J. S. Rosenshein
C. R. Goodwin
U. S. Geological Survey
Tampa, FL 33614
Antonio Jurado
U. S. Geological Survey
Miami, FL

Bottom Configuration and Environment of Tampa Bay

The bay bottom was mapped photogrammetrically, and a hydrodynamic model of the bay was constructed.

Abstract: *The hydrologic environment of Tampa Bay, a large estuarine system of about 350 square miles (910 square kilometres) on the Gulf Coast of Florida, is being studied by the U. S. Geological Survey. As part of the study, updated maps of the bay bottom have been prepared from existing bathymetric data furnished by the National Ocean Survey and from new data. The new data were obtained both by photogrammetric techniques for water depths of as much as 15 feet (5 metres), and by boat-mounted, bottom-profiling and positioning equipment that supplied digital observations for computer processing. Detailed definition of the bay bottom is needed for direct evaluation of alternative plans for dredged material placement and also for use in a hydrodynamic, digital computer model of the bay system.*

Introduction

The U. S. Geological Survey is making an intensive investigation of the hydrologic environment of Tampa Bay. This investigation began in late 1970 in cooperation with the Tampa Port Authority and currently (1975) is under joint cooperation with the Port Authority and the U. S. Army Corps of Engineers. Among its goals, the investigation is directed toward (1) determining circulation patterns in the bay; (2) defining flushing mechanisms; (3) providing interpretation of hydrologic environment and predictions of changes in circulation and water quality likely to result from improvements to the existing ship channel; and (4) aiding the development of techniques to evaluate the hydrologic environment of other estuarine and related water bodies.

The key element in providing predictions of changes in circulation and water quality in the bay is a two-dimensional digital computer simulation model of the hydrodynamics and water quality of the bay system. This model is currently operational and was jointly developed by Dr. R. A. Baltzer, U. S. Geological Survey, and Dr. Jan Leendertse, the Rand Corporation.

During planning of the Tampa Bay investigation, the bay-bottom configuration was identified as possibly the most important factor in determining the flow pattern and water-quality distribution in the bay system. As a result, more detailed bottom information than that available on navigation charts would be needed to satisfactorily simulate the bay's hydrodynamic and water-quality conditions. Detailed maps of the bottom also would aid those agencies responsible for developing plans and evaluating the impact of various material placement alternatives on the circulation and flow patterns in the bay. In addition to compilation and collection of accurate depth information, emphasis was also given to the detailed representation of the shape and form of bay-bottom features as interpreted from the depth data.

The purpose of this paper is to describe one significant aspect of the investigation, detailed definition of the bay bottom. Special photogrammetric techniques were used to define the bay-bottom configuration, a key factor needed for digital simulation modeling and also for direct evaluation of changes to the bay environment. The techniques used were experimental and directed toward providing detailed bottom maps for hydrologic use. These maps were not intended for navigational purposes. Therefore, no attempt has been made to show obstructions or navigational aids.

General Aspects and Environmental Setting

Tampa Bay forms an embayment of about 350 mi^2 (910 km^2) on the Gulf Coast of Florida (Figure 1). The bay is more than 10 mi (16 km) wide in places, and its upper part consists of two arms. The westernmost arm forms Old Tampa Bay and the easternmost arm, Hillsborough Bay.

Tampa Bay lies in parts of Hillsborough, Pinellas, and Manatee Counties and is bordered by the rapidly growing Tampa-St. Petersburg metropolitan area. The Hillsborough County part of the bay has a major port facility at Tampa. The port has a direct economic impact on west-central Florida and also provides significant benefits to the state and nation.

A large part of Tampa Bay is less than 15 ft (5 m) deep. The central part is deeper and, except where altered by man, generally is less than 30 ft (9 m) deep. The major man-made feature in Tampa Bay is a ship channel that stretches 35 mi (56 km) from the Gulf of Mexico to the port facilities at Tampa. This ship channel was constructed for most of its length in a natural channel that may represent a relict stream channel of the Hillsborough River. The present ship channel is 34 ft (10 m) deep and 400 ft (120 m) wide; efforts are underway to enlarge the channel to 43 ft (13 m) deep and 500 ft (150 m) wide in order to facilitate deeper draft vessels. At its mouth the bay is more than 45 ft (14 m) deep. The bay bottom is irregular in many places, has numerous depressions, and has at least three levels of terraces or wave-cut benches associated with lower stands of sea level.

