NOS Oceanographic Circulation
Survey Report No.9

Delaware River and Bay Circulation Survey: 1984 - 1985

Rockville, Md.
December 1986

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

NOS Oceanographic Survey Reports

This series of reports presents information on circulation surveys by the National Ocean Service. Normal activity includes measurements of water flow (currents), tides, temperature, salinity, and occasionally other parameters needed for understanding the physical processes. These surveys are made primarily for the Nation's navigational waterways; however, data are also obtained to describe the circulation patterns of estuaries and harbors.

These reports offer information on sampling locations, measurement techniques, processing and analysis routines, data formats, and general information on the survey area. They do not present technical interpretations of hydrodynamics of the areas.

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U.S. DEPARTMENT OF COMMERCE
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DELAWARE RIVER AND BAY CIRCULATION SURVEY: 1984-1985

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ABSTRACT

The Delaware River and Bay (DR&B) Circulation Survey (1984-1985) comprises the most comprehensive data collection effort ever conducted in the DR&B region. The data set will be used by the National Ocean Service (NOS) to improve existing products, including NOS' Tidal Current Tables and Tide Tables, and to verify a NOS real-time circulation model of the estuary. For researchers, the data set will provide a baseline of oceanographic conditions for use in future environmental studies. For the maritime community, these improved products will aid navigation and improve commerce. Although the survey operation was performed by NOS, important assistance was received during the planning stage from the academic community, state and Federal agencies, and private organizations. During the 15-month survey, data on currents, water levels, salinity, temperature, and weather conditions were collected from the adjacent inner continental shelf off New Jersey and Delaware, the entire Delaware Bay, the Delaware River up to Trenton, New Jersey, and the Chesapeake and Delaware Canal.

1.0. INTRODUCTION

1.1. Purpose of Report

The purpose of this report is to describe a circulation survey conducted in the Delaware River and Bay (DR&B) by the National Ocean Service (NOS) between March 1984 and May 1985. The report provides a detailed account of the kinds of data collected, instrumentation and methods used to collect the data, the data processing systems, tabulations of data collection statistics, and the locations in the DR&B where data were collected.

1.2. Survey Setting

The area surveyed includes Delaware Bay, Delaware River northward to near the fall line at Trenton, New Jersey, the Chesapeake and Delaware Canal, and the inner continental shelf out to approximately 90 nautical miles (167 kilometers) from the entrance of Delaware Bay (figure 1). Delaware Bay is bounded by New Jersey on the north and east, and Delaware on the south and west. The Delaware River forms the boundary between New Jersey and Delaware in the south; to the north it forms the boundary between New Jersey and Pennsylvania.

The shoreline bordering the survey area is a major center for maritime commerce, considered the third largest port in tonnage in the U.S., with 11 million short tons (10 metric tons) of cargo, according to the NOS National Requirements Study (NOS, 1984). The demographic significance of the region, with its major population and commercial centers at Trenton, Camden, Philadelphia, and Wilmington, is also highlighted by the fact that approximately five percent of the U.S. population is located within the Delaware River drainage basin (Sharp, 1983).

DELAWARE RIVER & BAY

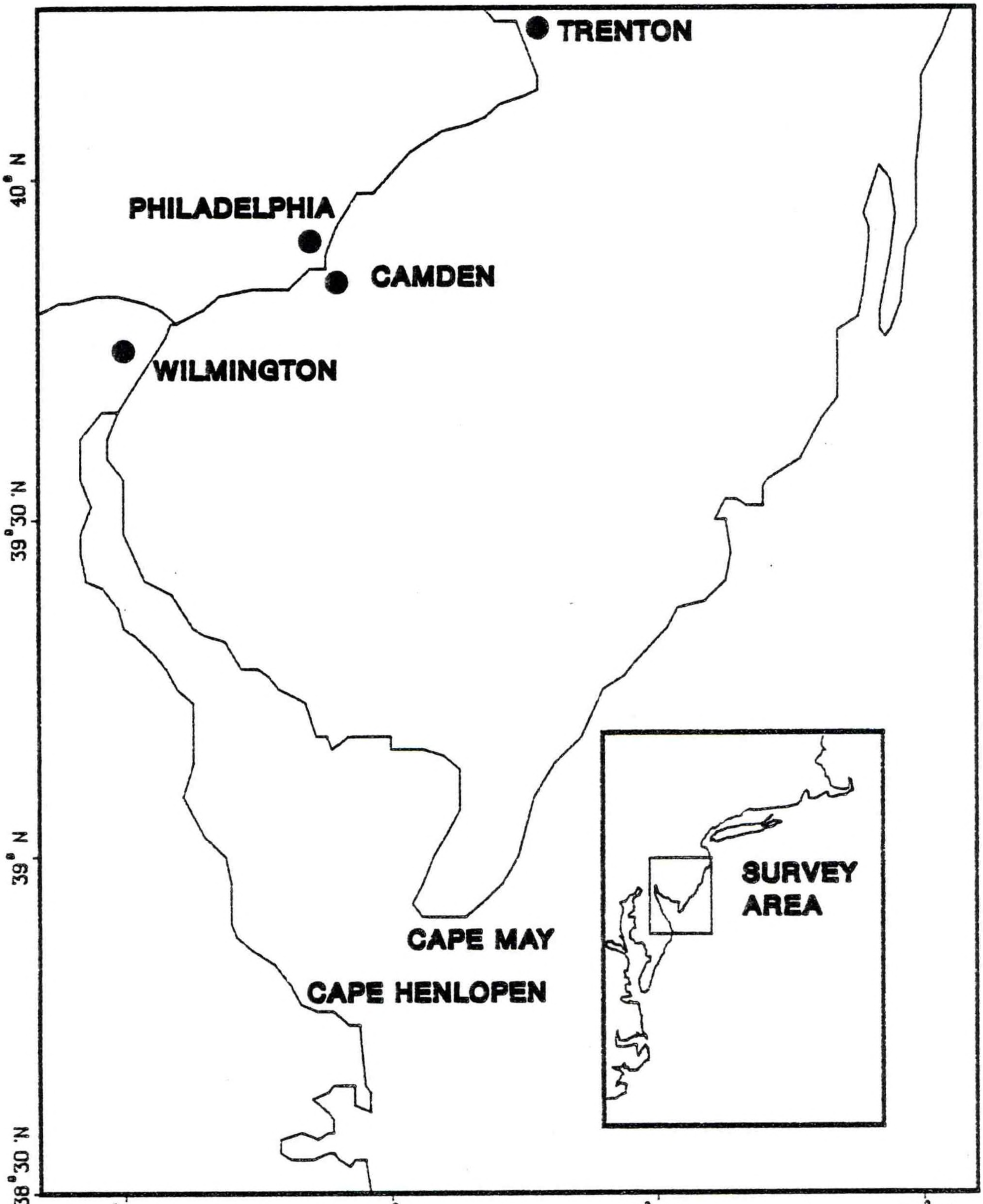


Figure 1. Geographic Setting.

The DR&B estuary extends approximately 115 nautical miles (213 kilometers) north from its mouth at the Capes to its tidal limit at Trenton, New Jersey. The Delaware River drains an area of approximately 12,765 square miles (33,048 square kilometers) including parts of Delaware, New Jersey, Pennsylvania, Maryland, and New York (Polis and Kupferman, 1973). The bay varies in width from about 10 miles (16 kilometers) at the Capes to a maximum of about 26 miles (42 kilometers) at its widest part. Upstream, the estuary narrows to approximately 1000 feet (304 meters) at Trenton.

Located in the Coastal Plain Physiographic Province, the Delaware Bay is the drowned river valley of an ancestral Pleistocene-age Delaware River. The bay is nearly continuously rimmed by a 5- to 10-mile (8- to 16-kilometers) wide band of salt marshes. North of Wilmington, the Delaware River parallels the fall line separating mostly unconsolidated Coastal Plain sedimentary deposits on the east from crystalline Piedmont rocks to the west. Structural basins partially filled with Triassic-age sandstones lie to the north of Trenton and are responsible for the physiographic feature designated the Triassic Lowlands.

The DR&B is a well-mixed estuary with the Delaware River serving as the major source of fresh water flow. The Schuylkill River contributes only about 14 percent (2753 ft^3/s or $78m^3/s$) of the total fresh water input (19415 ft^3/s or $550m^3/s$) and all other sources combined contribute less than 30 percent (5366 ft^3/s or $152m^3/s$) (Sharp, 1983, Polis and Kupferman, 1973) (figure 2).

The tidal wave in the Delaware Bay is progressive, requiring about 7 hours for high water to propagate from the Delaware Bay Capes to Trenton and about eight and one-half hours for low water to propagate the same distance (Hires, Mellor, Oey, and Garvine, 1983). Nontidal contributions to the circulation in the DR&B include primarily wind-driven currents, and gravitational flow resulting from the mixing of fresh water and seawater,

RIVER INPUT

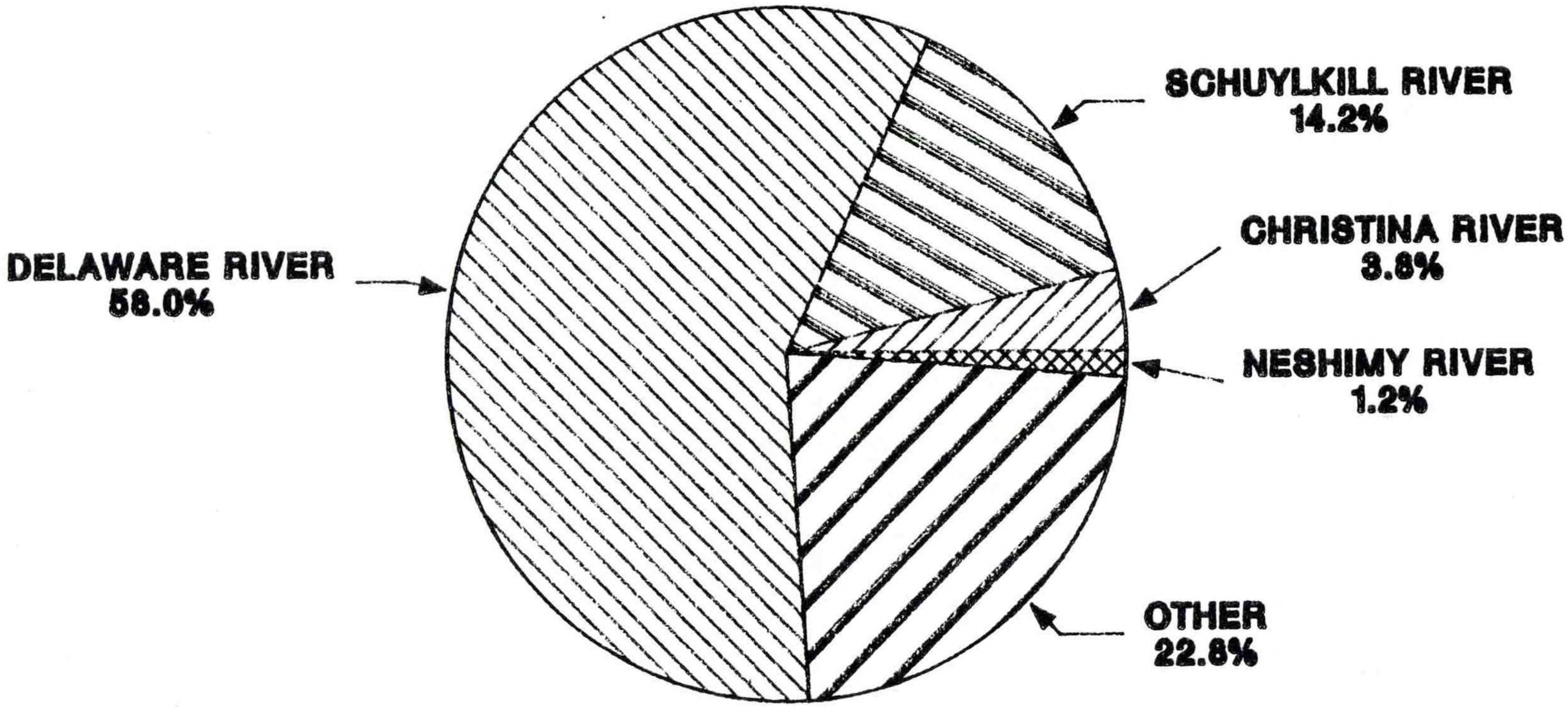


Figure 2. Percentage of River Input into the Delaware Bay.

modified by Coriolis force and the frictional drag caused by both the irregular shoreline topography and roughness of the bottom especially in the lower Bay (Hires, et al. 1983).

1.3. Circulation Survey Purpose

A circulation survey was conducted in the DR&B to fulfill two main objectives: 1) update existing NOS products including the Tidal Current Tables, Atlantic Coast of North America, and the Tide Tables, East Coast of North and South America, 2) facilitate the development of two new products comprising real-time current and water level predictions in DR&B, and a Circulation and Water Level Atlas of Delaware Bay. These products will have important applications in navigation for the safe and efficient use of the DR&B waterways, in environmental management for monitoring the movement of oil spills and other hazardous materials, in marine resource management, such as fisheries for predicting spawning locations, and in search and rescue operations for predicting the movement of disabled water craft.

The updating of the Tidal Current Tables is especially important because the tidal current predictions for the Delaware Bay reference station in table 1 of the Tidal Current Tables as well as the relative tidal current predictions for the subordinate stations in table 2 of the Tidal Current Tables are based on data collected more than 37 years ago. This old data, on which the reference station and subordinate stations are based, is inadequate for two reasons. First, changes in the physical characteristics of the DR&B during the last 37 years have occurred as a consequence of shoreline erosion and deposition and dredge and fill operations. Second, older measurement techniques are considerably less reliable than modern techniques. These old methods did not, in general, allow for a time series of data long enough to resolve all the important tidal constituents.

The Delaware Bay reference station, first used in 1916, is based on the weighted mean of a series of 29 day observations made between 1912 and 1921 utilizing current pole observations. These predictions were revised in 1943 with observations made between 1940 and 1941. The majority of the Delaware Bay subordinate stations in the Tidal Current Tables are based on relatively short periods of occupation, with most stations occupied for periods between 5 and 10 days compared to 15 days to 6 months in this survey. Sampling rates of the older surveys were two per hour while the new survey gathered data at the rate of six samples per hour.

The new Delaware Bay entrance reference station is based on the least squares harmonic analysis of a 221-day record from station 2 (See figure 6). It will appear in table 1 of the 1987 Tidal Current Tables, Atlanitc Coast of North America. Nonharmonic comparision analysis results from 42 station-depths will appear in table 2.

1.4. Description of a Circulation Survey

A circulation survey is an endeavor to collect data that describe the oceanographic and meteorologic characteristics of an estuary for the understanding and prediction of water movement. The kinds of oceanographic data collected include current speeds and directions, water levels, and water temperature and conductivity; meteorological data collected include wind speed and direction, barometric pressure, and air temperature.

Although the primary factor affecting water levels and currents in an estuary is the astronomical tide, meteorological conditions, especially wind, and river runoff can have major effects. In order to measure wind, collecting stations are sited where atmospheric conditions have the greatest influence on estuarine circulation, for example over the broadest areas of the bay where wind fetch are longest and where surface currents are often dominated by wind. Meteorological stations must also be sited high enough above the water surface to avoid recording turbulence at the air/sea interface. In addition to wind conditions, air temperature and pressure are also recorded. Air temperature and pressure provide the researcher with information on the passage of weather fronts, while air pressure changes alone may be helpful in explaining non-astronomical water level changes in an estuary.

Water conductivity and temperature recorded with respect to depth (CTD) provide information on density stratification. This data is useful for determining the influence of fresh water runoff on estuarine circulation and explaining water circulation driven by density differences. CTD casts are taken at slack-before-flood and slack-before-ebb, either independently at individual current stations, or at a series of stations along a transect of the estuary. Whichever method of observation is used, the data can be used to define the vertical density structure in the estuary at a particular time. In a third method CTD casts are taken consecutively (about every half hour) along one vertical profile during a tidal cycle to measure the variation of the density characteristics with respect to time.

Current measuring stations usually consist of two or three current meters moored together. The moorings usually include one meter near the bottom, one meter near the surface, and one meter near the middle of the water column. A typical current meter mooring configuration is given in figure 3. Some of the moorings are located close to the shipping lanes where present current predictions are considered especially inadequate. Other moorings are located to define the hydrodynamics of the estuary. These latter moorings are generally located along cross sections at the entrance to the estuary, at the mouth of major rivers or canals entering the estuary, and in areas of major changes in topography. Other moorings are located where users have indicated a particular

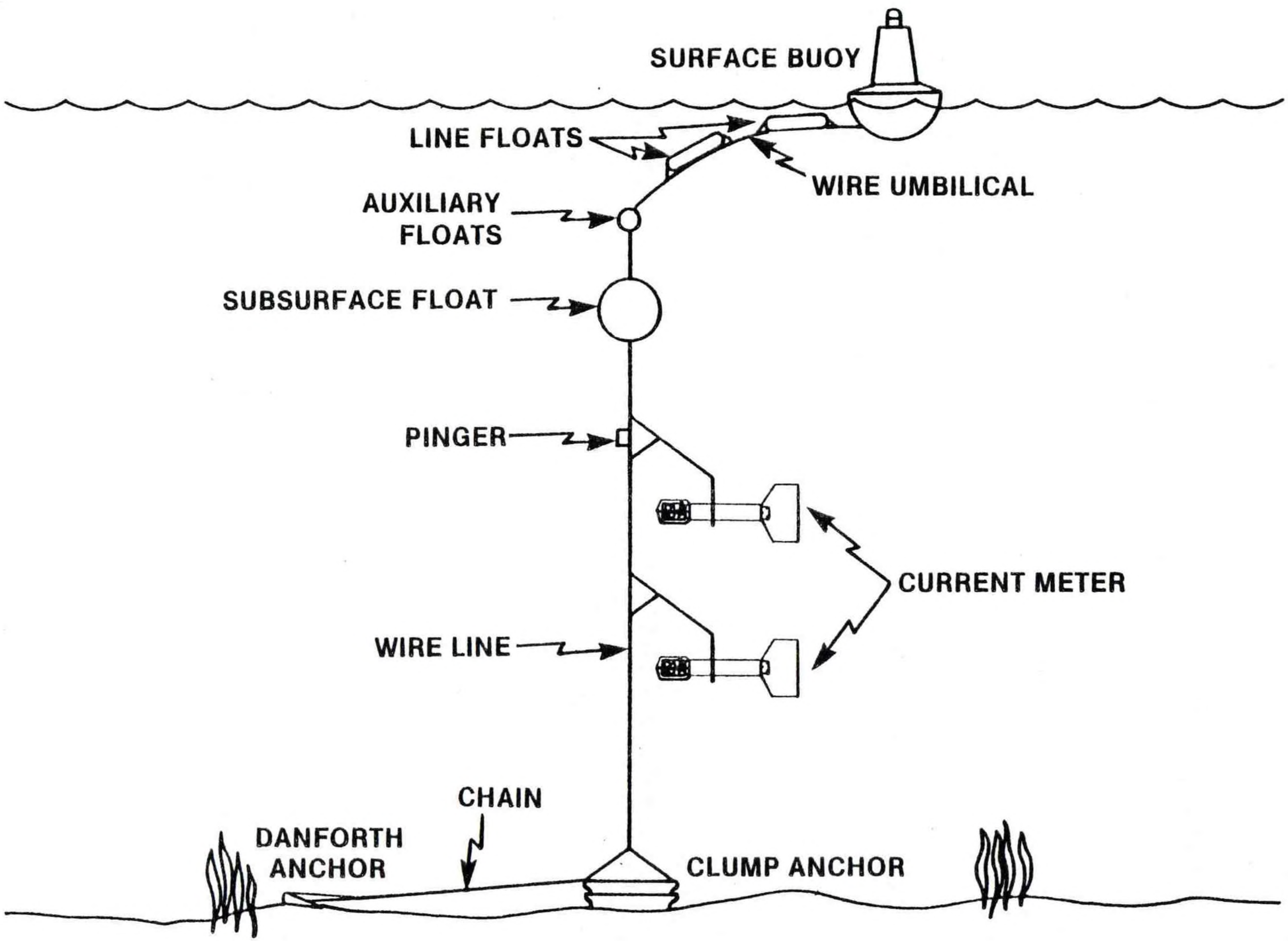


Figure 3. Current Meter Mooring.

need for data, such as locations of navigational importance, sites at the turbidity maxima, locations where effluent enters the estuary, or areas of important biological activity.

Water level gages are located similarly throughout the estuary. From a hydrodynamic standpoint, the gages are most useful near the mouth of the estuary since estuarine circulation are driven principally by the astronomical tide at the entrance. Water level data are also collected near the head of the estuary to monitor the contribution of runoff to the estuarine circulation. Futhermore, water level gages are also sited near points where the mouths of rivers or canals enter the estuary, to monitor the influence of these sources of flow. Water level gages are also installed at the sites of historical water level stations in order to redefine datums and determine land movements/sea level changes.

2.0. SUMMARY OF THE DELAWARE RIVER AND BAY CIRCULATION SURVEY

2.1. Development of the Survey Plan

Planning for the DR&B Circulation Survey was initiated by NOS' Estuarine and Ocean Physics Branch (EOPB). A final version of the DR&B circulation survey plan was produced after members of the EOPB met with the public. The first public meeting, held May 1983 at the University of Delaware in Newark, was attended by about 120 persons from local government, Federal agencies, academic institutions, maritime industry, and environmental organizations. This meeting resulted in the compilation of environmental and commercial characteristics of the Delaware estuary which served to guide the final survey plan.

In addition, an Informal Working Group was formed that aided the EOPB staff in developing a final survey plan. The technical and scientific expertise of the Working Group also proved to be a significant help during the execution of the survey plan.

