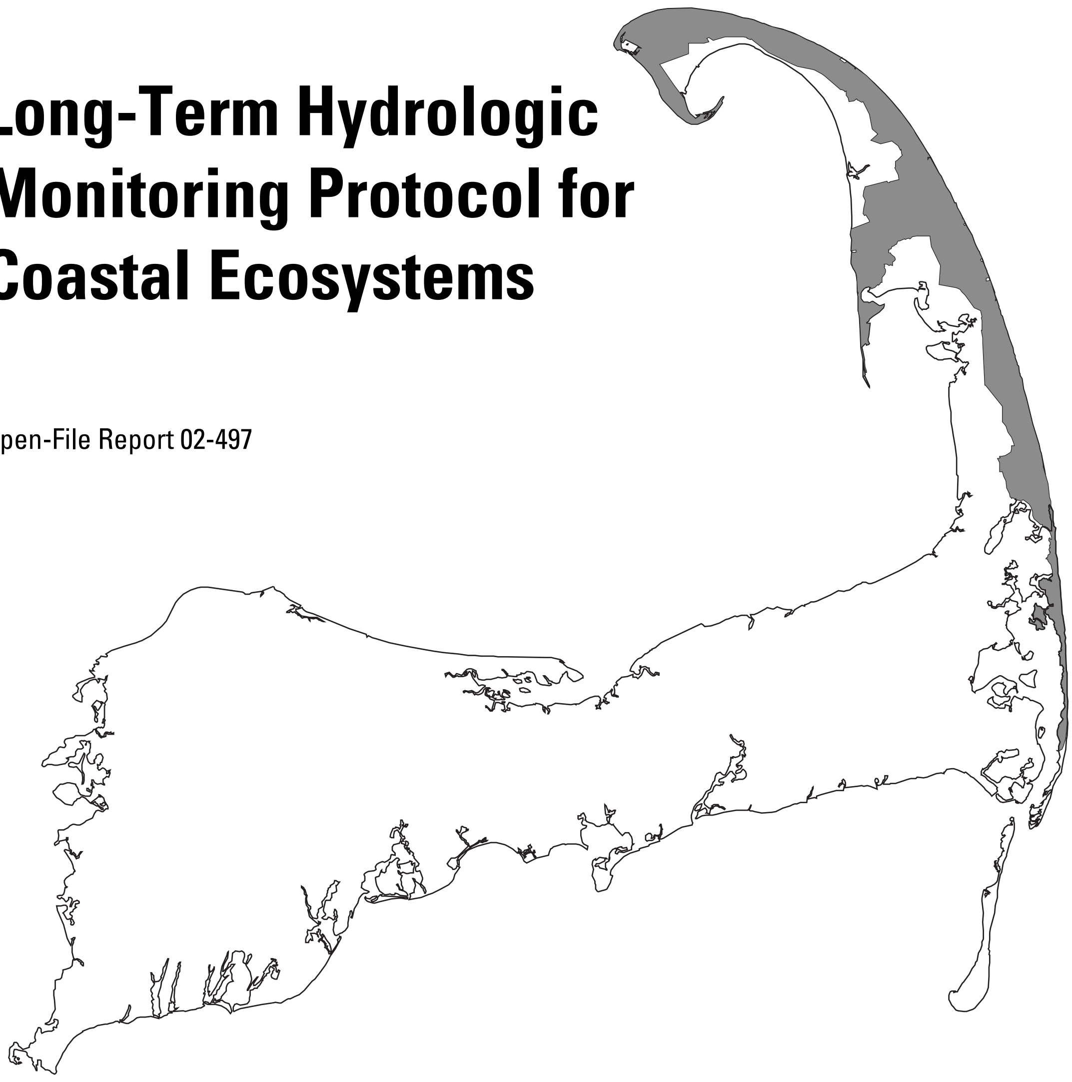
Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore

Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems



Open-File Report 02-497

In cooperation with the
NATIONAL PARK SERVICE,
CAPE COD COMMISSION, and the
U.S. GEOLOGICAL SURVEY
BIOLOGICAL RESOURCES DISCIPLINE

U.S. Department of the Interior
U.S. Geological Survey

Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems

By TIMOTHY D. McCOBB AND PETER K. WEISKEL

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In cooperation with the
NATIONAL PARK SERVICE
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U.S. GEOLOGICAL SURVEY BIOLOGICAL RESOURCES DISCIPLINE

As part of a series of monitoring protocols for the
LONG-TERM COASTAL ECOSYSTEM MONITORING PROGRAM
AT CAPE COD NATIONAL SEASHORE

Northborough, Massachusetts
2003

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

Chief, Massachusetts-Rhode Island District
U.S. Geological Survey
10 Bearfoot Road
Northborough, MA 01532

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

PREFACE

Overview of Long-Term Monitoring Program

The Cape Cod National Seashore serves as a National Park Service prototype-monitoring park for the Atlantic and Gulf Coast biogeographic region. The U.S. Geological Survey, in cooperation with the National Park Service, is charged with designing and testing monitoring protocols for implementation at the Cape Cod National Seashore. It is expected that many of the protocols will have direct application at other coastal park units, as well as U.S. Fish and Wildlife Service coastal refuges, within the biogeographic region.

The Long-term Coastal Ecosystem Monitoring Program at the Cape Cod National Seashore will rely upon numerous protocols that are relevant to the major ecosystem types (Estuaries and Salt Marshes, Barrier Islands/Spits/Dunes, Ponds and Freshwater Wetlands, Coastal Uplands). The hydrologic monitoring protocol is associated with all of these ecosystem types. The overall monitoring program is designed so that all of the protocols are interrelated. Roman and Barrett (1999) present a conceptual description of the entire monitoring program.

Protocol Organization

To maintain consistency among the various monitoring protocols, each protocol is organized as follows. PART ONE of the protocol details the objectives of the monitoring protocol and provides justification for the recommended sampling program. The relevant literature and data collected during the protocol development phase of the project are used to illustrate particular sampling designs, sampling methods, or data-analysis techniques. For example, PART ONE describes the objectives of a water-level monitoring program and provides the justification as to why certain monitoring wells and the measurement schedule were selected.

PART TWO is a description of the field, data-analysis, and data-management aspects of the protocol. For example, PART TWO explains the step-by-step procedure for measuring a ground-water level in a monitoring well.

EXECUTIVE SUMMARY

Long-term monitoring of hydrologic change using a standard data-collection protocol is essential for the effective management of terrestrial, aquatic, and estuarine ecosystems in the coastal park environment. This study develops a consistent protocol for monitoring changes in ground-water levels, pond levels, and stream discharge using methods and techniques established by the U.S. Geological Survey for use in the Long-term Coastal Monitoring Program at the Cape Cod National Seashore. The protocol establishes a hydrologic sampling network in the four ground-water-flow cells in the Seashore area, and provides justification for the measurement methods selected and for the spatial and temporal sampling frequency. Data collected during the first year of monitoring are included in this report; common hydrologic analyses such as hydrographs for ground-water and pond levels, and rating curves between stream stage and discharge for streamflow, are presented for selected sites. Long-term hydrologic monitoring at the Seashore will aid in interpretation of the findings of other monitoring programs. Developing and initiating long-term hydrologic monitoring programs will provide a better understanding of effects of natural and human-induced change at both the local and global scales on coastal water resources in park units.

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ACKNOWLEDGMENTS

The U.S. Geological Survey's (USGS) Water Resources Discipline, the Cape Cod Commission (CCC), and the National Park Service (NPS) supported development of this protocol, with funds administered by the USGS Biological Resources Discipline Patuxent Wildlife Research Center at the University of Rhode Island. The authors thank John Portnoy (NPS) for his advice and expertise in site selection and site access at the Cape Cod National Seashore, and Evan Gwilliam (NPS) and Van Morrill (CCC) for their dedication and hard work with instrument installation and data collection. The authors also appreciate the hard work of Glenn Berwick and David Kraemer (USGS) for their drilling services and Neil Gatwa of Wellfleet, MA for providing a unique, mobile drilling system suitable for remote drilling around sensitive pond shorelines. The authors thank Roy Socolow (USGS) for his stream-gaging training session and site-selection advice. Charles Roman (USGS) is thanked for his reporting advice and detailed reviews of this protocol.

CONVERSION FACTORS AND VERTICAL AND HORIZONTAL DATUMS

CONVERSION FACTORS

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

HORIZONTAL AND VERTICAL DATUMS

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Altitude, as used in this report, refers to distance above or below the NGVD 29.

PART ONE
Protocol Background and Justification

INTRODUCTION

The Cape Cod National Seashore (CACO) was selected by the National Park Service (NPS) as a prototype park for long-term coastal ecosystem monitoring. The Seashore consists of about 18,000 hectares (44,000 acres) of uplands, ponds, wetlands, and tidal lands on lower Cape Cod, Massachusetts (Godfrey and others, 1999). The hydrologic system of lower Cape Cod consists of four distinct ground-water lenses, or flow cells, which receive recharge through precipitation. These lenses are separated by tidal bays, freshwater streams, and marshes, which represent the discharge receptors (fig. 1). The combination of a vulnerable, sole-source water supply with the rapid urbanization of lower Cape Cod creates a serious situation that requires a comprehensive resource-protection, -management, and -monitoring program (Godfrey and others, 1999). Hydrologic features available for monitoring at the Seashore include: (1) ground water, (2) kettle ponds, (3) permanent and seasonal freshwater wetlands (vernal ponds), (4) freshwater streams, and (5) estuarine wetlands (Godfrey and others, 1999).

The purpose of this report is to establish a hydrologic monitoring protocol for the Cape Cod National Seashore. This protocol will be integrated with protocols from other disciplines in the long-term ecosystem monitoring program to aid in the interpretation of findings and the detection of long-term trends. Establishment of a detailed hydrologic monitoring protocol is essential for the collection of high-quality data that can be used to address current and future hypotheses and identify trends in complex data sets. Because changes in many hydrologic observations are near the limits of measurement error, each measurement must be carried out according to a specific protocol to ensure consistent data and minimize measurement error.

MONITORING QUESTIONS: Specific Hydrologic Trends and Issues to Address

Long-term hydrologic monitoring is essential for understanding the effects of sea-level rise, climate change, and urbanization on the hydrologic system of the Seashore and on the aquatic and estuarine ecosystems that depend upon that hydrologic system (fig. 2). These three “agents of change” affect the hydrologic system of the Seashore in different ways and on different time scales. It is useful to explore each of these agents of change briefly and to address several of the specific monitoring questions associated with these agents.

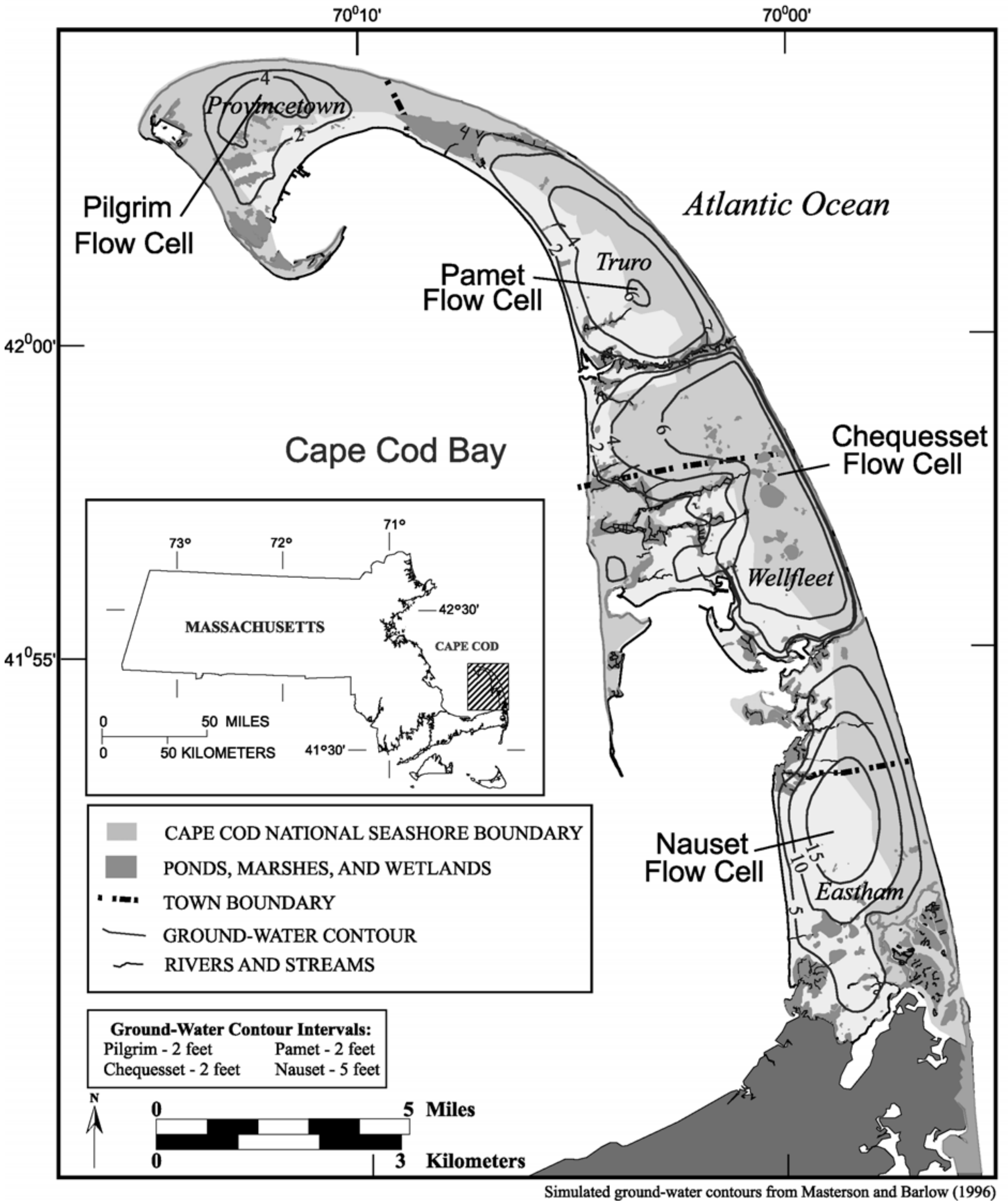


Figure 1. Hydrologic-monitoring-protocol area showing the Lower Cape Cod ground-water flow cells.

Sea-Level Rise

Sea-level change is a global phenomenon which can be modified by local conditions in the earth's crust. According to instrumental records collected since 1920 in Boston, relative sea level on the Massachusetts coast has risen at a rate of about 2.5 mm/yr (fig. 3). A recent summary of sea-level-rise projections for southern New England indicates that rates of relative sea-level rise are likely to increase to rates of 3.5 to 6.0 mm/yr by the year 2100, due to the projected effects of global warming and glacio-isostatic adjustment (Donnelly and Bertness, 2001). The response of the Cape Cod hydrologic system to accelerated sea-level rise will likely be an increased tendency for saltwater to intrude both the underlying aquifer at depth and the tidal streams at the surface. Some of the specific hydrologic questions posed by sea-level rise at the Seashore are the following:

1. Will the interface between salt and freshwater within the ground-water flow system respond immediately to accelerated rates of sea-level rise, and will this threaten existing public-supply wells?

2. How much farther inland will tidal influence and saline water penetrate the coastal streams and associated ecosystems?

3. How will the water balance of the Seashore landscape be affected by sea-level rise?

Hypotheses concerning these questions have already been posed in the literature (see Nuttle and Portnoy, 1992; Hull and Titus, 1986). Long-term hydrologic monitoring data will be required to test these hypotheses and adopt appropriate management responses.

Climatic Change

Climate change is also a global phenomenon with distinctly local aspects that can affect hydrologic systems across a range of time scales. On the basis of data from a national USGS stream-gaging network of 395 stations with more than 50 years of record on unregulated streams, Lins and Slack (1998) documented climatically induced variations in stream discharge in the United States during the 20th century. In general, streamflows in the conterminous U.S. are increasing, but are exhibiting fewer extremes.

On Cape Cod, where long-term streamflow records are lacking, observation-well records show the effects of long-term climate change on the hydrologic system. For example, the 50-yr hydrograph for well TSW-1-0068 (fig. 4) shows the impact of periods of drought around 1954, 1964, and 1980 upon ground-water levels in Truro. (The hydrograph also appears to show a rising trend of 2.1 mm/yr in average ground-water level, which may reflect sea-level rise.) Masterson and Barlow (1996) have shown that drought-induced ground-water declines over an extended period (5 yrs) can have a large impact on the position of the interface between salt and fresh waters at the base of a coastal aquifer (fig. 5); the position of the interface (in the absence of pumping by humans) is directly controlled by the aquifer recharge rate, which is sharply reduced during a drought.

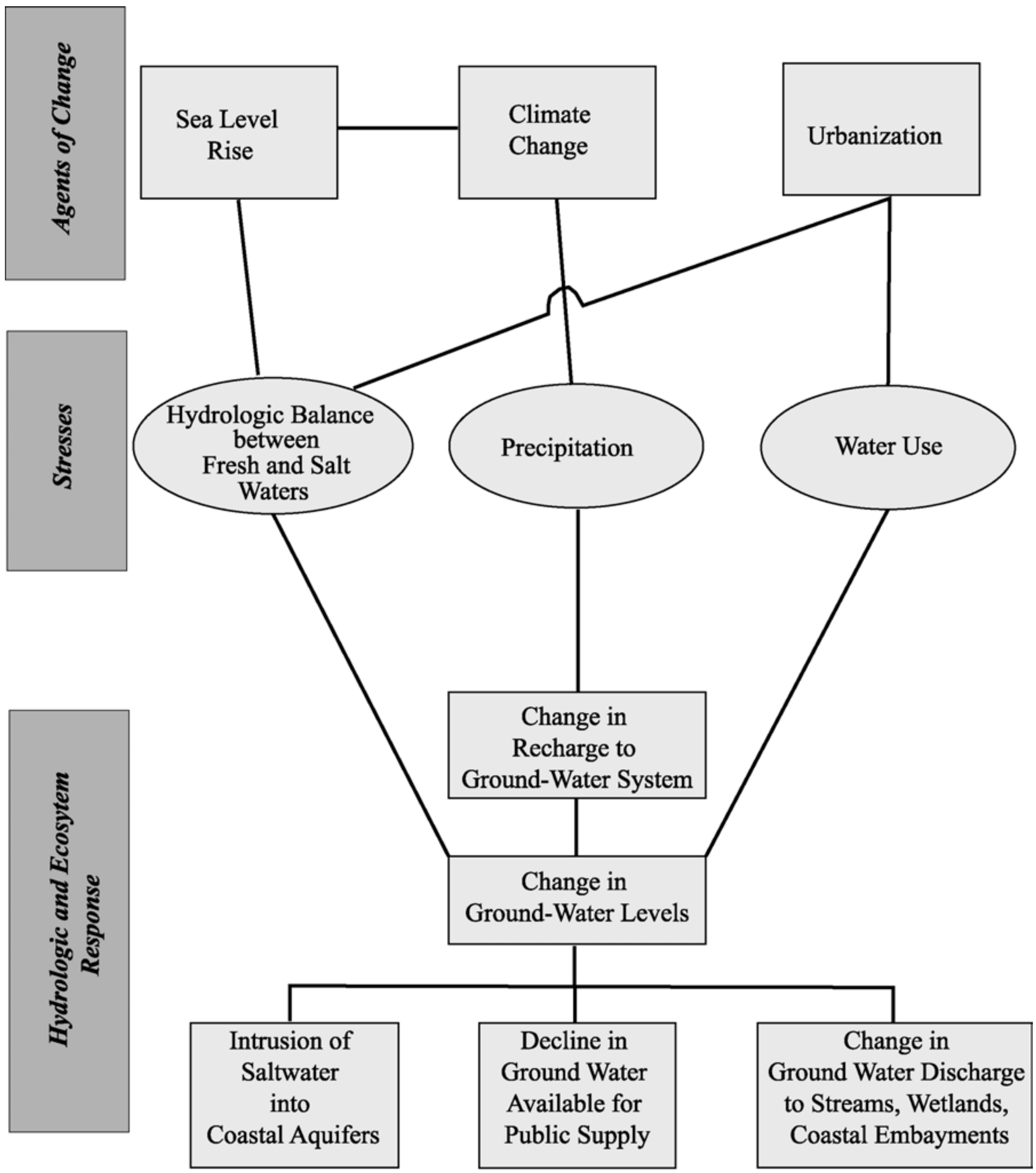


Figure 2. An example of how agents of hydrologic change can stress the hydrologic system at the Cape Cod National Seashore and cause a variety of ecosystem responses.

