REPLACEMENT OF NOAA'S NATIONAL TIDE AND WATER LEVEL MEASUREMENT SYSTEM

Thomas R. Bartholomew
Lt. Cdr. Don M. Spillman

U. S. Department of Commerce
National Oceanic and Atmospheric Administration
Rockville, Maryland 20852

ABSTRACT

This paper describes the missions, products and system requirements for the National Oceanic and Atmospheric Administration's (NOAA) next-generation tide and water level measurement system. It traces the ongoing process of system improvements which are necessary to: (1) maintain and enhance operation of the measurement system; (2) maintain and improve the quality of the data collected, and (3) ultimately improve the timeliness of the output products based on that data.

INTRODUCTION

Tide and water level measurement data collected by the National Ocean Survey (NOS) of NOAA are used directly in tide and water level-related publications and services to the general public, industry and other government agencies, and in the preparation of nautical charts. Tide and water level products and services produced by NOAA from the measurement data include:

1. Tables of predicted tide heights.
2. Observed hourly and high and low tide heights.
3. Computed tidal datums - (a tidal datum is a mathematically determined elevation of the ocean surface that is fixed through officially adopted definitions and procedures of NOS. It is used as a reference from which to reckon heights or depths).
4. Tables and charts of Great Lakes levels.
5. Coastal hazard warnings - storm surges and tsunamis.
6. Technical reports describing tide and water level phenomena.

The NOS collects the required tide and water level data through the operation and maintenance of the National Tide and Water Level Observation Network; a permanent network of approximately 140 tide data acquisition stations distributed along the Atlantic, Gulf, and Pacific coasts, including Alaska and the Hawaiian, Pacific and Caribbean Islands, and 54 water level data acquisition stations on the Great Lakes, which continuously measure and record tide and water level fluctuations. To supplement these permanent stations, about 100-200 temporary stations are operated each year, in the same regions.

MEASUREMENT MISSIONS

Tide and water level data measurement missions can be grouped into four categories. These are:

	<u>% of Total Station Months Collected</u>
1. Primary control and Great Lakes operations	27
2. Hydrographic and tidal current survey support	7
3. Marine boundary projects	55
4. Special projects	<u>11</u>
Total	100 percent

Primary control tide stations measure and record tidal fluctuations continuously through a 19-year metonic cycle, the period considered to constitute a full tidal cycle necessary to compute a primary tidal datum. These primary control tide stations provide the data necessary to compute datums from shorter term tide stations through the method of comparison of simultaneous observations. The 54 permanent Great Lakes stations provide data to support international monitoring agreements, monitor vertical crustal movements of the earth, determine lake water volumes and forecast lake levels. Tide data collected for hydrographic and tidal current survey support are used to provide datums for nautical charts and to reduce water depths to chart datum and are used to provide boundary conditions for determining estuarine circulation. Tide data collected through marine boundary projects are used to compute datums required to delineate marine boundaries. Special project data are used for such purposes as determining inundation frequencies or detection and analysis of harbor seiches.

Stations used in the four missions are categorized by deployment interval as follows:

<u>Station Type</u>	<u>Number (1978)</u>	<u>%</u>
1. Primary (19 yrs. or greater)	200	29
2. Secondary (1 to 19 years)	200	29
3. Tertiary (up to 1 year)	<u>280</u>	<u>42</u>
Total	680	100%

PRESENT DATA COLLECTION SYSTEM

The present primary data collection system, shown in Figure 1, consists of a recording gage, staff, permanent benchmark network and local contracted observer at each collection station. At long-term permanent stations, a house is constructed to protect the equipment from the elements. Stations are typically located on existing piers or other structures to save the cost of platform construction. Averages of the recorded gage values are referenced to the benchmark network through daily simultaneous gage and staff observations made by the local observer and by periodic (typically semi-annual) differential leveling between the staff and benchmarks.

The NOS presently has an inventory of 1,000 analog-to-digital recording (ADR) and analog tide and water level gages manufactured by Fischer & Porter, Co., and Leupold & Stevens, Inc., and 350 gas-purged pressure recording (bubbler) gages manufactured by Metercraft Corporation and Bristol-Babcock Division, Acco Industries, Inc., plus a few "standard" analog gages. An average of 300 ADR gages and 100 bubbler gages are in operation for tide measurement and 50 ADR and 40 analog gages for water level measurement (on the Great Lakes) at any time.

The NOS began using the bubbler gage in 1960 to satisfy a need for a portable gage to support hydrographic surveys. NOS engineers developed the gage from a design by Alfred C. Redfield of the Woods Hole Oceanographic Institute.

The NOS began using ADR gages manufactured by Fischer & Porter, Co. in 1965 as a result of a policy decision in 1964 to use computer-assisted data analysis techniques (the ADR gage produces a punched paper tape record in machine-readable format) and because of increasing difficulty in acquiring parts for the "standard" gage. The Fischer & Porter ADR was then phased into the inventory as the standard gage was phased out. In 1975 NOS began adding Leupold & Stevens ADR gages to the inventory.

FACTORS STIMULATING DEVELOPMENT OF A NEW SYSTEM

Several factors which influence the measurement system have changed since the adoption of the present systems. The demand for tidal data and data products and the amount of data collected annually have more than tripled during the past 10 years due to the increased interest in and use of the coastal zone.

Since 1970, labor costs have increased dramatically while Federal policies are now apparently aimed at providing services using fewer Federal personnel. NOS field offices, which were previously able to devote a portion of their time to maintenance of tide stations in their geographic regions, have closed and been consolidated into one office for the west coast, Alaska and the Pacific Islands, and one office for the east and Gulf coasts and the Caribbean.