Organizations that participated in the DR&B Informal Working Group include:

- U.S. Coast Guard
- U.S. Power Squadron
- U.S. Army Corps of Engineers
- U.S. Geological Survey
- Pilots Association for the Bay and River, Delaware
- Mariners' Advisory Committee for the Bay and River Delaware
- New Jersey Marine Science Consortium
- University of Delaware
- Princeton University
- Rutgers University
- Stevens Institute of Technology
- New Jersey Department of Environmental Protection

Delaware Department of Natural Resources and
Environmental Control
Delaware River Basin Commission

After a presurvey briefing and follow-up meetings of the Working Group, it was concluded that the DR&B Circulation Survey should investigate five general areas of interest:

1. Effect of river runoff on the estuary
2. Interaction between the Chesapeake Bay and Delaware Bay particularly with respect to the Chesapeake and Delaware (C&D) Canal
3. Support of the DR&B Circulation Model
4. Shelf/Estuary interaction
5. Cross Bay circulation

The influence of river runoff on the estuary is especially important to marine biologists. Fresh water runoff controls the degree of density stratification in the estuary, position of the turbidity maximum, and location of the salinity minimum, which are important factors in the biological productivity of the Delaware estuary, especially with regard to the dispersal of oyster larvae. In addition, information on runoff is helpful in determining the residual circulation in the estuary (the nontidal component of the circulation), the yearly variability of runoff and the effect of runoff on water levels in the estuary.

Knowledge of the interaction between the Delaware and Chesapeake Bays through the Chesapeake and Delaware Canal would be helpful in understanding to what extent water quality in one estuary affects that in the other. This information can also shed light on the possible hydrodynamic effect on circulation that variation in water levels in one estuary has on the other. Also, it can be determined whether one estuary has a dominant effect on water levels and currents in the C&D Canal (Wong and Garvine, 1984).

In order to support the validation process for the DR&B Circulation Model being developed by the EOPB, additional and longer term water level gages and current stations were planned at the boundaries of the estuary.

Current and CTD data were collected outside the estuary entrance in order to acquire data on the interaction between the estuary and shelf circulation. These latter CTD casts were taken for coordination with CTD studies being conducted by the Ocean Assessments Division (OAD) of the Office of Oceanography and Marine Assessment (OMA) of NOS.

In order to gain information on cross-Bay circulation, a scatter of current stations as well as CTD casts were taken in the lower part of the Bay. Such information may be helpful in explaining dispersal of blue crab larvae in the Bay.

The next phase in the planning of the DR&B Circulation Survey involved a reconnaissance of the survey area by officers of the NOAA Corps and personnel from EOPB. During the reconnaissance, water level bench marks were located, platforms for meteorological stations were visited, and positions of current station moorings were investigated.

The field reconnaissance and presurvey briefings resulted in a final DR&B survey plan. This survey plan was distributed to members of the Informal Working Group and other major offices within NOAA, including the Marine Charting Branch, Office of Public Affairs, and the NOAA Corps for their comments.

2.2. Summary of the Data Collection Program

Data collection during the DR&B Circulation Survey was carried out by the NOAA Ship FERREL under the command of LCDR Kurt Schnebele. The FERREL, which is 133 feet long and has a maximum draft of only 8 feet, is specially designed to operate in shallow estuaries. The ship was equipped with a PDP-11/34 computer on which initial data processing was performed. The PDP-11/34 along with the Circulation Measurement Data Processing (CMDP) software allowed the survey officer aboard the FERREL to detect data quality problems before survey instrumentation was reused.

The survey encompassed two field seasons. The first season (OPR-D802-FE84) began March 4, 1984 and ended December 2, 1984. The second field season (OPR-D802-FE85) began February 28, 1985 and ended May 5, 1985. During the winter period (November 28, 1984 to February 22, 1985) five of the seven long-term current stations (stations 2, 23, 33, 51, and 154) were not regularly maintained, but were left operating at a sampling rate, reduced from the normal six samples per hour to two samples per hour. Two stations (stations 16 and 17) on the shelf were maintained by EG&G Corp. (Gaithersburg, Maryland), using Vector Measuring Current Meters (VMCM) collecting samples at six per hour.

During the survey, current meter, water level, meteorological, CTD, and bottom roughness data were collected. The current measuring program consisted of seven long-term (15-month) stations and 39 other current stations that were occupied for at least 30 days each. This translates into about 8325 meter-days of current data. In addition to the 6 control stations continuously in operation in the survey area, 19 other water level gages were specially operated for the survey. Two meteorological stations were occupied continuously during the entire 15 months of the survey for a total of 825 meter-days of data. Single CTD casts were taken at each current station at slack-before-flood and at slack-before-ebb. CTD transects were taken at important cross sections of the estuary, once at slack-before-flood and once at slack-before-ebb. This process was repeated during the spring and fall of 1984 and again in the spring of 1985. A single CTD time series transect was also taken during the same periods. During the entire CTD program 755 casts were taken.

Bottom roughness information was collected near Brandywine Shoal in support of the Delaware River and Bay model. Since bottom roughness results from a combination of sediment grain size and frictional drag of bottom bedforms, both types of data were collected. A series of dives were made by personnel from the FERREL during which sediment samples were collected, the distribution of sediment was observed and recorded, and measurements concerning frequency, character, and dimension of bedforms were made.

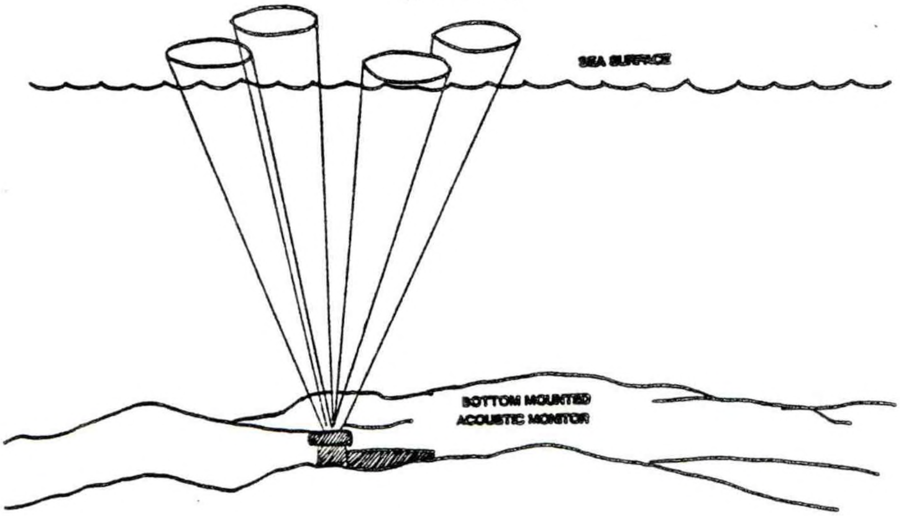
2.3. New Technologies

2.3.1. New Instrumentation

In addition to the Grundy 9021G and Aanderaa RCM4 current meters, new technologies for measuring currents were also investigated during the DR&B Circulation Survey. One of these new technologies is the Remote Acoustic Doppler System (RADS) (Appell, Mero, Williams, and Woodward, 1985). RADS is a real-time current measuring system. The instrument (figure 3) is bottom mounted, consisting of four transmitting and receiving beams. The beams are oriented 90 degrees apart on the same horizontal plane. Each beam is oriented 15 degrees off the vertical. Current speed and direction are determined by measuring the Doppler shift of the backscattered signal of each beam. These speeds and directions are resolved into predetermined vertical increments called "bins." The RADS station, located about 600 meters west of Brandywine Shoal, recorded data during the period September 1984 to August 1985. A "Sea Truth" experiment was conducted in September 1984 to quantify the performance of the RADS compared to traditional current meters (Magnell, 1985).

A HF radar technique was used to measure surface currents over a relatively large area. This method, using a system known

REMOTE ACOUSTIC DOPPLER SYSTEM (RADS)



COASTAL OCEAN DYNAMICS APPLICATIONS RADAR (CODAR)

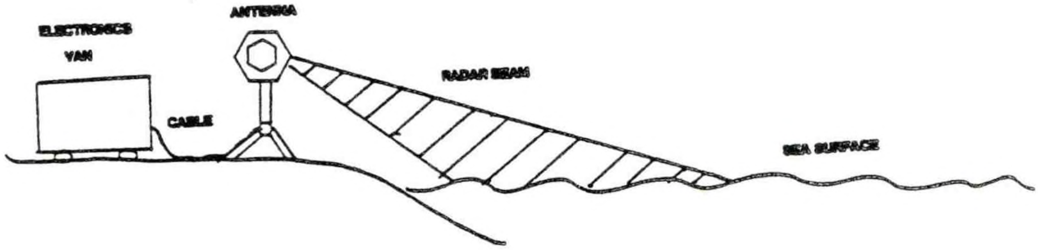


Figure 4. RADS and CODAR.

as the Coastal Ocean Dynamics Applications Radar (CODAR) (Lipa and Barrick, 1984) (figure 3), was deployed to measure currents over a large sector of the lower Delaware Bay during the period October 15 to November 5, 1984. CODAR calculates surface currents by measuring the combined Doppler shift of radio waves caused by both the phase velocity of the surface gravity waves and the surface currents. The results of an intercomparison between CODAR and RADS are described by Porter, Williams, and Swassing (1986).

Other state-of-the-art current measurement systems employed during the survey included the EG&G Vector Measuring Current Meter (VMCM) and the Marsh-McBirney electromagnetic current meter. The VMCM, more suitable than the Grundy for dynamic wave environments, was used to replace the Grundy current meters maintained at shelf stations 16 and 17 during the winter deployment period. The Marsh-McBirney electromagnetic current meter, a VMCM current meter, an Aanderaa current meter, and a Grundy current meter operated from September 19 to October 16, 1984, near the RADS-Brandywine Shoal site during the Delaware Bay Intercomparison Experiment (Magnell, 1985).

2.3.2. Delaware River and Bay Modeling System

Developed independently of the DR&B Circulation Survey, a circulation model was designed to predict real-time currents and water levels within DR&B. The model will be validated using current and water level data collected during the survey.

The model is a two-dimensional version of a three-dimensional nonlinear finite difference model developed for Delaware Bay by George Mellor and Alan Blumberg at Princeton University (Blumberg and Mellor, 1985). From Artificial Island on the Delaware River to the open boundary of the estuary, the equations are depth-averaged in two dimensions. North of Artificial Island the equations are one dimensional, averaged over the cross section of the river.

Applying real-time water level data or tidal predictions and wind speeds as forcing functions, the model was used during 1984 through June 1985 to provide once per hour real-time predictions and 36-hour real-time forecasts of currents and water levels. Since June 1985 the model has been maintained on a stand-by status, i.e. the model will only be run in response to emergencies such as groundings and oil spills.

A circulation model can be beneficial in a number of ways. It can be used to reduce the cost of circulation surveys by limiting the number of current measurement locations necessary and by aiding in the selection of station locations for areas that cannot be modeled. Models can generate forecasts, hindcasts, or simulations using nontidal forcing factors such as wind as well as tidal forcing. Possible products from a model include additional entries to the Tidal Current Tables, generation of special predictions, and a water level and circulation atlas of the Delaware River and Bay.

3.0. CURRENT DATA

3.1. Significance of Current Data in DR&B

The primary purpose of a circulation survey, as discussed in Section 2.0, is to collect data on currents that can be used to improve navigation in U.S. coastal waters by updating entries to the Tidal Current Tables and publishing tidal current charts (or atlases). Current data products may be derived directly from an analysis of survey current station data or may be obtained indirectly from running a circulation model that has been verified using current station data. Other data collected during a circulation survey (water levels, CTD, and meteorological data) are used to drive the circulation model and for understanding the dynamics of the estuary.

3.2. Location and Duration of Current Stations

Current station locations were selected to fulfill three major requirements:

1) Collection of current data along navigation channels

2) Description of cross-sectional views of the circulation at major changes in the geography of the estuary and at major sources of flow entering the estuary

3) Reoccupation of sites referenced in the Tidal Current Tables

Depths of observation at each mooring are standardized in such a way that near surface measurements are taken 15 feet (4.6 meters) from the surface, near bottom measurements are taken 5 feet (1.5 meters) from the bottom, and mid-depth measurements are taken near the center of the water column. The near-surface or bottom depths of observation may be adjusted if wave action extends below 15 feet from the surface or if fouling is significant above 5 feet from the bottom.

Current station occupation periods were planned so that the longest time periods were assigned to stations that would become reference stations (station 2) or would be located at points providing important information about the overall estuarine circulation (stations 23, 33, 16, 17, 51, 154). The majority of other stations were occupied for a minimum of 30 days, sufficiently long to resolve 6 of the principal tidal harmonic constituents.

A complete list of current station information including depth of observation (measured from bottom up), latitude and longitude, and start and stop dates of observations are listed in table 1. Table 2 is a chronological comparison of successful current station collection periods. Station location plots are provided in figures 5 thru 10.

Additional current station occupations in the Chesapeake and Delaware Canal and in the Delaware River near the entrance to the Canal were carried out during the 1983 field season of the NOS Chesapeake Bay Circulation Survey. See Browne and Fisher (1986) for details on these stations.

3.3. Instrumentation

The majority of current stations in DR&B employed Grundy 9021G current meters equipped with calibrated temperature and conductivity sensors, while some were also supplied with calibrated pressure sensors. The speed of the current is calculated by averaging the number of rotations of a Roberts-type rotor over a 10-minute interval. Current direction is recorded instantaneously at the end of each sampling interval. Other information, including an instrument diagram and manufacturer specifications

Table 1. Current Stations

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
1	38°47'58"	4/3 - 4/22/84	75	63	G	18.3	18.3	18.3	18.3
	75°04'54"	"	"	5	G	18.0	18.0	18.0	18.0
	"	4/22 - 5/06/84	"	63	A	14.1	14.1	14.1	14.1
	"	"	"	5	G	13.5	13.5	13.5	13.5
	"	7/16 - 7/31/84	"	"	G	14.0	14.0	14.0	14.0
	"	7/31 - 8/15/84	"	63	G	15.0	15.0	15.0	15.0
2	38°46'51"	4/24 - 5/23/84	60	47	G	27.8	27.8	27.8	27.8
	75°02'35"	"	"	22	G	27.8	27.8	27.8	27.8
	"	"	"	5	G	27.8	27.8	27.8	27.8
	"	5/23 - 6/21/84	"	47	G	27.7	27.7	27.7	27.7
	"	"	"	22	G	27.7	27.7	27.7	27.7
	"	"	"	5	G	27.7	27.7	27.7	27.7
	"	6/21 - 7/16/84	"	22	G	20.9	20.9	20.9	20.9
	"	7/16 - 8/13/84	"	47	G	27.2	27.2	27.2	27.2
	"	"	"	22	G	27.2	27.2	27.2	27.2
	"	"	"	5	G	27.2	27.2	27.2	27.2
	"	8/13 - 9/11/84	"	22	G	28.8	28.8	28.8	28.8
	"	"	"	5	G	28.8	28.8	28.8	28.8
	"	9/26 - 10/23/84	"	47	G	27.1	27.1	27.1	27.1
	"	"	"	22	G	27.1	27.1	27.1	27.1
	"	"	"	5	G	26.4	26.4	26.4	26.4
	"	10/23 - 11/21/84	"	47	G	28.9	28.9	28.9	28.9
	"	"	"	22	G	28.9	28.9	28.9	28.9
	"	"	"	5	G	10.2	10.2	10.2	10.2
	"	11/21 - 12/2/84	"	47	G	10.8	10.8	10.8	10.8
	"	"	"	22	G	10.8	10.8	10.8	10.8
	"	"	"	5	G	10.8	10.8	10.8	10.8

* G = Grundy 9021G current meter
A = Aanderaa RCM4 current meter

** 1 foot = .3048 meter

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
2	38°46'51"	3/7 - 4/5/85	60	22	G	28.6	28.6	28.6	28.6
	75°02'35"	3/7 - 3/26/85	"	5	G	17.3	17.3	17.3	17.3
	"	4/5 - 5/4/85	"	22	G	30.0	30.0	30.0	30.0
3	38°51'33"	4/3 - 5/4/84	33	15	G	30.7	30.7	30.7	30.7
	75°01'28"	"	"	5	A	30.7	30.7	0	0
	"	7/16 - 7/31/84	"	15	G	15.0	15.0	15.0	15.0
	"	7/31 - 8/15/84	"	"	G	15.0	15.0	15.0	15.0
	"	"	"	5	G	4.8	4.8	4.8	4.8
	"	10/19 - 11/3/84	"	15	G	14.1	14.1	14.1	14.1
	"	"	"	5	G	14.1	14.1	0	0
	"	11/3 - 11/21/84	"	15	G	14.8	14.8	14.8	14.8
	"	"	"	5	G	14.8	14.8	14.8	14.8
4	38°53'24"	4/3 - 5/4/84	21	6	G	30.7	30.7	30.7	30.7
	74°59'08"	7/16 - 7/31/84	"	"	G	13.9	13.9	13.9	13.9
	"	7/31 - 8/15/84	"	"	G	14.1	14.1	14.1	14.1
	"	3/1 - 3/12/85	"	"	G	10.8	10.8	10.8	10.8
	"	3/19 - 4/10/85	"	"	G	5.0	5.0	5.0	5.0
	"	4/10 - 5/1/85	"	"	G	21.0	21.0	21.0	21.0
5	38°54'22"	4/3 - 5/4/84	30	15	G	30.7	30.7	30.7	30.7
	74°58'41"	"	"	5	G	30.7	30.7	30.7	30.7
	"	5/4 - 5/21/84	"	15	G	12.1	12.1	12.1	12.1
	"	5/21 - 6/19/84	"	"	G	27.8	27.8	27.8	27.8
	"	"	"	5	G	27.8	27.8	27.8	27.8
	"	7/16 - 7/31/84	"	15	G	10.8	10.8	10.8	10.8
	"	"	"	5	G	10.8	10.8	10.8	10.8
	"	7/31 - 8/15/84	"	15	G	15.3	15.3	15.3	15.3
	"	7/31 - 8/11/84	"	5	G	11.2	11.2	0	6.6
	"	10/19 - 11/3/84	"	15	G	15.1	15.1	15.1	15.1
	"	"	"	5	G	15.1	15.1	15.1	15.1
	"	11/3 - 11/21/84	"	15	G	14.7	14.7	14.7	14.7
	"	"	"	5	G	14.7	14.7	14.7	14.7

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
11	38°47'18"	10/19 - 11/4/84	60	25	G	15.8	15.8	15.8	15.8
	74°42'41"	"	"	10	G	15.8	15.8	0	0
	"	11/4 - 11/19/84	"	35	G	13.9	13.9	13.9	13.9
	"	"	"	10	G	13.9	13.9	13.9	13.9
12	38°47'07"	10/20 - 11/4/84	116	90	G	15.2	15.2	15.2	15.2
	74°22'06"	"	"	50	G	15.2	15.2	15.2	15.2
	"	11/4 - 11/19/84	"	90	G	14.9	14.9	14.9	14.9
	"	11/4 - 11/19/84	"	50	G	14.9	14.9	0	14.9
	"	"	"	10	G	14.9	14.9	14.9	14.9
16	39°12'02"	3/8 - 4/17/84	59	35	G	40.7	40.7	40.7	40.7
	74°24'46"	"	"	25	G	40.7	40.7	40.7	40.7
	"	"	"	10	G	40.7	40.7	40.7	40.7
	"	4/17 - 5/22/84	"	35	G	34.8	34.8	34.8	34.8
	"	"	"	25	G	34.8	34.8	34.8	34.8
	"	"	"	10	G	35.0	35.0	35.0	35.0
	"	5/22 - 6/16/84	"	35	G	20.8	20.8	20.8	20.8
	"	"	"	25	G	20.8	20.8	13.5	13.5
	"	6/16 - 7/17/84	"	35	G	20.8	20.8	20.8	20.8
	"	"	"	25	G	29.9	29.9	8.5	8.5
	"	"	"	10	G	20.8	20.8	20.8	20.8
	"	7/17 - 8/16/84	"	35	G	20.9	20.9	20.9	20.9
	"	"	"	25	G	28.9	28.9	28.9	28.9
	"	"	"	10	G	28.9	28.9	0	0
	"	8/16 - 9/10/84	"	35	G	23.9	23.9	23.9	23.9
	"	"	"	10	G	22.9	22.9	22.9	22.9
	"	9/10 - 10/9/84	"	35	G	28.9	28.9	28.9	28.9
	"	10/9 - 11/5/84	"	"	G	25.0	25.0	25.0	25.0
	"	"	"	25	G	25.0	25.0	25.0	25.0
	"	"	"	10	G	20.2	20.2	20.2	20.2
	"	11/5 - 11/27/84	"	35	G	23.0	23.0	23.0	23.0
	"	"	"	25	G	23.0	23.0	23.0	23.0
	"	11/8 - 11/27/84	"	10	G	18.8	18.8	18.8	18.8

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
17	39°03'04"	3/7 - 4/17/84	100	10	G	40.9	40.9	40.9	40.9
	74°04'18"	4/17 - 5/22/84	"	75	G	34.6	34.6	34.6	34.6
	"	"	"	50	G	34.6	34.6	34.6	34.6
	"	5/22 - 6/16/84	"	75	G	24.9	24.9	24.9	24.9
	"	"	"	50	G	9.8	16.5	16.5	16.5
	"	"	"	10	G	4.3	4.3	4.3	4.3
	"	3/7 - 4/17/84	"	"	G	40.9	40.9	40.9	40.9
	"	4/17 - 5/22/84	"	75	G	34.6	34.6	34.6	34.6
	"	"	"	50	G	34.6	34.6	34.6	34.6
	"	5/22 - 6/16/84	"	75	G	24.9	24.9	24.9	24.9
	"	"	"	50	G	9.8	16.5	16.5	16.5
	"	"	"	10	G	4.3	4.3	4.3	4.3
	"	6/16 - 7/17/84	"	75	G	29.9	29.9	29.9	29.9
	"	"	"	50	G	29.9	29.9	29.9	29.9
	"	"	"	10	G	29.9	29.9	29.9	29.9
	"	7/17 - 8/16/84	"	"	G	29.2	29.2	29.2	29.2
	"	8/16 - 9/10/84	"	"	G	23.9	23.9	23.9	23.9
	"	9/10 - 10/9/84	"	75	G	28.9	28.9	28.9	28.9
	"	"	"	50	G	28.9	28.9	28.9	28.9
	"	"	"	10	G	23.9	23.9	23.9	23.9
	"	10/9 - 11/5/84	"	50	G	26.0	26.0	26.0	26.0
	"	"	"	10	G	26.0	26.0	26.0	26.0
	"	11/5 - 11/27/84	"	50	G	22.0	22.0	22.0	22.0
18	38°53'47"	9/18 - 10/3/84	20	6	G	15.1	15.1	15.1	15.1
	75°12'38"	10/3 - 10/18/84	"	"	G	15.0	15.0	15.0	15.0
19	38°56'28"	9/18 - 10/3/84	43	26	G	15.0	15.0	15.0	15.0
	75°06'19"	"	"	5	G	15.0	15.0	15.0	15.0
	"	10/3 - 10/18/84	"	26	G	15.0	15.0	15.0	15.0
	"	"	"	5	G	15.0	15.0	15.0	15.0
20	38°59'05" 74°59'17"	9/18 - 10/10/84	23	8	G	12.6	12.6	12.6	12.6

