T-SHEET USER GUIDE

Application of the Historical U.S. Coast Survey Maps to Environmental Management in the San Francisco Bay Area

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Figures and Tables

Acknowledgments

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Introduction

This guide discusses the historical maps of San Francisco Bay produced by the United States Coast Survey (USCS) and their application to present-day environmental efforts in the region. Under the direction of some of the leading American scientists of the 19th-century, the USCS created exceptionally accurate and detailed maps of the country's coastline. In the San Francisco Bay Area, these surveys (commonly referred to as "T-sheets") are the most important data sources for understanding the physical and ecological characteristics of the Bay's shoreline prior to Euro-American modification. This version (1.0) accompanies new digital and online resources recently made available by SFEI.

Limited Availability To-Date

General use of the early USCS maps of the Bay (1850-1860) has been limited by the lack of a full local repository, the difficulty of acquisition from federal archives, and the unavailability of high-resolution digital files. Additionally, the desire to compare 19th-century and modern features has been hindered by the challenges of accurately georeferencing the historical maps to modern coordinates for use in computerized Geographic Information System (GIS).

Newly Accessible Resources

Data files

To make the USCS maps usable for environmental research and management, SFEI has initiated acquisition, accurate georectification, vectorization, and web site access. This version 1.0 covers the first completed T-sheets, those for South San Francisco Bay. The following kind of files are now available for this set of San Francisco Bay T-sheets:

1. High-resolution, georeferenced scanned images of T-sheets;

2. Vector shapefiles of tidal marsh features digitized from the T-sheets;

3. Detailed metadata describing the technical attributes of each GIS file;

4. Lower resolution images of each T-sheet for use in reports, slide shows, etc.;

5. User Guide providing information about how and why T-sheets were created, their strengths and weaknesses, and potential uses.

Web Site Access

SFEI has also developed a web site that provides access to historical Coast Survey T-sheets as well as several related resources developed by SFEI to support their use in the region. Created jointly by SFEI's Historical Ecology, Wetlands Science, and Information Technology Programs, the *US Coast Survey Maps of SF Bay Web Site* (http://maps.sfei.org/tsheets) now allows these remarkable maps to be viewed in full detail and overlaid on modern aerial photography. GIS files with metadata and JPEG images can also be downloaded. These baseline data will be useful for a range of current concerns, including wetland restoration, shoreline protection, and identifying engineering hazards and potential contamination associated with Bay fill.

The site address is: http://maps.sfei.org/tsheets

The T-sheets and other historical wetland maps are also being incorporated into the Wetland Tracker for the Bay Area, a web-based tool for tracking wetland and stream habitats and projects at http://wetlandtracker.org.

Figure 1. SFEI web site providing access to historical Coast Survey T-sheets.

Current Status of Project

As of Winter 2006, we have completed initial T-sheet data for the South Bay. Additional refinements to the South Bay data, including feature coding and tiling, will be available in early 2006. Georeferencing and vectorization are underway for the maps of the San Leandro Bay-Oakland Estuary shoreline, T481 (Rodgers 1855) and T592 (Rodgers and Kerr 1856). We are seeking funds to complete the rest of the Bay shoreline.

Funders

Alameda Flood Control and Water Conservation District sponsored the development of this User Guide and the two T-sheets for the San Leandro Bay-Oakland Estuary shoreline.

The Santa Clara Valley Water District supported the development of the T-sheet data for the nine maps of the South Bay.

The Santa Clara Valley Urban Runoff Pollution Prevention Program and the California Coastal Conservancy funded refinements to the South Bay data for use in the South Bay Salt Pond Restoration Project.

The City of San Jose funded the website providing access to USCS data.

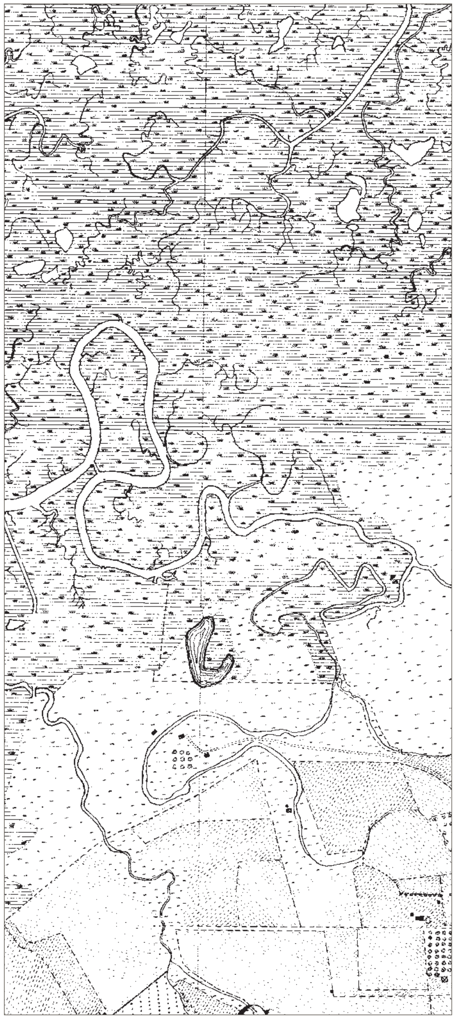


Figure 2: Detail from T-sheet 2313, US Coast and Geodetic Survey (Westdahl 1897).

Executive Summary

The purpose of this guide is to help resource managers, environmental scientists, and planners use the historical United States Coast Survey maps ("T-sheets") of the San Francisco Bay. We explain how and why surveyors, engravers, and printers originally created the T-sheets. We detail the modern-day process of interpretation to create new uses of the historical data. We also explain some of the challenges in using these data which are remarkably accurate, yet unstandardized in several aspects.

Key considerations that we address include:

1) The T-sheets can be valuable tools for environmental restoration, shoreline protection, hazard management, and estuarine research and education.

2) The T-sheets were produced for specific political and economic reasons. Thus they exclude some features and focus on others. Not all maps show the same features.

3) The Coast Survey developed the T-sheets using advanced methods for the times. Geodetic controls accounted for the shape of the earth and points were mapped directly in the field using plane table and triangulation survey methods. In contrast, most mapping of the time simply used a compass to measure angles and a chain to measure distances, without any geodetic controls.

4) Individual surveyors, operating distant from central authority, had substantial responsibility

for determining some aspects of map specifications, such as the level of detail. We describe substantial differences in detail between the several Bay Area surveyors. This variation should be considered when interpreting local maps.

5) One of the basic obstacles in using the T-sheets is the absence of a standardized legend. Based upon our experience, we have created a legend to overcome this obstacle. However, the best way to confirm accurate interpretation of features is always the comparison of multiple, independent historical sources (Grossinger and Askevold 2005). Even at this time, after much change in the landscape, field work is helpful to understand historical maps.

6) Despite their tremendous value, the T-sheets present only a single source of information about San Francisco Bay. They should be used in concert with other sources, especially historical maps and early aerial photography, to maximize understanding about earlier conditions. As noted here, even the T-sheets have gaps in detail and coverage which must be filled by other sources.

Potential Uses of the T-sheets

As the fundamental data source for understanding the physical and ecological characteristics of the Bay shoreline prior to Euro-American modification, the historical T-sheets support a wide range of potential uses. Some examples of ways the vectorized and georeferenced T-sheets have or can be used are described below.

Restoration of Estuarine Habitats

Efforts to improve the ecological health of San Francisco Bay are focused on large-scale restoration of tidal marshes (Goals Project 1999). These efforts can use the georefererenced historical T-sheets in the following ways.

- Determine the absolute and relative distribution and abundance of different intertidal habitats, such as marshes and mudflats. The T-sheets are being used to estimate the appropriate mixture of restored estuarine habitat types for each local watershed around the Bay.

- Determine the location and extent of hydro-geomorphic linkages between watersheds, the intertidal zone, and subtidal environments. The T-sheets help to show to what extent the channels of local rivers and streams used to extend into the subtidal environment, and to what extent the subtidal channels extended into local watersheds. The T-sheets thus provide evidence of the extent to which local watersheds, with restored tidal marshes, might be expected to support anadromous fisheries and maritime commerce without dredging or other channel modifications.

