4. Tides and Water Levels Requirements

4.1. General Project Requirements and Scope

4.1.1. Scope

The requirements and specifications contained in this section cover the water level and vertical datum requirements for operational support of hydrographic surveys conducted as part of the NOAA Nautical Charting Program. The scope of this support comprises the following functional areas:

1. Tide and water level requirement planning
2. Preliminary tidal zoning development

3a. Control water level station operation;

3b. Supplemental water level station installation, operation and removal

4. Data quality control, processing, and tabulation
5. Tidal datum computation and tidal datum recovery
6. Generation of water level reducers and final tidal zoning

For in-house surveys, personnel from the National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) are responsible for functional areas 1, 2, 4, 5, and 6. NOS hydrographers and CO-OPS Field Operations Division will be responsible for functional area 3 above.

For contract surveys, CO-OPS personnel are responsible for functional areas 1, 2 and 3a. NOS contract hydrographers will be responsible for functional areas 3b through 6 above. NOS continues to be responsible for operating, maintaining, and processing data from the control stations (e.g., the NWLON).

4.1.2. Objectives

The work performed under the requirements and specifications of this section is required for NOS major program areas of navigational products and services. The first objective for the support detailed in this section is to provide time series of water level reducers that can be applied to hydrographic soundings so that they can be corrected to chart datum. A second objective is to establish and/or recover tidal datums relative to local benchmarks at each station that can be used for continuing and future hydrographic surveys in the area. A third objective is to provide new or updated information that can be used to update NOAA tide prediction products and tidal zoning for promoting safe navigation applications.

4.1.3. Planning and Preliminary Tidal Zoning

CO-OPS is responsible for all planning of tide requirements for NOS hydrographic surveys. CO-OPS will analyze historical data and tidal characteristics for each project area, specify operational NOS control stations, specify subordinate tide station locations to be installed, and provide the preliminary tidal zoning to be used during survey operations. CO-OPS will provide 6-minute interval tide predictions relative to chart datum for appropriate NOS control stations prior to each survey and will also provide historical published bench mark information available for all historical tide stations specified for reoccupation. If CO-OPS provides a new preliminary tidal zoning scheme, the contractor must use that zoning scheme first for each project, and then, may generate a new scheme if the one provided is not adequate. At the conclusion of the survey, the contractor shall suspend the use of preliminary zoning scheme and develop final zoning scheme using correctors derived from the subordinate stations installed during the survey. Refer to Section 4.5.2 for further details.

4.1.4. NOS Control Stations and Data Quality Monitoring

National Water Level Observation Network

CO-OPS manages the National Water Level Observation Network (NWLON) of approximately 175 continuously operating water level observation stations in the U.S. coastal zone, including the Great Lakes. As most of these stations are equipped with satellite radios, near real-time (within about 3 hours of collection) raw data are made available to all users through the interface to the CO-OPS Home Page on the Web. Verified products, such as edited 6-minute data, hourly heights, high and low waters, and monthly means are made available over the Web within one to four weeks after data collection. NWLON data and accepted tidal datums are used in hydrographic surveys either to provide tide reducers directly or for control for datum determination at subordinate (short-term) stations. Preliminary and verified data are made available over the Web relative to MLLW datum, station datum, or special water level datum (such as Columbia River datum) as a user option in the interface.

Data Quality Monitoring

CO-OPS has an in-place Continuous Operational Real-Time Monitoring System (CORMS) that provides quality control and system monitoring functions on a 24 hour/day, 7 days/week, all year around basis. CORMS will monitor the status and performance of all hydro gauges equipped with satellite radios using the NOS satellite message format installed by the hydrographer, and once listed on the hydro hot list by CO-OPS, as it does for all other NOS water level systems, including all NWLON stations. The CORMS system description can be found in System Development Plan, CORMS. CORMS is a NOS provided support function to the operational field parties and does not relieve the hydrographer of responsibility for performing QC and ensuring proper gauge operation.

4.1.5. General Data and Reference Datum Requirements

The present NOAA Nautical Chart Reference Datum for tidal waters is Mean Lower Low Water (MLLW) based on the NOAA National Tidal Datum Epoch (NTDE) of 1983-2001 as defined in the Tide and Current Glossary. All tidal datum computations and water level reductions shall be referenced to this datum. In non-tidal areas, including the Great Lakes, special low water datums have been defined for specific areas and are used as chart datum in these locations.

In some cases where historical sites are re-occupied, site datum shall be zeroed to a pre-established MLLW datum held on a bench mark. In that case, data can be acquired relative to MLLW for immediate application during the survey. At present, in Great Lakes areas, a special Low Water Datum relative to IGLD 85 is the reference datum.

4.1.6. Error Budget Considerations

The water level reducers can be a significant corrector to soundings to reduce them relative to chart datum especially in shallow water areas with relatively high ranges of tide. The errors associated with water level reducers are generally not depth dependent, however. The portion of the error of the water level reducers must be balanced against all other sounding errors to ensure that the total sounding error budget is not exceeded. The allowable contribution of the error for tides and water levels to the total survey error budget falls between 0.20 m and 0.45 m (at the 95% confidence level) depending on the complexity of the tides.

The total error of the tides and water levels can be considered to have component errors of:

1) the measurement error of the gauge/sensor and processing error to refer the measurements to station datum. Gauges/sensors need to be calibrated, and sensor design and data sampling need to include

strategies to reduce measurement errors due to waves, currents, temperature and density effects. The measurements need to be properly referenced to the bench marks and tide staffs, as appropriate and monitored for vertical stability. The measurement error, including the dynamic effects, should not exceed 0.10 m at the 95% confidence level. The processing error also includes interpolation error of the water level at the exact time of the soundings. A estimate for a typical processing error is 0.10 m at the 95% confidence level.

2) the error in computation of tidal datums for the adjustment to an equivalent 19-year National Tidal Datum Epoch (NTDE) periods for short term stations. The shorter the time series, the less accurate the datum, i.e. bigger the error. An inappropriate control station also decreases accuracy. The NTDE does not apply in the Great Lakes, however the accuracy of datum based on shorter time series is analogous. The estimated error of an adjusted tidal datum based on one month of data is 0.08 m for the east and west coasts and 0.11 m for the Gulf coast (at the 95% confidence level).

3) the error in application of tidal zoning. Tidal zoning is the extrapolation and/or interpolation of tidal characteristics from a known shore point(s) to a desired survey area using time differences and range ratios. The greater the extrapolation/interpolation, the greater the uncertainty and error. Estimates for typical errors associated with tidal zoning are 0.20 m at the 95% confidence level. However, errors for this component can easily exceed 0.20 m if tidal characteristics are very complex, or not well-defined, and if there are pronounced differential effects of meteorology on the water levels across the survey area.

Project planning by NOS attempts to minimize and balance these potential sources of errors through the use and specification of accurate reliable water level gauges, and optimization of the mix of zoning required, the number of station locations required, and the length of observations required within practical limits of the survey area and survey duration. The practical limits depend upon the tidal characteristics of the area and suitability of the coastline for the installation and operation of appropriate water level stations.

4.2. Data Collection and Field Work

The hydrographer shall collect continuous and valid data series. Accurate datums cannot be computed for a month of data with a break in the water level measurement series in excess of three days. Even breaks of significantly less than three days duration will not allow for interpolation during times when strong meteorological conditions are present and in areas with little periodic tidal influence. Any break in the water level measurement series affects the accuracy of datum computations. Breaks in data also result in increased error in the tide reducers when interpolation is required to provide data at the time of soundings. At a critical measurement site where the water level measurement data cannot be transmitted or monitored during hydrographic operations, an independent backup sensor or a complete redundant water level collection system shall be installed and operated during the project.

4.2.1. Water Level Station Requirements

Data from NOS National Water Level Observation Network (NWLON) stations will be provided to support hydrographic survey operations where appropriate. Data provided are relative to Chart Datum which is Mean Lower Low Water for the 19-year National Tidal Datum Epoch (NTDE).

The acquisition of water level data from subordinate locations may be required for hydrographic surveys and if so shall be specified by NOS in each individual set of Project Instructions or Statement of Work. These stations shall be used to provide 6-minute time series data, tidal datum references and tidal zoning which all factor into the production of final tide reducers for specific survey areas. Station locations and requirements may be modified after station reconnaissance or as survey operations progress. Any changes shall be made only after consultation between the CO-OPS and the hydrographer (and COTR if contract survey) as moving required stations to new locations may require new seven-digit station identifier numbers and new/historical station and bench mark information.

The duration of continuous data acquisition shall be a 30-day minimum except for zoning stations. Data acquisition shall be from at least 4 hours before the beginning of the hydrographic survey operations to 4 hours after the ending of hydrographic survey operations, and/or shoreline verification in the applicable areas. Stations identified as “30-day” stations are the “main” subordinate stations for datum establishment, providing tide reducers for a given project and for harmonic analysis from which harmonic constants for tide prediction can be derived. At these stations, data must be collected throughout the entire survey period in specified areas for which they are required, and not less than 30 continuous days are required for accurate datum determination. Additionally, supplemental and/or back-up gauges may also be necessary based upon the complexity of the hydrodynamics and/or the severity of environmental conditions of the project area.

In non-tidal areas the correctors for hydrographic soundings are simply water level measurements relative to a specified local low water level datum established for navigational purposes. Laguna Madre and parts of Pamlico Sound are examples of such areas classified as non-tidal which have special low water datums. Some river areas also have special datums due to the effects of seasonal changes on the river, e.g., Columbia River Datum, Hudson River datum, and Mississippi River Low Water are examples of this case. Great Lakes NWLON permanent stations will provide water level data referenced to an established Low Water Datum relative to International Great Lakes Datum of 1985 (IGLD ‘85) (see Standing Project Instructions: Great Lakes Water Levels, June 1978).

4.2.2. Water Level Measurement Systems and Data Transmissions

Water Level Sensor and Data Collection Platform

The water level sensor shall be a self-calibrating air acoustic, pressure (vented), or other suitable type. The sensor measurement range shall be greater than the expected range of water level. Gauge/sensor systems shall be calibrated prior to deployment, and the calibration shall be checked after removal from operations. The calibration standard’s accuracy must be traceable to National Institute of Standards and technology (NIST). The required water level sensor resolution is a function of the tidal range of the area in which hydrographic surveys are planned. For tidal range less than or equal to 5 m, the required water level sensor resolution shall be 1 mm or better; for tidal range between 5 m and 10 m, the required water level sensor resolution shall be 3 mm or better; and for tidal range greater than 10 m, the required water level sensor resolution shall be 5 mm or better.

The Data Collection Platform (DCP) shall acquire and store water level measurements at every 6- minutes. The water level measurements shall consist of an average of at least three minutes of discrete water level samples with the period of the average centered about the six minute mark (i.e. :00, :06, :12, etc.). In addition to the average measurement, the standard deviation of the discrete water level samples which comprise the 6-minute measurements shall be computed and stored. The 6-minute centered average water level data is required for compatibility with the NWLON stations, and the standard deviation provides valuable data quality information regarding each measurement. The clock accuracy of a satellite radio system shall be within 5 seconds per month so that channel “stepping” does not occur. Non-satellite radio systems shall have a clock accuracy of within one minute per month. Known error sources for each sensor shall be handled appropriately through ancillary measurements and/or correction algorithms. Examples of such errors are water density variations for pressure gauges, sound path air temperature differences for acoustic systems, and high frequency wave action and high velocity currents for all sensor types.

The NOS is currently using the Aquatrak® self-calibrating air acoustic sensors at the majority of the NWLON stations. (For further information refer to Next Generation Water level Measurement System (NGWLMS) Site Design, Preparation, and Installation Manual, NOAA/NOS, January 1991 and User's Guide for 8200 Acoustic Gauges, NOAA/NOS, Updated August 1998). At stations where the acoustic sensor can not be used due to freezing or the lack of a suitable structure, either a ParoScientific intelligent pressure (vented) sensor incorporated into a gas purge system, or a well/float with absolute shaft angle encoder (Great Lakes Stations) are used for water level measurements. (For further information refer to User's Guide for 8200 Bubbler Gauges, NOAA/NOS, Updated February 1998).