The central part of the bay is underlain by sand, silt, and clay which were deposited on an undulating bedrock surface. Interbedded with the silt and clay are thin, discontinuous

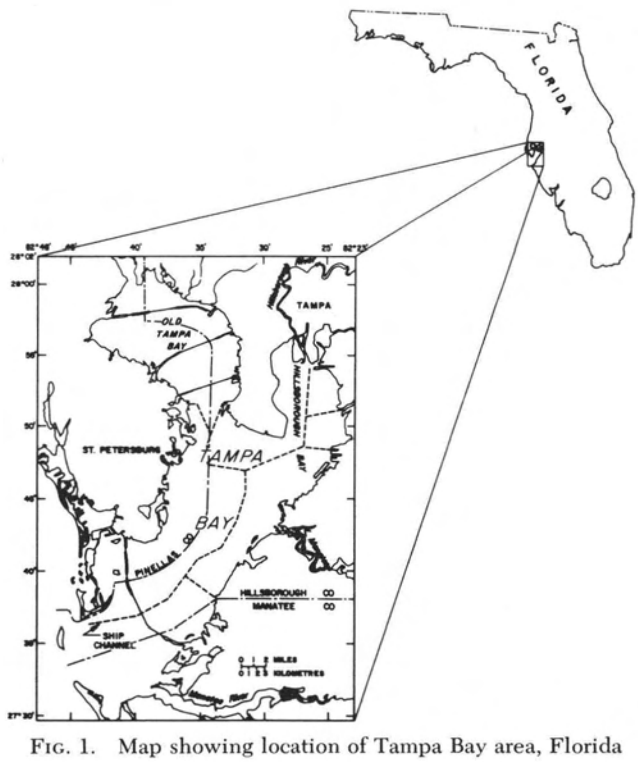

Fig. 1. Map showing location of Tampa Bay area, Florida

layers of limestone. The bedrock consists chiefly of limestone which in places lies just below the bay bottom. This limestone contains many filled sinkholes. Near the shore, at depths generally less than 10 ft (3 m), the bottom is covered by submerged vegetation.

Natural inflow to the bay is chiefly from discharge of the Hillsborough, Alafia, Little Manatee, and Manatee Rivers. Many small streams carry runoff to the bay during Florida's wet weather period, June-September, and carry little or no runoff during the rest of the year. Sewage treatment plants discharge effluent to the bay and during dry weather their discharge is a large part of the inflow. Most of the treatment plants discharge secondary-treated effluent. However, the largest single discharge is from a primary treatment plant at the head of Hillsborough Bay.

The turbidity of the water in Tampa Bay generally ranges from 0.4 to 5 JTU (Jackson Turbidity Units). The turbidity in some parts of the bay such as Hillsborough Bay may be more than 10 JTU at times, particularly near treatment plant outfalls or where boats or waves have stirred the bottom sediments. However, the turbidity in general is such that details of bay bottom can be viewed from the air through water depths as much as 15 ft (5 m) under proper conditions of sunlight, sun angle, and water surface condition.

Mapping Methods

DATA BASE

Early in 1971, several experimental test strips of the bay were photographed with color-negative film. This photography was flown at an altitude of 7,900 ft (2,400 m). The test strips indicated that some success could be anticipated by using photogrammetric techniques to delineate some parts of the bay bottom. In June 1971, the bay was photographed from an altitude of 6,000 ft (1,800 m) using both color-positive film and a blue-insensitive film. The images from this photography did not reveal sufficient bottom detail for investigation use. In October 1971, the bay was again photographed, this time from an altitude of 18,000 ft (5,500 m), with color-positive film. These images showed excellent detail of the bay bottom to water depths of as much as 15 ft (5 m) and were used during stereocompilation for model control, landmark recognition, and interpretation of the form of bottom features. In addition, black-and-white positive transparencies, obtained in 1971 by the Topographic Division of the U. S. Geological Survey, were used for bathymetric contouring. These photographs were taken at altitudes of 7,000 and 12,000 ft (2,100 and 3,700 m).