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
21	39°00'29"	9/18 - 10/3/84	20	5	G	13.0	13.0	13.0	13.0
	75°17'03"	10/3 - 10/18/84	"	"	G	16.0	16.0	0	0
22	39°00'58"	5/9 - 5/29/84	34	20	G	20.1	20.1	20.1	20.1
	75°15'04"	"	"	5	G	20.1	20.1	20.1	20.1
	"	5/29 - 6/13/84	"	20	G	13.7	13.7	13.7	13.7
	"	"	"	5	G	21.8	21.8	21.8	21.8
	"	7/16 - 8/2/84	"	20	G	15.7	15.7	15.7	15.7
	"	"	"	5	G	15.7	15.7	15.7	15.7
	"	8/2 - 8/15/84	"	20	G	11.7	11.7	11.7	11.7
	"	"	"	5	G	11.7	11.7	11.7	11.7
	"	9/18 - 10/3/84	"	20	G	14.0	14.0	14.0	14.0
	"	10/3 - 10/18/84	"	"	G	14.8	14.8	14.8	14.8
	"	"	"	5	G	15.0	15.0	15.0	1.0
23	39°02'19"	3/8 - 4/4/84	38	26	G	26.9	26.9	26.9	26.9
	75°09'29"	4/4 - 5/5/84	"	"	G	31.2	31.2	31.2	31.2
	"	"	"	8	G	28.5	28.5	28.5	28.5
	"	5/5 - 6/5/84	"	26	G	29.7	29.7	29.7	29.7
	"	"	"	8	G	13.7	13.7	13.7	13.7
	"	6/5 - 6/30/84	"	26	G	24.0	24.0	24.0	24.0
	"	"	"	8	G	24.0	24.0	24.0	24.0
	"	6/30 - 7/13/84	"	"	G	13.0	13.0	13.0	13.0
	"	7/13 - 7/27/84	"	26	G	12.9	12.9	12.9	12.9
	"	7/27 - 8/14/84	"	"	G	10.6	10.6	10.6	10.6
	"	"	"	8	G	17.0	17.0	17.0	17.0
	"	8/14 - 9/11/84	"	26	G	21.0	21.0	21.0	21.0
	"	9/11 - 10/4/84	"	8	G	22.9	22.9	22.9	22.9
	"	10/4 - 10/31/84	"	26	G	26.8	26.8	26.8	26.8
	"	"	"	8	G	26.8	26.8	26.8	26.8
	"	10/31 - 11/28/84	"	26	G	27.9	27.9	27.9	27.9
	"	"	"	8	G	27.9	27.9	27.9	27.9

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
23x	39°04'58"	3/8 - 3/26/85	35	26	G	18.0	18.0	18.0	18.0
	75°11'17"	"	"	5	G	18.0	18.0	18.0	18.0
	"	3/26 - 4/24/85	"	26	G	28.8	28.8	28.8	28.8
	"	"	"	5	G	19.8	19.8	19.8	19.8
24	39°04'00"	5/9 - 5/29/84	20	7	G	20.1	20.1	20.1	20.1
	75°04'13"	5/29 - 6/13/84	"	"	G	15.8	15.8	15.8	15.8
	"	7/16 - 8/14/84	"	"	G	28.0	28.0	28.0	28.0
	"	9/18 - 10/3/84	"	"	G	15.0	15.0	15.0	15.0
	"	10/3 - 10/18/84	"	"	G	15.0	15.0	15.0	15.0
25	39°04'41"	9/18 - 10/10/84	18	5	G	21.6	21.6	0	0
	74°58'53"	10/10 - 10/18/84	"	"	G	8.3	8.3	0	0
29	39°12'12" 75°21'30"	3/12 - 3/28/85	10	"	G	15.0	15.0	15.0	15.0
30	39°10'43"	5/9 - 5/29/84	43	27	G	21.0	21.0	21.0	21.0
30	75°16'24"	5/9 - 5/29/84	"	5	G	21.0	21.0	21.0	21.0
	"	5/30 - 6/15/84	"	27	G	14.9	14.9	14.9	14.9
32	39°15'03" 75°22'08"	5/15 - 6/4/84	19	5	G	19.7	19.7	19.7	19.7
	39°15'05" 75°21'29"	6/4 - 6/21/84	20	6	G	16.8	16.8	16.8	16.8
33	39°16'08"	3/8 - 4/4/84	48	36	G	26.9	26.9	26.9	26.9
	75°20'53"	4/4 - 5/4/84	"	"	G	24.7	24.7	24.7	24.7
	"	5/4 - 6/4/84	"	"	G	31.8	31.8	31.8	31.8
	"	6/15 - 7/15/84	"	"	G	29.0	29.0	29.0	29.0
	"	7/15 - 8/14/84	"	"	G	28.8	28.8	28.8	28.8
	"	"	"	5	G	28.9	28.9	28.9	28.9

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
33	39°16'08"	8/14 - 9/11/84	48	36	G	27.0	27.0	27.0	27.0
	75°20'53"	"	"	5	G	27.0	27.0	27.0	27.0
	"	9/11 - 10/4/84	"	"	G	22.5	22.5	22.5	22.5
33x	39°14'52"	11/17 - 11/30/84	30	15	G	13.0	13.0	13.0	13.0
	75°18'56"	3/12 - 4/12/85	"	"	G	30.9	30.9	30.9	30.9
	"	4/12 - 4/24/85	"	"	G	13.2	13.2	13.2	13.2
34	39°17'23"	5/30 - 6/9/84	17	5	G	9.7	9.7	9.7	9.7
	75°18'46"								
	39°17'12"	4/17 - 4/26/85	"	"	G	9.8	9.8	9.8	9.8
	75°19'34"								
36	39°22'40"	6/15 - 6/30/84	37	23	G	10.1	10.1	10.1	10.1
	75°28'04"	"	"	8	G	15.0	15.0	15.0	15.0
39	39°28'12"	6/15 - 6/30/84	42	28	G	15.0	15.0	15.0	15.0
	75°33'53"								
41	39°34'35"	6/14 - 6/29/84	28	14	G	15.0	15.0	15.0	15.0
	75°34'31"	6/29 - 7/14/84	"	"	G	15.0	15.0	15.0	15.0
42	39°36'22"	6/14 - 6/29/84	33	17	G	15.0	15.0	15.0	15.0
	75°34'28"	6/29 - 7/14/84	"	"	G	15.0	15.0	15.0	15.0
43.	39°39'24"	2/28 - 3/20/85	34	19	G	19.9	19.9	19.9	19.9
	75°32'23"	3/20 - 4/2/85	"	"	G	12.3	12.3	12.3	12.3
45	39°43'18"	6/29 - 7/14/84	34	"	A	15.0	15.0	15.0	15.0
	75°31'46"								
47	39°47'42"	6/14 - 6/29/84	43	28	G	15.1	15.1	15.1	0
	75°26"05"	6/29 - 7/14/84	"	"	G	15.0	15.0	15.0	0

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
47	39°47'42"	3/27 - 4/11/85	43	28	G	14.8	14.8	14.8	14.8
	75°26'05"	4/11 - 4/25/85	"	"	G	14.1	14.1	14.1	14.1
49	39°54'14"	3/4 - 3/27/84	30	18	G	22.8	22.8	22.8	22.8
	75°12'54"	3/27 - 4/6/84	"	"	G	9.9	9.9	9.9	0
50	39°58'02"	3/22 - 4/6/84	50	26	G	14.3	14.3	14.2	0
	75°07'08"								
51	39°52'49"	3/6 - 3/22/84	45	28	A	15.5	15.5	15.5	0
	75°10'23"	5/8 - 6/3/84	"	"	A	25.0	25.0	25.0	0
	"	6/3 - 6/29/84	"	"	G	25.6	25.6	0	0
	"	6/29 - 7/19/84	"	"	A	19.9	19.9	0	0
	"	7/26 - 8/10/84	"	"	A	14.3	14.3	14.3	0
	"	7/26 - 8/14/84	"	5	A	17.9	17.9	0	0
	"	8/14 - 9/5/84	"	28	A	21.1	21.1	0	0
	"	9/5 - 9/28/84	"	"	A	22.8	22.8	0	0
	"	"	"	5	A	22.8	17.9	22.8	0
	"	9/28 - 10/22/84	"	28	G	24.1	24.1	0	0
	"	"	"	5	A	24.1	24.1	24.1	0
	"	10/22 - 11/14/84	"	28	A	22.3	22.3	0	0
	"	"	"	5	A	22.3	22.3	0	0
	"	11/14 - 12/1/84	"	28	G	16.6	16.6	0	0
	"	"	"	5	A	16.6	16.6	16.6	0
	"	12/1 - 2/28/85	"	8	A	29.6	29.6	29.6	0
	"	2/28 - 3/27/85	"	28	A	27.2	27.2	27.2	0
	"	2/28 - 3/27/85	"	8	G	27.2	27.2	27.2	0
	"	3/27 - 4/25/85	"	28	A	28.9	28.9	28.9	0
	"	"	"	8	A	28.9	28.9	28.9	0
52	39°59'11"	3/6 - 3/22/84	34	14	A	14.8	14.8	14.8	0
	75°03'45"	3/22 - 4/6/84	"	"	A	15.0	15.0	15.0	0

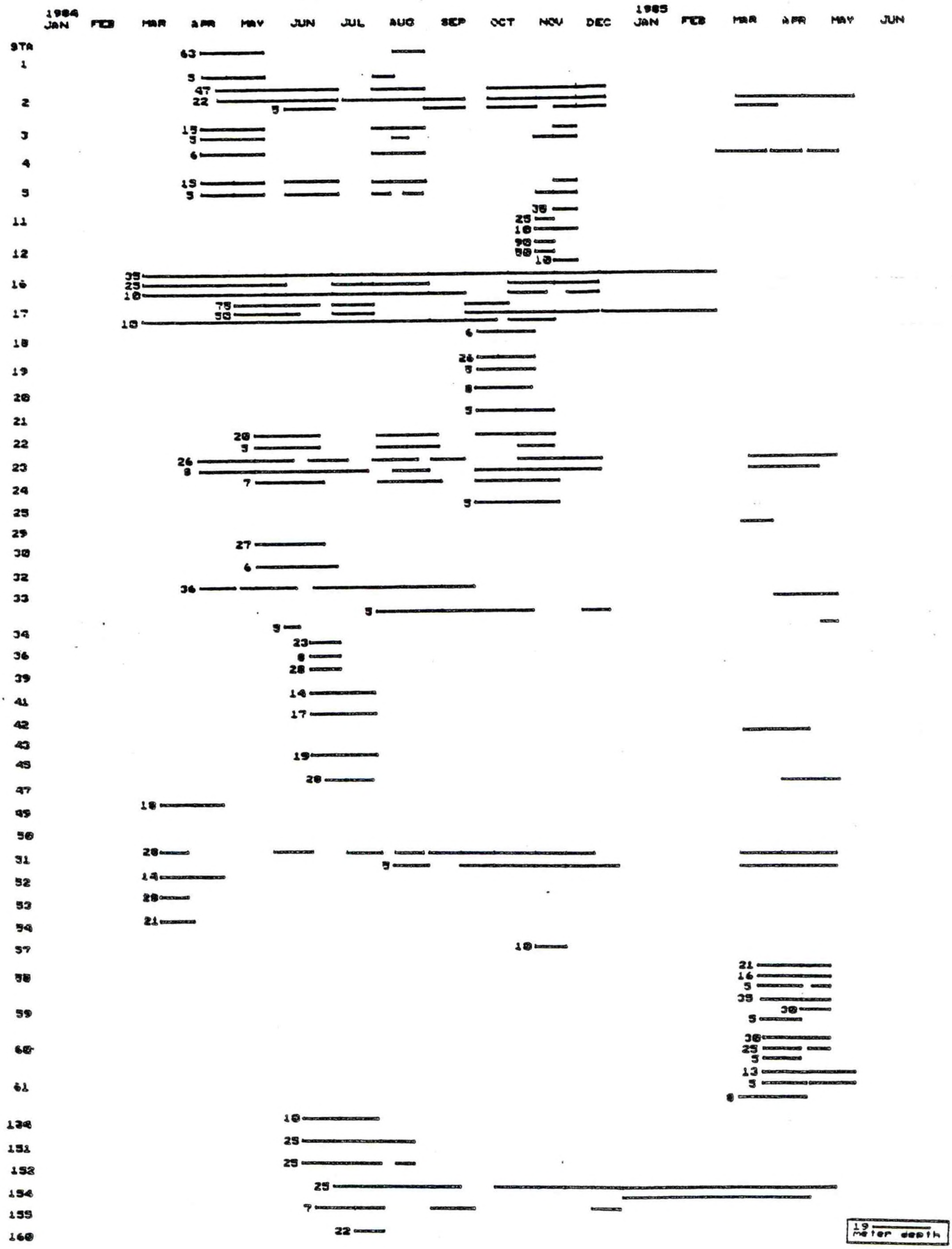
Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
53	40°04'39" 74°53'12"	3/6 - 3/22/84	49	28	A	16.9	16.9	0	0
54	40°08'02" 74°45'23"	3/6 - 3/26/84	36	21	A	19.9	19.9	19.9	0
57	38°19'35" 74°50'21"	10/20 - 11/18/84	59	10	G	29.0	29.0	29.0	29.0
58	38°57'54"	3/11 - 3/19/85	36	21	G	8.0	8.0	8.0	8.0
	75°06'14"	3/11 - 4/4/85	"	16	G	23.8	23.8	23.8	23.8
	"	"	"	5	G	23.8	23.8	23.8	23.8
	"	3/19 - 4/4/85	"	21	G	15.9	15.9	15.9	15.9
	"	4/4 - 5/1/85	"	"	G	26.9	26.9	0	0
	"	"	"	16	G	26.9	26.9	26.9	26.9
	"	4/23 - 5/1/85	"	5	G	8.7	8.7	8.7	8.7
59	38°58'59"	3/11 - 4/4/85	50	35	G	23.8	23.8	23.8	23.8
	75°07'39"	"	"	5	G	23.8	23.8	6.5	23.8
	"	4/4 - 5/1/85	"	35	G	27.9	27.9	27.9	27.9
	"	"	"	30	G	27.9	27.9	27.9	27.9
60	39°00'22"	3/13 - 4/10/85	45	30	G	27.1	27.1	27.1	27.1
	75°08'23"	"	"	25	G	21.3	21.3	21.3	21.3
	"	"	"	5	G	21.3	21.3	21.3	21.3
	"	4/10 - 5/2/85	"	30	G	21.6	21.6	21.6	21.6
	"	"	"	25	G	21.6	21.6	21.6	21.6
61	38°59'06"	3/13 - 4/10/85	28	13	G	28.1	28.1	28.1	28.1
	75°07'06"	3/13 - 4/7/85	"	5	G	25.3	25.3	25.3	25.3
	"	4/10 - 5/5/85	"	13	G	24.7	24.7	24.7	24.7
	"	4/10 - 5/4/85	"	5	G	23.1	23.1	23.1	23.1

Table 1. Continued

Sta.	Lat. (N) Long. (W)	Dates of Observation	Depth of Water MLLW (feet)**	Height of Meter Above Bottom (feet)	Meter* Type	Days of Good Data for Sensors in Operation: Speed	Dir.	Temp.	Cond.
134	39°26'42"	5/30 - 6/20/84	25	10	A	21.0	21.0	0	0
	75°59'56"	6/20 - 7/15/84	"	"	A	24.8	24.8	24.8	24.8
151	39°30'18"	5/30 - 6/20/84	40	25	A	21.0	21.0	0	0
	75°55'11"	6/20 - 7/15/84	"	"	A	24.8	24.8	0	0
	"	7/15 - 8/8/84	"	"	A	23.9	23.9	0	0
	"	3/27 - 4/25/85	"	15	A	28.9	28.9	0	0
152	39°31'33"	5/30 - 6/20/84	40	25	G	21.1	21.1	21.1	0
	75°52'21"	6/20 - 7/15/84	"	"	G	20.5	20.5	0	0
	"	7/19 - 8/8/84	"	"	G	24.8	24.8	0	0
154	39°33'38"	6/20 - 7/14/84	40	25	A	13.0	13.0	13.0	13.0
	75°34'12"	7/14 - 8/14/84	"	"	G	31.0	31.0	0	0
	"	8/14 - 9/5/84	"	"	A	20.8	20.8	0	0
	"	"	"	5	A	20.8	20.8	0	20.8
	"	9/5 - 9/13/84	"	"	A	7.5	7.5	0	7.5
	"	9/27 - 10/22/85	"	25	A	24.9	24.9	24.9	24.9
	"	10/22 - 11/17/84	"	"	A	26.3	24.3	24.3	0
	"	11/17 - 11/26/84	"	"	A	9.0	9.0	9.0	9.0
	"	12/1 - 12/28/84	"	8	A	8.8	8.8	8.8	8.8
	"	2/28 - 3/27/85	"	25	A	26.8	26.8	26.8	26.8
	"	2/28 - 3/11/85	"	5	A	10.3	10.3	10.3	10.3
	"	3/27 - 4/24/85	"	25	A	28.9	28.9	28.9	0
	"	3/27 - 4/7/85	"	5	A	10.4	10.4	0	0
155	39°33'11"	6/14 - 6/30/84	22	7	G	15.6	15.6	15.6	15.6
	75°32'12"	6/30 - 7/15/84	"	"	G	15.1	15.1	15.1	7.5
160	39°34'14"	6/30 - 7/15/84	37	22	G	15.1	15.1	15.1	15.1
	75°33'13"								

Table 2. Current Meter Deployment Chronology.



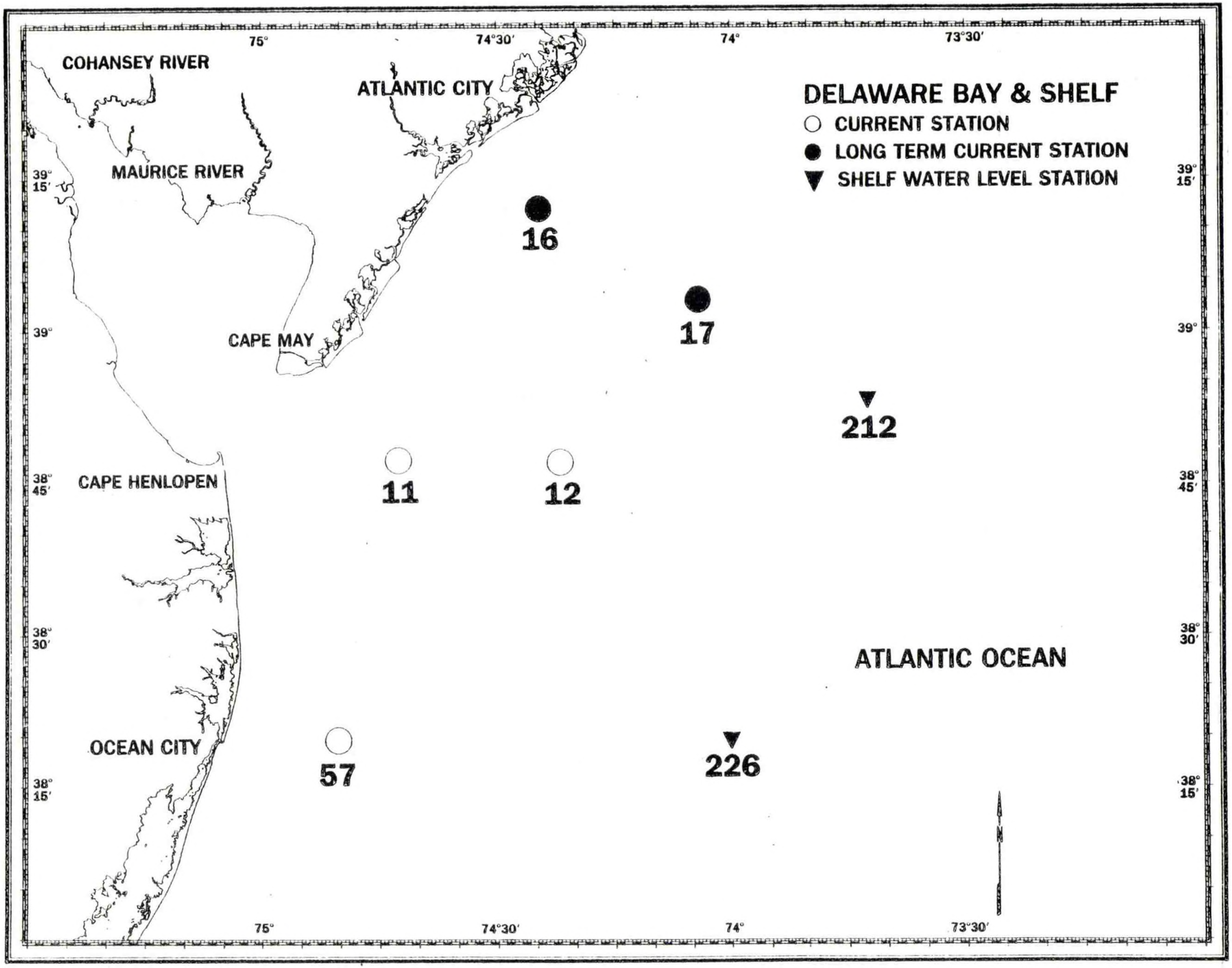


Figure 5. Shelf Current and Water Level Stations.

