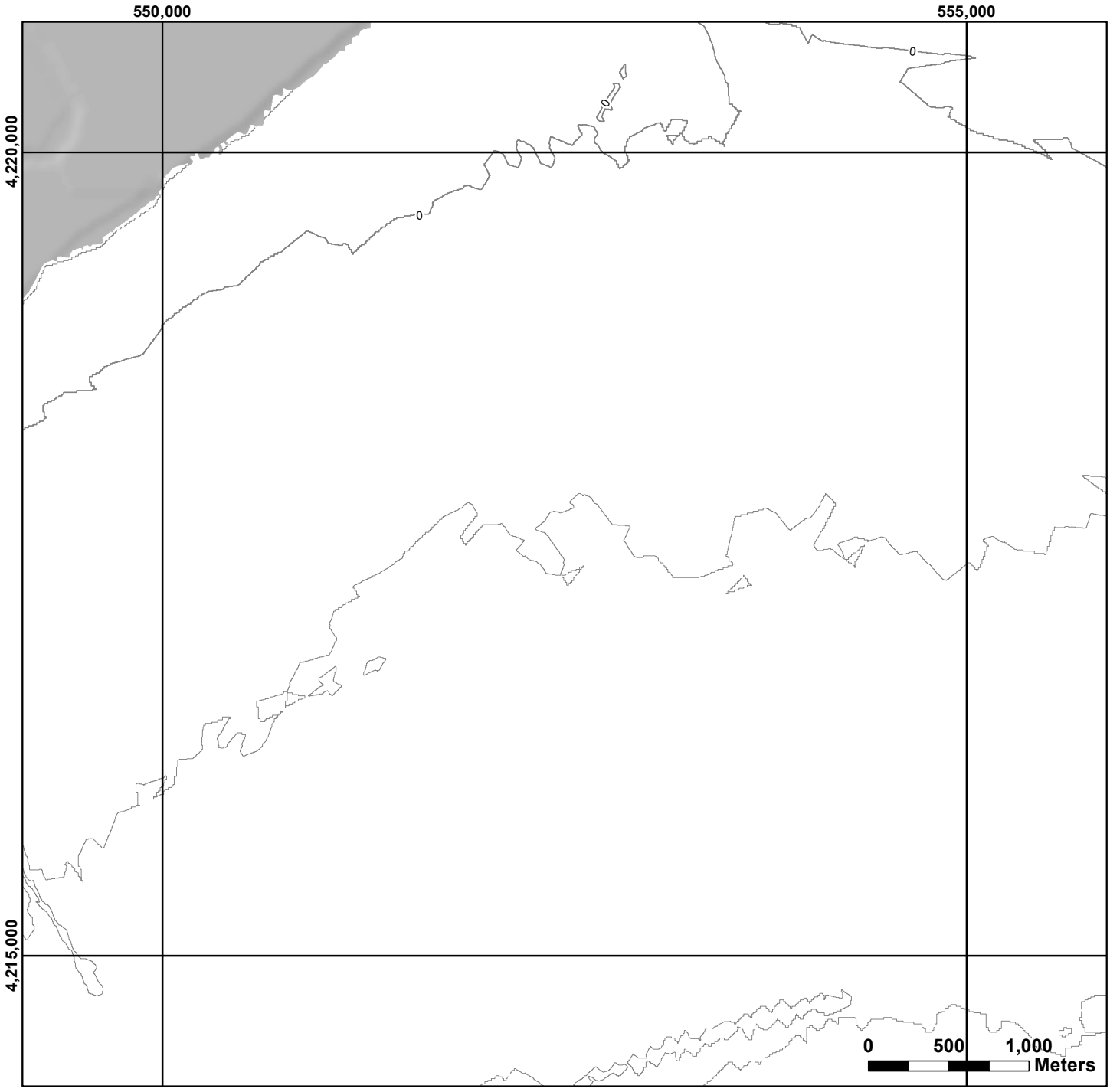





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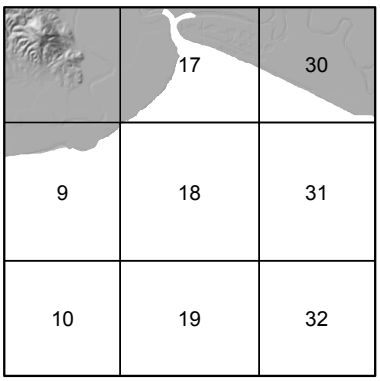

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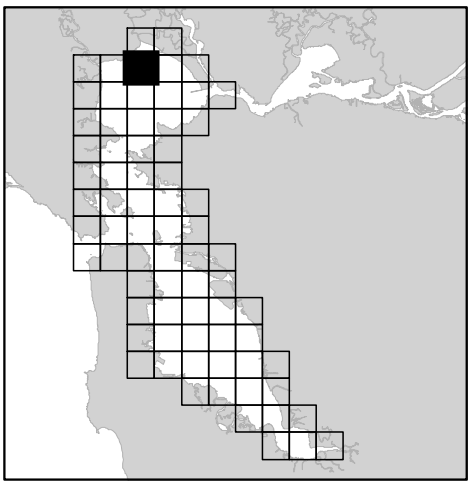
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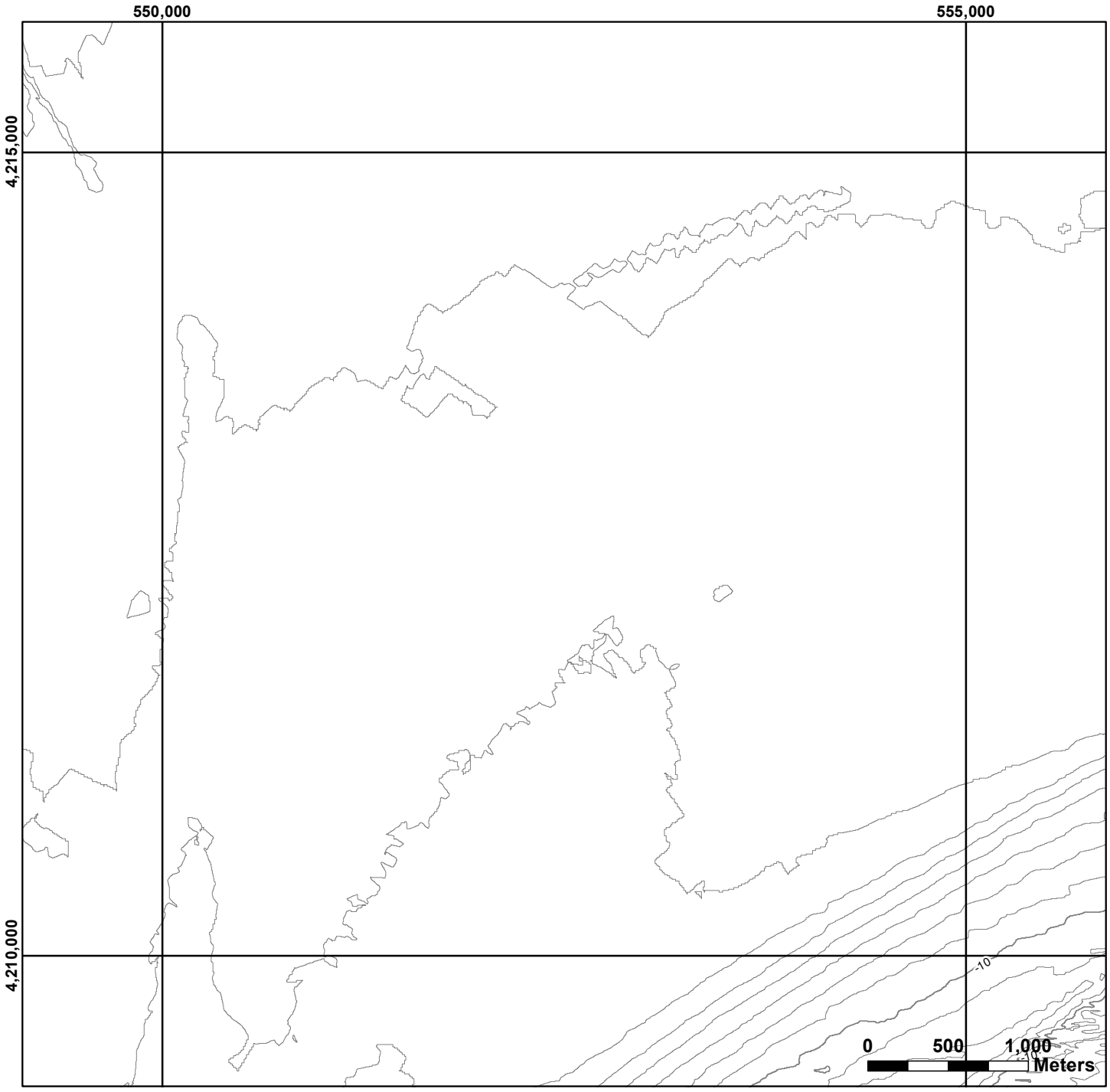





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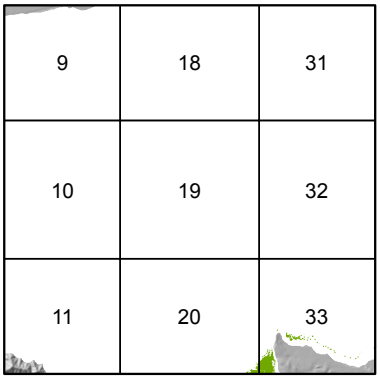

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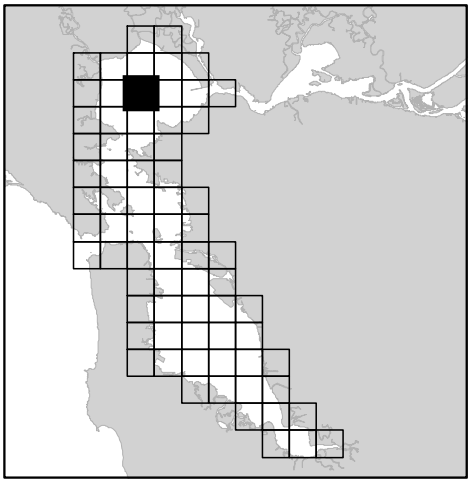
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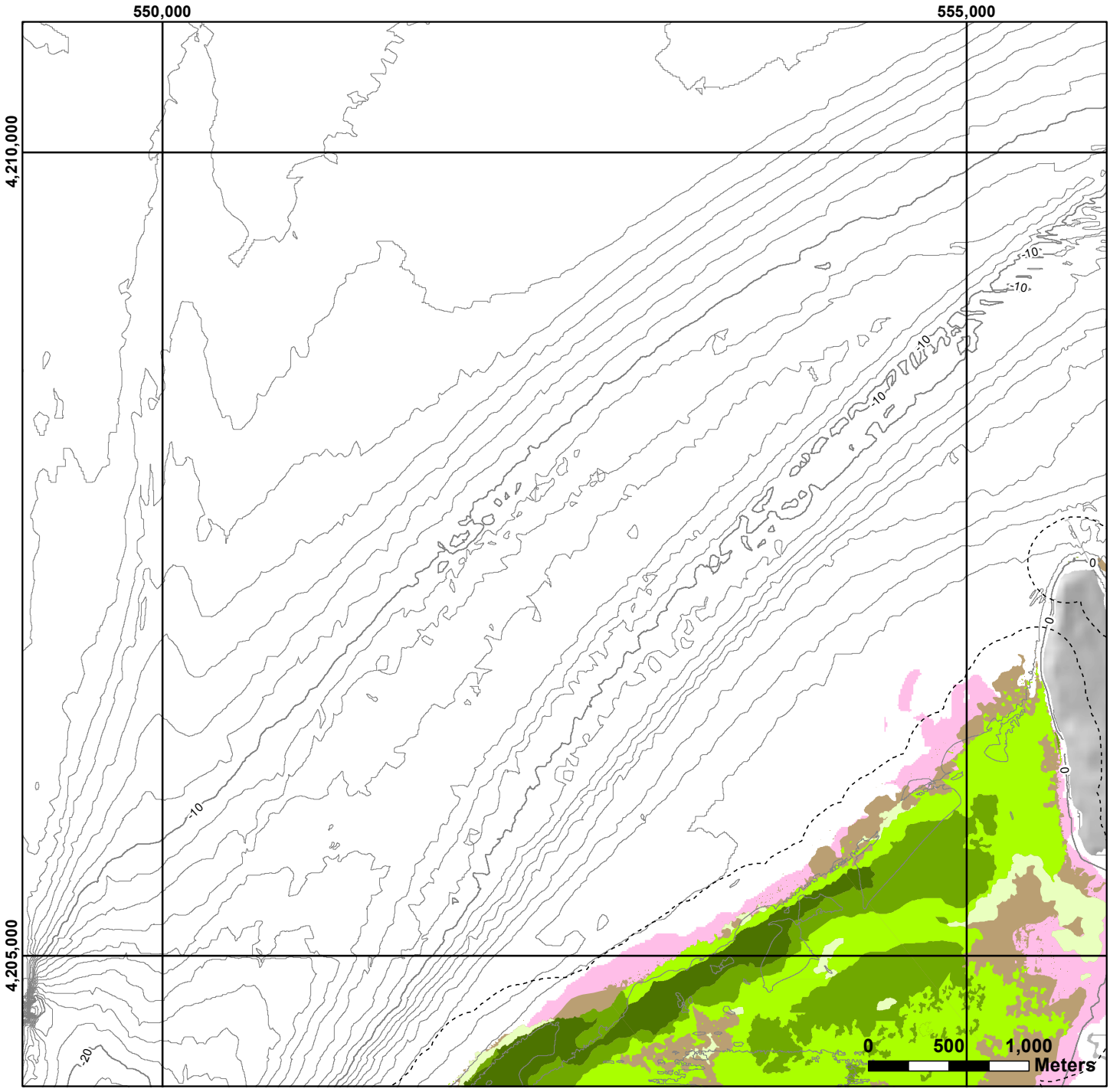





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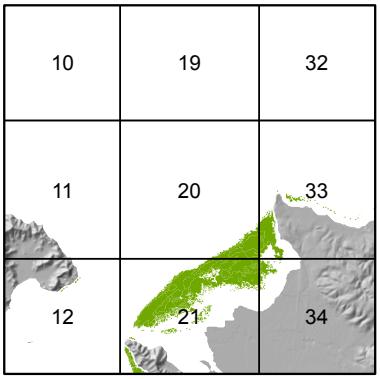

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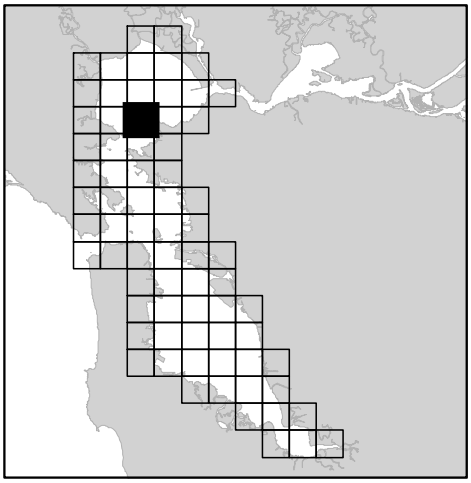
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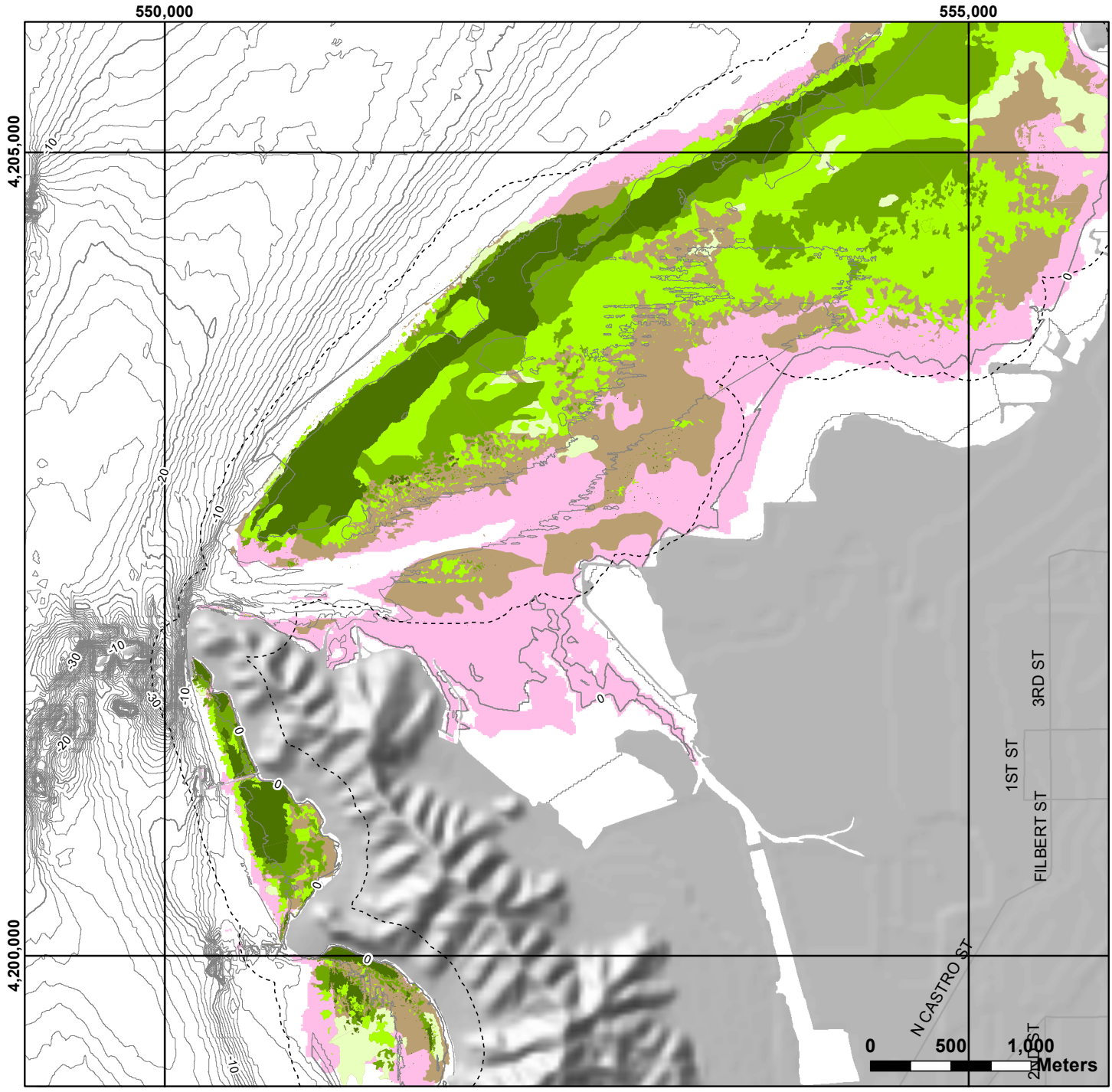


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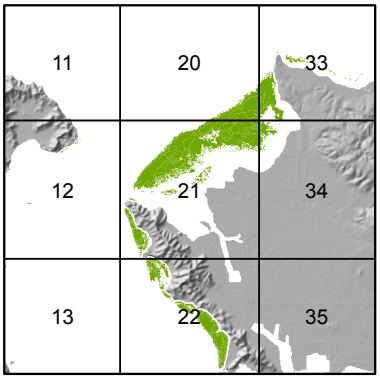

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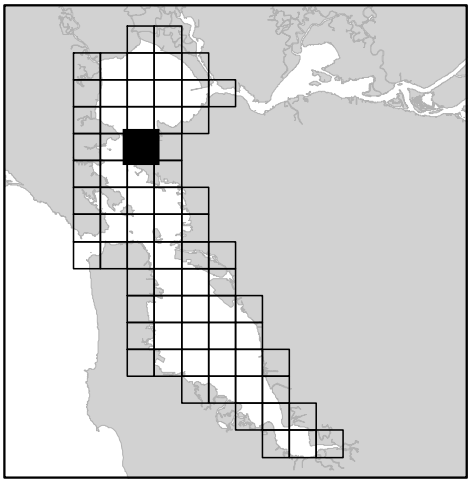
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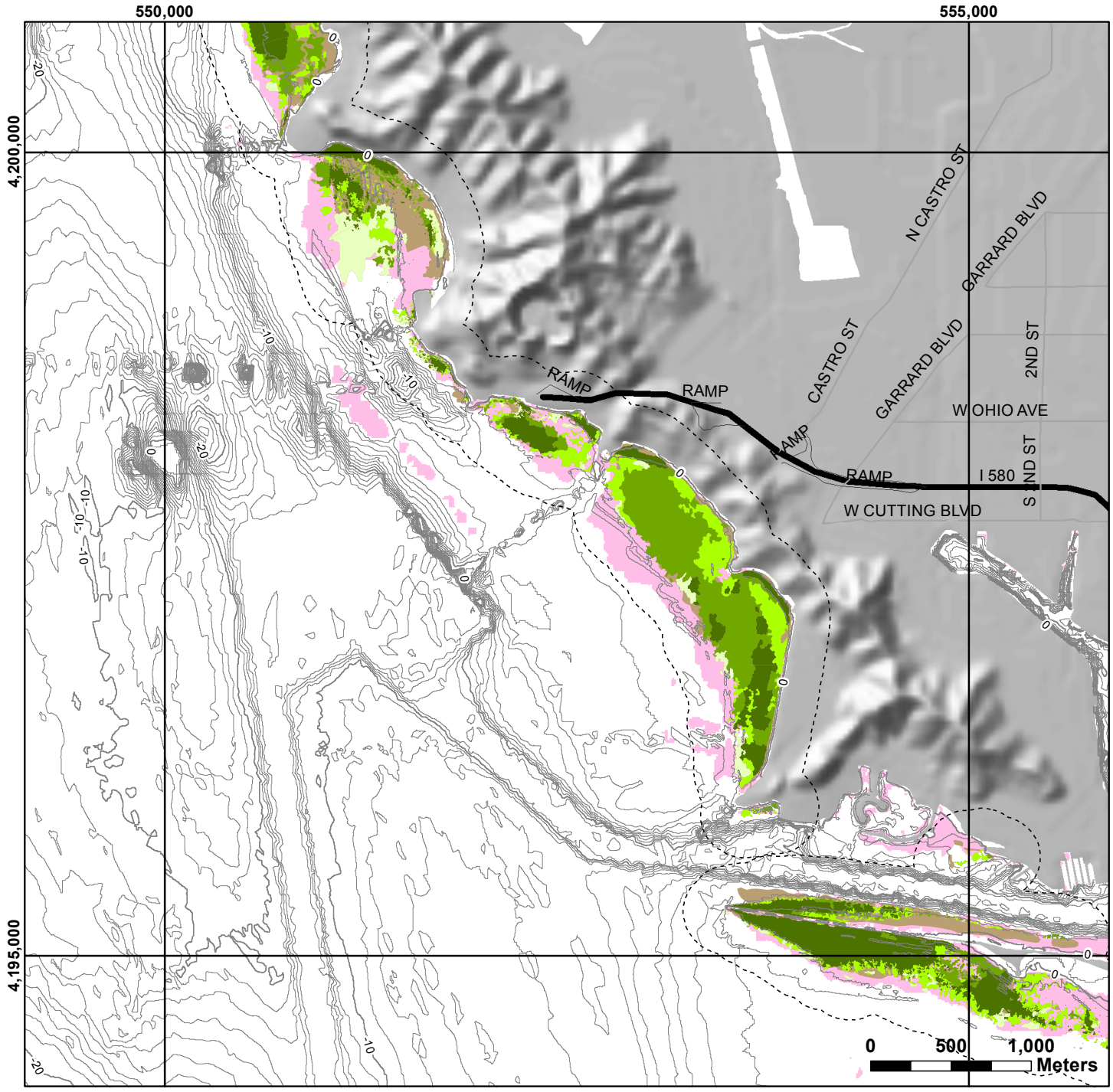

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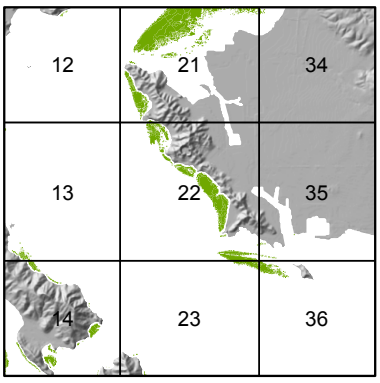

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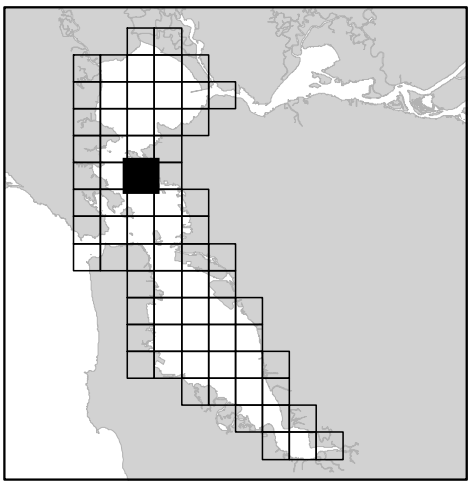
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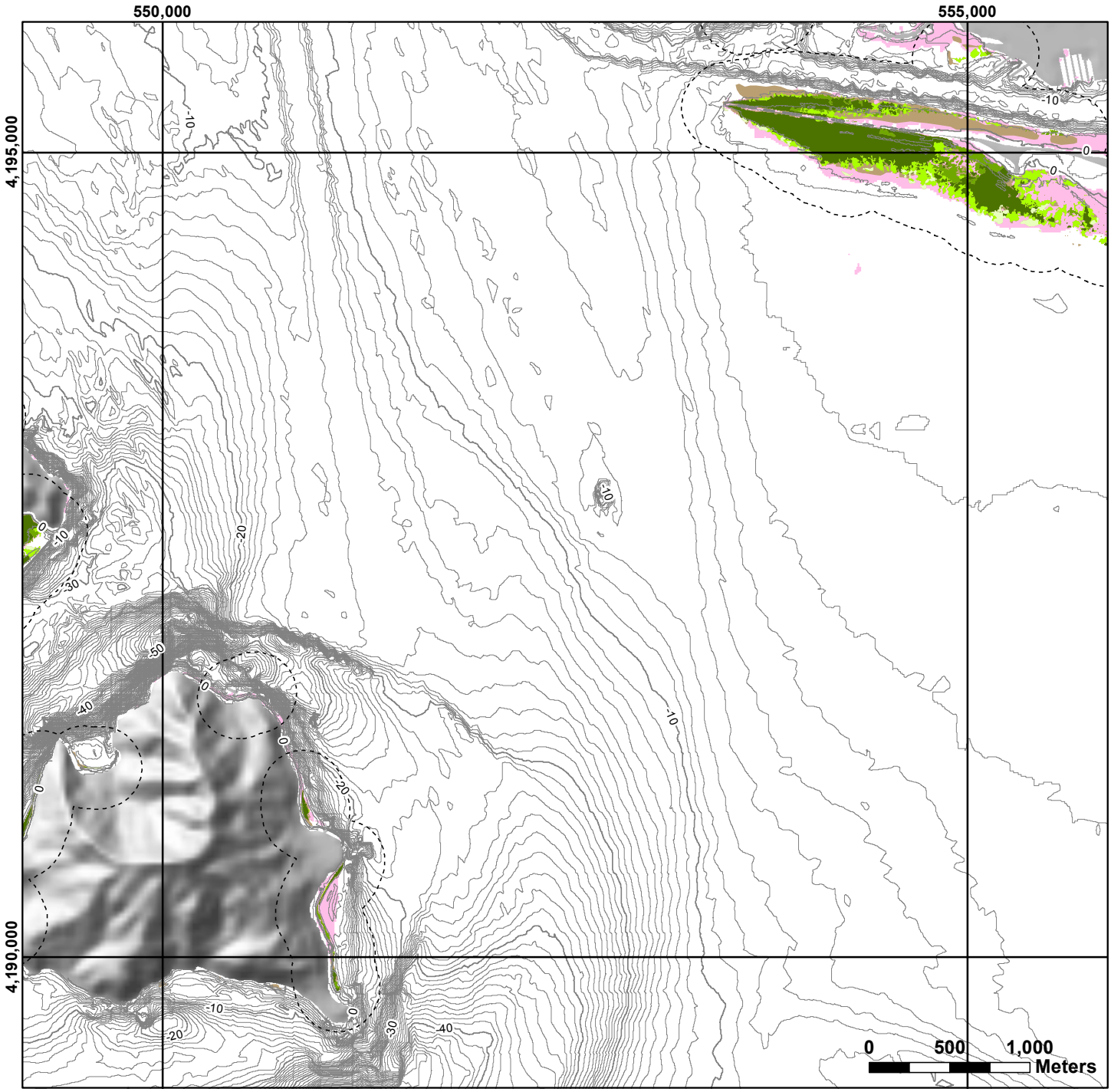


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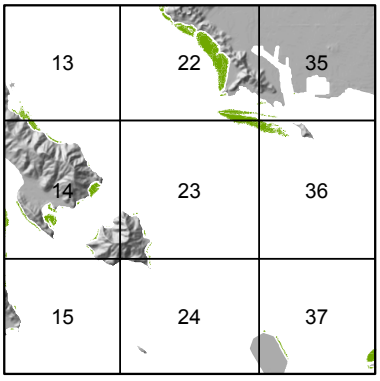

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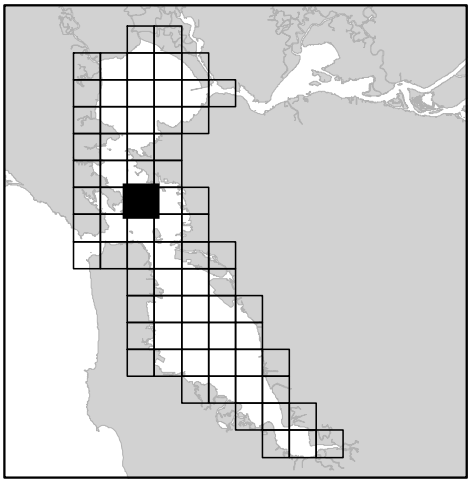
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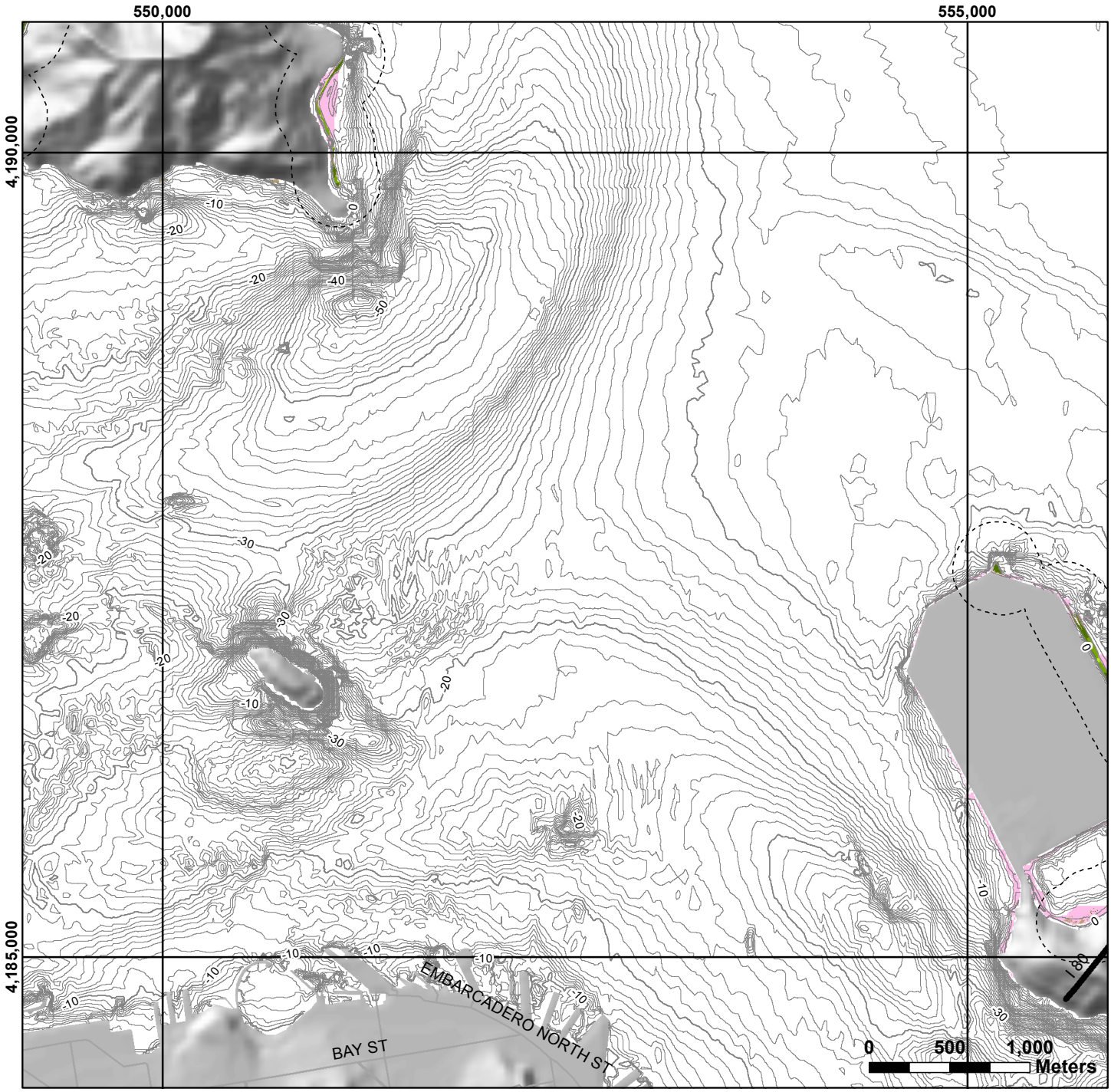