In each and any case, the water leveling sampling/averaging scheme shall be as described above. For short term subordinate stations which are installed to support NOS hydrographic surveys, the use of air acoustic sensor is preferred over pressure sensor whenever possible. Where the air acoustic sensor can not be installed, NOS uses a vented strain gauge pressure sensor in a bubbler configuration (Refer to User's Guide for 8200 Bubbler Gauges, NOAA/NOS, updated February 1998). When using the vented pressure sensor, a series of gauge/staff comparisons through a significant portion of a tidal cycle shall be required (1) at the start, (2) at frequent intervals during deployment, and (3) at the end of a deployment. Frequent gauge/staff comparisons (at least two times per week or minimum eight times per month) during deployment shall be required to assist in assuring measurement stability and minimizing processing type errors. The staff to gauge observations shall be at least three hours long at the beginning and end of deployment and the periodic observations during deployment shall be 1 hour long. Along with the averaging procedure described above which works as a digital filter, NOS uses a combination protective well/parallel plate assembly on the acoustic sensor and a parallel plate assembly (with 2" orifice chamber) on the bubbler orifice sensor to minimize systematic measurement errors due to wave effects and current effects, as shown in figure 4.1.

Data Transmissions

The ability to monitor water level measurement system performance for near real-time quality assurance is essential to properly support hydrographic survey operations. Therefore, it is required that, where access to the satellite is available, the measurement system shall be equipped with a GOES transmitter to telemeter the data to NOS every three hours. The data transmissions must use a message format identical to the format as currently implemented in NOS' Next Generation Water Level Measurement Systems (NGWLMS). This is required to assure direct compatibility with the NOS Data Management System (DMS). This data format is detailed in the reference document "NGWLMS GOES MESSAGE FORMATTING" (refer to Section 4.7 for References). Once station and gauge information is configured in DMS and station listed on the Hydro Hot List (HHL), the NOS Continuous Operational Real-Time System (CORMS) will monitor all water level measurement system GOES transmissions to assure they are operating properly, provided that the GOES data transmitted is compatible with NOS format. Data that is not transmitted by GOES, or data transmitted but not in NOS compatible GOES format, or is submitted to CO-OPS via diskette, CD-ROM, or such other digital media, must also conform to the format specified in the above document so that data can be loaded properly into DMS software. Refer to Section 4.6.3 for further details about the water level data format specifications.

Close coordination is required between hydrographer and Requirements and Development Division (RDD) of CO-OPS for all hydrographic water level installations with satellite transmission capability. NOS will assist in acquiring assigned platform ID's, time slots, etc. At least three business days prior to the initiation of GOES data transmission in the field, information about the station number, station name, latitude, longitude, platform-ID, transmit time, channel, and serial numbers of sensors, and DCP shall be faxed, phoned, or sent to RDD. Test transmissions conducted on site are outside this requirement. This station and DCP information must be configured in DMS before data transmissions begin so that the data will be accepted in DMS. The documentation required prior to transmission in field is defined in the NGWLMS Site

Report, Field Tide Note, or Water Level Station Report, as appropriate. (Refer to Section 4.6 Data Submission Requirements).

4.2.3. Station Installation, Operation and Removal

Hydrographers shall obtain all required permits and permissions for installation of the water level sensor(s), Data Collection Platforms (DCP), bench marks, and utilities, as required. The hydrographer shall be responsible for security and/or protective measures, as required. The hydrographer shall install all components in the manner prescribed by manufacturer, or installation manuals. The hydrographer or contractor shall provide CO-OPS of the position of all tide gauges installed before hydrography begins, including those that were not specified in the Statement of Work or Project Instructions, as appropriate. The positions of bench marks and stations installed or recovered shall be obtained as latitudes and longitudes (degrees, minutes, and hundredths of seconds).

The following paragraphs provide general information regarding requirements for station installation, operations and maintenance, and station removal.

Station Installation

A complete water level measurement gauge installation shall consist of the following:

(A) The installation of the water level measurement system (water level sensor(s), DCP, and satellite transmitter) and its supporting structure and a tide staff if required.

(B) The recovery and/or installation of a minimum number of bench marks and a level connection between the bench marks and the water level sensor(s), and tide staff as appropriate.

(C) The preparation of all documentation and forms.

Operation and Maintenance

When GOES telemetry and NOS satellite message format is used, the hydrographer shall monitor the near-real time water level gauge data daily for indications of sensor malfunction or failure, and for other causes of degraded or invalid data, such as marine fouling. This monitoring can be performed by accessing the CO-OPS web page (http://www.CO-OPS.NOS.NOAA.GOV) The data over this system are typically available for review within three to four hours after collection.

All repairs, adjustments, replacements, cleaning, or other actions potentially affecting sensor output or collection of data shall be documented in writing using appropriate maintenance forms (see section on water level station documentation below) and retained as part of the water level data record. This documentation shall include, but not be limited to, the following information: date and time of start and completion of the maintenance activity; date and time of adjustments in sensor/DCP, datum offset, or time; personnel conducting the work; parts or components replaced; component serial numbers; tests performed; etc.

Removal

A complete removal of the water level measurement gauge shall consist of the following:

(A) Closing levels - a level connection between the minimum number bench marks and the water level sensor(s) and tide staff as appropriate.

(B) Removal of the water level measurement system and restoration of the premises, reasonable wear and tear excepted.

(C) The preparation of all documentation, forms, data, and reports.

4.2.4. Tide Staffs

Staff

The hydrographer shall install a tide staff at a station if the reference measurement point of a sensor (zero of a gauge) cannot be directly leveled to the local bench marks, e.g. orifice is laid over sea floor in case of pressure based bubbler gauges. Even if a pressure gauge can be leveled directly, staff readings are still required for assessment of variations in gauge performance due to density variations in the water column over time. The tide staff shall be mounted independent of the water level sensor so that stability of the staff or sensor is maintained. Staff shall not be mounted to the same pile on which the water level sensor is located. The staff shall be plumb. When two or more staff scales are joined to form a long staff, the hydrographer shall take extra care to ensure the accuracy of the staff throughout its length. The distance between staff zero and the rod stop shall be measured before the staff is installed and after it is removed and the rod stop above staff zero height shall be reported on the documentation forms.

In areas of large tidal range and long sloping beaches (i.e. Cook Inlet and the Gulf of Maine), the installation and maintenance of tide staffs can be extremely difficult and costly. In these cases, the physical installation of a tide staff(s) may be substituted by systematic leveling to the water's edge from the closest bench mark. The bench mark becomes the "staff stop" and the elevation difference to the water's edge becomes the "staff reading".

Staff Observations

When using the vented pressure sensor, a series of gauge/staff comparisons through a significant portion of a tidal cycle shall be required (1) at the start, (2) at frequent intervals during deployment, and (3) at the end of a deployment. Frequent gauge/staff comparisons (at least three times per week or minimum eight times per month) during deployment shall be required to assist in assuring measurement stability and minimizing processing type errors. The staff to gauge observations at the start and end of deployment shall be at least each three hours long and the periodic observations during the deployment shall be 1 hour long.

If a gauge requiring independent staff readings is installed, the installation report must be accompanied by a 3-hour set of staff-to-gauge observations documenting the proper operation of the gauge. During the first or second day of gauge operations, the gauge and staff must be read simultaneously and recorded every 6 minutes for a 3-hour period. The staff-to-gauge differences should remain constant throughout the set of observations and show no increasing or decreasing trends. Gauge time should be set to Coordinated Universal Time (UTC). The gauge and staff shall be read simultaneously and recorded once a day (minimum of three days in each seven day period) for the duration of the water level measurements. The average staff-to-gauge difference shall be applied to water level measurements to relate the data to staff zero. A higher number of independent staff readings decreases the uncertainty in transferring the measurements to station datum and the bench marks. Refer to Figure 4.2 for an example pressure tide gauge record.

If the old staff is found destroyed by elements during the deployment, then a new staff shall be installed for the remainder period of the deployment and a new staff to gauge constant needs to be derived by new sets of staff to gauge observations. Also when a staff or an orifice is replaced or re-established, check levels shall be run to minimum of three bench marks including the PBM. Refer to Section 4.2.5 for leveling frequency and other leveling requirements. Bubbler Orifice and Parallel Plate Assembly

This bottom assembly is made of red brass, its chemical properties prevent the growth of marine life by the slowly releasing copper oxide on its metal surface. A Swagelok® hose fitting is screwed into the top end cap and is used to discharge the Nitrogen gas. The Nitrogen gas flows through the bottom of the orifice at a rate sufficient to overcome the rate of tidal change and wave height. This opening establishes the reference point for tidal measurements. The parallel plates produce a laminar flow across the orifice to prevent venturi effect. A two inch by eight inch pipe provides the correct volume gas for widest range of surf conditions encountered by most coastal surveys.

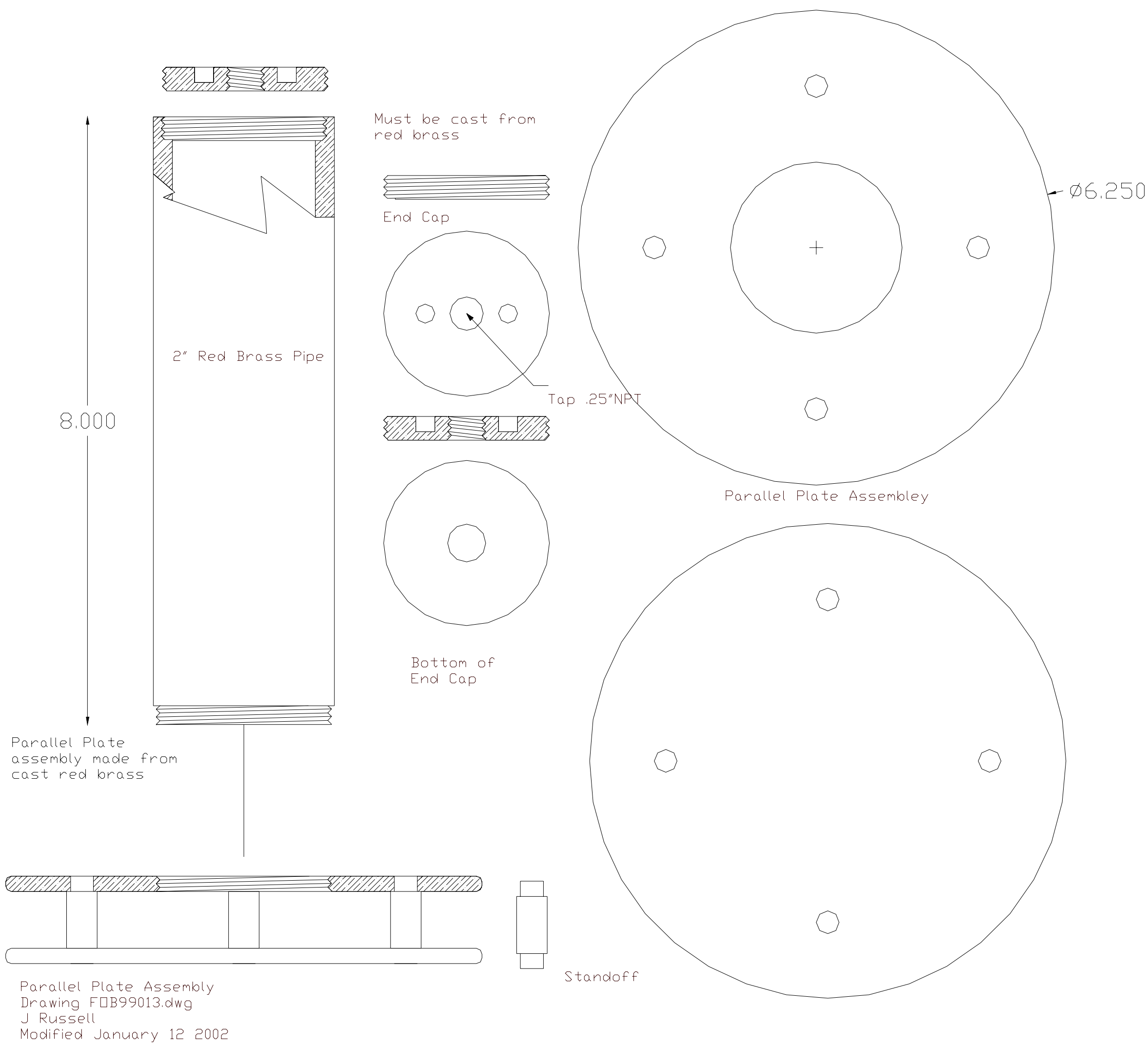

Figure 4.1 : Bubbler orifice bottom assembly

Figure 4.2 Example - Pressure Tide Gauge Record

4.2.5. Bench Marks and Leveling

PRESSURE TIDE GAUGE RECORD

Station Name: ____________________ **Station No. (7 digit #)** ____________________

Date	Time		Staff Reading		Gage/Staff	Gas Pressure		Wind	Air	
(M,D,Y)	Gage	Correct	High	Low	Diference	Cyln	Feed	(Dir/Spd)	Temp.	Remarks

Bench Marks

A bench mark is a fixed physical object or marker (monumentation) set for stability and used as a reference to the vertical and/or horizontal datums. Bench marks in the vicinity of a water level measurement station are used as the reference for the local tidal datums derived from the water level data. The relationship between the bench marks and the water level sensor or tide staff shall be established by differential leveling.