- Determine the appropriate plan-form designs and performance standards for intertidal channels and pannes. The T-sheets have been used to develop construction specifications and to estimate natural evolutionary conditions of channel width, sinuosity, length, and density by channel order, plus the size, abundance, shape, and intertidal location of pannes, in relation to intertidal drainage area and salinity regime. Channels and pannes are especially important intertidal habitats.

- Determine locations of levee breeches. Restoration designs are increasingly looking to breach levees at the historical locations of large channel mouths or confluences. Accurately georectified T-sheets can be used to locate these features in the modern landscape. For example, restoration engineers recently used the georectified T-sheets to set the location of levee breeches for the "Island Ponds" of the South Bay Salt Pond Restoration Project.

- Determine the location and extent of local freshwater gradients. Known relations between tidal marsh form and salinity regime (Grossinger 1995) permit experts to use the T-sheets to identify local salinity gradients that can be restored to enhance biological diversity.

- Estimate the volumes of sediment that the restoration of tidal marshes might generate through tidal scour of historical channels. Large-scale reclamation of tidal marshes caused the remaining channels between the reclaimed lands to shoal and narrow. The T-sheets provide a picture of what the channels will look like if their tidal prism is restored. The T-sheets also show what portion of natural channels is subtidal and how much is intertidal, thus providing a basis for estimating the kinds and levels of ecological services that the restored channels will provide.

Protection of Infrastructure and Shoreline Development

San Francisco Bay is one of the most urbanized estuaries in the world. Almost 85% of the historical marshlands and mudflats has been reclaimed for agriculture, industry, and residential development (Goals Project 1999). Major highways, railroads, pipelines, and communications lines parallel the shoreline of the Bay within the historical extent of the tides. Georeferenced versions of the historical T-sheets can assist in the design, maintenance, and protection of infrastructure and shoreline development in a variety of ways.

- Identify and monitor likely points of legacy shoreline pollution. Dozens of urban landfills and industrial dumps of varying ages, sizes, and contents have been created over the past 150 years on top of historical tidal marshes. The channels of these old marshes represent potential pathways of contaminant movement from the landfills and disposal sites to the Bay. The T-sheets can be used to identify and locate the potential pathways, including places to monitor pollutants along the modern shoreline.

- Identify and locate constraints on shoreline roadways and other linear infrastructure. Levees, highways, railroads, major sewers, major waterlines, fuel pipelines, high-tension power transmission lines, and communications corridors are subject to differential settling and related stresses where they intersect historical shorelines and hidden tidal channels. This can lead to uneven road grades, levee failures, pipeline separations, and general increased costs for maintenance and operation. The T-sheets can be used to identify and locate potential and existing threats to the integrity of linear infrastructure.

- Map seismic hazards. It is well documented that the historical tidal marshes and mudflats are poor foundations for development due to their tendency to amplify seismic waves and to liquefy during major earthquakes. These hazards may be even greater for development on buried sand beaches and large tidal channels. T-sheets have historically been used to identify these seismic hazards associated with Bay fill. The georectified T-sheets will permit planners and engineers to identify places that are especially subject to seismic hazards with greater accuracy and detail.

- Locate areas of potential drainage problems. Groundwater extractions and diversions of surface runoff for agriculture has lowered water tables and reduced the amount of rainwater stored on the land surface adjacent to the Bay. However, as agriculture is being replaced by urban and suburban land uses, local water tables are rising, and many communities around the Bay are experiencing drainage problems. The historical T-sheets, along with other historical sources , contain evidence of high water tables and artesian or emergent groundwater conditions in the uplands adjacent to the Bay. The T-sheets can therefore be used to predict where drainage problems are likely to recur.

- Plan and design engineered crossings and public access for shorelines and tidal channels subject to restoration. Most of the ecological restoration projects for San Francisco Bay include objectives for improved public access to the Bay shoreline. Some of the larger projects involve restoring tidal channels upstream of bridges that were constructed after the channels had narrowed and shoaled due to adjacent reclamation. The georectified T-sheets can be used to design public access facilities that fit within the likely mosaic of restored habitats, and to size bridges according to the likely width and depth of the restored channels that they must cross.

Education and Research

The historical T-sheets are the essential dataset for studying and illustrating changes in intertidal landforms and adjacent landscapes around San Francisco Bay, having been used by researchers for decades. The California State Lands Commission uses the T-sheets in legal delineations of lands of Public Trust. Landmark scientific studies of intertidal processes in the Bay were illustrated with T-sheets (Gilbert 1917, Atwater *et al.* 1979). Reports on the changing distribution and abundance of intertidal habitats have referred to the T-sheets to estimate historical conditions (Dedrick 1993). Efforts to restore the Bay have attempted to use the T-sheets to guide restoration design (Josselyn *et al.* 1982, Goals Project 1999). However, partly because of their inaccessibility, they remain a largely untapped resource for research. A few of the potential uses of the T-sheets in research and education are described below.

- Determine spatial patterns and locations of shoreline erosion and accretion. Expert analyses of the historical

T-sheets reveals that some reaches of shoreline were eroding and other reaches were accreting during the time of the first survey. Georeferenced versions of the T-sheets can help identify shorelines that might be naturally prone to erode and those that tend to accrete. This may help to locate concentrations of pollutants that tend to be deposited with inorganic sediment. Spatial patterns of deposition as indicated by the T-sheets may also help determine the importance of local watersheds as sediment sources, relative to the Delta throughput of suspended sediment.

- Develop regime equations for tidal marsh channels. The existing regime equations that relate the plan-form metrics of intertidal channels to tidal prism were derived from natural and restored sites that are smaller than many of the proposed restoration projects. The historical T-sheets contain all the information needed to predict natural plan-form characteristics for any size channel based on tidal prism and marsh age.

- Recover indigenous land use and traditional ecological knowledge. Indigenous peoples were successfully managing the Bay Area landscape for thousands of years. Careful studies of the historical T-sheets have revealed features, such as straight creeks, large intertidal ponds, and large stands of willows, which may be signs of indigenous land management practices. The georectified T-sheets, in combination with anthropological data linked to a GIS, will help understand the traditional relationships between landforms and land use. This will enable planners to test the efficacy of indigenous land use for maintaining restored ecosystems.

- Visualize landscape change through time. The public has shown a keen interest in the environmental history of the Bay Area. The T-sheets can be a valuable resource for a diverse range of educational ventures. For example, the recently published SFEI-Oakland Museum map *Baylands and Creeks of South San Francisco Bay* uses the T-sheets to show a detailed picture of the historical South Bay marshlands. Also, now people who live near the Bay can use the T-sheet web site to locate their home sites on the georeferenced T-sheets.

Original Purpose and Techniques

The USCS maps are remarkably accurate documents for their era. However, as with any historical data source, accurate interpretation depends largely upon understanding the inherent characteristics of the document. Elsewhere, we have recommended understanding three basic aspects of historical documents: the social/personal context; the methods or techniques used to create the document; and its timing in relation to previous and contemporary land use (Grossinger and Askevold 2005). This section provides this context for interpreting information from the Coast Survey maps of the Bay.

Agency Context

The Coast Survey maps provide the best early pictures of coastal and estuarine habitats prior to substantial Euro-American modification. Tidal channels depicted on these early T-sheets of San Francisco Bay are extremely detailed and accurate (Askevold 2005; Grossinger and Askevold 2005). When georeferenced and overlaid with aerial photography, the T-sheet channels correspond closely to remaining channels (Figure 3).