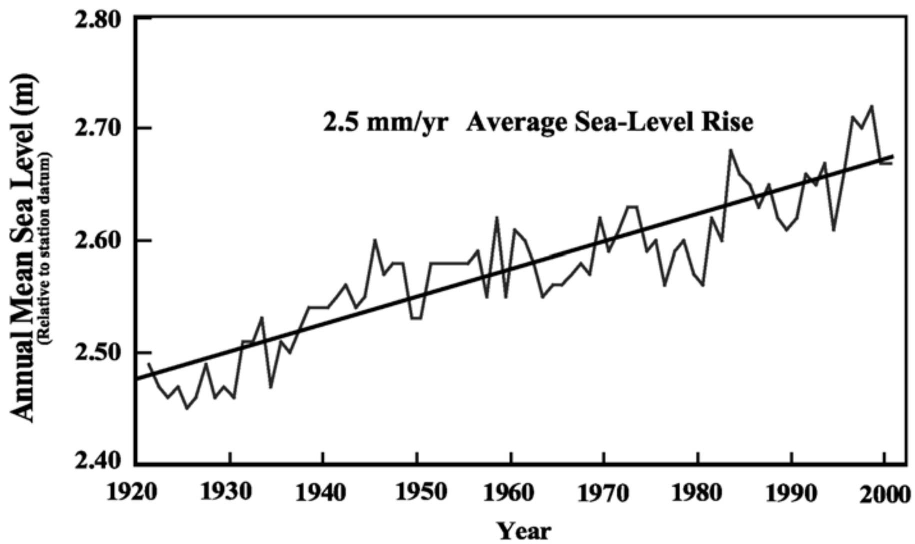


Figure 3. Annual mean sea-level rise at the Boston, Massachusetts, tide gage (National Oceanic and Atmospheric Administration, 2001).

Finally, it can be inferred that streams and wetland ecosystems on Cape Cod are similarly affected by declines in ground-water levels, because of the close interaction between ground water, streams, and wetland systems on the Cape (LeBlanc and others, 1986; Sobczak and Cambareri, 1995; Masterson and others, 1998). Some of the specific monitoring questions related to the effects of climate change on the hydrologic system are the following:

1. What are the long-term trends and periodicities in ground-water levels and how are they related to available climatic records?

2. Are ground-water, streamflow, and climatic data correlated for their short period of common record on Cape Cod, and what can be inferred regarding likely ecosystem impacts of future droughts?

3. What would be the combined effects of projected sea-level rise and drought-induced recharge decline on public water supplies?

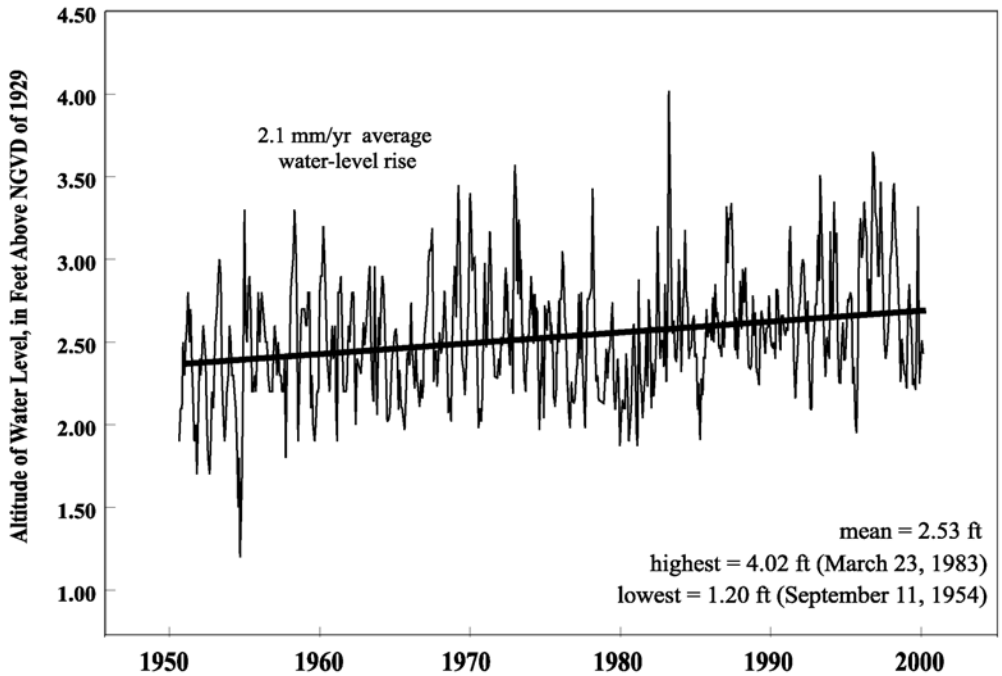


Figure 4. Long-term hydrograph of water levels in observation well TSW 1-0068 near the coast and near a water-supply well in Truro, Massachusetts.

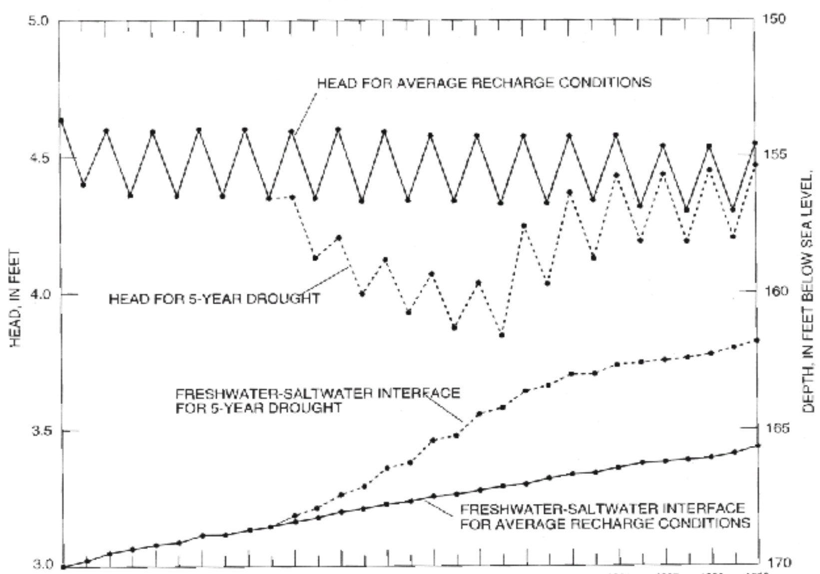


Figure 5. Model-calculated water-table altitude and position of the freshwater saltwater interface at observation well TSW 89 for average conditions and for simulation of a 5-year drought and 1989 pumping rates, Cape Cod, Massachusetts.
[Masterson and Barlow, 1996]

Urbanization
Urbanization can affect the water balance of a coastal aquifer in several ways, with associated impacts upon human water supplies and coastal ecosystems. (Urbanization can also have large impacts upon ground- and surface-water quality, which will be addressed in other protocol documents). First, increased pumping for public-water supply or irrigation can alter the dynamic balance between fresh and salt water at depth in the aquifer. This pumping can lead to shifts in the position of the interface between fresh and salt waters and possibly cause salt-water intrusion into pumping wells (Barlow, 2000; Lacombe and Carleton, 1992; Spechler, 1994; Lusczynski and Swarzenski, 1966). Second, urbanization can result in the reduction of aquifer recharge rates (and affect the interface position) by increasing the fraction of impervious surface on the landscape that generates direct surface-water runoff to coastal water bodies. Finally, urbanization can lead to exports or imports of water between adjacent flow cells in an aquifer system; these exchanges in turn affect the water balance of both cells. Such changes in the water balance not only affect the interface between salt and fresh water at depth in the aquifer, but also have the potential to directly affect pond levels, wetland levels, streamflow, and the salinity regime of tidal creek systems. Specific monitoring questions that need to be addressed regarding urbanization are:

1. Is there evidence that existing pumping patterns on and near the Seashore cause salt-water intrusion and could proposed pumping patterns cause intrusion?

2. Do land-use changes in the urbanizing areas of lower Cape Cod lead to changes in recharge rates (as shown by trends in ground-water levels)?

3. What are sustainable, long-term rates of ground-water export from the Pamet flow cell (fig. 1) that will not cause undue change in ground-water levels?

4. What are the local drawdown effects of ground-water pumping upon vernal ponds?

SAMPLING METHODS

Many types of sites are available in coastal systems for hydrologic monitoring. Monitoring sites can be categorized into three classes: (1) ground water, (2) ponds and wetlands, and (3) streams. An optimal hydrologic monitoring network spans the region of concern with particular sites selected on the basis of clear monitoring objectives. In general, monitoring sites designed to measure the effects of global change, such as climatically induced changes in aquifer water levels, are best located in areas not influenced by local stresses to the system, such as public-supply wells. Local effects, such as the changes in a hydrologic system caused by ground-water development, are generally best measured on a restricted scale with a greater density of monitoring sites in areas of larger stresses. An optimal monitoring network includes all types of sites spaced appropriately over the region of concern.

Ground Water

Ground-water levels within an aquifer are determined by measurements of water levels in observation wells. Mapping of the water-table surface and construction of observation well hydrographs are the most basic methods for analyzing these data spatially and temporally, and can provide information on the direction of ground-water flow, hydraulic gradients, saturated thickness of a surficial aquifer, and spatial and temporal fluctuations in available water resources. Water-level data can assist in the interpretation of the effects of global and local agents of change, provide data for the management of water supplies, and assist with interpretations of ecological change.

Site Selection

The design of a comprehensive observation network for ground-water-level measurements requires a thorough review of existing data for the region of concern. This includes a review of existing water-table maps, well networks, water-supply studies, and published and unpublished reports. These data (modified from Dalton and others, 1991) should be reviewed to identify:

- Thickness and characteristics of saturated zones
- Depth to the water table
- Probable ground-water-flow directions
- Presence of vertical gradients
- Hydrologic features and human stresses which may cause ground-water levels to fluctuate, such as water-supply pumping, fluctuating river stages, and tidal influence
- Probable frequency of fluctuations in levels
- Observation wells that are available for use
- Regions that lack previous water-table definition

The site-selection criteria below for ground-water-level monitoring have been collected from various USGS monitoring programs with different network objectives (U.S. Geological Survey, 1980; Lapham and others, 1995, 1996; Taylor and Alley, 2001). General site-selection procedures and criteria have been tabulated (tables 1 and 2), and applications at the Seashore are explained below.

Site Selection Procedure

1. Identify the monitoring objectives and the extent of the monitoring area.
2. Identify and inventory existing instrumentation, public-supply wells, observation wells, and existing networks in area of interest.
3. Select sites based on minimum recommended criteria as stated in table 1. Note that the number of sampling sites depends in part upon the amount of time budgeted per sampling round. Each monitoring field trip should be accomplished as a single “snapshot” event with no precipitation events immediately prior to or during measurements.
4. Prior to network implementation, visit field site, do depth sounding of well, check response to aquifer, and create site map. Altitude and positional surveying should be done if necessary.
5. Map network using a geographic information system. Route of shortest travel time through the network should be noted.

Table 1. General criteria for selection of observation monitoring well sites

Criteria	***Rationale***
Well-construction information is available	Material, depth, screen specification data are critical for well use
Well has a sound connection to the aquifer	Screened zone inside the well should be representative of the aquifer outside the casing
Hydrologic unit of well screen is known	Well operation is dependent on the geologic conditions at the screen
Well site has long-term accessibility	Multiple site visits over many years will be necessary with minimal interruption to the network
Screen is positioned near (within 20 feet of the lowest recorded water level) water table for measuring variations due to climatic changes	Screen position must provide the unconfined static water level
The monitoring well is not susceptible to going dry	Well must be operational under all hydrologic extremes of the region
In order to represent a large hydrologic area; the well occupies an optimized placement in the aquifer	With a limited number of sites possible, each site must represent a large area in the network
A detailed lithologic log is available for the borehole	Full lithologic logs provide vertical information at each site which can be used as the framework to build a hydrologic model

Table 2. Specific criteria used for choosing sites for monitoring wells at Cape Cod National Seashore (CACO)
[U.S. Geological Survey (1980), Lapham and others (1995), Godfrey and others (1999)]

Location	***Purpose***	***CACO example***	***Monitoring Category***
Wells located at points of inflow to the aquifer	Monitors changes in levels at the thickest part of the aquifer. Sea level effects are constant and minimal	Top of ground-water lenses Example: new well installed in Truro (TSW 258-0135)	Climatic, long-term
In locations of anticipated hydrologic changes and developmental impacts	To monitor human-induced changes to the system	Near municipal well sites or areas receiving water from other flow cells Examples: Knowles Crossing well, Nauset Marsh area	Human-induced, long-term
In locations of ground-water discharge	To monitor hydrologic changes at ground-water receivers	Near kettle ponds, between flow cells, on stream shores Example: Inflow sides of all of the kettle ponds represent ground-water discharge areas	Climatic and human-induced, long-term
At locations where head definition is insufficient	To provide regional analysis of the aquifer and to define the water-table configuration	Lombard Hollow was a large area where water table was ill-defined due to limited access. Example: New well installed TSW 257-0034	Regional, climatic, long-term
At existing sites where long-term records (longer than 25 years) are available	Allows for continued analysis of long-term trends in the aquifer	11 observation wells on Lower Cape area that are measured bi-monthly by the Cape Cod Commission	Long-term, climatic and human-induced

For the Seashore network, 32 wells compose the selected observation well network. Of that network, 11 are measured by the CCC as part of a long-term (longer than 25 years) index-well network (fig. 6). Three of the wells were installed during development of this protocol to augment the existing well sites. The remaining “protocol” wells were recovered from various USGS, NPS, town and environmental-consultant investigations. The final selected observation well network and pertinent construction information for each of the wells is given in table 3.

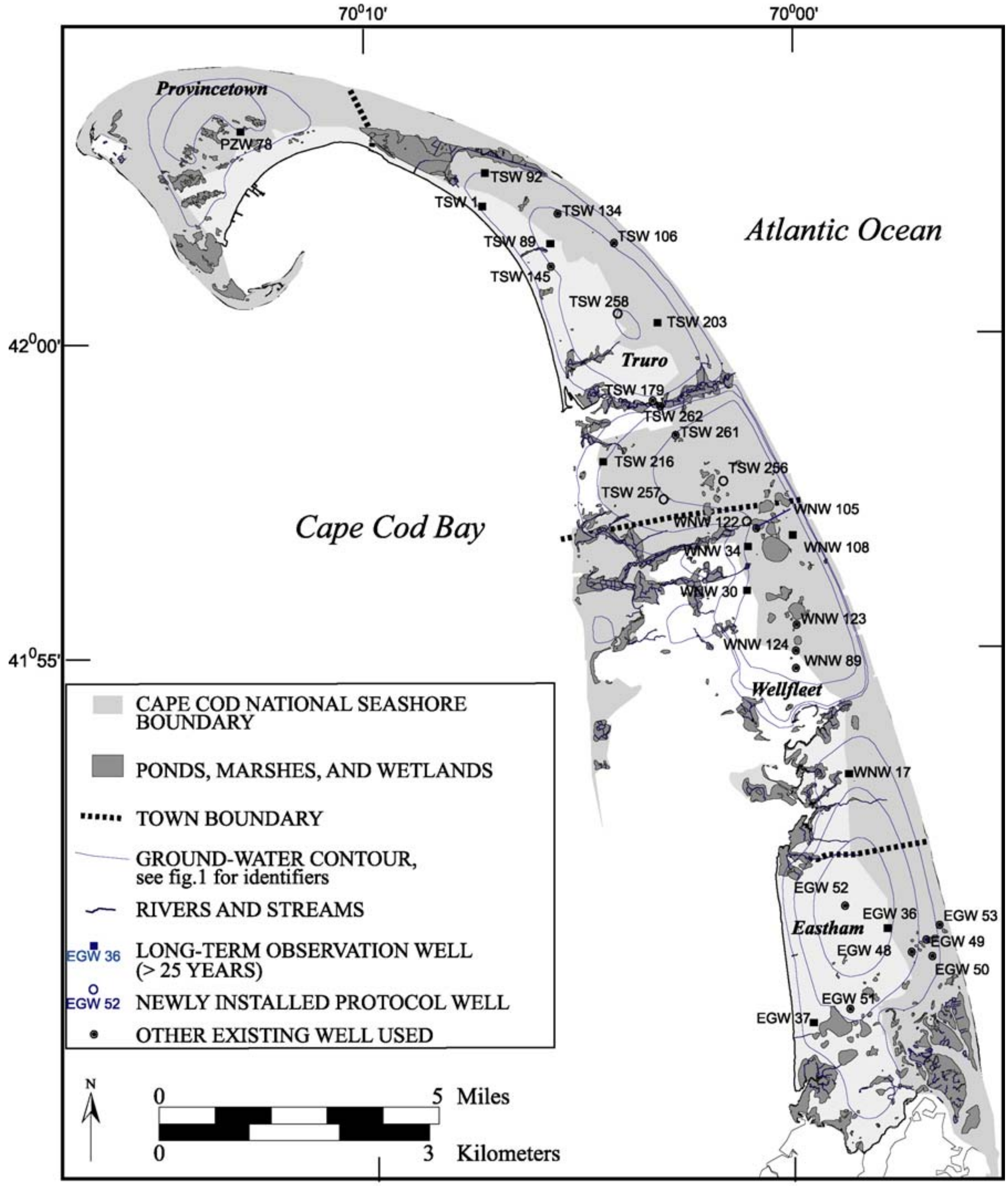


Figure 6. Selected long-term observation-well network for monthly water-level monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore.

