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Geodetic Phase of NOS' San Francisco Bay Demonstration Project

David B. Zilkoski
Spatial Reference System Division, National Geodetic Survey

Don D'Onofrio
California State Geodetic Advisor, National Geodetic Survey

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by

David B. Zilkoski
Spatial Reference System Division
National Geodetic Survey
Don D'Onofrio
California State Geodetic Advisor
National Geodetic Survey

ABSTRACT

The modernization of the height component of the National Spatial Reference System, using the Global Positioning System (GPS) Continuously Operating Reference Stations (CORS) network and state-of-the-art technology will actuate the full potential of electronic charts for navigation, provide a smooth transition between the Bay and land interface for more accurate modeling of storm surge and pollution trajectory modeling. Height modernization will increase the overall accuracy of land and marine GIS data, and facilitate a major breakthrough in efficiency in determining relative changes in geodetic elevations for surveying and engineering applications.

NOS has observed a dense network of heights (both ellipsoidal and orthometric) along a "pilot" area of the Bay-land interface. By using GPS tracking data simultaneously collected at CORS sites in the area, NOS will exploit GPS-controlled, tide-coordinated photography, Soft-copy photogrammetry techniques, GPS-derived ellipsoid heights, leveling-derived orthometric heights, and high-resolution National geoid models to map Bay coastal features and bathymetry. The final product will include the geo-referencing by GPS of all historic tide gauge bench marks, geodetic control, areas of crustal motion, and selected underwater features. This paper discusses the status of the Geodetic Height Modernization phase of the project.

A BRIEF DESCRIPTION OF THE SAN FRANCISCO BAY DEMO PROJECT

San Francisco Bay is home to six major ocean shipping ports, oil refineries, and petroleum blending facilities. In marine transportation, the Bay is the fifth largest U.S. port in crude oil handling and the fourth largest container port. About 6,000 large-vessel transits were forecast for the Bay in 1995, with the number growing by 2,000 vessel transits every 5 years. Vessel navigation in the Bay is complicated by confined maneuvering areas, depth limitation, fog, and strong currents. These factors inhibit vessel transit flexibility, increase the risk of an oil or hazardous materials spill, and complicate spill mitigation efforts.

In partnership with the Bay Conservation and Development Commission, and working with Bay clients and management agencies, the National Ocean Service (NOS), National Oceanic and Atmospheric Administration has participated in the development of the San Francisco Bay Demonstration Project to provide solutions essential to ensuring that the Bay Area's marine-based economic activities can continue to expand while the Bay's ecological resources are protected and properly managed. The project will integrate technology and data into products focused on navigation and safety while providing important tools for coastal management. Collaborating with public and private entities, NOS has designated specific tasks that need to be accomplished. By pursuing these tasks jointly, sharing costs and benefits, and agreeing to measures of success, the project will maximize the effectiveness of public and private sector resources.

The project's objective is to link current and planned NOS programs together into solutions, providing an information infrastructure necessary for organizations cooperatively managing use, development, and conservation. Discussions with potential clients generated several issues that define the project core. These include: (1) efficient navigation, (2) navigation safety, (3) dredging and beneficial use of dredged materials, (4) managing wetland resources, (5) hazardous materials spills preparedness and planning, (6) monitoring contaminant levels, and (7) military base closures.

The San Francisco Bay Demonstration Project consists of 10 activities which are categorized into two groups: Improving Marine Safety and Tools for Coastal Management (see table 1). This report discusses the status of the Geodetic Height Modernization phase of the project.

Table 1. San Francisco Bay Demonstration Project Activities	
Group	Activities
Improving Marine Safety	Physical Oceanographic Real-Time System for Maritime Commerce and Environmental Monitoring Electronic Chart Systems Nautical Chart Enhancements
Tools for Coastal Management	Coastal Framework GIS Integration T-Sheet Digital Products Photogrammetric Survey of San Francisco Bay Geodetic Height Modernization Environmental Sensitivity Mapping Digital Hydrographic Data Contaminants Evaluation

DESCRIPTION OF THE GEODETIC HEIGHT MODERNIZATION PHASE

NOS is demonstrating a significant increase in efficiency that the modernization of the National Height System in the San Francisco Bay-Delta region will provide. This modernization using the Global Positioning System (GPS) Continuously Operating Reference Stations (CORS) and other state-of-the-art technology will actuate the full potential of electronic charts for navigation, provide a smooth transition between the Bay and land interface for more accurate modeling of storm surge and pollution trajectory modeling. Height modernization will increase the overall accuracy of land and marine GIS data, and facilitate a major breakthrough in efficiency in determining relative changes in geodetic elevations for surveying and engineering applications.