The Survey of the Coast was established in 1807 by Thomas Jefferson and assigned the responsibility of "completing an accurate chart of every part of the coasts" (Shalowitz 1964). The Survey of the Coast became the U.S. Coast Survey in 1836; was renamed the U.S. Coast and Geodetic Survey in 1878, when the agency began establishing a geodetic

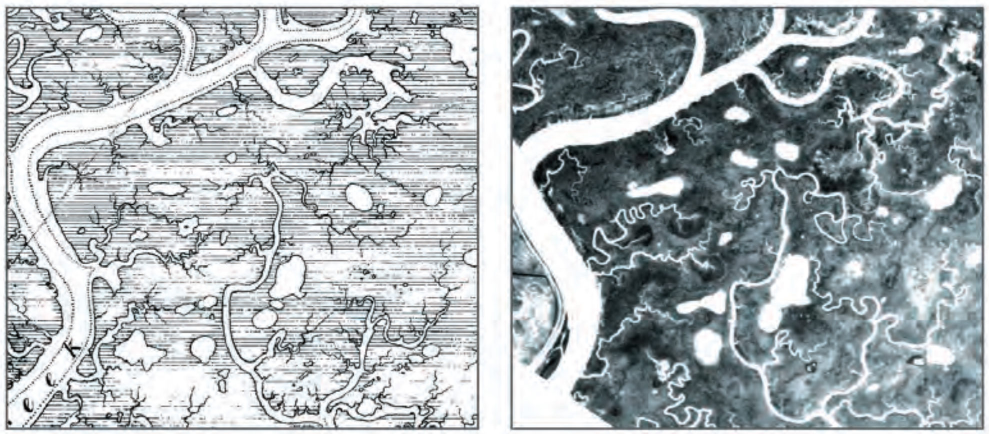


Figure 3. Comparison of US Coast Survey Topographic Sheet T817 (Rodgers and Kerr 1860) to 1955 aerial photograph at Petaluma marsh, Sonoma County. Comparison of corresponding features shows that the map closely represents most of the sloughs and pannes visible in the photograph. Much of the apparent differences can be attributed to natural processes operating during the 95 years bracketed by the two images.

connection between the two coasts; and since 1970 has been part of NOAA as the National Geodetic Survey (Edney 1986; Shalowitz 1964).

The Coast Survey was established in part for defense of the coastline, but the most pressing reason was the need for accurate navigational charts for safe passage of ships carrying foreign trade and commerce between states. Until the transcontinental railroad was completed in 1869, coastal ports and waterways were the only viable way to move freight and passengers from place to place. There were no buoys, lighthouses, or nautical charts, and shipwrecks were common and costly (Shalowitz 1957). Additionally, the military and pioneering settlement needed maps for both safe navigation and a better understanding of a local coastlines (Manning 1988). Commercial needs ultimately pushed the funding forward, while the information for military use provided Congress with the constitutional basis for funding (Dupree 1986).

Jefferson—who himself had a keen interest in both science and precise measurements (Linklater 2002)—appointed Ferdinand Hassler as superintendent of the survey of the coast. Hassler was a Swiss engineer brought to the United States in 1805 by the U.S. Military Academy at West Point to teach mathematics (Thompson 1979). Hassler embraced modern mapping techniques, having applied the latest theories when working as a surveyor in Europe (Guthorn 1984). When asked to develop a methodology for the survey, Hassler proposed an approach that incorporated geodesy—the accurate measurement of the size and shape of the earth—with topographic and hydrographic surveying (Thompson 1979). Hassler was a visionary who sought to bring the most exacting standards of science to the Coast Survey, but was not adept at the political maneuvers required to ensure support for the agency.

Congress was already reluctant to fund any comprehensive mapping program (Edney 1986). Though it seems fairly obvious that a systematic program to map coastlines and the nation's interior would be beneficial to 19th century America, Jefferson and Congress both were concerned about the constitutionality of any federal program. Additionally, the War of 1812 diverted the nation's attention and resources; the equipment and personnel to carry out the European-based scientific method of mapping proposed by Hassler were not available in the United States, making the task seem daunting (Theberge 2001).

Though coastal charts were urgently needed for safe navigation, lack of support by Congress, ambivalence about the need for a federal mapping program, and the painstaking science-based approach taken by the Coast Survey almost resulted in the agency's elimination several times. The Coast Survey was never intended to be a permanent agency, but rather was expected to be dismantled once the coast was surveyed. Edney (1986) argues that both the Coast Survey and the U.S. Geological Survey were established through *ad hoc* legislation in Congress and individual efforts, and not by any accepted notion that a comprehensive mapping *program* should be funded by Congress.

The motivating force within the Coast Survey and by individuals participating in the mapping efforts was competition with Europe in use of the latest scientific techniques. When the Coast Survey was first established by Thomas Jefferson, the practice of geodetic mapping in the U.S. was nonexistent and science in general was in an unsophisticated state when compared to European practices (Dupree 1986). Jefferson envied the large-scale and precise surveys made by France and Great Britain and while Coast Survey's immediate purpose was to provide charts for safe navigation, Jefferson also had in mind establishing a scientific agency that would rival European efforts (Linklater 2002).

Individuals and Map Variation

In 1857, the Coast Survey was still establishing itself as an agency and still developing standardized methods and procedures. The decisions the directors and assistants made affected the direction of the agency's work and decisions made in the field affected the contents of any given map.

Much is written on the supervisors of the Coast Survey, and extensive information is available for the first two directors Ferdinand Hassler and Dallas Bache. Coast Survey directors were invariably scientists interested in pursuing the astronomy, hydrography, geodesy, tidal-related studies, and terrestrial magnetism related to surveying, and in keeping the Coast Survey at the forefront of science (Slotten 1993). Less is available regarding the various assistants, though notable assistants such as George Davidson have been more widely considered (see Lewis 1954 and Manning 1988). Even less in known about the aids, many of whom worked several seasons at relatively low pay before disappearing from Coast Survey accounts.

In the first decades of the agency's operations, all Coast Survey employees—except those involved in administrative duties and printmaking activities in the Washington, D.C. office (see U.S. Coast Survey, 1857c)—participated in field work. Supervisors Hassler and Bache both measured baselines and made angle measurements with the theodolite. Hassler died in 1843 from pneumonia after suffering a fall when protecting surveying equipment during a storm (Dupree 1986). Bache was involved in supervising field operations on the east coast, especially the measurement of baselines, and though he was never directly involved in field work on the West Coast, he fine-tuned efforts through correspondence and direction to his assistants (Lewis 1954).

Coast Survey aids worked in the field with the assistants and sub-assistants. Field work was rigorous and often dangerous. James Lawson, who arrived on the West Coast as an aid to George Davidson (who was then a sub-assistant) in 1850, recorded his experiences in an autobiography (Lawson 1879), and his account may be considered typical of the experiences an aid faced in the field. Lawson arrived by ship—after passing through Panama in a canoe with all the Coast Survey equipment—in San Francisco, where the Coast Survey could ill afford the highly inflated Gold Rush wages, housing, and food. While each of the aids received only $30 per month, the cook they hired for field work received $125. Lawson describes field work in detail, describing various hardships and difficulties from West Coast weather, stormy seas, a Native American community suspicious of the Coast Survey motives, and repeated illness (Lawson 1879).

Individual surveyors working in the field—from superintendents to aids—had significant impact on the final product, despite attempts to standardize procedures and methods. Differences in the level of detail on surveys can be attributed to a number of factors, including the urgency of the survey, the preferences of individual surveyor, and the relative importance of the area being mapped. One Coast Survey employee argues that such an "elastic system" for standards of accuracy was not practiced (Maher 2004); however, Shalowitz suggests areas considered relatively unimportant were mapped to a lesser degree of accuracy. "To have surveyed every then unimportant creek or slough with the same degree of detail as was included in surveys of an important river of harbor," notes Shalowitz, "could not have been justified administratively or otherwise" (1964).