Table 3. Final well network selected for long-term hydrologic monitoring at Cape Cod National Seashore

(State plane coordinates are NAD83 in meters; Altitudes in feet above or (-) below NGVD 29; Long-term, Cape Cod Commission long-term network; Protocol, existing wells added to network; New Protocol, newly installed wells. The number following the dash in each station name reports the approximate depth of the well. This depth identifier is not used in fig. 6 and in text)

Station Name	Town	Flow Cell	Classification	Easting (m)	Northing (m)	Longitude (° ' ")	Latitude (° ' ")	Altitude of Land Surface (ft)	Stick-Up From Land Surface (ft)	Top of Casing Altitude (ft)	Depth to Bottom of Screen Below Land Surface (ft)	Altitude of Bottom of Screen (ft)	Diameter of Well Casing (in)	Length of Screen (ft)
EGW 36-0062	Eastham	Nauset	Long-term	326996.910	847133.103	41 51 25	69 58 15	55.13	0.00	55.13	62.20	-7.07	1.25	2
EGW 37-0027	Eastham	Nauset	Long-term	324895.753	843331.234	41 49 59	69 59 49	26.80	0.00	26.80	27.20	-0.40	1.25	2
EGW 48-0035	Eastham	Nauset	Protocol	327665.627	847145.134	41 51 03	69 57 46	18.66	0.50	19.16	35.00	-16.34	0.75	2
EGW 49-0050	Eastham	Nauset	Protocol	328103.752	847153.051	41 51 14	69 57 27	12.99	0.50	13.49	50.00	-37.01	0.75	2
EGW 50-0050	Eastham	Nauset	Protocol	328380.462	847158.065	41 51 07	69 57 15	51.01	0.50	51.51	50.00	1.01	0.75	2
EGW 51-0043	Eastham	Nauset	Protocol	325877.424	845230.858	41 50 02	69 59 05	23.86	0.00	23.86	45.00	-21.14	2.00	10
EGW 52-0046	Eastham	Nauset	Protocol	325797.827	847111.687	41 51 48	69 59 07	50.97	0.00	50.97	46.00	4.97	2.00	10
EGW 53-0015	Eastham	Nauset	Protocol	328495.758	847160.158	41 51 28	69 57 10	11.81	1.00	12.81	15.00	-3.19	0.75	5
PZW 78-0040	Provincetown	Pilgrim	Long-term	308506.955	867560.545	42 03 55	70 11 23	14.99	2.70	17.69	40.00	-25.01	2.50	5
TSW 1-0068	Truro	Pamet	Long-term	315504.461	865789.306	42 02 39	70 06 20	13.30	3.50	16.80	68.40	-55.10	1.25	10
TSW 89-0028	Truro	Pamet	Protocol	317367.325	865820.023	42 02 06	70 04 59	16.63	1.70	18.33	27.70	-11.07	1.25	5
TSW 92-0064	Truro	Pamet	Long-term	315496.653	867671.438	42 03 13	70 06 19	59.10	3.40	62.50	64.30	-5.20	6.00	5
TSW 106-0090	Truro	Pamet	Protocol	319184.184	865850.455	42 02 06	70 03 40	71.40	1.10	72.50	90.10	-18.70	6.00	7
TSW 134-0053	Truro	Pamet	Protocol	317666.302	865824.999	42 02 33	70 04 46	52.98	1.55	54.53	53.00	-0.02	0.75	5
TSW 145-0012	Truro	Pamet	Protocol	317398.621	863938.280	42 01 45	70 04 59	6.35	2.75	9.10	12.20	-5.85	0.50	5
TSW 179-0010	Truro	Pamet	Protocol	320260.727	862073.302	41 59 40	70 02 56	9.17	0.80	9.97	9.70	-0.53	0.50	5
TSW 203-0035	Truro	Pamet	Long-term	320444.284	862107.285	42 00 51	70 02 48	26.32	2.10	28.42	35.40	-9.08	1.25	3
TSW 216-0108	Truro	Chequesset	Long-term	318842.741	860167.070	41 58 43	70 03 59	103.13	1.00	104.13	108.00	-4.87	1.25	2
TSW 256-0061	Truro	Chequesset	New Protocol	328118.386	860329.183	41 58 22	69 57 16	58.76	1.50	57.51	60.71	-1.95	2.00	2
TSW 257-0034	Truro	Chequesset	New Protocol	320592.005	860196.704	41 58 08	70 02 43	25.12	1.63	26.75	34.55	-9.43	2.00	2
TSW 258-0135	Truro	Pamet	New Protocol	307069.524	863774.153	42 01 08	70 12 28	129.98	1.50	131.48	135.45	-5.47	2.00	2
TSW 261-0053	Truro	Chequesset	Protocol	320439.965	858311.871	41 57 05	70 02 51	39.20	2.00	41.20	53.00	-13.80	2.00	5
TSW 262-0010	Truro	Chequesset	Protocol	320513.842	862077.615	41 59 33	70 02 45	4.95	1.09	6.04	9.57	-4.62	2.00	5
WNW 17-0043	Wellfleet	Nauset	Long-term	326053.555	850880.735	41 53 53	69 58 53	19.10	1.13	20.23	42.50	-23.40	2.50	5
WNW 30-0083	Wellfleet	Chequesset	Long-term	322682.823	856468.196	41 56 38	70 01 15	15.77	1.70	17.47	83.00	-67.23	2.50	10
WNW 34-0055	Wellfleet	Chequesset	Long-term	322995.480	858355.876	41 57 22	70 01 00	15.71	1.65	17.36	55.00	-39.29	2.50	10
WNW 89-0026	Wellfleet	Chequesset	Protocol	324397.047	854615.899	41 55 28	70 00 02	8.00	3.00	11.00	26.00	-18.00	2.00	4
WNW 105-0031	Wellfleet	Chequesset	Protocol	323271.751	858360.689	41 57 38	70 00 48	28.34	0.50	28.84	30 .80	-1.96	2.00	3
WNW 108-0037	Wellfleet	Chequesset	Long-term	324284.743	858378.427	41 57 32	70 00 04	38.84	1.00	39.84	36.70	2.14	2.00	3
WNW 122-0015	Wellfleet	Chequesset	Protocol	322995.480	858355.876	41 57 47	70 01 00	9.91	0.50	10.41	14.50	-4.59	0.75	10
WNW 123-0042	Wellfleet	Chequesset	Protocol	324386.946	856497.972	41 56 09	70 00 01	40.79	2.00	42.79	42.00	-1.21	2.00	10
WNW 124-0068	Wellfleet	Chequesset	Protocol	324374.012	854615.494	41 55 45	70 00 03	65.07	2.50	67.57	68.00	-2.93	2.00	10

Ground-Water Monitoring Wells

Ground-water levels can be measured through a variety of methods. The use of observation wells and piezometers, and, at times, direct surface-water measurements are acceptable means for obtaining measurements of ground-water levels. Most monitoring programs involve the use of observation wells. Several methods are available to install observation wells (table 4). Wells typically are designed to accommodate water-level readings as well as water-quality sampling. Piezometers are generally less than 1 in. in diameter and are traditionally used in geotechnical engineering applications, such as head measurements in dams and embankments (Dalton and others, 1991). Of the 32 wells in the network, only one was a piezometer (well WNW 122-0015), newly installed to the network. The piezometer was chosen for use at this site because a large drilling rig could not access this location. On the basis of the site-selection process it was determined that three new 2-in-diameter monitoring wells would be installed with a hollow-stem-auger drilling rig (fig. 7) and included in the network of 32 wells. Details on installation of these wells are included in Part II of this document (Ground-Water-Level Monitoring).

Water-level measurements can be made by means of a variety of methods. One traditional method is to apply chalk to a steel measuring tape (wetted-tape method), lower the tape into the well until the end audibly hits the water, hold the tape at the established measuring point (typically the top of the well casing), retrieve the measuring tape, and observe the highest watermark (Stallman, 1971, USGS, 1980). The measuring point should be established as permanently as possible, clearly defined, and easily located (USGS, 1980). The most common method of water-level measurement presently used is the electric-tape method (fig. 8). The water level is determined while the tape is hanging in the well casing. When the probe at the end of the tape contacts the water surface in the well, an electrical circuit is completed through two electrodes in the probe head, causing an audible tone and visible indicator light at the land surface (USGS, 1980, Sander, 1984).

Table 4. Summary of well-construction methods
(Modified from Lapham and others, 1996)

Well Construction Method	Drilling fluid	Casing advance possible	Geologic materials (u, unconsolidated; R, consolidated; S, some restrictions apply)	Borehole depth (in ft)[1]	Borehole diamter[2] (common range of sizes, in in.)	Well completion with filter pack and annular seal possible	Geologic samples obtainable from cuttings	Core samples possible
Hollow-stem power auger	None	Yes	U (slightly indurated)	Less than 150	6 to 18	Yes	Yes	Yes
Solid-stem power auger	None	No	U (slightly indurated)	Less than 150	2 to 10	Can be difficult	Yes	Yes
Power bucket auger	None	No[3]	U (slightly indurated)	Less than 150[4]	18 to 48	Can be difficult	Yes	Yes
Hand auger (with/without Power)	None	No[3]	U	Less than 70[4]	2 to 6	Can be difficult	Yes	Yes
Direct rotary with water-based fluid	Water, mud	Yes	U,R,(s)	More than 1,000	2 to 36	Yes	Yes	Yes
Wireline rotary	Water, air, foam	Yes	U,R	More than 1,000	3 to 6	Yes	Yes	Yes
Reverse rotary: with water-based fluid; with air assistance	Water, mud, air, foam	Yes	U,R,(s)	Less than 2,000	12 to 36	Yes	Yes	Yes
Air rotary: Direct rotary air and down-the-hole air hammer; with casing driver[5]	Water, air, foam	Yes	U,R	Less than 2,000	4 to 16	Yes	No[6]	Yes
Cable tool	Water	Yes	U,R	Approx. 500	6 to 8	Yes	Yes	Yes
Jet wash and jet percussion[7]	Water	No	U	Less than 50	2 to 4	Yes	Yes	Yes
Direct push[8]	None	No	U	Less than 100[8]	0.5 to 4	No	Yes	Yes
Vibration rig	None, water, air	Yes	U,R	Approx. 500	4 to 12[2]	Yes	Yes	Yes

[1]Depths can be greater than shown, depending on site conditions and equipment used (for example, large, high-torque auger rigs can reach depths exceeding 300 ft under favorable site conditions).

[2]Borehole diameters achievable can differ, and can be larger than indicated for some methods, depending on site condition, equipment used, and the application intended. For vibration drilling, the optimum diameter is 8 in. or less; with diameter of 10 in. or greater, borehole depth is limited to approximately 100 ft.

[3]Casing (culvert for bucket auger) advance is not routine but possible if needed for special applications.

[4]Above water table only. Below water table, borehole must be kept full of drilling fluid.

[5]Casing-driver systems are used in combination with rotary rock bits or down-the-hole hammers for penetrating consolidated and difficult unconsolidated (cobbles and boulders) materials; penetration depth usually is limited to approximately 300 ft. Wells can be completed through the advanced casing and cores and cuttings are collected.

[6]Coring is possible in combination with additional equipment and methods.

[7]Jet wash/jet percussion methods are not recommended for water-quality monitoring wells.

[8]Some direct-push systems allow for backfilling and sealing the well.

Figure 7. Rotary drilling rig (CME-75) with 6-in-OD hollow-stem augers used to install 2-in-diameter observation wells.

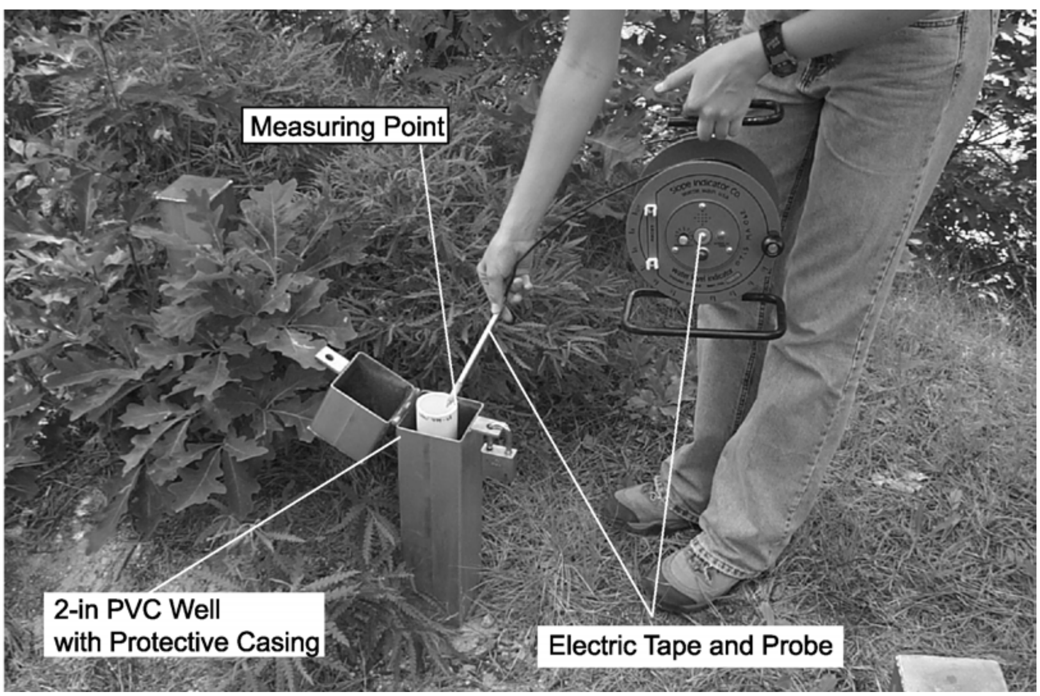


Figure 8. Hydrologic technician measuring a water level in an observation well. Protective casing, 2-in. PVC well, locking cap, measuring point, and electric measuring tape shown.

Sampling Program

A comprehensive program to monitor ground-water-levels requires consideration of the spatial distribution of the wells to be used and the frequency that these wells will be measured. At CACO, data was evaluated over a one-year period to optimize these considerations.

Spatial distribution

Water-level rounds, or snapshots, provide a concurrent view of the water-table surface that can be used, for example, to analyze long-term trends and changes in flow directions, and to provide calibration data for ground-water models. Each snapshot should consistently include the same well set. The well set should be well distributed over the complete monitoring area. Wells at high points, intermediate points, and low points in the flow system, for each flow cell, should be represented in the network. Examples of selected locations of wells in the network (fig. 6) include areas at the tops of water-table mounds (TSW 258), at intermediate points in the flow cell (TSW 89), near discharge areas such as streams and kettle ponds (TSW 179), and areas near municipal water-supply wells (TSW 1).

Observation-well data collected over a one-year period is shown in table 5. Water-table altitudes in the protocol area ranged from a maximum of 16.06 ft above sea level (EGW 52 in the Nauset flow cell), to a minimum of 2.21 ft above sea level (TSW 1 in the Pamet flow cell). The data show substantial changes in elevation of the water table over a very short distance within the same flow cell. Typical monthly average changes by location ranged from 0.13 to 0.20 ft in the Nauset flow cell, 0.14 to 0.16 ft in the Chequesset flow cell, and 0.19 to 0.25 ft in the Pamet flow cell (table 6). Changes in each flow cell, with the exception of the Pamet cell, were largest in the upper (top) portions of the flow cell and smallest in the lower portions. The largest changes in the Pamet flow cell were at TSW 1 due to pumping of nearby water-supply wells. This pattern of changes is consistent with previous observations that ground-water levels vary the most at the thickest part of the aquifer, where sea-level effects are constant and minimal. At lower elevations, sea level dampens changes in fresh-water levels.

Table 5. Observed monthly water-table altitudes for the long-term Cape Cod National Seashore network, February 23, 1999 - January 24, 2000
(Altitudes in feet above or (-) below NGVD 29; ----, site not measured or not yet installed)

Station Name	Top of casing elevation (feet above NGVD 29)	Water-level altitudes, in feet above NGVD 29											
		2/23/1999	3/25/1999	4/13/1999	5/21/1999	6/21/1999	7/21/1999	8/24/1999	9/23/1999	10/21/1999	11/23/1999	12/22/1999	1/24/2000
EGW 36-0062	55.13	12.26	12.48	12.72	12.68	12.47	12.13	11.85	11.58	11.41	11.27	11.13	10.99
EGW 37-0027	26.80	7.74	8.59	8.93	8.84	8.22	7.82	7.32	7.17	7.09	7.49	7.69	7.64
EGW 48-0035	19.16	---	10.11	10.36	10.03	9.87	9.34	9.00	8.72	8.58	8.55	8.60	8.63
EGW 49-0050	13.49	---	8.18	8.11	7.89	7.70	7.30	7.18	7.19	7.08	7.01	7.06	7.07
EGW 50-0050	51.51	---	6.09	6.22	5.96	5.78	5.60	5.54	5.73	5.39	5.38	5.37	5.40
EGW 51-0043	23.86	---	9.51	9.39	8.92	8.57	8.07	8.02	7.98	8.27	8.28	8.58	8.68
EGW 52-0046	50.97	15.99	15.48	15.76	16.06	15.89	15.28	15.00	15.54	15.11	14.75	14.60	14.39
EGW 53-0015	12.81	---	---	5.40	5.19	5.16	4.72	4.68	4.76	4.73	4.65	4.68	4.90
PZW 78-0040	17.69	---	5.69	5.59	5.23	4.80	4.23	3.87	3.71	4.08	4.27	4.48	4.51
TSW 1-0068	16.80	2.70	2.85	2.62	2.58	2.24	2.28	2.21	2.74	3.32	3.25	2.74	2.51
TSW 89-0028	16.88	4.65	5.21	5.16	4.87	4.60	4.37	4.39	4.35	4.42	4.50	4.52	4.63
TSW 92-0064	62.50	3.47	3.59	3.57	3.37	3.14	3.04	3.05	3.04	3.07	3.29	3.16	3.30
TSW 106-0090	72.50	---	---	---	3.66	3.29	2.89	3.17	3.38	3.22	3.35	3.46	3.59
TSW 134-0053	54.53	---	---	5.55	---	5.12	4.51	4.42	4.41	4.47	4.50	4.54	4.56
TSW 145-0012	9.10	---	4.95	4.92	4.87	4.43	4.19	4.13	4.12	4.17	4.25	4.28	4.35
TSW 179-0010	9.97	---	5.03	5.23	5.05	5.05	4.78	5.03	4.61	4.54	4.48	5.09	4.96
TSW 203-0035	28.42	5.24	5.70	5.83	5.75	5.55	5.27	5.04	4.95	4.83	4.73	4.39	4.30
TSW 216-0108	104.13	4.04	4.48	4.49	4.32	4.12	3.96	3.90	3.75	3.65	3.75	3.66	3.86
TSW 256-0061	57.51	---	---	---	---	---	---	---	7.18	7.16	7.08	7.01	6.98
TSW 257-0034	26.75	---	---	---	---	---	---	---	5.13	4.97	4.86	4.79	4.68
TSW 258-0135	131.48	---	---	---	---	---	---	---	6.17	6.09	6.09	6.09	6.08
TSW 261-0053	41.20	---	---	---	---	---	---	---	---	6.05	5.96	5.87	5.62
TSW 262-0010	6.04	---	---	---	---	---	---	---	---	---	4.11	4.15	4.00
WNW 17-0043	20.23	7.33	7.81	7.97	7.88	7.59	7.31	7.01	6.78	6.78	7.03	7.06	7.08
WNW 30-0083	17.47	6.13	6.50	6.73	6.71	6.50	6.26	6.03	5.98	6.03	6.15	6.11	6.08
WNW 34-0055	17.36	7.47	7.88	8.10	8.07	7.87	7.54	7.25	6.98	6.97	7.03	7.07	7.28
WNW 89-0026	11.00	6.48	6.36	6.55	6.58	6.34	5.99	5.64	5.38	5.27	5.45	5.42	5.32
WNW 105-0031	28.84	---	---	6.54	6.34	6.07	5.91	5.79	5.80	6.17	6.20	6.37	6.48
WNW 108-0037	39.84	6.98	7.43	7.75	7.65	7.26	7.08	6.77	6.53	6.53	6.63	6.74	6.79
WNW 122-0015	10.41	---	---	6.88	6.67	6.26	6.09	5.96	5.95	6.57	6.37	6.50	6.62
WNW 123-0042	42.79	---	8.82	8.83	8.66	8.41	7.83	7.72	7.49	7.60	7.55	7.50	7.45
WNW 124-0068	67.57	---	8.31	8.44	8.38	8.17	7.91	7.60	7.32	7.25	7.29	7.23	7.24