Manuscript copies of Tampa Bay navigation charts were obtained from the National Ocean Survey. The depth data on these charts were digitized and provided to the Geological Survey on magnetic tape. The manuscripts themselves were used to aid and supplement the stereocompilation.

Soundings also were collected by the Geological Survey in November 1971 and in February-April 1973. This effort was concentrated along the main ship channel, in spoil areas, and along newly constructed channels. Two different automated bathymetric systems, one in 1971 and one in 1973, were used to collect these data.

The system used in 1971 consisted of an Atlas digital depth sounder, a Cubic Autotape DM 40 radio-ranging system[1], a data interface unit designed by the Geological Survey, and a magnetic tape recorder. This equipment was installed on a 36-ft (11-m) vessel supplied by the Tampa Port Authority. Shore units for the positioning equipment, called responders, were placed at several sites around the bay. The horizontal position and distance between sites were determined by the Topographic Division. The distances from two responder sites to the vessel were recorded continuously on magnetic tape for later processing to triangulate the position of the vessel. Thousands of individual distance and depth readings were recorded in digital format that allowed processing on the Geological Survey's computer. Bottom profiles were taken perpendicular to the ship channel every 2,600 to 3,000 ft (790 to 910 m) from the head of the channel to the Gulf, and a longitudinal profile was made along the entire length of the ship-channel centerline.

The system used in 1973 (Figure 2) consisted of an Atlas digital sounder, a Cubic Autotape DM 40 and a Cubic System data converter, magnetic tape recorder and position-plotting system. As in 1971, depth and position were recorded on magnetic tape along with other information necessary for computer processing of the recorded data. The position-plotting system was especially helpful in maintaining preselected courses and profile intervals. In 1973, profiles perpendicular to the ship channel were

[1] The use of brand names in this report is for identification purposes only and does not imply endorsement by the U. S. Geological Survey.

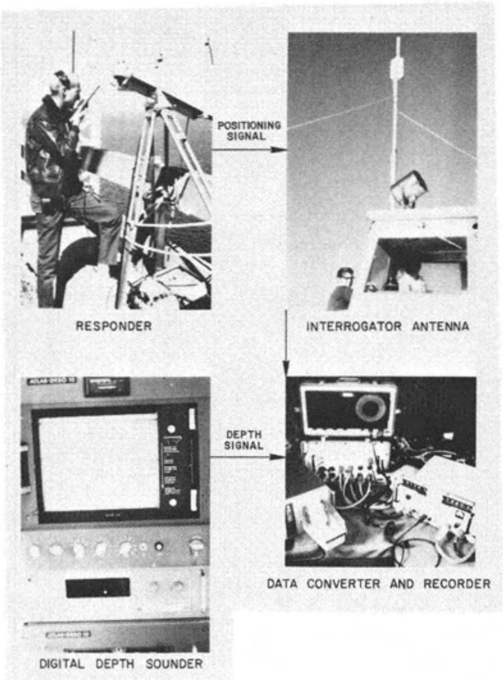

FIG. 2. Photographs of system used to collect bathymetric data for Tampa Bay investigation

made at 500-ft (150-m) intervals from the head of the channel to the Gulf. Particular care was taken not only to define the main ship channel, but also to define the configuration of existing submerged spoil areas. In addition, three longitudinal traverses were made the length of the channel—one along the center line, and one on each side of and 250 ft (75 m) from the center line.

Prior to any extensive photogrammetric and bathymetric data collection, a network of 14 tide-stage gages was established around the bay. Data recorded at these gages were used to correct the 1971 and 1973 depth soundings for tide fluctuations.

Incidental to the bottom profiling, the positioning system was also used for biological, sediment, and water sampling activities as well as for seismic profiling of the bay subbottom. At predetermined sites along the ship channel and submerged spoil areas, samples were collected by divers. The purpose of using the positioning system for these efforts was to permit biological resampling at each exact site during and after ship-channel deepening and to provide accurate location of seismic profiles.