Historical Setting

In 1857, the San Francisco Bay Area was in transition between several cultures and economies. The Spanish missions had effectively decimated much of the Native American population and culture. However, small communities of Native Americans, often of mixed tribes, existed in the 1860s scattered throughout Northern California (Margolin 1978). Though no longer controlled by either Spain or Mexico, the area still was culturally influenced by the former ruling classes and shaped by many of the area residents, who were of Hispanic heritage. The region's economy, which had been limited to cattle ranching for hides and tallow, and rudimentary agriculture for local consumption, had exploded during the Gold Rush. The Bay Area's population—restricted to non-foreign born by the Spanish—had grown exponentially during the Gold Rush. The San Francisco Bay saw little activity as a harbor until the Gold Rush, but shipping traffic rose dramatically with the sudden influx of population (Lewis 1966).

Congress was relatively slow to respond to the rapidly changing and rather urgent situation. California was ceded to the United States from Mexico by the Treaty of Guadalupe-Hidalgo on February 2, 1848, and the United States acquired California for $15 million (Hosen 1988). Even prior to this—no doubt in anticipation of this event after the annexation of Texas by the United States in 1845—Superintendent Bache suggested in his reports to Congress that surveying parties be sent to the Pacific (Theberge 2001). Early in 1848—before President Polk's announcement in December of that year set off the gold rush—Congress agreed with Bache, and the Coast Survey sent a party to begin the survey of the West Coast.

In many respects, the survey of the West Coast began too late for the safety of American ships and interests. The massive migration touched off by the discovery of gold brought intense economic forces to bear on the area, and the U.S. had not yet fully gained control of the area (Cutter 1999). Hundreds of ships ventured into San Francisco Bay without the benefit of accurate charts, and shipwrecks were numerous and frequent (Lewis 1954). Vancouver's charts from 1798 guided some; others used maps torn from school atlases; William Beechey's map from 1826 was used by some; and others were fortunate to use more recent maps prepared by the Wilkes expedition in 1841 (Lewis 1954). However, none had the benefit of the lighthouses, buoys, markers, and detailed charts that would ultimately result from the Coast Survey work.

The Gold Rush made the survey of the West Coast an immediate priority for commerce and safety, though ironically, the Gold Rush made it virtually impossible to hire the required crew (Theberge 2001). The upsurge in population during the Gold Rush strained the area's resources and infrastructure. Many of the immigrants arrived by ship; all required goods and supplies transported by ship. The Coast Survey employees arrived as the Gold Rush made resources scarce (Lewis 1954).

Methods and Techniques

Early in the 19th century, science as it is known today did not really exist. Science was not separate from philosophy, the arts, or literature, and there were no professionals, specialization, training available, or boundaries between theoretical and applied science (Dupree 1986). Additionally, things we take for granted—such as consistent units of measurement and accurate reckoning of longitude—are relatively new advances. For example, as late as 1789, less than 20 years before the Coast Survey was established, land was often measured in France by a variable unit called journées, which was the amount of land one man could plough in a day (Linklater 2002).

From its inception, the Coast Survey used highly accurate methods and the latest science-based techniques to map the coast and shorelines (Manning 1988). The agency adopted a rigorous approach to mapping that included developing geodetic controls (taking into account the shape of the earth); plane table surveying and triangulation in the field; and such innovations as geomagnetic measurements and use of the telegraph to determine exact longitude (Shalowitz 1957). Each of these is discussed more fully below.

Geodesy. Without taking the curve of the earth into account, independent but adjacent surveys would not fit together at the edges, and discrepancies as to size, scale, and shape would be evident. A coordinated survey using geodetic controls employs a horizontal geodetic datum and a single point from which all other positions are tied to. Datums-—the algorithms used to calculate the shape of the earth-—change as geodesists develop a new understanding of the earth's shape and the varying density of the earth's crust (Shalowitz 1957). While we currently use the North American Datum of 1983, which replaces the datum developed in 1927, the pre-1927 Coast Survey maps were based on even earlier measurements. Though determining this datum can present problems when georeferencing pre-1927 Coast Survey maps, the early Coast Survey maps show remarkable consistency and accuracy because a systematic method of measuring the earth was used.

Plane Table Surveying. Most early surveying in the U.S. used a compass traverse method, in which each corner of the area of interest was used to measure the angle to the next station, and a metal chain was probably employed to measure the distance between stations (Uzes 2005). Writing about 19th century property surveying, Hilliard notes that surveying involved the following steps—"laying out a tract of land, locating and marking the corners, running lines by compass direction to connect all corner, measuring the lines, and calculating the acreage of the tract" (Hilliard 1982). A rough sketch may have been made of the survey, but the final map was usually made from the survey notes indicating compass direction and distance (Greenhood 1964).

Unlike the compass traverse method, the Coast Survey used a plane table (Figure 4) combined with the geodetic tie points, to survey an area. A plane table is simply a drawing board—usually about 30 by 24 inches in size—that sits on a tripod and can be rotated and leveled. An alidade—which resembles a telescope on top of a compass and allows the surveyor to measure angles—is mounted on top of the plane table.

The surveyor worked in the field with the plane table (Figure 5), attached alidade, and a field survey sheet marked with the available triangulation stations (Shalowitz 1964). The field team would locate one of the triangulation stations, placing the table directly on top of it, and orienting the plane table so that features on the field survey sheet would line up with and be parallel with the features in the landscape (Shalowitz 1964). A distant triangulation station would be located in the sights of the alidade, which sits on a ruler that corresponds to the direction the alidade is pointed, and the two stations would be connected with a line on the map. Undetermined points would be located in a similar way—i.e. features lined up within the sights of the alidade, with a line drawn to their location. The actual geographic locations were determined through triangulation,

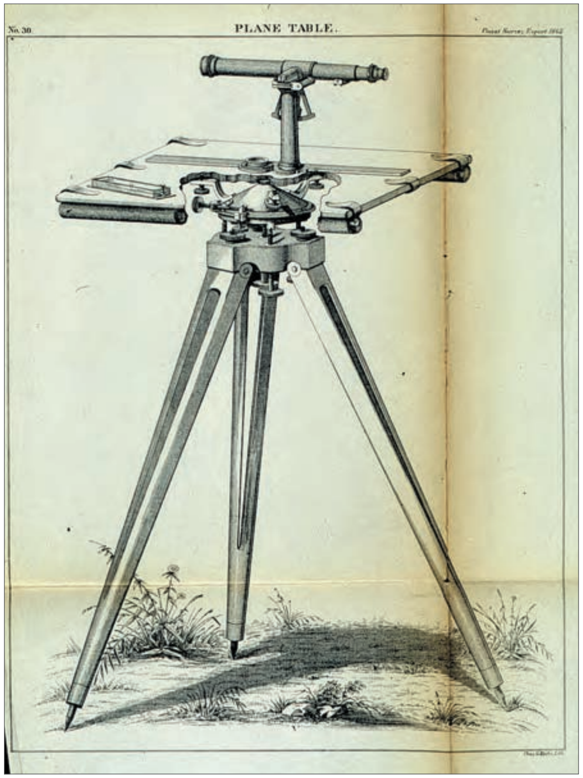


Figure 4. Plane table. The 1865 Superintendent's report included a diagram of plane table with cutaway showing tripod head, which allowed the table to rotate and level independently of the tripod. The alidade is mounted on top, with a ruler for establishing lines. (U.S. Coast and Geodetic Survey 1865).

when the plane table was moved to the second triangulation station, and all the undetermined points were connected with a third line (Figure 6). To map a coastline, the plane table surveyor was assisted by another Coast Survey employee who would walk along the shoreline and set a rod when the shoreline changed direction. The plane table surveyor would align the rod with the alidade and draw in the corresponding line, and the shoreline in between would be sketched on the map (Shalowitz 1964).

Using the plane table in this fashion, the surveyor had the advantage of completing the map in the field, while all the features being captured were still visible (Denny 2000). In instructions on plane table mapping, published in the 1867 superintendent's report, notes that "sketching and plotting in the office from notes, unless the country be near at hand for reference in the case of doubt of a defective sketch, is objectionable" (U.S. Coast Survey 1867). Because all angles and distances were transferred immediately to the field sheet, there was usually no record of the measurements—especially on the earlier maps—and field notes were not typically kept (Shalowitz 1964). This had "regrettable consequences for historians", who might have found useful information in the field notes (Allen 1997).