Table 6. Range in water-table elevations in protocol wells at selected locations by flow cell

Flow Cell	Station Name	Well position in flow cell (U,I,L)	Maximum water-table elevation (in ft)	Minimum water-table elevation (in ft)	Range in elevation over 1 year (in ft)	Average monthly change in elevation over 1 year (in ft)
Nauset	EGW 52-0046	U	16.06	14.39	1.67	0.20
	EGW 48-0035	I	10.36	8.55	1.81	0.19
	EGW 53-0015	L	5.40	4.65	0.75	0.13
Chequesset	WNW 123-0042	U	8.83	7.45	1.38	0.16
	WNW 30-0083	I	6.73	5.98	0.75	0.15
	TSW 216-0108	L	4.49	3.65	0.84	0.14
Pamet	TSW 203-0035	U	5.83	4.30	1.53	0.19
	TSW 89-0028	I	5.21	4.35	0.86	0.16
	TSW 1-0068	L	3.32	2.21	1.11	0.25
Pilgrim	PZW 78-0040	U	5.69	3.71	1.98	0.28

U - Distributed spatially in the upper (top) portion of the flow cell
I - Distributed spatially in middle portion of the flow cell
L - Distributed spatially in the lower (bottom) portion of the flow cell

These observations justify the spatial frequency of the well measurements. As supported by the one-year data set, each well in a three-well cross-section across the flow cell accounts for 35-45 percent of the head loss from the top of the flow cell to the bottom. Changes in water levels as little as 0.01 ft can have significant effects on the magnitude and direction of the hydraulic gradient over small areas of analysis (McCobb and others, 1999a).

Frequency

The sampling frequency is determined by the frequency fluctuations of the water table produced by factors such as recharge, withdrawal of water from supply wells, transpiration, tidal effects, and other factors. The frequency of measurements in any monitoring program depends on the observation objectives. Figure 9 compares daily, weekly, and monthly observations for a single well, and the difference in response for three different wells with daily measurements. Well 1, measured daily, is slowly affected by long-term withdrawal, while well 2, which is not affected by pumping, shows seasonal fluctuations that are caused by natural recharge, transpiration from plants, and summer evaporation. Monthly observations in these wells would be adequate. More frequent measurements would be required for an intensive investigation for trends with responses shorter than other annual or longer-term timeframes. The three graphs representing well 3 show the level of detail acquired with increased sampling frequency (USGS, 1980). In this case, the daily measurements may be justified to capture the weekly fluctuations that occur; the weekly measurements capture only some of these fluctuations. If the longer term, seasonal fluctuations are of primary importance, then in this case, monthly measurements are adequate.

At a minimum, for long-term hydrologic monitoring, 12 monthly water-level snapshots should be made to encompass varying hydraulic conditions (such as high water in the spring, late summer low-water periods, and intermediate conditions). If possible, the monthly sampling interval should be similar so that the interval between measurements is close to 30 days. Water-level measurements should be made as close to simultaneously as possible. That is, all measurements should be made over a 1-2 day period with no hydrologic events, such as precipitation, during the measurement period.

The CACO pilot monitoring program allowed for monthly measurements of ground-water levels. One person accomplished this round over a period of 1-2 days. This sampling was done concurrently with the monthly measurements made by the CCC. Measurements by the CCC have been included in the data collection. Justification for monthly measurements can be seen through the collected data (table 5). Typical changes in water levels in the same well over a 1-month period ranged from 0 to 0.85 ft throughout the monitoring area. The total monthly average change over the 1-year monitoring period was +0.05 ft. The protocol data revealed slight seasonal trends in all wells with the highest levels measured in the early spring when recharge rates are high and water use is low. The lowest levels were measured in the late summer and early fall when recharge rates are low and water use is high. At CACO, a monthly sampling frequency is adequate to detect seasonal trends and will be sufficient to detect long-term fluctuations related to drought or flood conditions. If monitoring questions are asked that go beyond the response of ground-water levels to seasonal and climatic trends, then an increase in sampling frequency may be warranted.

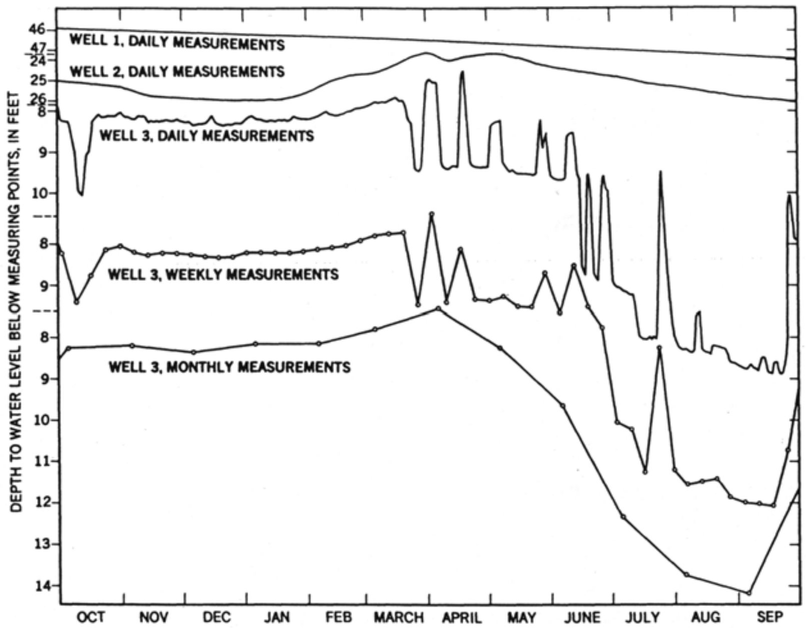


Figure 9. Graphs showing different types of water-level flucuations in three observation wells and a comparison between the graphs plotted for daily, weekly, and monthly water levels in the same observation well (U.S. Geological Survey, 1980).

Streamflow

Streamflow is essential to biota in estuarine ecosystems of the Seashore. Streamflow monitoring is needed to calibrate and verify ground-water-flow models, to detect change in response to human-induced factors, such as altered land use and ground-water withdrawals, and to provide base-line information for ecosystem health assessment. Streamflow measurements are made periodically to define or verify the stage-discharge relation and to define the time and magnitude of variations in that relation (see p. 35). On Cape Cod, a substantial percentage of water in the ground-water-flow system exits through discharge to streams and surface-water bodies. Effective site selection, correct design and construction, and regular maintenance of both continuous stream-gaging stations and partial-record stream-gaging stations can make the difference between efficient and accurate determination of flow or time-consuming, poor estimations of flow (Socolow, R.S., U.S. Geological Survey, written commun., 2000). Standard methods of stream-gaging are described by Rantz and others (1982) and in the U.S. Geological Survey's publication series Techniques of Water-Resources Investigations (Carter and Davidian, 1968; Davidian, 1964; Kilpatrick and Schneider, 1983).

Site Selection

The siting of stream-gaging stations is dependent upon the objective of the data-collection effort. Objectives can range from specific water-project monitoring, such as management of a dam, to general hydrologic monitoring in which long-term trends in regional hydrology may be addressed. Regardless of the objective, hydrologic principles must be followed to ensure that optimal information is obtained for the monetary resources spent to operate the data collection station (Rantz and others, 1982). A fully-instrumented stream-gaging station obtains a continuous record of stage and discharge at the site (Carter and Davidian, 1968). In many cases, only intermittent measurements are necessary, and non-continuous, or partial-record stations are sufficient. In either case, the siting criteria are the same.

Once the general area or reach of the stream to be measured is determined, specific site considerations can be followed. In general, selected stream-gaging sites should be far enough downstream from hydrologic features that would cause temporal non-uniformity in flow across any part of the width of the stream and far enough upstream from hydrologic features to avoid variable backwater effects (Rantz and others, 1982). Hydrologic features can include confluence of streams, spillway outlets, and areas of steep streambed-elevation changes. Hydrologic features also can create areas of increased instability in the stream channel; this instability can cause streambed sediment to mobilize and the geometry of the measurement section to change. Specific site criteria from Rantz and others (1982) are presented in table 7.

Table 7. Specific site criteria for an ideal stream-gaging station
(Modified from Rantz and others, 1982)

1. The general course of the stream is straight for about 100 m upstream and downstream from the stream-gaging site.
2. The total flow is confined to one channel at all stages, and no flow bypasses the site as subsurface flow.
3. The streambed is not subject to scour and fill and is free of aquatic growth.
4. Banks are permanent, high enough to contain floods, and free of brush.
5. A pool is present upstream from the control at extremely low stages to ensure recording a stage at extremely low flow and to avoid high velocities near stream-gaging-station intakes during periods of high flow.
6. The stream-gaging site is far enough upstream from the confluence with another stream or from tidal effects to escape from any variable influence the other stream or the tide may have on the stage at the stream-gaging location.
7. A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the stream-gaging station. (It is not necessary that the low and high flows be measured at the same stream cross section.)
8. The site is readily accessible for ease in installation and operation of the stream-gaging station.

Rarely will all criteria be satisfied in streamflow site selection. Similar to ground-water monitoring, stream-gaging-station site selection begins with the review of existing maps and information. Stream reaches that have many of the characteristics defined in table 7 should be identified. Reaches having the following pertinent characteristics should be particularly noted:

-Straight alignment
-Exposed consolidated rock as opposed to alluvium
-Banks subject to overflow
-Steep banks for confined flow
-Divided channels
-Possible variable backwater effect from a tributary or confluent stream or from a reservoir
-Potential sites for discharge measurement by current meter

Field reconnaissance is performed at potential sites to review flow patterns and uniformity, streambed stability, and site accessibility. Flow lines should be parallel and uniform in velocity throughout the section (Rantz and others, 1982).

Based on these criteria, four partial-record gaging sites along two streams were selected for pilot monitoring (fig. 10). Continuous-record stream-gaging stations were considered but determined to be infeasible due to (1) shifting, sandy-bottom stream channels and (2) insufficient resources for maintaining continuous-station infrastructure. Specific site descriptions for these sites are shown in table 8a. The four sites are as follows:

1. Pamet River – upstream side of Castle Road
2. Pamet River - upstream side of Pamet Connector Road
3. Herring River – upstream of Old Kings Highway at previous partial record station (011058793)
4. Herring River – downstream side of High Toss Road

Review of these data after one year of collection indicated that only one Pamet River site was necessary due to the proximity (less than 200 m) of the two sites. A comparison of the data collected at the two Pamet River sites showed that streamflow at the downstream (Castle Road) section was 1.2 cubic feet per second (ft^3/s) greater on average than the upstream section (Pamet Connector Rd.). This greater flow reflects a slight increase in contributing area to the stream section. The variation in the difference of flow between the two stations on a given date is due to tidal effects at both sites. The downstream side of the Pamet River at Castle Road was selected for further monitoring because the tidal effects are more predictable. The Pamet River at Connector Road has a less defined tidal cycle due to a culvert-and-flapper gate system upstream of the Castle Road site. The Herring River site at High Toss Road could not be used due to rapidly changing stage caused by tidal influences (range about 1 ft) and inadequate stream-gaging sections.

After monitoring the four sites over a one-year period and then eliminating two of the sites for the above reasons, it was decided that additional sites should be selected, so that all substantial flow-cell outflow from streamflow could be measured. Concurrent ground-water modeling showed that many potential stream-gaging locations existed and field reconnaissance identified stream-gaging sites at six additional locations. Streamflow data was collected only for one sampling period (September 26-28, 2000) for the additional sites. Table 8b and figure 11 show the final eight streamflow-gaging sites recommended for measurement at the Seashore. The quality of their data needs to be analyzed after a certain measurement period in order to establish a stage-discharge relation and determine whether future monitoring should continue at these sites.

Table 8. Stream-gaging stations selected for long-term monitoring at Cape Cod National Seashore

(a) Four sites measured during first year of monitoring program (fig. 10)

								Field Reconnaissance Data					
Station Name	**Flow Cell**	**Tidally Influenced**	**Reference Point Description**	**Site Number**	**Latitude**	**Longitude**	**Arbitrary Reference Point Elevation (ft)**	**Date**	**Time**	**Gage Height, (ft)**	**Discharge (ft^3/s)**	**Specific Conductance (uS/cm)**	**Temp °C**
Herring River at Old Kings Highway, Wellfleet, MA	Chequesset	No	Top of orange mark on upstream center of bridge wall	011058793	415734	700116	8.39	2/23/1999	1300	2.60	0.41	---	---
Herring River at High Toss Road. Wellfleet, MA	Chequesset	Yes	Top of orange mark on downstream side of metal culvert pipe	415636070032801	415663	700328	9.99	2/23/1999	1400	1.11	20.66	---	---
Pamet River at Castle Road at Truro, MA	Pamet/Chequesset	Yes	Top of orange mark on upstream corner of downstream granite block	415937070030201	415937	700302	9.99	2/23/1999	1530	2.15	8.77	---	---
Pamet River at Pamet Roads Connector, Truro, MA	Pamet/Chequesset	Yes	Top of orange mark at top edge of concrete headwall over culvert	415939070030201	415939	700302	9.99	9/23/1999	0900	1.97	6.23	---	---

(b) Final eight sites recommended for long-term monitoring program (fig. 11)

								Field Reconnaissance Data					
Station Name	**Flow Cell**	**Tidally Influenced**	**Reference Point Description**	**Site Number**	**Latitude**	**Longitude**	**Arbitrary Reference Point Elevation (ft)**	**Date**	**Time**	**Gage Height, (ft)**	**Discharge (ft^3/s)**	**Specific Conductance (uS/cm)**	**Temp °C**
Herring River at Herring Pond outlet, Wellfleet, MA	Chequesset	No	Top of aluminum I-beam at footbridge	415748070005901	415748	700059	9.99	9/26/2000	1432	8.24	0.22	148	17.6
Herring River at Old Kings Highway, Wellfleet, MA	Chequesset	No	Top of orange mark on upstream center of bridge wall	011058793	415734	700116	8.39	9/26/2000	1325	5.82	0.22	147	15.9
Herring River at Bound Brook Island Road, Wellfleet, MA	Chequesset	Yes	Top of orange mark on upstream headwall of culvert	415714070032501	415714	700325	9.99	9/27/2000	1245	7.26	4.06	210	---
Hatches Creek at West Road, Eastham, MA	Nauset	Yes	Top of orange mark at center of upstream end culvert pipe	415238069593601	415238	695936	9.99	9/27/2000	0844	9.65	0.09	189	12.7
Fresh Brook at Route 6, South Wellfleet, MA	Nauset	Yes	Top of orange mark on large rock at right upstream side culvert	415326069591601	415326	695916	9.99	9/27/2000	0945	8.80	0.79	1361	14.2
Little Pamet River at Corn Hill Road, Truro, MA	Pamet	Yes	Top of orange stake in stream bed, 20 ft. downstream headwall	415957070044201	415957	700442	9.99	9/28/2000	0832	9.87	1.48	4000	14.2
Pamet River at Castle Road at Truro, MA	Pamet/Chequesset	Yes	Top of orange mark on upstrm corner of large granite block 20 ft downstream	415937070030201	415937	700302	9.99	9/28/2000	0932	8.68	6.65	1170	13.7
Pole Dike Creek at Bound Brook Island Road, Wellfleet, MA	Chequesset	Yes	Top of orange mark on center of upstream side of culvert	415653070024001	415653	700240	9.99	9/27/2000	1201	---	---	---	---

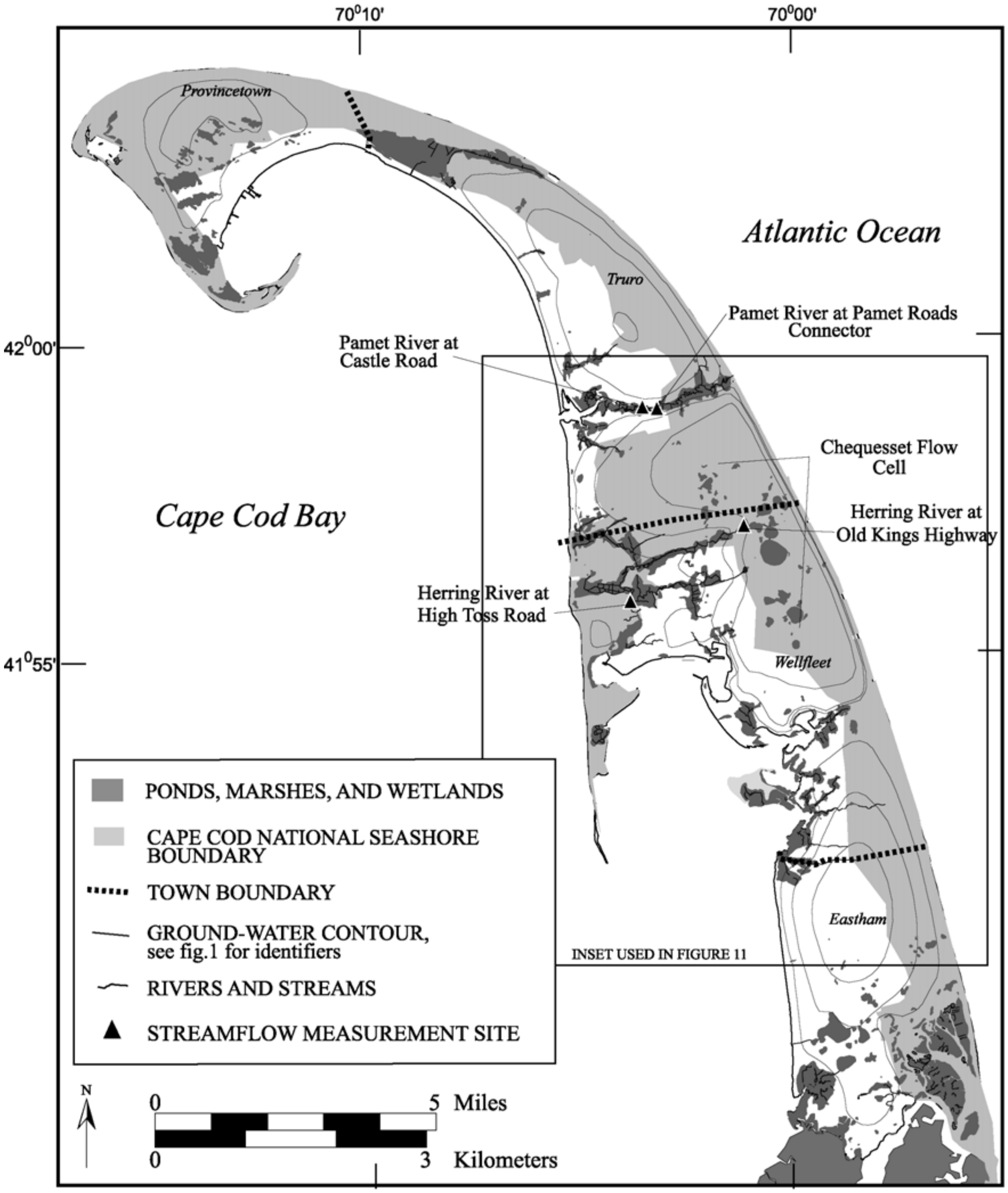


Figure 10. Selected sites for long-term monthly streamflow monitoring through the first year of monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. Final network shown on figure 11.