Conventional geodetic leveling and tidal observations determine heights relative to surfaces approximated by the physical sea level surface (the geoid). GPS determines heights relative to a mathematical surface (the ellipsoid). The true sea level surface (which defines all charted depths) is only approximated by a sparse set of tide station observations averaged over long periods of time, hence limiting the accuracies of charted depths. GPS, on the other hand, can provide consistent depths and heights for a dense network on the ellipsoid. An adequate knowledge of the difference between the geoid and ellipsoid surfaces is necessary for full implementation of the height modernization effort.

NOS has observed a dense network of heights (both ellipsoidal and orthometric) along a "pilot" area of the Bay-land interface. By using GPS tracking data simultaneously collected at CORS sites in the area, NOS will exploit GPS-controlled, tide-coordinated photography, LIDAR, Soft-copy photogrammetry techniques, GPS-derived ellipsoid heights, leveling-derived orthometric heights, and high-resolution National geoid models to map Bay coastal features and bathymetry. The final product will include the geo-referencing by GPS of all historic tide gauge bench marks, geodetic control markers, areas of crustal motion, and selected underwater features in a pilot area.

A seamless digital data base, that takes full advantage of both CORS and the modernized height system, will be created for the pilot area. Analytical stereo plotters will be used for the photographic measurements. Soft-copy photogrammetry technology will be used to experiment with the generation of digital terrain models which are otherwise too labor-intensive to create with existing in-house technology.

Explicit Objectives A modernized height system primarily based on the CORS will ensure a common foundation for all spatially related geographic data, including land and marine GIS data, and provide reliable height information for FEMA's Flood Plain Mapping program and for local surveyors, engineers, and planners. It will also support GIS requirements for regional and national transportation GISs, and provide data critical to monitor watershed planning and protection.

A more accurate data base will: allow an increase in the rate and accuracy of chart revision surveys; increase the efficiency of hydrographic and photogrammetric coastal surveys for coastal management; support the monitoring of pollution and environmental studies; allow more frequent studies of shoreline movement and coastal erosion studies; and develop near-shore bathymetry and identify selected significant seabed characteristics.

Key Outside Links Primary user links include the U.S. Army Corps of Engineers (dredging), U.S. Coast Guard (electronic charts), Federal Emergency Management Agency (accurate modeling of storm surge, digital data for coastal management, flood insurance rate mapping, and coastal erosion studies), Environmental Protection Agency (pollution trajectory modeling), National Marine Fishery Service (marine GIS), Federal Geographic Data Committee members (surveying and mapping applications), and Port Authorities and the Shipping Industry (real-time water levels, electronic chart displays, real-time GPS dynamic draft applications, and accurate circulation modeling).

A common interest in the modernization of the vertical datum exploiting GPS technology via statewide implementation will also create links with individual State Departments of Transportation, Departments of Natural Resources, universities, and geodetic survey agencies. In California, a common interest in the modernized height system via statewide implementation of the new North American Vertical Datum of 1988 (NAVD 88) is being shown by an ongoing forum involving NOS and the County Engineers Association of California, Consulting Engineers and Land Surveyors of California, California State University, Metropolitan Water District of Southern California, California Department of Transportation (Caltrans), California Geodetic Control Committee, State Lands Commission, California Dept. of Water Resources, FEMA, Bureau of Reclamation, U.S. Geological Survey (USGS), and others.

The geodetic portion of the San Francisco Bay Demonstration Project, involving GPS technology, which was critical to the overall success of the project, would not have been accomplished without the support of the California Department of Transportation.