The Coast Survey adapted and developed innovative methods for accurately completing the surveys. While the chain had commonly been used as a measuring device in the field, there were several concerns that made it less than ideal, as sources of error could be introduced when the chain stretched, pacing instead of measuring was occasionally substituted, and chaining required additional employees to both make the measurements and check the results (U.S. Coast Survey 1867). The 1867 report notes that "care should be exercised in the selection of intelligent chainmen...[as the] correctness of the survey in a great measure depends" on their measurements (U.S. Coast Survey 1867). To largely replace the problematic chain as a measuring device, the Coast Survey was an early adapter of the telemeter, a wooden rod about 10 feet long with graduated numbers painted on the surface that could be sighted through the alidade (Shalowitz 1964). The use of the telemeter reduced the time measurements took, the number of employees required, and could be used where the chain was not practical (U.S. Coast Survey 1867).

Figure 5. Coast Survey plane table mapping. The surveyor is using the plane table on an offshore rock in Cook Inlet, Alaska, circa 1910. The alidade can be seen on top of the surface of the plane table (U.S. Coast and Geodetic Survey c. 1910).

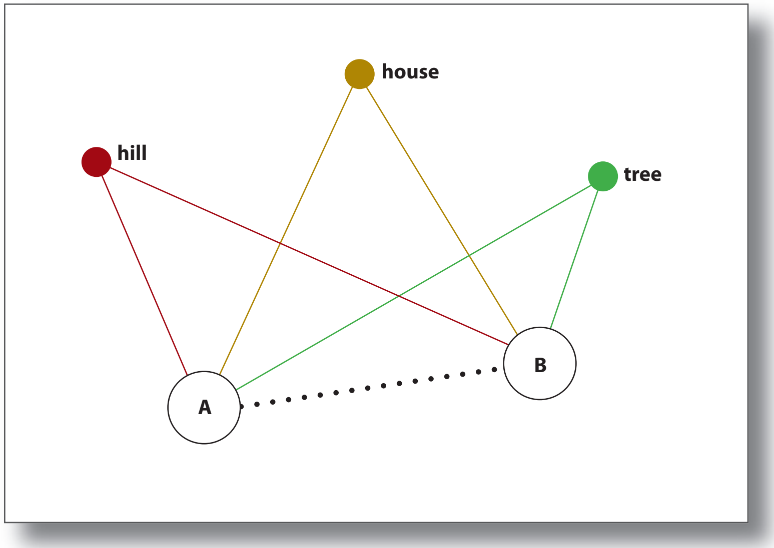


Figure 6. Example of plane table mapping. The surveyor would place the plane table directly over a triangulation station (A) and locate the second triangulation station through the alidade (A to B). From station A, the surveyor would use the alidade to draw lines to the features to be mapped (such as the hill, house, and tree, above). Then, moving to station B, the surveyor would draw lines to the same features, creating a triangle. Triangulation operates on knowing the length of one side of a triangle—the distance between A and B). The angles of the other sides of the triangle are measured, and then the lengths of the other sides are computed.

The telemeter was widely accepted by 1865, though it was used by Coast Survey employees earlier (Shalowitz 1957).

Making accurate longitude measurements had been problematic for map makers through the first half of the 19th century. In theory, because longitude was known at the Greenwich Meridian, it could be measured by comparing local time to the time at the Greenwich Meridian and then converting the time difference into degrees (Stachurski 2003). In theory, these measurements were accurate with possible errors of +/-0.50 seconds, though in reality these errors were often larger (Stachurski 2003). In 1846, Bache began directing experiments to use the telegraph to determine longitude, rather than chronometers or lunar measurements (Shalowitz 1964, 19). Use of the telegraph proved highly accurate, and the new technique of measuring longitude became known as the "American Method" (Stachurski 2003).

While using the telegraph for longitude was a regular part of Coast Survey work on the East Coast by 1856, because it entailed considerable infrastructure, the telegraph was not used on the West Coast for Coast Survey measurements until 1869 (Stachurski 2003). It was not part of the methodology used during the first set of Bay T-sheets in the 1850s, though it would have been employed at the time of the Coast Survey re-surveys in 1897. Assistant Supervisor Schott described the measurements he made before and after the telegraph was employed and notes that the early longitude of Telegraph Hill was three-quarters of a mile westward of where it was found to be once the telegraph was used. "Thus the country was considerably wider than had been known before the advent of the telegraphic method," he notes (U.S. Coast Survey 1897).

Printing Processes. Unlike manuscript maps, which are single copies of maps never printed, the Coast Survey maps were printed on a press, making multiple copies available, and the choices the Coast Survey made about reproducing its maps are indicative of both the careful attention to detail and innovation methods practiced by the agency (Shalowitz 1964). Printed maps required cooperation between the cartographer and the printer, and Robinson notes the advantage of multiple map copies through publishing meant the cartographer had to submit his work to the compromises introduced by someone else engraving and printing the map (Robinson 1975). The Coast Survey controlled all steps of mapmaking from initial authorship to production and publishing, which meant some of the potential conflict between the cartographer and printer was lessened.

From the inception of the agency, the Coast Survey maps were engraved on copper plates, constraining their production to a limited print run for each engraving. The delicately engraved lines on the copperplates could only withstand perhaps 500 to 2000 impressions before they required re-engraving. Guthorn refers to this process as "slow, laborious, and cumbersome...[resulting in] maps with intricate detail from nearly microscopic size to large lettering, fine to heavy lines, tone variations, and great character" (Guthorn 1984). Copper plate engraving entailed use of sharp tools to incise the surface of a smooth copper plate. The surface was coated with ink; the ink was wiped from the plate except for where it remained in the engraved recesses of the plate; a slightly damp printing paper was placed on top of the copperplate; the plate and paper was run through rollers to exert tremendous pressure and imprint the ink in the incised areas onto the paper. The next print required the process be started over with the inking of the plate forward (Guthorn 1984).

This was a tedious and costly method of printing, and the Coast Survey experimented with various techniques for reducing the inefficiencies of this process while still maintaining the high standards afforded by engraving. By the early 1850s, the agency was successfully combining copperplate engraving with a process called electrotyping, in which a cast was made of the plate (Harris 1975). This innovation made it possible to print from a raised surface, and imbed type, rather than engraving type into the plate (Harris 1975, 131). Guthorn suggests this was primarily used for preliminary charts that were bound into the annual superintendent's reports and not for final charts, which remained printed by traditional copperplate engraving (Guthorn 1984). After the Civil War, the agency also experimented with photomechanical printing (Harris 1975).

Explanation of Features

Conventional symbols on Coast Survey maps were not standardized until the early 20th century, though many attempts were made to make the use of symbols consistent (Shalowitz 1964). In 1840—over 30 years after the founding of the agency—the Coast Survey published a standardized legend, though this was only for cultural features (Allen 1997). The symbols on the topographic maps continued to vary even after the 1840 standard symbol set was published, and in 1860, the Coast Survey issued a new set of standards for symbols.

Though many maps used legends and standardized symbols, they were not a universal cartographic practice at the time. However, given the meticulous control of Coast Survey mapping tasks, the lack of a standardized symbol set seems surprising (Allen 1997). Early Coast Survey mappers were given little direction for keys or legends; individual surveyors may have been experimenting with symbology on map sheets (Allen 1997), and it is plausible the West Coast surveyors developed their own set of symbology to depict unique or wide-spread features.

Despite the variations between individual map sheets and between map sets over time, maps that were drafted by the same group of cartographers in a specific geographic area often use the same symbols, and these can be interpreted as a set. For example, between 1854 and 1857, three Coast Survey employees mapped over 100 square miles of tidal marshland around San Francisco Bay. On T-sheet 676, Kerr depicts salt marshes with a series of closely drawn parallel lines, though the standard already used widely and adapted as a standard by the 1860 incorporates tufts of grass at regular intervals along each line (Figure 7). By 1865, symbols became more standardized through instructions provided to survey employees and appended to the annual report (U.S. Coast Survey 1865).