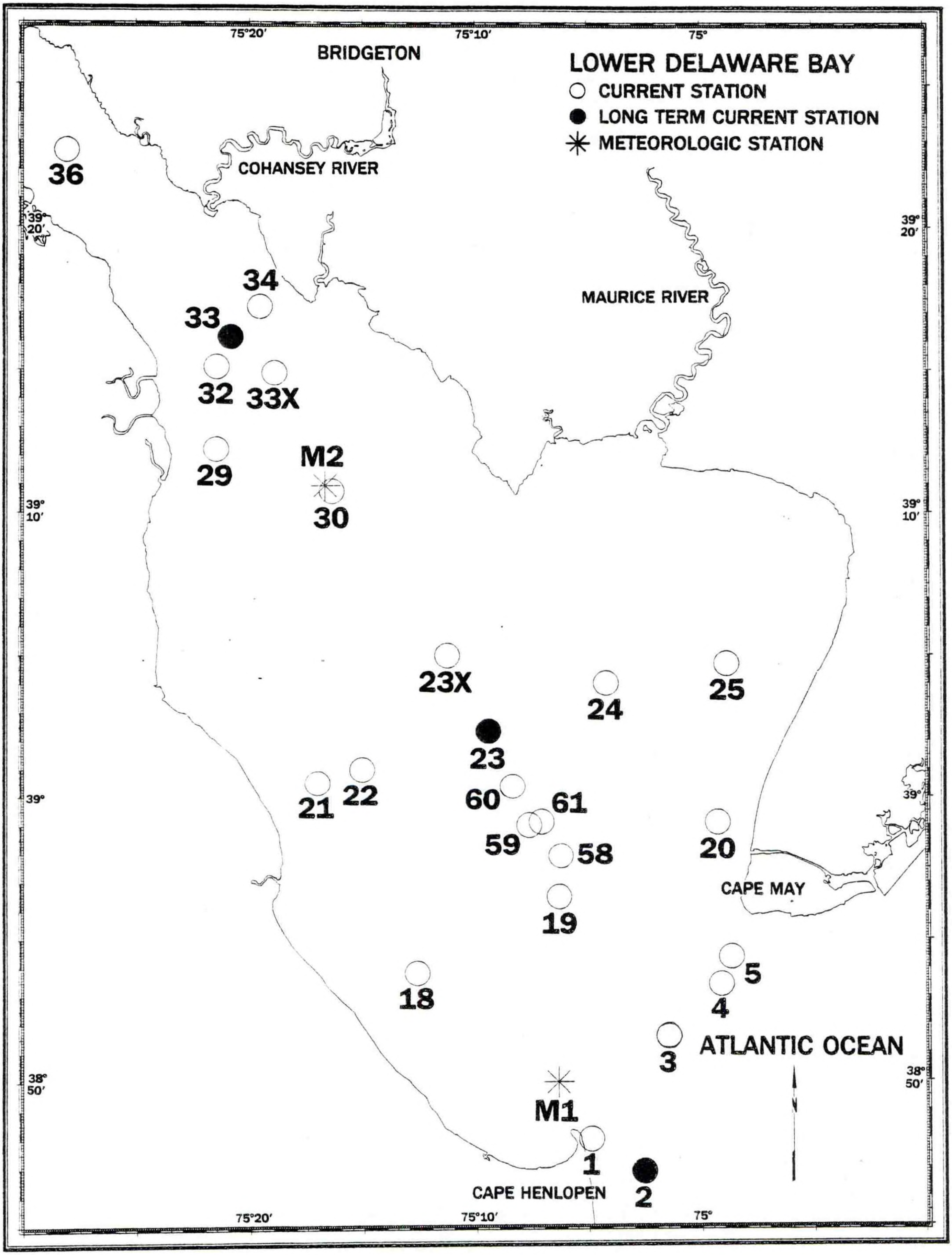


Figure 6. Current and Meteorological Station Locations.

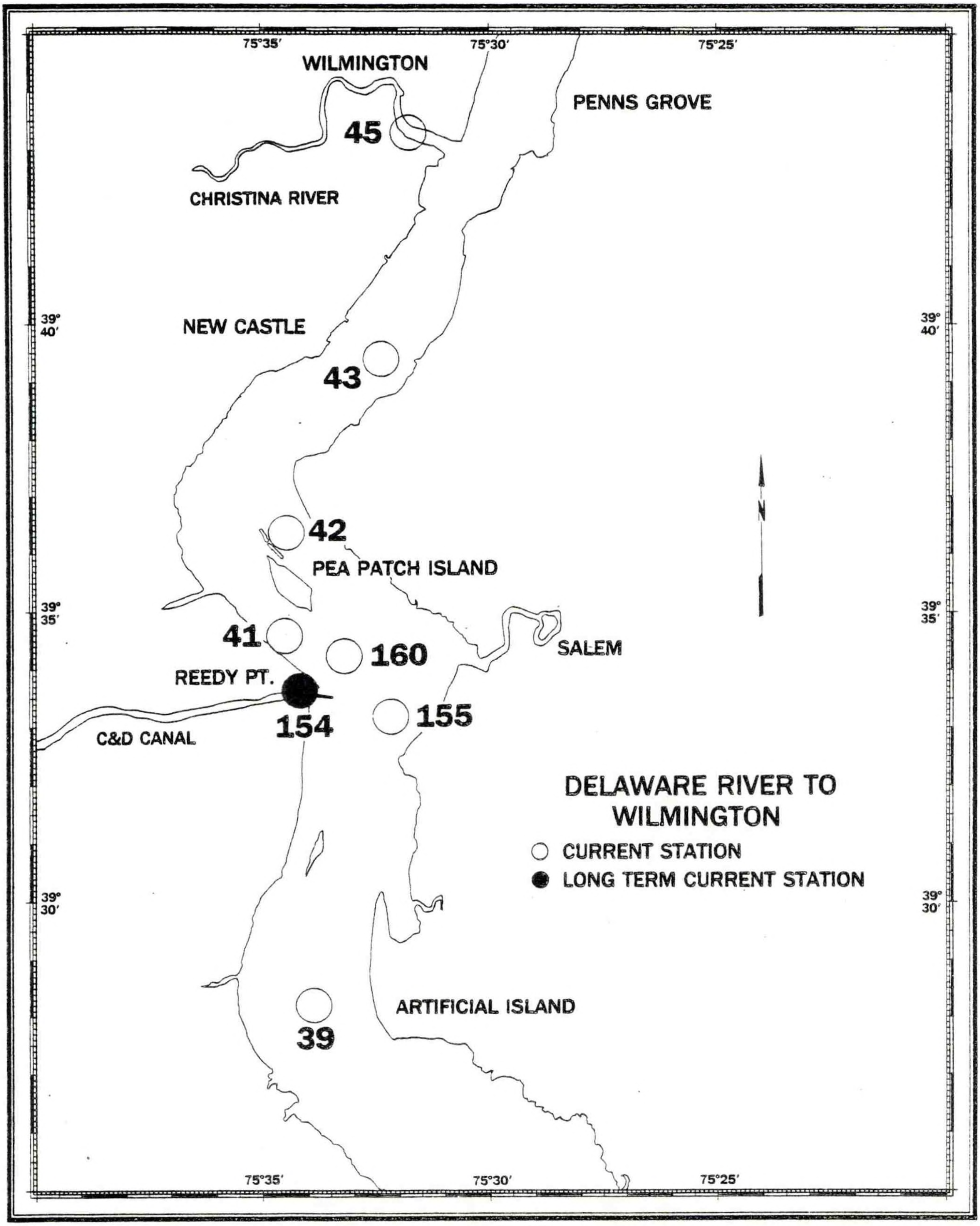


Figure 7. Current Station Locations.

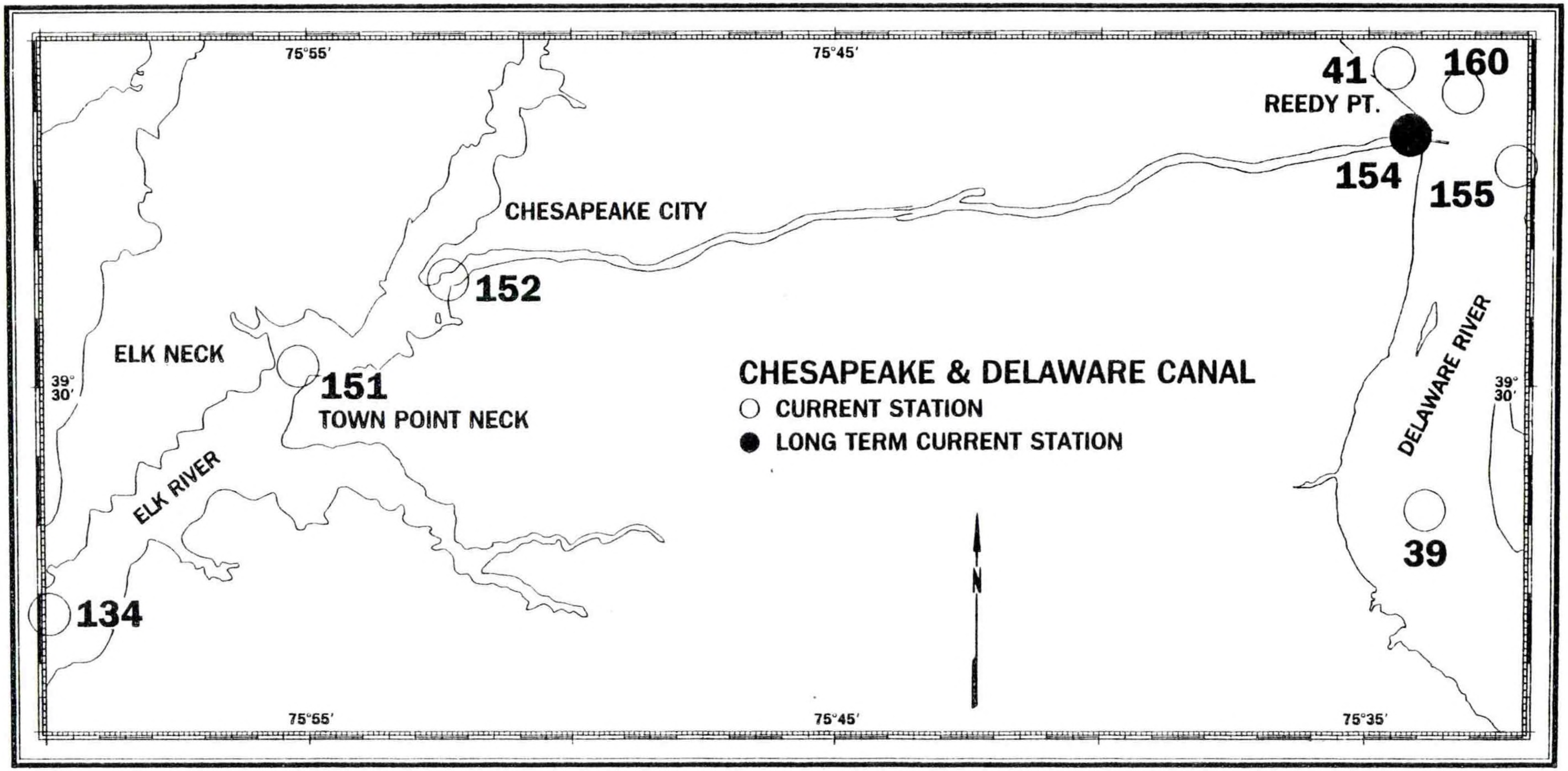


Figure 8. Current Station Locations.

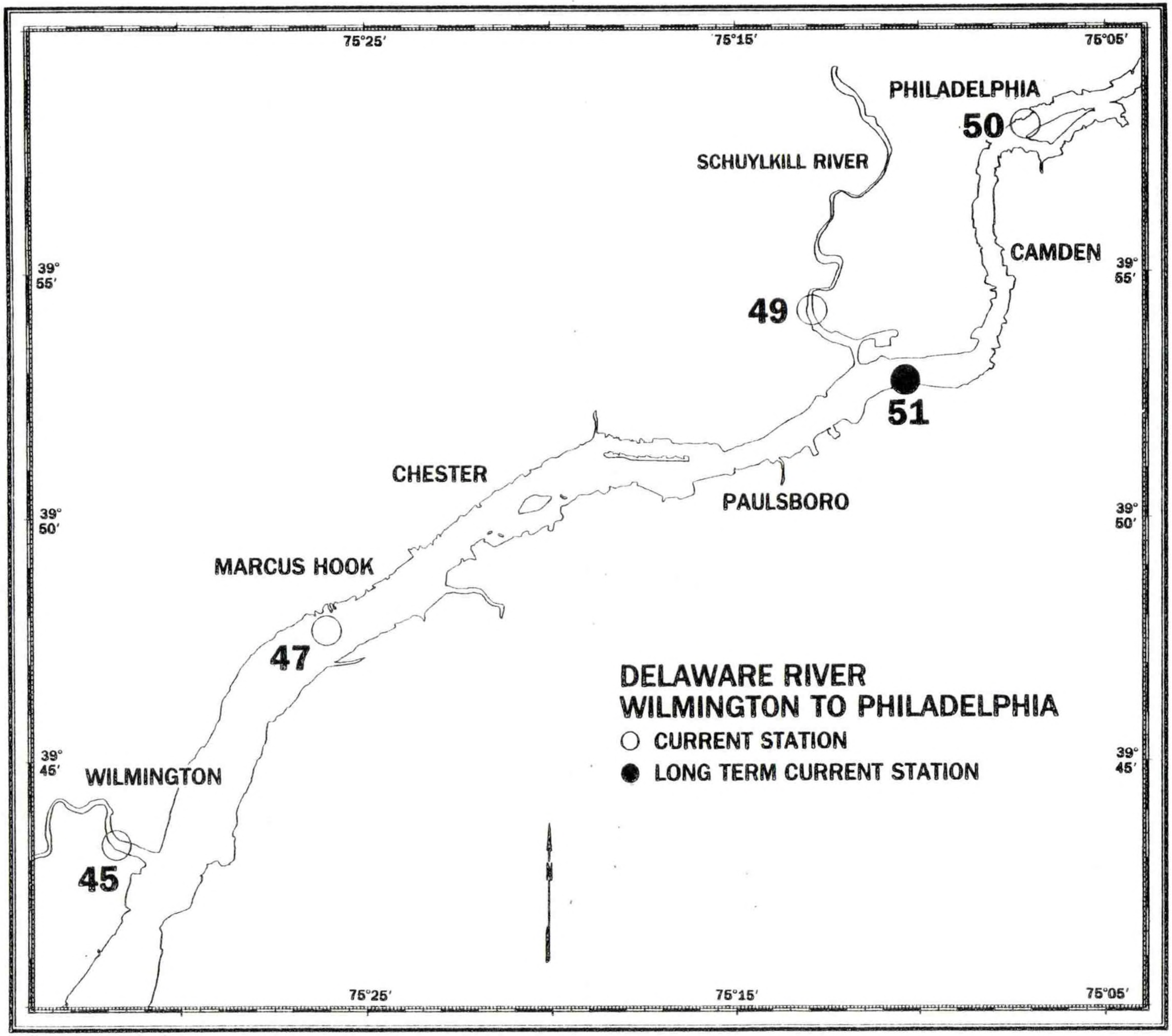


Figure 9. Current Station Locations.

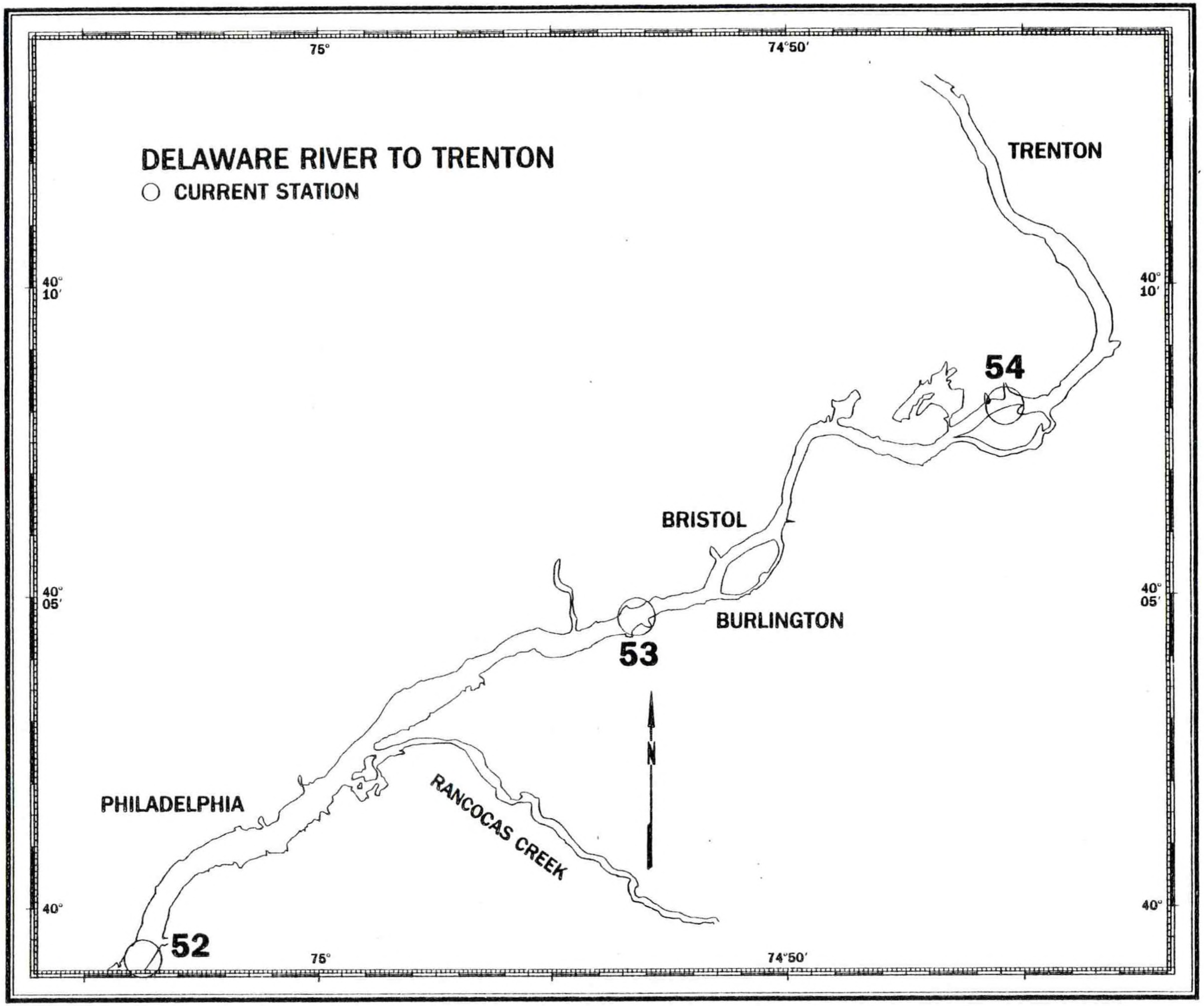


Figure 10. Current Station Locations.

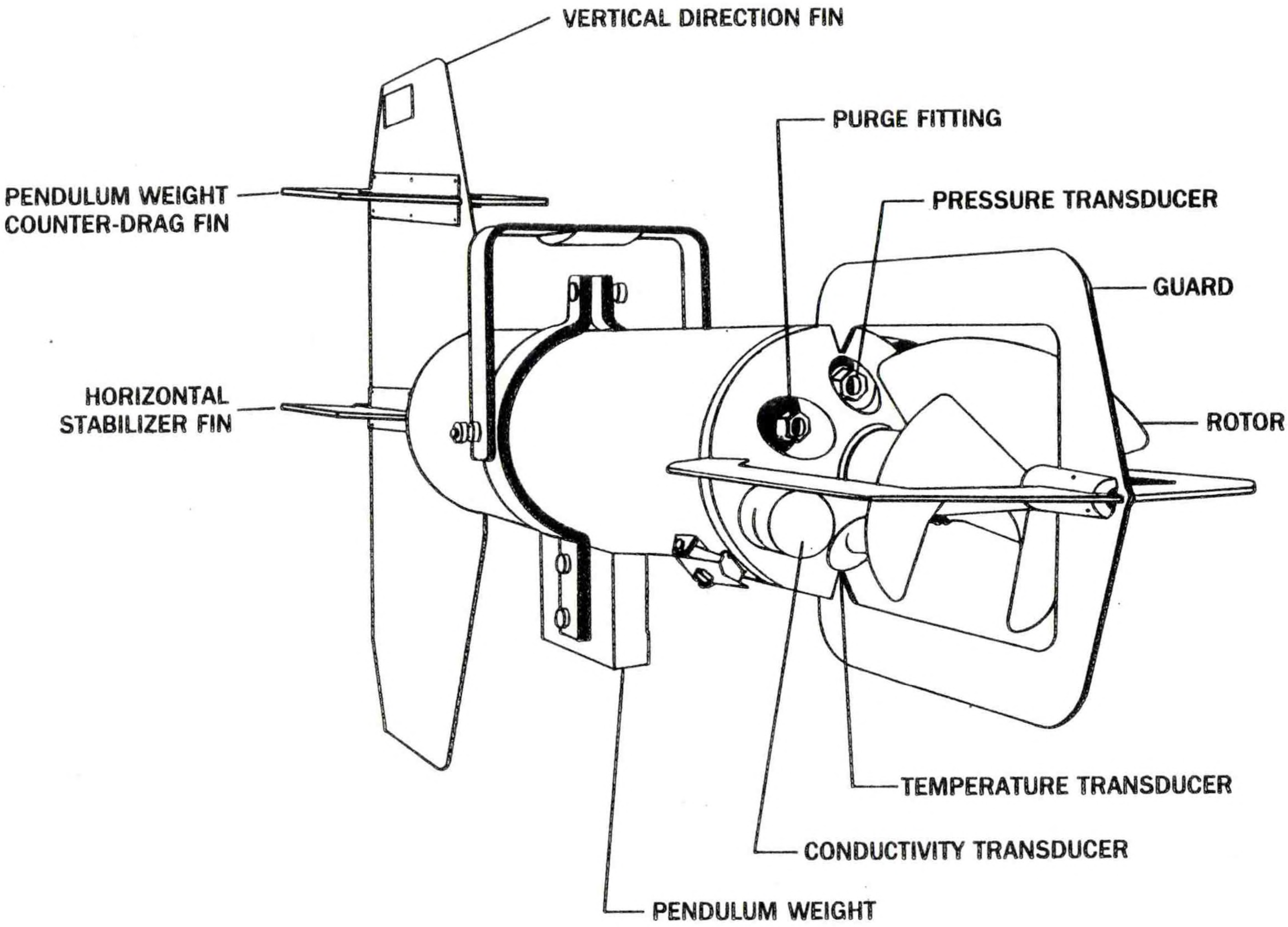


Figure 11. Grundy 9021G Current Meter.

of the Grundy 9021G current meter are provided in figure 11 and Appendix A, respectively. Changes were made to the speed, direction, temperature, and conductivity sensors, on the Grundy current meters used by NOS. These modifications were engineered by the Testing and Evaluation Laboratory (T&EL) of NOS in 1978 in support of NOS' Strategic Petroleum Reserve Support Project (Frey, Szabados, and Hickman, 1981). The changes reduced the measurement uncertainties of all the sensors, especially in regard to the operation of current meters under conditions of high pitch and roll. Detailed descriptions of these modifications along with data on the performance of the Grundy current meter system as well as the mooring configuration can be found in volume 2 of NOS Strategic Petroleum Reserve Support Project: Final Report (Frey and Appell, editors, 1981).