Number and Type of Bench Marks

The number and type of bench marks required depends on the duration of the water level measurements. The User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Level Stations, dated October 1987, specifies the installation and documentation requirements for the bench marks. Each station will have one bench mark designated as the primary bench mark (PBM), which shall be leveled to on every run. The PBM is typically the most stable mark in close proximity to the water level measurement station. The contractor shall select a PBM at sites where the PBM has not already been designated. For historic NOS station reoccupations, CO-OPS will furnish the name of the PBM and PBM elevation above station datum, as appropriate and if available.

The most desirable bench mark for GPS observations will have 360 degrees of horizontal clearance around the mark at 10 degrees and greater above the horizon and stability code of A or B. Refer to Section 4.2.8 GPS Observations, and User's Guide for GPS Observations, Updated January 2003, for further information.

If the PBM is determined to be unstable, another mark shall be designated as PBM. The date of change and the elevation difference between the old and new PBM shall be documented. NOAA will furnish the individual NOS standard bench mark disks to be installed. Bench mark descriptions shall be written according to User's Guide for Writing Bench Mark Descriptions, updated January 2003.

Leveling

At least third-order levels shall be run at short-term subordinate stations operated for less than one-year. Requirements for higher order levels will be specified in individual project instructions, as appropriate. Standards and specifications for leveling are found in Standards and Specifications for Geodetic Control Networks and Geodetic Leveling (NOAA Manual NOS NGS 3). Additional field requirements and procedures used by NOS for leveling at tide stations can be found in the User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Level Stations. Electronic digital/barcode level systems are acceptable. Specifications and standards for digital levels can be found in Standards and Specifications for Geodetic Control Networks and additional field requirements and procedures used by NOS for electronic leveling at water level stations can be found in the User's Guide for Electronic Levels, updated January 2003.

Leveling Frequency

Levels shall be run between the water level sensor(s) or tide staff and the required number of bench marks when the water level measurement station is installed, modified (e.g., water level sensor serviced, staff, or orifice replaced), for time series bracketing purposes, or prior to removal. In any case, levels are required at a maximum interval of six (6) months during the station's operation, and are recommended after severe storms, hurricanes, earthquakes to document stability (see stability discussed below).

Bracketing levels to appropriate number of marks (five for 30-day minimum stations) are required (a) if smooth tides are required 30 days or more prior to the planned removal of a applicable gauge(s), or (b) after 6 months for stations collecting data for long term hydrographic projects.

Stability

If there is an unresolved movement of the water level sensor or tide staff zero relative to the PBM, from one leveling to the next of greater than 0.010 m, the hydrographer shall verify the apparent movement by rerunning the levels between the sensor zero or tide staff to the PBM. This threshold of 0.010 m should not be confused with the closure tolerances used for the order and class of leveling.

4.2.6. Water Level Station Documentation

The field team shall maintain a documentation package for each water level measurement station installed for hydrographic projects. The documentation package shall be forwarded to CO-OPS within 10 business days of a) installation of a station, b) performance of bracketing levels, c) gauge maintenance and repair, or d) removal of the station.

Generally, all documentation submitted (see Section 4.6 for Data Submission Requirements) shall be forwarded to CO-OPS when a station is installed. For other situations, only information that has changed shall be submitted (e.g., levels and abstract for bracketing or removal levels, NGWLMS Site Report for maintenance and repair or station removal, etc.)

4.2.7. Additional Field Requirements

(A) Generally upon completion of the data acquisition for each gauge installed, the data must be sent all together for 30-day minimum stations unless the data are transmitted via satellite. For long term stations running more than three months, the data shall be sent periodically (monthly) unless the data are transmitted via satellite.

(B) All water level data from a gauge shall be downloaded and backed up at least weekly on diskettes whether the gauge data are sent via satellite or not.

(C) For new stations that do not have station numbers assigned, once the location of the gauge has been finalized then contact CO-OPS and provide latitude and longitude of the gauge site at least three business days prior to actual installation of the gauge in field. CO-OPS will assign a new station number within three business days and inform the hydrographer.

(D) The progress sketch shall show the field sheet, layout, area of hydrography, gauge locations, and other information as appropriate. Verify the location of the gauge as shown on the progress sketch, bench mark and tide station location sketch, field tide note, NGWLMS Site Report (or Tide Station Report or Great Lakes Water Level Station Report, as appropriate).

4.2.8. GPS Observations

GPS observations are required to obtain elevation ties between the tidal datums and GPS derived datums.

(A) High accuracy static differential GPS surveys require a geodetic quality, dual frequency, full-wavelength GPS receiver with a minimum of 10 channels for tracking GPS satellites.

A choke ring antenna is preferred, however, any geodetic quality ground plane antenna may be used. More important than antenna type, i.e. choke ring or ground plane, is that the same antennas or identical antennas should be used during the entire observing sessions. If not, a correction for the difference in antenna phase patterns (modeled phase patterns) must be applied. This is extremely critical for obtaining precise vertical results. The antenna cable length between the antenna and receiver should be kept to a minimum when possible; 10 meters is the typical antenna cable length. If a longer antenna cable is required, the cable must be fabricated from low loss coaxial cable (RG233 for up to 30 meters and RG214 over 30 meters).

(B) A fixed height precise GPS antenna tripod is required for this type of a survey. This is a fixed height, 2 meter pole with three adjustable legs, a bulls eye bubble to plumb the antenna, and a magnetic compass to align the antenna to North. These fixed height tripods reduce the chance of introducing an Height of Instrument (HI) “blunder” during the post-processing of the data.

(C) The manufacturer, model, and complete serial numbers of all receivers and antennas must be included for each occupation on each station/bench mark observation log sheet as shown in Figure 4.18

(D) The station bench mark selected for GPS observations shall have stability code either an A or B. GPS observations on the PBM are preferred if the PBM has the stability code of A or B and also if it is suitable for satellite observations. Stability code C and D bench marks shall not be used for GPS observations. Generally once a mark is selected for GPS observations, future GPS observations shall be done on the same mark. It may be necessary to select new GPS marks, or set new marks, at some stations to ensure stability over time as the case may be.

(E) Additional GPS suitable marks shall also be connected during the static survey using rapid static GPS procedures to verify bench mark stability, if time and personnel resources are available. Priority shall be given to connecting to the NSRS, particularly to the North American Vertical Datum of 1988 (NAVD 88) bench marks.

(F) All existing station bench marks at operating stations shall be assessed for feasibility of GPS observations, as time and resources permit. A note shall be made, either in the APP field of the electronic leveling HA file, if electronic levels are used, or on the bench mark descriptions sheet, stating the suitability of GPS observations for each mark. GPS visibility obstruction diagram shall also be completed for each mark observed as shown in Figure 4.20.

(G) The most desirable bench mark for GPS observations will have 360 degrees clearance around the mark at 10 degrees and greater above the horizon. Newly established marks shall be set in locations that have the required clearances, if at all possible. Public property is usually a good location choice. If a station does not have any marks suitable for GPS observations, and it has been selected as needing GPS observations, a new 3-D rod mark or a mark installed in rock outcrop with stability A shall be established according to NOS standard procedure. This new mark shall be connected to the station bench mark network through conventional geodetic leveling, and then GPS observations shall be made.

(H) Static GPS surveys shall be conducted on a minimum of one bench mark, preferably two marks if time and resources permit, at each subordinate water level station installed/occupied for hydrography.

(I) Static GPS surveys shall be conducted at water level stations concurrently with the occupation of NAVD 88 marks, if possible, to accomplish water level datum transfers using GPS-derived orthometric heights.

(J) A digital photo of the stamping of the bench mark occupied must be made as shown in Figure 4.22. If digital photo is not available, then a rubbing of the bench mark must be done as shown in Figure 4.21. A digital photo of the stamping is preferred over rubbing of the mark.

(K) Set the epoch update or recording interval (REC INT) for 15-seconds, which should agree with the recording interval of the reference stations (IGS or CORS) used to post-process the data. For GPS sessions greater than 30 minutes, collect data at 15-second epoch intervals, starting at an even minute. The elevation mask (ELEV MASK) is typically set for 10 degrees for static surveys; low angle satellites can degrade the final solution. Set the minimum number of satellites to four. For static surveying, setting the minimum number of satellites (MIN SV) is not as critical as for kinematic surveying. However, if the number of satellites tracked drops below four, it could be an indication of other problems, such as an antenna or antenna cable connection problem, RF interference, or an obstruction from traffic (vehicle or vessel). The GPS signal from the satellite is not very strong when entering the receiver, so anything that produces further attenuation of the signal can cause the receiver to stop tracking satellites

(L) The length of GPS observation sessions depends upon the length of the time field crew has available for GPS observations, number of satellites available at a site, number of bench marks available for GPS observations, etc. The basic requirement for GPS observations on a bench mark is minimum two sessions of 6 hours each and both sessions should begin with proper antenna setup. The two GPS observation sessions on the same bench mark shall be done on the same day or on two different days. When two sessions are done (whether on the same day or on two different days), then close down the antenna at the end of the first session and re-setup the antenna at the beginning of the second session. If two sessions are done on the same day, then start the second session at least after ½ hour after the completion of the first session. If two GPS observation sessions are selected on two different days, then ideally the second session should start 28 hours after the beginning of the first session so that a different set of GPS satellites are available for the second session. When two sessions are done on the same day, the gap between the end of the first session and the beginning of the second session can be, or need to be increased if PDOP is not suitable for observations, this is applicable only if PDOP information is available to the field crew.

For contract and NOAA hydrographic surveys and special projects three GPS observation sessions of 6 hours each on two or three different days are recommended, if time and resources permit. If three GPS sessions are done then they should be spread over minimum two different days. Two GPS sessions can be done the same day, or on two different days.

If only one GPS observation session is possible for the available time, then record minimum of 24 hours of GPS observations on a bench mark. Minimum two GPS observation sessions of 6 hours each are preferred over one long 24 hour GPS session.

Always collect a little bit of extra data if time and schedule permit, so that blunders or invalid data, if any, can be removed during processing still leaving minimum of 24 hours of valid data for one GPS session, or 6 hours of valid data for each session for two (or three as the case may be) GPS sessions.

(M) It is recommended that after the session is complete, two independent downloads be done from the GPS receiver to the laptop computer, so that if one downloaded file gets corrupted, the other file may have good data. Since two downloads of the GPS observation file is a requirement, do not make copy of the downloaded file twice to the laptop instead, as both the files will have the same problem, if there exists a problem. Send both copies of digital GPS data so that one copy of the data can be forwarded to NGS and other copy will be kept for record in CO-OPS.