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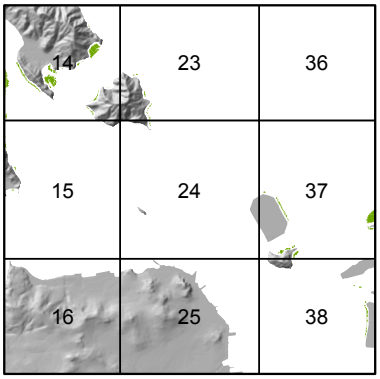

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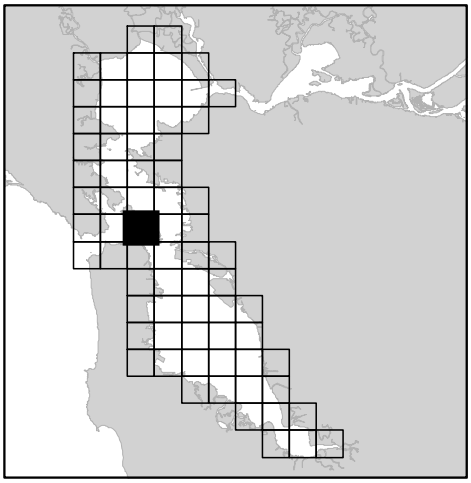
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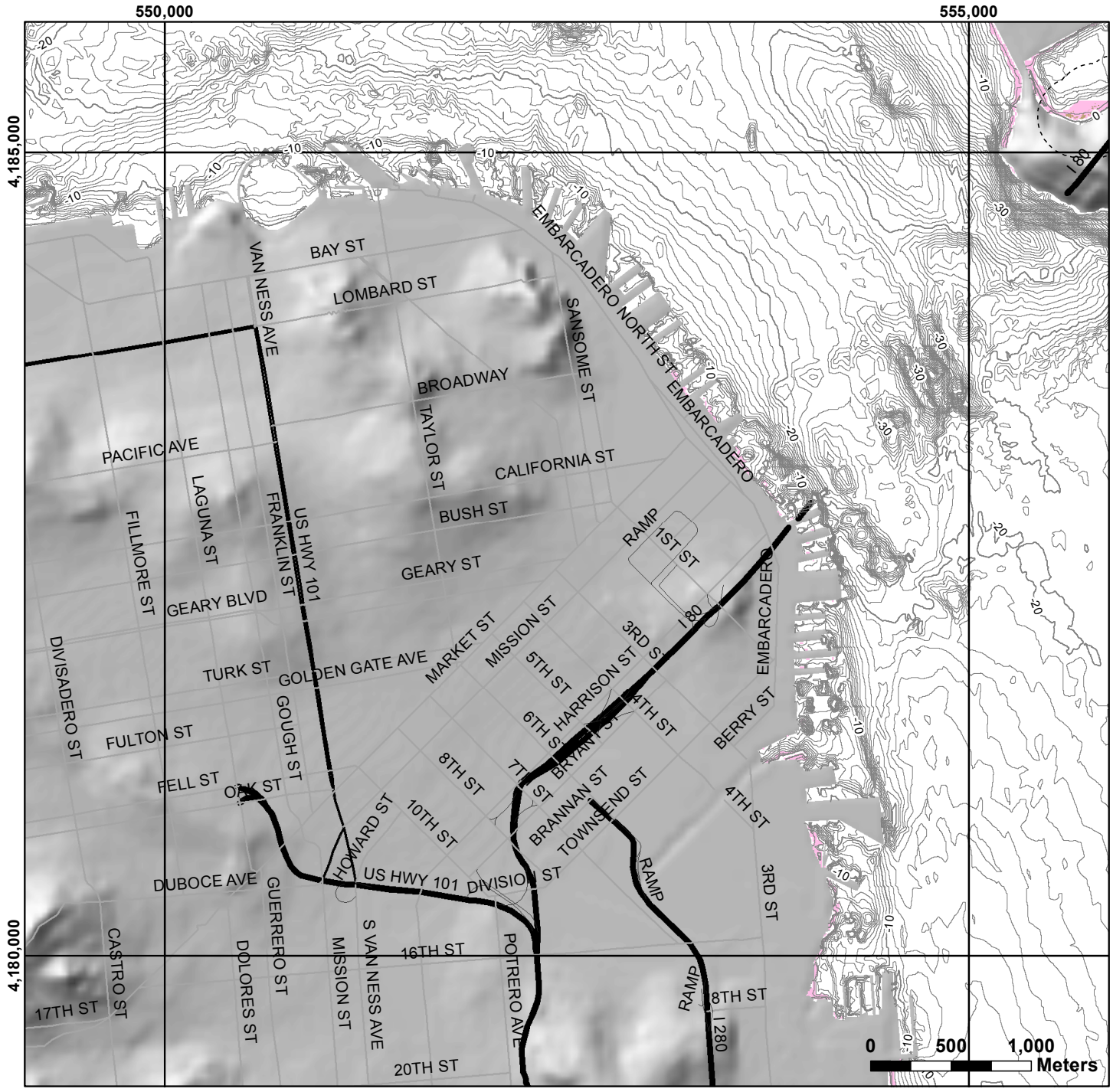


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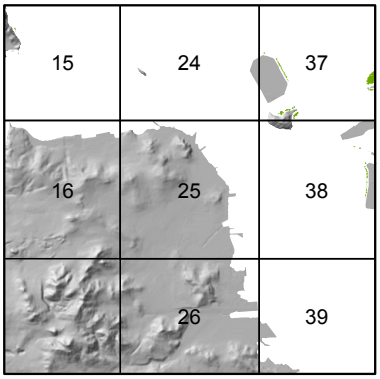

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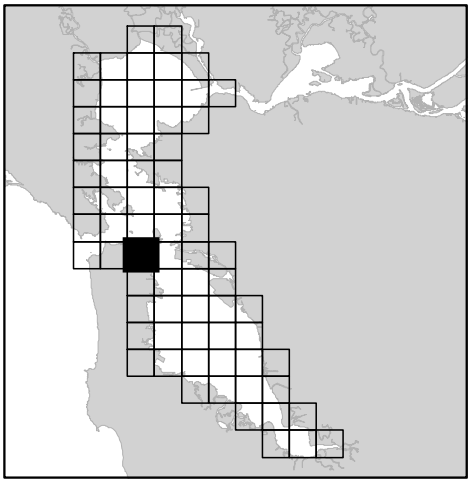

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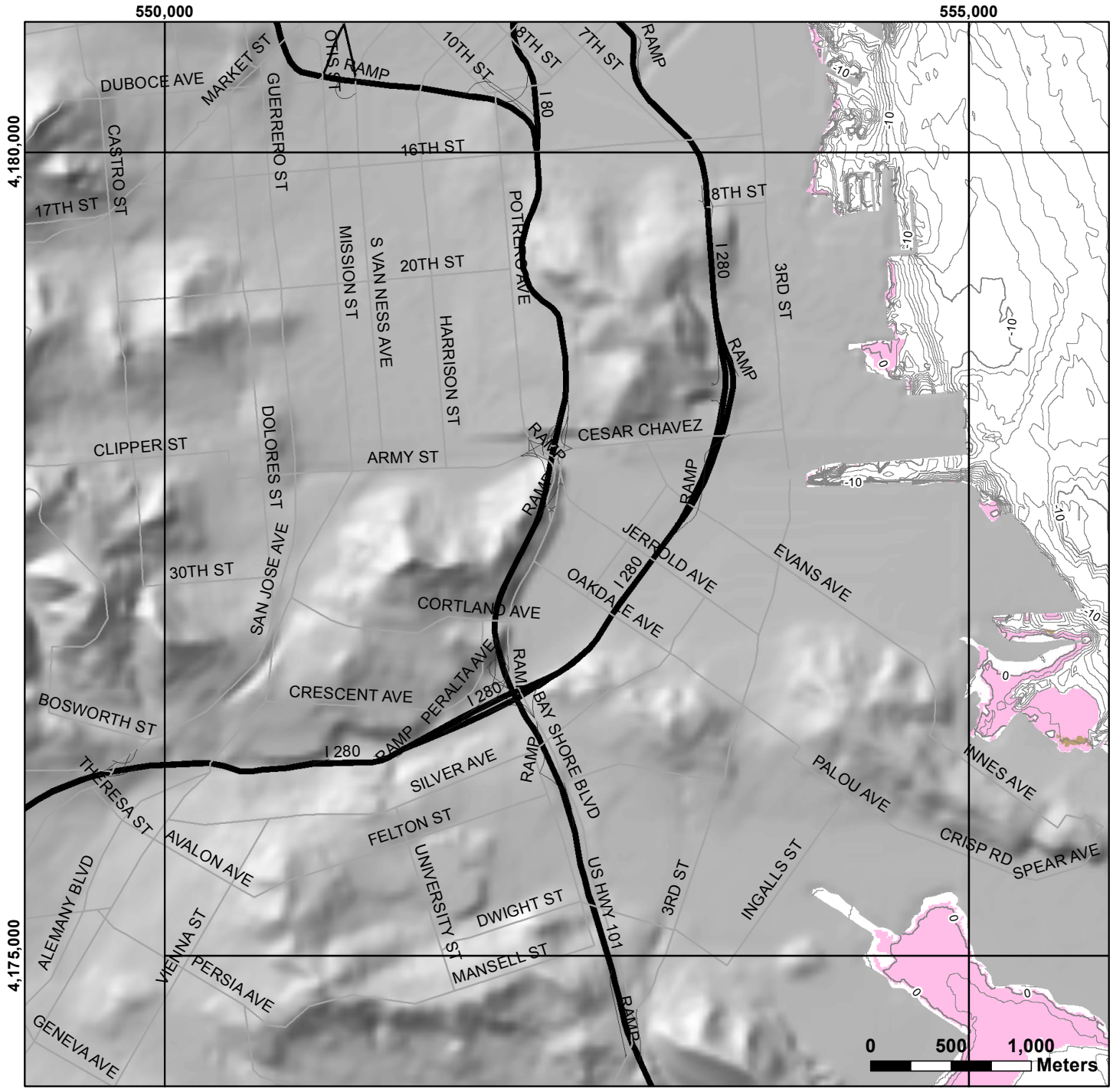


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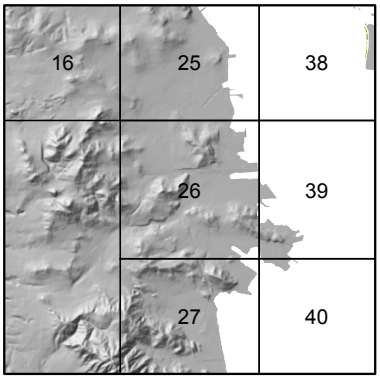

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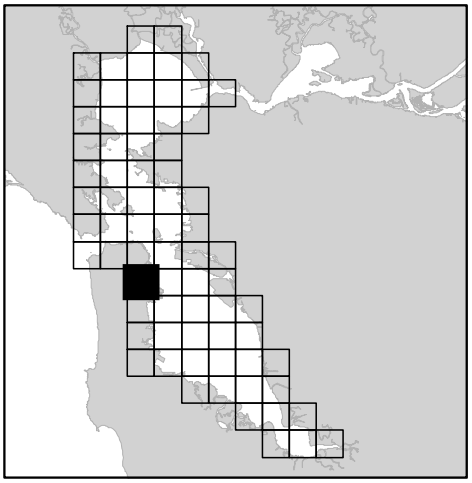

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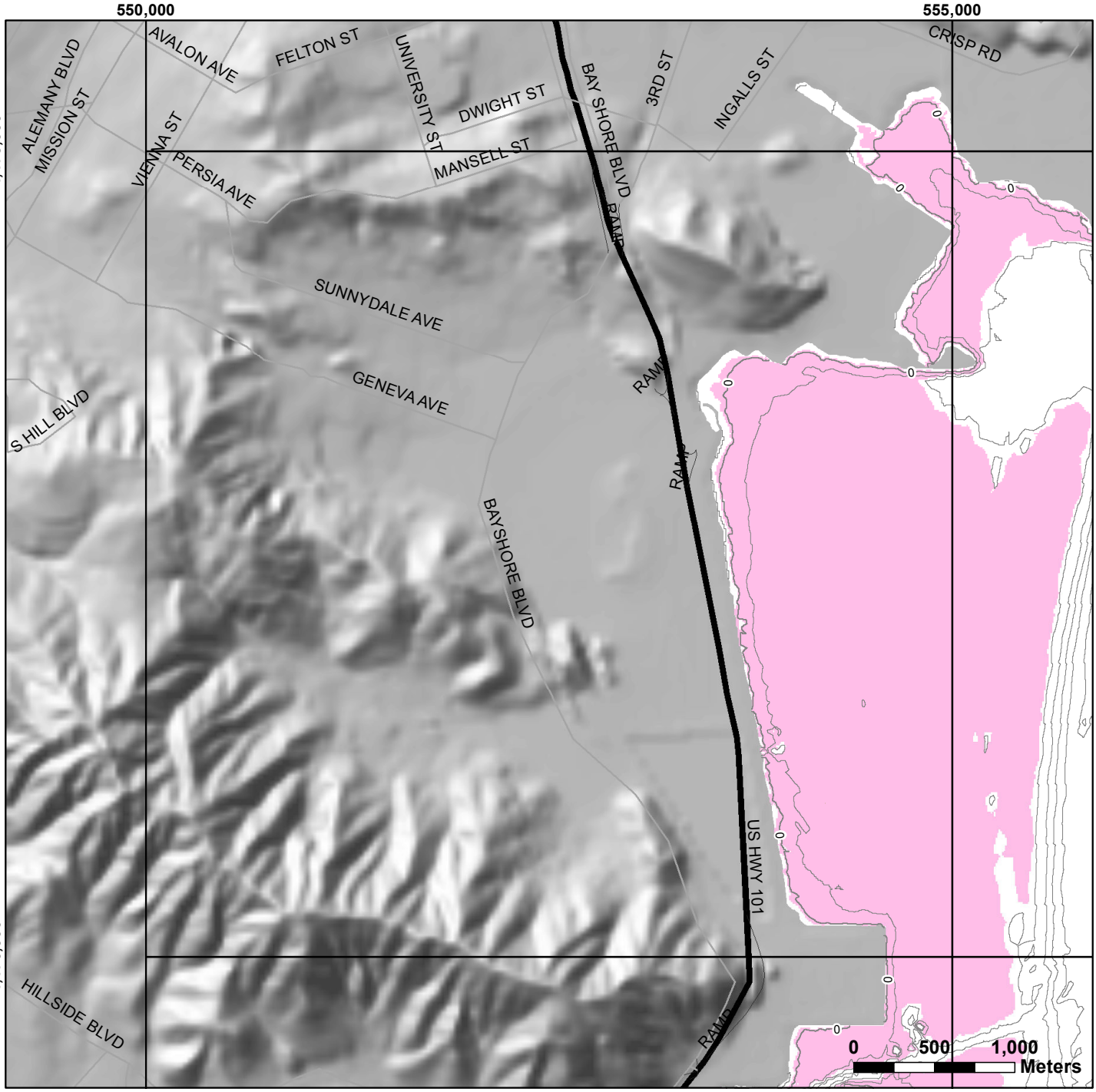


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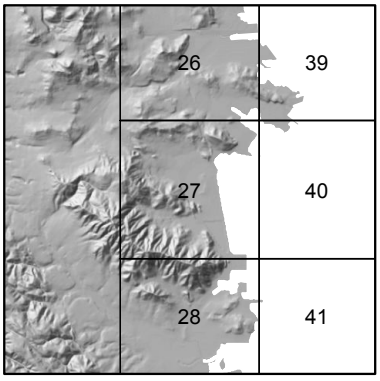

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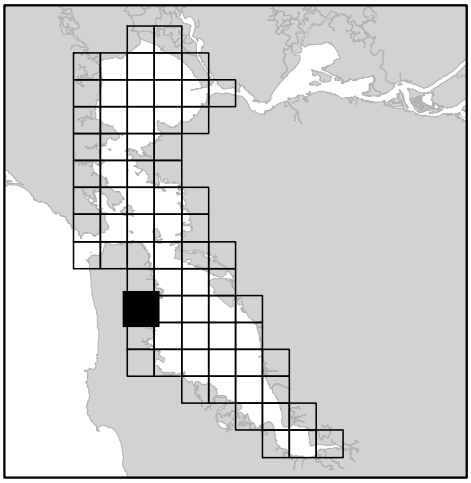
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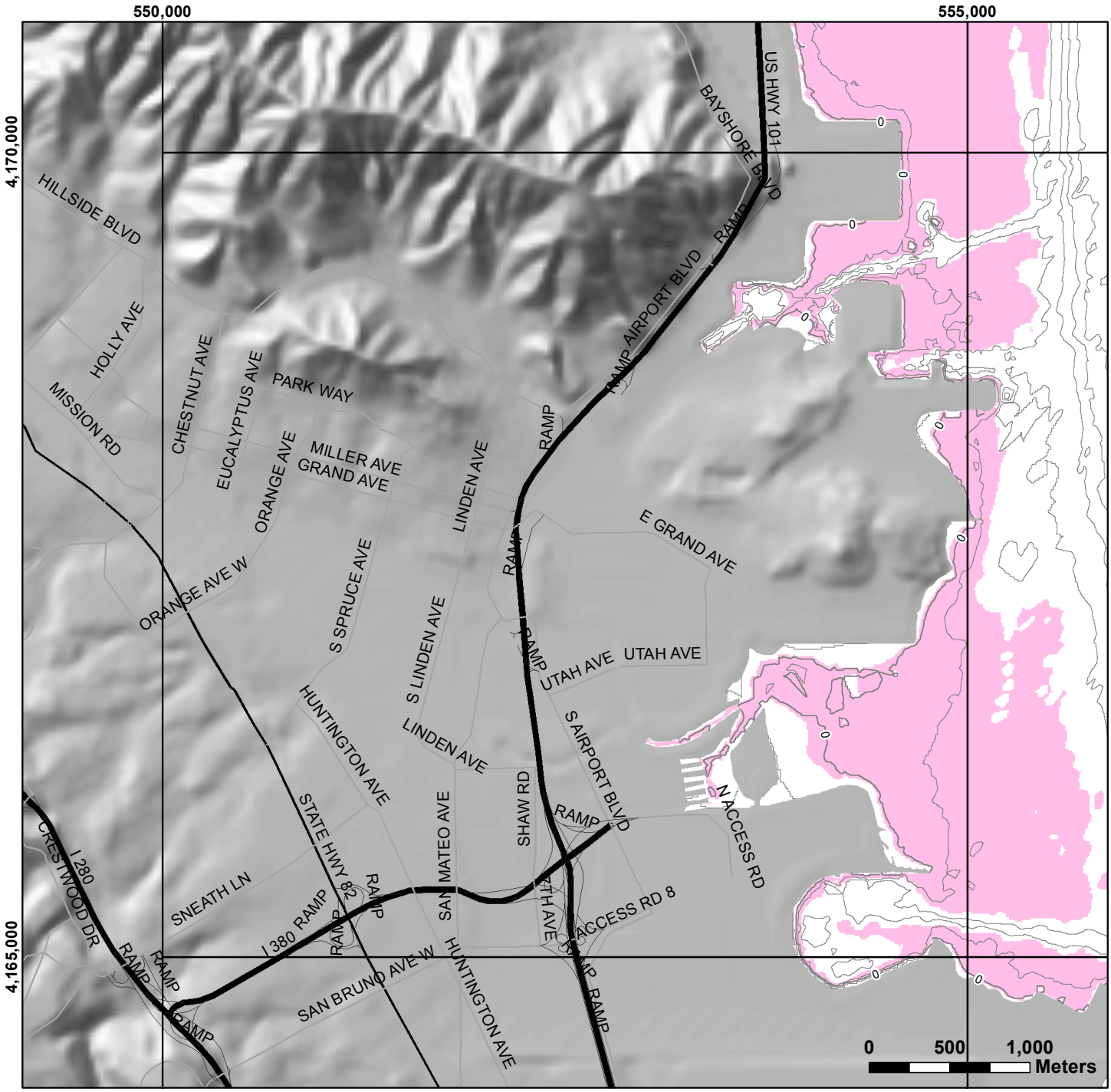


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- 6-20%
- 21-40%
- 41-100%

- Maximum Documented Eelgrass Extent
- 2014 Eelgrass 250m Locator Buffer
- ELVS Predictive Model



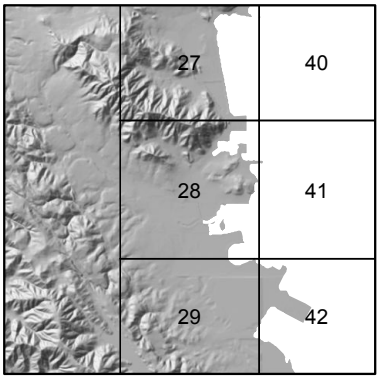

# SAN FRANCISCO BAY, CALIFORNIA
## Eelgrass 2014


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San Diego, CA - Tel: (858) 560-5465

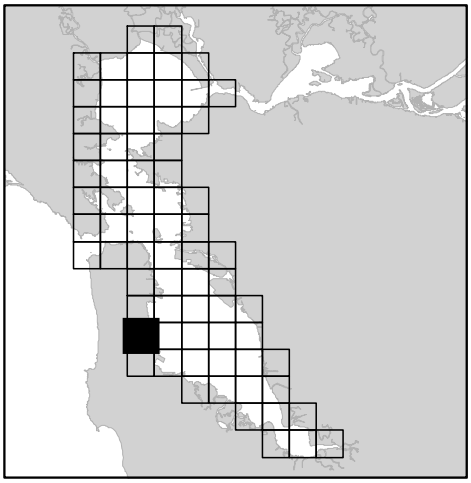

Horizontal Datum: UTM NAD83 Zone 10N (meters)
Vertical Datum: MLLW (meters)

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SHEET VICINITY




SHEET LOCATOR

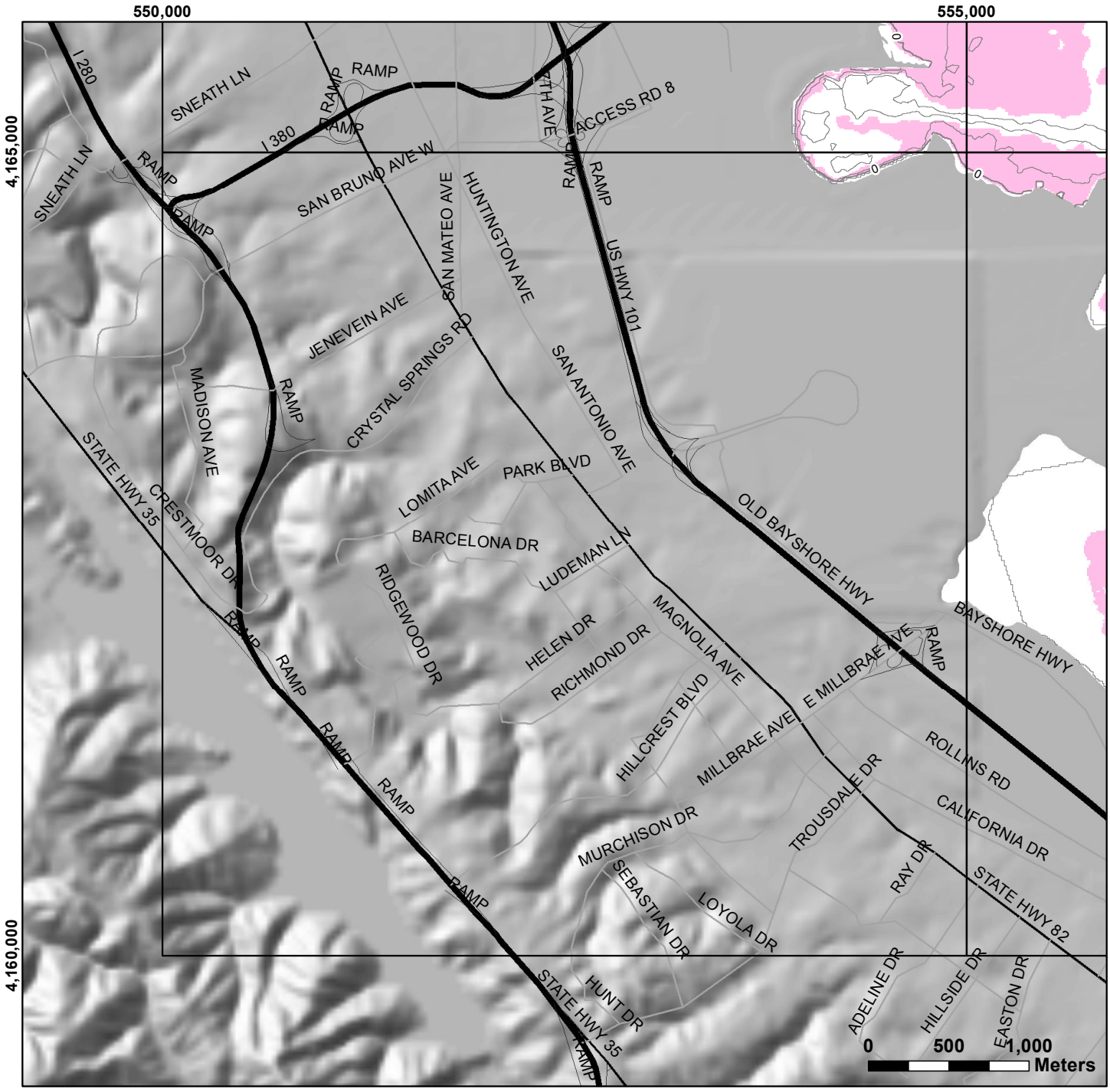


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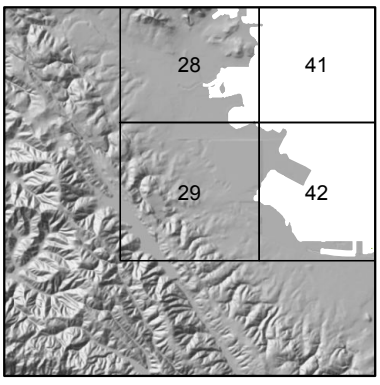

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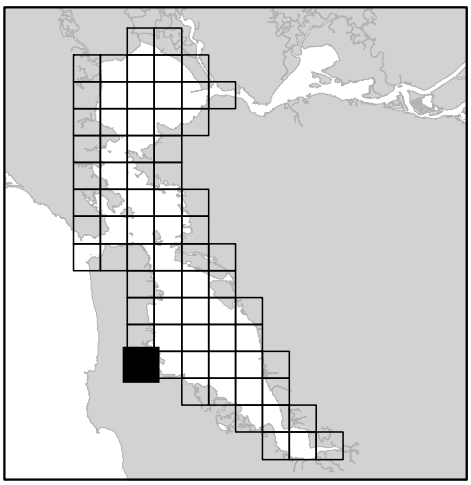

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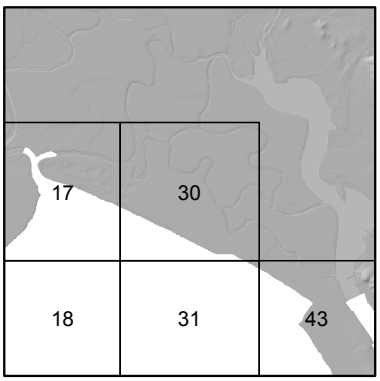

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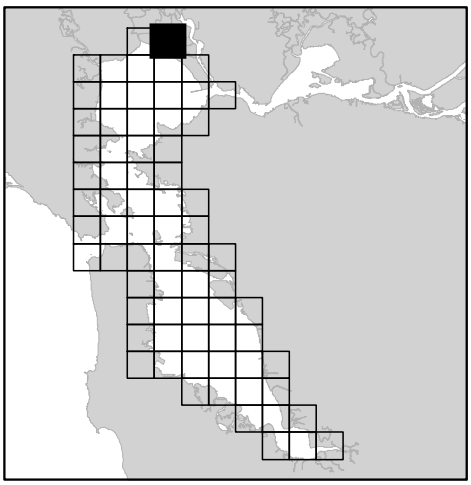
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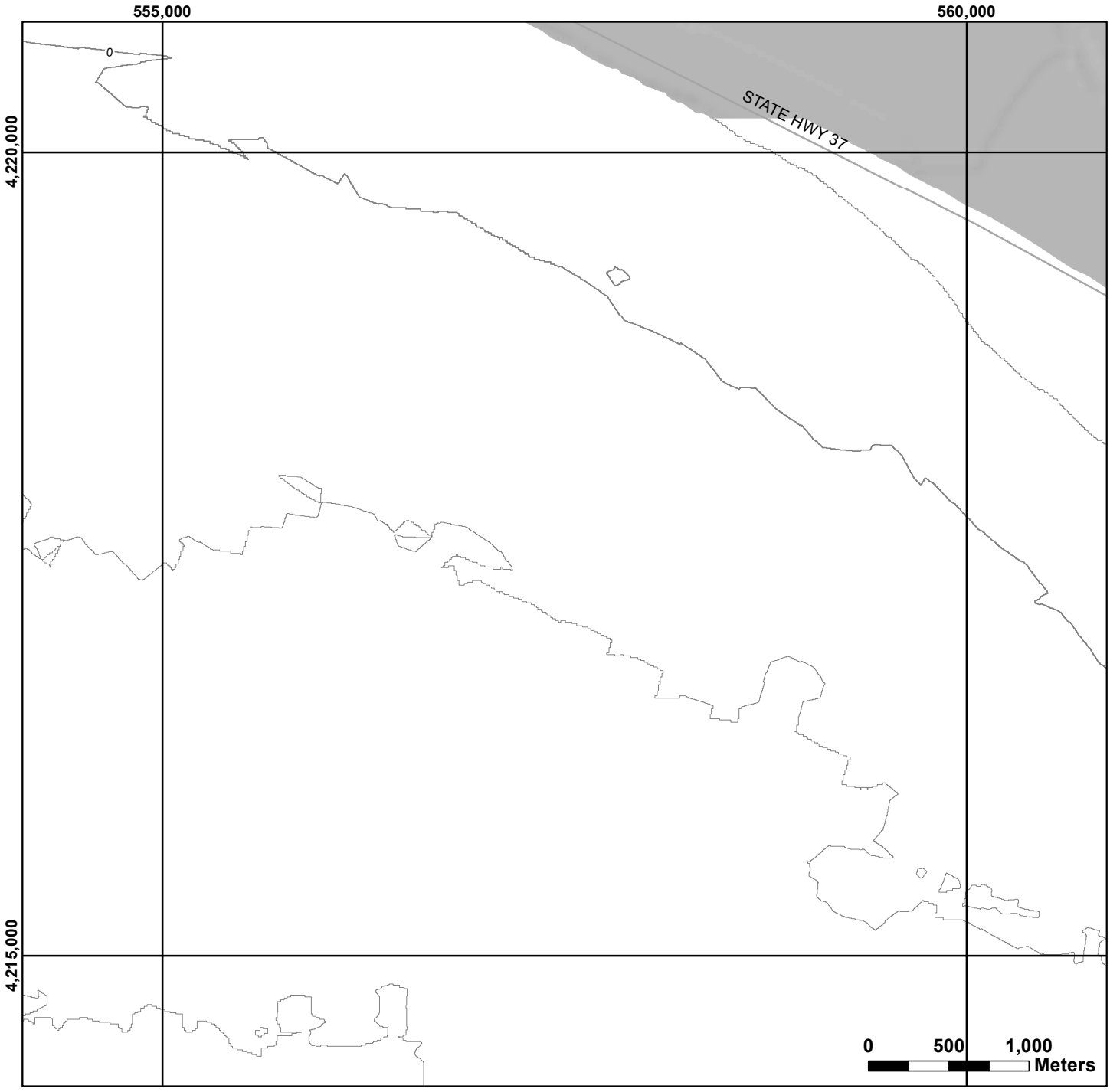