GEODETIC PHASE PROJECT PLAN

Figure 1(22K) depicts the project area. The basic plan and status of the tasks are presented below. An objective of the project is to demonstrate how GPS-derived ellipsoid heights can be used instead of traditional orthometric heights and local mean sea level values for mapping, charting, and navigation applications. Therefore, using specially-designed static GPS surveying techniques, ellipsoid height values of three long-term tidal gauges in the San Francisco Bay area were estimated to the 2 cm uncertainty level (95% confidence level): San Francisco (941 4290), Alameda (941 4750), and Richmond (941 4863). The static GPS surveying project followed all guidelines documented in the latest version of NGS' document titled "Guidelines for Establishing GPS-Derived Ellipsoid Heights" (Zilkoski, D'Onofrio, and Frakes, 1996). All stations were occupied for at least three hours on two different days under different satellite geometry using dual-frequency, full-wavelength GPS instruments.

In addition to the three tidal stations, ellipsoid height values (at the 2 cm uncertainty level) at 13 other bench marks in the project area were estimated using the same specially-designed static GPS surveying techniques stated above. The field work for this phase of the project was performed during a one-week period in September 1995 and the office processing was completed during October 1995.

Federal Government agencies are partnering with other local and state government agencies, as well as private industry to share the cost of developing and transferring new technology and techniques to geodetic users. Transferring technology may seem to cost a bit more in the beginning, but it costs less in the long-run. The San Francisco Bay Demonstration Project was an excellent example of government agencies' partnering between agencies with common interests and goals. They worked together to develop cost-effective and more efficient techniques of establishing heights that meet defined Federal standards. The agencies which were involved in the actual field work of the San Francisco Bay project included surveyors from the California Department of Transportation (Caltrans), California State Lands Commission, U.S. Army Corps of Engineers, NOAA's Office of Coast Survey, and NOAA's Office of National Geodetic Survey.

Caltrans, which provided the most assistance and equipment for the observation sessions, felt that partnering was worthwhile because its personnel could observe NGS' methods of performing static and pseudo-kinematic GPS surveys. Not only did NGS personnel demonstrate their field techniques, they also spent time with Caltrans personnel demonstrating NGS base line processing techniques and answering numerous other questions pertaining to GPS. Caltrans has implemented these new techniques into their survey operations.

Other agencies involved in the project included the USGS, Port of Oakland, Bay Conservation and Development Commission, the University of California at Berkeley, and Trimble Navigation.

Five GPS CORS were involved in the survey - Angel Island, U.S. Coast Guard DGPS site; Point Molate, Trimble site; Briones, near Briones Regional Park, University of California site; Chabot, near Anthony Chabot Regional Park, USGS site; and Winton, near Hayward Municipal Airport, USGS site (figure 1).

Figure 2(3K) depicts the differences in ellipsoid heights for repeat base lines for the stations occupied during the 2-cm static GPS survey. The standard deviation was 0.6 cm. The GPS-derived orthometric height values for all marks occupied by GPS were computed using GEOID93. Figure 3(17K) depicts the difference between the GPS-derived orthometric heights and the published NAVD 88 height values after a trend was removed. Notice that the difference from one side of the bay to the other is only 1.6 cm and from the southern edge of the project to the northern edge is only about 0.8 cm. There does, however, appear to be something systematic occurring near the Golden Gate Bridge. The Golden Gate Bridge is near the difference value labeled -2.3 cm. This is most likely due to inaccurate NAVD 88 heights. The area was last leveled to in 1989.

Using GPS results and tidal information, the relationship between ellipsoid heights of tidal bench marks and local sea level measurements, e.g., mean low water and mean lower low water, was established. This provides ellipsoid heights for local water level values placing water levels on a common, accurate spatially referenced datum rather than approximated sea level heights.