(N) Meteorological data (air temperature, barometric pressure, and relative humidity) need to be collected, if available, during the GPS observations. Collect appropriate meteorological data at the beginning, middle, and at the end of each GPS session, if a sensor is available and GPS session length is greater than 2 hours. If a sensor is available, then air temperature must be observed and recorded to the nearest 1° Celsius, and barometer must be observed and recorded to at least nearest 1 millibar. Meteorological data should be collected at or near the antenna phase center. All equipment should be checked for proper calibration periodically.

If none of the meteorological sensors (air temperature, barometric pressure, and relative humidity) are available for recording observations, then note any change in the atmospheric conditions on the GPS station/bench mark observation log form under Remarks section.

(O) GPS (horizontal) positions (latitude and longitude) of each bench mark installed or recovered shall be listed on the HA files for laser levels, if used, or on the bench mark descriptions sheet for optical leveling, as applicable, at each subordinate water level station occupied for hydrography.

(P) Refer to Section 4.6.2. for GPS Project Documentation requirements later in this document.

4.3. Data Processing and Reduction

4.3.1. Data Quality Control

The required output product used in generation of tide reducers and for tidal datum determination is a continuous time series of 6-minute interval water level data for the desired time period of hydrography and for a specified minimum time period from which to derive tidal datums. CO-OPS will monitor the installed system operation information for all gauges equipped with GOES satellite radios. The 6-minute interval water level data from the water level gauges shall be quality controlled to NOS standards by the contractor for invalid and suspect data as a final review prior to product generation and application. This includes checking for data gaps, data discontinuities, datum shifts, anomalous data points, data points outside of expected tolerances such as expected maximum and minimum values and for anomalous trends in the elevations due to sensor drift or vertical movement of the tide station components and bench marks.

Quality control shall include comparisons with simultaneous data from backup gauges, predicted tides or data from nearby stations, as appropriate. Data editing and gap filling shall use documented mathematically sound algorithms and procedures and an audit trail shall be used to track all changes and edits to observed data. All inferred data shall be appropriately flagged. Water level measurements from each station shall be related to a single, common datum, referred to as Station Datum. Station Datum is an arbitrary datum and should not be confused with a tidal datum such as MLLW. All discontinuities, jumps, or other changes in the gauge record (refer to the specific gauge user's guide) that may be due to vertical movement of any the gauge, staff, or bench marks shall be fully documented. All data shall be recorded on UTC and the units of measurement shall be properly denoted on all hard-copy output and digital files. Refer to Section 4.6 Data Submission Requirements for details.

4.3.2. Data Processing and Tabulation of the Tide

The continuous 6-minute interval water level data are used to generate the standard tabulation output products. These products include the times and heights of the high and low waters, hourly heights, maximum and minimum monthly water levels, and monthly mean values for the desired parameters. Examples of these tabulation products are found in Figures 4.3 and 4.4 for tide stations and 4.5 for Great Lakes stations. The times and heights of the high and low waters shall be derived from appropriate curve-fitting of the 6-minute interval data. For purposes of tabulation of the high and low tides and not non-tidal high frequency noise, successive high and low tides shall not be tabulated unless they are greater than 2.0 hours apart in time and 0.030 meters different in elevation. Hourly heights shall be derived from every 6-minute value observed on the hour. Monthly mean sea level and monthly mean water level shall be computed from the average of the hourly heights over each calendar month of data. Data shall be tabulated relative to a documented consistent station datum such as tide staff zero, arbitrary station datum, MLLW, etc.. over the duration of the data observations. Descriptions of general procedures used in tabulation are also found in the *Tide and Current Glossary, Manual of Tide Observations,* and *Tidal Datum Planes.*

4.3.3. Computation of Monthly Means

Monthly means are derived on a calendar month basis in accordance with the definitions for the monthly mean parameters as found in the Tide and Current Glossary. Examples of the desired monthly means are found in figures 4.4 and 4.6. For purposes of monthly mean computation, monthly means shall not be computed if gaps in data are greater than three consecutive days.

4.3.4. Data Editing and Gap Filling Specifications

When backup sensor data are not available, data gaps in 6-minute data shall not be filled if the gaps are greater than three consecutive days in length. Data gap filling shall use documented mathematically and scientifically sound algorithms and procedures and an audit trail shall be used to track all gap-fills in observed data. Data gaps of less than 3-hours can be inferred using interpolation and curve-fitting techniques. Data gaps of longer than three hours shall use external data sources such as data from a nearby station. All data derived through gap-filling procedures shall be marked as inferred. Individual hourly heights, high and low waters, and daily means derived from inferred data shall also be designated as inferred.

Figure 4.3

TIDES, HIGH AND LOW WATERS July 1998
National Ocean Service (NOAA)
Water Level Heights in meters on Station Datum

Station: 9414290 SAN FRANCISCO, SAN FRANCISCO BAY , CA
Time Meridian: 0 W Tide Type: Mixed

	HIGH		LOW			HIGH		LOW	
DAY	TIME	HEIGHT	TIME	HEIGHT	DAY	TIME	HEIGHT	TIME	HEIGHT
1	> 1.4	3.337	6.8	2.521	16	> 0.6	3.550	6.2	2.343
	12.6	2.996	> 18.5	2.253		12.6	3.187	> 18.1	2.195
2	> 2.0	3.393	7.8	2.434	17	> 1.4	3.654	7.4	2.205
	13.9	2.950	> 19.4	2.406		14.1	3.096	19.0	2.335
3	> 2.6	3.458	> 9.1	2.367	18	> 2.2	3.725	> 8.6	2.054
	15.2	2.941	20.1	2.498		15.6	3.132	20.2	2.504
4	> 3.2	3.524	> 9.7	2.210	19	> 3.1	3.819	> 9.7	1.891
	16.5	2.988	21.1	2.612		16.9	3.188	21.5	2.586
5	> 4.0	3.584	> 10.3	2.018	20	> 4.1	3.899	>10.7	1.763
	17.6	3.054	22.0	2.644		18.0	3.267	22.5	2.597
6	> 4.6	3.656	> 11.1	1.913	21	> 4.9	3.903	>11.6	1.654
	18.3	3.124	22.7	2.682		18.8	3.309	23.4	2.583
7	> 5.1	3.711	> 11.8	1.812	22	> 6.0	3.884		
	19.1	3.194	23.4	2.697		19.6	3.347	>12.4	1.587
8	> 5.8	3.754			23	> 6.4	3.880	0.2	2.587
	19.7	3.223	> 12.4	1.730		20.3	3.390	>13.1	1.611
9	> 6.3	3.789	0.1	2.703	24	> 7.4	3.833	1.1	2.586
	20.4	3.285	> 13.1	1.669		20.9	3.409	> 13.9	1.659
10	> 7.3	3.795	0.9	2.709	25	> 8.1	3.780	1.7	2.562
	21.1	3.306	> 13.7	1.627		21.6	3.445	> 14.5	1.719
11	> 8.0	3.712	1.6	2.614	26	> 8.7	3.668	2.6	2.564
	21.7	3.302	> 14.4	1.579		22.2	3.437	> 14.9	1.826
12	> 8.8	3.639	2.5	2.584	27	> 9.3	3.510	3.2	2.549
	22.3	3.356	> 15.1	1.609		>22.8	3.416	> 15.6	1.932
13	> 9.3	3.547	3.1	2.530	28	10.1	3.356	4.1	2.538
	23.1	3.419	> 15.6	1.692		>23.5	3.430	> 16.1	2.042
14	10.1	3.443	4.1	2.522	29	10.9	3.202	5.0	2.495
	> 23.9	3.484	> 16.5	1.800				> 16.6	2.199
15	11.3	3.282	5.1	2.422	30	> 0.1	3.432	5.9	2.492
			> 17.0	1.967		12.0	3.099	> 17.3	2.402
					31	> 0.8	3.472	> 6.9	2.431
						13.1	3.018	18.5	2.513

HIGHEST TIDE: 3.903 4.9 HRS Jul 21 1998
LOWEST TIDE: 1.579 14.4 HRS Jul 11 1998

MONTHLY MEANS FOR July 1998

HWL	3.903				
MHHW	3.641	DHQ	0.208		
MHW	3.433			GT	1.720
MTL	2.832			MN	1.203
DTL	2.781				
MSL	2.816				
MLW	2.230	DLQ	0.309		
MLLW	1.921				
LWL	1.579				
		HWI	7.570 HRS		
		LWI	0.760 HRS		

> higher high/lower low waters [ ] denotes inferred water level values Data Status: Verified

Figure 4.4

HOURLY WATER LEVELS

National Ocean Service (NOAA) July 1998

Water Level Heights in meters on Station Datum

Station: 9414290 SAN FRANCISCO, SAN FRANCISCO BAY , CA Time Meridian 0 W Tide Type: Mixed

HOUR	Jul 1	Jul 2	Jul 3	Jul 4	Jul 5	Jul 6	Jul 7	Jul 8	Jul 9	Jul 10	Jul 11	Jul 12	Jul 13	Jul 14	Jul 15	Jul 16
00	3.247	3.183	3.119	3.052	2.936	2.837	2.770	2.724	2.717	2.763	2.814	2.960	3.152	3.354	3.481	3.529
01	3.329	3.333	3.319	3.274	3.157	3.066	2.972	2.851	2.762	2.694	2.637	2.723	2.901	3.162	3.365	3.517
02	3.311	3.391	3.449	3.437	3.378	3.293	3.173	3.060	2.913	2.799	2.627	2.602	2.653	2.868	3.123	3.395
03	3.164	3.312	3.463	3.526	3.526	3.504	3.423	3.298	3.171	2.988	2.750	2.618	2.529	2.621	2.792	3.103
04	2.948	3.158	3.338	3.469	3.595	3.629	3.617	3.555	3.420	3.261	2.985	2.755	2.606	2.523	2.523	2.741
05	2.725	2.914	3.091	3.304	3.474	3.628	3.714	3.707	3.652	3.519	3.247	3.012	2.757	2.576	2.423	2.459
06	2.558	2.651	2.811	3.012	3.209	3.430	3.640	3.740	3.782	3.711	3.508	3.252	2.986	2.745	2.472	2.302
07	2.528	2.451	2.531	2.651	2.833	3.112	3.342	3.580	3.746	3.785	3.668	3.485	3.217	2.954	2.619	2.399
08	2.581	2.453	2.387	2.366	2.448	2.653	2.915	3.225	3.496	3.677	3.715	3.628	3.433	3.155	2.804	2.480
09	2.648	2.510	2.375	2.228	2.133	2.243	2.435	2.701	3.060	3.348	3.540	3.626	3.535	3.354	2.997	2.651
10	2.778	2.568	2.400	2.229	2.017	1.994	2.057	2.236	2.477	2.819	3.159	3.410	3.510	3.444	3.185	2.870
11	2.890	2.696	2.494	2.280	2.057	1.909	1.859	1.919	2.081	2.327	2.576	2.970	3.257	3.389	3.283	3.040
12	2.976	2.813	2.643	2.431	2.159	1.972	1.826	1.719	1.774	1.922	2.101	2.422	2.818	3.165	3.248	3.162
13	2.995	2.917	2.750	2.581	2.327	2.124	1.913	1.756	1.674	1.667	1.781	2.000	2.350	2.735	3.051	3.175
14	2.904	2.945	2.897	2.760	2.559	2.338	2.117	1.908	1.744	1.633	1.588	1.706	1.946	2.305	2.737	3.069
15	2.742	2.903	2.922	2.898	2.778	2.611	2.387	2.154	1.944	1.759	1.625	1.612	1.732	1.965	2.365	2.831
16	2.505	2.783	2.909	2.986	2.937	2.862	2.683	2.455	2.260	2.014	1.791	1.690	1.697	1.794	2.053	2.492
17	2.359	2.594	2.814	2.976	3.040	3.034	2.954	2.786	2.585	2.366	2.084	1.911	1.852	1.854	1.971	2.258
18	2.250	2.473	2.649	2.915	3.028	3.137	3.124	3.015	2.936	2.739	2.449	2.242	2.074	1.986	2.020	2.177
19	2.272	2.401	2.550	2.773	2.960	3.099	3.190	3.187	3.141	3.021	2.814	2.618	2.419	2.256	2.193	2.269
20	2.336	2.413	2.484	2.647	2.812	2.990	3.149	3.215	3.271	3.239	3.094	2.975	2.797	2.595	2.462	2.415
21	2.508	2.514	2.527	2.637	2.690	2.843	2.999	3.128	3.251	3.310	3.275	3.220	3.131	2.954	2.781	2.677
22	2.736	2.685	2.631	2.636	2.634	2.709	2.835	2.982	3.130	3.233	3.280	3.369	3.339	3.242	3.104	2.961
23	2.965	2.912	2.814	2.752	2.703	2.700	2.688	2.779	2.916	3.063	3.177	3.322	3.422	3.417	3.336	3.284
Mean	2.761	2.791	2.807	2.826	2.808	2.822	2.824	2.820	2.829	2.819	2.762	2.755	2.755	2.767	2.766	2.802