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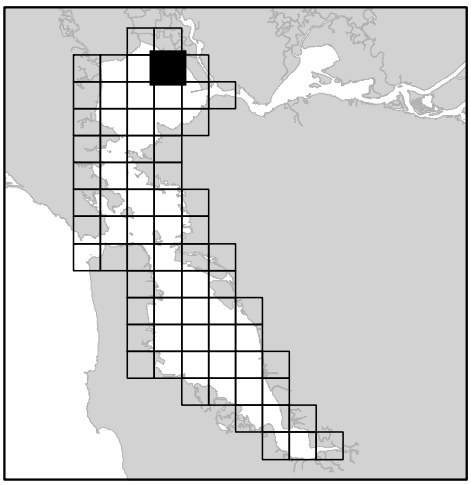
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SHEET VICINITY

| | | |
|---|---|---|
| 17 | 30 | |
| 18 | 31 | 43 |
| 19 | 32 | 44 |

SHEET LOCATOR

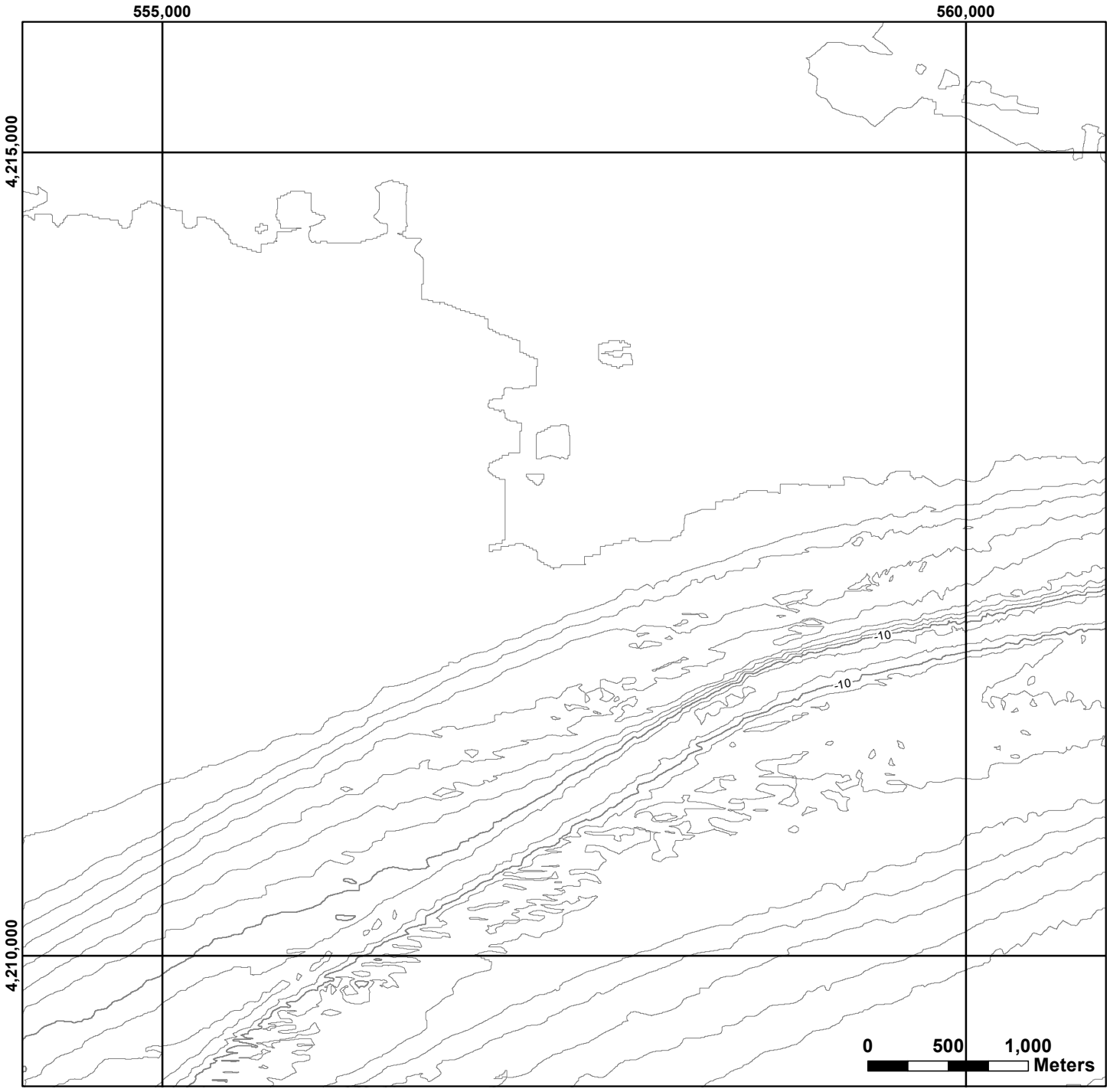


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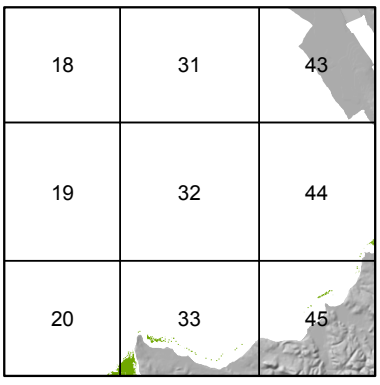

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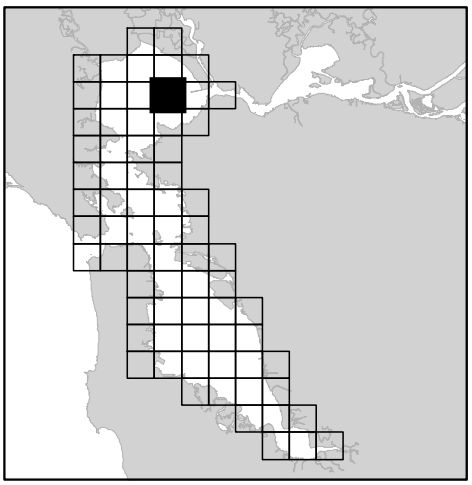
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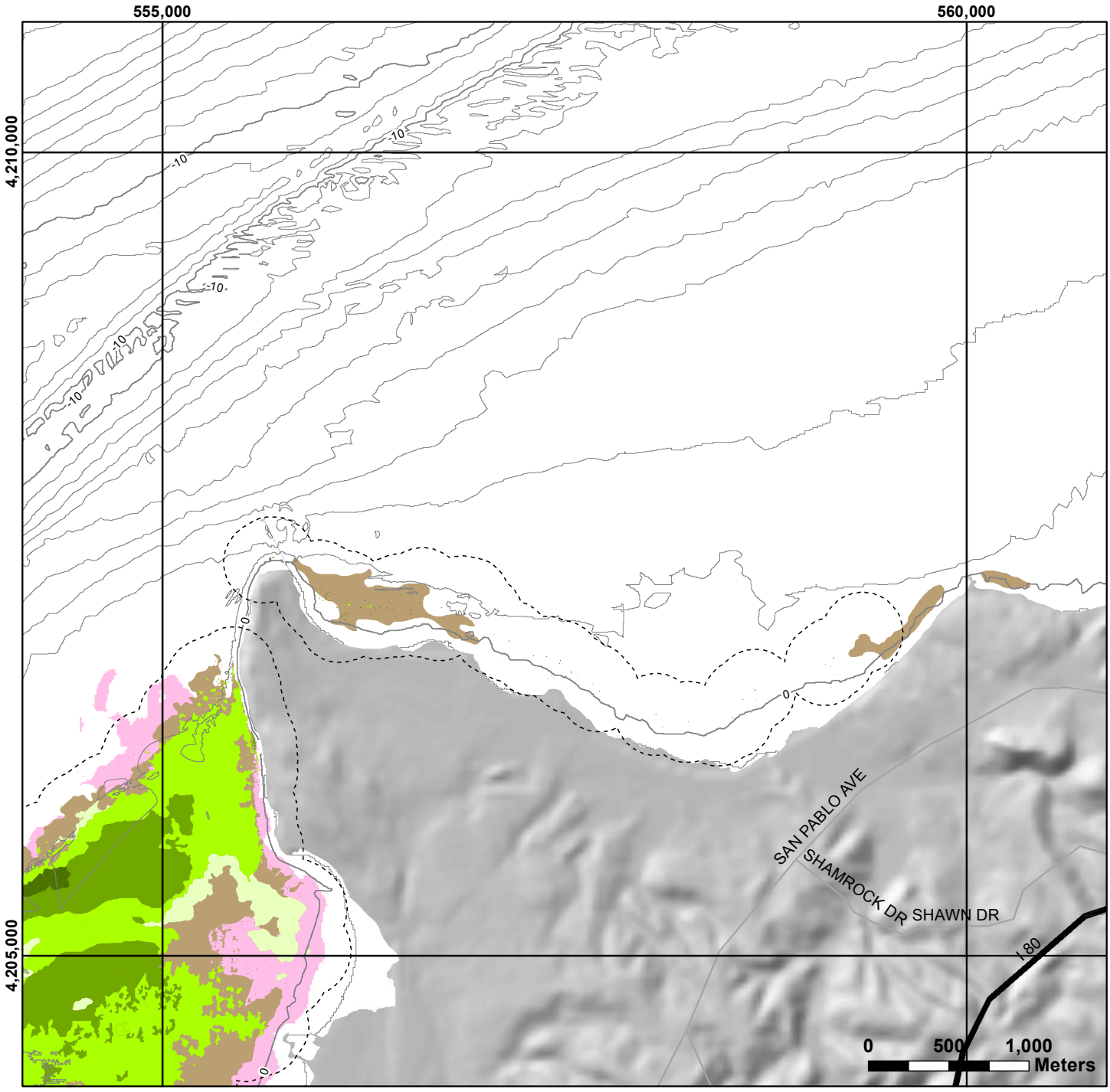


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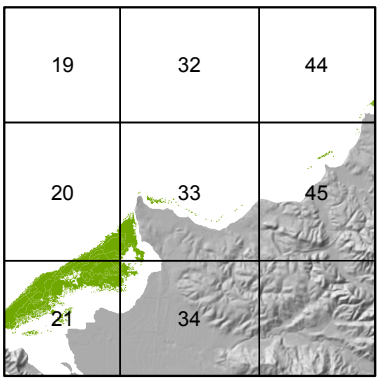

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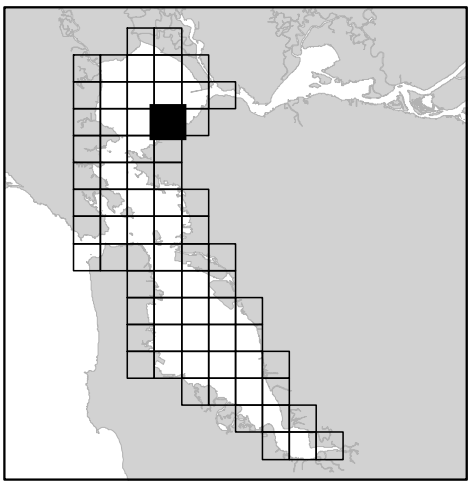
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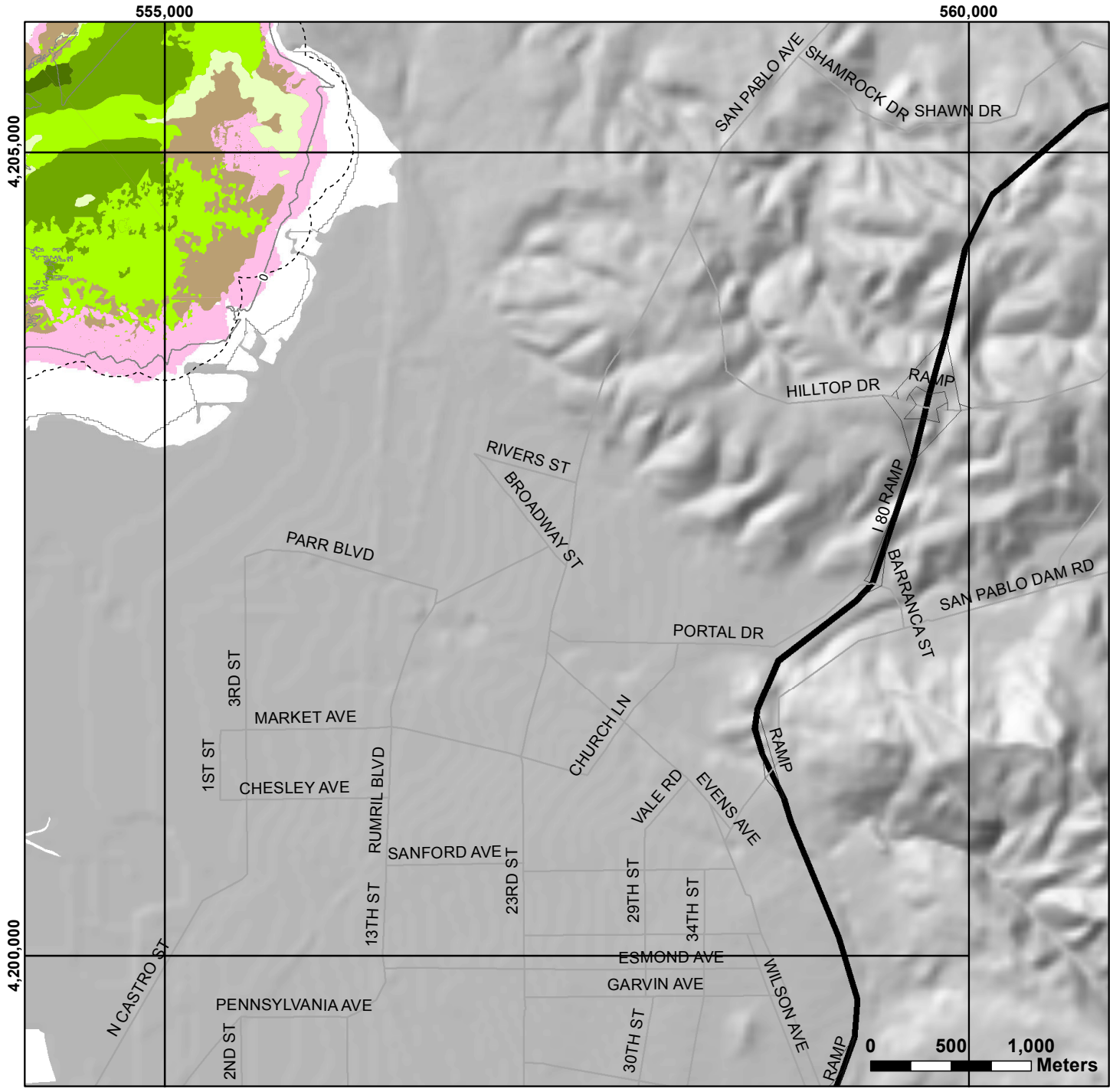


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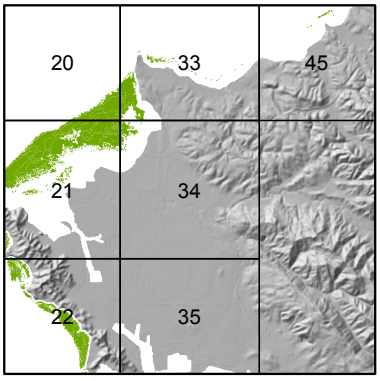

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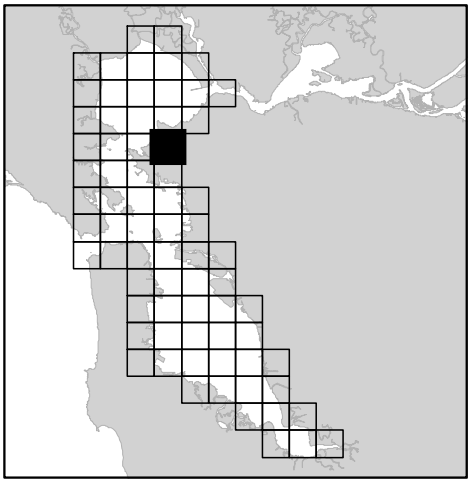

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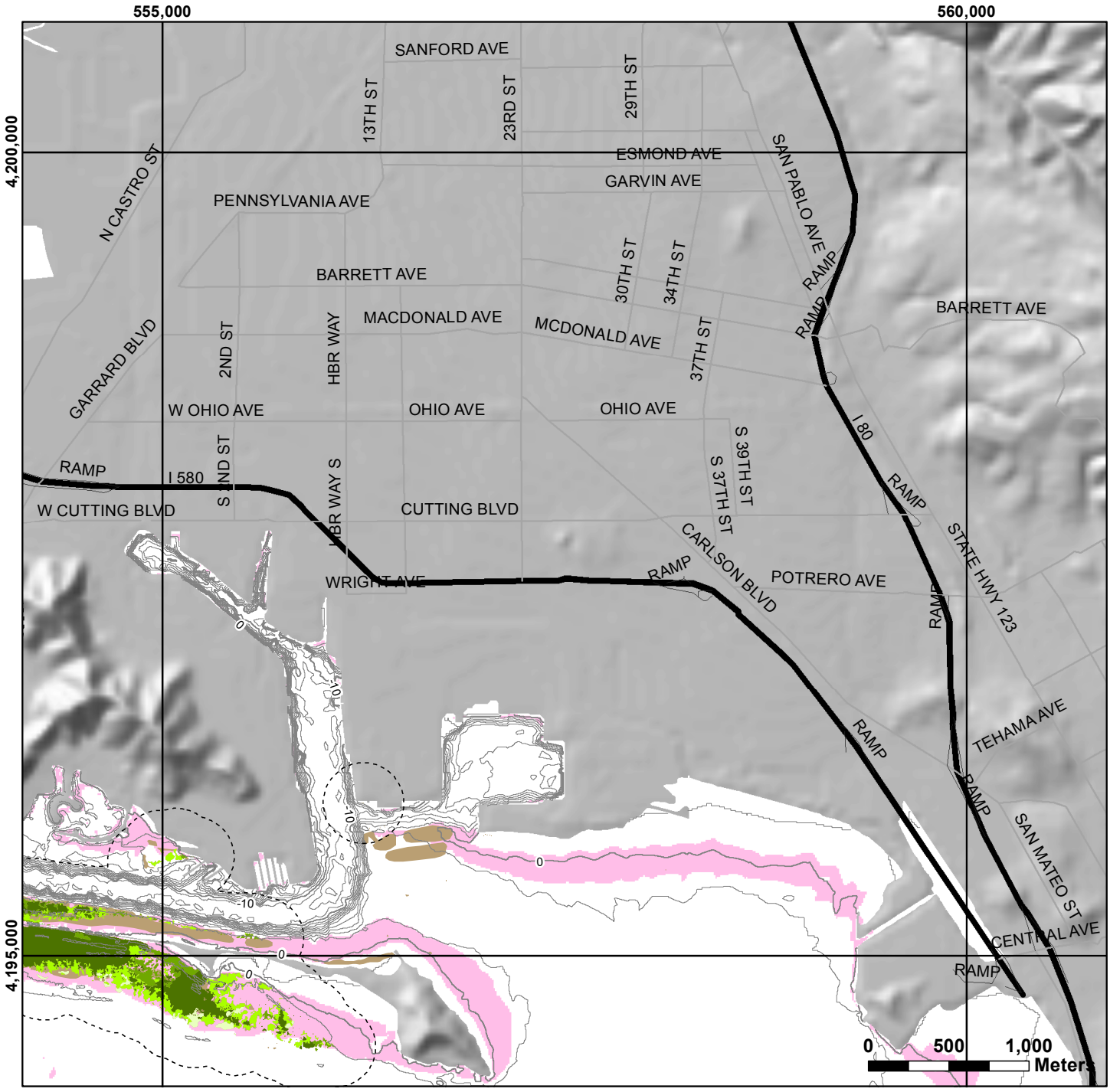

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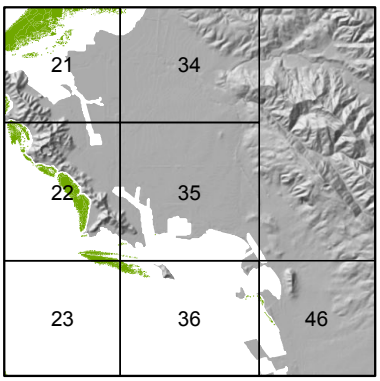

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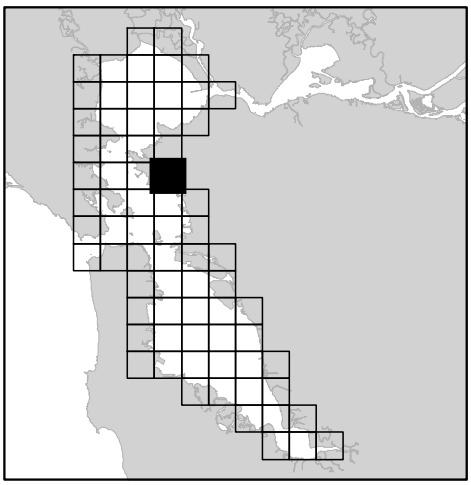

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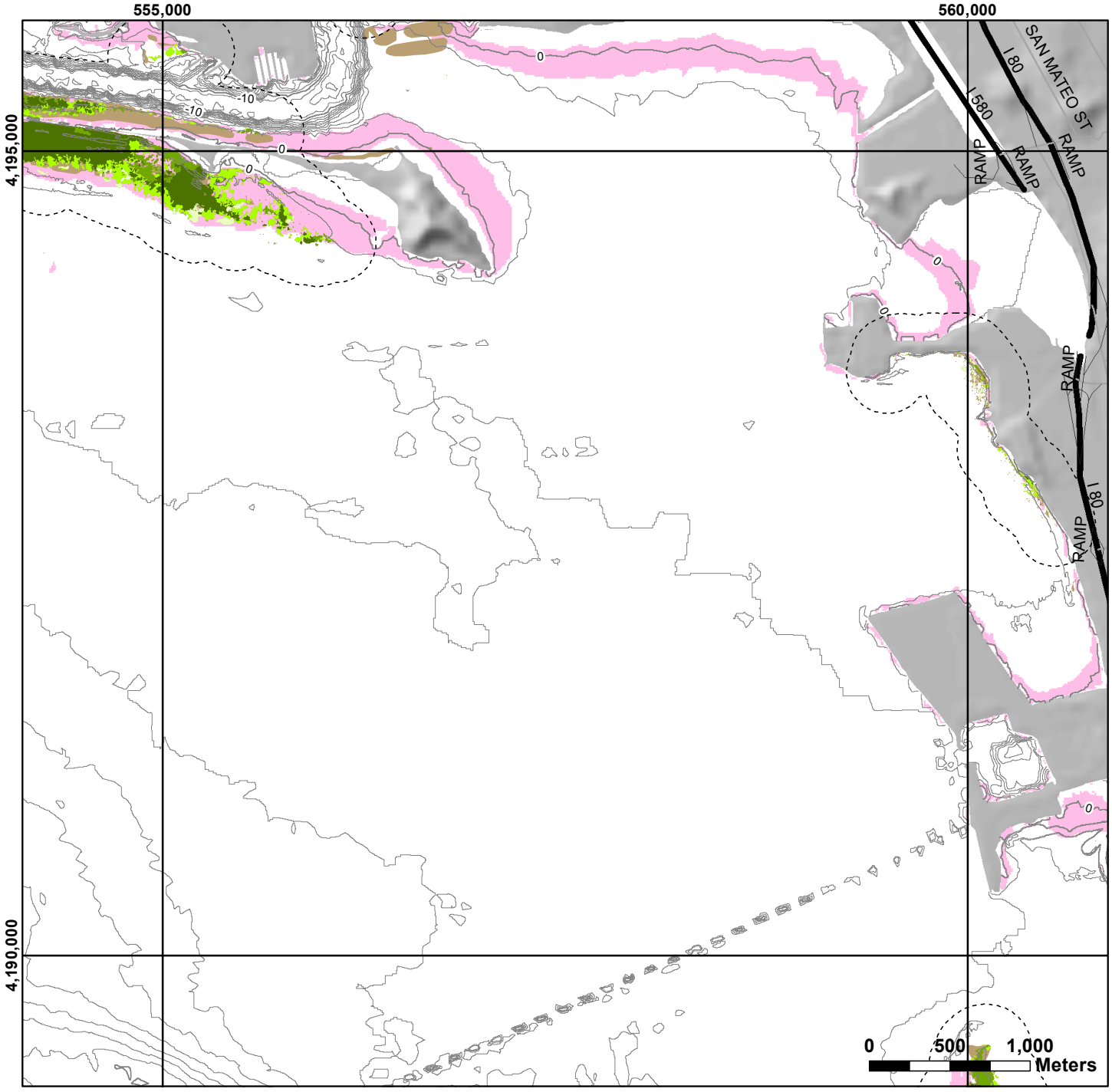


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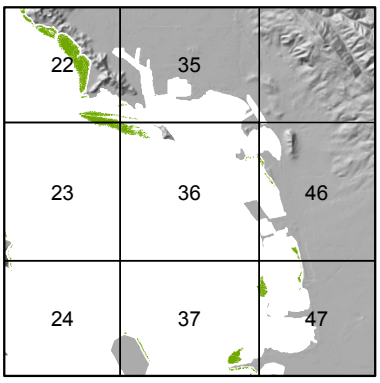

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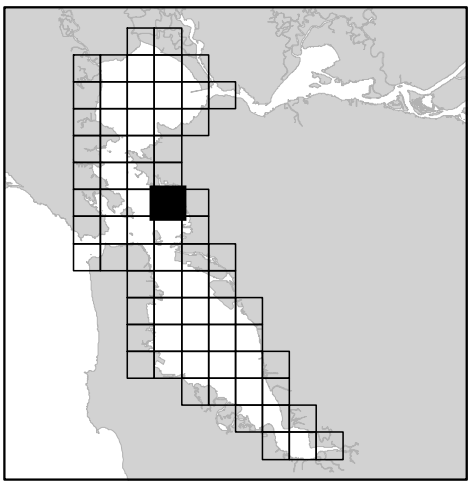
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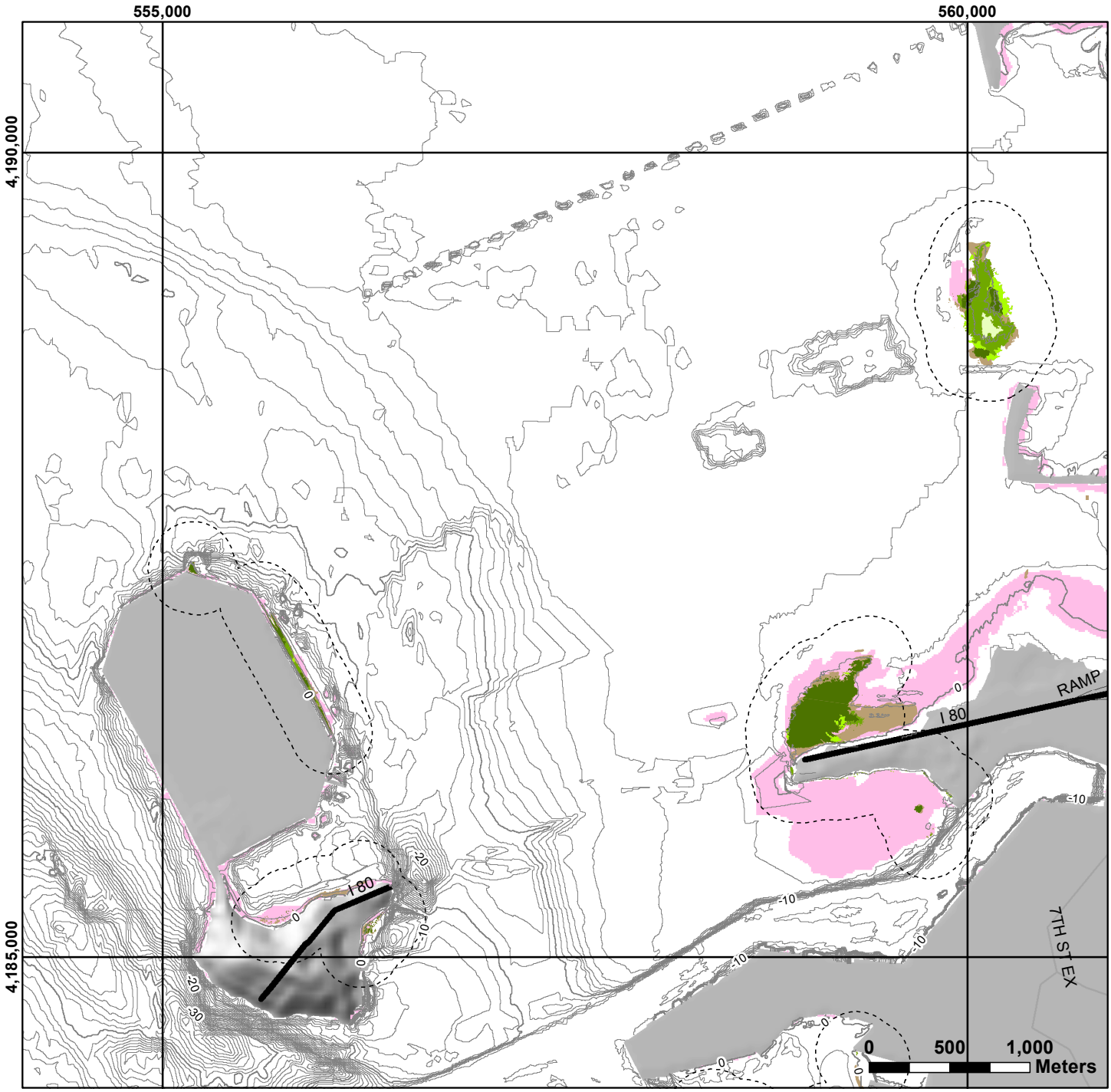


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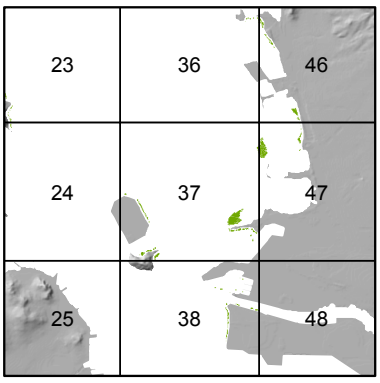

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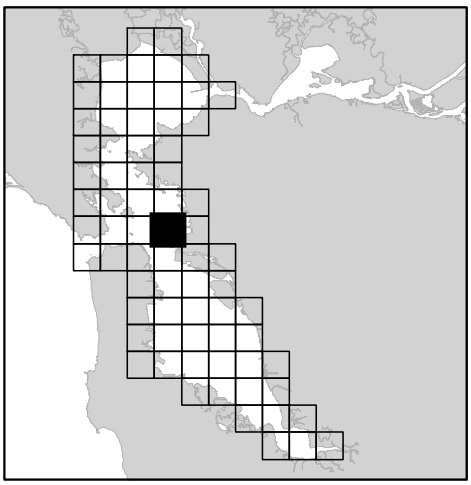
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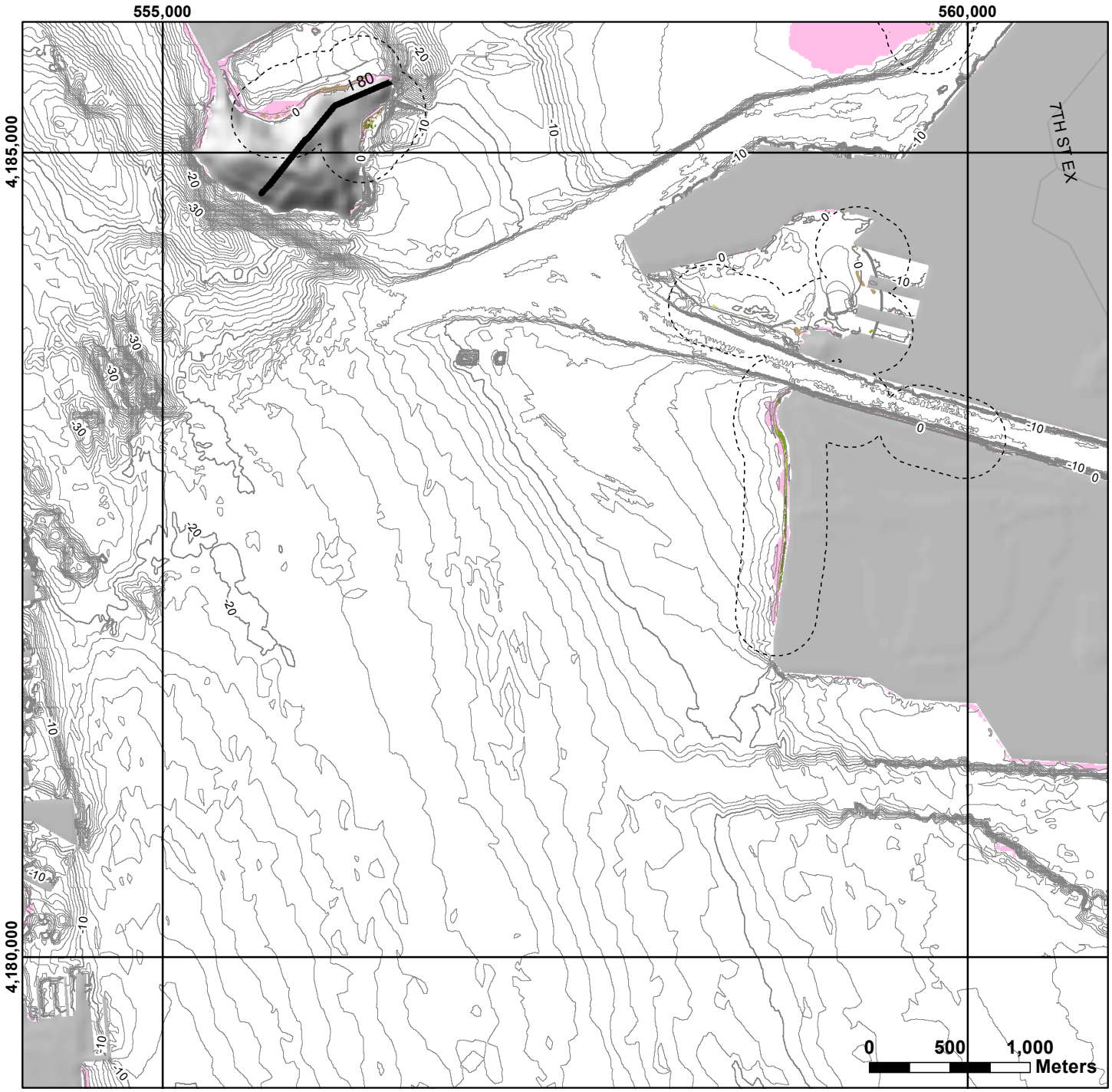


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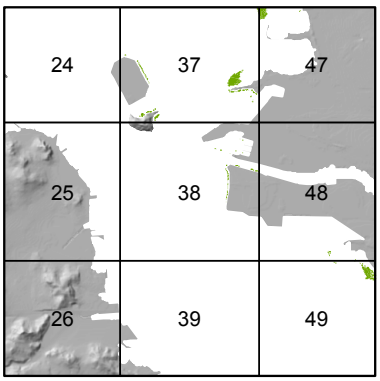