The existing, essentially mechanical, measurement system is labor intensive with relatively high maintenance costs, and low reliability and of questionable supportability since one of the system manufacturers has stopped manufacturing the gages. A review of the data analysis system in 1974 suggested that the major contributor to data analysis problems was the data acquisition system. A study of 6,000 station months (1 month of data from 1 tide station) of tide data in 1978 indicated that 50 percent of the data had defects which required from 2 to 5 times as many analysis staff-hours as defect-free data to produce quality data products. The study also indicated that nearly one-half of this defective data could not be turned into final data products.

Measurement and recording technologies have changed significantly since the early 1960's. The above factors, considered together, provided the impetus for the next-generation development effort.

DEVELOPMENT PROCESS

As the initial step in the development process, a requirements study was undertaken to establish functional specifications and performance characteristics required of the system. The study considered the following areas:

- Missions
- Products/applications
- Range/resolution/accuracy
- Sampling/filtering
- Leveling and measurement reference
- Calibration and measurement drift check
- Environment
- Reliability
- Integrated Logistics Support
- Service intervals/requirements
- Electrical power
- Compatibility
- Human factors and packaging
- Life-cycle costs and cost effectiveness
- Installation

It is beyond the scope of this paper and the limit of the reader's patience to describe in detail the complete results of that study, but it may be of some interest to examine the measurement accuracy analysis.

Table 1¹ shows the allowable error specification for NOS' various applications. The most stringent accuracy requirement (using the present system configuration) for the gage/recording subsystem is found in the hydrographic mission which has the largest specified overall error. This results from the requirement for instantaneous heights while in the remaining applications, heights are averaged over time. Figure 2 illustrates the method used to obtain instantaneous tide level relative to mean water level. The term ($\Delta S - G'$) is the staff-gage difference as read by the observer several times per month (G' is used to emphasize the point that G and G' are not necessarily simultaneous readings). ($\Delta S - G'$) is a constant and

equals the difference between the staff reference and the gage reference, unless either the staff or gage has moved relative to the benchmark.

The resulting error expression, assuming a calibrated gage with no systematic error and that the remaining errors are random and independent, is as follows:

$$S_0^2 = S_G^2 + \frac{S_{SG}^2}{N} + S_L^2 + S_D^2$$

Where S_0 = sample standard deviation of overall system error

S_G = gage error

S_{SG} = staff-gage comparison (observer error)
 N = number of staff-gage readings over the measurement period

S_L = residual systematic error

S_D = datum transformation² error.

Solving for S_G : $S_G = (S_0^2 - \frac{S_{SG}^2}{N} - S_L^2 - S_D^2)^{\frac{1}{2}}$

Plugging in the values determined from the requirements, analysis and experiment --

S_0 = 0.2' NOS requirement for hydrographic survey support mission

S_{SG} = 0.3' from actual data

N = 10 estimated from experience with typical hydro station

S_L = 0.025' estimated

S_D = 0.13' see reference 2.

This yields: $S_G \approx 0.1'$

and the conclusion that the gage/recording subsystem accuracy required to attain the specified mission accuracy is 0.1 foot 1σ .

Error expressions for the remaining missions were examined using $S_G = 0.1'$ and found to yield overall accuracies within the NOS requirements.

TABLE 1¹

Mission	Allowable Error	Comment
Hydrographic Survey Support	0.2'	Instantaneous readings to correct sounding
Marine Boundary Determinations	0.05'	Short-term averages (3 mo. to 1 year)
Great Lakes Level Monitoring	0.05'	
Great Lakes Datum Determination	0.01'	5-year average
Tsunami Warning	0.2'	Measurement initiated during alert periods
Tide Height Predictions	0.1'	Tidal constituent errors of $\pm 5\%$ amplitude and ± 15 min. phase allowable
Sea Level Monitoring	0.03'	Long-term averages (1 yr. to 19 yrs.)

Upon completion of the requirements analysis, a three-phase contractual effort was initiated. Phase I, contracted to Raytheon Ocean Systems Co., has produced detailed technical system specifications. Phase II will see the construction of a number of prototypes for thorough test and evaluation, and Phase III will procure operational systems.

The output of Phase I is complete. The system configuration selected by NOAA for further development will consist of an air acoustic sensor recording data on a unique UV PROM "cartridge" under the control of a microprocessor. This system will be brought to the prototype stage in the Phase II contract scheduled for award in Fiscal Year 1982.

REFERENCES

¹Bartholomew, T. R., and T. R. Crane, "Next-Generation Tide & Water Level Sensing and Recording Subsystem - Functional/Performance Requirements, NOS Internal Report, January 1979.

²Swanson, Cdr. Robert L., "Variability of Tidal Datums and Accuracy in Determining Datums from Short Series of Observations," NOS Technical Report 64, October 1964.

FIGURE 1: A TYPICAL LONG-TERM TIDE STATION
The leveling instrument and survey rod are brought to the tide station by a field unit when leveling operations are conducted.

$$\begin{aligned}
 TL/MWL &= TL/p - MWL/p \\
 TL/p &= \Delta_S - \Delta_{PS} \text{ \& } \Delta_S = \Delta_S + G - G \\
 TL/MWL &= G + (\Delta_S - G') - \Delta_{PS} - MWL/p
 \end{aligned}$$

Figure 2. TIDES FOR HYDROGRAPHY