The following retrospective map legend was created by SFEI based upon many comparisons of US Coast Survey depictions to other historical sources (Figure 8 and Figure 9). This process of intercalibration, in combination with the references described above, has helped us interpret T-sheet depictions. However, the best way to interpret the T-sheets, or any other historical map, remains to compare it with other early maps of the same area to provide independent verification or corroboration of feature presence, size, and location.

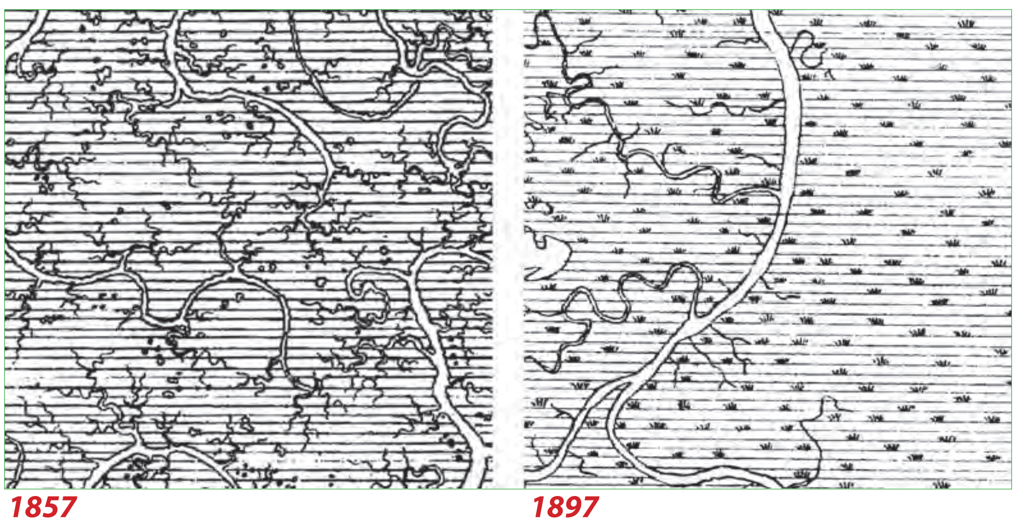
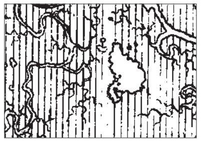
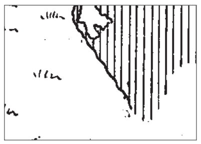


Figure 7. Variation in salt marsh symbols. On T-sheet 676, in 1857, Kerr depicts salt marshes with a series of closely drawn parallel lines. By 1897, on T-sheet 2313, Westdahl incorporates tufts of grass at regular intervals along each line (Rodgers and Kerr 1857a; Westdahl 1899).

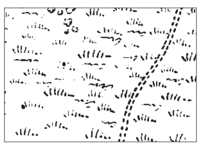
Figure 8. ***Symbols and interpretation, U.S. Coast and Survey map T676, 1857 (Rodgers and Kerr 1857a)***



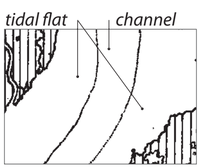
Tidal marsh pattern. Tidal marsh is indicated by closely spaced parallel lines (without tufts of grass); sloughs and channels running through the tidal marsh are drawn with double or single lines; pannes are depicted as round or irregularly shaped, enclosed features.



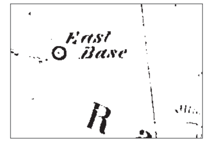
Tidal marsh–upland interface. On early local Coast Survey maps the line between the tidal marsh and uplands is indicated in one of two ways. In most cases, a solid line is used to separate the tidal marsh from other features. When the tidal marsh is at the outermost edge of the survey, the parallel lines of the tidal marsh simply cease.



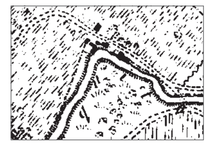
Grassland. Grassy upland areas adjacent to the tidal marsh were depicted with a symbol representing tufts of grass. Note the road, indicated by double dashed lines, cutting through the grasslands. Several trees are shown at upper left.



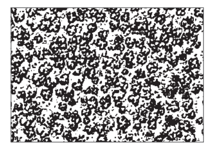
Tidal flats and MLLW. Tidal flats are shown on either side of the deeper channel, distinguished by a series of very closely spaced dots indicating MLLW (mean lower low water).



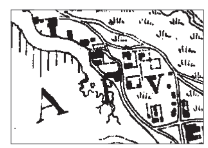
Triangulation stations. Primary triangulation stations are shown on early surveys as a circle with a dot in the middle; secondary triangulation stations are shown as a triangle with a dot in the middle.



Cultural features. Buildings are shown as solid rectangles; steep banks along the creek are depicted as closely spaced hatches; a field crop is indicated with broken parallel lines; roads are shown as parallel dashed lines.

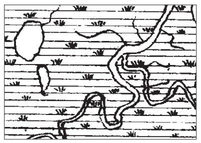


Forest and trees. Early Coast Survey maps depicted a few wooded areas close to the tidal marsh. The dense pattern here indicates a sausal or a grove of willow trees. The same symbol can represent live oak, valley oak, or other trees in other places.

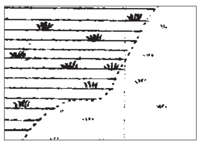


Landings. Landings—where a large tidal channel came close to land and infrastructure was established for shipping—are shown on the Coast Survey maps with roads, levees, and buildings at the edge of or jutting into the tidal marsh.

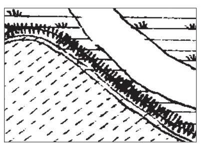
Figure 9. ***Symbols and interpretation, U.S. Coast and Geodetic Survey map T2313, 1897 (Westdahl 1897)***



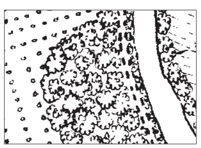
Tidal marsh pattern. Tidal marsh is indicated by straight lines with tufts of grass; sloughs and channels running through the tidal marsh are drawn with double or single lines; pannes are depicted as round or irregularly shaped enclosed features.



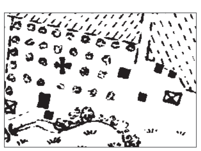
Tidal marsh–upland interface. The line between the tidal marsh and upland is indicated here with a dotted line separating the two. A dotted line is used because of the indistinct, gradual nature of the boundary in this flat area.



Levees on the tidal marsh. Levees were built in early attempts to reclaim tidal marsh for agriculture. Levees are depicted by closely spaced hatches following a central line.



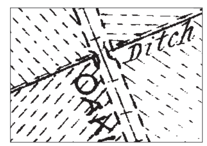
Riparian areas along creek. Trees along a creek are depicted with clusters of tree symbols on either side of the creek. Note crop symbols beyond riparian area and dashed double lines indicating a road along creek.



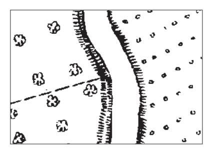
Buildings and structures. Houses are typically depicted as rectangles with a solid fill; outbuildings are open rectangles with a 'X' in the center. A windmill is indicated by a solid thick cross symbol.

Landings. Landings—where a deepwater channel came close to land and infrastructure was established for shipping—are shown on the Coast Survey maps with roads, levees, and buildings at the edge of or jutting into the tidal marsh.

Towns. Shown here are houses and buildings in Milpitas. Significant structures are shown as solid rectangles, and lesser structures are depicted with 'X's in the center. Windmills are shown as heavy cross symbols; railroad line runs vertically on right side.



Railroads. Railroads are shown as lines with widely spaced hatches. Shown here, the railroad crosses a ditch; a bridge is indicated by two back-to-back curved lines.



Levees along creek. Early levees were built to contain flooding on the lower reaches of Coyote Creek. In the resurveys, closely spaced hatches along creeks represent levees.