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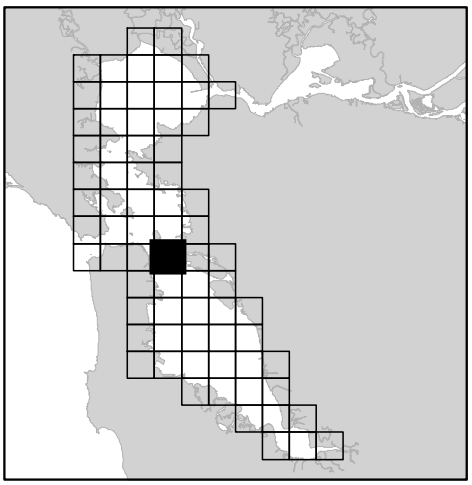
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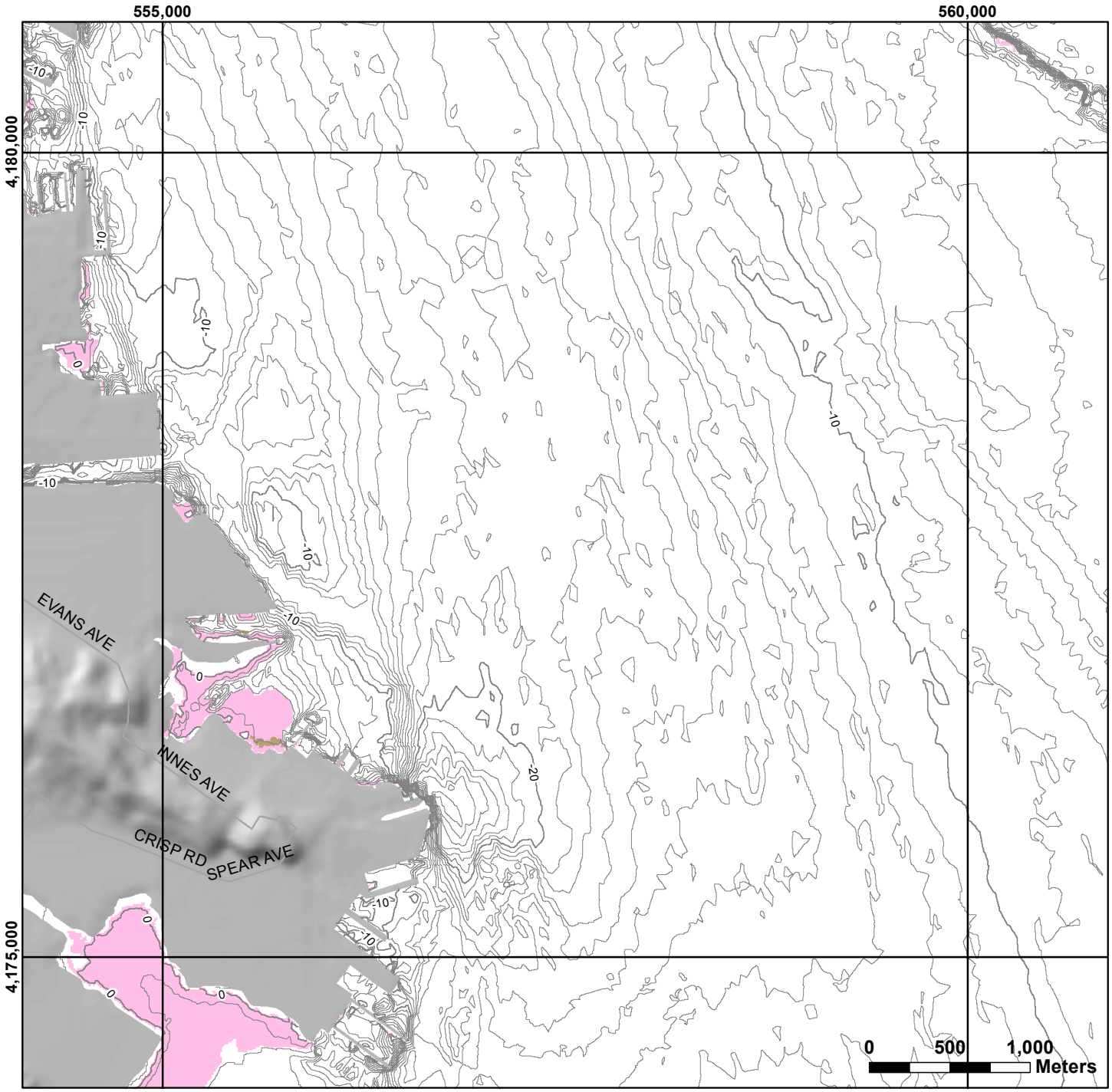


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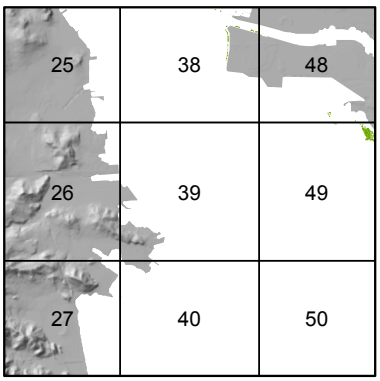

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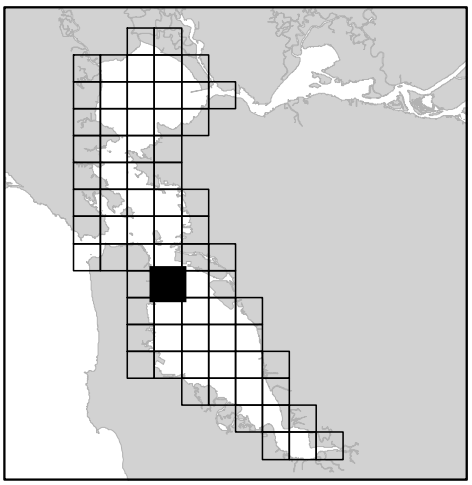
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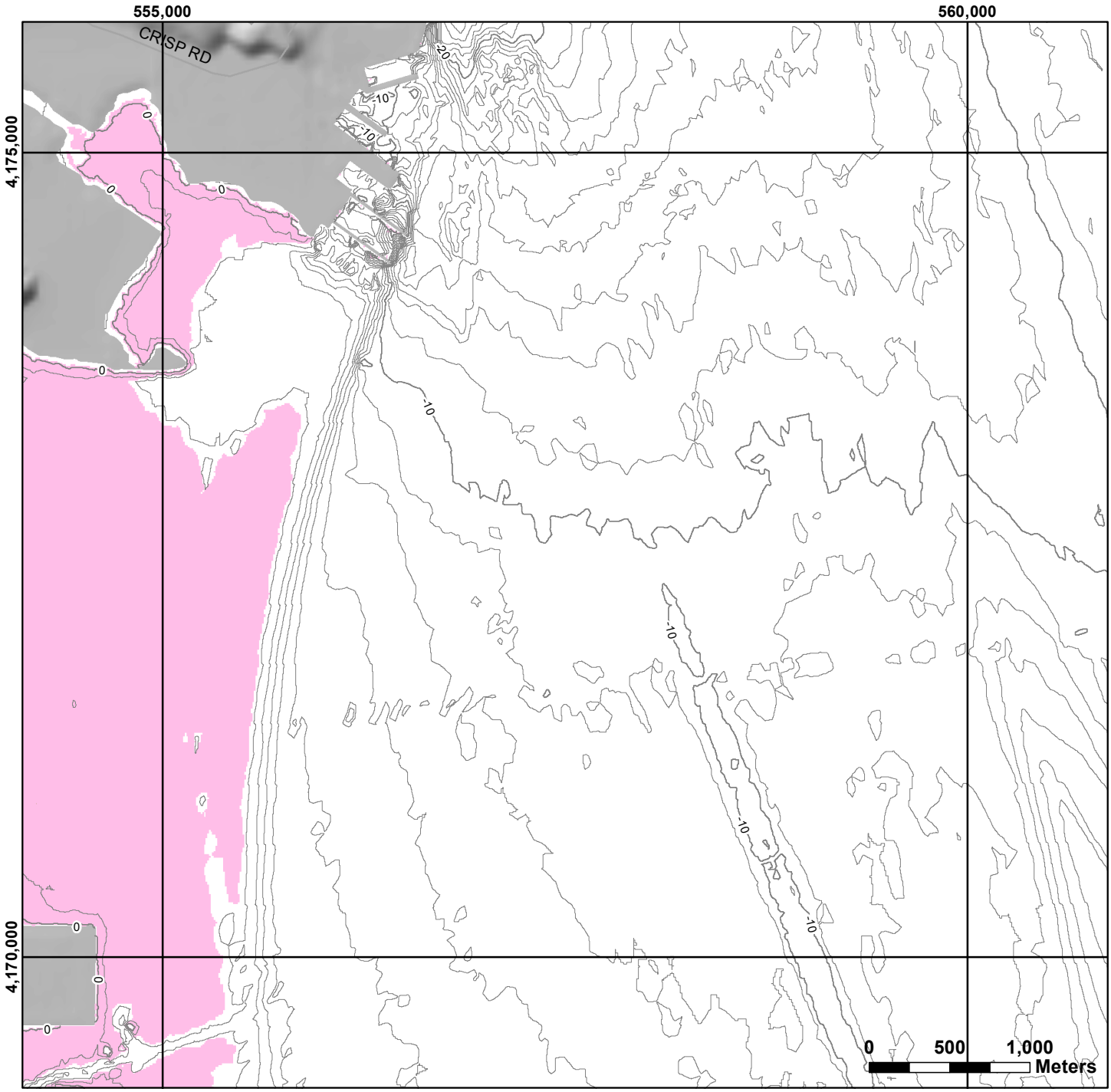


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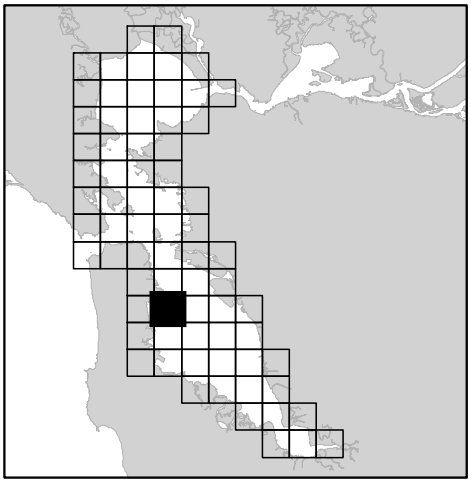
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SHEET VICINITY

| | | |
|---|---|---|
| 26 | 39 | 49 |
| 27 | 40 | 50 |
| 28 | 41 | 51 |

SHEET LOCATOR

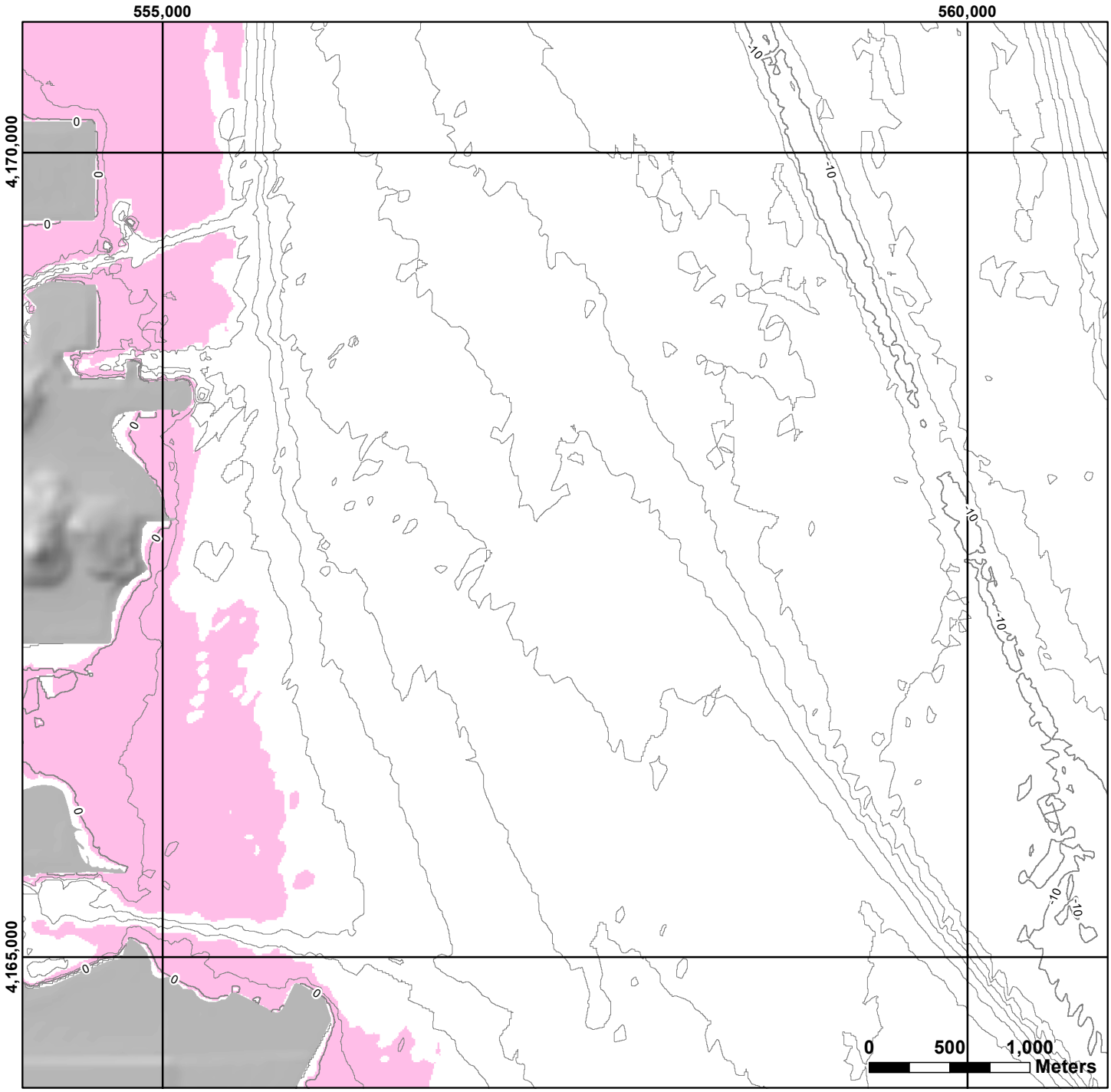


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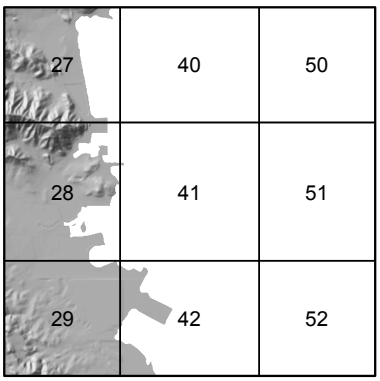

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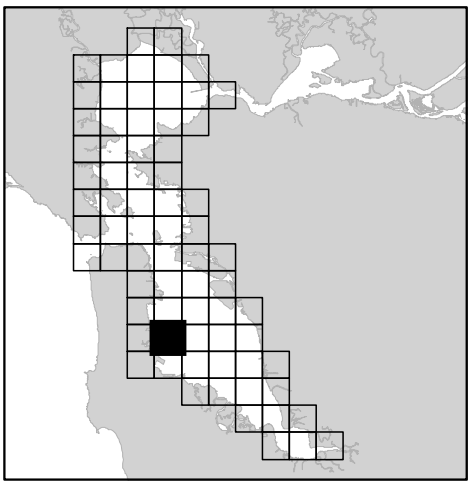
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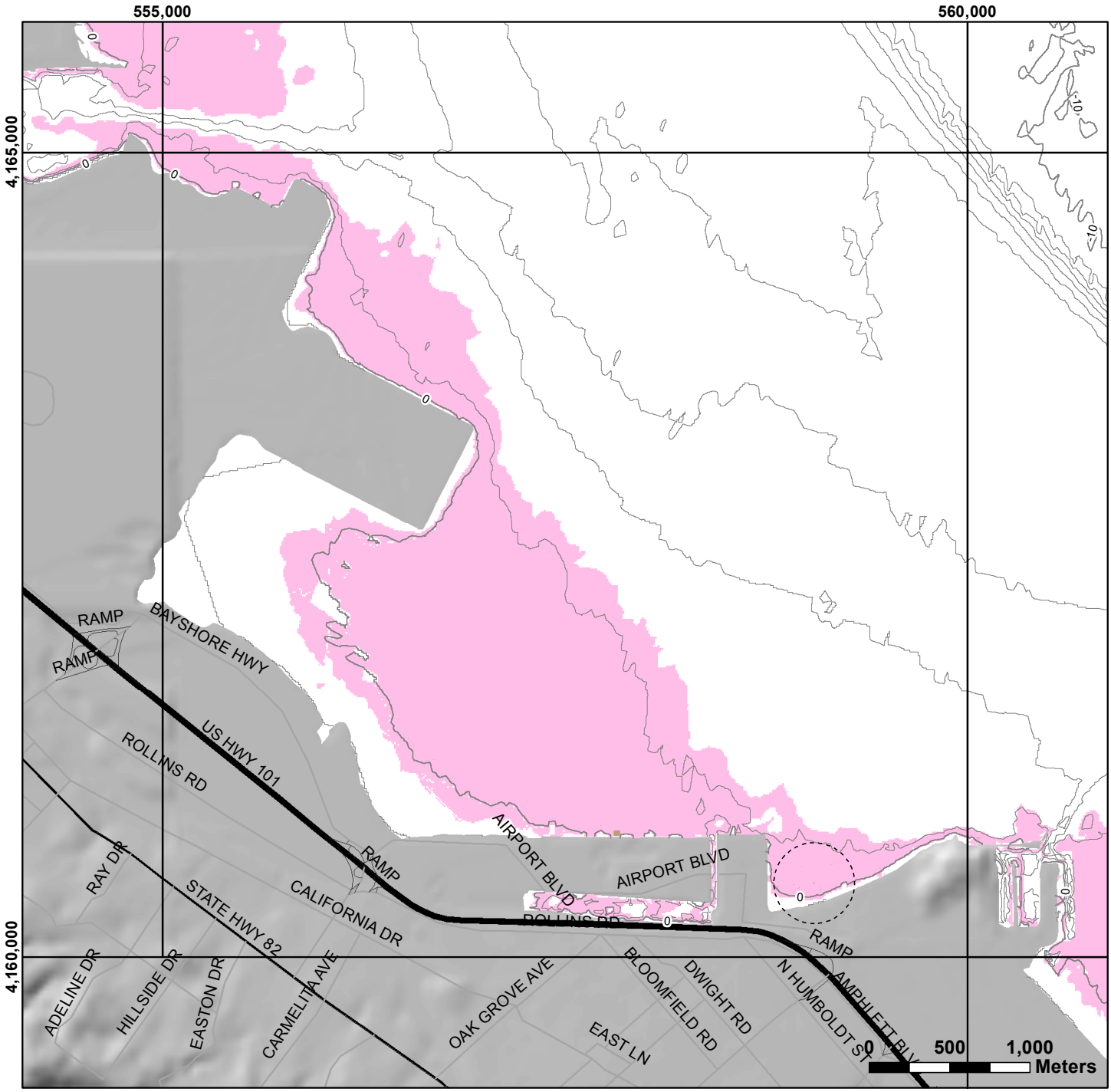


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- 41-100%

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- ELVS Predictive Model



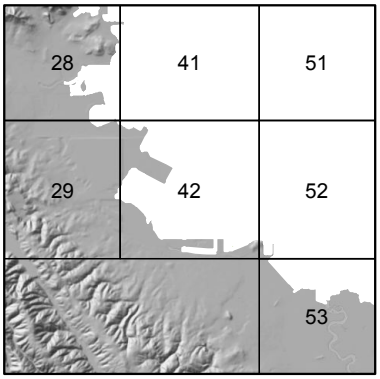

# SAN FRANCISCO BAY, CALIFORNIA
## Eelgrass 2014


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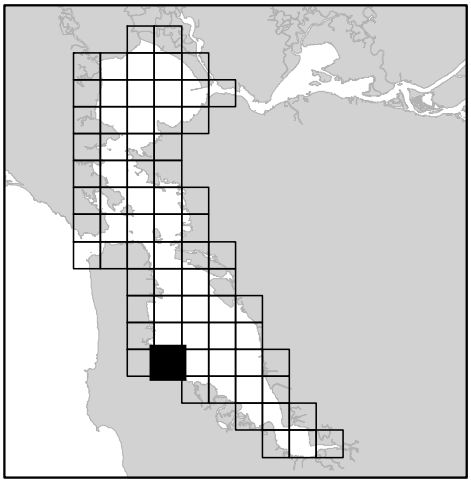

Horizontal Datum: UTM NAD83 Zone 10N (meters)
Vertical Datum: MLLW (meters)

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SHEET VICINITY




SHEET LOCATOR

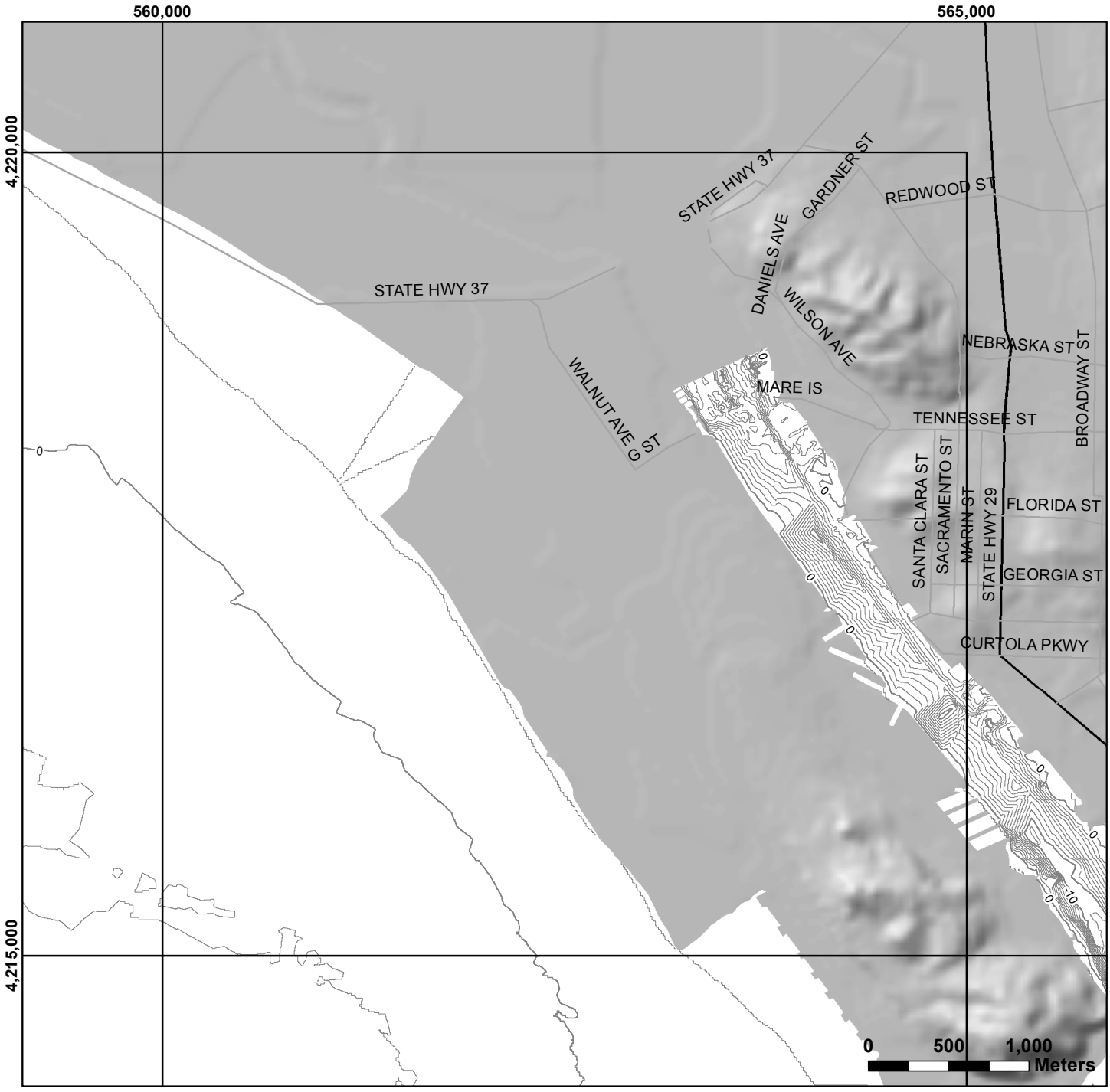


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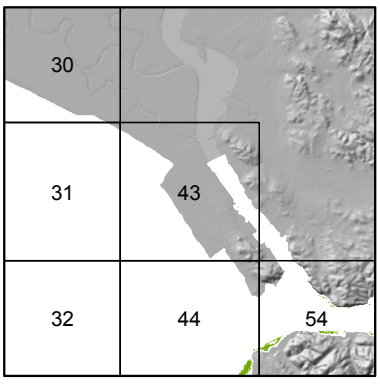

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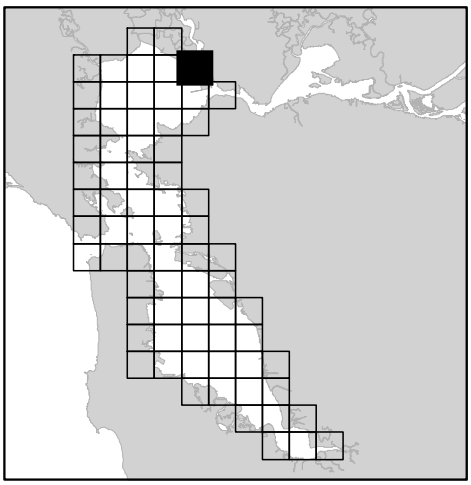
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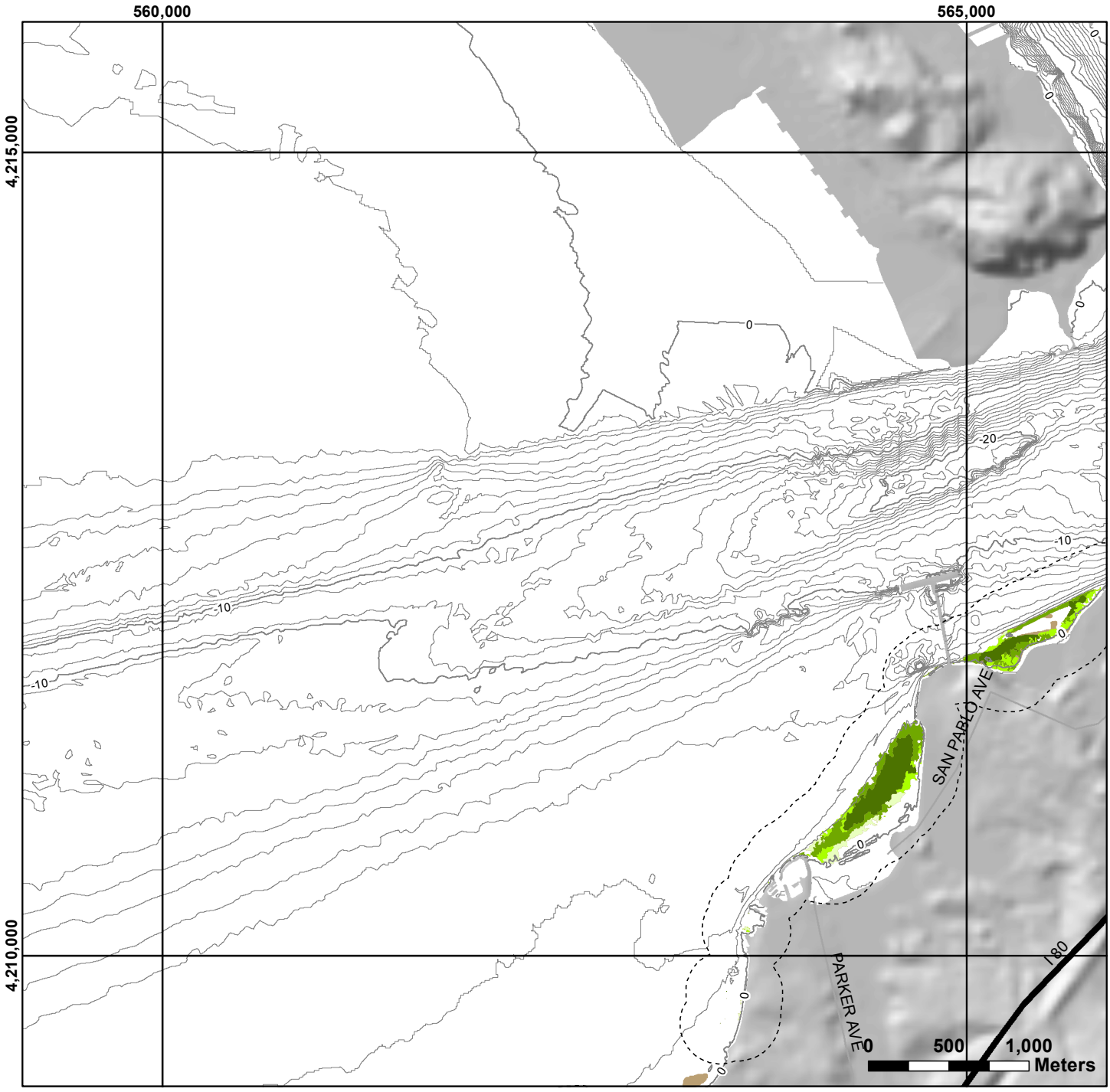


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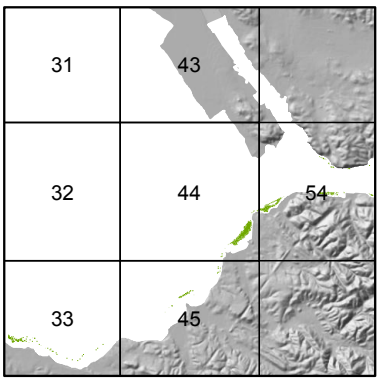

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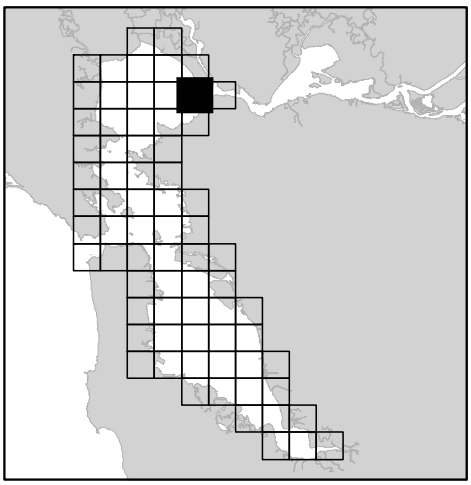
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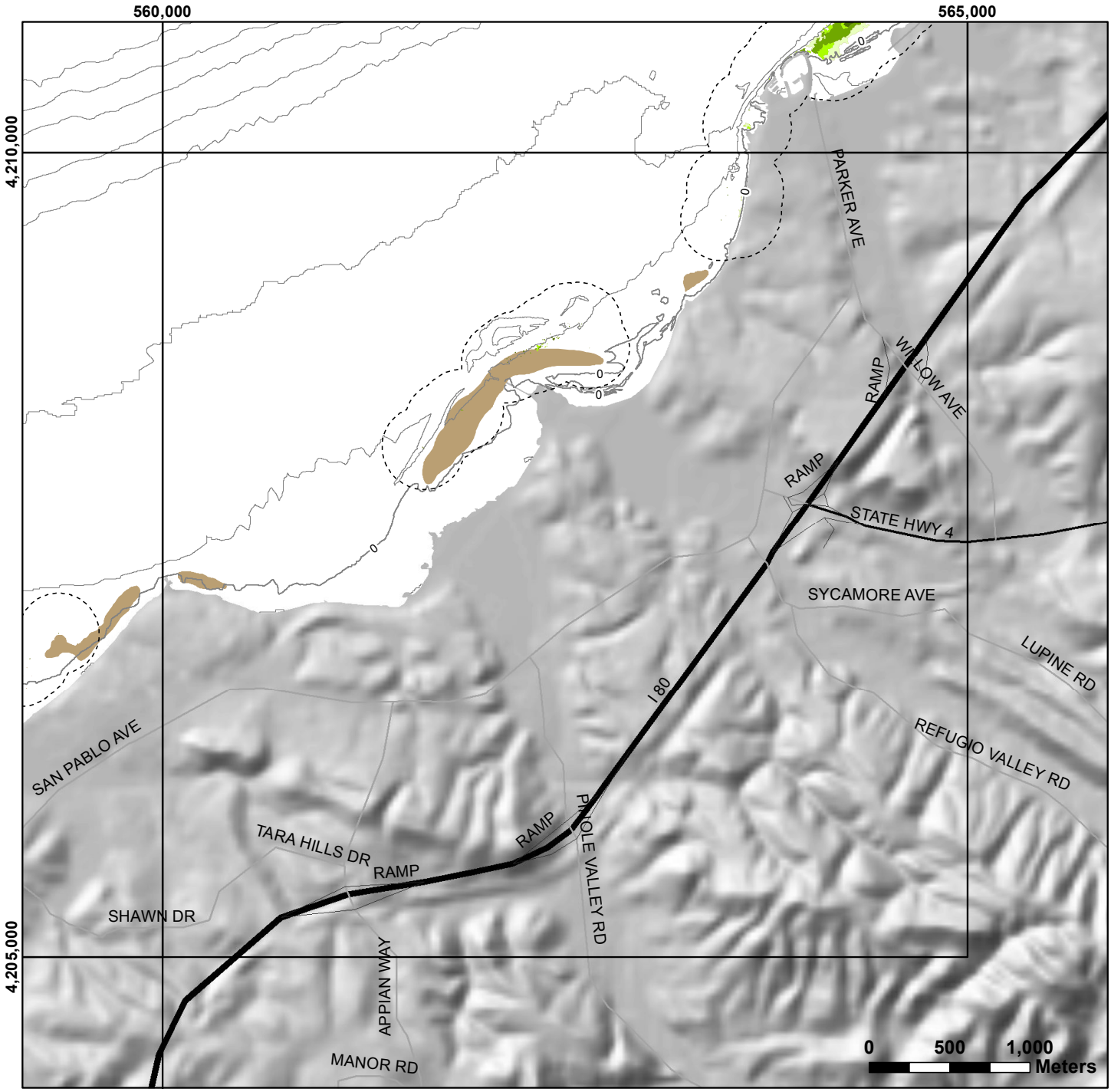