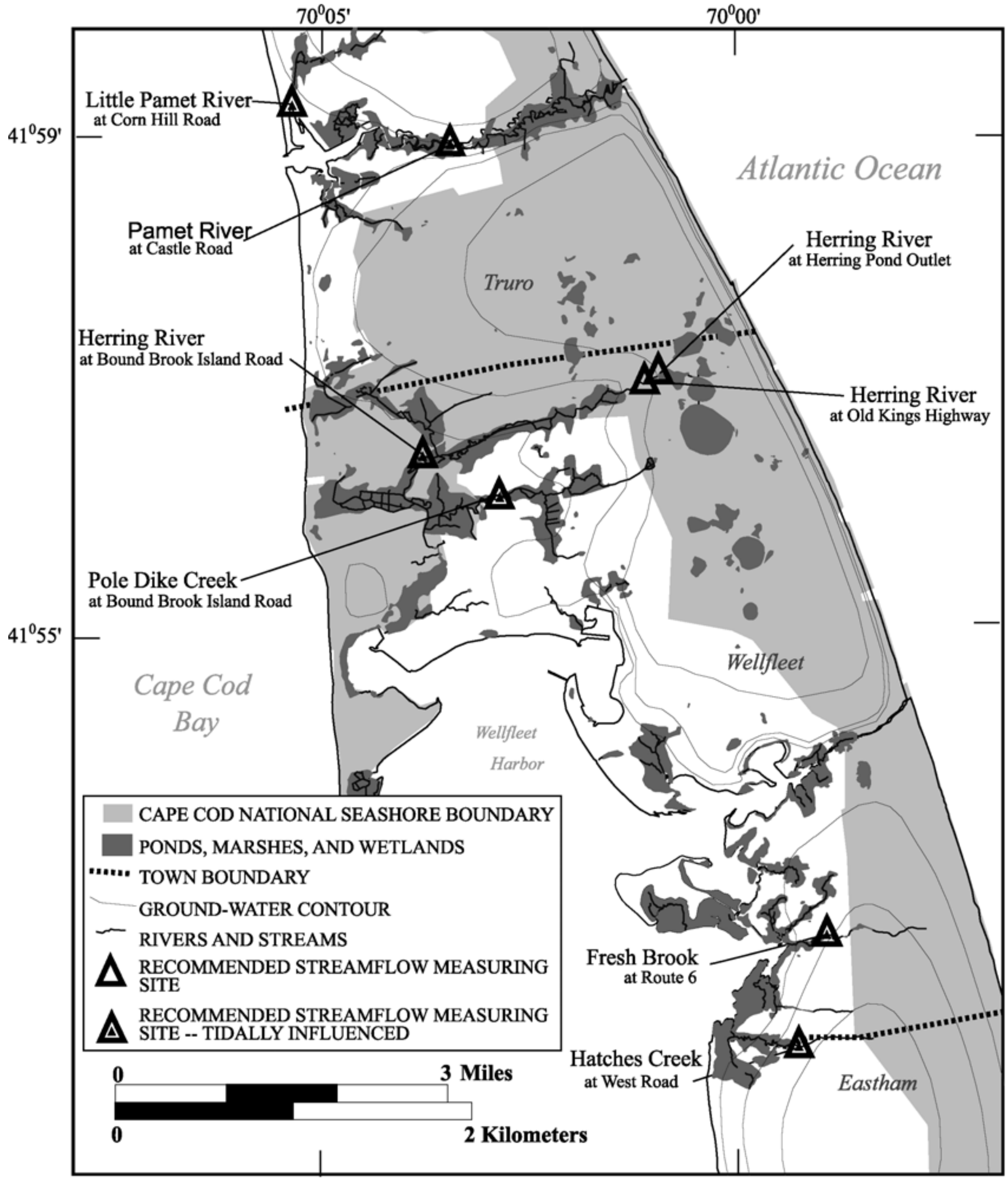


Figure 11. Recommended stream-gaging sites for long-term monthly monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program at the Cape Cod National Seashore on the basis of data review and site reconnaissance after first year of operation.

Stream-Gaging Methods

Stage

A stage measurement records the level of the water surface of the stream at a given time. River stage provides an index to which discharge measurements can be related based on a stage-discharge rating developed from simultaneous measurements of stage and discharge. Stage is easily measured. It is also useful in water-resources projects, such as planning of flood-plain use, and construction of over-water infrastructure.

Many types of instruments are available for measuring the water stage at a stream-gaging station. There are non-recording and recording stream gages (Rantz and others, 1982). In general, operation of a stream-gaging station for the purpose of determining daily discharge requires stage data at the accuracy of + or - 0.01 ft (U.S. Geological Survey, 1989). Table 9 includes various types of stage-measurement methods.

Table 9. Methods of measuring stage (recording and non-recording)

Method	*Recording/Non-Recording*
Float Sensor	Both
Bubble-Gage Sensor	Both
Staff Gage	Non-Recording
Wire-Weight Gage	Both
Electric-Tape Gage	Both
Crest-Stage Gage	Non-recording

Stage measurements in the protocol area were made by a direct measurement of the water-level surface from a reference point at an overhead bridge culvert at each station. Stage measurements for the initial four sites that were monitored for one year are reported in table 10. All aspects of stage measurements can be reviewed in the U.S. Geological Survey's Techniques of Water-Resources Investigations (TWRI) publication series entitled "Stage Measurement at Gaging Stations" (Buchanan and Somers, 1982).

Table 10. Measured streamflow for the first year of monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program National Seashore, February 23, 1999 -January 24, 2000

(Altitudes in feet above or (-) below NGVD 29; —, site not measured)

Date	011058793 Herring River at Old Kings Highway, Wellfleet, MA				415636070032801 Herring River at High Toss Road, Wellfleet, MA				415937070030201 Pamet River at Castle Road, Truro, MA				415937070030202 Pamet River at Pamet Roads Connector, Truro, MA			
	Stage (ft)	Total Area (ft^2)	Average Velocity (ft/s)	Total Discharge (ft^3/s)	Stage (ft)	Total Area (ft^2)	Average Velocity (ft/s)	Total Discharge (ft^3/s)	Stage (ft)	Total Area (ft^2)	Average Velocity (ft/s)	Total Discharge (ft^3/s)	Stage (ft)	Total Area (ft^2)	Average Velocity (ft/s)	Total Discharge (ft^3/s)
02-23-1999	5.79	1.55	0.26	0.41	8.88	15.39	1.32	20.37	7.84	4.66	1.80	8.64	---	---	---	---
03-25-1999	5.99	1.91	0.87	1.67	8.13	12.56	1.38	17.42	7.94	5.15	2.18	11.47	---	---	---	---
04-13-1999	5.71	1.49	0.98	1.48	8.69	14.45	1.59	22.97	7.90	5.08	2.08	10.67	---	---	---	---
05-21-1999	6.29	1.71	0.34	0.62	8.11	12.20	1.31	16.00	7.88	4.87	2.09	10.29	---	---	---	---
06-21-1999	5.89	0.50	0.02	0.01	8.30	13.68	0.67	9.21	7.56	3.89	1.34	5.43	---	---	---	---
07-21-1999	5.96	1.24	0.00	0.00	7.92	16.37	0.28	4.62	7.59	3.96	1.23	4.97	---	---	---	---
08-24-1999	5.89	0.93	0.00	0.00	8.48	13.51	0.65	8.69	7.72	4.17	1.45	6.22	---	---	---	---
09-23-1999	5.83	0.62	0.00	0.00	9.08	12.88	0.73	9.34	8.01	4.97	0.89	4.50	8.02	8.94	0.70	6.23
10-21-1999	6.29	0.71	1.02	0.77	8.53	13.55	1.38	18.65	7.81	5.40	2.19	11.99	7.91	9.46	0.87	8.16
11-23-1999	6.29	1.36	0.00	0.00	8.60	14.12	1.16	16.46	7.71	4.45	1.57	7.06	7.80	8.47	0.64	5.38
12-22-1999	6.40	1.55	0.00	0.00	8.80	13.82	1.36	18.83	7.65	4.38	1.53	6.86	7.83	8.56	0.65	5.56
01-24-2000	6.30	1.24	0.00	0.00	8.35	13.01	0.91	11.91	7.99	5.78	0.91	5.28	7.93	9.12	0.48	4.43

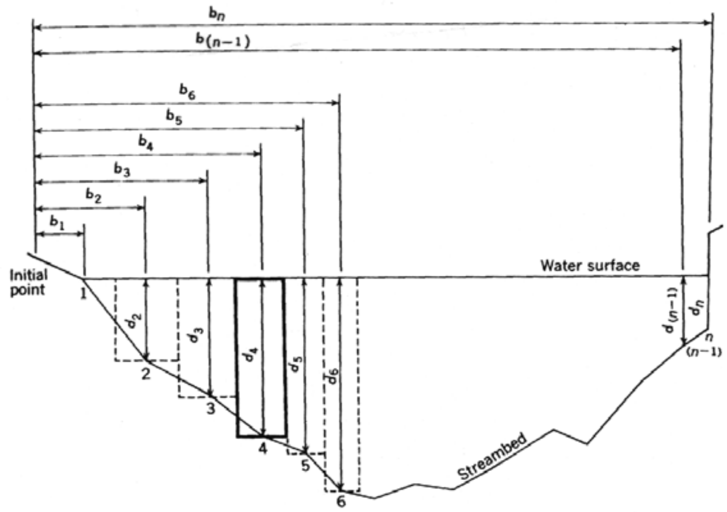
Direct Measurement of Discharge

The most common method for measuring discharge is the velocity-area method. This requires the physical measurement of cross-sectional area and the velocity of the flowing water (Wahl and others, 1995) (fig. 12). Discharge is calculated by determining the product of the area and velocity. The instrument used for measuring velocity typically consists of a bucket wheel mounted on a vertical axis that revolves when suspended in flowing water. The speed of rotation depends on the velocity of the flowing water. A fine wire called a catwhisker contacts the rotating shaft with each rotation and closes an electrical circuit, which creates a sound (click) that can be counted over a set period of time. Procedures used for current-meter measurements are described by Rantz and others (1982), Carter and Davidian (1968), and Buchanan and Somers (1969).

The cross section of a stream is divided into a number of increments based on the stream size. The size of each increment is determined by the stream depth and velocity. The goal of the incremental method is to divide the cross section into at least 25 vertical subsections with approximately equal discharges so that no more than 5 percent of the total flow occurs in one subsection. Fewer verticals can be used when stream width is very narrow (about 1-ft wide when a standard AA current meter is used and about 0.5-ft wide when the smaller pygmy meter is used) (R.S. Socolow and others, written commun., 2000). Streams at the Cape Cod National Seashore are generally narrow in their non-tidal portions. For each segment of the cross section, the stream depth and average velocity is measured. Measurements are taken at the vertical point of average velocity, which has been determined to be approximately 0.6 of the distance from the water surface to the streambed when depths are shallow (less than 1.5 ft for pygmy meter, less than 2.5 ft for the standard AA current meter). For deeper waters, the average velocity is best represented by averaging velocity readings at 0.2 and 0.8 of the distance between the water surface and the streambed.

The product of the width, depth and velocity of the section is the discharge through that subsection. The total of the subsection discharges equals the discharge of the stream (Wahl and others, 1995). Discharge is usually expressed in cubic feet per second or cubic meters per second.

Current-meter selection depends on the depth of water throughout the measurement cross section. USGS Office of Surface Water Technical Memorandum No. 85.07 provides guidance in choosing which type of meter to use for various field conditions and it consolidates information on current meters from several USGS Techniques of Water-Resources Investigations (TWRI) reports (Rantz and others, 1982; Carter and Davidian, 1968; Davidian, 1964; Kilpatrick and Schneider, 1983). Table 11 shows the recommended depth and velocity ranges for USGS current meters. Meters should be used with caution outside these ranges. Field notes should reflect any deviations from these recommendations and the rating quality should be downgraded accordingly (U.S. Geological Survey, 1985).



EXPLANATION

1, 2, 3 .... n	Observation verticals
$b_1, b_2, b_3, \ldots b_n$	Distance, in feet or meters, from the initial point to the observation vertical
$d_1, d_2, d_3, \ldots d_n$	Depth of water, in feet or meters, at the observation vertical
Dashed lines	Boundaries of subsections; one heavily outlined is discussed in text

$$q_x = v_x \left[\frac{(b_x - b_{(x-1)})}{2} + \frac{(b_{(x+1)} - b_x)}{2}\right] d_x$$

$$= v_x \left[\frac{b_{(x+1)} - b_{(x-1)}}{2}\right] d_x \qquad (10)$$

where
- q_x = discharge through subsection x,
- v_x = mean velocity at vertical x,
- b_x = distance from initial point to vertical x,
- $b_{(x-1)}$ = distance from initial point to preceding vertical,
- $b_{(x+1)}$ = distance from initial point to next vertical, and
- d_x = depth of water at vertical x.

Figure 12. Schematic diagram of the velocity-area method for determining stream discharge (Modified from Rantz and others, 1982).

Table 11. Configuration and recommended velocity and depth ranges for United States Geological Survey current meters (U.S. Geological Survey, 1985)

Meter Type	Bucket	Contact	Velocity Range	Depth of Water Range
Price Type AA	Metal	Catwhisker	0.03 - 3.65 m/s (0.1 - 12 ft/s)	0.45 m or greater (1.5 ft or greater)
Price Pygmy	Metal	Catwhisker	0.15 – 3.65 m/s (0.5 – 12 ft/s)	0.09 – 0.45 m (0.3 – 1.5 ft)

Errors can be reduced during stream-discharge measurements through attention to procedures and the maintenance of equipment (Sauer and Meyer, 1992). The errors in discharge measurements include errors in depth associated with soft, uneven, or mobile streambeds, uncertainties in mean velocity associated with vertical-velocity distribution errors and pulsation errors, and systematic errors associated with improperly calibrated equipment or improper use of such equipment (R.S. Socolow and others, U.S. Geological Survey, written commun., 2000). Measurements should be made by different personnel to minimize such errors. Current meters should be inspected before and after each measurement and tested at the conclusion of each measurement round. Calibration of the current meter, by performing a "spin test", should be done at the beginning and end of each field trip.

Direct discharge measurements were made at CACO along the four selected stream sections (fig. 10). Water depths dictated the use of a Rickley Hydrologic-brand (model 6205) pygmy current meter with headset (fig. 13). Typical water depths at the measured streams ranged from 0 (dry) to 3.3 ft with velocities ranging from 0 to 2.8 ft/s. Stream-channel widths ranged from 0 to 4.9 ft.

Other methods are available for direct discharge measurements. They include volumetric measurements (Rantz and others, 1982) and methods involving portable weirs and flumes (Kilpatrick and Schneider, 1983).

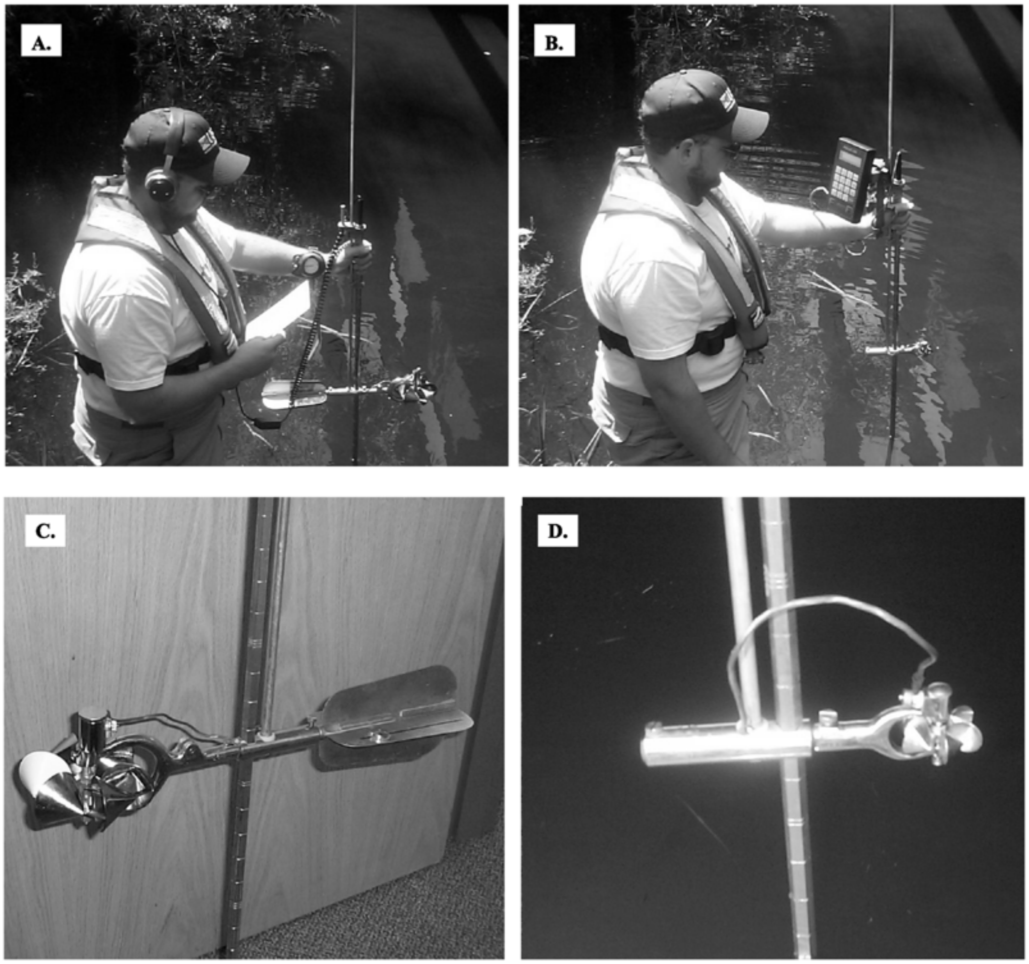


Figure 13. Streamflow-measurement equipment includes: (A) Type AA current meter with headset and stopwatch, (B) Pygmy current meter with automated digitizer, (C) Type AA current meter on a wading rod, and (D) a Pygmy current meter on a wading rod.