Aanderaa RCM4 current meters, using a Savonius-type rotor, were deployed primarily at current stations in the Chesapeake and Delaware Canal (stations 154, 152, 151) and at some stations in the Delaware River (stations 136, 41, 45, 51, 52, 53, and 54). Most of these meters were calibrated (See section 7.0) for current speed and direction only. An instrument diagram and manufacturer's specifications are provided in figure 12 and Appendix B, respectively. Current speed, as in Grundy meters, is calculated by averaging the number of rotations of the rotor over a 10-minute interval, and direction is an instantaneous value.

The majority of the moorings used for both the Grundy- and Aanderaa-equipped stations are taut-wire moorings, consisting of a surface buoy with a light, a subsurface buoy, a pinger, and an umbilical line, all connected to a cable anchored to the bottom by three railroad wheels. Where deployed in shallow water, less than about 20 feet (6.1 meters) deep, a single current meter is attached to a bottom platform at 5 feet (1.5 meters) from the bottom. The configuration of the taut-wire mooring is illustrated in figure 3.

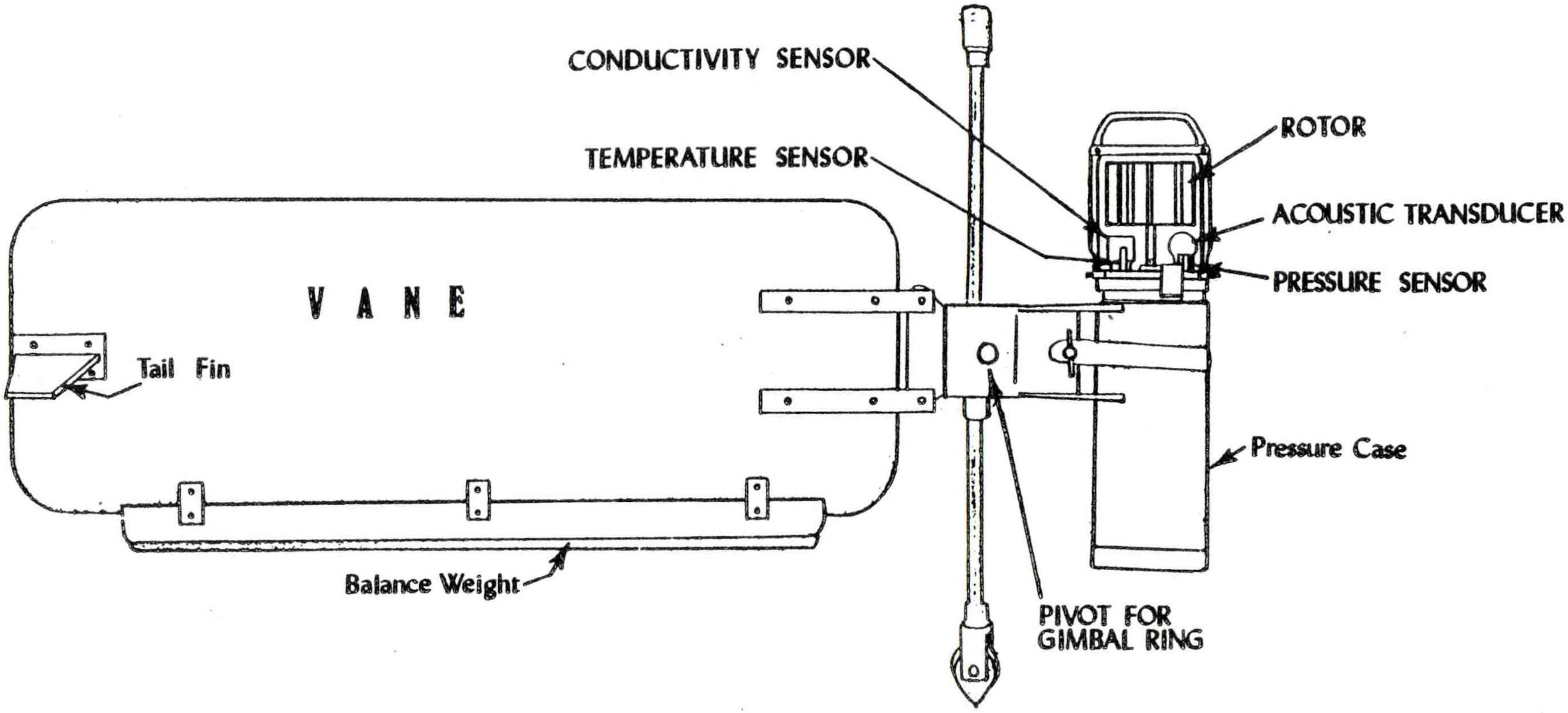


Figure 12. Aanderaa RCM4 Current Meter.

3.4. Data Processing

Current meter data processing is a function shared by both shipboard personnel and NOS employees in Rockville, Maryland. The shipboard system for data processing is termed the Circulatory Measurements Data Processing System (CMDP) (Patchen, Johnson, Stepka, Petrae, and Connolly, 1982). In addition to use in processing Grundy and Aanderaa current meter data, the system is also the principal one used for processing Aanderaa meteorological, Aanderaa (WLR-5) water level, and Applied Microsystems Ltd. (AML) CTD data.

The processing of current data started when each instrument was deployed. At this moment the Field Operations Officer recorded, in the deployment log, the precise time the current meter entered the water. Similarly, on recovery, the time the current meter left the water was recorded on the recovery log. For the current data to be acceptable, this elapsed time (between deployment and recovery) must be equal to the number of time intervals counted internally by the meter (i.e. the data "time checks"). This information (current meter deployment and recovery logs) along with latitude and longitude of the current station, mooring configuration, maintenance information, navigation fix logs, and station chartlet were carefully documented and transmitted to NOS in Rockville.

The CMDP aspect of shipboard data processing allowed the ship's Field Operations Officer to scrutinize the quality of the data recorded by each instrument and to check whether the elapsed time of instrument operation matches the time increments recorded. Each 3-inch instrument tape was translated onto a 5-inch tape using the Grundy Model 8321 translator or the CAMAC translator. The tape was then read by the PDP 11/34 using the CMDP shipboard processing system. If the CMDP system determined that the current meter data "time checked", the CMDP software then applied actual times to each of the time increments on the 9-track output tape. This output tape also contained a record of all alignment changes made to the data, file heading information (start and stop of meter operation, latitude and longitude, depth of meter), and calibration constants for each sensor operating on the meter.

When the 9-track CMDP tape was received at NOS in Rockville, the second stage of the CMDP data processing began. The tape was copied onto a permanent disc file; separate files were created with the uncalibrated meter data, calibration constants, heading information, and alignment changes. These files were carefully scrutinized to ensure that alignment changes had been correctly made and that calibration constants matched those supplied by the calibration engineers. Time checking of each file was also reviewed to corroborate the field checks. If missing or extra data points were indicated, an attempt was made to determine if they could be located on the data file and corrected.

The final phase of data processing included the correcting, if necessary, of missing or extra data points, eliminating data points recorded by the current meters before the meter entered the water or after the meter was retrieved, and applying actual times to each data point.

Final data processing also included applying a statistical editing algorithm (Zetler and Grove 1964) that corrects data points in error as a consequence of obvious meter malfunction. The final processed data file was verified by a team leader. If acceptable, a time series plot was made of each file.

3.5. Data Analysis

Data collected at Delaware Bay Entrance (station 2) was analyzed to develop a reference station for table 1 of the

Tidal Current Tables. This process involved analyzing the data with a least-squares harmonic analysis computer program (Harris, Pore, and Cummings, 1965) that calculated values for tidal constituents from which yearly predictions of the tidal current can be made. The remaining data collected was analyzed with a nonharmonic comparison analysis (Parker, 1977) for derivation of times and magnitudes of flood, ebb, and slack water, relative to the new reference station at the Delaware Bay Entrance. These values will be used as new stations or revised stations in table 2 of the Tidal Current Tables.

4.0. WATER LEVEL DATA

4.1. Significance of Water Level Data in DR&B

Water level data collected during the DR&B Circulation Survey will be used to correlate information gathered about the circulation in the estuary (currents and density stratification) with the progression of the tidal wave through the estuary. Real-time water level measuring stations at Cape May, Artificial Island, Philadelphia, and Lewes were used as inputs to the DR&B Circulation Model. Water level data recorded during the Survey will also be used to update the Tide Tables, East Coast of North and South America.

Water level changes in DR&B appear to be affected by geography. After the tidal wave enters Delaware Bay, the wave is funneled as the estuary narrows northward so that the tidal range increases from 3.9 feet (1.2 meters) at the mouth to 6.9 feet (2.1 meters) at Trenton. Anthropogenic-induced geographic changes caused by dredging in the Delaware River have also affected tidal ranges (Hires, et al., 1983). For example, dredging has caused the tidal range at Trenton to nearly double in the last 100 years, while during the same period tidal ranges at Marcus Hook have decreased. A Coriolis influence on Delaware Bay circulation is also evident (Hires, et al., 1983). Tidal ranges tend to be greater on the northeastern or right side of the Bay than the left side. A complete description and explanation of the tidal hydrodynamics of the Delaware River and Bay, including shallow water and frictional effects, can be found in Parker, 1984.

4.2 Water Level Station Information

In addition to the control stations in operation at Cape May, and Trenton, New Jersey, Philadelphia, Pennsylvania, Indian

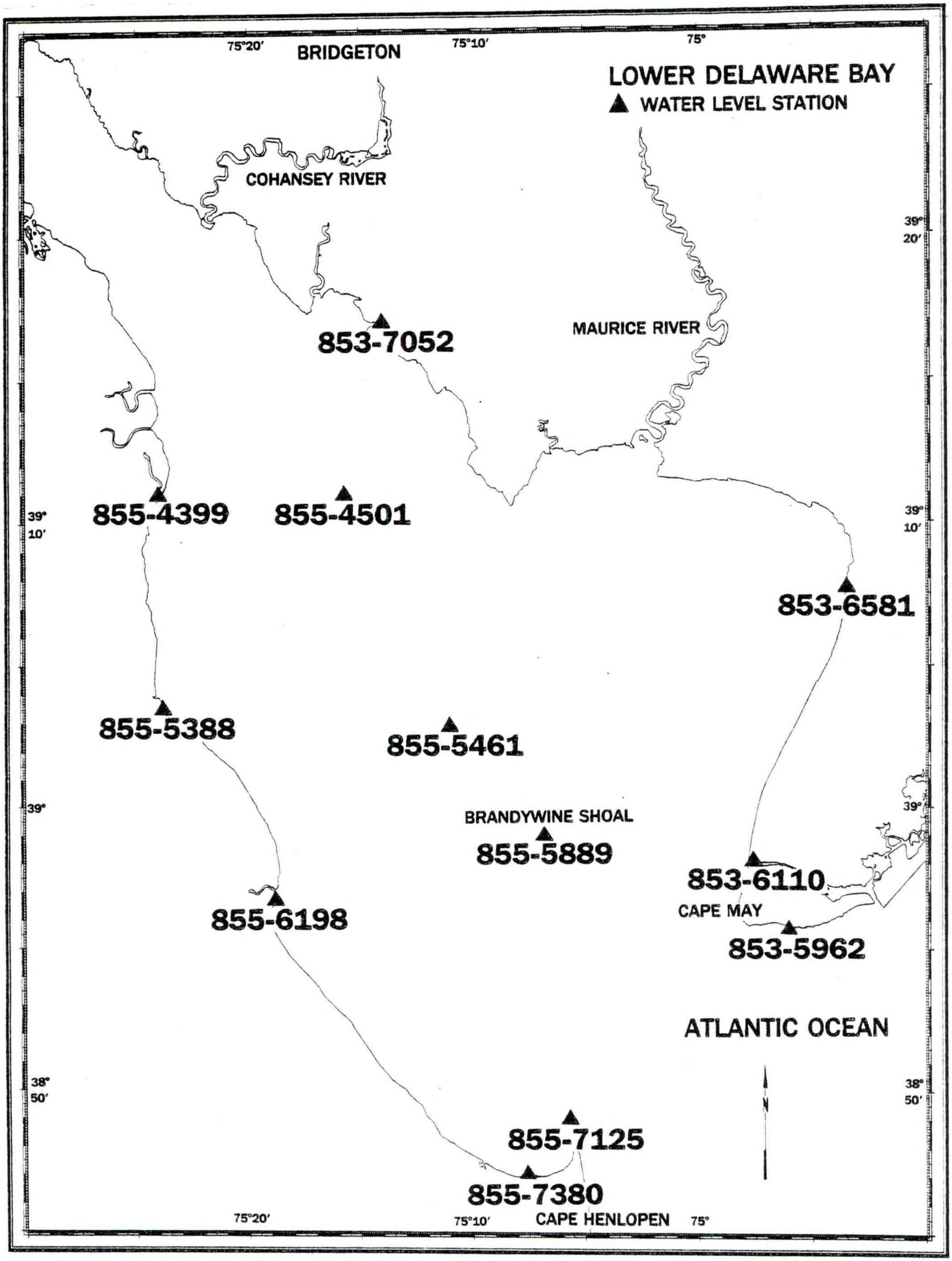


Figure 13. Water Level Station Locations.

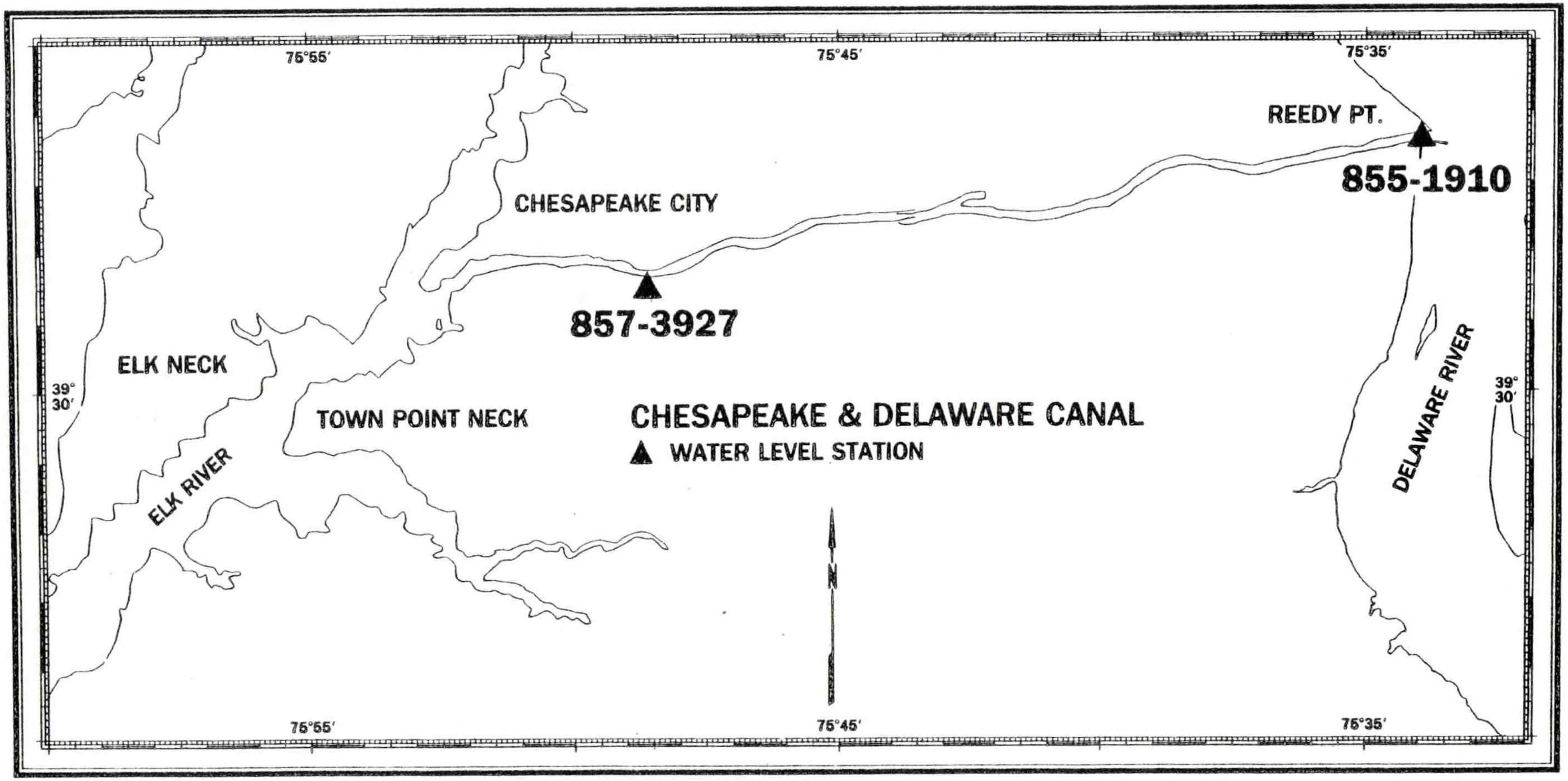


Figure 14. Water Level Station Locations.

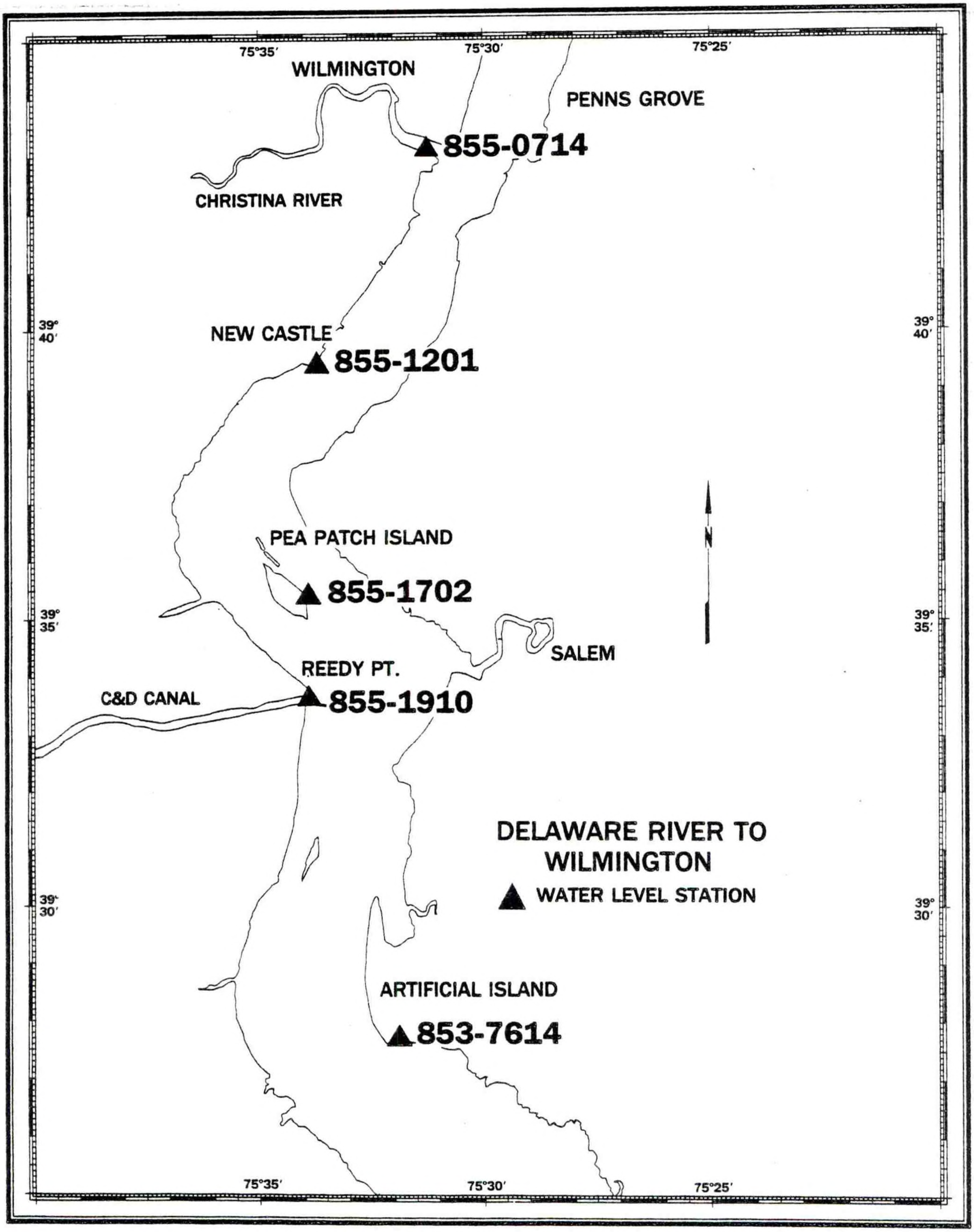


Figure 15. Water Level Station Locations.