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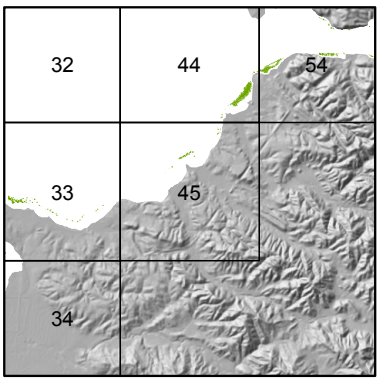

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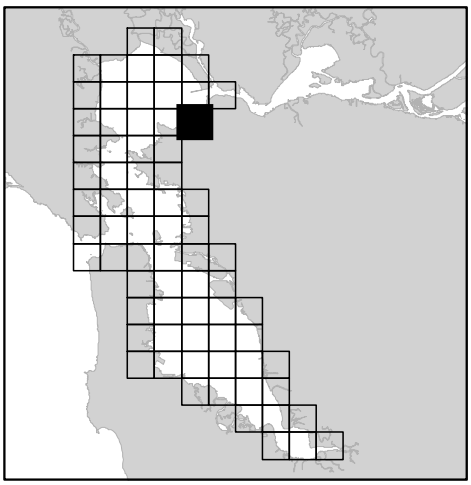

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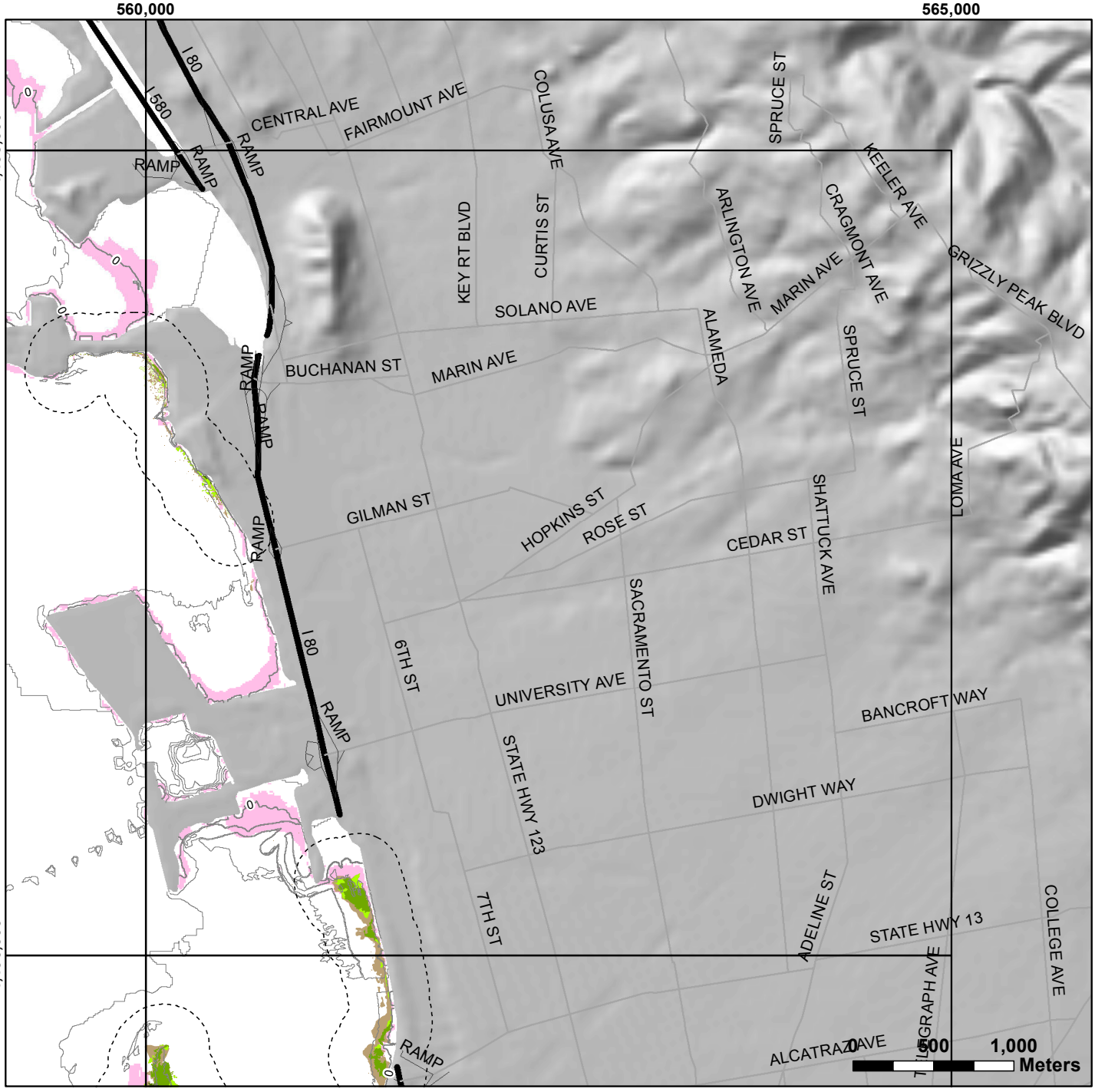


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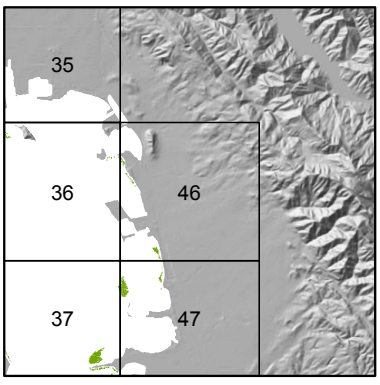

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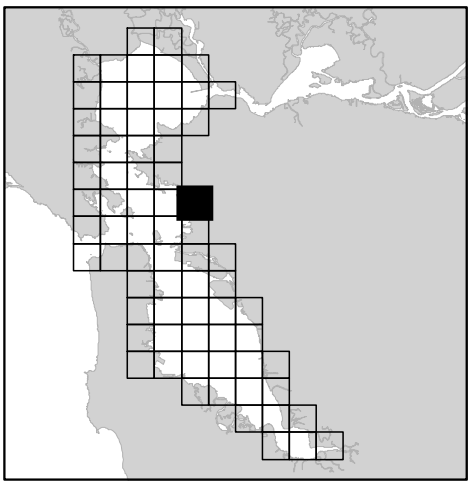

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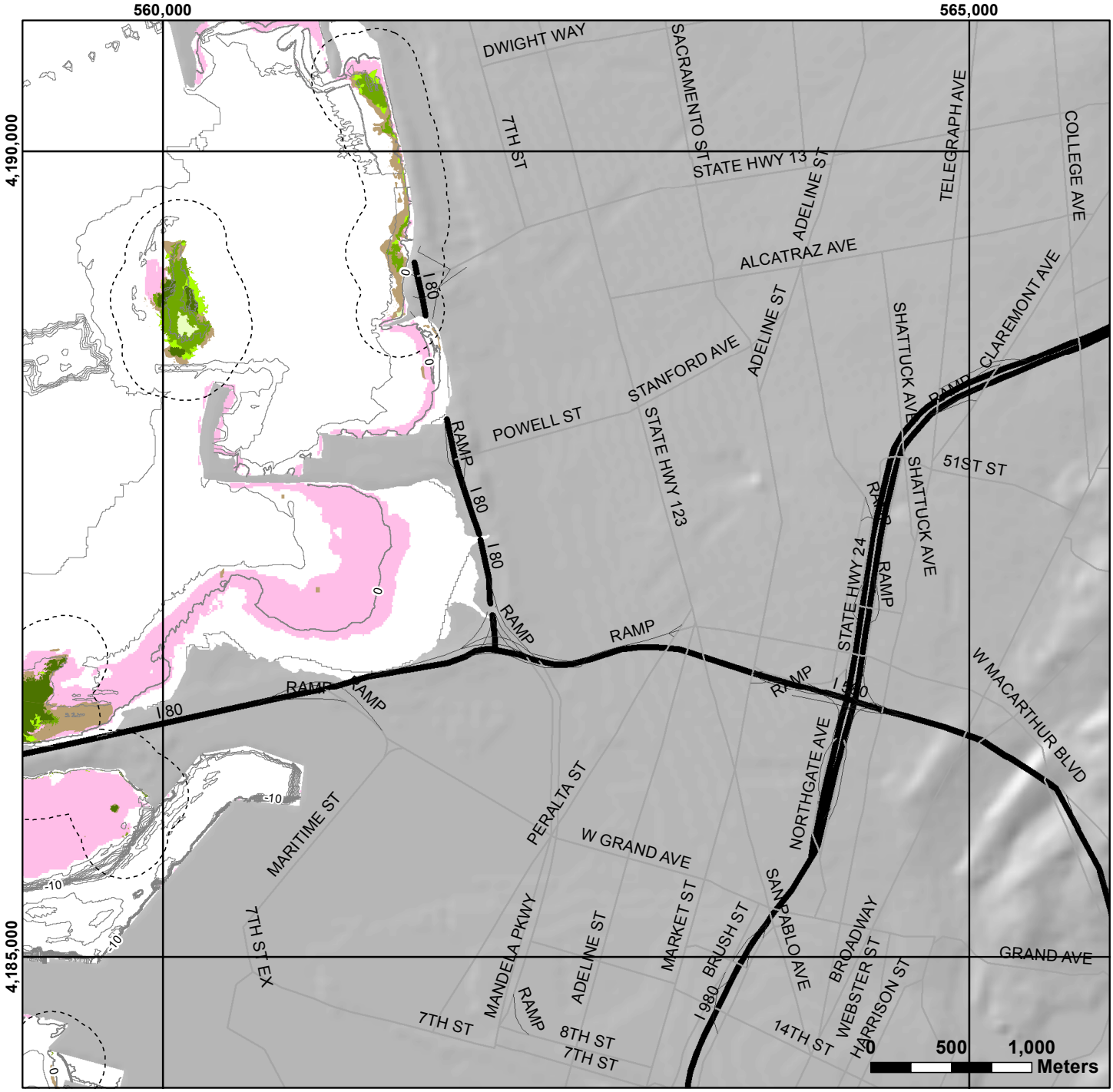


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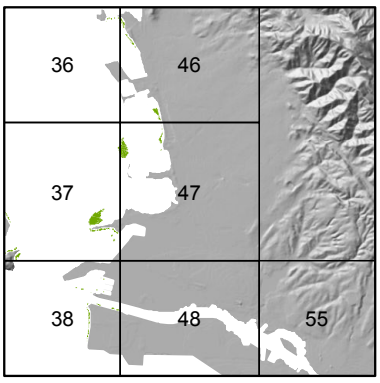

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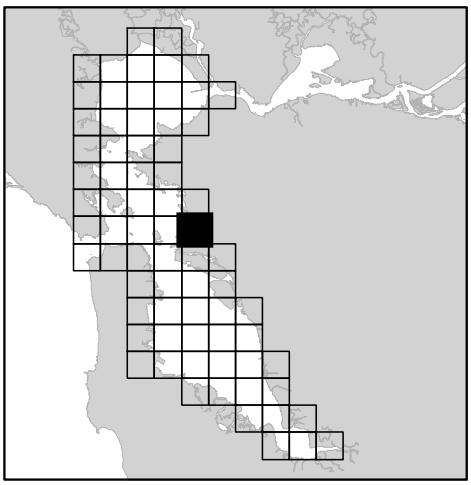

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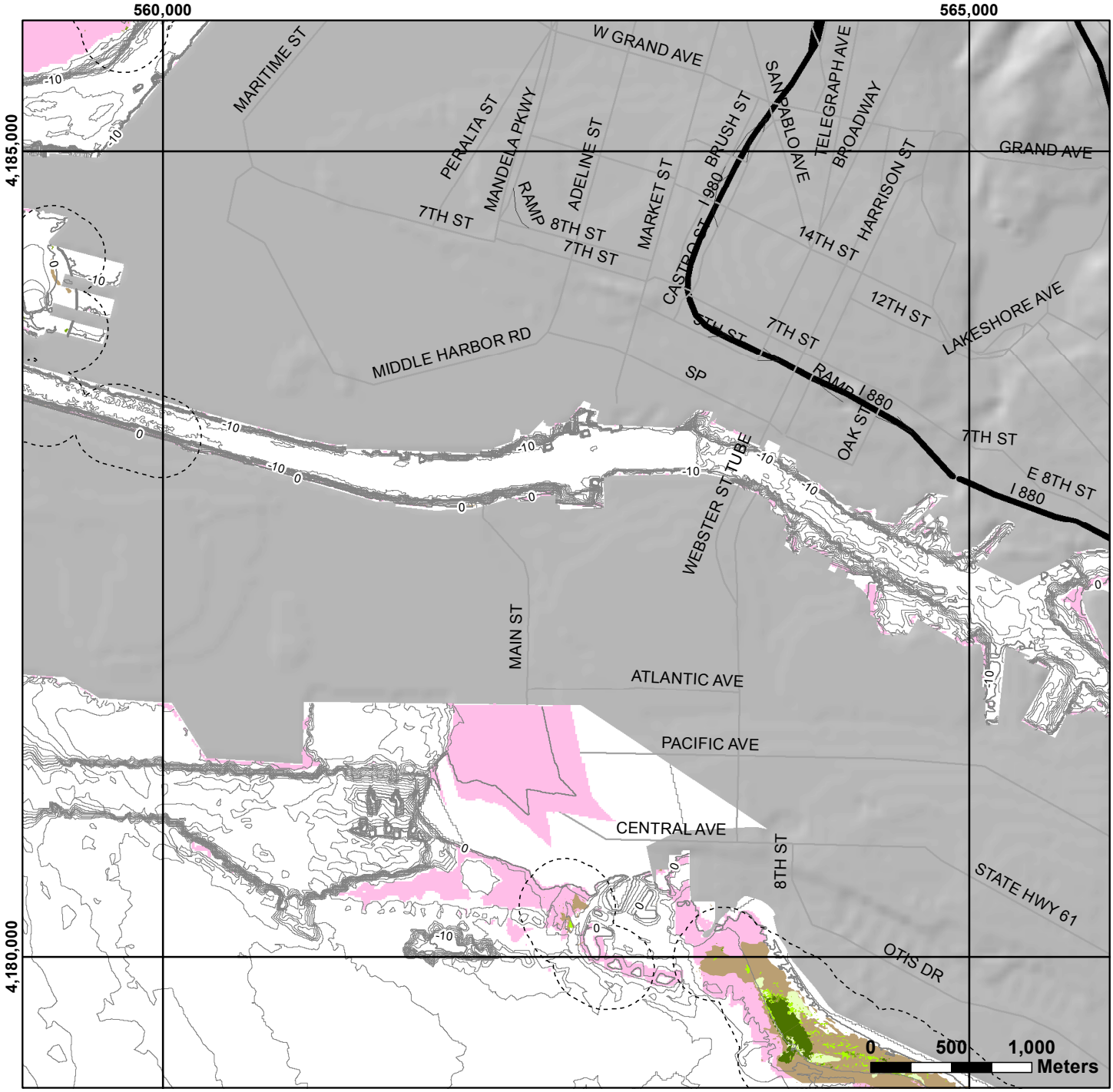


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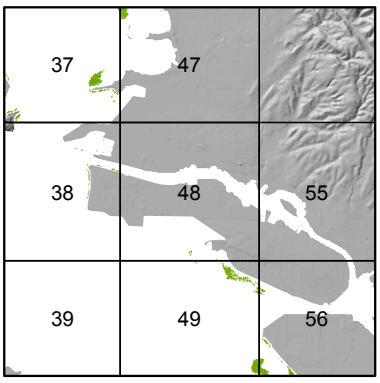

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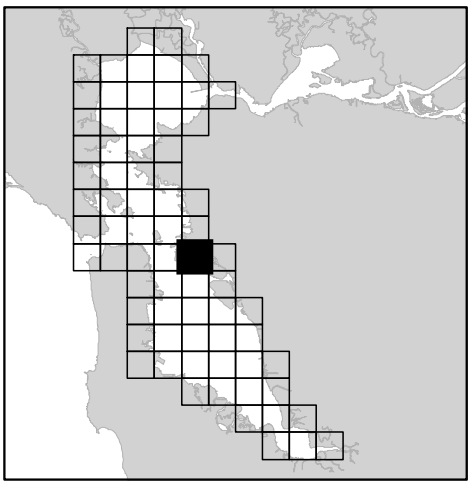

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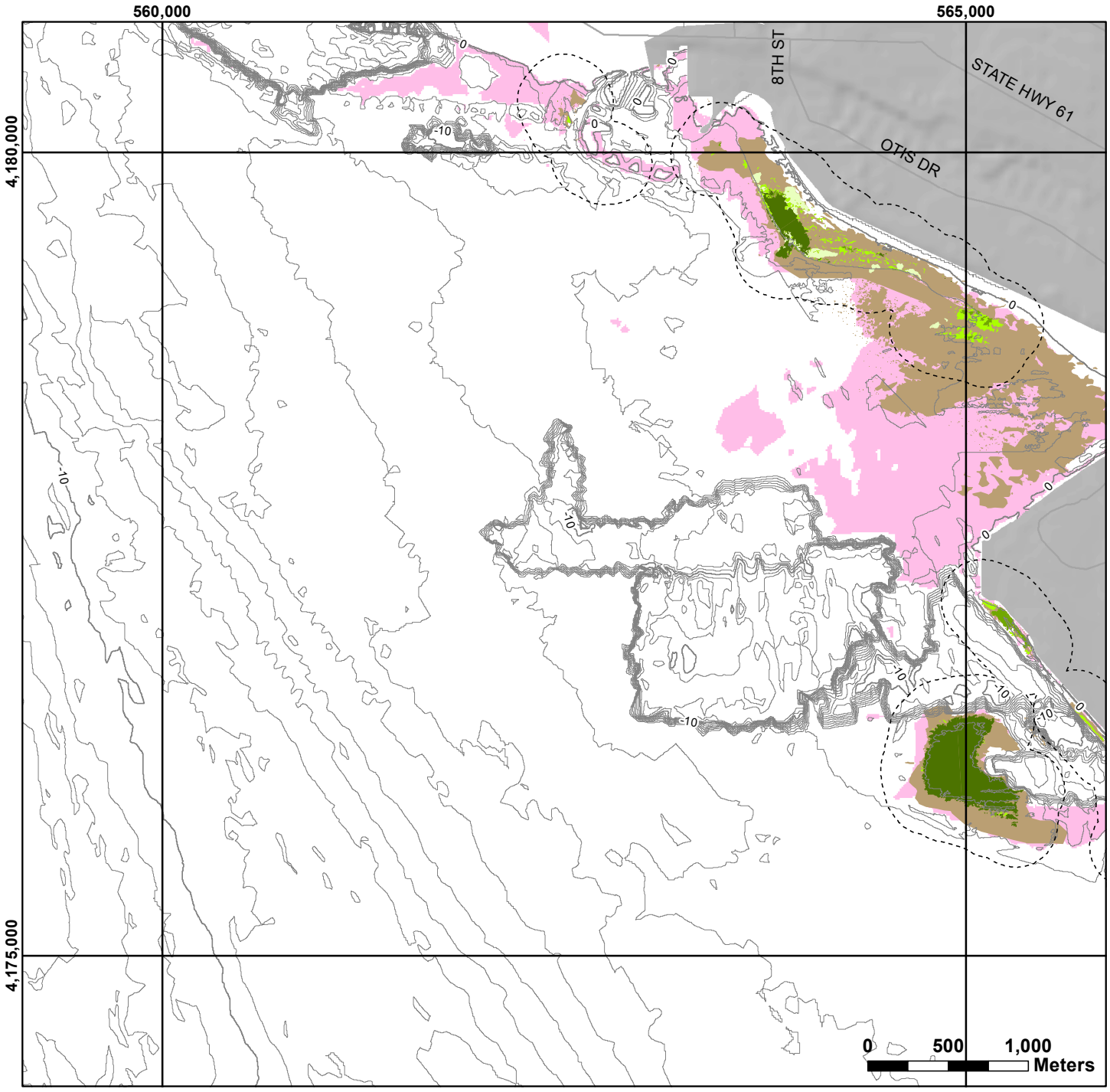


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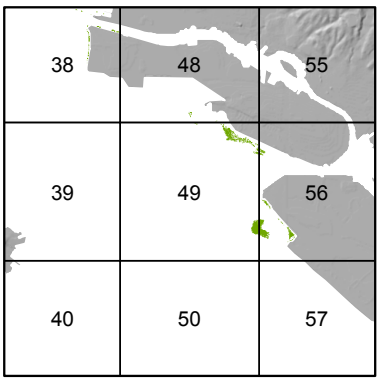

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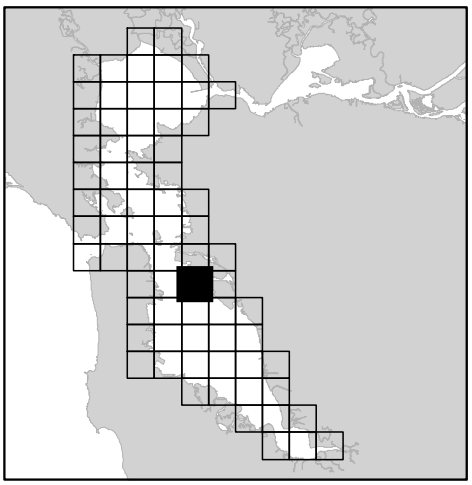
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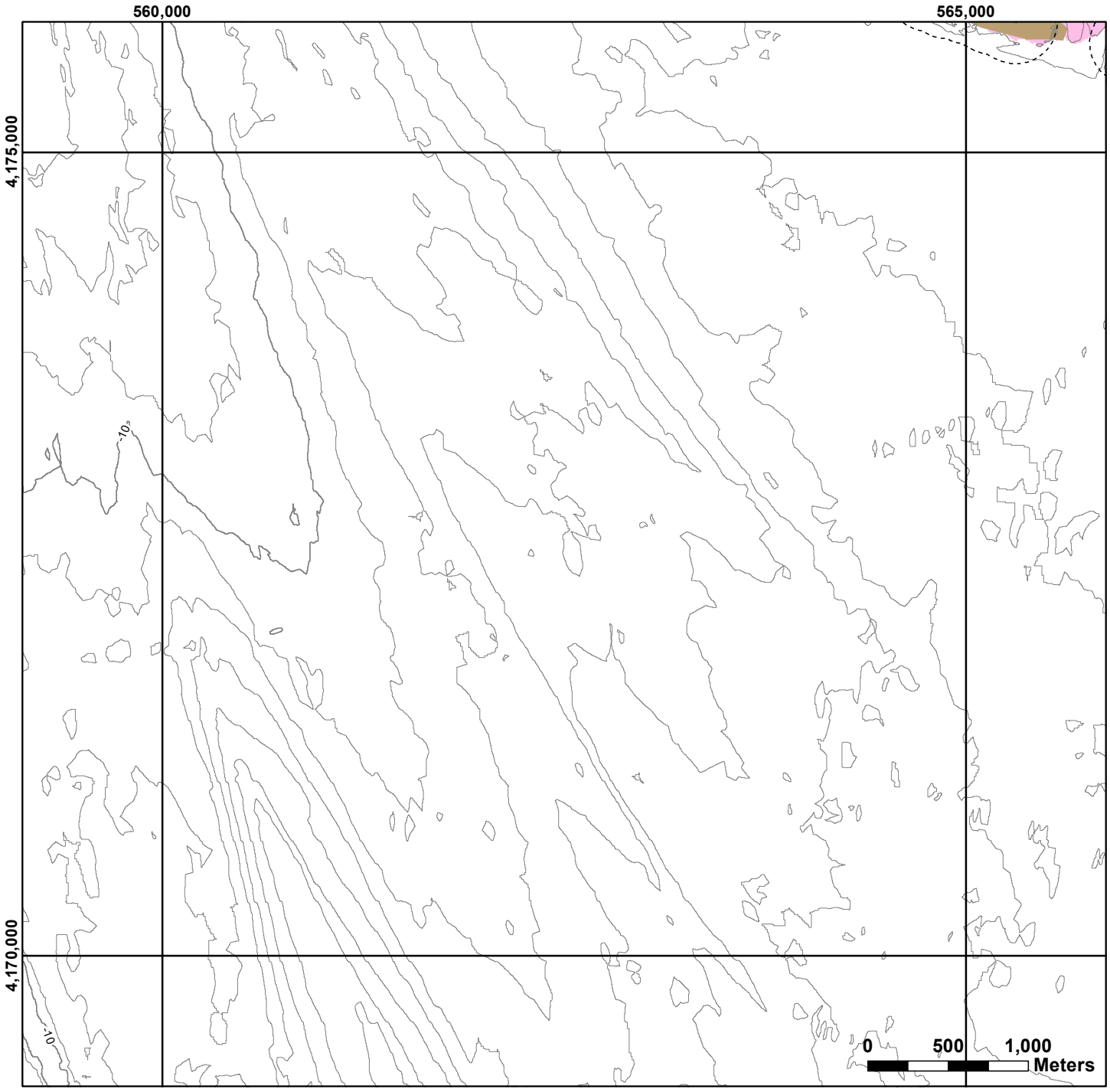


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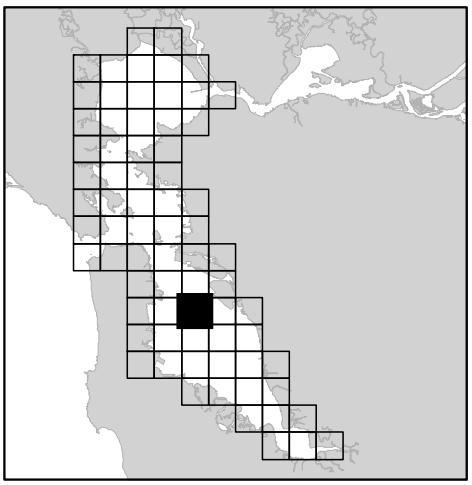
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SHEET VICINITY

| | | |
|---|---|---|
| 39 | 49 | 56 |
| 40 | 50 | 57 |
| 41 | 51 | 58 |

SHEET LOCATOR

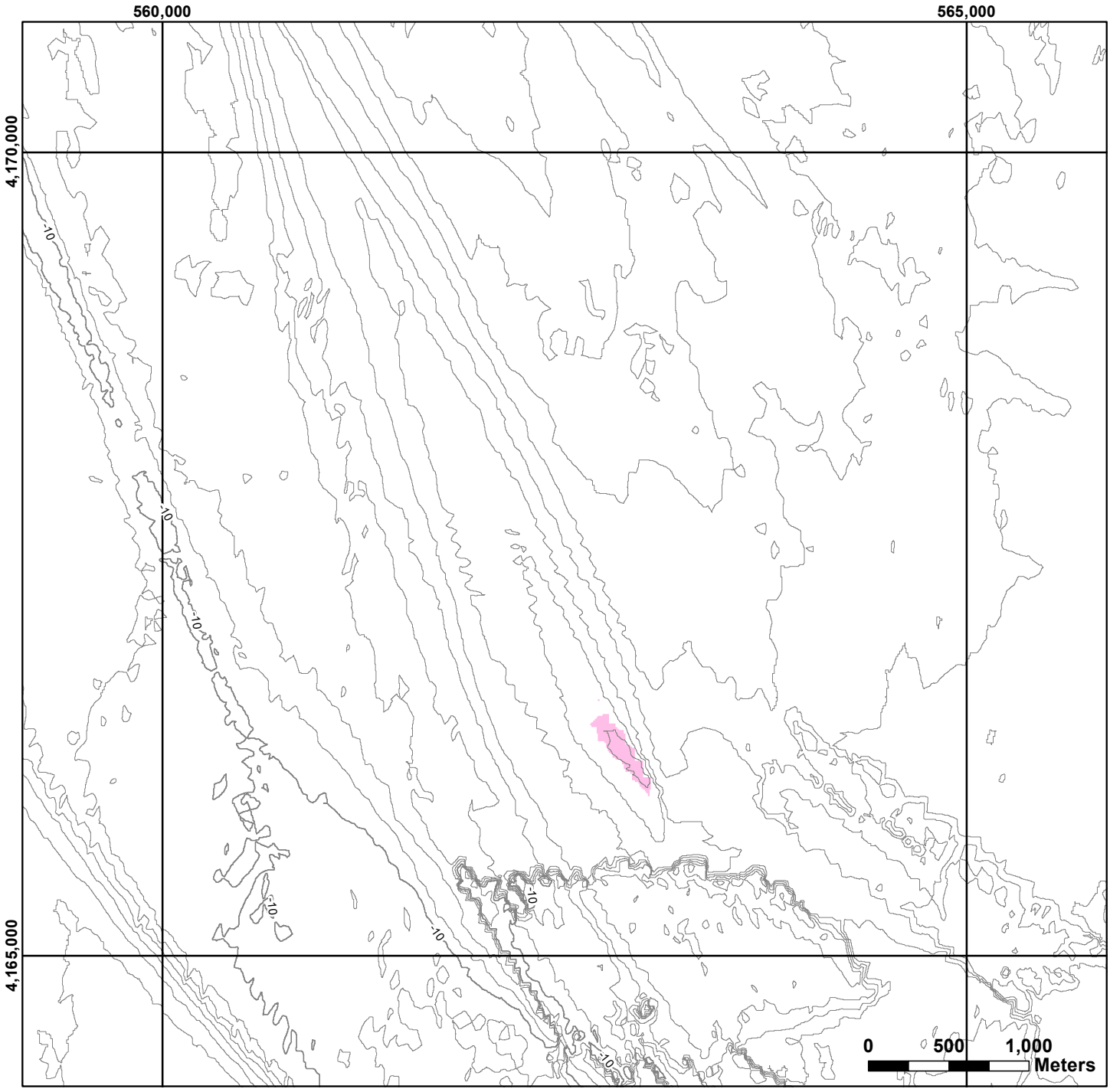


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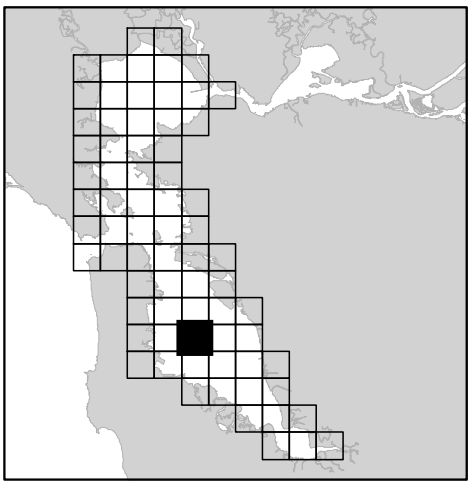
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| | | |
|---|---|---|
| 40 | 50 | 57 |
| 41 | 51 | 58 |
| 42 | 52 | 59 |

SHEET LOCATOR

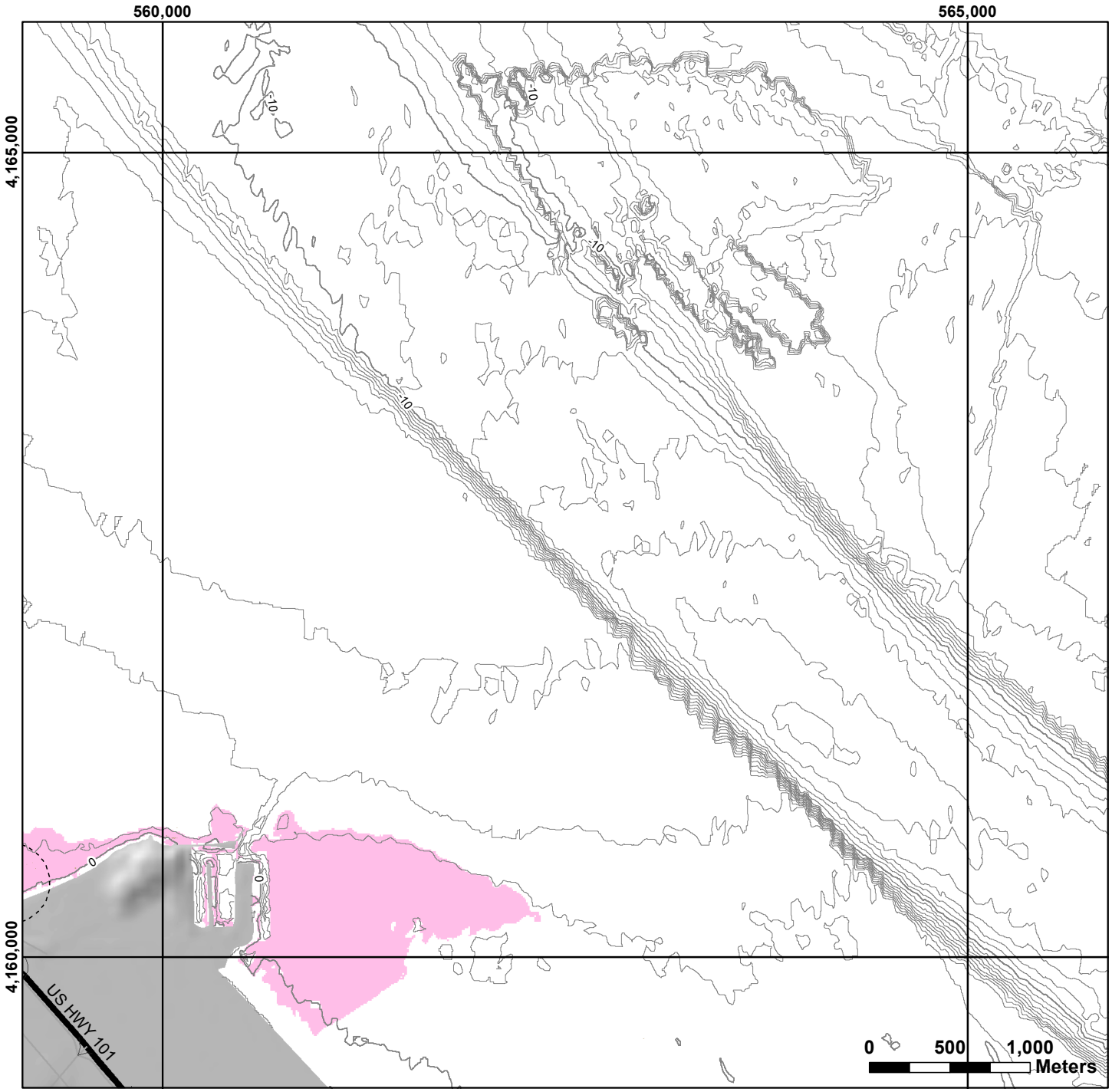


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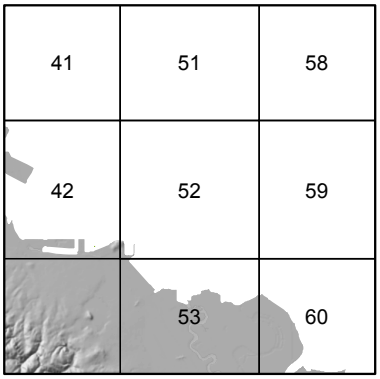