Sampling Program

A comprehensive program to monitor streamflow requires consideration of the spatial distribution of the stream reaches to be measured and the temporal frequency that these stations will be visited. At CACO, data was evaluated over a one-year period to optimize these considerations.

Spatial Distribution

As project objectives dictate, the goal of streamflow gaging is to measure inflow and outflow of surface water to a basin, and the flow of that stream at different water stages. Streamflow monitoring is confined to measurable stream reaches that meet site-selection criteria and, therefore, the spatial frequency of sampling is limited. On the measurable streams, sites are positioned spatially at various reaches of the stream so that sections are evenly distributed. A typical example of a well-distributed stream-station network would include the first station slightly downstream of the stream's origin (such as a pond or lake outlet). Intermediate stations would be set at various sections upstream and downstream of hydrologic features. One final station near the mouth of the stream represents the flow just before discharge out of the stream into another stream, a lake, or the ocean. This distribution provides valuable cumulative data for the determination of how each reach contributes (losing or gaining) to the total discharge of the stream.

In determining the spatial distribution, the main goal is to account for as much surface water leaving the flow system as possible. The Herring and Pamet Rivers are the major streams receiving discharge from the aquifer at the Seashore, and eventually discharging to Cape Cod Bay. The measurement sections were spatially distributed to determine changes in flow conditions on the same stream at different stream stages and reaches. This flow increase can be seen in the data from both of the original stream pairs (table 10). In the Pamet River (a gaining stream), the increase between the two stations, which are less than 650 ft apart, ranged from 0.9 to 3.8 ft^3/s. In the Herring River (a gaining stream), the increase in flow between the two stations about 4.5 mi apart ranged from 4.6 ft^3/s during summer low-flow periods to 21.5 ft^3/s during early spring high-flow periods. Substantial increases in flow over a very short stream reach may reflect the convergence of many smaller tributaries and drains; such increases suggest the need for additional measurement sites along the stream.

At Cape Cod, the spatial distribution of the partial-record stations was determined by site-selection criteria as discussed. In the final selected network (fig. 11), only one stream (Herring River) in the protocol area necessitated multiple stations (three), one at the Herring Pond outlet, one intermediate station at Old King Highway Road, and one final station at Bound Brook Island Road where tidal influences were minimal. All other streams, small in length and in discharge, had only one measurement section, each in the downstream reach of the stream. These sites were chosen so that all substantial streamflow out of each flow cell could be quantified (fig. 11). At the Herring River site at Old King Highway Road (011058793), many of the monthly measurements (6 out of 12) revealed no-flow conditions in that portion (the upper reach) of the stream, while downstream sites had significant flow. The determination of the location of measurable streamflow and contribution of the upstream pond depends on the spatial distribution of the measurement sites. For this reason, additional long-term sites have been added both upgradient (at the Herring Pond outlet) and downgradient (at Bound Brook Island Road) of the original site.

Frequency

The frequency of streamflow measurements, like spatial distribution, is determined primarily by project objectives and the detail of the data series needed for analyses. Periods of measurement should be selected to represent high, low, and average hydrologic conditions. Initially, discharge measurements are made with the frequency necessary to define the station rating (stage-discharge relation) over a wide range of stages. Measurements are then made at periodic intervals, usually monthly, to verify the rating and to define any changes in the rating caused by shifting streambed conditions (Rantz and others, 1982).

Tidal influences in coastal streams must be accounted for when selecting measurement times. Guidelines for measurement and computation of tidally affected streams, including temporal frequency of the measurements, are reviewed in Davidian (1964). At CACO, six of the eight streamflow sites selected for monitoring are affected by tides to varying degrees (fig. 11). For this reason, the six tidally influenced streams were measured about 2 hours after the predicted low tide. Field reconnaissance included observation of flow velocity and patterns through a tidal cycle with intermittent specific-conductance measurements to determine the characteristics of the outflow of the tide. All streams showed freshwater or baseflow conditions at this point in the cycle.

Monthly measurements were made at the four original stream-gaging sites to help define a station rating over a large range in stage. Much variability in the monthly data was observed (table 10). At the Herring River station (011058793), a slight increase in stage (0.20 ft) over a 1-month period resulted in a 1.26 ft^3/s increase in flow or over 300 percent. Three months later, between May and June, a significant decrease in stage (0.40 ft) resulted in a 0.61 ft^3/s decrease in flow (98 percent). As with ground water at the Seashore, streamflow changes rapidly, as a reflection of recharge to and withdrawals from the aquifer system.

Ponds, Lakes, and Seasonal Wetlands

The monitoring of surface-water-levels is an important aspect of many water-resources studies. Lake- and pond-level data provide information that can be used to: (1) calculate surface-water-body volume for water-supply and ecological studies, (2) create hydrographs that show long-term trends in hydrologic conditions, (3) determine ground-water levels in unconfined systems for water-table mapping, and (4) provide hydrologic information in areas of critical ecological importance, such as vernal pools and wetlands.

Site Selection

Reasons for site selection of a lake or pond for hydrologic monitoring can differ from providing aquifer head data in an area not defined in the ground-water-well network, to providing a reference level for a pond at the start of an ecologically sensitive stream. The surface-water body is selected for reasons of location in the flow system, size of the surface-water body, ecological importance, and proximity to urban development.

Once a water body has been identified for monitoring, the measurement-station site must be selected. An optimal site has easy access, a nearby datum for elevation surveying, low visibility to minimize tampering potential, and a solid structure to support instrumentation such as a staff gage or another type of outside gage (McCobb and others, 1999b).

Considerations for site selection of ponds and lakes in the protocol area were typical of ground-water monitoring stations. Ponds were selected in areas with poor water-table definition, areas of sensitive ecological importance such as stream headwaters, and at ponds and lakes which represent large areas in the aquifer. At the Seashore, nine kettle ponds, one wetland, one brackish lake, and one vernal pool were selected for long-term monitoring of water levels (table 12 and fig. 14). Typical ponds at the Seashore are permanently flooded glacial kettle holes that range in area from 1.2 to 109 acres and depth from 6 to 60 ft. Wetlands and intermittent vernal pools typically range in size from 15 to 100 ft. rim Lake, the only brackish lake in the region, was once a salt-water bay that has been subjected to natural and anthropogenic alterations to form a eutrophic, shallow, brackish lake of over 127 acres.

Table 12. Final siphon-gage network selected for long-term pond-level monitoring at Cape Cod National Seashore

(State plane coordinates are NAD83 in meters. Altitudes in feet above NGVD 29)

Site	Town	Flow Cell	Type	Easting (meters)	Northing (meters)	Latitude (° ' ")	Longitude (° ' ")	Altitude Top of Casing (ft above NGVD 29)	Water Level (ft below top of casing)	Water Level Date	Altitude Water Level (ft above NGVD 29)
Duck Pond	Wellfleet	Chequesset	Kettle pond	307564.257	867546.118	41 55 56	70 00 06	13.90	4.26	12/19/2000	9.64
Dyer Pond*	Wellfleet	Chequesset	Kettle pond	323603.971	856484.240	41 56 23	70 00 35	12.63	4.99	12/19/2000	7.64
Great Pond	Truro	Chequesset	Kettle pond	321890.394	858336.733	41 58 25	70 01 21	14.19	6.19	12/19/2000	8.00
Great Pond	Wellfleet	Chequesset	Kettle pond	324304.907	854614.279	41 56 26	70 00 12	12.64	4.84	12/19/2000	7.80
Gull Pond	Wellfleet	Chequesset	Kettle pond	324133.631	856493.519	41 57 25	70 00 14	12.24	5.35	12/19/2000	6.89
Herring Pond	Wellfleet	Chequesset	Kettle pond	323350.656	856479.816	41 57 43	70 00 43	11.58	5.06	12/19/2000	6.52
Long Pond*	Wellfleet	Chequesset	Kettle pond	323386.864	858362.697	41 56 36	70 00 46	14.41	6.65	12/19/2000	7.76
Ryder Pond	Truro	Chequesset	Kettle pond	321949.981	860220.008	41 57 54	70 01 48	11.99	4.82	12/19/2000	7.17
Snow Pond*	Truro	Chequesset	Kettle pond	322479.361	860229.163	41 58 09	70 01 44	11.58	3.77	12/19/2000	7.81
E-9	Eastham	Nauset	Vernal pool	327665.627	847145.134	41 51 03	69 57 46	18.76	8.31	12/19/2000	10.45
Little Bennett Pond	Provincetown	Pilgrim	Wetland	312047.803	867615.856	42 03 32	70 12 04	10.31	4.86	7/31/2000	5.45
Pilgrim Lake*	Provincetown	Pilgrim/Chequesset	Brackish lake	324054.518	858374.383	42 03 52	70 08 49	5.36	4.48	12/19/2000	0.88

*Siphon gages were installed at these sites on September 21, 1999, to supplement the network as a special initiative project of the U.S. Geological Survey Massachusetts/Rhode Island District

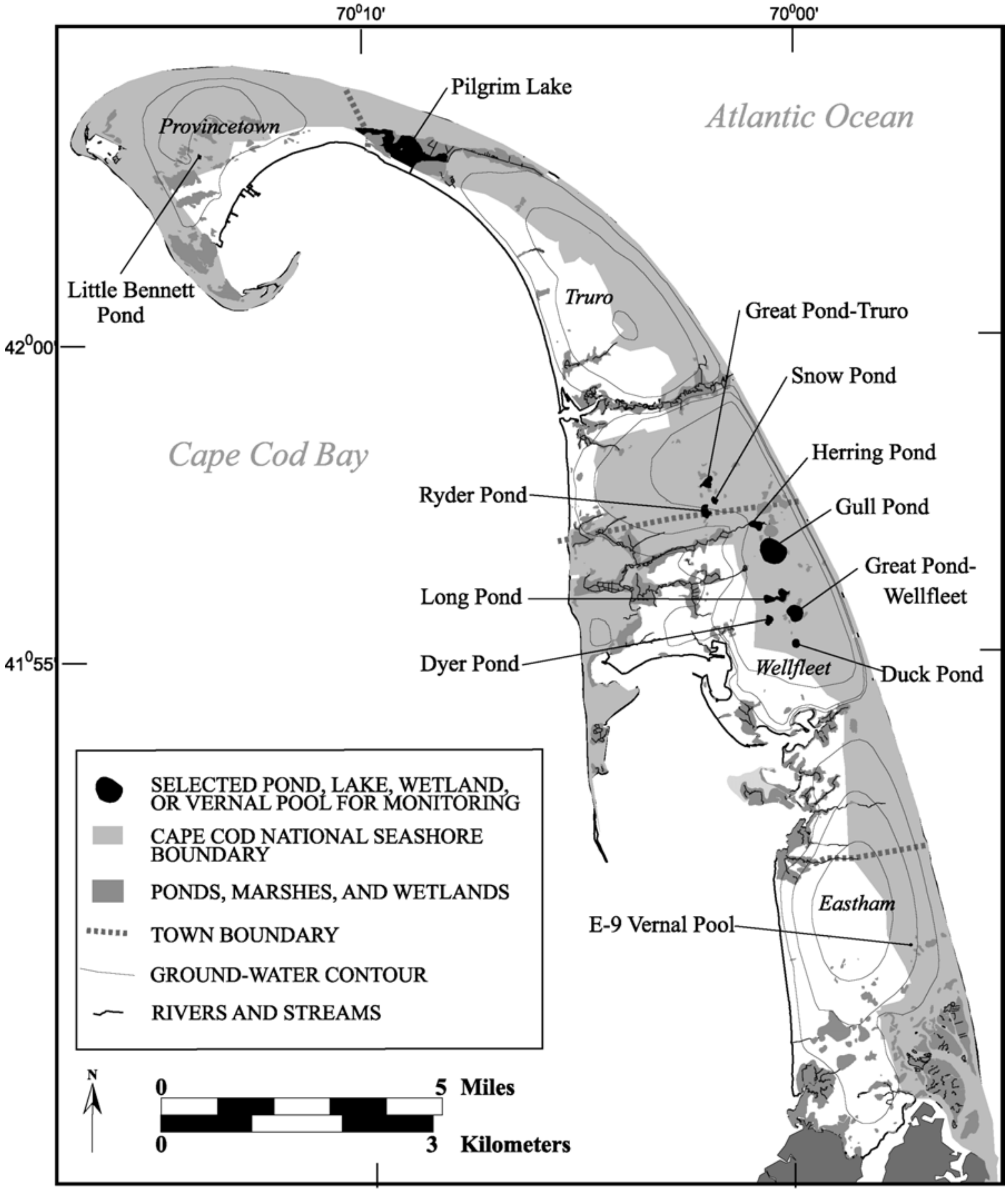


Figure 14. Selected ponds for long-term monthly water-level monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore.

Pond- and Lake- Level Monitoring Devices

The method of stage measurement is dictated by the accessibility of and structures on the surface-water body to be monitored. Pond and lake-level measurement methods are similar to stage measurements made for stream-gaging purposes. Available monitoring devices for measuring pond, lake, and wetland stages include several designs, such as graduated staff plates (staff gages), pressure transducers in the water body, floats in stilling wells (Buchanan and Somers, 1982), and a standpipe on the shoreline connected to the water body by a siphon tube (McCobb and others, 1999b).

Staff gages (fig. 15A) and various forms of graduated stakes are the most common devices for monitoring pond water level (Rantz and others, 1982). Staff gages provide a direct reading for the observer near the shoreline on the open water. Staff gages and any other vertical fixtures in the open water can become nonfunctional because of declining water levels or damage by winter ice. For this reason, all vertical gages must be surveyed and referenced to fixed/permanent datums at least semi-annually to detect gage movement and provide correction factors.

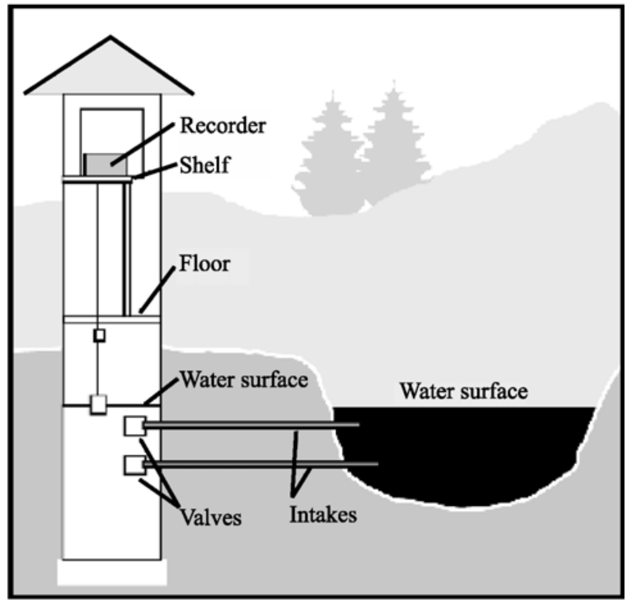
A stilling well (fig. 15B) is a simple, low-cost device that connects an onshore measuring standpipe to the water body through an intake pipe (Rantz and others, 1982). Stilling wells are practical where a vertical structure, such as a large diameter pipe, can be installed on a surface-water shoreline, and measurements can be made from the structure's reference point. Stilling wells are not practical where fluctuations in water levels are large and in areas of large shoreline movement (low shoreline slope) because of the required depth of the well. Stilling wells also require periodic cleaning of the sump and intake pipes.

Pressure-transducer devices, such as bubble gages, can provide accurate pond-stage data (Rantz and others, 1982). Pressure transducers usually have a fixed orifice tube beneath the water surface that is connected to a continuous gas source (fig. 15C). The gas source is regulated to flow evenly and a manometer device measures a change in pressure for the gas bubble to be released to the surface. Pressure transducers are expensive but provide very accurate data when the orifice tube is unobstructed by debris. The fixed end of the orifice tube requires periodic surveying and cannot be disturbed. Pressure-transducer systems allow for continuously logged measurements that can be stored for long periods of time in an onsite datalogger.

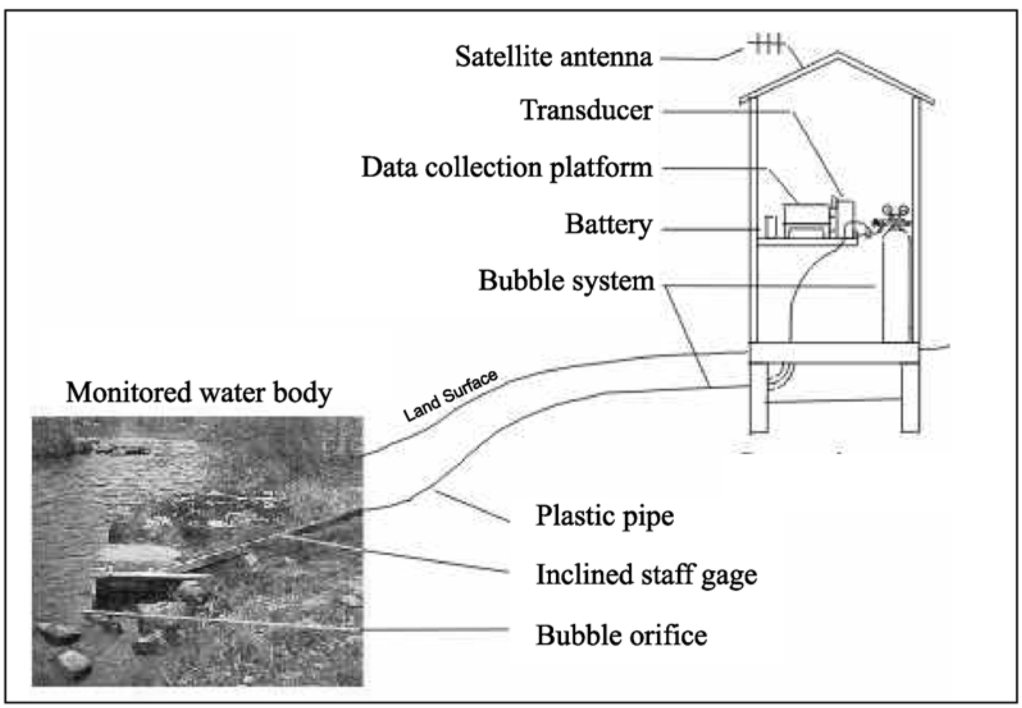
A siphon gage for the measurement of pond levels (fig. 16) was recently designed, tested, and documented (McCobb and others, 1999b). The design consists of an onshore standpipe that is connected with a flexible hose to a point in the water body below the lowest anticipated water level. After a siphon connection between the standpipe and pond is established, the water level in the standpipe equilibrates to the water-body level. The standpipe is a standard 3-in-diameter monitoring well that is sealed instead of screened and installed at an easily accessible onshore location. Measurement of the pond is as simple as making a ground-water-level measurement. The siphon gage is not affected by ice and can be monitored continuously. Maintenance of the siphon gage can include recharging the system (simply pouring enough water into the standpipe to flush out the collected air) or resetting the siphon tube in the pond bottom as water levels recede or if the tube has been disturbed. The siphon gage can bear high initial cost in drilling and trenching, but as with monitoring wells, the siphon gage requires only one-time leveling of the measuring point, and therefore the operational costs are minimized.