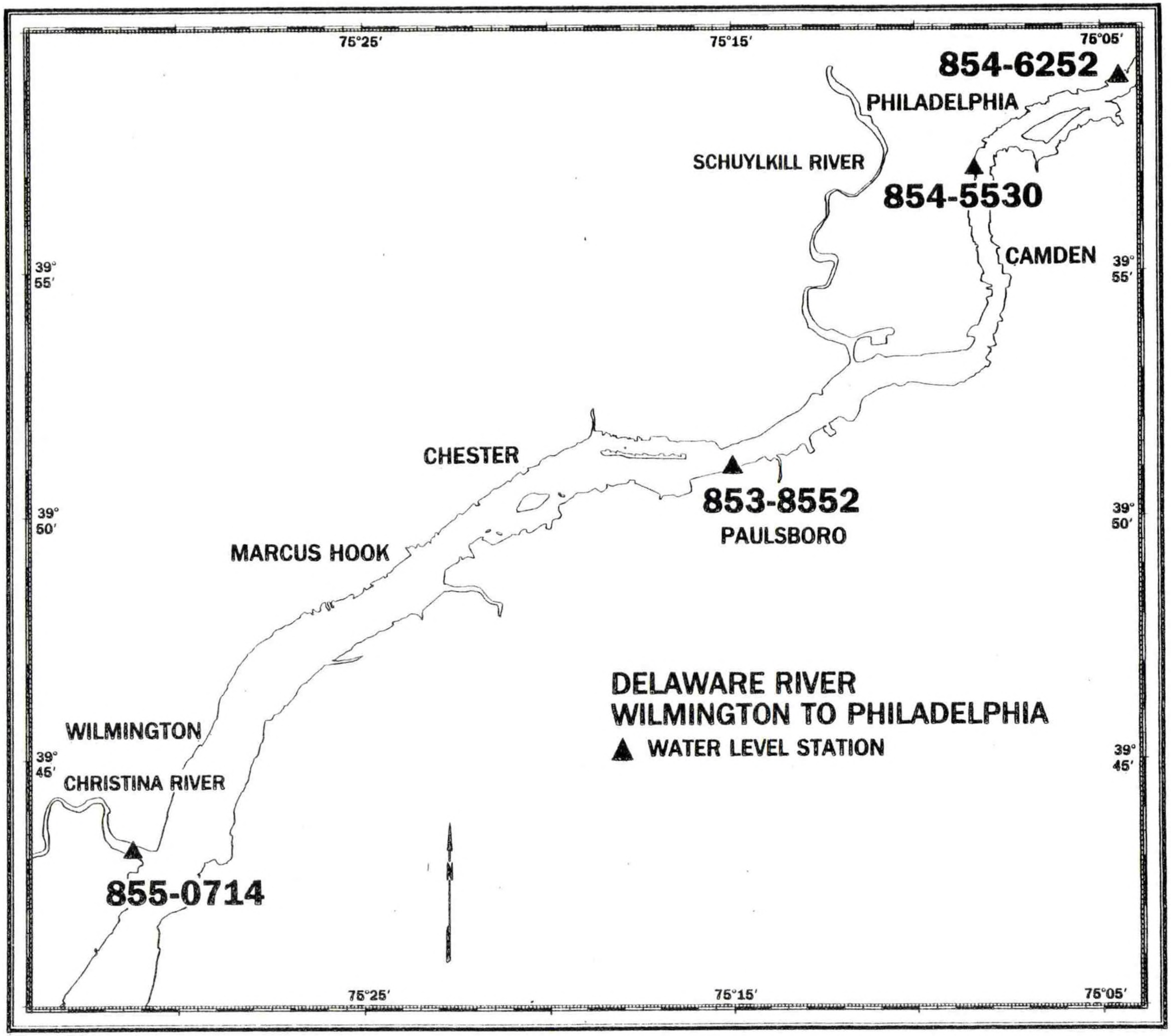


Figure 16. Water Level Station Locations.

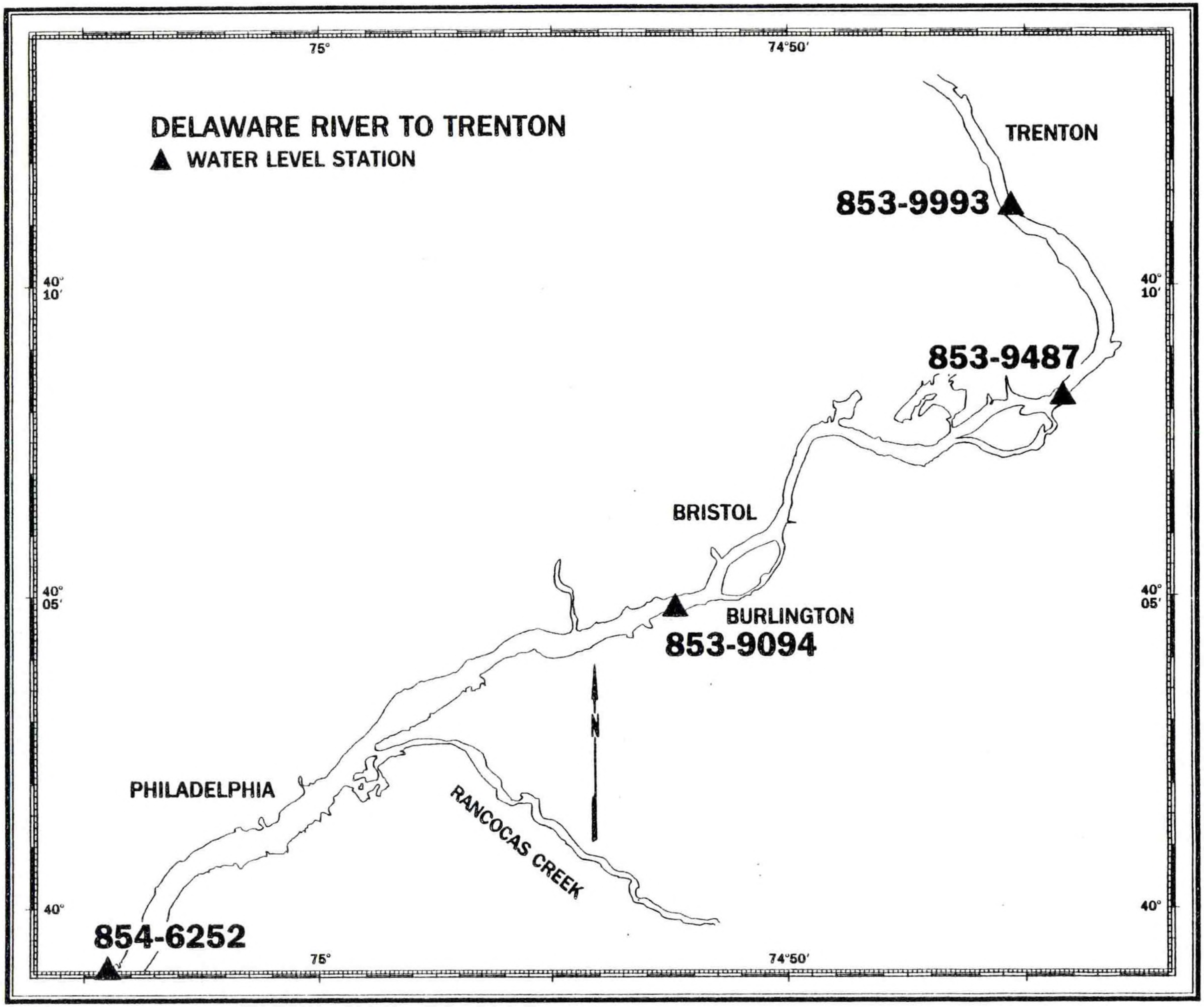


Figure 17. Water Level Station Locations.

Table 3. Water Level Stations

Station*	Gage Type	Latitude	Longitude	1984 Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	1985 Jan-Mar	Apr-Jun
Money Island (853-7052)	ADR	39°17.0'N	75°14.0'W	3/15					5/4
Bridesburg (854-6252	ADR	39°59.0'N	75°04.5'W	2/14					4/29
14-ft Bank Lt (855-5461)	BUB	39°02.9'N	75°11.0'W		4/10		11/12		
Brandywine Shoal Lt (855-5889)	ADR	38°59.0'N	75°06.8'W	3/18					5/5
Harbor of Refuge Lt (855-7125)	ADR	38°49.0'N	75°05.7'W		5/18		12/2		
Bidwell Cr. Ent.(853-6581)	ADR	39°07.7'N	74°53.5'W			8/10			4/19
Artificial Is. (853-7614)	ADR	39°27.7'N	75°31.9'W		5/1				5/1
Billingsport (853-8552)	ADR	39°51.0'N	75°15.0'W	2/13--	4/6				4/6 -- 5/3
Burlington (853-9094)	ADR	40°04.8'N	74°52.4'W	2/9 --	4/6				
Fieldsboro (853-9487)	ADR	40°08.2'N	74°44.2'W	2/9 --	4/7				
New Castle (855-1201)	ADR	39°39.4'N	75°33.7'W					2/22	4/29
Pea Patch Island (855-1702)	ADR	39°35.4'N	75°33.9'W		6/13 --	7/19			
Mahon River (855-4399)	ADR	39°11.0'N	75°24.0'W		5/9		12/15	3/6 --	4/15
Murderkill R. (855-5388)	ADR	39°03.5'N	75°23.8'W			8/30	11/8		
Mispillion R. (855-6198)	ADR	38°56.7'N	75°18.8'N			8/28	11/7		
Chesapeake City(857-3927)	ADR	39°31.5'N	75°48.6'W		6/7		11/6		
Cross Ledge (855-4501)	BUB	39°11.0'N	75°15.7'W		5/5 -- 6/30				

*New Jersey (853), Pennsylvania (854), Delaware (855), Maryland (857)

River, Delaware, Atlantic City, New Jersey and Ocean City, Maryland (the last three outside the Bay), 17 subordinate water level gages were installed for this survey (figures 13-17, table 3). Three of the gages were operated nearly continuously during the survey at Money Island, Bridesburg, and Brandywine Shoal. The remaining 14 gages were operated for shorter periods, in coordination with current station occupation periods. Water level gages were also deployed on the shelf near the entrance to Delaware Bay during the 1985 field season.

Table 3 lists all water level stations in operation in the DR&B Survey area. In addition, the type of gage used, location of gage, and the period of gage operation are included.

4.3. Instrumentation

All of the gages at the control stations and all but two of the gages at the subordinate stations were the Analog-to-Digital (ADR) type. The remaining two gages at Elbow of Cross Ledge and 14-Foot Bank were the bubbler (or gas purged) type. Specifications for each type of gage are provided in Appendix C. For the ADR gage, water levels were determined by measuring the change in position of a float in a stilling well. The stilling well "damps-out" short period, nontidal oscillations in the water column. Data were recorded every six minutes on a punched-tape.

The water level gages at the subordinate stations were installed and maintained by personnel on board the NOAA Ship FERREL. A typical water level gage installation plan is diagrammed in figure 18. Installation required referencing the gage location to three bench marks in accordance with the <u>User's Guide for the Establishment of the Tidal Bench Marks and Leveling Requirements for Tide Stations</u> (Bodnar, 1977). A detailed description of water level gage installation, operation,

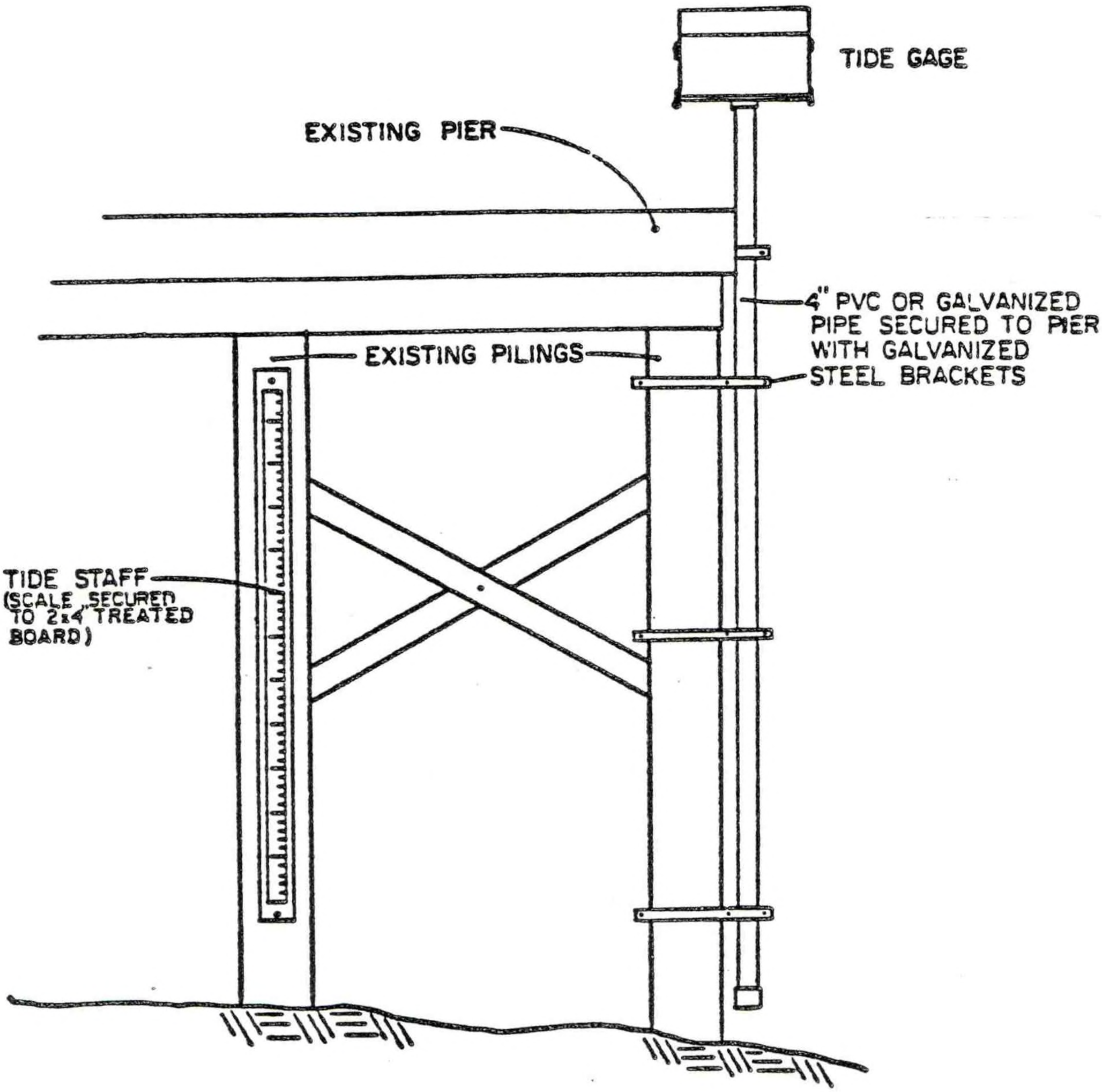


Figure 18. Water Level Gage Installation.

maintenance, and data processing can be found on pp. 73-97 of San Francisco Bay Area Circulation Survey: 1979-1980 (Welch, Gartner, and Gill, 1985) and Manual of Tide Observations (C&GS, 1965).

Offshore water level stations used the Aanderaa water level model WLR-5 as the measurement system. Specifications for the WLR-5 are provided in Appendix D. Mounted on a bottom platform, the water level instrument records changes in time-integrated pressure which are converted by a calibration equation to changes in depth. Processing offshore water level data requires the CMDP shipboard processing system described in the previous section concerning current meter data processing.

4.4 Real-Time Water Level Data

Telemetry systems were installed at Cape May, Artificial Island, Philadelphia, and Lewes water level stations. Three of the systems, at Cape May, Philadelphia, and Lewes are still in operation. These stations are automatically interrogated to check data quality and to provide information for the NOS database.

5.0. CONDUCTIVITY AND TEMPERATURE DATA (CTD)

5.1. Significance of CTD Data in DR&B

CTD data, after conversion into salinity and density (sigma-T), provides information that can be used to interpret the density structure of the DR&B. Both the lateral and upstream/downstream density gradients can serve as important factors in water movement in Delaware Bay. Temporal changes in the vertical density structure of DR&B, during a tidal cycle and seasonally, provide information concerning the contribution of runoff to the Bay's circulation.

5.2. CTD Casts

CTD casts were taken twice at each current station, once at slack-before-flood and once at slack-before-ebb. During each surface-to-bottom cast, temperature, conductivity, and the associated depth (as a function of pressure) are recorded. A series of special CTD casts were taken along transects (numbered 1, 2, 3, and 4) during spring and summer of the 1984 field season and every 15 days during the 1985 field season (figures 19, 20, table 4). These transects were repeated twice, once at slack-before-flood and once at slack-before-ebb. A supplemental CTD transect on the inner shelf adjacent to Delaware Bay was run in conjunction with the Ocean Assessments Division (OAD) during the Northwest Monitoring Program Cruises.

Time series operations, at which CTD casts are taken every 30 minutes during a tidal cycle were conducted at three stations during the 1984 field season (TS2, TS33, TS47) and one station (TS19) during the 1985 field season. The time series stations were repeated during the same intervals as the CTD transects, spring and summer during 1984 and every 15 days during the 1985 field season.

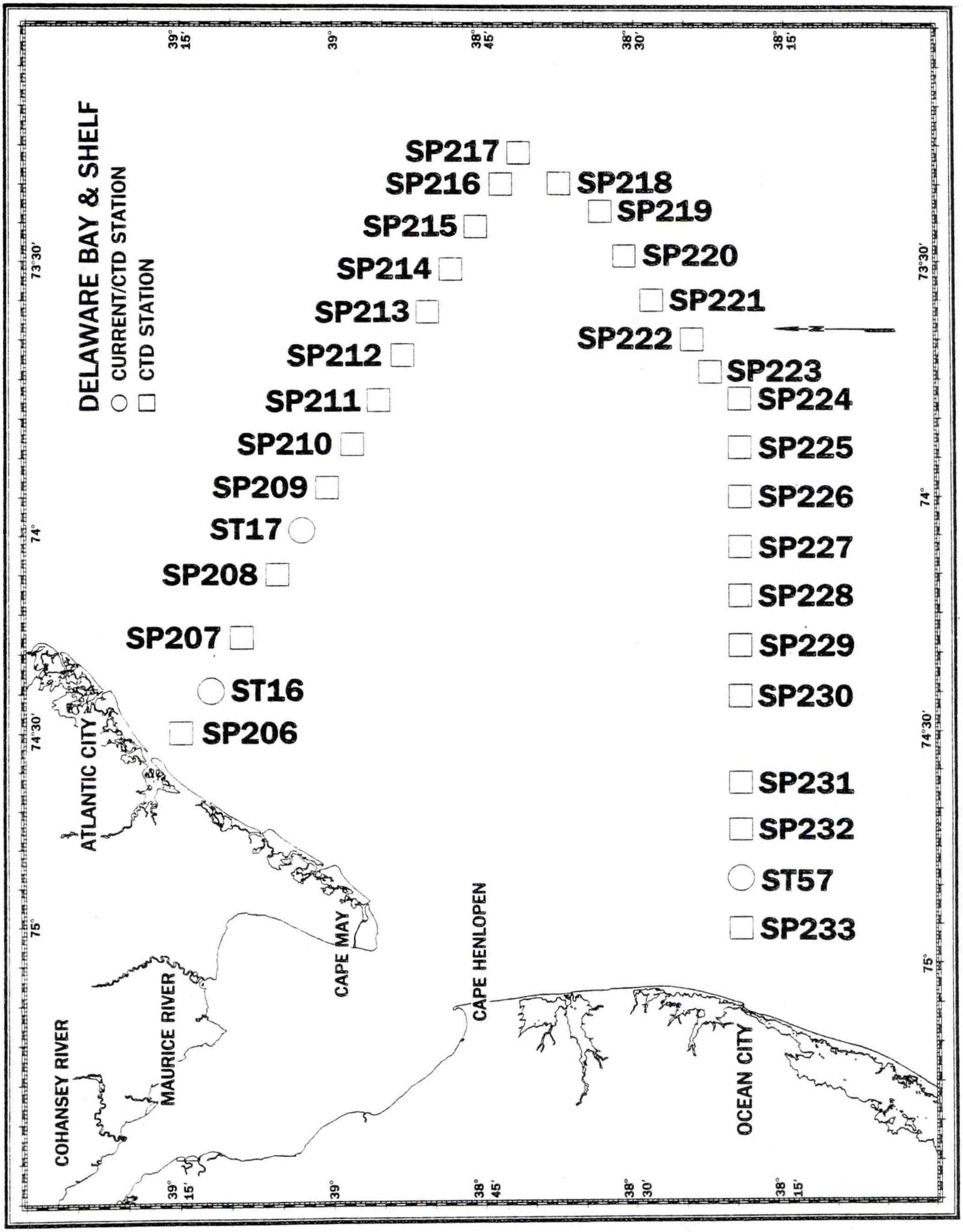


Figure 19. CTD Cast Locations.