MAP COMPILATION

About 60 percent (200 mi² or 520 km²) of the bay (Figure 3) was mapped photogrammetically by using a Kelsh plotter equipped with a visual polarization projection system. The plotter was adapted to use both color and black-and-white photography. In the stereocompilation, both types of photography were used to map the bay bottom through water as much as 15 ft (5 m) deep. Parts of 12 7-½-minute quadrangle maps were compiled in this manner. Results of the mapping are being included on an experimental printing of undated, photo-revised quadrangle maps of the Tampa Bay area; some of these are in press.

Most of the photographs used in stereocompilation had 60 percent forward lap. However, experience gained from the effort indicates that 65 to 75 percent forward lap would have been preferable. Each stereoscopic model was worked at a scale of 1:3,000 and reduced to a map scale of 1:24,000. Vertical and horizontal control for each model was obtained from existing Geological Survey 7-½-minute quadrangle maps, and supplemental control was added in the field where needed. Vertical control was referenced to mean low water. In general each stereoscopic model was compiled with sufficient detail and overlap to provide a good match with the adjacent model.

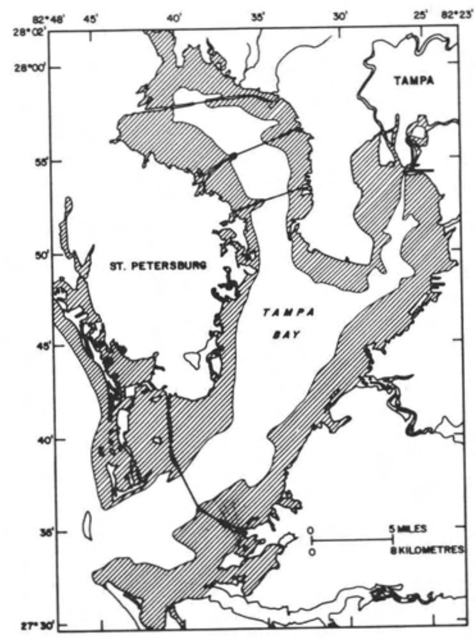

FIG. 3. Map showing part of Tampa Bay for which bathymetric contours were obtained using photogrammetric techniques (patterned area only).

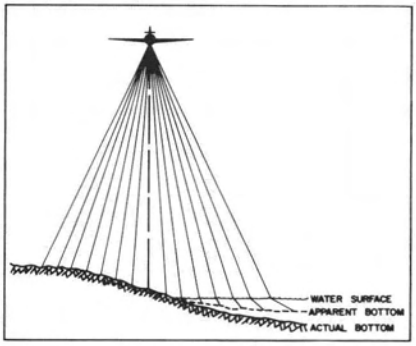

FIG. 4. Diagrammatic sketch showing the effects of depth displacement due to index of refraction of bay water.

The shoreline configuration was updated during map compilation by using the most recent photography.

Variable correction factors were applied to water depths obtained from the stereoscopic models in order to adjust for depth displacement due to light refraction caused by the bay water (Figure 4). A constant index of refraction, representing average bay water temperature and salinity, was used. This introduces an error of about 0.3 percent. The direct method for refraction adjustment was used (Harris and Umbach, 1972). Appropriate correction factors were added to the tracing-table reading of apparent depth to obtain true vertical water depth.

An example of the detail which can be obtained using photogrammetric methods is shown in Figure 5. A section of a conventional topographic map is compared with the experimental edition. Considerable difference exists between the contours depicted by conventional and photogrammetric methods.

About 40 percent of Tampa Bay could not be mapped by photogrammetric techniques because of high turbidity, water depths exceeding 10 to 15 ft (3 to 5 m), or the sun's reflection or wind-produced surface ripples obscuring the bottom detail. Where one or more of these conditions existed, bottom contours were compiled from 1958 bathymetric data collected by the National Ocean Survey and from bathymetry collected by the Geological Survey in 1971 and 1973. The Survey's bathymetry was also used where channels had been dredged since 1958. This was necessary since the channels did not exist in 1958 and channel depths generally exceeded the penetration depth of the stereophotography.