To assist in the evaluation of the GPS-controlled photogrammetry and photogrammetry soft-copy results, three-dimensional positions (5-cm uncertainty level, 95 percent confidence level) of selected piers, shoreline features, roads, and photo-identifiable points in the project area using pseudo-kinematic GPS surveying techniques were established (Zilkoski, D'Onofrio, and Frakes, 1996). A total of 40 stations were occupied during the last week of September 1995 and the office processing was completed in October 1995. Each station was occupied twice for at least 15 minutes during each occupation which were on two different days under different satellite geometry configuration. The distance from the base stations was less than five kilometers. Figures 4(3K) depicts the differences in ellipsoid heights for these repeat base lines. The standard deviation was 0.9 cm. Figure 5(48K) shows a sample setup on a pier and figure 6 depicts the locations of the piers positioned using GPS. The dots represent the locations of the pier facings and can be used in development of electronic chart displays. Notice that the dots by themselves do not appear to be interesting and may even seem to be meaningless. It would be good if these pier locations could be overlaid on a map that contains the shoreline and bathymetry but they would not appear to be placed in the proper location because the existing maps of shoreline and bathymetry are not as accurate as the locations of the piers.

During the September 1995 survey, a small beach near Emery Point in Emeryville on the Oakland side of the bay was profiled using pseudo-kinematic GPS techniques following NGS 5-cm GPS Vertical Guidelines. Using the results from the GPS survey, a three-dimensional surface of the beach area was generated. Figure 7(20K) depicts the beach profile. In July 1996, NGS with assistance from Bay Conservation and Development Commission (BCDC) personnel reprofiled the Emery Point Beach and profiled another beach in the Crown Beach area of Alameda. The reason for reprofiling the Emery Point beach was to demonstrate that GPS ellipsoid heights can be used to show any changes from one period to the next. Figure 8(32K) is a plot of the differences between the 1995 and 1996 GPS beach surveys. The plot indicates that the small beach area did not change significantly between 1995 and 1996; at least not to the accuracy level of the GPS profiling, which is between 5 and 10 cm because non-monumented discrete points on the beach were used to generate three-dimensional surfaces.

Using the results from the 2-cm standard survey described above, the ellipsoid heights of the different water levels were computed and overlaid on the beach profile. Figure 9 depicts the different water levels on the beach. Note that figure 9(17K) was rotated so the reader can visualize what the different water levels look like from the waters edge.

Figure 10(20K) is a plot of the small profile performed in the Crown Beach area by BCDC personnel on July 15, 1996. These profiles can be very helpful in determining the high water line location as well as what will happen in the area if there are some unusually high storm surges.

The remaining tasks of the geodetic phase portion of the demonstration project include:

(1) using tide-coordinated, GPS-controlled photogrammetry, estimate the ellipsoid height of the shoreline (15 cm standard) and specific features (10 cm standard) that were positioned during the pseudo-kinematic GPS survey; *the photography was obtained in August-September 1996 and is scheduled to processed during fiscal year 1997*;

(2) using photogrammetric soft-copy techniques, estimate the positions of features that were also positions using land-based GPS surveying techniques; *the photogrammetry was obtained in August-September 1996 and is scheduled to be processed during fiscal year 1997*;

(3) using GPS-controlled LIDAR techniques, estimate ellipsoid height values (10 cm standard) of sea surface, bathymetry, and shoreline; *due to scheduling this may not be performed until 1997*;

(4) integrate photogrammetry and geodetic survey results; *this is scheduled for completion during fiscal year 1997*; and

(5) generate three-dimensional topography models to show effects of changes in sea level and differences between ellipsoid heights and orthometric heights; *this is also scheduled for completion during fiscal 1997.*

CONCLUSION

The demonstration project is a project that demonstrates the latest available geodetic technology and how this information can be helpful to managers. The National Geodetic Survey has partnered with several agencies to perform this project and has learned as much from the personnel of these agencies as these agencies have learned from NGS personnel. This project has been instrumental in developing, improving, and documenting NGS' GPS Vertical Guidelines to obtain 2 and 5-cm ellipsoid height standards. There are still remaining tasks which need to be accomplished and additional tasks will arise as more managers, planners, surveyors, ship pilots, and others understand the results of this partnering effort. The ultimate goal is to map the bottom of the Bay in the ellipsoid height system and use GPS on ships in an electronic chart display to transit the Bay and dock during zero visibility. This <u>will</u> happen, it is only a matter of time.

REFERENCES

Zilkoski, D.B., J. D. D'Onofrio, and S. J. Frakes, 1996. Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm) - Version 4.1. NGS Unpublished Document, Spatial Reference System Division, Station 8752, 1315 East-West Highway, Silver Spring, Maryland 20910.