HOUR	Jul 17	Jul 18	Jul 19	Jul 20	Jul 21	Jul 22	Jul 23	Jul 24	Jul 25	Jul 26	Jul 27	Jul 28	Jul 29	Jul 30	Jul 31	
00	3.514	3.373	3.180	2.993	2.778	2.625	2.586	2.678	2.821	3.048	3.228	3.317	3.411	3.444	3.438	
01	3.654	3.617	3.485	3.264	3.035	2.810	2.649	2.586	2.613	2.749	2.951	3.122	3.270	3.357	3.466	
02	3.620	3.720	3.720	3.573	3.322	3.071	2.848	2.682	2.573	2.590	2.680	2.834	3.030	3.195	3.394	Monthly
03	3.427	3.686	3.818	3.785	3.641	3.379	3.133	2.884	2.694	2.576	2.550	2.625	2.735	2.937	3.148	Max HWL
04	3.111	3.433	3.737	3.907	3.840	3.659	3.444	3.201	2.926	2.761	2.591	2.538	2.547	2.704	2.888	04:54/21
05	2.704	3.048	3.487	3.775	3.898	3.849	3.697	3.460	3.206	2.978	2.759	2.586	2.487	2.523	2.660	3.903
06	2.398	2.607	3.017	3.452	3.745	3.887	3.866	3.717	3.505	3.247	2.976	2.757	2.553	2.486	2.467	
07	2.215	2.254	2.539	2.948	3.376	3.678	3.851	3.828	3.704	3.501	3.210	2.928	2.697	2.545	2.448	
08	2.255	2.073	2.167	2.436	2.810	3.269	3.593	3.770	3.778	3.652	3.390	3.150	2.860	2.659	2.477	Monthly
09	2.319	2.064	1.953	2.018	2.299	2.662	3.083	3.430	3.637	3.659	3.504	3.302	3.031	2.809	2.571	Min LWL
10	2.483	2.155	1.884	1.806	1.896	2.146	2.526	2.942	3.284	3.486	3.479	3.358	3.144	2.948	2.725	14:24/11
11	2.691	2.304	1.993	1.757	1.696	1.794	2.071	2.397	2.758	3.107	3.252	3.294	3.203	3.055	2.856	1.579
12	2.876	2.544	2.195	1.877	1.664	1.603	1.743	1.981	2.282	2.618	2.907	3.090	3.119	3.107	2.975	
13	3.037	2.784	2.453	2.094	1.808	1.637	1.621	1.723	1.924	2.215	2.471	2.741	2.953	3.037	3.031	
14	3.088	2.995	2.738	2.387	2.076	1.816	1.662	1.644	1.740	1.919	2.149	2.402	2.658	2.905	2.975	Monthly
15	3.038	3.104	2.978	2.738	2.434	2.122	1.918	1.797	1.762	1.827	1.956	2.144	2.396	2.676	2.908	Mean
16	2.880	3.119	3.134	3.028	2.790	2.510	2.249	2.056	1.942	1.882	1.950	2.016	2.231	2.493	2.725	MSL
17	2.621	3.011	3.191	3.220	3.078	2.887	2.646	2.422	2.219	2.117	2.061	2.118	2.218	2.398	2.595	2.816
18	2.400	2.812	3.107	3.284	3.266	3.162	3.018	2.791	2.604	2.412	2.302	2.244	2.299	2.432	2.508	
19	2.323	2.600	2.938	3.179	3.300	3.316	3.273	3.162	2.978	2.775	2.615	2.496	2.465	2.490	2.527	
20	2.402	2.513	2.731	3.013	3.210	3.336	3.394	3.345	3.271	3.109	2.939	2.795	2.688	2.663	2.620	
21	2.554	2.550	2.605	2.755	3.012	3.214	3.345	3.401	3.415	3.335	3.215	3.075	2.963	2.884	2.766	
22	2.789	2.698	2.619	2.612	2.735	2.975	3.189	3.316	3.427	3.428	3.369	3.310	3.184	3.109	2.984	
23	3.073	2.920	2.760	2.631	2.613	2.707	2.912	3.118	3.300	3.400	3.407	3.429	3.373	3.308	3.178	
Mean	2.811	2.833	2.851	2.855	2.847	2.838	2.847	2.847	2.848	2.850	2.830	2.820	2.813	2.840	2.847	

[ ] denotes inferred water level values Data Status: Verified

Figure 4.5

HOURLY WATER LEVELS

National Ocean Service (NOAA) July 1998

Water Level Heights in meters IGLD (1985)

Station: 9052030 Oswego, Lake Ontario , NY Time Meridian: 75 W Data Type: Great Lakes

HOUR	Jul 1	Jul 2	Jul 3	Jul 4	Jul 5	Jul 6	Jul 7	Jul 8	Jul 9	Jul 10	Jul 11	Jul 12	Jul 13	Jul 14	Jul 15	Jul 16
01	75.21	75.21	75.19	75.18	75.19	75.17	75.15	75.17	75.17	75.20	75.21	75.21	75.20	75.17	75.17	75.17
02	75.25	75.21	75.19	75.19	75.22	75.14	75.17	75.16	75.19	75.19	75.20	75.22	75.18	75.17	75.18	75.16
03	75.26	75.21	75.19	75.17	75.19	75.18	75.18	75.16	75.16	75.19	75.21	75.19	75.18	75.18	75.15	75.17
04	75.25	75.20	75.19	75.20	75.21	75.18	75.17	75.16	75.17	75.20	75.21	75.18	75.17	75.18	75.16	75.16
05	75.25	75.21	75.20	75.19	75.21	75.18	75.17	75.20	75.20	75.18	75.21	75.20	75.19	75.17	75.19	75.16
06	75.25	75.21	75.19	75.20	75.20	75.19	75.17	75.16	75.19	75.20	75.20	75.20	75.17	75.17	75.14	75.15
07	75.25	75.20	75.19	75.19	75.19	75.17	75.18	75.20	75.20	75.19	75.21	75.20	75.18	75.17	75.14	75.17
08	75.24	75.21	75.19	75.21	75.20	75.17	75.17	75.14	75.19	75.20	75.22	75.20	75.19	75.15	75.18	75.15
09	75.24	75.21	75.19	75.20	75.19	75.19	75.16	75.17	75.18	75.18	75.22	75.20	75.19	75.18	75.16	75.14
10	75.24	75.20	75.19	75.18	75.19	75.18	75.16	75.20	75.17	75.20	75.22	75.22	75.18	75.18	75.17	75.16
11	75.23	75.19	75.17	75.18	75.20	75.18	75.15	75.15	75.19	75.20	75.22	75.20	75.19	75.18	75.16	75.15
12	75.22	75.21	75.18	75.18	75.17	75.17	75.17	75.16	75.17	75.19	75.22	75.20	75.18	75.18	75.17	75.16
13	75.22	75.20	75.18	75.19	75.18	75.16	75.16	75.15	75.17	75.18	75.21	75.19	75.19	75.17	75.16	75.16
14	75.23	75.20	75.19	75.21	75.18	75.19	75.14	75.15	75.16	75.18	75.20	75.22	75.17	75.17	75.18	75.17
15	75.22	75.21	75.17	75.19	75.17	75.15	75.14	75.18	75.17	75.19	75.20	75.18	75.18	75.17	75.17	75.17
16	75.21	75.20	75.19	75.18	75.19	75.16	75.18	75.18	75.17	75.19	75.19	75.19	75.17	75.16	75.16	75.16
17	75.21	75.20	75.20	75.21	75.20	75.17	75.17	75.18	75.17	75.19	75.20	75.18	75.17	75.17	75.17	75.15
18	75.22	75.20	75.20	75.21	75.21	75.20	75.18	75.18	75.15	75.17	75.20	75.18	75.16	75.15	75.16	75.16
19	75.21	75.20	75.19	75.21	75.19	75.19	75.18	75.20	75.18	75.22	75.19	75.19	75.17	75.16	75.16	75.17
20	75.20	75.22	75.19	75.25	75.19	75.17	75.18	75.18	75.20	75.22	75.20	75.20	75.16	75.16	75.16	75.13
21	75.20	75.18	75.18	75.15	75.19	75.19	75.15	75.19	75.22	75.18	75.21	75.19	75.18	75.16	75.15	75.17
22	75.21	75.20	75.17	75.17	75.19	75.18	75.19	75.17	75.23	75.20	75.21	75.19	75.18	75.18	75.15	75.13
23	75.20	75.19	75.17	75.24	75.19	75.16	75.18	75.19	75.22	75.22	75.21	75.17	75.18	75.16	75.17	75.13
24	75.21	75.20	75.17	75.20	75.18	75.17	75.17	75.19	75.18	75.21	75.21	75.18	75.18	75.15	75.16	75.15
Mean	75.23	75.20	75.19	75.19	75.19	75.18	75.17	75.17	75.18	75.20	75.21	75.19	75.18	75.17	75.16	75.16

HOUR	Jul 17	Jul 18	Jul 19	Jul 20	Jul 21	Jul 22	Jul 23	Jul 24	Jul 25	Jul 26	Jul 27	Jul 28	Jul 29	Jul 30	Jul 31	
01	75.17	75.17	75.14	75.12	75.13	75.14	75.11	75.16	75.14	75.11	75.09	75.07	75.07	75.10	75.09	
02	75.17	75.18	75.14	75.16	75.12	75.16	75.12	75.16	75.14	75.10	75.08	75.09	75.06	75.11	75.08	
03	75.16	75.19	75.15	75.15	75.11	75.16	75.12	75.15	75.13	75.10	75.08	75.06	75.06	75.10	75.08	Monthly
04	75.17	75.18	75.14	75.14	75.13	75.15	75.10	75.14	75.14	75.10	75.07	75.09	75.02	75.09	75.08	Max HWL
05	75.16	75.18	75.16	75.13	75.14	75.13	75.14	75.16	75.13	75.10	75.06	75.11	75.07	75.08	75.08	03:00/01
06	75.17	75.16	75.15	75.16	75.10	75.17	75.12	75.16	75.12	75.10	75.06	75.07	75.16	75.07	75.08	75.259
07	75.16	75.16	75.17	75.14	75.12	75.13	75.14	75.14	75.13	75.10	75.07	75.06	75.14	75.07	75.07	
08	75.16	75.16	75.14	75.15	75.15	75.12	75.14	75.16	75.13	75.10	75.06	75.08	75.11	75.05	75.07	
09	75.15	75.15	75.11	75.14	75.12	75.20	75.15	75.17	75.13	75.11	75.06	75.06	75.10	75.08	75.07	Monthly
10	75.16	75.15	75.11	75.14	75.11	75.18	75.10	75.15	75.13	75.12	75.08	75.07	75.11	75.07	75.06	Min LWL
11	75.16	75.16	75.13	75.14	75.11	75.16	75.11	75.16	75.12	75.11	75.08	75.06	75.11	75.06	75.07	04:00/29
12	75.16	75.17	75.16	75.14	75.12	75.12	75.13	75.14	75.11	75.11	75.09	75.07	75.12	75.10	75.07	75.021
13	75.16	75.15	75.14	75.14	75.12	75.14	75.13	75.14	75.11	75.10	75.07	75.05	75.08	75.08	75.07	
14	75.16	75.17	75.13	75.15	75.10	75.11	75.14	75.14	75.10	75.11	75.06	75.08	75.08	75.08	75.06	
15	75.17	75.16	75.13	75.13	75.12	75.12	75.12	75.13	75.11	75.09	75.07	75.06	75.07	75.08	75.05	Monthly
16	75.16	75.16	75.13	75.13	75.13	75.14	75.14	75.13	75.12	75.09	75.08	75.05	75.09	75.05	75.06	Mean
17	75.18	75.16	75.13	75.13	75.08	75.11	75.16	75.13	75.10	75.07	75.08	75.07	75.08	75.09	75.06	MSL
18	75.17	75.15	75.14	75.16	75.12	75.13	75.13	75.13	75.10	75.07	75.08	75.06	75.08	75.09	75.06	75.152
19	75.16	75.16	75.13	75.14	75.11	75.11	75.10	75.14	75.10	75.08	75.06	75.05	75.07	75.09	75.06	
20	75.17	75.16	75.16	75.15	75.12	75.13	75.16	75.14	75.11	75.09	75.06	75.07	75.09	75.07	75.06	
21	75.18	75.14	75.11	75.13	75.16	75.12	75.17	75.14	75.11	75.08	75.07	75.05	75.09	75.07	75.04	
22	75.18	75.15	75.14	75.13	75.10	75.15	75.17	75.14	75.11	75.08	75.07	75.06	75.09	75.08	75.06	
23	75.18	75.14	75.14	75.12	75.09	75.14	75.18	75.14	75.11	75.08	75.09	75.05	75.10	75.08	75.05	
24	75.19	75.14	75.11	75.11	75.09	75.12	75.17	75.15	75.11	75.09	75.10	75.08	75.09	75.09	75.06	
Mean	75.17	75.16	75.14	75.14	75.12	75.14	75.14	75.15	75.12	75.10	75.07	75.07	75.09	75.08	75.07	