Surveyor Variability in the Depiction of Landscape Features

In addition to the technical concerns about geodesy of the T-sheets and their spatial accuracy, an important basic question is what natural features of the landscape they depicted and how well. In this regard, we have found that the earliest T-sheets of the USCS vary both within and among the survey parties working within the Estuary. Even the most accurate survey party did not always map all the ecologically significant detail. But the most accurate maps can nevertheless serve as an adequate baseline from which historical, local changes in the intertidal zone of the Estuary can be assessed.

All the T-sheet survey parties depicted the plan forms of the major features, such as the largest sloughs and pannes, with remarkable accuracy. The best maps appear to accurately show the number and extent of all the channels large and small, but the plan form of the smallest channels is less precise. No maps show all the pannes. Natural waxing and waning of the foreshore of remnant marshlands prevent any quantitative assessment of its historical representation, although it seems to have been a major focus of all the survey parties. Despite this focus on the foreshore, its sandy beaches were not always mapped. Some of the T-sheets do not extend landward to the backshore of the marshlands. It is evident that the variability in geomorphic accuracy within and among the survey parties should be understood before they are used in land use planning and management.

Variability among the Surveyors

Of the 27 T-sheets comprising the original survey of the Bay, the five earliest ones are not signed and thus are not attributable to any one person, or chief surveyor. These earliest T-sheets also primarily pertain to the early commercial ports with relatively steep shore terrain and correspondingly little marshland. Of the subsequent twenty-two T-sheets, twenty-one are attributed, either singly or in concert, to two surveyors, Augustus Rodgers and David Kerr, and one is attributed to A. M. Harrison. Because of the large body of potentially useful work by Rodgers and Kerr, our efforts to understand mapping variability related to surveyor focused on their T-sheets.

As discussed earlier, individual surveyors could interpret there assignments differently, particularly in the earlier years of the Survey. All three chief surveyors dutifully represented the boundaries of large features covering hundreds or even thousands of acres, such as shallow bays, tidal flats, and tidal marshes. These surveyors also consistently represented the largest channels, of fourth- to sixth-order. However, it is apparent that each survey party mapped a different suite of landscape features, and in some cases they depicted the same features differently.

At the same time, survey detail is generally consistent among the different maps made by a single surveyor. Those of David Kerr are particularly consistent, which is fortunate since he made the most maps of the region. However, as an aide pressed into service because of short staffing, he often received only secondary credit (Askevold 2005). Table 1 shows the results of a qualitative comparison of the survey parties, based upon the contents of their T-sheets. Several comparative examples are shown.

Table 1. Landscape features mapped by different US Coast Survey Parties in the S.F. Bay, 1850-1860.

Survey Chief	Large Channels	Small Channels	Pannes	Beaches
Rodgers	yes	sometimes	mostly not	yes
Kerr	yes	yes	yes	yes
Harrison	Yes	?	yes	no

At Angelo Creek, a map by Kerr overlaps the earlier map by Rodgers, providing a single direct comparison of the two surveyors (Figure 10). In this case, both surveyors show all of the major features in similar detail, but Kerr shows more of the minor features.

At another site, a 1920s-era low altitude, oblique aerial photograph provided an unusually high-resolution comparison to Rodgers 1854 survey of San Leandro Bay (T481; Rodgers 1855). All the major channels are clearly and similarly represented in both images. However, the photograph also shows that pannes of various sizes are common in the marsh, while Rodgers map shows no such features in this same area. Rodger's omissions, if

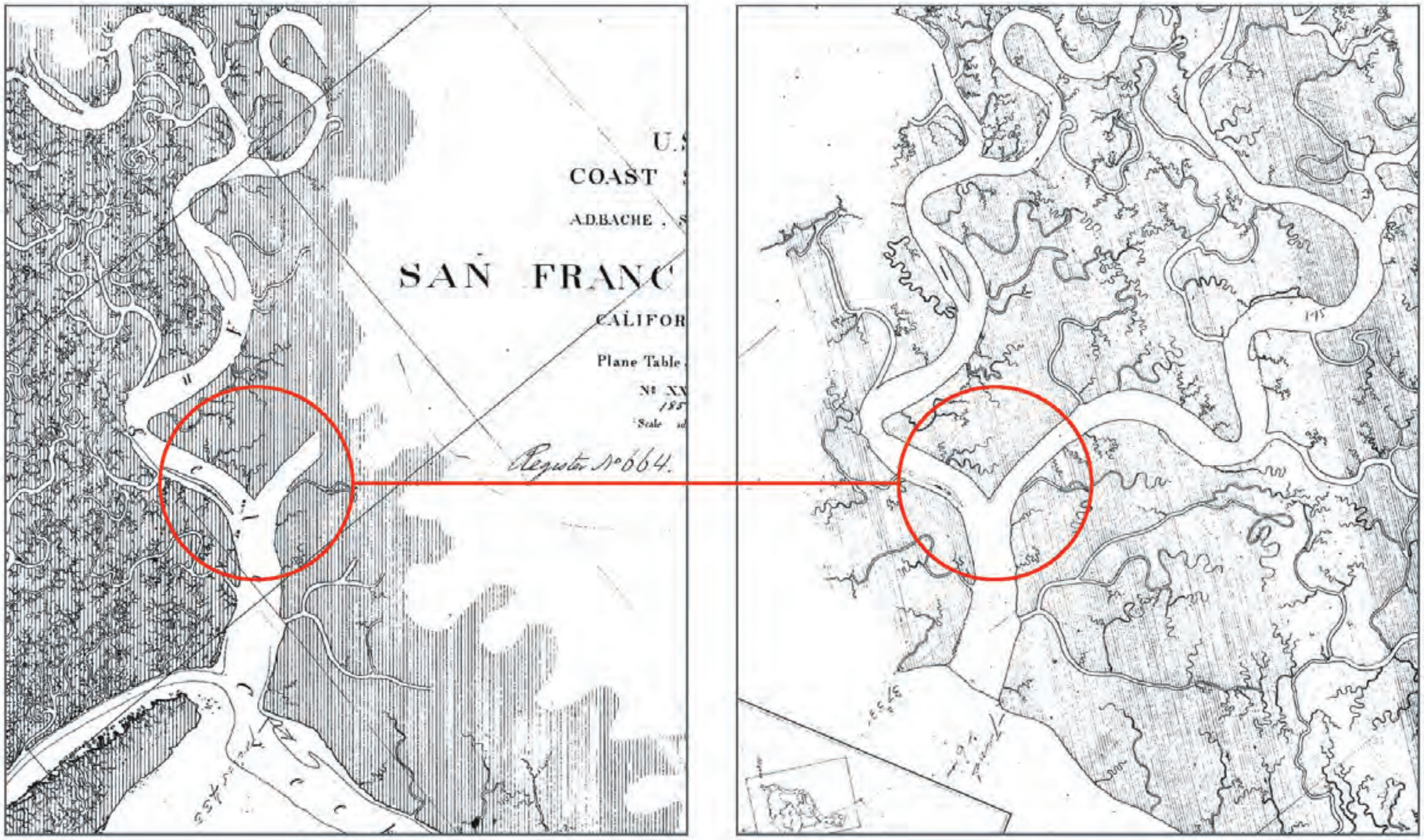


Figure 10. Variation in detail between USCS surveyors. The survey on the left (Rodgers and Kerr 1857b) adjoins the survey on the right (Rodgers 1853) at Angelo Slough in the vast tidal marshlands of San Mateo County. While the overlapping information corresponds closely, Rodgers shows only the larger sloughs while Kerr depicts numerous pannes and smaller sloughs (after Grossinger 1995).

not recognized, could severely bias any assessment of the natural geomorphic form of tidal marshlands in this Estuary.

Kerr consistently mapped the smaller channels and pannes, as well as the larger features, at many other sites of comparison. When maps by Kerr are compared to modern photographs (see Figure 3), there is a high degree of similarity for many features, such as channels and pannes of large and medium size. There is substantial but less similarity between the images for smaller channels, as would be expected given their natural dynamics and rapid rates of change.