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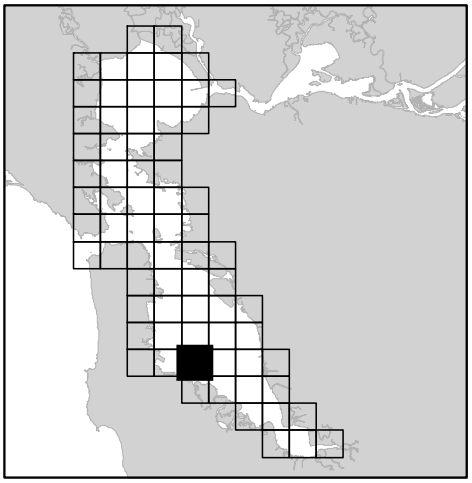
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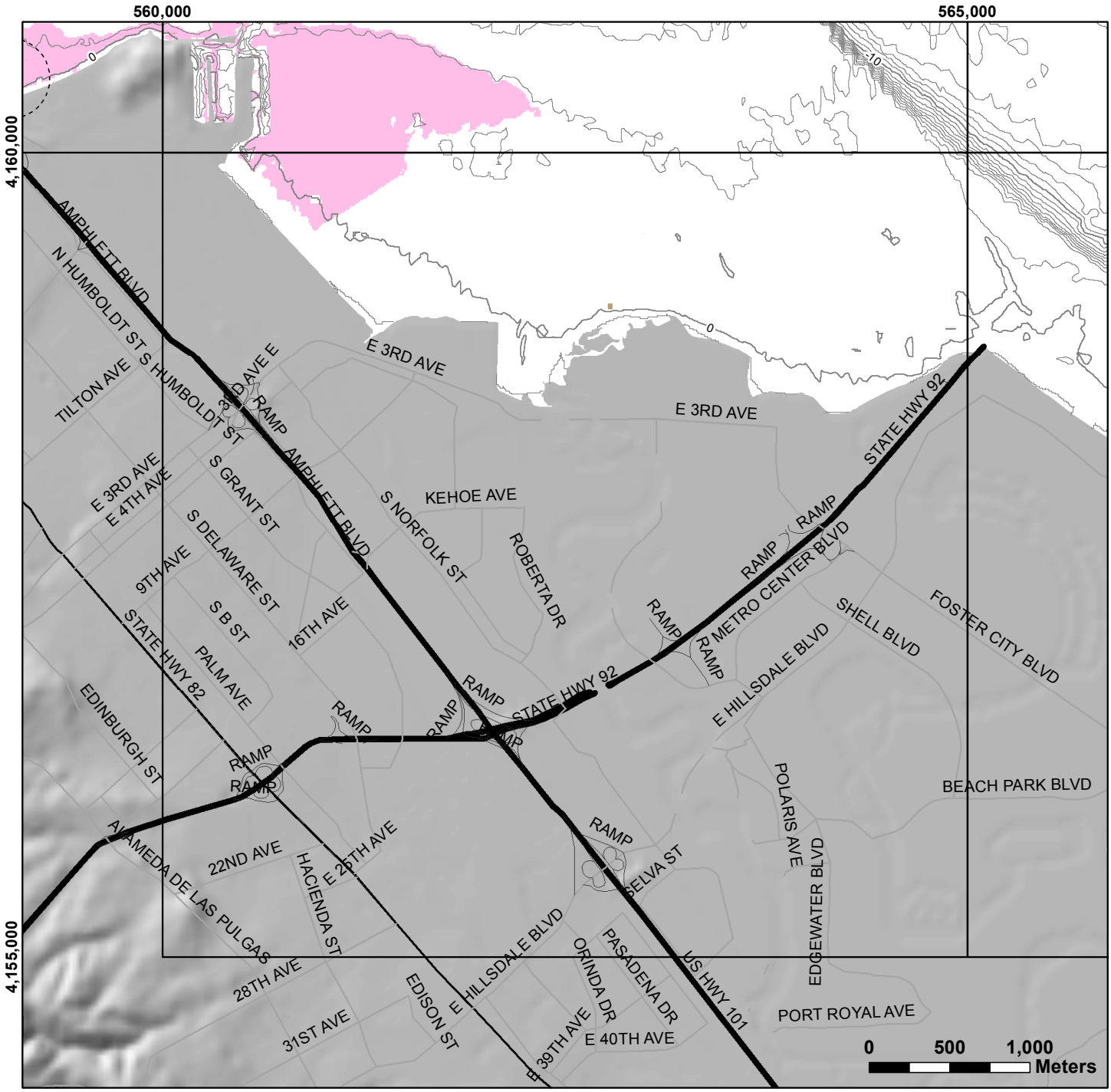


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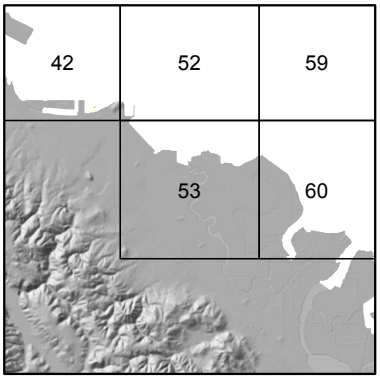

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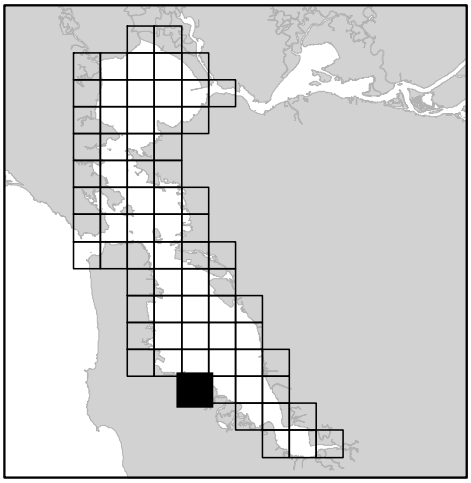

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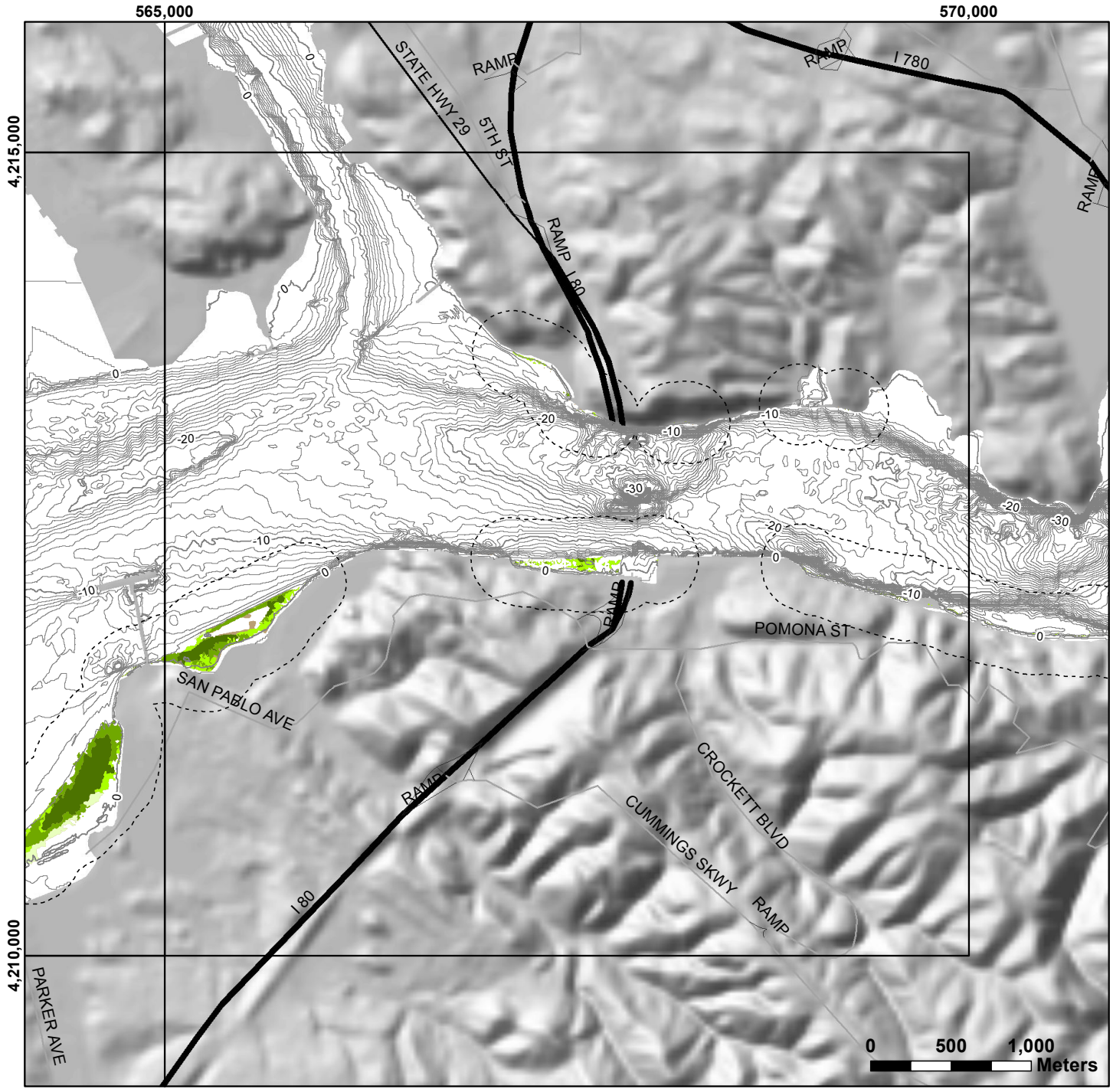

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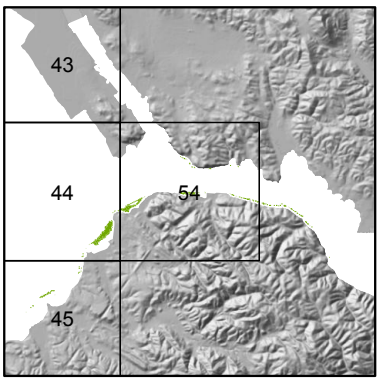

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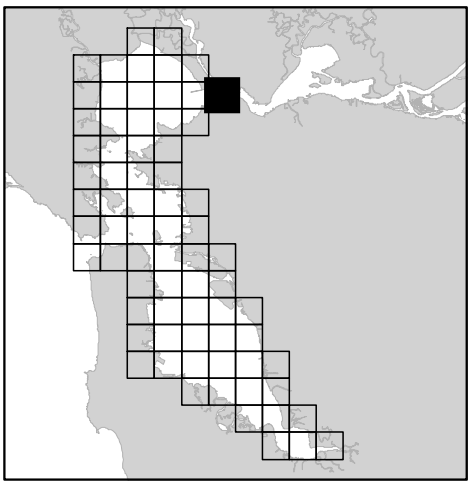
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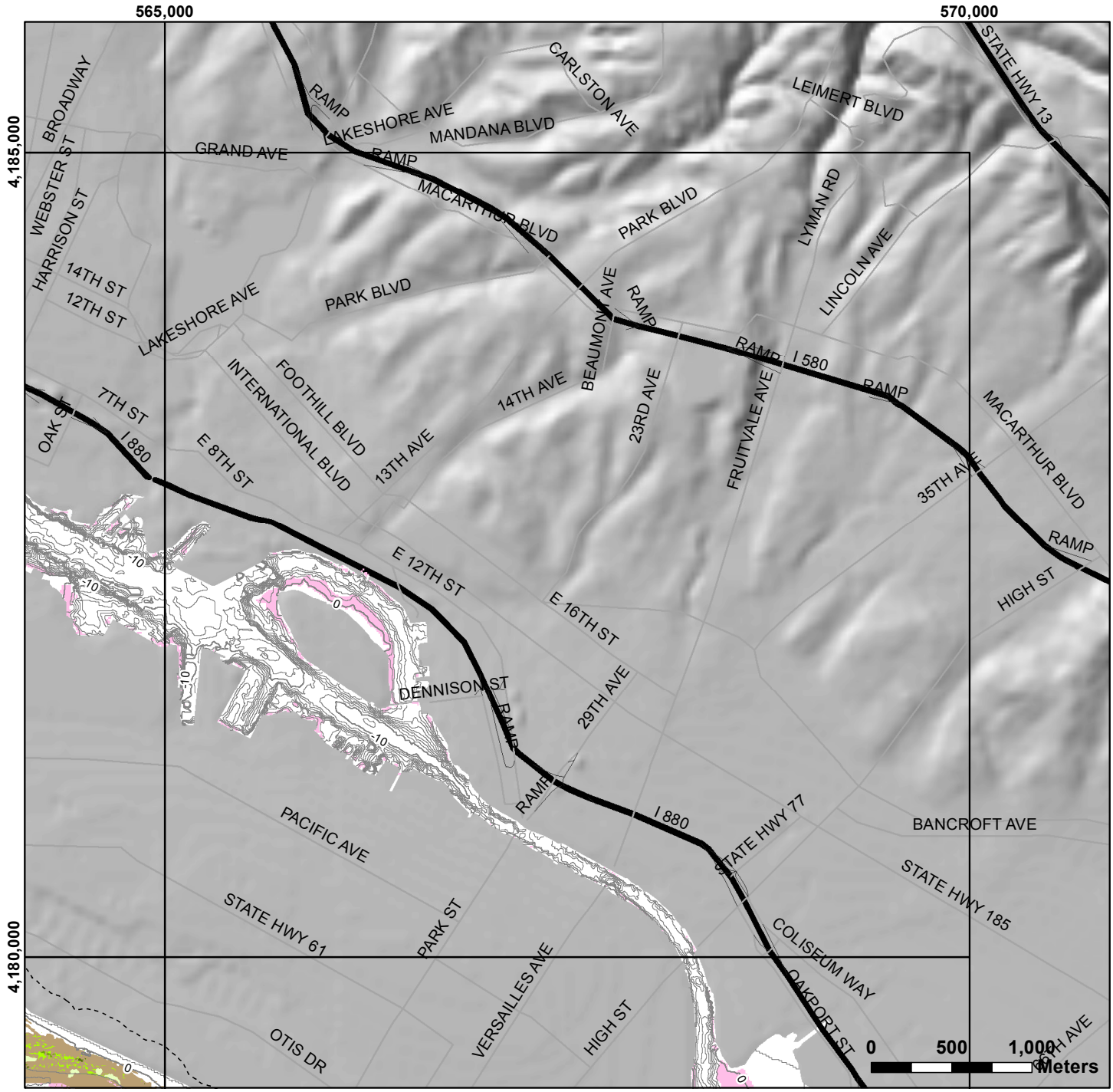

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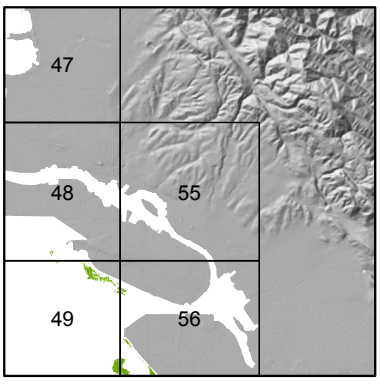

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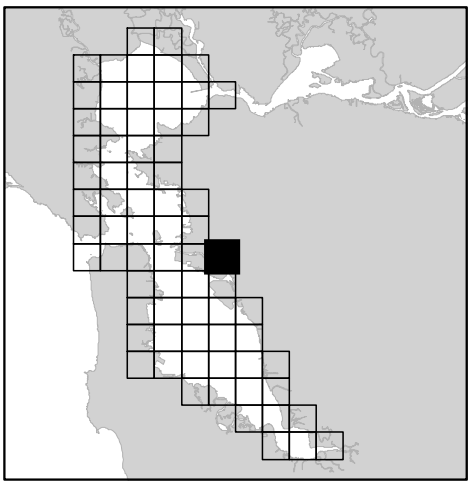

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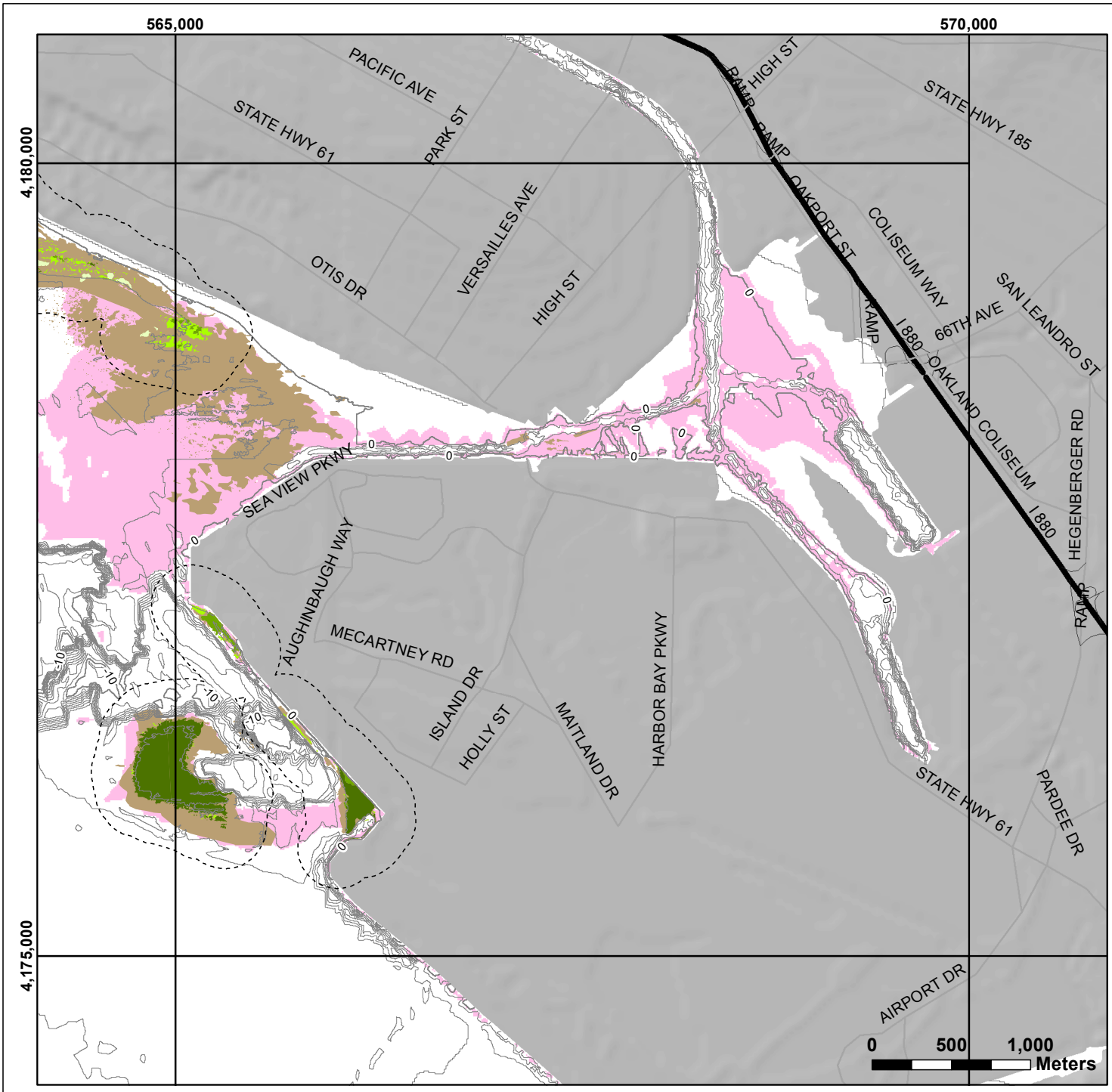

SHEET LOCATOR



**2014 Eelgrass Coverage**

- 1-5%
- 6-20%
- 21-40%
- 41-100%

- Maximum Documented Eelgrass Extent
- 2014 Eelgrass 250m Locator Buffer
- ELVS Predictive Model



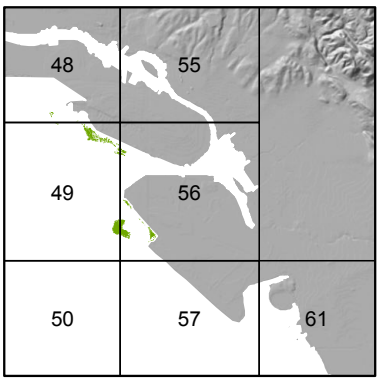

# SAN FRANCISCO BAY, CALIFORNIA
## Eelgrass 2014


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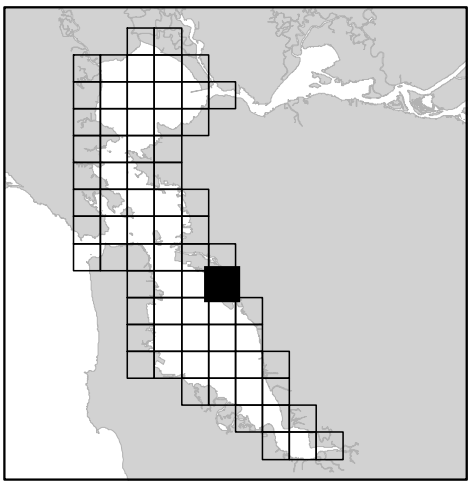

Horizontal Datum: UTM NAD83 Zone 10N (meters)
Vertical Datum: MLLW (meters)

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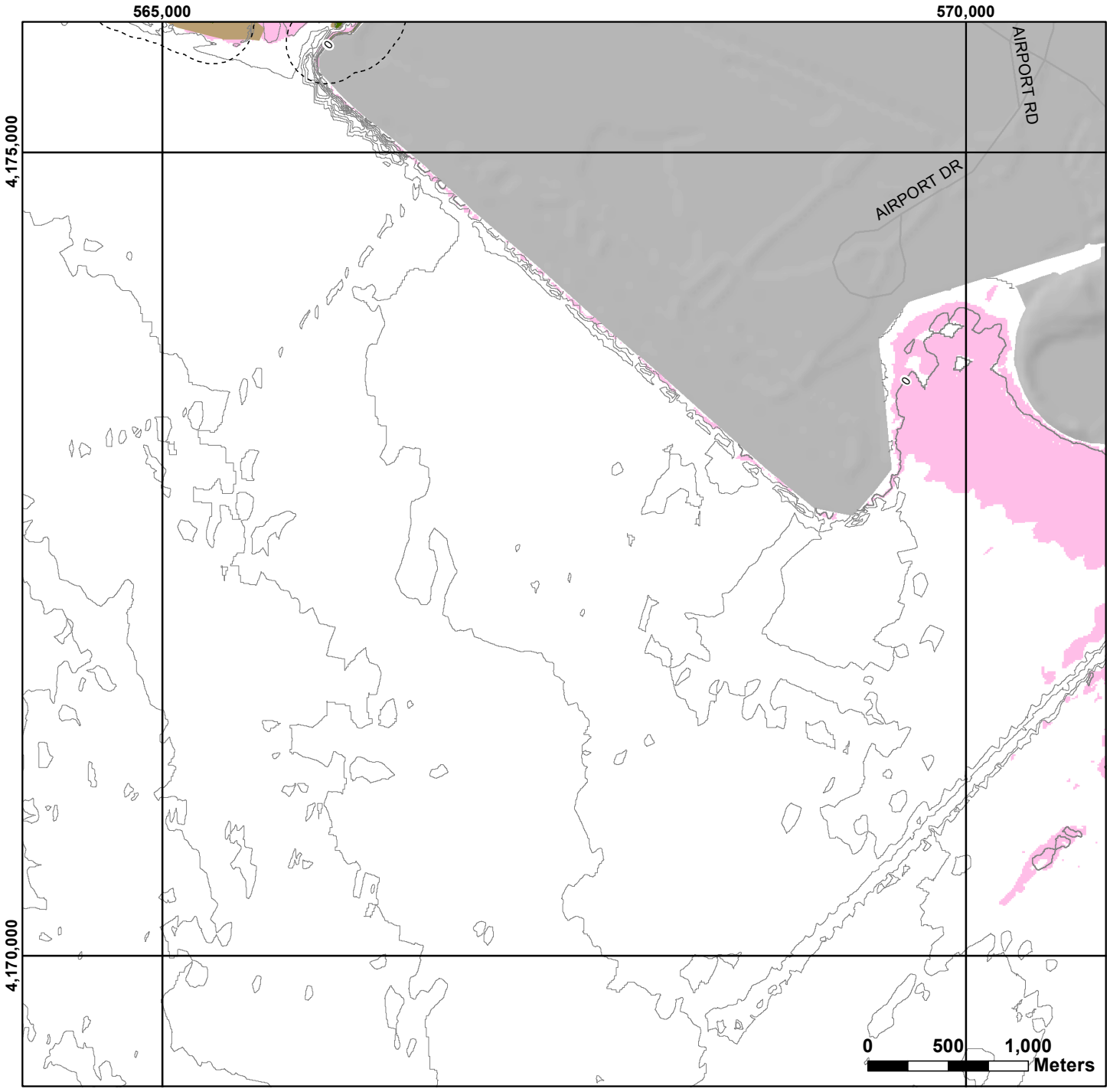

SHEET LOCATOR



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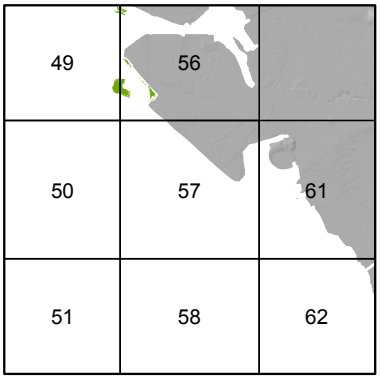

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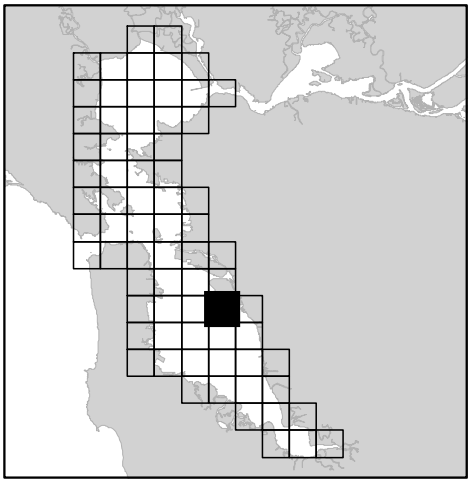
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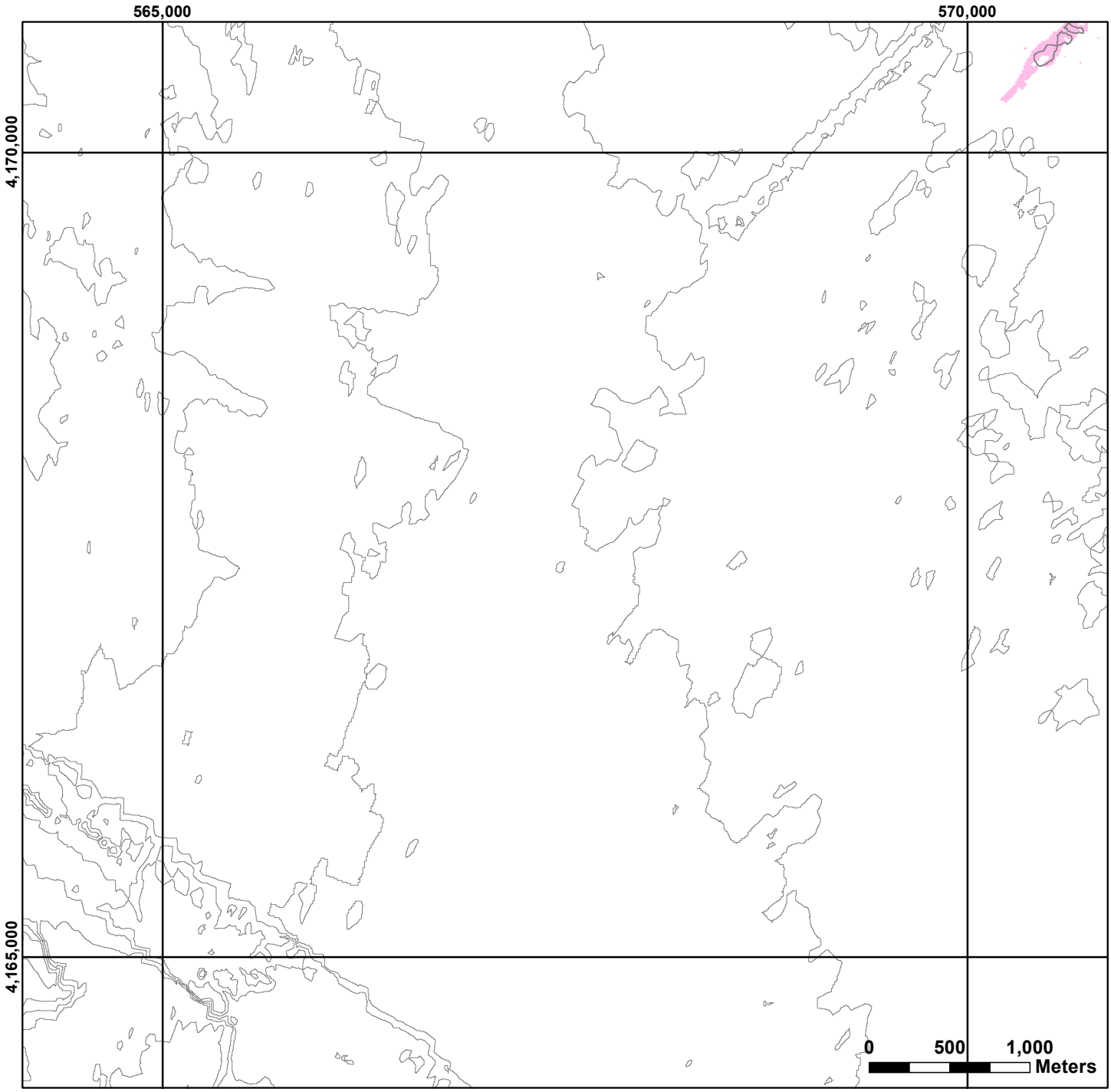