[ ] denotes inferred water level values Data Status: Verified

4.4. Computation of Tidal Datums and Water Level Datums

4.4.1. National Tidal Datum Epoch

Tidal datums must be computed relative to a specific 19 year tidal cycle adopted by the National Ocean Service (NOS) called the National Tidal Datum Epoch (NTDE). The present NTDE is the period 1983 through 2001. A primary datum determination is based directly on the average of tide observations over the 19 year Epoch period at NOS permanent long term primary control stations in the National Water Level Observation Network (NWLON). The data from NOS primary stations are used to compute datums at short term subordinate stations by reducing the data from those subordinate stations to equivalent 19 year mean values through the method of comparison of simultaneous observation.

4.4.2. Computational Procedures

The equivalent 19 year tidal datums for subordinate stations are computed for certain phases of the tide using tide-by-tide comparisons or monthly mean comparisons with an appropriate NOS long term control station. Accepted 19 year mean values of mean tide level (MTL), mean range (Mn), diurnal high water inequality (DHQ), diurnal low water inequality (DLQ), diurnal tide level (DTL), and great diurnal range (Gt) are required in the reduction process in which a "short series" of tide observations at any location are compared with simultaneous observations from an NOS control station. Datums are computed by the "standard" method of range ratio comparison generally on the West coast and Pacific Islands where there exists a large diurnal inequality in the low and high waters. The "modified" method of range ratio comparison is generally used on the East coast and Caribbean where small differences exist in the low and high water diurnal inequalities. For stations requiring a datum determination, at least 30 continuous days of tide observations are required for stations where adequate primary datum control exists. For error budget purposes, one month of data results in a datum accuracy of 0.11 m (95% confidence level) for Stations in the Gulf of Mexico and 0.08 m (95% confidence level) for east and West Coast stations. Examples of a tide by tide and a monthly mean simultaneous comparison for datum determination are found in Figures 4.6 and 4.7. Descriptions of the tidal datum computational procedures are found in the *Tide and Current Glossary, Tidal Datum Planes, Manual of Tide Observations, NOAA Special Publication NOS CO-OPS 1Tidal Datums and Their Applications and Computational Techniques for Tidal Datums.*

4.4.3. Tidal Datum Recovery

Whenever tide stations are installed at historical sites, measures shall be taken to "recover" the established tidal datums through leveling which shall be accomplished by referencing the gauge or tide staff zero "0" to more than one existing bench mark (three bench marks are preferred) with a published tidal elevation. Through this process, the published MLLW elevation is transferred by level differences to the "new" gauge or tide staff and compared to the MLLW elevation computed from the new data on the same zero "0". Factors affecting the datum recovery (i.e. differences between old and newly computed datums) include the length of each data series used to compute the datums, the geographical location, the tidal characteristics in the region, the length of time between reoccupations, the sea level trends in the region, and the control station used. Based on all of these factors, the datum recovery can be expected to vary from +/- 0.03 m to +/- 0.08 m. Hence, this process also serves as a very useful quality control procedure. After a successful datum recovery is performed and benchmark stability is established, the historical value of Mean Lower Low Water (MLLW) shall be used as the operational datum reference for data from the gauge during hydrographic survey operations. An example of a published tidal datum sheet for a station for which a datum recovery could be made is found in Figure 4.8.

Figure 4.6

COMPARISON OF SIMULTANEOUS OBSERVATIONS FOR 98 6 15 TO 98 7 14 9/11/1998
1960-1978 TIDAL EPOCH (EXPECTED DIFFERENCE (STATION A - STATION B) = .0 HOURS)

(A) SUBORDINATE STATION 9414863 RICHMOND, CHEVRON OIL PIER ACCEPTED TM (0W) TIDE TYPE (M)
(B) STANDARD STATION 9414290 SAN FRANCISCO, SAN FRANCISCO BAY ACCEPTED TM (0W) TIDE TYPE (M)

	(A) STATION TIM E OF			(B) STATION TIM E OF		(A) - (B) TIME DIFFERENCE		(A) STATION HEIGHT OF		(B) STATION HEIGHT OF		(A) - (B) HEIGHT DIFFERENCE	
	H W	L W		H W	L W	H W	L W	H W	L W	H W	L W	H W	L W
DATE	HOURS	HOURS	DATE	HOURS	HOURS	HOURS	HOURS	METERS	METERS	METERS	METERS	METERS	METERS
JUN 15	10.6	15 5.2	JUN 15	10.4		.2		5.248	4.455	3.459		1.789	
		17.5			16.7		.8		3.553		1.858		1.695
16	1.0	16 6.4	16	.6	5.5	.4	.9	5.225	4.469	3.420	2.750	1.805	1.719
	11.9	18.4		11.5	17.7	.4	.7	5.169	3.694	3.391	2.019	1.778	1.675
17	1.6	17 7.6	17	1.4	6.6	.2	1.0	5.304	4.304	3.509	2.638	1.795	1.666
	13.1	19.3		12.6	18.7	.5	.6	5.057	3.841	3.285	2.185	1.772	1.656
18	2.5	18 8.6	18	2.1	7.6	.4	1.0	5.378	4.112	3.585	2.411	1.793	1.701
	14.3	20.2		14.0	19.3	.3	.9	4.948	3.887	3.162	2.229	1.786	1.658
19	3.3	19 9.6	19	2.8	8.7	.5	.9	5.450	3.911	3.653	2.197	1.797	1.714
	15.9	21.2		15.6	20.6	.3	.6	4.972	4.041	3.173	2.326	1.799	1.715
20	4.0	20 10.6	20	3.6	9.9	.4	.7	5.581	3.698	3.786	1.955	1.795	1.743
	17.2	22.2		16.7	21.5	.5	.7	5.009	4.157	3.208	2.423	1.801	1.734
21	4.7	21 11.6	21	4.4	10.9	.3	.7	5.677	3.495	3.870	1.762	1.807	1.733
	18.2	23.1		17.8	22.6	.4	.5	5.072	4.195	3.261	2.450	1.811	1.745
22	5.5	22 12.6	22	5.2	11.8	.3	.8	5.725	3.362	3.935	1.635	1.790	1.727
	19.2	23 .1		18.8	23.5	.4	.6	5.102	4.258	3.290	2.505	1.812	1.753
23	6.2	13.6	23	6.0	12.5	.2	1.1	5.748	3.257	3.943	1.550	1.805	1.707
	20.3			19.8		.5		5.144		3.329		1.815	
24	7.2	24 1.0	24	6.8	.3	.4	.7	5.759	4.339	3.951	2.587	1.808	1.752
	21.1	14.3		20.6	13.3	.5	1.0	5.198	3.249	3.371	1.514	1.827	1.735
25	7.7	25 1.8	25	7.5	1.1	.2	.7	5.708	4.355	3.892	2.625	1.816	1.730
	22.0	15.0		21.5	14.1	.5	.9	5.198	3.246	3.366	1.540	1.832	1.706
26	8.7	26 2.6	26	8.4	2.1	.3	.5	5.559	4.363	3.763	2.625	1.796	1.738
	22.6	15.6		22.4	14.6	.2	1.0	5.158	3.236	3.343	1.536	1.815	1.700
27	9.3	27 3.6	27	9.0	2.9	.3	.7	5.432	4.360	3.625	2.629	1.807	1.731
	23.5	16.2		23.1	15.4	.4	.8	5.195	3.350	3.382	1.625	1.813	1.725
28	10.1	28 4.4	28	9.7	3.7	.4	.7	5.293	4.389	3.494	2.661	1.799	1.728
29	.2	16.7		23.8	16.1	.4	.6	5.190	3.487	3.376	1.762	1.814	1.725
	10.9	29 5.6	29	10.6	4.7	.3	.9	5.105	4.360	3.315	2.649	1.790	1.711
		17.6			16.8		.8		3.605		1.907		1.698
30	1.0	30 6.6	30	.6	5.7	.4	.9	5.150	4.288	3.354	2.589	1.796	1.699
	12.0	18.5		11.6	17.9	.4	.6	4.897	3.738	3.120	2.077	1.777	1.661
JUL 1	1.6	1 7.8	JUL 1	1.4	6.8	.2	1.0	5.123	4.195	3.337	2.520	1.786	1.675
	13.1	19.2		12.6	18.5	.5	.7	4.764	3.899	2.995	2.253	1.769	1.646
2	2.4	2 8.8	2	2.0	7.8	.4	1.0	5.161	4.112	3.392	2.434	1.769	1.678
	14.3	20.0		13.9	19.4	.4	.6	4.713	4.078	2.950	2.406	1.763	1.672
3	3.1	3 9.9	3	2.6	9.1	.5	.8	5.232	4.036	3.458	2.366	1.774	1.670
	15.6	20.8		15.2	20.1	.4	.7	4.697	4.200	2.940	2.498	1.757	1.702
4	3.7	4 10.4	4	3.2	9.7	.5	.7	5.301	3.895	3.524	2.209	1.777	1.686
	16.7	21.8		16.5	21.1	.2	.7	4.751	4.326	2.987	2.612	1.764	1.714
5	4.2	5 11.1	5	4.0	10.3	.2	.8	5.365	3.737	3.584	2.017	1.781	1.720
	17.9	22.7		17.6	22.0	.3	.7	4.833	4.384	3.053	2.644	1.780	1.740
6	4.8	6 11.8	6	4.6	11.1	.2	.7	5.442	3.620	3.656	1.913	1.786	1.707
	18.7	23.5		18.3	22.7	.4	.8	4.905	4.418	3.124	2.681	1.781	1.737
7	5.6	7 12.6	7	5.1	11.8	.5	.8	5.506	3.532	3.710	1.812	1.796	1.720
	19.5	8 .2		19.1	23.4	.4	.8	4.991	4.434	3.193	2.697	1.798	1.737

Figure 4.6 (cont.)