All 12 ponds, lakes, and wetlands at the Seashore were monitored using the siphon gage technique. The siphon gages at CACO provided an inexpensive, easily maintained data-collection instrument that was well suited for kettle ponds subject to large changes in shoreline position. For most sites, the siphon gage provided accurate, reliable monthly data. A comparison of surveyed pond elevations and pond elevations determined by siphon gages was made (n = 9; table 13). The siphon-gage reflects the surveyed pond levels with a slight bias to lower values, with an average difference of 0.01 ft and a maximum difference of 0.03 ft. Many sites required return visits to repair siphon tubes disturbed by users of the ponds. Little Bennett Pond, a wetland, developed a slow siphon response due to organic-rich pond-bottom sediments that clogged the tubing intake. Because vernal pool E-9 was intermittently dry (during 6 of 12 months during the pilot test period), the siphon gage there required periodic recharging as water levels became measurable.

A. Staff gage



B. Stilling well with recording device
(Wahl and others, 1995)



C. Pressure transducer system, bubble orifice, and outside gage
(U.S. Geological Survey, 2001)

Figure 15. Photographs and schematic diagrams of stage monitoring devices including: (A) staff gage, (B) stilling well, and (C) pressure-transducer system.

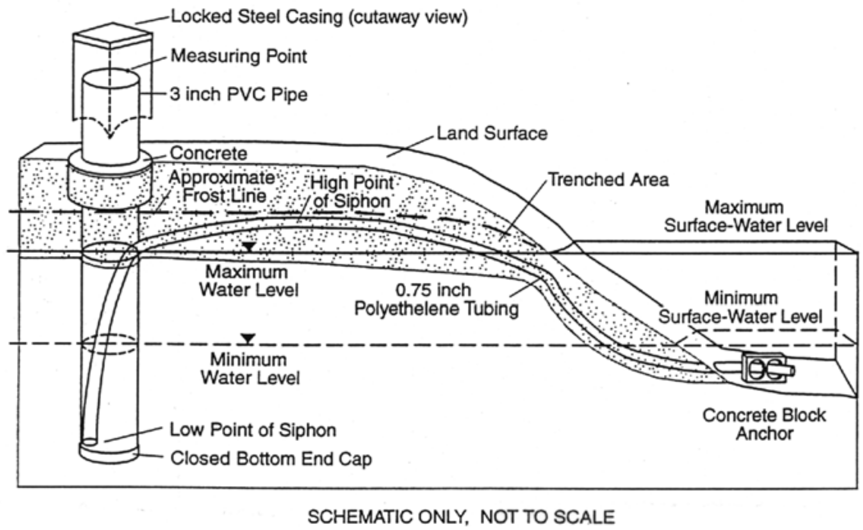


Figure 16. Schematic construction diagram of a siphon gage for monitoring pond levels (McCobb and others, 1999a)

Table 13. Comparison of pond-level surveying and pond levels determined by siphon gage at selected Cape Cod National Seashore ponds

Station Name	Date	Siphon Gage MP Elevation (ft above NGVD 29)	Siphon Gage Depth to Water (ft)	Siphon Gage Pond Elevation (ft above NGVD 29)	Surveyed Pond Elevation (ft above NGVD 29)	Difference (ft)
E-9	11-18-1998	18.76	7.93	10.83	10.84	-0.01
Great Pond (Wellfleet)	12-13-2000	12.64	4.96	7.68	7.69	-0.01
Dyer Pond	12-13-2000	12.63	5.12	7.51	7.53	-0.02
Herring Pond	12-19-2000	11.58	5.10	6.48	6.51	-0.03
Long Pond	12-13-2000	14.41	6.75	7.66	7.67	-0.01
Great Pond (Truro)	11-18-1998	14.52	5.04	9.48	9.48	0.00
Ryder Pond	11-18-1998	10.95	3.94	7.01	7.01	0.00
Snow Pond	12-13-2000	12.08	3.88	8.20	8.21	-0.01
Duck Pond	11-18-1998	13.90	4.61	9.29	9.29	0.00
Average						*-0.01*

Sampling Program

A comprehensive program to monitor pond levels requires consideration of the spatial distribution of the ponds in the aquifer to be used and the frequency that these ponds will be measured. At CACO, data was evaluated over a one-year period to optimize these considerations.

Spatial distribution

The spatial distribution of pond-level measurements is dictated by the pond's locations in the aquifer system. Like sites for ground-water monitoring, ideal pond-level monitoring locations are well distributed and represent most of the network area. Once the measurement network is established, the complete set of pond levels should be measured during each measurement round.

At the Seashore, the pond levels provide an excellent reflection of the local water table due to the unconfined aquifer conditions. As with ground-water levels, the elevation of the pond generally reflects the position of the surface-water body in the flow cell. All but three of the monitored surface-water bodies (Pilgrim Lake, E-9 vernal pool, and Little Bennett Pond) are glacial kettle ponds situated at or near the center of the Chequesset flow cell. The elevation of Pilgrim Lake ranged from 0.64 to 1.17 ft above NGVD 29; this elevation reflects the lake's position between the Pilgrim and Pamet flow lenses and close proximity to the ocean. Site E-9 is a vernal pool in the Nauset cell; it was dry on 6 of the 12 measurement dates. Little Bennett Pond, in the Pilgrim flow cell, is a marshy wetland in which organic bottom sediment caused slow pond-siphon response. Each kettle pond provides a flat surface expression of the water table. The pond elevation, along with measurements of the ground-water altitudes, provides the information needed to determine the shape of the flow cell and the direction of flow through the pond. The data collected through the 1-year monitoring period is given in table 14. All surface-water bodies were measured during each sampling round.

Table 14. Observed monthly pond-level elevations for the long-term Cape Cod National Seashore network, February 23, 1999 - January 24, 2000

(Altitudes in feet above NGVD 29;---, site not measured or not yet installed)

Station Name	Top of Casing Elevation (ft above NGVD 29)	Water Level Altitude, in feet above NGVD 29											
		02-23-1999	03-25-1999	04-13-1999	05-21-1999	06-21-1999	07-21-1999	08-24-1999	09-23-1999	10-21-1999	11-23-1999	12-22-1999	01-24-2000
Duck Pond	13.90	9.47	9.09	9.08	9.45	8.76	---	7.77	8.12	8.15	---	---	---
Dyer Pond*	12.63	---	---	---	---	---	---	---	7.42	7.61	7.46	7.46	7.42
E-9	18.76	pool dry	10.86	10.82	10.70	10.50	pool dry	10.47	pool dry	10.45	pool dry	pool dry	pool dry
Great Pond (Truro)	14.19	8.87	8.80	8.75	8.65	8.37	8.14	7.88	7.75	7.82	7.77	7.77	7.76
Great Pond (Wellfleet)	12.64	9.02	9.03	8.82	8.71	8.32	7.98	7.63	7.66	8.08	8.62	8.85	8.56
Gull Pond	12.24	6.86	7.02	6.93	6.77	6.63	6.53	6.42	6.44	6.75	6.68	6.84	6.93
Herring Pond	11.58	6.70	6.91	6.77	6.61	6.29	6.16	6.06	6.07	6.50	6.55	6.67	6.82
Long Pond*	14.41	---	---	---	---	---	---	---	7.55	7.75	7.55	7.49	7.47
Ryder Pond	11.99	7.59	7.95	7.88	7.74	7.66	---	6.92	6.77	6.95	6.83	6.79	6.84
Snow Pond*	11.58	---	---	---	---	---	---	---	7.44	7.61	7.45	7.39	7.36
Little Bennet Pond	10.31	5.39	5.50	5.49	---	6.42	6.99	7.10	7.27	7.53	7.69	7.89	7.45
Pilgrim Lake*	5.36	---	---	---	---	---	---	---	0.64	0.85	0.87	1.03	1.17

*Siphon gages were installed on September 21, 1999, to supplement the network as a special initiative project of the U.S. Geological Survey Massachusetts/Rhode Island District

The kettle-pond monitoring data reveal very slight changes in gradient among adjacent ponds that vary in magnitude and direction as the position of the top of the Chequesset flow cell changes. Although the kettle ponds are part of the same flow cell, there are two separate high points in the cell with the Herring River as a common sink between the highpoints (fig. 14). The pond-level elevations in the six ponds to the south of Herring River (Duck, Great (Wellfleet), Dyer, Long, Gull, and Herring) ranged from a maximum elevation of 9.47 ft above NGVD 29 at Duck Pond to a minimum elevation of 6.06 ft above NGVD 29 at Herring Pond over the 1-year monitoring period. The six ponds are fairly evenly spaced, providing a natural decrease in head from the top of the flow cell into the Herring River Valley. To the north of the Herring River, three ponds were measured (Great (Truro), Snow, and Ryder). Great Pond (Truro) and Snow Pond fall roughly along the same elevation contour; Snow Ponds level consistently measures between 0.04 and 0.23 ft lower than the level of Great Pond (Truro). Ryder Pond is lower in elevation than Great and Snow Ponds, with a difference in elevation from Great Pond ranging from 0.87 to 0.98 ft. These differences create a hydraulic gradient of about 0.0006 between ponds. Measurement of all ponds at the same time provides long-term data for water-table mapping and thus analysis of changes in flow direction and magnitude through the two pond complexes.

Frequency

Like well monitoring, water-level rounds, or snapshots, provide a concurrent view of the water-table surface that can be used, for example, to analyze long-term trends and changes in flow directions, and to provide calibration data for ground-water models.

At the Seashore, unconfined conditions dictate that each kettle pond closely represents the local ground-water table and therefore provides an opportunity to represent a large area of the water table with a single measurement. For this reason, this monitoring should be done concurrently with ground-water monitoring. The year-long data set shows monthly changes in elevation, ranging from 0.00 to 0.57 ft. An example of the importance of monitoring changes over a 1-month monitoring period can be seen in figure 17, a map showing Long Pond, Dyer Pond, and Great Pond (Wellfleet) at the measurement periods in September and October of 1999. The average difference in elevation for the three ponds over the two periods is 0.27 ft. Estimates of the hydraulic gradient between these three ponds show that the gradient direction and magnitude can change substantially over a 30-day interval especially at the top of the flow cell. Horizontal hydraulic-gradient calculations show a change in flow direction of 8.4^{o} with an increase in elevation resulting in a more northwesterly flow path. The gradient magnitude is almost 2.5 times greater at the higher than at the lower water levels. At lower water levels, the top of the mound is fairly flat, whereas at higher levels, the mound is steeper. Monthly monitoring of pond water level is required to detect these changes.

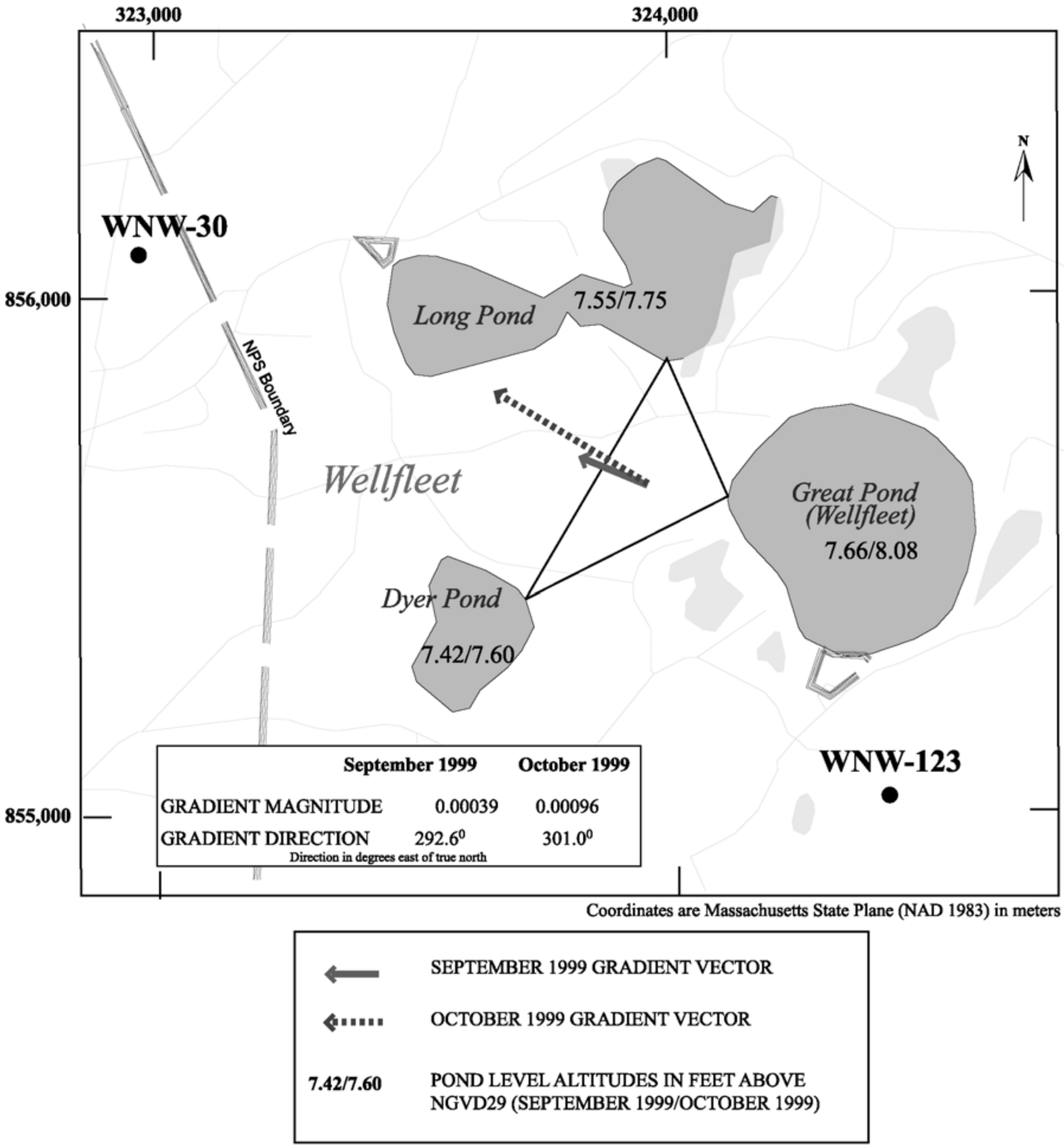


Figure 17. Comparison of hydraulic-gradient estimations among three ponds over a one-month period (September 1999 to October 1999).

PART TWO
Specific Hydrologic Protocols followed for CACO

Ground-Water-Level Monitoring

A 32-well ground-water monitoring network has been established for long-term water-level monitoring at CACO. Three of these 32 wells were newly installed at CACO during protocol development to enhance the existing network. The most common method of drilling used by the USGS in sand and gravel settings such as the Seashore is the hollow-stem power-auger rig mounted on a truck (see table 4 for drilling methods). The three new wells were installed with a Central Mine Equipment (CME) model 75 drilling rig owned by the USGS New Hampshire District. The following general procedures should be followed in the future for proper installation of observation wells (see also Driscoll, 1986; Nielsen and Schalla, 1991):

<u>General Well Installation Procedures</u>

1. Select observation-well site on the basis of monitoring-program objectives and established selection criteria.
2. Request site access and permission from landowner. A written contract stating the proposed use of land should be developed.
3. Mark site with a flagged and labeled stake (such as “USGS Site 1”). Measure Global Positioning System (GPS) position.
4. Call Dig Safe (1-888-DIG-SAFE) for utility company marking and clearance (required by Massachusetts state law).
5. Clear site with drill rig operator with a prior site visit. Observe site for potential problems with rig access, road stability, and overhead and overall road clearance.
6. Clear site (with owner permission), if necessary, so that a large work area is available around all sides of the rig. At least 10 ft of clearance on each side of the rig is suggested. Overhead clearance must allow for deployment of a 25 ft drilling mast.
7. Estimate target drilling depth and anticipated depth of water (from available ground-water maps). For water table-wells, the well screen should be set 5 to 10 ft below the lowest anticipated water level in order to prevent a dry well screen. For example: At new well site TSW 256-0061, the estimated land-surface elevation from the USGS quadrangle map was about 60 ft above NGVD 29, and the predicted water-table elevation was about 10 ft above NGVD 29. Subtracting the land-surface elevation from the water-table elevation and adding 10 ft for the range in water-table elevation gives a target depth for the bottom of the screen of 60 ft below the land surface.
8. Select well material and specifications and order supplies. At the Seashore, 2-in OD flush-threaded PVC casing with a 0.010-in slotted-PVC screen, 2 ft in length, was employed.
9. Select drilling method as discussed above. Well-drilling matrix (table 4) should be followed as a guideline. At the Seashore, a rotary-drilling rig with hollow-stem augers (fig. 6) was chosen.

10. In drilling the well:
    -The drill-rig operator is responsible and in control of all operations at the drilling site.
    -It is the Driller's responsibility to provide a safety review prior to initial drilling; this review should include location of drill-rig kill switches and the use of hard hats, steel-toed boots, eye protection, and gloves by all onsite personnel at all times (U.S. Geological Survey, 2000).
    -A drilling plan is stated and discussed with the driller prior to setup at the drill site. The drill operator is informed of exact target depths, anticipated depth to water, and predicted geologic material to be encountered.
    -Once drilling has begun, the hydrologist or geologist is responsible for keeping clear, descriptive notes on drill cuttings and driller's observations, and for developing a well construction diagram (Appendix 1), site sketch (Appendix 2), and a well lithologic log at sites where sediment samples are collected (Appendix 3).
11. Prepare all well materials (unboxed and unwrapped) for installation. Count the number of well casings needed and note and verify the length of each piece. At the target depth, fill the augers with water to help prevent flow of sediment (heaving) into the augers. Assemble the well casing and insert it down inside the hollow-stem augers by adding consecutive 10 ft PVC sections from the top.
12. Once the entire well casing has been installed, the driller knocks the well through the temporary knockout plate that is inserted in the lead auger prior to drilling. At this point, the point of the casing is outside of the lead auger. Remove the augers 5 ft at a time.
13. After removing all augers from the ground, backfill the screened portion of the well with a sand or gravel pack (or ambient sand, if available). Place seal material (such as bentonite) in the hole around the casing to prevent any vertical movement of fluids in the annulus space. Backfill the remaining hole to grade.
14. Trim the well at the land surface to a desired casing stick-up (either a "curb box" flush to the ground or a stick-up steel casing) and cement a protective outer casing with locking cap around the well casing (fig. 8).
15. Clearly marked the MP with a permanent marker or notch at the top of the PVC casing (fig. 8).
16. Grade and landscape the site in order to minimize the impact of the well construction on the surrounding area.
17. Finally, sounded the well is using a weighted steel tape and measure the starting water level (see measuring water levels, below).