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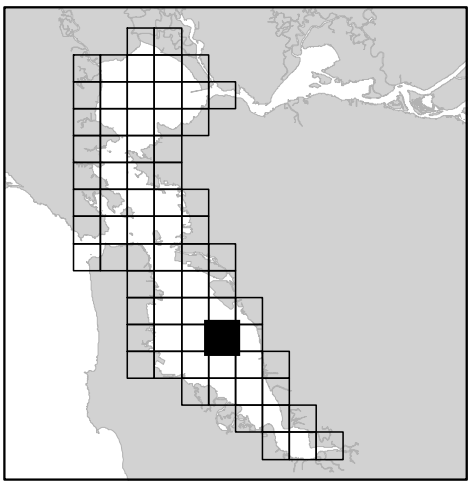
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SHEET VICINITY

| | | |
|---|---|---|
| 50 | 57 | 61 |
| 51 | 58 | 62 |
| 52 | 59 | 63 |

SHEET LOCATOR

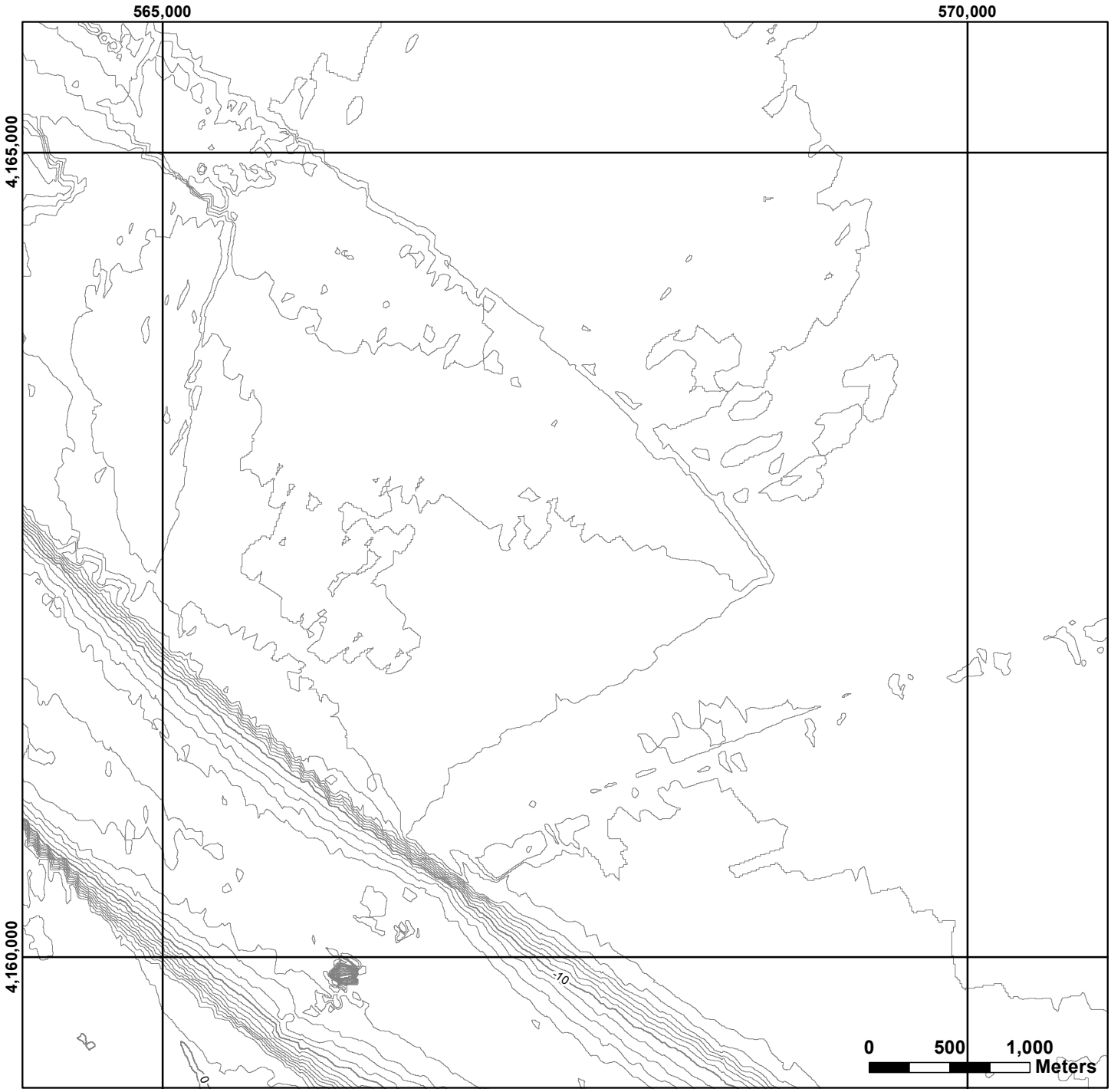


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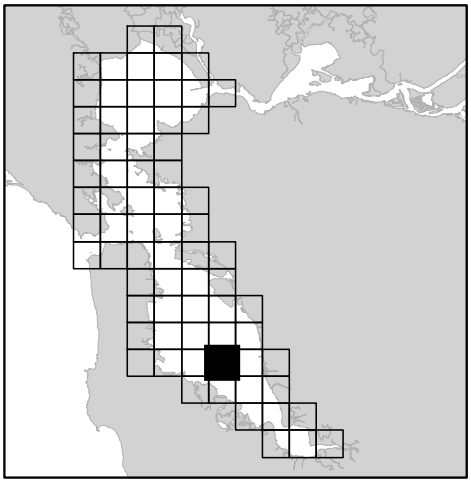
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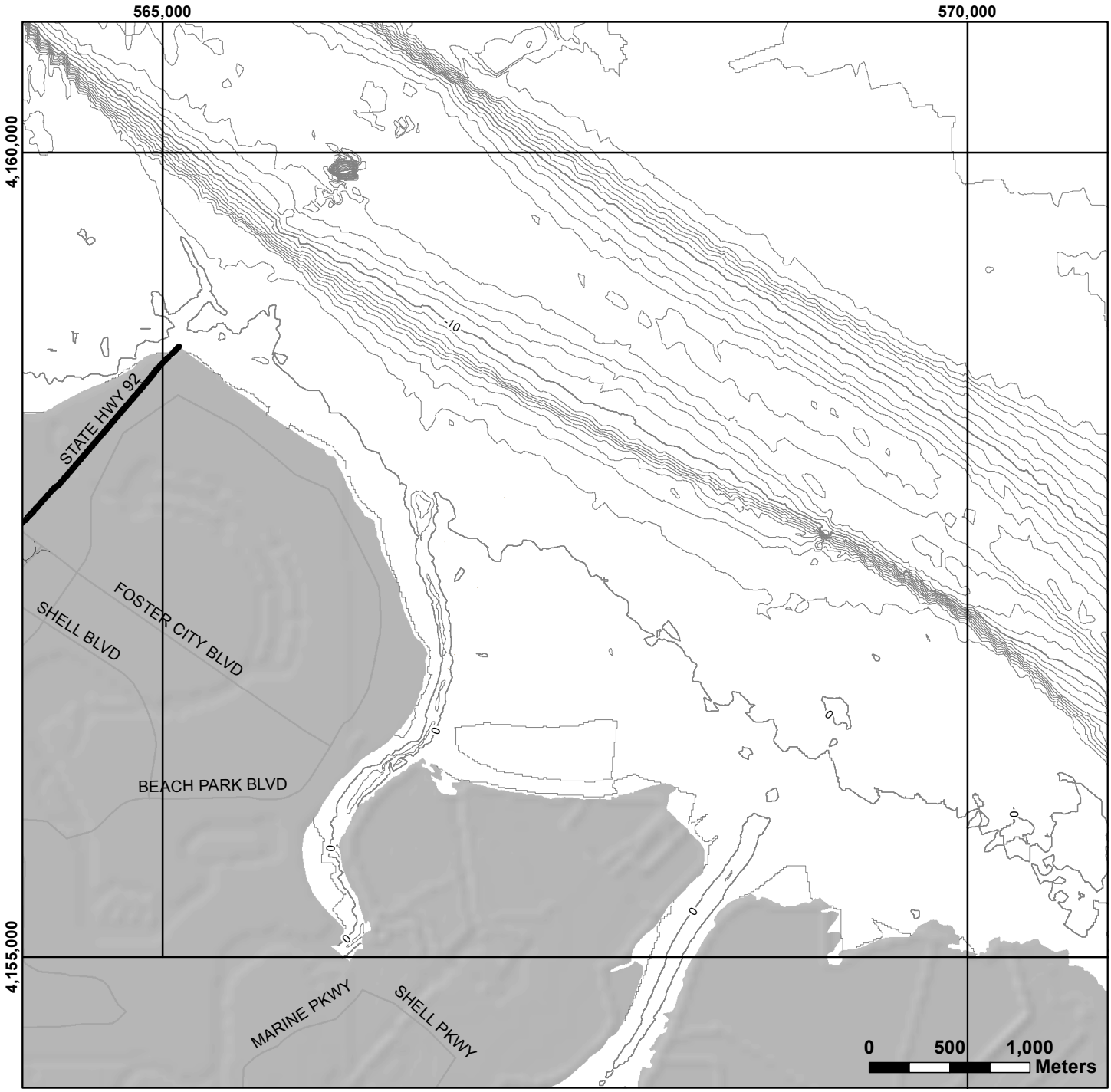


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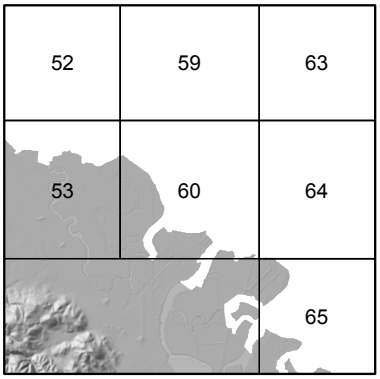

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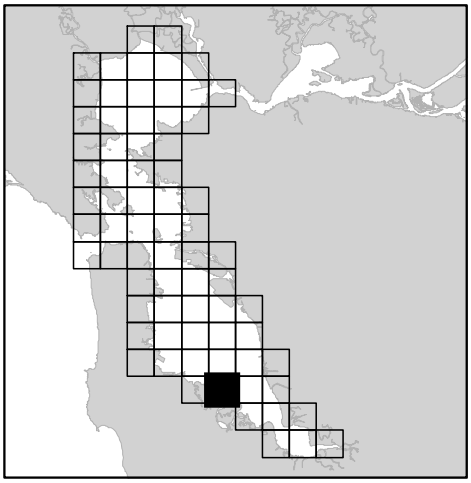
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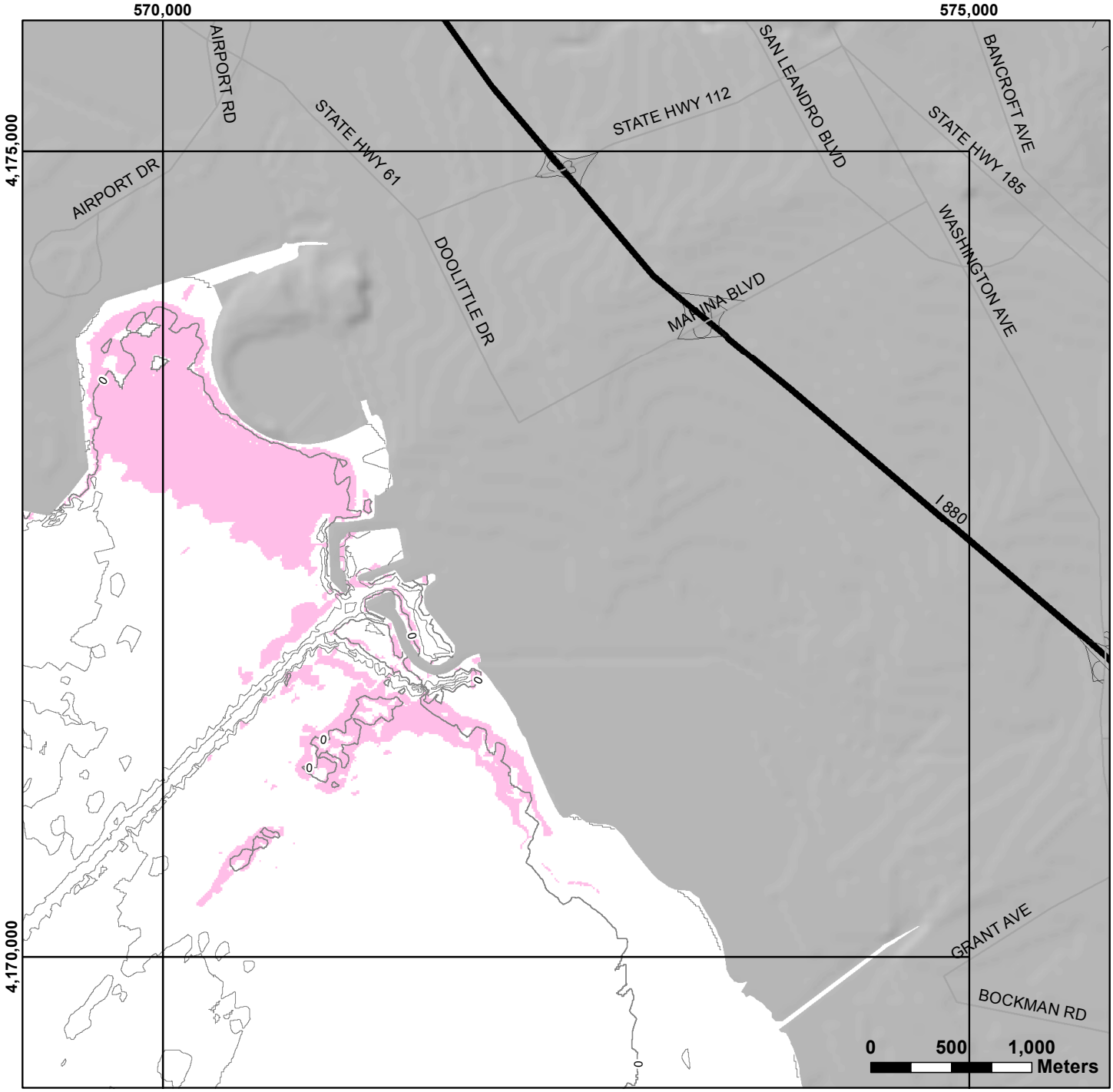


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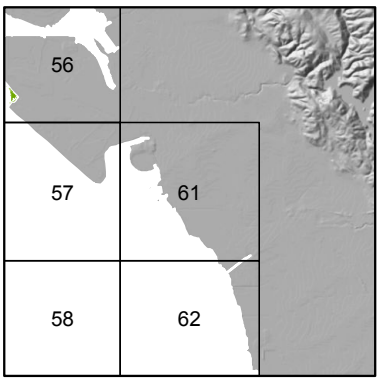

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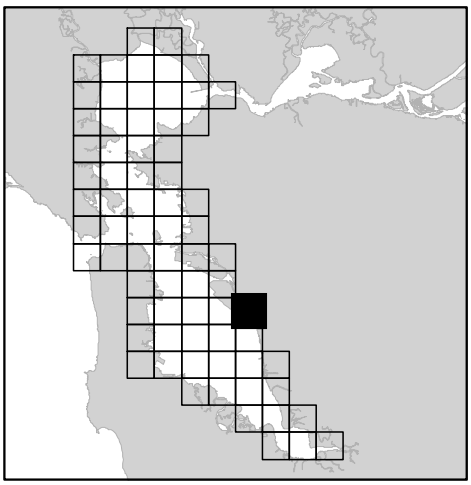
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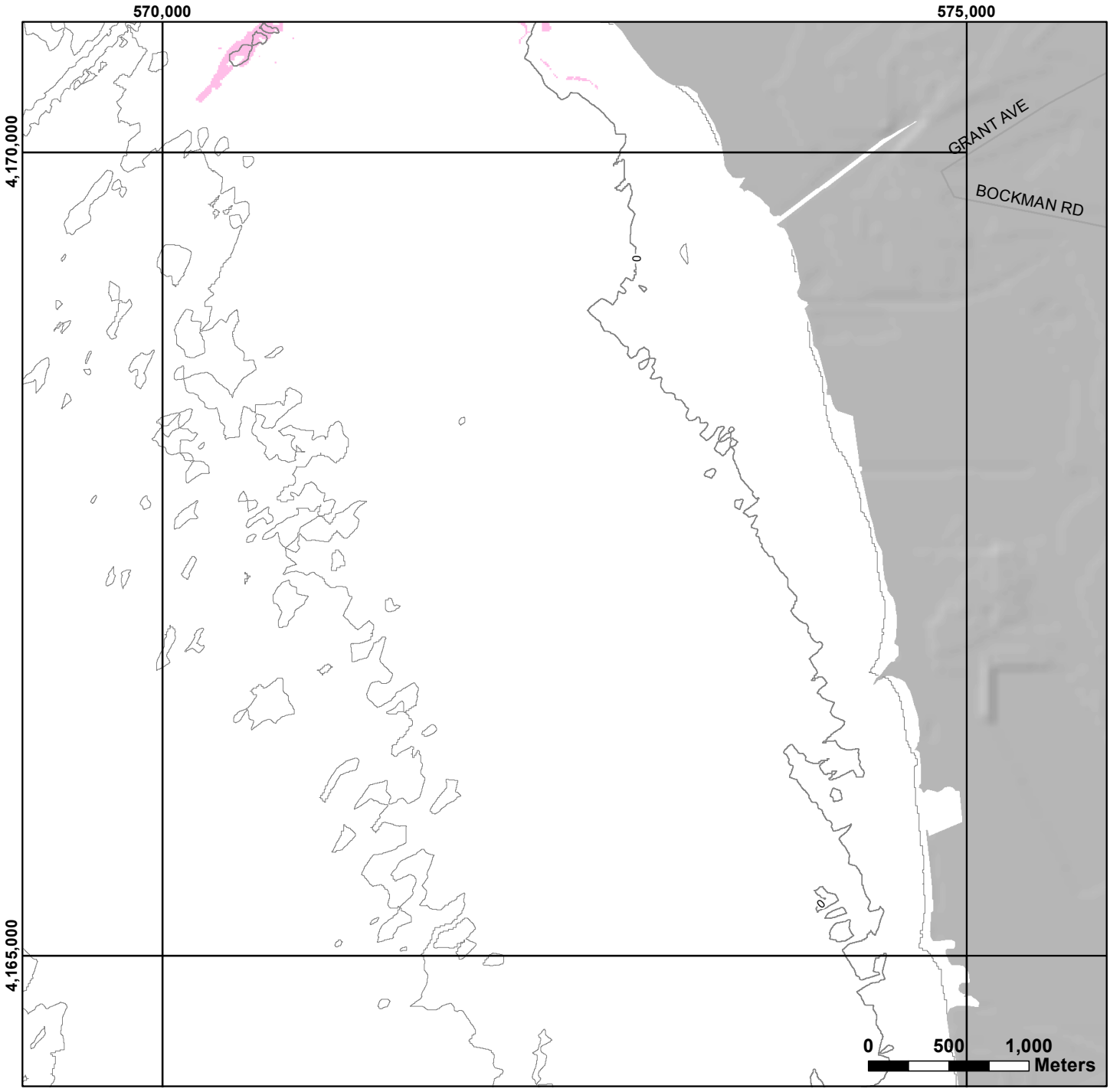

SHEET LOCATOR



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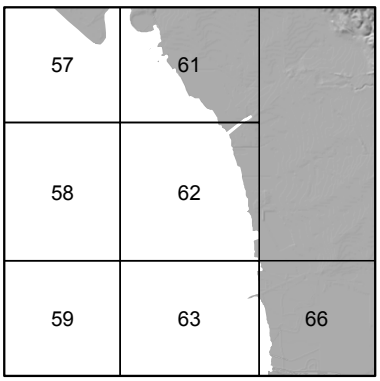

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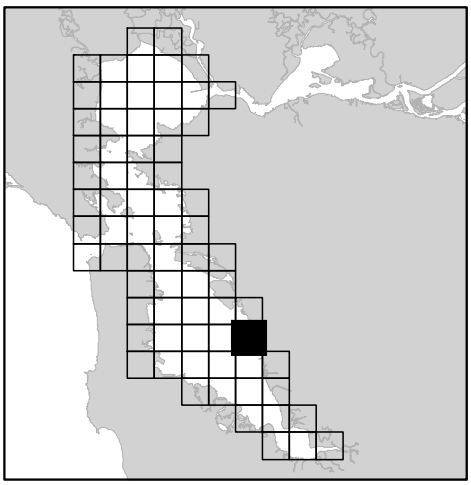
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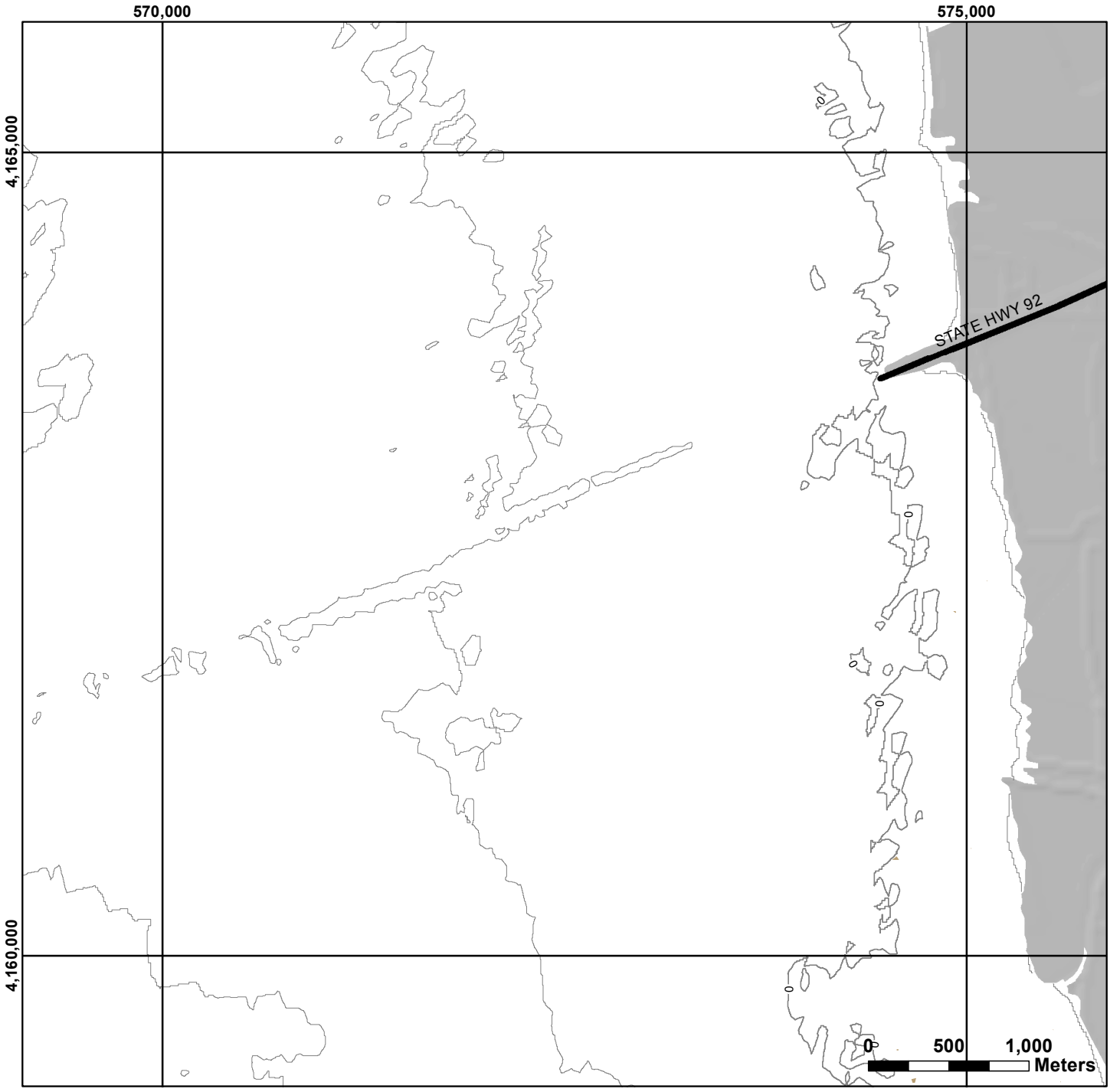

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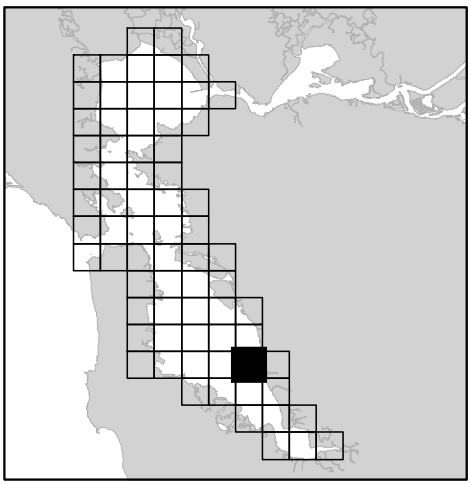
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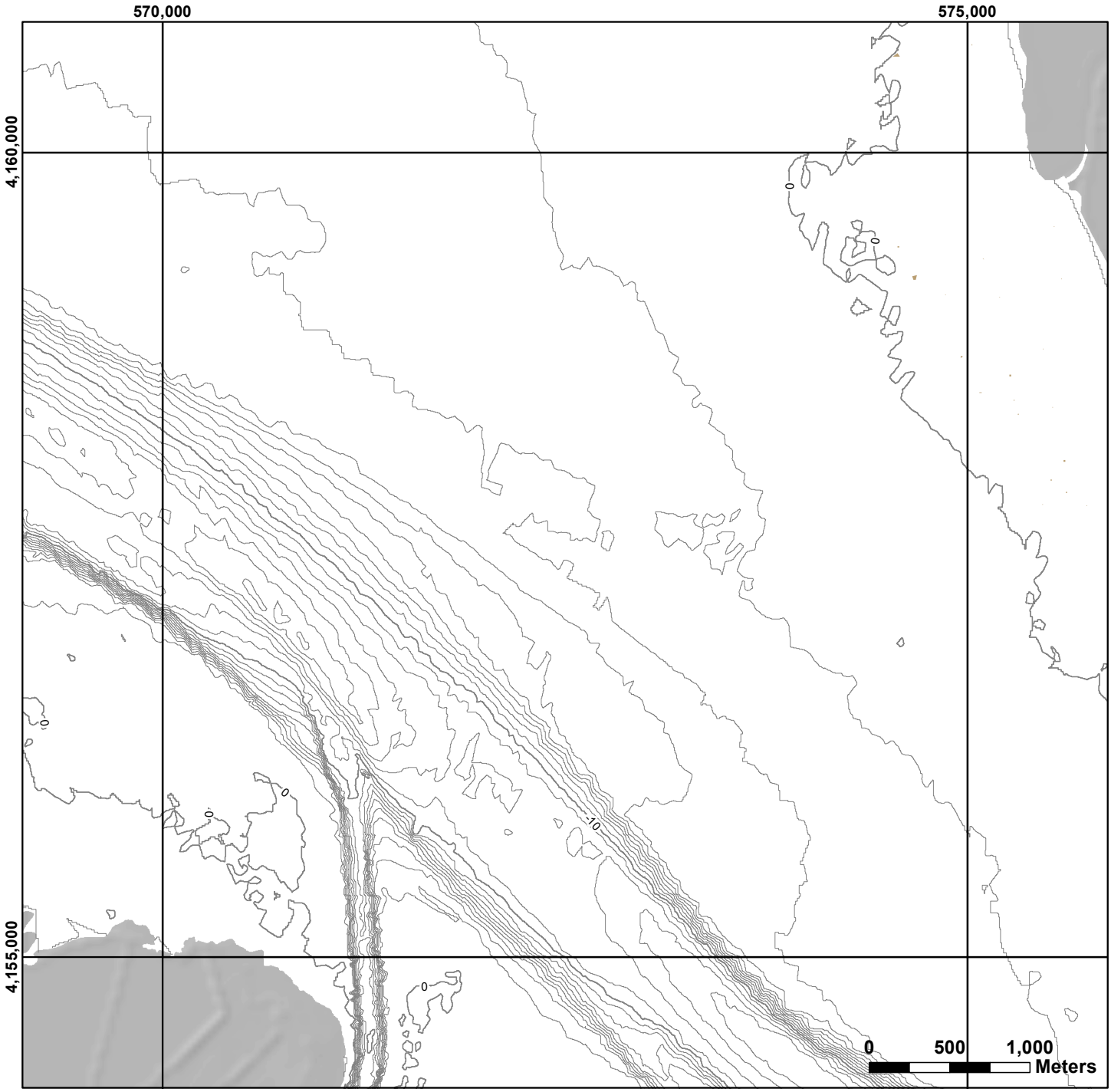

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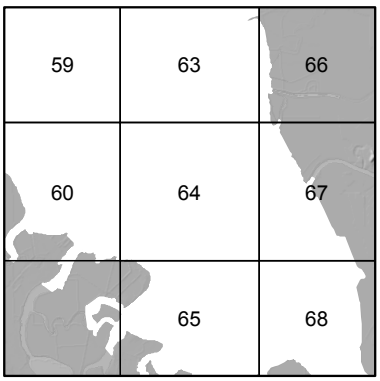

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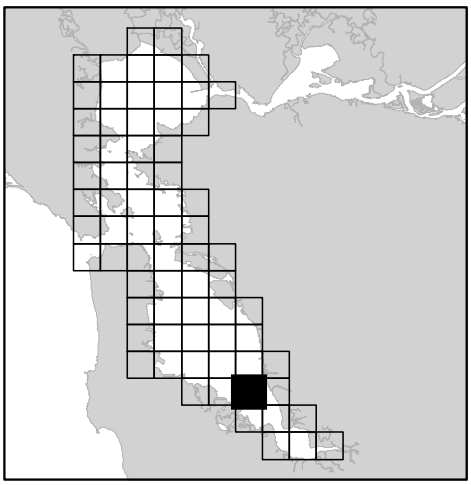
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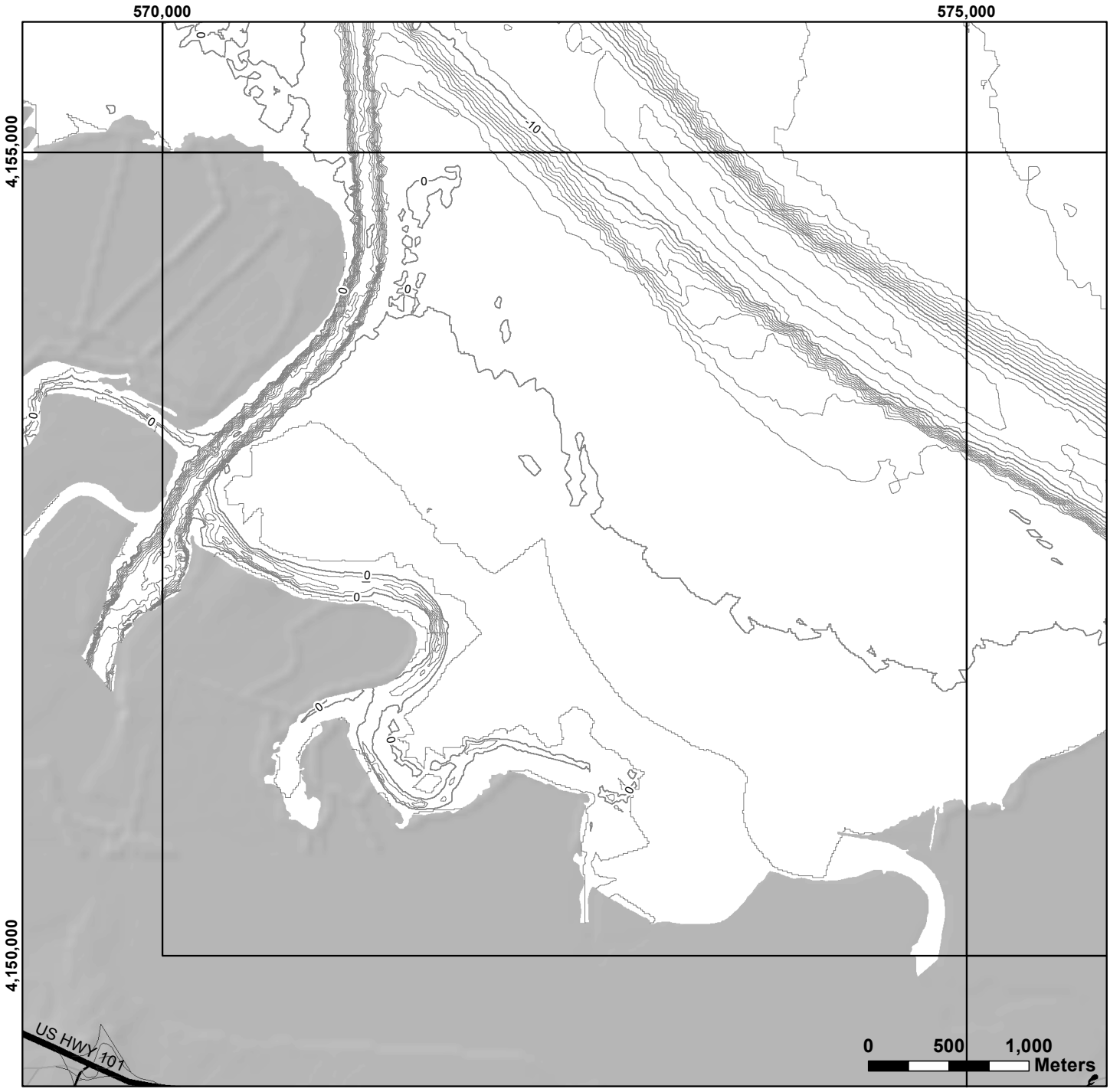


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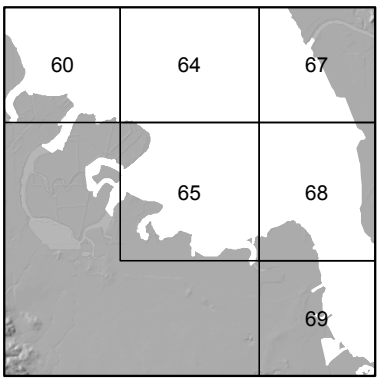

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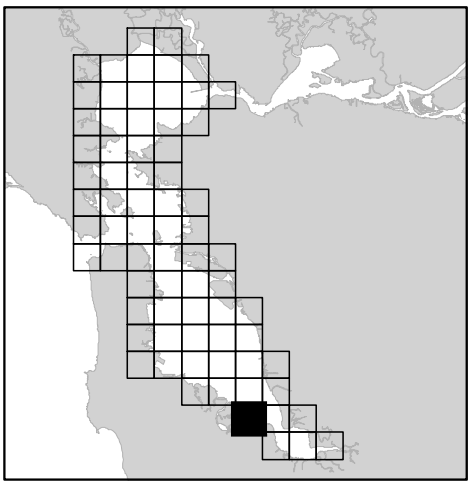
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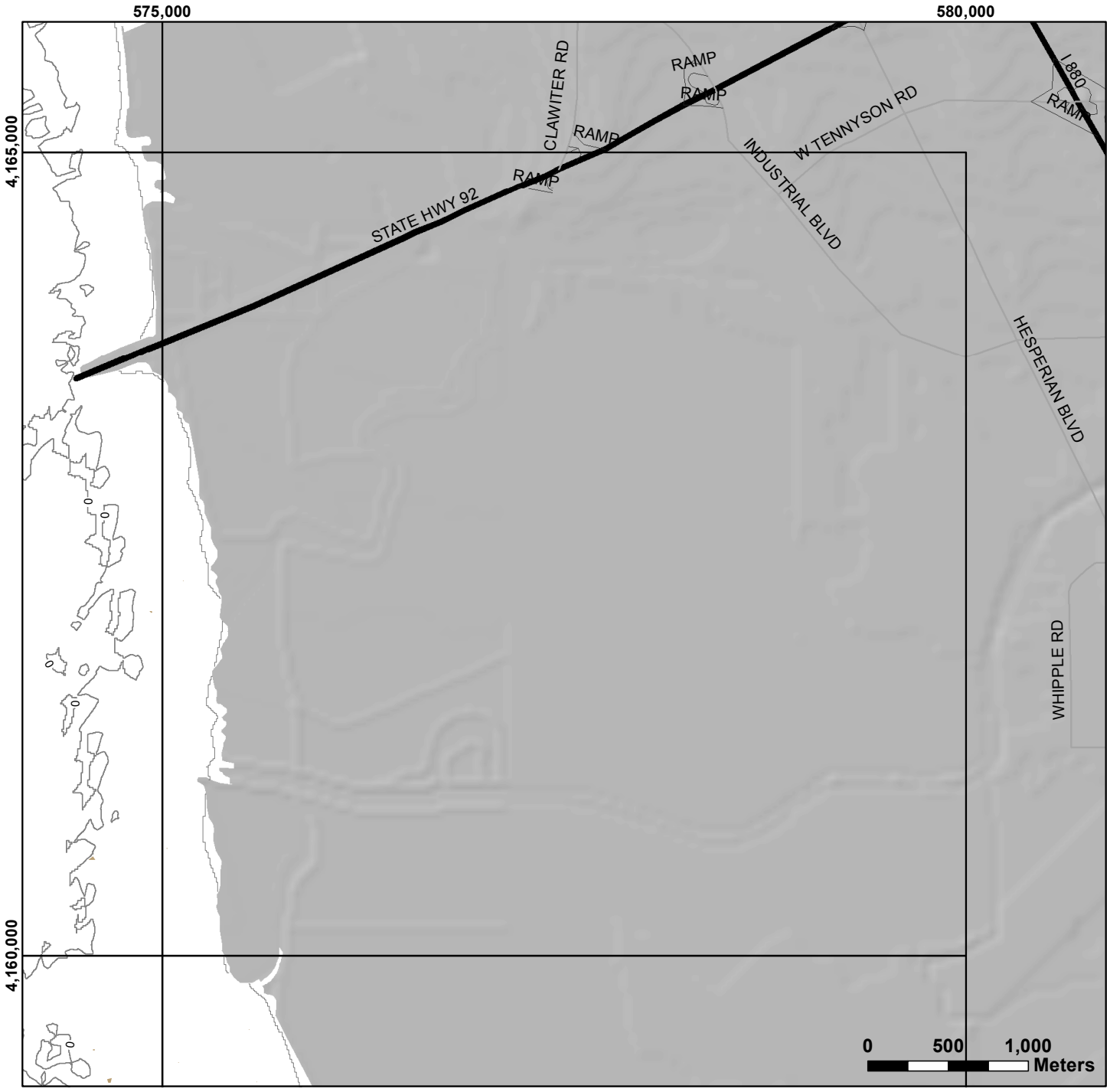