We also found several square miles of overlapping portions of T-634 and T-635 that represent a resurvey by Kerr. Numerous small differences between the two T-sheets indicate their mutual independence. Whether the differences are the result of actual changes in the field during the months between the two surveys or survey errors is not certain, but it is clear that Kerr attempted to map more details than the other surveyors.

Only a single survey was attributed to Harrison. A close-range photograph taken by the renowned landscape photographer Carleton Watkins in 1861 (Watkins 1861) of marshland mapped by Harrison eight years earlier affords an opportunity for some assessment of Harrison's accuracy (Figure 11). The photograph indicates that there were only two areas of large pannes in the marsh; the map accurately records the same scene, as well as the channels faintly visible in the photograph. However, the photograph shows a narrow beach bordering the marsh, a feature not mapped by Harrison. Similar beaches were mapped on the adjacent T-sheet produced by Rodgers and Kerr in 1856. We conclude that Harrison's

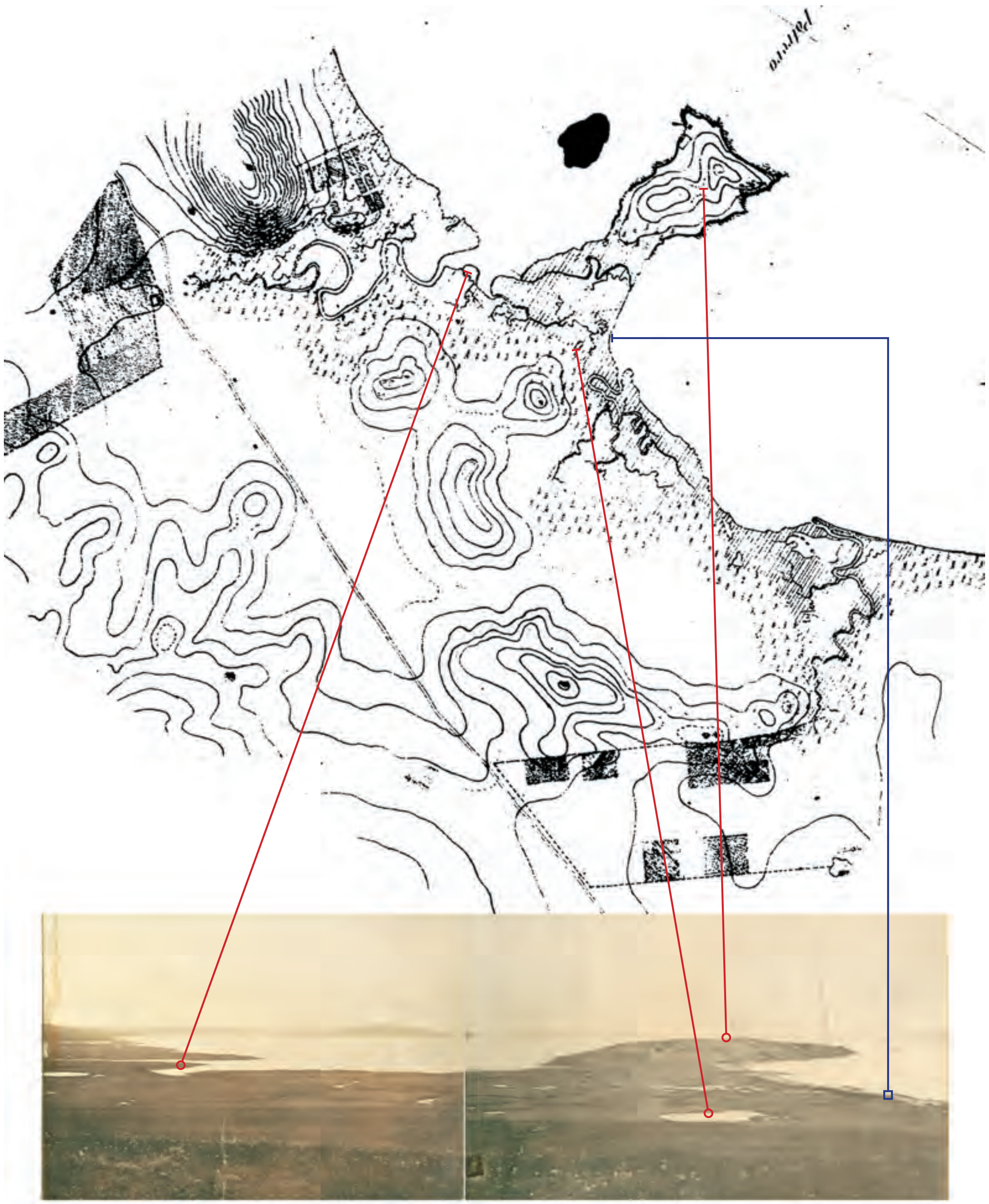


Figure 11. Comparison of US Coast Survey Topographic Sheet to landscape photograph. The photograph by Carleton Watkins (1861) provides a visual comparison with the map of the same area, surveyed by Harrison in 1853. Areas of correspondence are indicated with connecting red lines. A beach visible on the photograph (far right) but not mapped as such on Harrison's survey is indicted by a connecting blue line. (Watkins 1861; Harrison 1853).

map is accurate for the features shown, but incomplete because it does not show all the major features.

These assessments reveal substantially different interpretations of the landscape among the survey parties. Kerr's party was consistently attentive to small features. Rodger's party showed large features well and smaller features to a much lesser and more variable extent than Kerr's party. The one sample of Harrison's work shows that he mapped the detail of large channels and pannes, but that he chose not to map the obvious beaches.

There is a general increase in detail during the first USCS survey of the Estuary. It is likely that, as the region became more important economically, the surveyors were given increasingly greater assistance, time, or instruction. It is also possible that the increase in detail is mostly due to the increasing influence of Kerr. His name first appears on the legends of T-sheets for the Estuary in 1856, when he received second credit behind Rodgers. These maps show detail more typical of Kerr than Rodgers. It is conceivable that Kerr also participated in other USCS maps produced for San Pablo Bay in 1856 and attributed to Rodgers as these show more detail than Rodgers usually depicted. Later T-sheets, dating from 1857-1860, give full or lead credit to Kerr. It appears that Kerr, fortunately, dominated the region's first USCS survey in its later years.

Considerations for Use

The guide is designed to help resource managers, environmental scientists, and planners use the historical United States Coast Survey maps ("T-sheets") of the San Francisco Bay. We have explained some of the challenges in using these data that are remarkably accurate, yet unstandardized in several important aspects.

Key considerations for use include:

1) The T-sheets can be valuable tools for environmental restoration, shoreline protection, hazard management, and estuarine research and education.

2) The T-sheets were produced for specific political and economic reasons. Thus they exclude some features and focus on others. Not all maps show the same features.

3) The Coast Survey developed the T-sheets using advanced methods for the times. Geodetic controls accounted for the shape of the earth and points were mapped directly in the field using plane table and triangulation survey methods. In contrast, most mapping of the time simply used a compass to measure angles and a chain to measure distances, without any geodetic controls.

4) Individual surveyors, operating distant from central authority, had substantial responsibility for determining some aspects of map specifications, such as the level of detail. We describe substantial differences in detail between the several Bay Area surveyors. This variation should be considered when interpreting local maps.

5) One of the basic obstacles in using the T-sheets is the absence of a standardized legend. Based upon our experience, we have created a

legend to overcome this obstacle. However, the best way to confirm accurate interpretation of features is always the comparison of multiple, independent historical sources (Grossinger and Askevold 2005). Even at this time, after much change in the landscape, field work is helpful to understand historical maps.

6) Despite their tremendous value, the T-sheets present only a single source of information about San Francisco Bay. They should be used in concert with other sources, especially historical maps and early aerial photography, to maximize understanding about earlier conditions. As noted here, even the T-sheets have gaps in detail and coverage which must be filled by other sources.

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