COMPARISON OF SIMULTANEOUS OBSERVATIONS FOR 98 6 15 TO 98 7 14 9/11/1998
1960-1978 TIDAL EPOCH (EXPECTED DIFFERENCE (STATION A - STATION B) = .0 HOURS)

(A) SUBORDINATE STATION 9414863 RICHMOND, CHEVRON OIL PIER ACCEPTED TM (0W) TIDE TYPE (M)
(B) STANDARD STATION 9414290 SAN FRANCISCO, SAN FRANCISCO BAY ACCEPTED TM (0W) TIDE TYPE (M)

	(A) STATION TIM E OF				(B) STATION TIM E OF		(A) - (B) TIME DIFFERENCE		(A) STATION HEIGHT OF		(B) STATION HEIGHT OF		(A) - (B) HEIGHT DIFFERENCE	
	H W		L W		H W	L W	HW	LW	H W	LW	H W	L W	H W	L W
DATE	HOURS		HOURS	DATE	HOURS	HOURS	HOURS	HOURS	METERS	METERS	METERS	METERS	METERS	METERS
JUL 8	6.0	8	13.2	JUL 8	5.8	12.4	.2	.8	5.568	3.463	3.754	1.729	1.814	1.734
	20.2				19.7		.5		5.024		3.222		1.802	
9	6.7	9	.7	9	6.3	.1	.4	.6	5.589	4.445	3.789	2.702	1.800	1.743
	20.8		13.9		20.4	13.1	.4	.8	5.092	3.402	3.285	1.669	1.807	1.733
10	7.6	10	1.6	10	7.3	.9	.3	.7	5.605	4.442	3.794	2.709	1.811	1.733
	21.5		14.5		21.1	13.7	.4	.8	5.120	3.349	3.306	1.627	1.814	1.722
11	8.4	11	2.2	11	8.0	1.6	.4	.6	5.527	4.342	3.712	2.613	1.815	1.729
	22.1		15.2		21.7	14.4	.4	.8	5.112	3.294	3.302	1.578	1.810	1.716
12	8.8	12	3.2	12	8.8	2.5	.0	.7	5.445	4.309	3.638	2.584	1.807	1.725
	22.7		15.8		22.3	15.1	.4	.7	5.163	3.334	3.355	1.608	1.808	1.726
13	9.6	13	3.8	13	9.3	3.1	.3	.7	5.354	4.264	3.547	2.529	1.807	1.735
	23.5		16.6		23.1	15.6	.4	1.0	5.243	3.438	3.419	1.691	1.824	1.747
14	10.6	14	4.7	14	10.1	4.1	.5	.6	5.235	4.262	3.443	2.521	1.792	1.741
			17.1		23.9	16.5		.6		3.521	3.483	1.800		1.721

			HHW	HLW	HHW	HLW	HHW	HLW
SUMS			152.420	120.010	102.090	71.841	50.330	48.169
ITEMS			28	28	28	28	28	28
MEANS			5.444	4.286	3.646	2.566	1.797	1.720

			LHW	LLW	LHW	LLW	LHW	LLW
SUMS	20.6	43.5	146.092	103.320	93.990	53.800	52.102	49.520
ITEMS	57	57	29	29	29	29	29	29
MEANS	.36	.76	5.038	3.563	3.241	1.855	1.797	1.708

COMPARISON OF SIMULTANEOUS OBSERVATIONS FOR 98 6 15 TO 98 7 14 9/11/1998
1960-1978 TIDAL EPOCH (EXPECTED DIFFERENCE (STATION A - STATION B) = .0 HOURS)

(A) SUBORDINATE STATION 9414863 RICHMOND, CHEVRON OIL PIER ACCEPTED TM (0W) TIDE TYPE (M)
(B) STANDARD STATION 9414290 SAN FRANCISCO, SAN FRANCISCO BAY ACCEPTED TM (0W) TIDE TYPE (M)

ERROR SCAN FOR TIME DIFFERENCE OF HW
STANDARD DEVIATION= .111
ERROR IN 98 7 12 88 (SUBORDINATE STATION) .0
ERROR SCAN FOR TIME DIFFERENCE OF LW
STANDARD DEVIATION= .141
ERROR IN 98 6 23 136 (SUBORDINATE STATION) 1.1
ERROR SCAN FOR HEIGHT DIFFERENCE OF HHW
STANDARD DEVIATION= .013
ERROR IN 98 7 2 24 (SUBORDINATE STATION) 1.769
ERROR SCAN FOR HEIGHT DIFFERENCE OF LHW
STANDARD DEVIATION= .020
ERROR SCAN FOR HEIGHT DIFFERENCE OF HLW
STANDARD DEVIATION= .026
ERROR IN 98 6 17 76 (SUBORDINATE STATION) 1.666
ERROR IN 98 6 18 202 (SUBORDINATE STATION) 1.658
ERROR SCAN FOR HEIGHT DIFFERENCE OF LLW
STANDARD DEVIATION= .027
ERROR IN 98 7 1 192 (SUBORDINATE STATION) 1.646

Figure 4.6 (cont.)

COMPARISON OF SIMULTANEOUS OBSERVATIONS FOR 98 6 15 TO 98 7 14 9/11/1998
1960-1978 TIDAL EPOCH (EXPECTED DIFFERENCE (STATION A - STATION B) = .0 HOURS)

(A) SUBORDINATE STATION 9414863 RICHMOND, CHEVRON OIL PIER ACCEPTED TM (0W) TIDE TYPE (M)
(B) STANDARD STATION 9414290 SAN FRANCISCO, SAN FRANCISCO BAY ACCEPTED TM (0W) TIDE TYPE (M)

MEAN DIFFERENCE IN HIGH (.36) AND LOW (.76) WATER INTERVALS

MEAN HHW HEIGHT AT (A) = 5.444	MEAN HLW HEIGHT AT (A) = 4.286
MEAN LHW HEIGHT AT (A) = 5.038	MEAN LLW HEIGHT AT (A) = 3.563
DHQ AT (A) = .207	DLQ AT (A) = .355
MEAN HW HEIGHT AT (A) = 5.237	MEAN LW HEIGHT AT (A) = 3.918
MN AT (A) = 1.319	MTL AT (A) = 4.578
GT AT (A) = 1.881	DTL AT (A) = 4.503

MEAN HHW DIFFERENCE = 1.797	MEAN HLW DIFFERENCE = 1.720
MEAN LHW DIFFERENCE = 1.797	MEAN LLW DIFFERENCE = 1.708
DHQ DIFFERENCE = .000	DLQ DIFFERENCE = .006
MEAN HW DIFFERENCE = 1.797	MEAN LW DIFFERENCE = 1.714
MN DIFFERENCE = .083	MTL DIFFERENCE = 1.755
GT DIFFERENCE = .090	DTL DIFFERENCE = 1.753
MN RATIO = 1.067	DHQ RATIO = 1.002
GT RATIO = 1.050	DLQ RATIO = 1.018
MSL AT (A) = 4.570	
MSL AT (B) = 2.804	
MSL DIFFERENCE = 1.766	

	HWI	LWI	MTL	MN	DHQ	DLQ
	HOURS	HOURS	METERS	METERS	METERS	METERS
ACCEPTED FOR B	7.56	.83	2.728	1.250	.183	.344
DIFFERENCES AND RATIOS	.36	.76	1.755	1.067	1.002	1.018
CORRECTED FOR A	7.92	1.59	4.483	1.334	.183	.351

	MSL	DTL	GT
	METERS	METERS	METERS
ACCEPTED FOR B	2.713	2.646	1.777
DIFFERENCES AND RATIOS	1.766	1.753	1.050
CORRECTED FOR A	4.479	4.398	1.866

MRR METHOD
MHHW= 5.331 MLLW= 3.465
DHQ = .181 DLQ = .351

SRANDARD METHOD
MHHW= 5.334 MLW = 3.816
MHW = 5.150 MLLW= 3.466

DIRECT METHOD

	MHHW	MHW	MLW	MLLW
	METERS	METERS	METERS	METERS
ACCEPTED FOR B	3.536	3.353	2.103	1.759
DIFFERENCES AND RATIOS	1.797	1.797	1.714	1.708
CORRECTED FOR A	5.333	5.150	3.817	3.466

MN = 1.333
GT = 1.867

Figure 4.7 - Monthly Mean Simultaneous Comparison Example

COMPARISON OF MONTHLY MEANS (JAN-98 - JUN-98) 1960-78 TIDAL EPOCH
(A) SUBORDINATE: 9414863 RICHMOND, CA TM (000W) TIDE TYPE:MIXED
(B) CONTROL: 9414290 SAN FRANCISCO, CA TM (000W) TIDE TYPE:MIXED

month/year		MTL			MSL			HWI	
	A	B	A - B	A	B	A - B	A	B	A - B
	meters	meters	meters	meters	meters	meters	hours	hours	hours
Jan-98	4.736	3.001	1.735	4.726	2.981	1.745	7.900	7.510	0.390
Feb-98	4.841	3.103	1.738	4.839	3.082	1.757	7.900	7.580	0.320
Mar-98	4.624	2.883	1.741	4.615	2.859	1.756	7.840	7.520	0.320
Apr-98	4.542	2.798	1.744	4.532	2.776	1.756	7.880	7.530	0.350
May-98	4.562	2.811	1.751	4.547	2.787	1.760	7.890	7.540	0.350
Jun-98	4.600	2.849	1.751	4.588	2.826	1.762	7.930	7.570	0.360

month/year		LWI			MN			DHQ	
	A	B	A - B	A	B	A/B	A	B	A/B
	hours	hours	hours	meters	meters	ratio	meters	meters	ratio
Jan-98	1.460	0.790	0.670	1.367	1.287	1.062	0.207	0.213	0.972
Feb-98	1.570	0.820	0.750	1.208	1.101	1.097	0.161	0.183	0.880
Mar-98	1.430	0.660	0.770	1.321	1.215	1.087	0.118	0.125	0.944
Apr-98	1.450	0.660	0.790	1.309	1.210	1.082	0.111	0.117	0.949
May-98	1.460	0.690	0.770	1.306	1.217	1.073	0.155	0.158	0.981
Jun-98	1.490	0.720	0.770	1.292	1.205	1.072	0.194	0.196	0.990

month/year		DLQ			MHW			MLW	
	A	B	A/B	A	B	A - B	A	B	A - B
	meters	meters	meters	ratio	meters	meters	meters	meters	meters
Jan-98	0.331	0.337	0.982	5.420	3.644	1.776	4.053	2.357	1.696
Feb-98	0.251	0.261	0.962	5.445	3.653	1.792	4.237	2.552	1.685
Mar-98	0.210	0.207	1.014	5.284	3.490	1.794	3.983	2.275	1.708
Apr-98	0.279	0.268	1.041	5.196	3.403	1.793	3.887	2.193	1.694
May-98	0.336	0.328	1.024	5.215	3.420	1.795	3.909	2.203	1.706
Jun-98	0.360	0.352	1.023	5.246	3.452	1.794	3.954	2.247	1.707

month/year		DRL(TL)			GT			MHHW	
	A	B	A - B	A	B	A/B	A	B	A - B
	meters	meters	meters	meters	meters	ratio	meters	meters	meters
Jan-98	4.675	2.939	1.736	1.905	1.837	1.037	5.627	3.857	1.770
Feb-98	4.806	3.063	1.743	1.640	1.545	1.061	5.626	3.836	1.790
Mar-98	4.578	2.841	1.737	1.649	1.547	1.066	5.402	3.615	1.787
Apr-98	4.458	2.723	1.735	1.699	1.595	1.065	5.307	3.520	1.787
May-98	4.471	2.726	1.745	1.797	1.703	1.055	5.370	3.578	1.792
Jun-98	4.517	2.772	1.745	1.846	1.753	1.053	5.440	3.648	1.792

month/year		MLLW	
	A	B	A - B
	meters	meters	meters
Jan-98	3.722	2.020	1.702
Feb-98	3.986	2.291	1.695
Mar-98	3.753	2.068	1.685
Apr-98	3.608	1.925	1.683
May-98	3.573	1.875	1.698
Jun-98	3.594	1.895	1.699

Figure 4.7 - Monthly Mean Simultaneous Comparison Example (cont.)