APPLICATION OF MAPPING TO HYDROLOGIC EVALUATION

TAMPA BAY BATHYMETRY AS RELATED TO HYDRODYNAMIC MODELING

Depth information collected and bottom configuration maps generated as part of the Geological Survey's Tampa Bay investigation were used directly to define the bottom boundary of the simulation model. In addition, an important factor needed for estuarine computer modeling is a coefficient

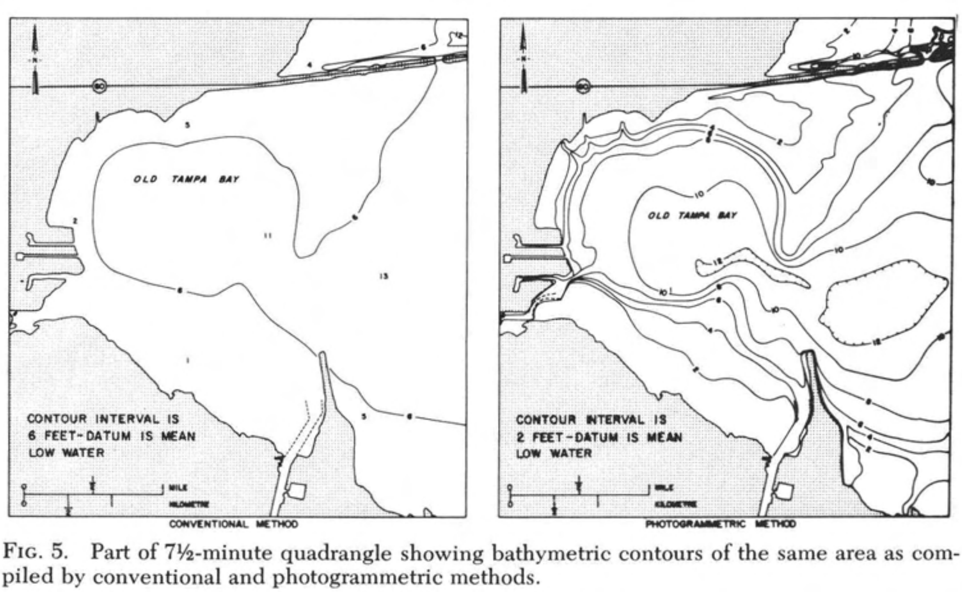

FIG. 5. Part of 7½-minute quadrangle showing bathymetric contours of the same area as compiled by conventional and photogrammetric methods.

whose value is dependent on the local roughness of the bay bottom. Realistic values have been assigned to this roughness coefficient based on bottom features delineated by the detailed contouring of bay bathymetry, as previously described.

The model has been used to simulate historic and existing hydrodynamics of the bay system, and its calibration using observed tide, wind, inflow, and bottom data has progressed to the point where tide fluctuation can be simulated to within 0.1 ft (0.03 m) in displacement and to within a few minutes of the phase lag recorded in the bay. As part of the research effort, calibration and verification using several different periods of actual data, will continue until even closer agreement between model and bay hydrodynamics is achieved. Currently, the model is suitable for use in evaluating the impact of changes in bay geometry on circulation patterns in the bay.

An example of model output is shown in Figure 6. Instantaneous, vertically averaged velocity vectors are shown every 1,500 ft (460 m) in the bay; contours connect points of equal velocity magnitude.