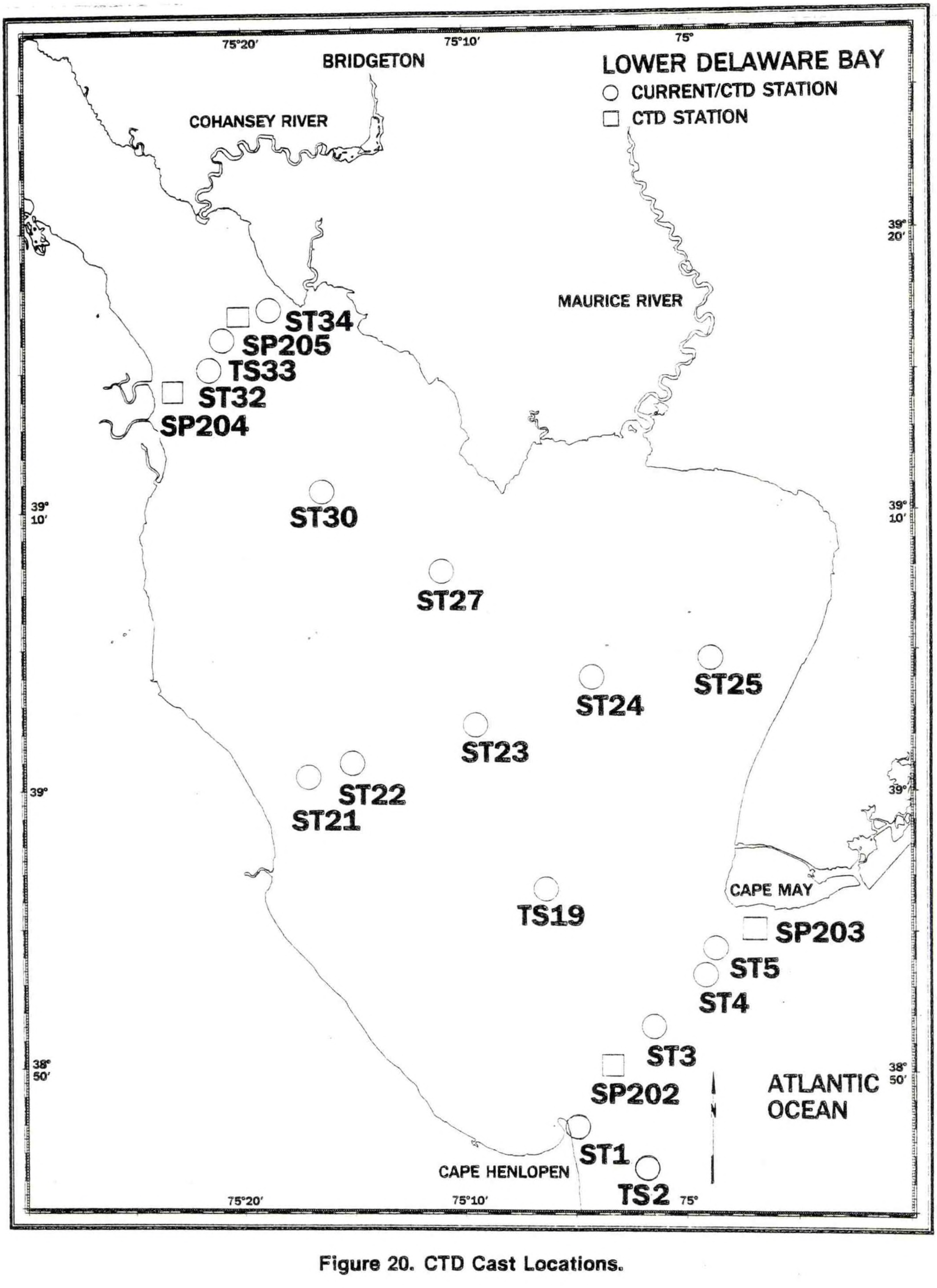


Figure 20. CTD Cast Locations.

Table 4. CTD Casts

Year 1984

Transect	CTD Stations
#1	ST1, SP202, ST3, ST4, ST5, SP203
#2	ST21, ST22, ST23, ST24, ST25
#3	SP204, ST32, TS33, SP205, ST34
#4	SP206, ST16, SP207, SP208, ST17, SP209, SP210, SP211, SP212
#5	SP206, ST16, SP207, SP208, ST17, SP209-SP230, SP231, SP232, ST57, SP233

Time Series

TS2
TS33
TS47

*Transect #3 is a time series transect.

Year 1985

Transect	CTD Stations
#1	ST3, SP206, TS19, ST23, ST27, ST30, TS33, SP207
#2	ST1, SP202, ST3, ST4, ST5, SP203
#3	ST21, ST22, ST23, ST24, ST25
#4	SP204, ST32, TS33, SP205, ST34
#5	SP206, ST16, SP207, SP208, ST17, SP209-SP230, ST8, SP231, SP232, ST57, SP233

Time Series

TS19

One special time series, a time series transect, consisted of CTD casts taken at each station along a transect at hourly intervals, during a complete tidal cycle. This transect (number 3) was performed near the head of Delaware Bay (figure 20, table 4) during the 1984 field season.

In addition to individual CTD casts, conductivity and temperature were also recorded simultaneously with current speed and direction at all current stations using Grundy current meters and at some stations employing Aanderaa current meters. As in the case of current data measurements, conductivity and temperature readings were taken every ten minutes.

5.3. Instrumentation

Two instrument types were used to collect CTD data in DR&B; the Grundy 9400 CTD Profiler, and the Applied Microsystems AML CTD-12 Portable CTD Profiler. The primary instrumentation employed was the Grundy 9400. The conductivity, temperature, and water pressure (converted to depth during initial data processing) data collected by the Grundy 9400 were transmitted by cable back to the Grundy 8400 data logger aboard ship and were simultaneously recorded on a 9-track magnetic tape. The tape, along with a listing of the uncalibrated raw data outputted from the PDP 11/34 shipboard computer, was sent to NOS in Rockville, Maryland for final processing. A table of manufacturing specifications for the Grundy 9400 is provided in Appendix E.

The other CTD measuring system used during the Survey, the AML Portable CTD Profiler, records data internally on a 3-inch magnetic tape. Shipboard processing of the tape relied on the CMDP processing method described earlier with reference to the processing of current meter data. A table of manufacturing specifications for the AML Portable CTD system is provided in Appendix F.

5.4. Data Processing

The CMDP shipboard processing system was not able to process Grundy CTD data. However, the Field Operations Officer routinely checked the performance of the Grundy CTD system by examining the raw data listings dumped by the PDP 11/34.

Processing of the Grundy 9041 CTD data at NOS in Rockville comprised four main stages, which included transferring the raw data tape to paper output using the PDP 11/34 shipboard computer; assigning calibration constants to the temperature, conductivity, and pressure data; inserting heading information for each data file; and final editing.

AML CTD data was processed aboard ship through the CMDP shipboard processing system. Final processing of the data followed a similar sequence as that involved in processing current data including: applying calibration, incorporating heading information, and editing the final data set.

6.0. METEOROLOGICAL DATA

6.1. Significance of Meteorological Data in DR&B

The lower Delaware Bay is affected by a combination of local and regional wind systems that can affect water level and circulation. Local winds blowing from the west, although having a minor influence on currents, can cause a lowering of water level in the western part of the Bay and a raising of water level in the eastern part of the Bay (Wong and Garvine, 1984).

Regional winds, on the other hand, affect water level and circulation in a different manner. A cross-shelf transport component of water circulation produced by the regional wind system causes near surface waters to flow to the right of the wind, and near bottom waters to flow to the left (Hires, et al., 1983). Thus, for example, if the wind direction is from the north, surface water over the shelf would flow into the Bay, tending to cause a rise in the water level at the mouth of the Bay. On the other hand, southerly winds would cause near-surface water to flow away from the mouth, tending to lower the water level.

6.2. Meteorological Station Information

Two meteorological stations were deployed during the DR&B Circulation Survey. One station was located near the mouth of the Bay at Harbor of Refuge. The second station was situated near the center of Delaware Bay at Elbow of Cross Ledge. Both stations are plotted on figure 6. Table 5 contains a list of the meteorological station locations, elevation of sensors, periods of data collection, and the latitude and longitude of each station.

Table 5. Meteorological Stations

1984

STATION	ELEV.	LATITUDE	LONGITUDE	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
M1	15	38°49'57"N	75°6'22"W			5/3--6/28		7/29----------10/3				11/3--12/2				3/1-----5/5		
M2	19	39°10'56"N	75°16'8"W	3/18--4/30		5/21--6/12	6/30-----8/2			9/4-----11/9						3/12----4/23		

6.3. Instrumentation

Aanderaa instruments were used at each meteorological station. The Aanderaa Meteorological Package is an automated weather station equipped with an internal battery power source. Each station measured wind speed and direction, temperature, and pressure with respect to time.

The electronic data logger, a 6-channel unit, and the aneroid pressure transducer were housed in a canister base. The sensors for measuring temperature, wind speed and direction were mounted on an aluminum mast three meters above the canister. Detailed instrument specifications, including a labeled diagram can be found in Appendix G and figure 20, respectively.

Meteorological data were recorded on a 3-inch magnetic tape, digitized as 10-bit binary words. The initial processing of the tape was performed (as in the case of the current meter data) on a PDP 11/34 computer using the CMDP shipboard processing software. Final processing and analysis was completed at NOS in Rockville.

6.4. Data Processing

Final processing of meteorological station data required nearly the same procedures as required for current data. Processing included applying calibration, checking times, assigning times to the data, correcting erroneous data, and plotting the data graphically in a time series format.

6.5. Real-Time Wind Data

Two systems to provide real-time telemetered wind speed and direction data to Rockville were designed and fabricated by the Johns Hopkins University Applied Physics Laboratory (APL). The

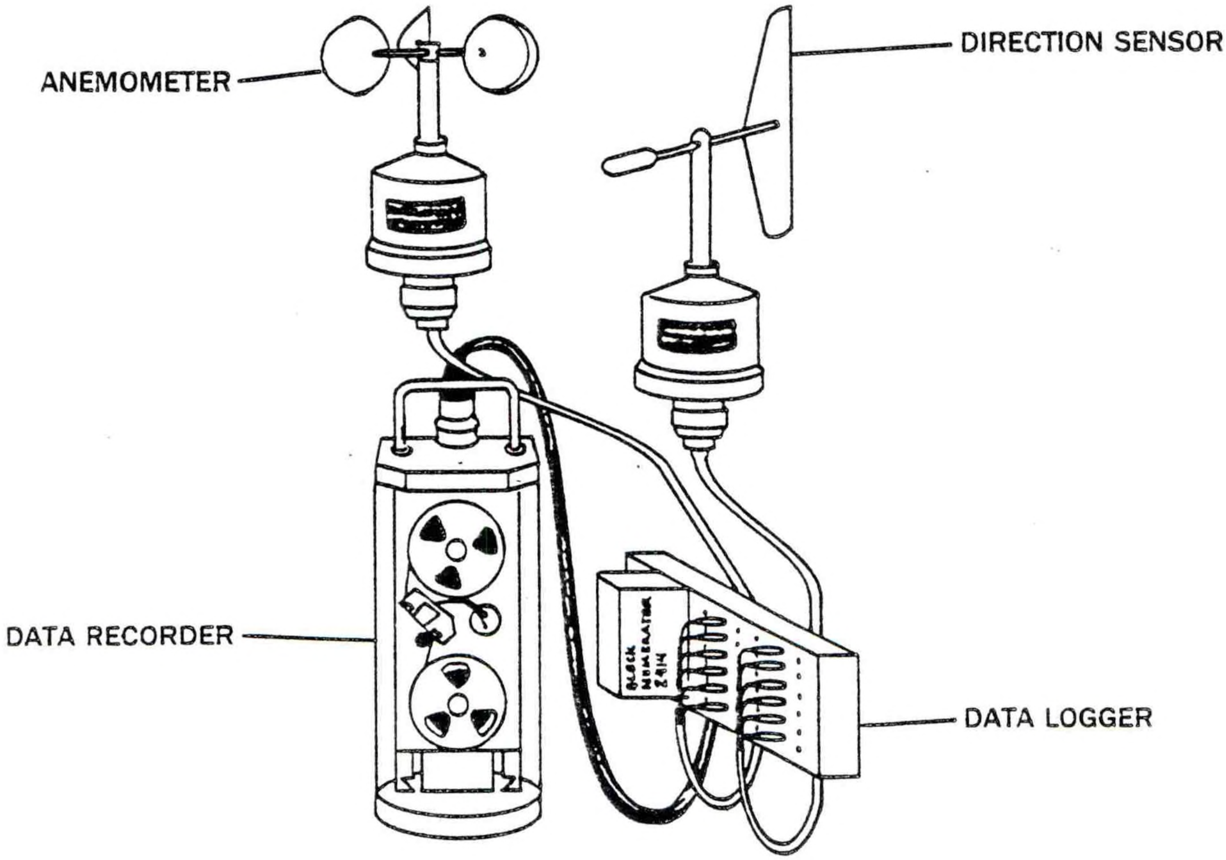


Figure 21. Aanderaa Meteorological Station.

first station consisted of anemometers mounted on a buoy at 7.5 feet (2.3 meters) and 13 feet (4 meters) above the water surface moored about 2,000 feet (600 meters) southwest of the Brandywine Shoals Light (APL, 1985). The second station, located on a stone breakwater surrounding the lighthouse consisted of anemometers located 13.2 feet (4 meters) and 33 feet (10 meters) above the water surface (APL, 1985).

The station was installed and maintained by the Ocean Systems Division of the Office of Oceanography and Marine Assessment. It remained in operation from August 1984 to August 1985 (Basileo, 1985).

The real-time wind speed and direction data along with real-time water level data were used in the DR&B Circulation Model to calculate real-time currents and water levels caused by atmospheric forcing in the vicinity of Brandywine Shoals.

7.0. DATA QUALITY ASSURANCE

The first attempt to estimate the accuracy of oceanographic data collected during a circulation survey by NOS was compiled in volume 2 of the NOS Strategic Petroleum Reserve Project (Frey and Appell, 1981). These estimates of instrumentation uncertainties were compiled for a circulation survey conducted on the Louisiana inner continental shelf between 1978 and 1979. Included in these estimates were measurement uncertainties for CTD, meteorological, and water level data as well as current meter data.

Although a similar study was not performed for data collected during the DR&B Circulation Survey, an active program of data quality assurance was pursued. The program included a pre-survey calibration of all instruments, an instrument presurvey field check, instrument operation data checks using the CMDP shipboard processing system, testing of CTD system operation using Niskin bottle samples, and a post-survey calibration of all survey instrumentation.

Pre-survey and post-survey calibration of temperature, conductivity, and pressure sensors were performed by Wylie Laboratories, Inc. (Hampton, Virginia), on all Grundy 9021G current meters. Included in these calibration activities were compass checks on the accuracy of all direction sensors. The operation of the speed sensors were checked during the pre-survey calibration as well as preceding each field deployment. Aanderaa RCM4 current meter sensors and Aanderaa WLR-5 water level gages were calibrated (pre-survey and post-survey) by Northwest Regional Calibration Center (NRCC) (Bellevue, Washington). Sensors on the Aanderaa meteorological package were calibrated by NRCC, Wylie Laboratories, and the National Bureau of Standards. Sensors on the AML CTD-12 Portable CTD Profiler were calibrated (pre-survey and post-survey) by NRCC and Grundy 9400 CTD sensors were calibrated by Wylie Laboratories.

Prior to the actual deployment of each data collecting instrument, the instrument (including current meters, meteorological sensors, CTD systems, and water level gages) was tested in the field to determine if minimum operations standards were met.

Operating standards, termed Data Quality Level (DQL) standards, were first developed for a NOS circulation survey during the NOS Strategic Petroleum Reserve (SPR) Support Project (Appell, Kalvaitis, Mero, and Roman, 1981). DQL standards developed during the SPR Project (for Grundy 9021G current meter sensors, for Aanderaa meteorological sensors, and for Grundy 9400 CTD sensors) are part of the standard operating procedures for NOS circulation surveys. The DQL standards or manufacturer specifications (for Aanderaa RCM4 current meter, Aanderaa WLR-5 water level gage, and AML Portable CTD) were used for field testing of survey instrumentation during the DR&B Survey. Generally, if the inaccuracy of a sensor is above the DQL range but below the Rejection Level, a prescribed procedure (table 6) was followed such as sensor adjustments, replacement of parts, cleaning of sensors, etc. The sensor was usually replaced if the inaccuracy was above the Rejection Level. Field testing procedures of the ADR and bubbler water level gages followed the Integrated Logistics Support Plan (Office of Oceanography, 1980).

During the survey operation, data received from each instrument were examined using the CMDP shipboard processing system. Any instrument indicated by the data to be malfunctioning was adjusted or repaired.

The accuracy of the CTD measuring system was continuously checked during the survey. Niskin bottle water samples were collected and salinity tested with the use of an Autosal. The frequency of salinity testing corresponded to the CTD program in the following manner. Niskin water samples were taken every 20

Table 6. Instrumentation Data Quality Control

Instrument/Parameter	Data Quality Level (DQL)	DQL Action	Rejection Level (R.L.)		R.L. Action
Grundy 9021G					
speed thruput	±5 counts	note A	±10 counts	±5cm/s	No deployment
speed	template 68 counts	note A	template	-5cm/s	No deployment
direction	512 counts +40 counts	none	512 counts	+100±35°	No deployment
temperature	±0.2°C	none	±1.0°C		Deploy if no spare
conductivity	±4 count ±0.23 mS/cm	note B	±10 counts	±0.6mS/cm	9021's are available
time base	60 s ±0.001s	none	±0.005 sec	±7.2 s/day	No deployment note C
Aanderaa Meteorological Sensors					
speed thruput	±1 count	none	±4 counts	±0.3 m/s	
speed	template	none	template	-.5 m/s	
direction	±5°	none	±10°		Do not deploy sensor use spare.
temperature	±0.2°	none	±1.0°C		
pressure	±3 mb	none	±10 mb	±10 cm H_20	
time	61.03516 ps ±1 ns	none	5 ns	±7 s/day[2]	
Grundy 9400					
temperature	±0.2°C	none	±1.0°C		Do not profile if one or more parameters are not operating properly
conductivity	±2.0 Hz 0.04 mS/cm	none	±Hz	±.12 mS/cm	
pressure	±55 mb	none	±100 mb	±1 m H_20	

Note A: (1) Adjust bearing clearance.
(2) Clean bearings, lubricate.
(3) Replace rotor.
(4) Replace bearing assemblies.
(5) Adjust reed switch bias magnetic.

Note B: (1) Check condition of conductivity cell.

Note C: (1) Instrument oscillator can be adjusted w/C3 on 9021 tape deck circuit board. Time base frequency frequency before & after after adjustment should be noted on deployment log form.
(2) If adjustment fails to bring instrument into DQL levels, crystal (Y1) should be replaced and adjusted. A FAILog form must be prepared for the instrument

to 25 casts, at the beginning and end of each CTD transect and time series or at least once a week during intermittent CTD work. During time series casts, two Niskin bottle samples were collected at each cast--one at about three feet below the surface, and a second at about three feet above the bottom.

8.0. DATA PRODUCTS

Data products resulting from the DR&B Circulation Survey include:

1. Updated <u>Tidal Current Tables</u> (1987)
2. Data Set Archived at NODC (12/85)
3. TIDES-ABC (5/86)
4. Water Level and Circulation Forecast Atlas (tidal volume in Spring, 1987)
5. Technical Report (7/87)

Analysis of the tidal current data from the DR&B Circulation Survey resulted in a new reference station for table 1 in the <u>Tidal Current Tables</u>, replacing the reference station at the Delaware Bay Entrance. New subordinate stations were generated and old subordinate stations were revised in table 2 of the <u>Tidal Current Tables</u>.

The entire current data set, meteorological data set, and the CTD data set from the DR&B Circulation Survey have been archived at the National Oceanographic Data Center (NODC). These data sets can be obtained from:

Director
NOAA/National Oceanographic Data Center
1825 Connecticut Avenue
Washington, D.C. 20235
(202) 673-5549

The Water Level and Circulation Forecast Atlas is a new model-generated product of the NOS; the portion dealing with the tide and tidal current is scheduled to be available Spring 1987. The following year the atlas will be expanded to include river discharge, wind, and other meteorological effects. Use of the charts with appropriate reference station predictions will allow tide and tidal current predictions throughout the estuary. The chart will also allow corrections to these tidal predictions according to wind or river conditions. The Atlas is planned to contain the following charts:

- Tidal Current Charts
- Tidal Height Charts
- Wind-Induced Current Charts
- Wind-Induced Water Level Charts
- River-Induced Current (Upper River) Charts
- River-Induced Water Level Charts
- Corange Tidal Charts
- Cotidal Charts
- Coamplitude (current) Charts
- Cophase Current Charts

A technical report focusing on the dynamics and circulation in the lower Delaware Bay is scheduled for publication in 1987.

Water level data collected during the DR&B Circulation Survey, including control and subordinate stations will be archived at the Sea and Lake Levels Branch, National Ocean Service (NOS).

TIDES-ABC is a new NOS software product. It allows a user to obtain real-time water level data at various estuaries by interrogating the site through linkage of the users' personal computer with the tide gage. Information on TIDES-ABC as well as water level data archived at NOS may be obtained from:

Director
NOAA/NOS/Office of Oceanography
and Marine Assessment
6001 Executive Blvd.
Rockville, MD 20852
(301) 443-8487

9.0. NOS HISTORICAL DATA

Current data has been collected by NOS or predecessor organizations in the DR&B since the middle of the nineteenth century. The U.S. Coast and Geodetic Survey (C&GS) initiated the first current data collection in 1847. Additional collection projects occurred in 1874, 1885, 1886, and 1902. These early current observation projects consisted of a total of 17 stations, located primarily in the lower Bay and at Philadelphia, with each station occupied for no more than two days. In all these early surveys, current speed and direction were calculated using a six-foot calibrated pole submerged in the water column.

The first major current survey in the DR&B was conducted in 1924 under the command of W.H. Overshiner using the C&GS ships Michael Martin, B.H. Minch, and A.E. Blackman. During the survey 42 current stations were occupied from Trenton, New Jersey to the Delaware and New Jersey Capes. Length of station occupations were short, however, comprising one to two days except for a station in the upper part of Delaware Bay near the Smyrna River, which was occupied for 34 days. Data was collected using poles for surface observations and Price current meters for subsurface observations. The Price current meters only measured current speeds and recorded the data internally on a punched paper tape at half hour intervals. Current directions were extrapolated from current pole measurements at the surface.

The next major circulation survey in DR&B was carried out in 1947 and was similar to the 1924 survey in both instrumentation used and area surveyed. Ships used for this survey were the C&GS ships Wainwright and Hilgard. The survey was under the command of L.C. Johnson. Sixty-two current stations were occupied, mostly for four days or less.