COMPARISON OF MONTHLY MEANS (JAN-98 - JUN-98) 1960-78 TIDAL EPOCH
(A) SUBORDINATE: 9414863 RICHMOND, CA TM (000W) TIDE TYPE:MIXED
(B) CONTROL: 9414290 SAN FRANCISCO, CA TM (000W) TIDE TYPE:MIXED

	MTL	MSL	HWI	LWI	MN	DHQ	DLQ
	A - B	A - B	A - B	A - B	A/B	A/B	A/B
	meters	meters	hours	hours	ratio	ratio	ratio
months	6.000	6.000	6.000	6.000	6.000	6.000	6.000
sums	10.460	10.536	2.090	4.520	6.473	5.825	6.046
means	1.743	1.756	0.348	0.753	1.079	0.971	1.008
accepted B	2.728	2.713	7.560	0.830	1.250	0.183	0.344
corrected A	4.471	4.469	7.908	1.583	1.349	0.178	0.347

	MHW	MLW	DRL(TL)	GT	MHHW	MLLW
	A - B	A - B	A - B	A/B	A - B	A - B
	meters	meters	meters	ratio	meters	meters
months	6.000	6.000	6.000	6.000	6.000	6.000
sums	10.744	10.176	10.441	6.337	10.718	10.162
means	1.791	1.696	1.740	1.056	1.786	1.694
accepted B	3.353	2.103	2.646	1.777	3.536	1.759
corrected A	5.144	3.799	4.386	1.877	5.322	3.453

METHOD	DATUM	VALUE
		meters
MRR	MHHW	5.325
MRR	MLLW	3.448
MRR	DHQ	0.179
MRR	DLQ	0.349
STANDARD	MHW	5.146
STANDARD	MLW	3.797
STANDARD	MHHW	5.323
STANDARD	MLLW	3.450
DIRECT	MN	1.345
DIRECT	GT	1.870
DIRECT	DHQ	0.179
DIRECT	DLQ	0.346

FINAL/PRELIMINARY DATUMS
METHOD : STANDARD 1960-78 EPOCH

DATUM	VALUE
	meters
MHHW	5.323
MHW	5.146
MTL	4.471
MSL	4.469
DRL(TL)	4.386
MLW	3.797
MLLW	3.450
MN	1.349
GT	1.873
DHQ	0.178
DLQ	0.347

Figure 4.7 - Monthly Mean Simultaneous Comparison Example (cont.)

COMPARISON OF MONTHLY MEANS (JAN-98 - JUN-98) 1960-78 TIDAL EPOCH
(A) SUBORDINATE: 9414863 RICHMOND, CA TM (000W) TIDE TYPE:MIXED
(B) CONTROL: 9414290 SAN FRANCISCO, CA TM (000W) TIDE TYPE:MIXED

OUTLIER REPORT: MAXIMUMS AND MINIMUMS WHEN INDIVIDUAL MONTHLY MEAN DIFFERENCE EXCEEDS TWO STANDARD DEVIATIONS FROM OVERALL MEAN

	MTL	MSL	HWI	LWI	MN	DHQ	DLQ
STD.DEV.	0.004	0.003	0.018	0.019	0.008	0.012	0.017
MAXIMUM	1.752	1.762	0.384	0.791	1.095	0.994	1.041
MINIMUM	1.734	1.750	0.313	0.715	1.062	0.948	0.974
month/year							
Jan-98		1.745	0.390	0.670	1.062		
Feb-98					1.097		0.962
Mar-98						0.944	
Apr-98							1.041
May-98							
Jun-98							

	MHW	MLW	DTL	GT	MHHW	MLLW
STD.DEV.	0.003	0.006	0.003	0.006	0.004	0.004
MAXIMUM	1.796	1.708	1.746	1.068	1.794	1.703
MINIMUM	1.785	1.684	1.734	1.045	1.779	1.685
month/year						
Jan-98	1.776			1.037	1.770	
Feb-98						
Mar-98						
Apr-98						1.683
May-98						
Jun-98						

Figure 4.8: Published Bench Mark Sheet

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CALIFORNIA 941 4290
U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
TIDAL BENCH MARKS
THE PRESIDIO, SAN FRANCISCO
LATITUDE: 37° 48.4' N LONGITUDE: 122° 27.9' W
NOAA CHART: 18649 USGS QUAD: SAN FRANCISCO NORTH

TO REACH TIDE STATION: To reach the tide station from the intersection of U.S. Highway 101 (north) and Lincoln Boulevard (last exit before the Golden Gate toll plaza), proceed NE on Lincoln Boulevard approximately 1.6 km (1.0 mile) to Cowles Street, turn left onto Cowles Street and proceed 0.8 km (0.5 mile) to McDowell Avenue, turn left onto McDowell Avenue and proceed 0.5 km (0.3 mile) to Crissey Field Avenue, turn left onto Crissey Field Avenue and proceed 0.3 km (0.2 mile) to a stop sign, turn right and then immediately left onto Mason street, proceed along the National Parks Service parking lot fence where Mason Street turns into Hamilton Street, and proceed 0.5 km (0.3 mile) to a parking lot at the end of the street. The tide station is located in the 2nd building on the L-shaped wooden pier formerly owned by the U.S.Coast Guard, now owned by the National Park Service.

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BENCH MARK STAMPING: 180 1936

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Seawall
The primary bench mark is set in the top of a 0.9-m (3') high concrete seawall at the NW end of Crissy Field on the Coast Guard property, 15 m (49') east of the NE corner of the crews quarters building, 6 m (20') south of the south side of the garage building, and 1.1 m (3.5') north of an angle in the seawall.

BENCH MARK STAMPING: 181 1945

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Seawall
The bench mark is set in the top of the NW corner of a seawall at the Fort Point Coast Guard Station, 62 m (204') west of the inshore end of the Coast Guard wharf, 46 m (151') NW of a flagpole, 22 m (71') NE of the north corner of Building S.F. 19.4 (paint shop and storage building), and 1.2 m (4.0') above grade.

Figure 4.8 **(cont.)**
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CALIFORNIA 941 4290
THE PRESIDIO, SAN FRANCISCO

BENCH MARK STAMPING: 4290 J 1976
MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Copper Clad Steel Rod
The bench mark is in an elevated beach area midway between the Fort Point Coast Guard pier and the engineer's dock, 133 m (435') WNW of the west end of the seawall surrounding the Coast Guard crews quarters, 27 m (89') SW of the shoreward end of the old seaplane ramp, 18.3 m (60.0') SE of the shoreward end of the concrete discharge pipe, and 0.8 m (2.5') north of a chain link fence surrounding U.S. Army Field Maintenance Building #937. The mark is crimped to a copper-clad steel rod driven 15 m (48'), encased in a 4-inch diameter PVC pipe, and marked by a witness post.

BENCH MARK STAMPING: 4290 K 1976
MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Bedrock
The bench mark is set vertically in bedrock on the south side of Marine Drive, 24 m (79') SSW of the SE corner of National Park Service building #T989, 14.7 m (48.2') SW of Bench Mark 174 1925, and 2.4 m (8.0') south of the south curb of Marine Drive.

BENCH MARK STAMPING: BM 174 1925
MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Monument
The bench mark is set in a concrete monument level with the ground inside a brick circle in the pavement at the center of the Y-junction between Marine Drive and the road leading SE to Fort Winfield Scott, 38 m (125') west of the extension of the west edge of the engineer's dock where it crosses Marine Drive, 13.0 m (42.5') SW of a fire hydrant, and 8.7 m (28.5') south of the south edge of an iron manhole cover.

BENCH MARK STAMPING: BM 175 1925
MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Seawall
The bench mark is set in the seawall near the National Park Service building, 62.2 m (214') NE of Bench Mark 4290 L 1976, 59 m (193') west of the NW corner of the park service building, 28.9 m (94.8') WNW of the northernmost post of a pedestrian gate, 6.9 m (22.5') north of the centerline of Marine Drive, and 0.7 m (2.4') south of the north edge of the seawall. (Note: The seawall was repaired in April 1981 and the elevation of the bench mark was changed after the repair, but the elevation seems stable since then.)

Figure 4.8 (cont.)

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CALIFORNIA 941 4290
THE PRESIDIO, SAN FRANCISCO

BENCH MARK STAMPING: BM 176 1925
MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Step
The bench mark is set in the west end of the lowest concrete step at the main entrance to the porch of the U.S. Army Logistic Control office at #651 Mason Avenue, 30 m (98') SE of the intersection of Crissy Field and Mason Avenues, 15 m (50') south of the centerline of Mason Avenue, and about 0.2 m (0.7') above the sidewalk.

BENCH MARK STAMPING: CLARK 1948
MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Triangulation Mark
SETTING CLASSIFICATION: Concrete Seawall
The bench mark is set in the top of a concrete seawall, about 549 m (1800') NW of the Fort Point Coast Guard station, 24.2 m (79.5') west of the west edge of the engineer's dock, 6.9 m (22.5') NE of the NW corner of corrugated iron building #985, 3.0 m (10') west of the NW corner of a stucco paint locker building, and about 1.1 m (3.6') above ground.

BENCH MARK STAMPING: NO 2 1948
MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Reference Mark
SETTING CLASSIFICATION: Concrete Seawall
The bench mark is set flush in the top of a concrete seawall, 11.4 m (37.5') west of the west edge of the engineer's dock, 8.1 m (26.5') NE of the NE corner of corrugated iron building #985, and about 0.9 m (3.0') above ground.

Figure 4.8 (cont.)

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CALIFORNIA 941 4290
THE PRESIDIO, SAN FRANCISCO

Tidal datums at THE PRESIDIO, SAN FRANCISCO are based on the following:

LENGTH OF SERIES = 19 YEARS
TIME PERIOD = 1960-1978
TIDAL EPOCH = 1960-1978
CONTROL TIDE STATION =

Elevations of tidal datums referred to mean lower low water (MLLW) are as follows:

HIGHEST OBSERVED WATER LEVEL (01/27/1983) = 8.87 FEET
MEAN HIGHER HIGH WATER (MHHW) = 5.83 FEET
MEAN HIGH WATER (MHW) = 5.23 FEET
MEAN TIDE LEVEL (MTL) = 3.18 FEET
MEAN SEA LEVEL (MSL) = 3.13 FEET
MEAN LOW WATER (MLW) = 1.13 FEET
*NORTH AMERICAN VERTICAL DATUM-1988 (NAVD) = 0.14 FEET
MEAN LOWER LOW WATER (MLLW) = 0.00 FEET
LOWEST OBSERVED WATER LEVEL (12/17/1933) = -2.67 FEET

*NAVD is based on elevations published in Quad 371221, 1993, and NOS leveling of 1995.

Bench mark elevation information:

	ELEVATION IN FEET ABOVE:	
BENCH MARK STAMPING	MLLW	MHW
180 1936	13.24	8.01
181 1945	13.29	8.06
4290 J 1976	11.18	5.95
4290 K 1976	19.31	14.08
BM 174 1925	16.65	11.42
BM 175 1925	13.84	8.61
BM 176 1925	15.99	10.76
CLARK 1948	14.08	8.85
NO 2 1948	14.04	8.81

Figure 4.8 (cont.)

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CALIFORNIA 941 4290
THE PRESIDIO, SAN FRANCISCO

MSL is the local mean sea level and should not be confused with the fixed datums of NGVD (sometimes referred to as Sea Level Datum of 1929) or NAVD 88. NGVD is a fixed datum adopted as a standard geodetic reference for heights. It was derived from a general adjustment of the first order leveling nets of the U.S. and Canada. Mean sea level was held fixed as observed at 26 stations in the U.S. and Canada. Numerous adjustments have been made since originally established in 1929.

NAVD 88 involved a simultaneous, least squares, minimum-constraint adjustment of Canadian-Mexican-United States leveling observations. Local mean sea level at Father Point/Rimouski, Canada was held fixed as the single constraint. These fixed datums do not take into account the changing stands of sea level and because they represent a "best" fit over a broad area, their relationship to local mean sea level is not consistent from one location to another.