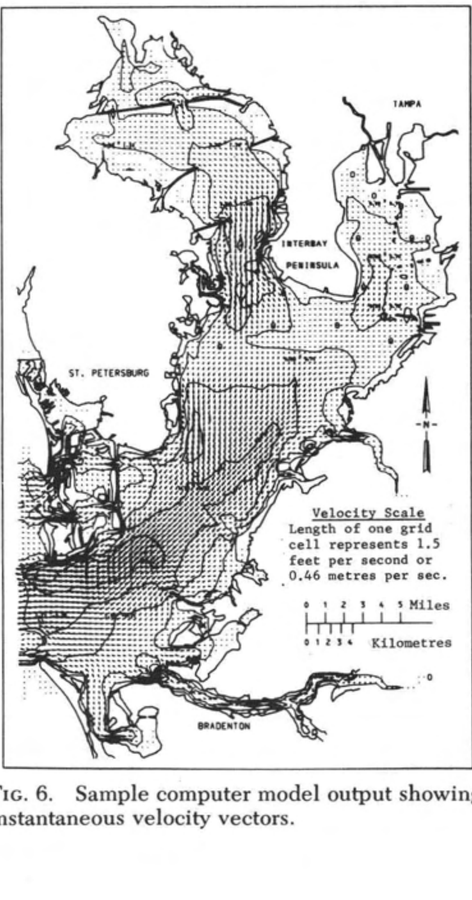

FIG. 6. Sample computer model output showing instantaneous velocity vectors.

TAMPA BAY BATHYMETRY AS RELATED TO HYDROLOGIC IMPACT OF CHANNEL DEEPENING

Deepening of the ship channel in Tampa Bay involves removal of subbottom deposits from the channel and placement of this material on spoil areas. Published navigation charts and topographic maps delineate areas designated for spoil placement but do not show detailed information on bay bottom geometry in these areas. The maps compiled by the U.S. Geological Survey for the Tampa Bay study provide this information. They have also been useful to agencies responsible for developing alternative plans for selection, alignment, and design of possible submerged and emerged spoil areas. In addition, the maps have helped in selection of previously deposited spoil areas where material might possibly be removed to enhance bay circulation. Several alternative plans involving changes in bay bottom geometry have been tested by using the Tampa Bay model in order to predict the impact that each plan would have on the hydrologic environment. An example of the model-predicted effects on circulation of one proposed placement plan is shown in Figure 7. This figure shows the circulation pattern and net transport over one tidal cycle in the northeastern area of Tampa Bay caused by

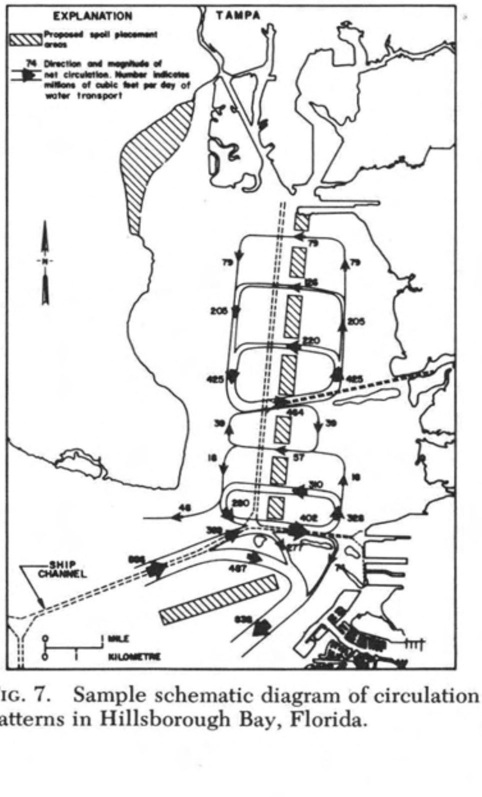

FIG. 7. Sample schematic diagram of circulation patterns in Hillsborough Bay, Florida.

many small islands created from dredged material. The circulation pattern is such that little water would interchange between the upper and lower parts of the area with this particular island configuration. As a result, flushing action would be minimal with little or no chance for upgrading the water quality in the upper part of the area.

Summary

Photogrammetric and other methods have been used successfully to provide detailed information on bottom configuration as part of an evaluation of the hydrology of Tampa Bay. About 200 mi² (520 km²) of bay bottom have been mapped using photogrammetric methods. Color transparencies taken at 18,000 ft (5,500 m) and black-and-white transparencies taken at 7,000 and 12,000 ft (2,100 and 3,700 m) were used for compilation. Detailed information on bottom configuration has played an important part in the calibration of a hydrodynamic model of the bay and in the use of this model to predict effects on circulation resulting from proposed deepening of the ship channel in Tampa Bay. Availability of both the digital model and detailed maps of bottom geometry have aided development of alternative plans for removal and placement of subbottom materials to help improve tidal circulation and flushing in the bay.

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