The last major circulation survey, prior to the 1984-1985 circulation survey, was carried out in 1953 under the command of H.A. Paton. During Paton's survey 26 current stations were occupied between the Delaware Bay Capes and the Chesapeake and Delaware Canal. Current data were collected at three stations for a duration of ten days at each, while the remaining stations were occupied for about five days each. The currents measured by the Roberts radio current meter were recorded aboard the survey ship, rather than in the current meter as in the case of the Price current meter. In 1959, during a relatively small survey, five days of current data were collected at each of four stations in the vicinity of Delaware City.

Water level measurements have been taken in DR&B since 1840. The earliest measurements were conducted manually using a tide staff. The first water level gage which automatically recorded water level on a diagram was introduced in the Delaware River in 1854. All present control stations for DR&B listed below utilize ADR water level gages. ADR water level gages record data digitally in binary code every six minutes. The control stations used for the DR&B Survey, including the first year of continuous occupation, include:

Trenton, N.J. (1977)
Philadelphia, PA (1900)
Reedy Point, DE (1956)
Lewes, DE (1919)
Cape May, N.J. (1965)
Atlantic City, N.J. (1911)
Indian River Inlet, DE (1972)
Ocean City, MD (1975)

Historical water level and current data for the DR&B may be obtained from:

Director
NOAA/NOS, Office of Oceanography
and Marine Assessment
6001 Executive Boulevard
Rockville, MD 20852
(301) 443-8487

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REFERENCES

APPELL, G.F., T.N. MERO, R. WILLIAMS, AND W.E. WOODWARD.
1985. Remote acoustic doppler sensing; its application to environmental measurements: Paper presented to Estuarine Remote Sensing Seminar and Workshop, Washington, D.C., December 1985.

APPELL, G.F., A.N. KALVAITIS, T.N. MERO, and C.R. ROMAN.
1981. Field data quality control. In H.R. Frey and G.F. Appell (editors), NOS Strategic Petroleum Reserve Support Project: Final Report, Vol. Two-Measurement and Data Quality Assurance, pp. 71-123.

APPLIED PHYSICS LABORATORY (APL)
1985. Description of Brandywine Shoal meteorological system: Unpublished Technical Report STH-85-051, Johns Hopkins University Applied Physics Laboratory, February 1985.

BLUMBERG, A.F. AND G.L. MELLOR.
1985. A description of a three-dimensional coastal ocean circulation model, three-dimensional shelf models. In N. Heaps (editor), Coastal and Estuarine Sciences, Vol.5: American Geographical Union.

BASILEO, M.A.
1985. Real-time systems in the Delaware Bay and River Modeling Project, Presented at: Current Practices and New Technology in Ocean Engineering, the Ninth Annual Energy-sources Technology Conference and Exhibition, New Orleans, February 23-27, 1986, Ocean Engineering Div., American Society of Mechanical Engineers.

BODNAR, A. N.
1977. User's guide for the establishment of tidal bench marks and leveling requirements for tide stations. Unpublished Report, Tides and Water Levels Division, NOAA, National Ocean Service, 33p.

BROWNE, D. R. and C. W. FISHER.
1986. Chesapeake Bay Circulation Survey, 1981-1983. NOS Oceanographic Circulation Survey Report, No. 8, 71 pages.

FREY, H. R. and G. F. APPELL (editors).
1981. NOS Strategic Petroleum Reserve Support Project: Final Report, Vol. Two-Measurement and Data Quality Assurance, 182p.

FREY, H.R., M.W. SZABADOS, AND L.E. HICKMAN .
1981. NOS Strategic Petroleum Reserve Support Project: Final Report, Vol. One - Oceanography on the Louisiana Inner Continental Shelf, NOAA, National Ocean Service, 343p.

HARRIS, D.L., N.A. PORE, and R. CUMMINGS.
1965. Tide and tidal current predictions by high speed computer. Intl. Hydrogr. Rev., Vol.. 62, pp. 95-103.

HIRES, R.I. G.L. MELLOR, L.Y. OEY, and R.W. GARVINE.
1983. Circulation of the estuary. In J.H. SHARP (editor), The Delaware Estuary: Research and Background for Estuarine Management and Development, Unpublished report to the Delaware River and Bay Authority, Lewes, De., pp. 27-49.

LIPA, B.J. and D.F. BARRICK.
1984. Least-squares methods for the extraction of surface currents from CODAR crossed-loop data: application at ARSLOE. IEEE J. Oceanic Engineering, Vol. OE-8, pp. 226-253.

MAGNELL, B.A.

1985. Delaware Bay intercomparison experiments, fall 1984: Unpublished report to NOAA, EG&G Washington Analytical Services, Inc., November 1985, 2 volumes.

NATIONAL OCEAN SERVICE (NOS).

1984. NOS National requirements study: Unpublished report, NOAA, NOS Planning Staff.

OFFICE OF OCEANOGRAPHY AND MARINE ASSESSMENT (OMA).

1980. Integrated logistics support plan: Unpublished report, Tides and Water Levels Division, National Ocean Service.

PARKER, B.B.

1977. ROTARY. Unpublished manuscript, Office of Oceanography, NOAA, National Ocean Service.

PARKER, B.B.

1984. Frictional Effects on the Tidal Dynamics of a Shallow Estuary, Ph.D. dissertation, The Johns Hopkins University, Baltimore, Maryland, 300 pages.

PATCHEN, R.C., J.J. JOHNSON, T.N. STEPKA, G.D. PETRAE, and M.J. CONNOLLY.

1982. Certification of the circulation measurements data processing system: Unpublished report, NOAA, National Ocean Service.

POLIS, D.F., and S.L. KUPFERMAN.

1973. Physical Oceanography: Delaware Bay Report Series, Vol.4, University of Delaware, Newark, De., 145p.

PORTER, D.L., R.G. WILLIAMS, and C.W. SWASSING.
1986. An intercomparison of surface circulation in the Delaware Bay obtained from CODAR, drifting transponders and RADS. Paper submitted to IEEE Third Working Conference on Current Measurements, Ocean Engineering Society, January 22-24, 1986, Airlie, Virginia.

SHARP, J.H.
1983. Introduction. In J.H. Sharp (editor), The Delaware Estuary: Research and Background for Estuarine Management and Development, Unpublished report to the Delaware River and Bay Authority, Lewes, De., pp. 1-7.

SZEKIELDA, K.
1973. Chemical Oceanography: Delaware Bay Report Series, Vol. 4, University of Delaware, Newark, De., pp. 145-170.

U. S. COAST AND GEODETIC SERVICE (C&GS).
1965. Manual of Tide Observations: C&GS Publication No. 30-1, 92p.

U.S. DEPARTMENT OF COMMERCE.
1853-1986. Tide Tables, East Coast of North and South America. NOAA, National Ocean Service.

1890-1986. Tidal Current Tables, Atlantic Coast of North America. NOAA, National Ocean Service.

WELCH, J.M., J.W. GARTNER, and S.K. GILL.
1985. San Francisco Bay Area Circulation Survey: 1979-1980. NOS Oceanographic Circulation Survey Report No.7, 179p.

WONG, K., and R.W. GARVINE.
1984. Observations of wind-induced, subtidal variability in the Delaware estuary. J. Geophysical. Res., Vol. 89, pp. 10589-10597.

ZETLER, B., and G.W. GROVE.
1964. A program for detecting and correcting errors in long series of tidal heights. Int. Hydro. Rev., Vol. 41, pp.103-107.

APPENDIX A. MANUFACTURER SPECIFICATIONS FOR THE GRUNDY 9021G CURRENT METER

Current Speed Sensor

Speed Range: 2.5 to 500 cm/sec (approximately 0.05 to 10 knots)
Starting Velocity: 1.5 cm/sec
Accuracy: ±2 cm/sec or 2%, greater

Current Direction Sensor

Type: Vane
direction: 0° to 360° continuous
Minimum movement velocity: Less than 30 mm/sec
Compass resolution: ±1°
Compass precision: ±3°
Allowable Pitch & Roll: ±30° from horizontal

Recording System
Type: ¼ inch magnetic tape
Digital, serial form
Storage capacity: 70,000 words (or 10,000 seven word samples)
Resolution: 0.1% Instrument
Drive: Brushless stepper motor
m; 56 lb (25 Kg) for 6000 m
Timing Mechanism
Type: Solid state clock
interval: Programmable minutes
Precision: Better than ±2 sec/ day from -5°C to +40°C

Sampling

Parameters to be measured: 6 data channels plus identification number
Measuring speed: 0.6 sec per measurement
Rate: Continuous or preset by timing mechanism for 0.8 to 120 samples per hour (sample intervals 0.5 to 75 min.)

Magnetic Tape

Standard ¼ in magnetic tape on a 3 inch spool can be used. To obtain the data storage capacity of 70,000 words, 600 ft of whichever is triple-play tape is necessary.

Dimensions

Diameter: 5.5 in (14 cm) for Magnetic 2000 m depth capability; 5.7 in (15 cm) for 6000 m
Width: 8 in (20 cm)
Height: (instrument and fin): 24 in (61 cm)
Length (instrument and fin): 56 in. (142 cm)
Height overall (including suspension frame): 96 in (244 cm)
Length overall (including suspension frame): 76 in (193 cm) Format:

Weight

In air: 51 lb (23 Kg) for 2000

Instrument (including suspension frame)
In air: 75 lb (34 Kg) for 2000 m; Timing 90 lb (41 Kg) for 6000 m from 0.5 to 75
In water: 46 lb (21 Kg) for 2000 m; 60 lb (28 Kg) for 6000 m

Suspension System

Mounting: In-line splice or clamp on.
Gimbal: Active ball bearing, low torque gimbal not subjected to tensile stress from mooring line.
Tilt (maximum): Independent of mooring line angle up to 30° from vertical.
Material: 316 stainless steel
Tensile strength: 9000 lbs (4100 Kg)

Sample count: optional (for spliced mounting)
Sample interval in minutes:
$\frac{N \times T}{8}$, where
N=number of parameters
T=number of days to record-not to exceed 180

Telemetering System response

Type: Acoustic
Frequency: 32,768 Hz (nominal)
Telemetering speed: 0.6 sec per measurement
Range: Approximately 800 m depending on conditions

Electronics

Circuits: All solid state
Power: 12v sealed, lead-acid battery; rechargeable with Model 8021 charger

Operating Environoments

Medium: Saline or fresh water
Operating temperature range: -5°C to +40°C
Storage temperature range: -30°C to +40°C
Maximum operating depth: 2000m (6000 m optional)
Maximum pressure: 3000 psi (9000 psi optional)

Optional Measurands

Temperature
Range: -2° to 35°C
Precision: ±0.1°C
Response time: 15 sec for 99%

Conductivity
Range: 0 to 60 mmho/cm (other ranges available on special order)
Precision: ±0.12 mmho/cm
Response time: 4 sec
Depth/Pressure
Precision: ±0.5% of full scale
Response time: 10 m sec

APPENDIX B. MANUFACTURER SPECIFICATIONS FOR THE AANDERAA RCM4 CURRENT METER

Weight in Air
Recording unit: 12.5 kg
Vane assembly: 12.0 kg

Dimensions

Overall length: 136 cm
Recording unit diameter: 12.8 cm
Vane size: 36 x 100 cm

Depth Capability
Standard version: 2000 m
High pressure version: 6000 m

Materials Exposed to Sea Water
Pressure case 90/10 CuNi alloy, nickel plated. Other parts acid resistant steel or nickel plated bronze. Vane 8 mm red PVC.

Mooring
Spindle end pieces designed for 14 mm max. diameter wire or rope and force of 2000 kg. A gimbal mounting permits ± 30° deviation between instrument and mooring line.

Measuring Ranges and Accuracies
Current speed: 1.5 to 250 cm/sec
Direction: 0-360° ± 5° magnetic
Temperature: choice between 3 ranges:
  Low range: - 2.46°C to 21.40°C
  High range: 10.08°C to 36.00°C
  Wide range: - 0.34°C to 32.17°C
  Standard calibration curves are accurate to +0.1°C. Calibration to ± 0.0125°C is possible.
Conductivity: 0-60 mmho
Pressure: choice between 5 ranges:
  0-200 PSI, 0-500 PSI, 0-1000 PSI, 0-5000 PSI, 0-8000 PSI
Accuracy: better than ±1% of range.

The channels are: Reference (a control measurement), Temperature, Conductivity (optional), Depth (optional), Current Direction, Current Speed.

Recording System
Serial recording of 10-bit binary words on 6.4 mm magnetic tape by use of short and long pulses. Total storage capacity: 60,000 words. Tape: 183 m on 7.62 cm or 8.25 cm spools. End of record pulse (sync pulse) after each completed cycle.

Telemetry
By crystal controlled pulse coded acoustic carrier 16.385 kHz, 6 words sent in the course of 30 sec. Detecting range with tuned hydrophone receiver is typically 800 m.

Rotor Speed Reduction Gear
6000:1 is standard. 40,000:1 and 1200:1 available on request... These rates are recommended for sampling intervals of 5 to 20 min., 30 to 60 min., and 0.5 to 2.5 min., respectively.

Clock
Accuracy: ± 2 sec/day over temperature range 0-20°C. Operating time on new battery: 3 years.

Sampling Intervals
60, 30, 20, 15, 5, 2.5, 2, 1, and 0.5 min. according to interval selecting plug. The 10 min. plug is standard.

External Triggering
Is possible by applying a 6-volt positive pulse to electric terminal on top end plate. Same terminal also gives output signals (5-volt pulses of negative polarity).

Measuring System
Rotary encoder system with sequential measuring of 6 channels by self-balancing bridge. Bridge is balanced in 10 binary steps and gives a 10-bit binary word for each channel. Measuring speed: 4.5 sec/channel.

Batteries
Main battery: Tudor 9T1 or similar battery (9-volt battery, 63 x 50 x 80 mm, nonmagnetic)
Clock battery: Mallory type TR-113 (16.6 mm diameter, 21.1 mm long)

APPENDIX C. MANUFACTURER SPECIFICATIONS FOR THE WATER LEVEL GAGES

BUBBLER WATER LEVEL GAGE

Range:	0-10 feet to 0-5- feet
Precision:	1 percent of full scale
Recorder:	6-inch strip chart
Record Format:	Analog, curvilinear
Sampling Rate:	Continuous
Duration:	Chart - 1 month Chart drive, spring wound - 8 days
Processing:	Visual
Mode of Operation:	Compressed nitrogen is purged through the system, actuating a pressure-sensitive element, which measures water level fluctuations.

ADR (ANALOG - DIGITAL RECORDER) WATER LEVEL GAGE

Range:	0-99.99 feet
Precision:	± 1/2 binary count
Recorder:	Foil-backed paper tape (punch)
Record Format:	Binary - decimal code
Sampling Rate:	6-minute intervals
Duration:	Chart - 3 months Chart drive, battery - 3 months
Processing:	Mechanical translator
Mode of Operation:	Float movement is translated into binary code and recorded on paper tape.

APPENDIX D. MANUFACTURER SPECIFICATIONS FOR THE AANDERAA WATER LEVEL GAGE WLR-5

Measuring System
A digital system consisting of four channels measured in sequence. A ten-bit word is used for each channel. Measuring speed: 4 seconds each channel. The channels are:

1. Reference
This is a fixed reading obtained from hardwiring a shift register inside the electronic board. It acts as a control on the performance of the unit and also as an identification of individual instruments and recorded tape.

2. Block Number
This number shows the number of successive blocks of data. Each block consists of 120 words (i.e., 30 samples). The first block is given the number one. The counter is reset when the power to the Water Level Recorder is switched off.

3. and 4. Pressure
These sensors are based on pressure controlled quartz crystal oscillators in the range 36 -40KHz. Ranges: 0-400 psia (standard) and 0-900 psia. Accuracy: 0.01% of full scale range. Resolution: 0.001% of full scale range. Integration Times: 7 and 55 seconds, 7.5, and 29 minutes approximately. 55 seconds standard.

Sampling Intervals:
0.5, 1, 2, 5, 10, 15, 20, 60, and 180 minutes selected by interfal selection switch. Derived from the time base quartz crystal oscillator. Accuracy: 0.5 sec./day within 0 to 25°C. External Triggering: Possible by applying a six volts pulse to terminal on top end plate. This is for calibration purposes and real-time monitoring.

Recording System
Internal:
Type: Reel to reel 6.4 mm magnetic tape.
Coding: 10-bit binary words (short and long pulses) in serial form. Storage Capacity: 15,000 samplings using 183 m of magnetic tape on 7.62 cm reel

Telemetry
Acoustically:
By switching on and off carrier from acoustic transducer.
Frequency: 16,384KHz ± 5 Hz.
Detection Range: Typically 800 meters with Hydrophone Receiver 2247.
By Cable:
5 volts negative short and long pulses from terminal on top end plate. May be used for real-time readings and for calibration purposes by use of Printer 2152.

Power
Battery 2291: 9 volts 5ah., alkaline type (6 Mallory MN 1400).
size: 63 x 50 x 80 mm.
Capacity: Sufficient for one full tape or 1 year of recordings.

External Materials
Aluminum 6061/T6 alloy. To minimize corrosion, all external parts are covered with epoxy coating.

Depth Capacity
Limited by sensor range.

Weight
In Air: 5.9 kilograms
In Water: 1.4 kilograms

Dimensions
Overall height: 432 mm.
Diameter: 128 mm.

APPENDIX E. MANUFACTURER SPECIFICATIONS FOR THE GRUNDY MODEL 9400 CTD

Parameter	Measurand: Conductivity	Measurand: Temperature	Measurand: Pressure
Measurement Range	0 to 60 mmho/cm	-2°C to 35°C	600 meters (profiling) 300 meters (moored)
Accuracy	±0.03 mmho.cm	±0.02°C	±0.25% of full scale
Output Signal Frequency	4995-7901 Hz	2127-4193 Hz	9712-11288 Hz
Resolution	0.0001 mmho/cm	0.0001°C	0.0002% FS
Time Constant	0.1 sec	0.35 sec	0.1 sec

Frame	
Dimensions	12 in (30.48 cm) dia x 16 in (40.64 cm) high
Weight	26 lb (11.8 Kg) in air; 18 lb (8.2 Kg) in water
Material	Stainless steel
Power Requirements	150 to 250 ma constant currnt at a minimum of 33 vdc plus cable drop, i.e., voltage = 33v + cable resistance x 0.25

APPENDIX F. MANUFACTURER SPECIFICATIONS FOR THE AML PORTABLE CTD-12

SENSORS

CONDUCTIVITY:	Six electrode conductivity cell. Accuracy ± 0.03 PPT equivalent salinity over range 0 PPT to 41 PPT.
TEMPERATURE:	Accuracy ± 0.02°C. Range - -2°C to 30°C. Thermistor sensor.
DEPTH:	Monolithic strain gauge. Repeatability ± 0.1% FSP. (Full scale depth as selected to 650 m).
RESPONSE TIME:	Less than 250 msec all sensors. To respond to 63% of step input, at lowering rate 1m/sec.

RECORDING SYSTEM

TYPE:	Reel to reel, stepping motor drive, ¼" magnetic tape, ½ mil, 600 feet.
STORAGE CAPACITY:	60,000 ten-bit words. (20,000 samples C, T & D)
RECORDING SPEED:	Nominally 560 msec per parameter. (Limited by printout rate of Digi-Print 701).
SPOOL SIZE:	3 or 3¼" diameter.
DATA RECOVERY:	Magnetic tape from this instrument can be translated using Tape Reader Model 769.

DATA LOGGER

SAMPLE INTERVALS:	Crystal derived hours, minutes and seconds, plug programmable (or external manual trigger).
DIGITIZER:	12-bit successive approximation technique employing ratiometric operation. (Only 10 bits retained from recording purposes.)
NUMBER OF CHANNELS:	Expandable to eight.
CIRCUITRY:	Micropower digital and linear MSI elements mounted on two single PC boards.
OUTPUT:	Serial long/short pulse burst. (11.7 msec and 3.9 msec respectively.)
INPUT:	Single negative pulse for trigger on; external analogue input.
SIZE:	Electronics chassis (two PC board enclosure) nominally 105 mm x 30 mm aluminum cabinet.

POWER

QUIESCENT: 1 mW

BATTERIES: 8 Alkaline D cells or nickel cadmium rechargeable cells.

CAPACITY: Equivalent to 20,000 recorded samples.

CONSTRUCTION

PRESSURE CASE: 6061-T6 Aluminium.

LENGTH: 570 mm.

WIDTH: 300 mm.

CAGE: Stainless steel removable sensor protection cage.

WEIGHT: 9 kg (including batteries) 6 kg (in water).

APPENDIX G. MANUFACTURER SPECIFICATIONS FOR THE AANDERAA METEOROLOGICAL STATION

Weight

Recording unit: 4 kg

Dimensions

Recording unit length: 38 cm
Recording unit diameter: 14 cm
Housing: 1 m x 25 cm x 25 cm
Wind sensors at 10 m above water.

Materials

Data logger: PVC plastic, nickel plated, bronze, acrylic.
Mast and housing: aluminum

Measuring Ranges and Accuracies

Wind speed: threshold 30-50 cm/sec ±2% of full scale.
Direction: 0-360° ±5° magnetic
Temperature: -44.05-44.09°C ±0.25°C
Pressure: 720-1070 mbar ±0.67% of full scale.

Measuring System

Rotary encoder system with sequential measuring of 6 channels by self-balancing bridge. Bridge is balanced in ten binary steps and gives a 10-bit binary word for each channel.
Measuring speed: 4.0 sec/channel
The channels are: Reference number, Average Speed, Maximum Speed, Direction, Temperature, Pressure.

Recording System

Serial recording of 10-bit binary words on 0.6 cm magnetic tape by use of short and long pulses. Total storage capacity: 5,000 samplings
Tape: 183 m on 7.6 cm spool

Clock

Accuracy: ±2 sec/day over temperature range 0-20°C.

Sampling Intervals

180, 60, 30, 20, 15, 10, 5, 2.5, 1, and 0.5 min according to interval selected.

External Triggering

Is possible by applying a 6 volt positive pulse to programming board.

Batteries

Main battery: Tudor 9T1 or similar battery (9 volt battery 63 x 50 x 80 mm, nonmagnetic).