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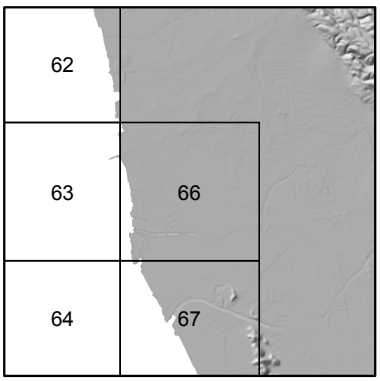

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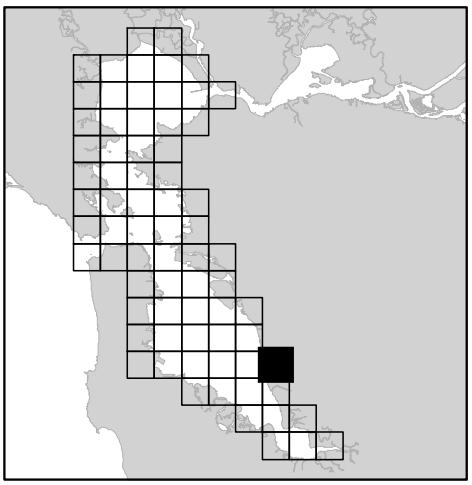
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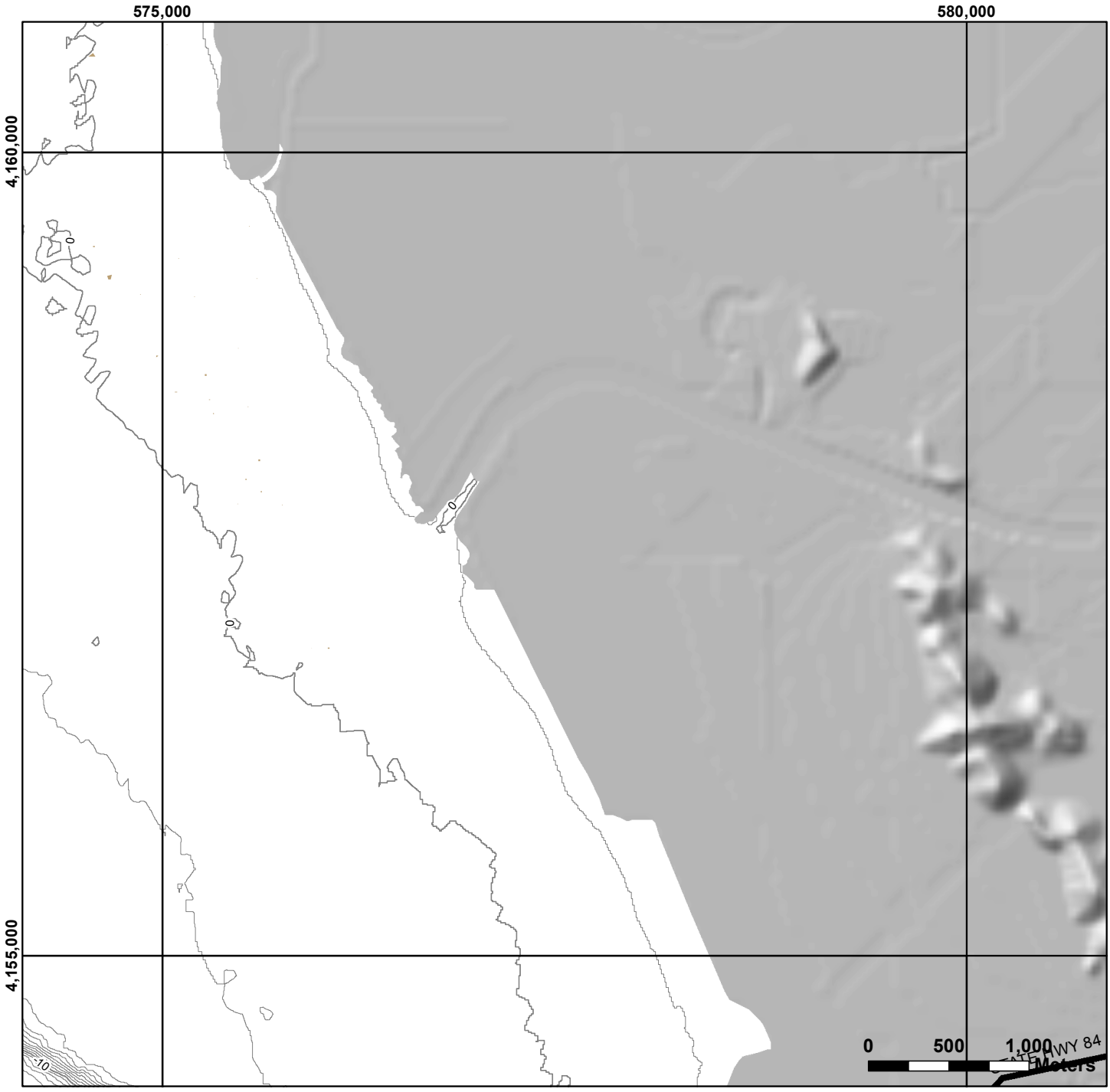


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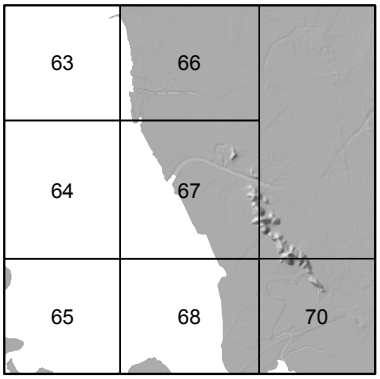

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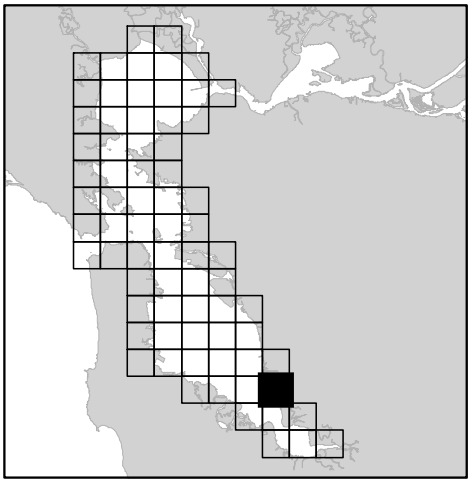
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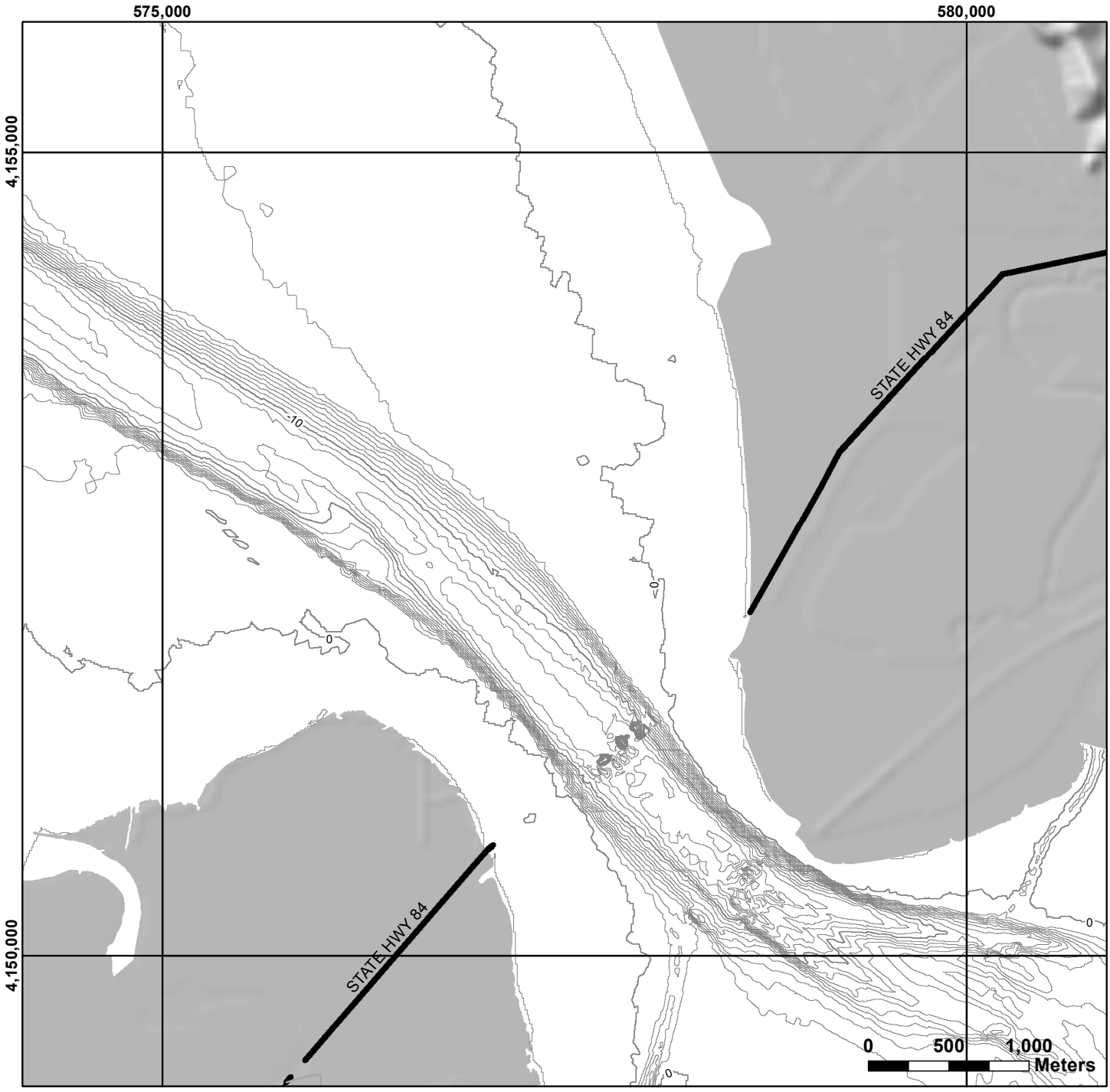





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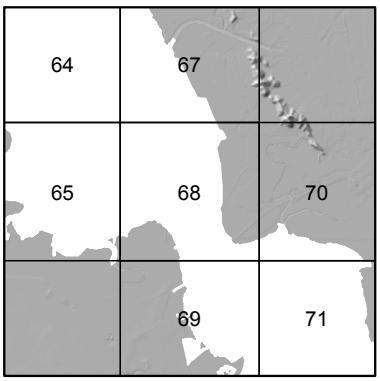

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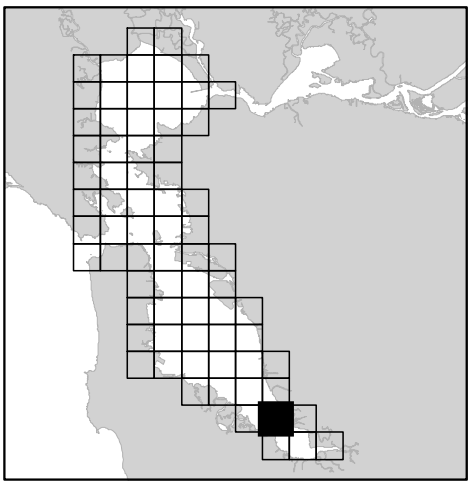
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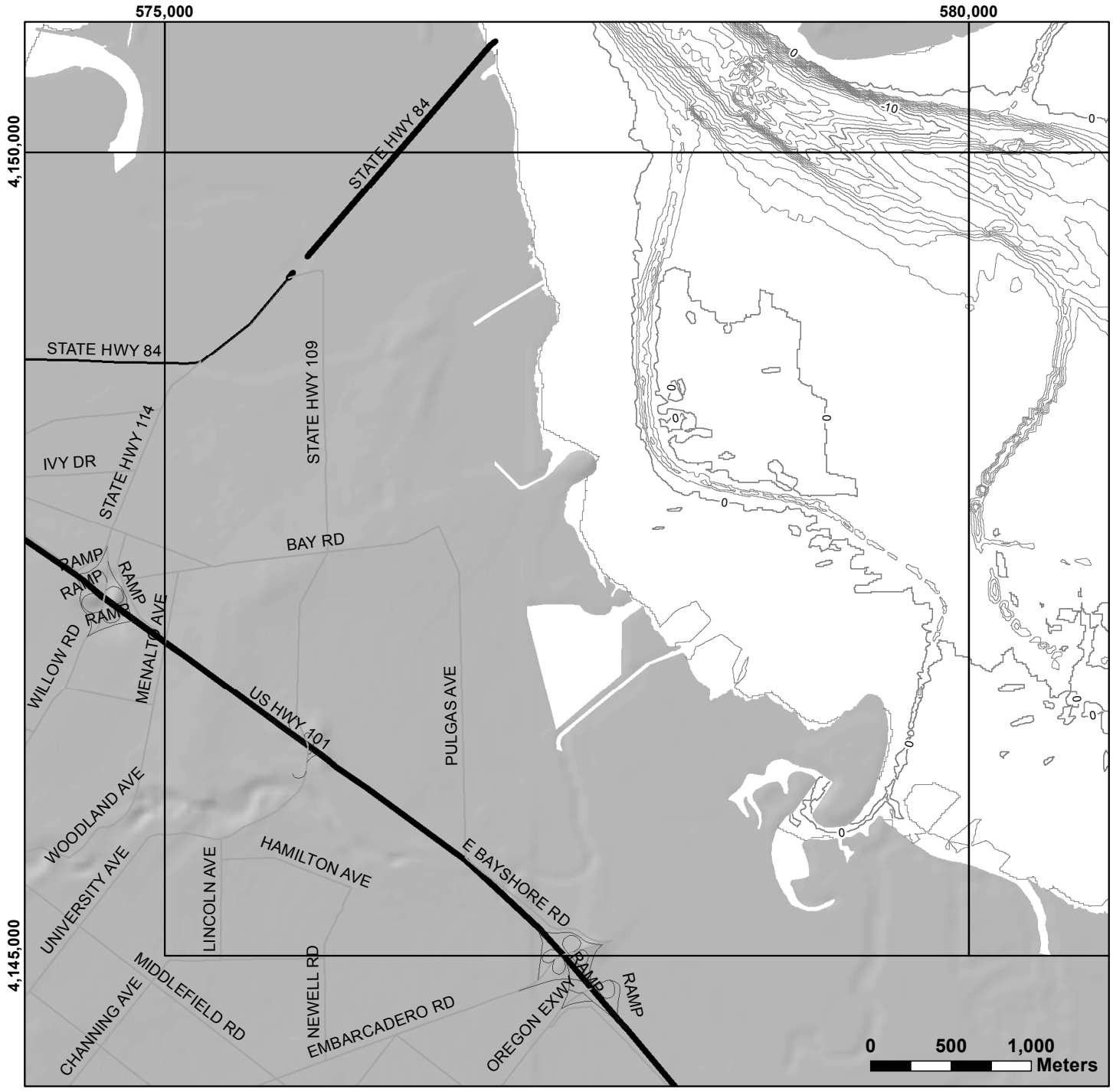


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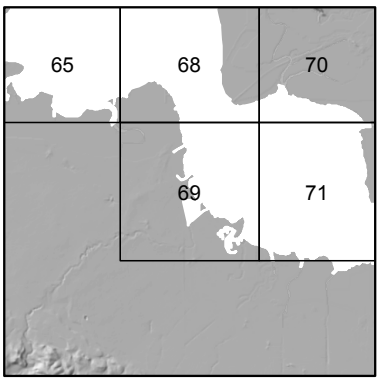

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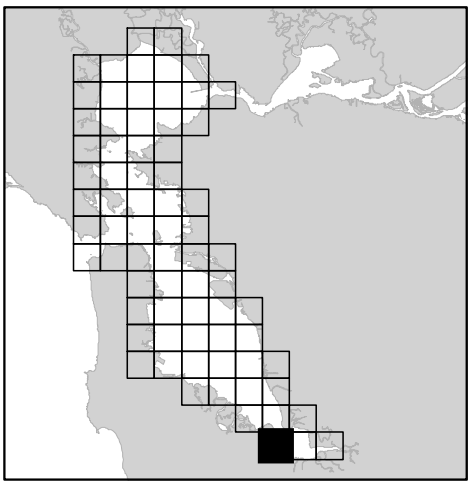

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SHEET VICINITY




SHEET LOCATOR

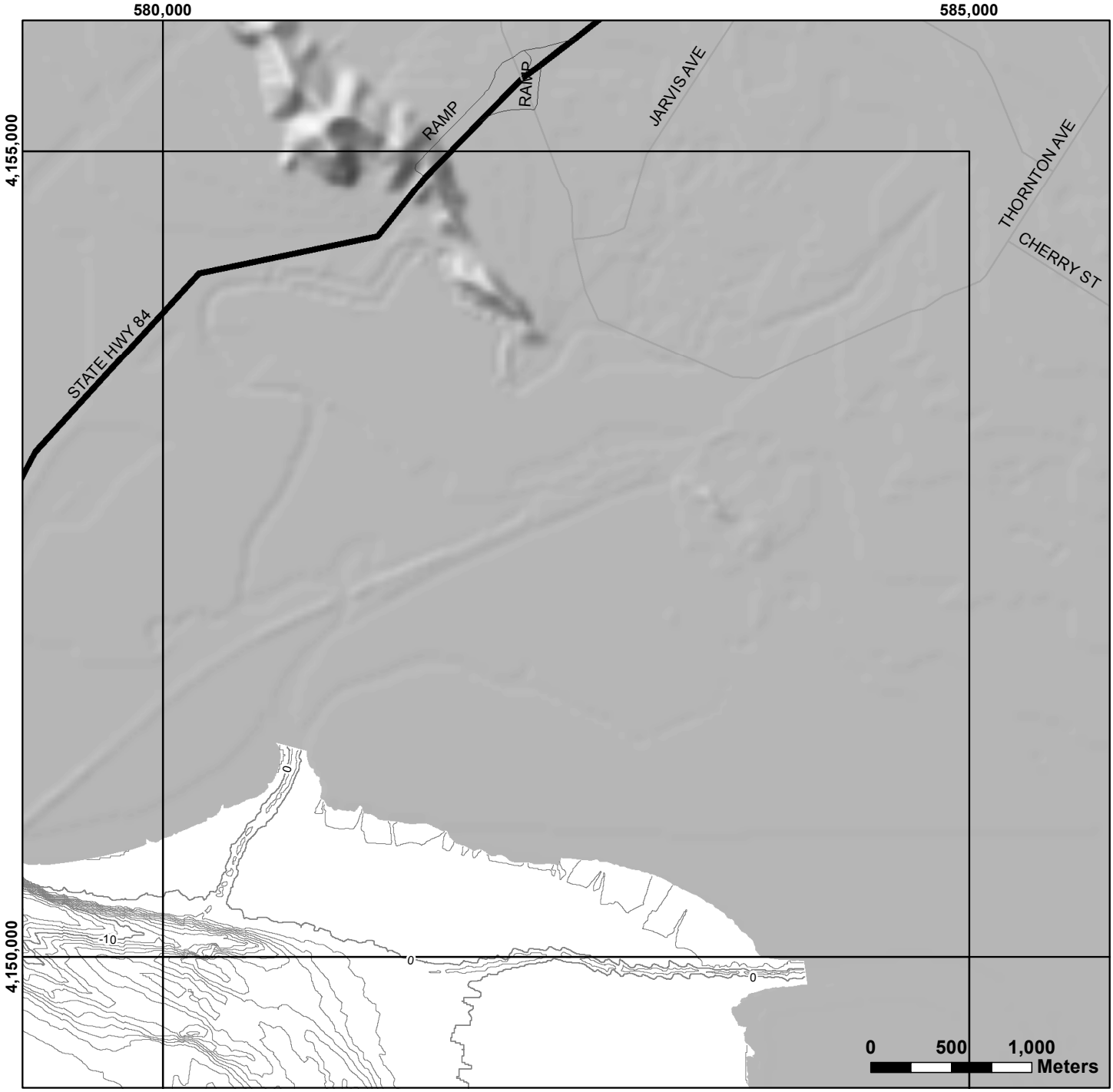





**2014 Eelgrass Coverage**

- 1-5%
- 6-20%
- 21-40%
- 41-100%

- Maximum Documented Eelgrass Extent
- 2014 Eelgrass 250m Locator Buffer
- ELVS Predictive Model



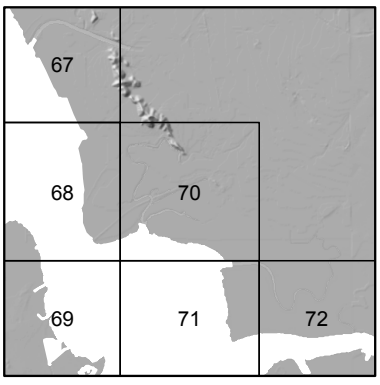

# SAN FRANCISCO BAY, CALIFORNIA
## Eelgrass 2014

Merkel & Associates, Inc.
San Diego, CA - Tel: (858) 560-5465

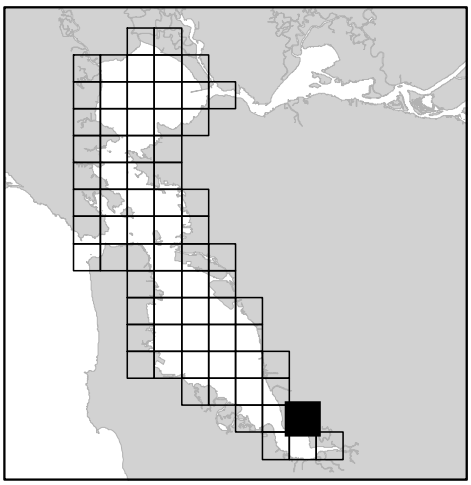
Horizontal Datum: UTM NAD83 Zone 10N (meters)
Vertical Datum: MLLW (meters)

*Note: Charts are for planning and management purposes only. Information application is limited by survey scale and some error is expected. Information is not to be used for navigation or specific project applications.*

SHEET VICINITY




SHEET LOCATOR

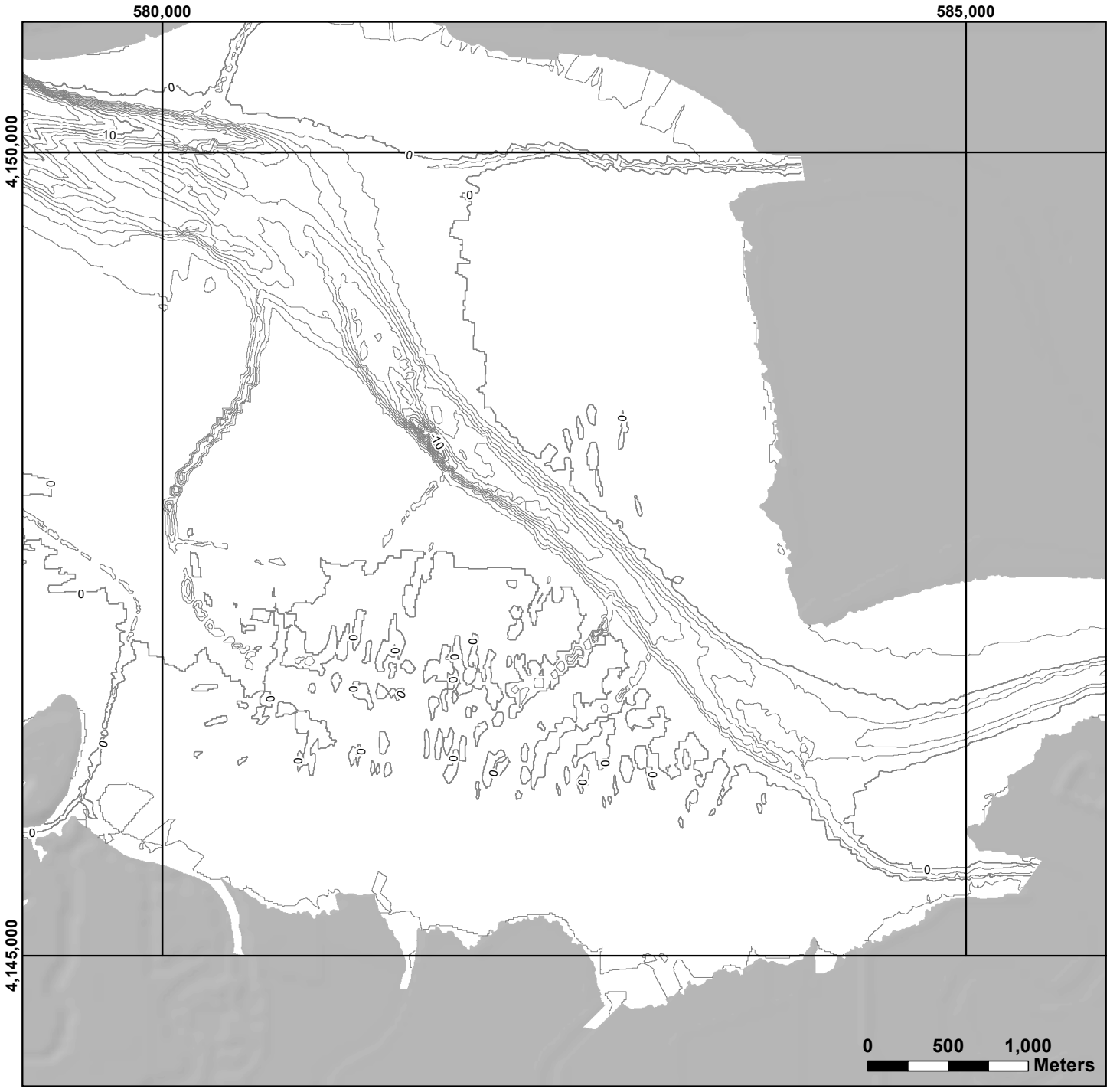


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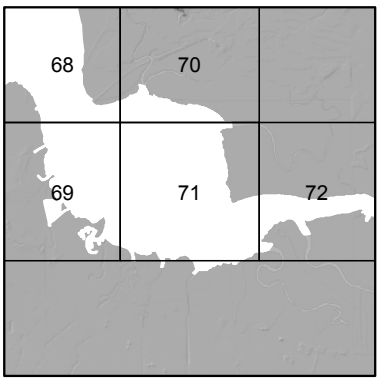

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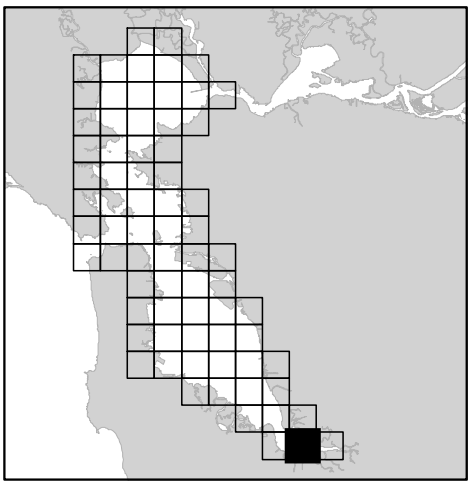
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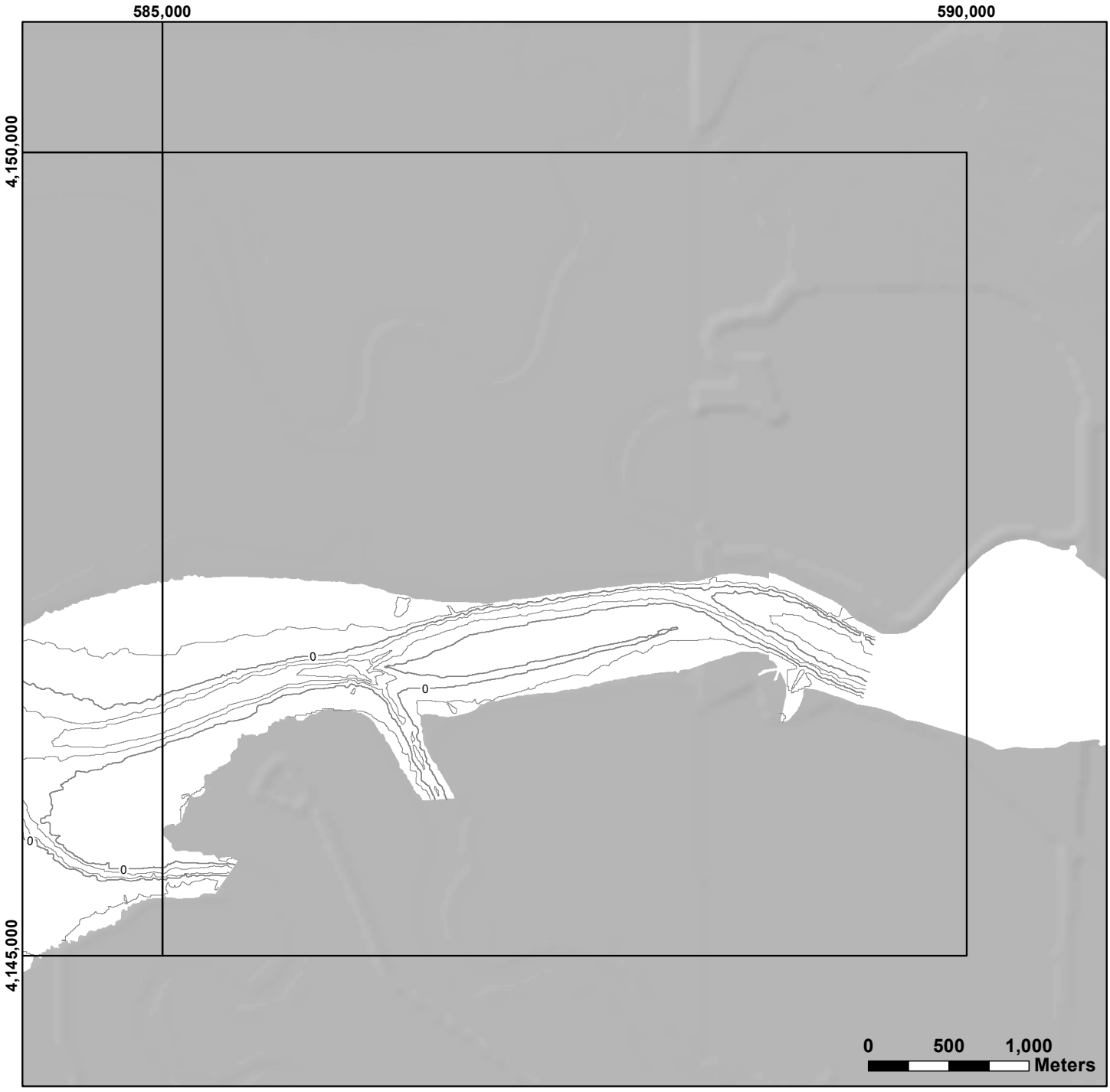





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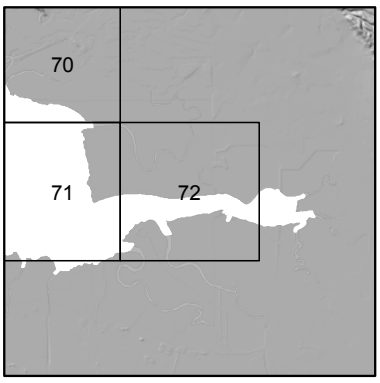

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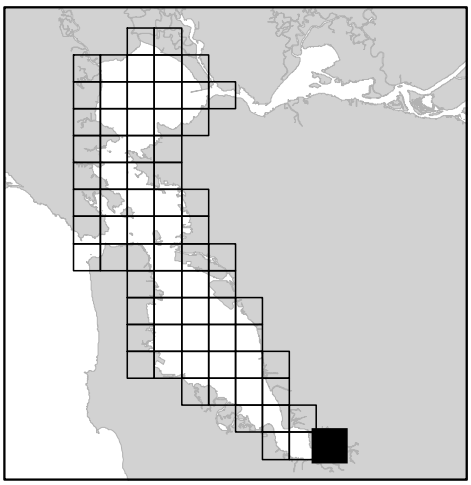
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