Determination of well measuring-point elevation

Measuring-point elevations were determined for all of the 32 wells in the network. Ground surveying by differential leveling with an engineer's level is the most common method for determination of the well elevation. Other methods include the estimation of elevation from 7½-minute USGS quadrangle maps and the use of GPS. Leveling measurements must be clearly recorded on surveying level forms (Appendix 4) or a similar note sheet with columns for station name, back sight measurement (BS), height of instrument (HI), foresight measurement (FS), elevation, and remarks (Lapham and others, 1996). The well elevation is determined at a point at the top of the well (the MP) that is identifiable by a permanent mark or notch in the well casing. The procedure for differential leveling from a known elevation generally consists of a series of back sight and foresight readings (Lapham and others, 1996; Kennedy, 1990):

1. After setting up the tripod and level at a location away from the known elevation, a back sight is taken to the rod on the known elevation.
2. The rod reading is added to the known elevation to determine the elevation of the line of sight of the level (HI).
3. A rod reading (FS) is then taken at an established turning point (TP) or the well measuring point if it is within 100 ft. Turning points can include lag bolts installed in trees, nails in pavement, and temporary stakes.
4. The TP elevation is then determined by subtracting the FS reading from the HI elevation. This point now becomes the BS for the following tripod setup.
5. These loops are repeated until enough distance is traveled to reach the well. After determining the MP elevation, the loop returns to a known elevation. Closure should be within 0.01 ft of the known elevation.

Water-level measurements

Water-level measurements are a routine aspect of hydrologic monitoring. The determination of the water-table elevation, and subsequently of the ground-water-flow direction, flow rate, hydraulic gradient, and location of ground-water discharge and recharge areas depends on the accuracy of the leveling of the MP elevation and the depth-to-water measurement. Water-level measurements are made as follows (Stallman, 1971; Bennett, 1976; Sanders, 1984; Lapham and others, 1996):

1. Water-level measurements are recorded on the standard USGS water-level field sheet (Appendix 5). Required data include well name, date of measurement, time of measurement, and depth to water from MP.
2. For the electric-tape method, turn on the electric-tape sensor and slowly lower the probe down the well. When an audible indicator and surface light are triggered, pull the electric tape back to feel for the water line and fine-tune the position of the water table. Read the graduated line at the MP position and record. The depth below MP is a direct measurement (no correction required).

3. For the steel-tape and chalk method, apply chalk to the bottom 5 to 10 ft of steel tape (above the weight). Lower the weight until the water is contacted (the weight makes an audible noise); then lower the tape an additional 3 ft, or the amount sufficient to place the graduated portion of the tape in the water. Hold the tape to the MP, read and record the "tape held" value. Typically, the tape is held at an easily read graduation, such as an even foot. Retrieve the steel tape and view the water mark made on the tape. Read the tape at the water mark, and record. The depth of water below MP is equal to the "tape held" value minus the water mark value.
4. For any water-level measurement, the depth to water should be measured for two or more consecutive measurements to an accuracy of 0.01 ft, with a steel tape and chalk or an electric tape (Lapham and others, 1996). If the steel-tape-and-chalk method is used, each measurement will become progressively more difficult to accomplish, as the well casing remains wet from the previous measurement.
5. If the steel-tape-and-chalk method is used, the weight should be made of a nontoxic material (not lead) to prevent metal contamination in the well.

Specific Data Collected at Each Well Site

Prior to implementation of the monitoring network, information on each well must be obtained and a master information sheet created. This information must include all of the following:

Well identification number – for example: TSW 258-0135. This alphanumeric code is the U.S. Geological Survey's well-identification number. The letters represent the town name (Truro, MA), the number is the well number (258), and the hyphenated number is the approximate well depth from the land surface in feet.
Town name
Latitude and longitude
State plane XY coordinates
Altitude of land surface
Length of casing stick-up from the land surface to the top of the MP
Total depth of the hole
Depth to the bottom of the screen
Length of the screen
Altitude of the measuring point
A description of the well site with directions and a well-site sketch map (Appendix 2)

For each measurement round, the weather conditions and personnel involved must be noted. Water-level measurements should be entered on one pre-designed field sheet with the date and time of measurement at each observation point (Appendix 5) and the method (including instrument identification) used. The field personnel must note the depth to water from the MP (in hundredths of a foot) and any correction factor for the tape being used. Notes should be taken regarding well maintenance, changes to the site layout, and well damage. New field sketches should be created if features such as roads or trees in the vicinity of the well change.

This information is available and on file at the CACO Headquarters and the U. S. Geological Survey Massachusetts-Rhode Island District office for all 32 wells in the network.

Streamflow Measurements

A network of four partial-record stream-gaging sites was established at CACO during protocol development and measured monthly for a one-year period. After evaluation of the data from the first year of operation, two sites were removed from the network and six additional sites were recommended for long-term monitoring. The following general procedures should be followed in the future for establishing stream-gaging stations and measuring streamflow at CACO (see also Rantz and others, 1982):

<u>Reference-point establishment and leveling</u>

The datum of the stream-gaging station is the established elevation of the zero point of the reference gage, preferably referred to a fixed datum, such as the National Geodetic Datum of 1929 (NGVD 1929) (Rantz and others, 1982). The elevation of the stream-gaging station datum must be determined through a series of differential levels run from nearby reference points or benchmarks. Periodically, the stream-gaging station datum must be resurveyed to check for movement of any of the structures. The USGS publication series Techniques of Water-Resources Investigations includes a report on the relevant procedures (Kennedy, 1990).

The following procedures should be followed to establish a stream-gaging station datum:

1. In the vicinity of the discharge measurement section, select a stable over-water landmark to use as a reference structure. At the Seashore, bridge culverts were used as stable reference structures.
2. Clearly mark the exact reference point by making a permanent indentation or installing a nail or bolt to the structure. This mark should be painted and marked so that it is visible from a distance.
3. After the reference point is established, the elevation (relative to a fixed datum) should be determined by standard leveling methods described above and by Kennedy (1990). In general, the differential leveling should originate at an established and maintained benchmark and return to closure in a loop within 0.3 mm (0.001 ft) of the reference elevation. Clear notes including the names of party members and instruments used must be recorded as in Appendix 4.

Stage and discharge measurements

Discharge measurements are recorded by field personnel on a standard USGS discharge-measurement note sheet (Appendix 6) to ensure that clear, thorough, and systematic notations are made during field observations. Original observations written on the field sheets should never be erased. Original data are corrected by crossing the value out then writing the correct value. Some examples of original data on a measurement sheet include:

-Gage-height readings
-Depth
-Distance along the cross section from initial point
-Meter revolutions
-Angle corrections
-Time

Examples of information on the measurement sheet that are not original data but are derived from original data include:

-Calculated total discharge
-Mean gage height
-Width
-Area
-Velocity

Derived data can be erased for the purpose of correction. (R.S. Socolow, U.S. Geological Survey, written commun., 2000).

The following procedures should be followed in making stage and discharge measurements (Rantz and others, 1982; Kennedy, 1984; R.S. Socolow, USGS, written commun., 1999):

1. A safety check of the measurement area must be made prior to working on the stream.
2. Pre-measurement observations and notes are made on a USGS discharge measurement field sheet and must include:

    -Initials and last name of all field-party members
    -Date
    -Time of arrival at site
    -Type of meter
    -Meter serial number
    -Location of measurement section
    -Description of the cross section
    -Flow conditions
    -Weather conditions
    -Description of the stream-channel control

3. For automatic digital-calculation devices, the datalogger should be prepared with pertinent information including site name, meter type, correct meter settings, and the correct time and date.
4. Measure the stream stage by recording the distance from an established overhead reference point.
5. String tagline across section. Distances should increase from the left edge of water (LEW) to the right edge of water (REW)(facing downstream). Note starting time, tape distance, and LEW measurement.
6. Calculate the number of measurements to be made in the section. In general, each measurement should not represent more than 5% of the total flow across the section. It is recommended that 25-30 measurements per section be performed. For narrower reaches, the number of measurements is determined by the meter-cup width; this width is 2.5 and 6 in., for pygmy and standard meters, respectively. For example, a 3 ft-wide stream with flow suitable for a pygmy meter would only have a maximum of 14 measurements in the section (3 ft / 2.5 in = 14.4 measurements).
7. Starting at the LEW, for each measurement location, read and note the distance from the initial starting point (LEW). Read and note the depth of water on the wading rod. Start timer and count revolutions of the meter (either audibly or digitally). For audible methods, count revolutions until the number of seconds that have passed is listed on the standard rating tables (Appendix 7 and 8).
8. After all sections have been measured, look up and note on the field sheet the corresponding velocity (for standard rating tables) associated with the observed number of meter revolutions and time elapsed. Velocities should be adjusted for any non-perpendicular horizontal flow in the measurement section.
9. Leave the tagline in position in case the section needs remeasuring. For each subsection calculate the width (usually constant per measurement), area (Width x Depth), and discharge (q) per measurement (Velocity x Area). Calculate the total discharge by summing the discharges across the entire width of the stream. ($Q_{total} = q_1 + q_2 + \ldots + q_n$).
10. At the end of the measurement, note the end time and the tagline readings for the right and left edges of water. Example: 1105, 10.0 ft, LEW
    1225, 42.5 ft, REW
11. Read stage measurement again from the established reference point (bridge, staff gage) to check for sudden changes in stage during measurement.
12. At sites where rating curves for the stream section have been established, plot and check the measurement in the field. If the measurement differs by more than 5% from the current rating, then check by measuring the section again with a different meter.

Water-Level Measurements in Ponds and Seasonal Wetlands

The following general procedure should be followed for collecting water-level data at ponds and seasonal wetlands fitted with siphon gages. Prior to implementation of the monitoring network, information on each monitoring station must be obtained and a master information sheet created. This information must include:

Site identification – for example: Great Pond at Truro, MA
Town name
Latitude and longitude position
State plane XY coordinates
Altitude of land surface at standpipe
Length of casing stick-up from the land surface to the top of the MP
Total depth of the standpipe
Altitude of the measuring point
A description of the site with directions and a site-sketch map (Appendix 2)
An estimated range in pond fluctuation

For each measurement round, the weather conditions and personnel involved must be noted. Water-level measurements should be entered on a pre-designed field sheet, with the date and time of measurement at each observation point (Appendix 4) and the method (including instrument identification) used. The field personnel must note the depth to water from the MP (in hundredths of a foot), and any correction factor for the tape being used. For siphon-gage measurements, a slug of water (about 1 liter) should be added to the standpipe after the initial depth-to-water measurement is made. After 5 minutes, the siphon gage should be measured again to check the functionality of the gage. Each measurement and the amount of purge water added should be documented. Notes should be taken regarding siphon-gage maintenance issues, changes to the site layout, and any damage to the siphon gage (Kennedy, 1990; McCobb and others, 1999b). New field sketches should be created if features such as roads and trees in the vicinity of the well change.

<u>Siphon-Gage Installation</u>

1. Select desired site location based on site-selection criteria.
2. Request site access and permission from landowners. In most communities, work around ponds and wetlands require review by from local conservation commissions under the Wetlands Protection Act. A written contract stating the proposed and permitted use of land should be developed.
3. Mark site with a flagged and labeled stake (such as “USGS Siphon 1”). Determine and record GPS position.
4. Call Dig Safe (1-888-DIG-SAFE) for utility-company marking and clearance (required by Massachusetts state law).

5. Clear site (with owner permission) if necessary, so that an adequate work area is available around all sides of the rig. At least 10 ft of clearance on each site of the rig is suggested. Overhead clearance must allow for deployment of a 25 ft drilling mast.
6. Use the drilling methods as describe above. Install a 3-in-diameter standpipe with a sealed end cap in an 8-in hollow-stem-auger to a depth of at least 3 ft below the lowest expected pond-water level.
7. At remote locations where large-rig access is not feasible, portable drilling methods must be employed. At the Seashore, a hand-operated auger with supporting tripod was used. The augers were solid and needed to be removed from the hole before the standpipe was installed.
8. Use a trenching machine to dig a 4-in-wide trench from the PVC standpipe to the pond edge.
9. Drill a 0.875-in-diameter hole at a downward angle through the 3-in standpipe at the level of the base of the trench. Then insert polyethylene tubing (0.75-in-OD) into the drilled hole and set the end of the tube about 1 ft above the bottom of the standpipe. Seal the hole in the standpipe around the tubing with silicone.
10. Place the remainder of the tubing in the trench and extend to the pond. Bury the tubing below the pond bottom by jetting the tubing down with a water jet from a gasoline-powered pump.
11. Cover the end of the tubing with a protective screen and anchor it to a concrete block.
12. Install a protective casing with locking cap and cement the casing around the standpipe. The trench and remaining hole is now backfilled.
13. Mark the MP permanently and clearly at this time with a permanent mark or notch at the top of the PVC casing (fig. 7).
14. Finally, charge the siphon gage by adding enough water to displace all air from the tubing. With both tubing ends submerged in water and the tubing end in the pond unobstructed by silt and debris, the two levels should equilibrate quickly.

<u>Reference-point and pond leveling</u>

1. Leveling of the pond siphon MP is described above in the well MP leveling section.
2. Measurement by means of staff gages and direct pond-level measurements can also be accomplished as above, once stable MPs have been established.

Measurement procedure for siphon gages

1. The functionality of the siphon must be determined by measuring the water level at least two times.
2. After the initial readings, add 1 liter of water to the standpipe and make sure that the water level in the gage returns to the pond level.
3. Make one more water-level measurement after waiting 5 minutes. This will ensure that the level in the standpipe has re-equilibrated with the actual pond level.
4. If the level is not repeated, add a 3-ft extension standpipe to the top of the siphon gage and add enough water to fill the extension pipe, completely flushing the system.
5. Allow enough time for equilibration, and repeat steps 2 and 3 until the values are comparable.

Data Management

Data collected for water-resource-related projects are usually processed, documented, organized, and archived to meet the particular requirements of the project that collected the data. Even data determined to be unusable for a particular project's objectives could be invaluable for a future project if the information was properly documented and stored. Incomplete data documentation in computer databases and paper files limits the utility of the data collected. For this reason, a comprehensive data-management plan must be established to ensure that all data documentation is consistent and thorough. For this protocol, the unpublished data-management plan (1999) from the Massachusetts-Rhode Island District of the U.S. Geological Survey entitled, "Policy and Procedures for the Management and Archival Storage of Data Collected for Basic Data and Hydrologic Investigations" served as a guideline. A copy of this document can obtained from the Massachusetts-Rhode Island District of the U.S. Geological Survey. The document explains the databases and archival procedures used by the USGS and gives examples in order to clarify the valuable and necessary attributes of a hydrologic database for the NPS monitoring program.

All required field data should be recorded on an established field sheet during each site visit. The mark of an excellent field hydrologist is the creation of first-class field notes. Field notes should be clear, descriptive, legible, and well organized so that others can obtain the information easily.

In addition to the pre-designed field sheets, the field hydrologist should carry a general field-log notebook that holds the basic information of the field trip. The field log should note the following (modified from Fetter, 1994):

1. Date
2. Personnel

3. Time of personnel arrival
4. Weather conditions of the day
5. Objectives and brief description of the work to be performed
6. Any observations of events that were out of the ordinary
7. General summary of accomplishments
8. Time of personnel departure

Detailed information related to the specific tasks performed should be recorded on specific field data sheets presented in appendices 1-6:

Well Installation *(from construction log –* Appendix 1a*)*
An example of a completed construction log (well TSW 257-0034) can be reviewed in Appendix 1b.

Raw data required:

General Data

Site number	Date of construction
Other identifier	Record keeper/inventory by
Town	Drillers
Location description	Drilling rig and auger type
7.5-minute quadrangle location	Sediment samples collected (Y or N)
Latitude	Drilling fluid
Longitude	Lock type

Well Specifications (Length unit (L) should be recorded)

Total depth of borehole (L)	Stickup to top of casing (L)
Depth to bottom of screen (L)	Type of protective casing
Well casing inside diameter (L)	Type of surface seal
Type of casing	Backfill type
Screen Type	Borehole diameter (L)
Screen length (L)	Type of annular seal
Slot size (L)	Depth to top of annular seal (L)
Inside diameter of screen (L)	Type of screen sand pack
Elevation of top of casing (MP) (L above datum)	Depth to top of sand pack (L)
Elevation of land surface (L above datum)	

Water-Level Measurements *(from water level measurement field sheet* – Appendix 4a*)*
An example of a completed water level fieldsheet (month of January 2000) can be reviewed in Appendix 4b.

<u>Raw Data Required:</u>

Project name	Measurement personnel
Date	Time of each measurement
Well name	Depth to water from MP
Water-level method	Meter or tape used
Tape correction, if needed	Final depth to water from MP

Stream-Discharge Measurements *(from discharge measurement fieldsheet* – Appendix 5a) An example of a completed discharge fieldsheet (Herring River, 011058793, 9/26/2000) can be reviewed in Appendix 5b.

<u>Raw Data Required:</u>

Initials and last name of all the field-party members	Gage readings
Date	Depth
Times associated with gage readings	Distance from initial point
Type of meter used	Meter revolutions
Meter number	Angle corrections
Location of measurement	
Measurement rating (excellent, good, fair, or poor)	
Descriptions of the cross section	
Flow conditions	
Weather conditions	
Description of the stream-channel control	

Data requirements and storage

An important aspect of a quality hydrologic monitoring program is the proper management of the collected data. Maintenance of the project files and storage of the data in a secure database is critical for the success of the monitoring program

Maintenance of project files

While a monitoring network is active, the files for each data-collection station are maintained in folders under the control of project staff. The folders contain all the necessary information to verify the data in a report. At a minimum the required data listed above, if applicable, are to be contained in the monitoring projects files. The following pieces of information should also be included in project's files:

1. Site description including access routes and topographic map
2. Safety information including site-safety plan
3. Photographs of relevant features of the site-network area
4. Permission and permit documentation for sampling and installation of equipment.

Any changes to data, including errors in calculations, and changes in site locations, must be explained, dated, and initialed in the project folders.

As suggested by the Massachusetts-Rhode Island District Data-Management Plan, non-standard digital data, such as GPS data, datalogger records, digital site-survey records, and other data that originally exists in digital formats, must be stored as ASCII files whenever practicable. The digital data should be stored in a manner that identifies the data by monitoring site ID, date, and type of data.

Data Storage in Information System Database

Hydrologic data collected during hydrologic monitoring and investigations provide valuable information that can be used for management of water resources. Easy access to these data is best provided through a database. An example of such a system is the USGS National Water Information System (NWIS) database, a water-data storage and retrieval system.

The system consists of the Automated-Data Processing System (ADAPS), the Ground-Water Site Inventory (GWSI) System, the Quality-of-Water System (QWMENU), and the Water-Use Data System (Mathey, 1989). For hydrologic monitoring, the GWSI and ADAPS systems are used to store site-file and hydrologic data. All water data, including ground-water, streamflow, and stage measurements collected by the USGS, are stored in the NWIS database.

Internet access to some of the information in NWIS is available (http://water.usgs.gov/nwis/). The goal of NWISWeb is to provide both internal and external users of USGS water information with an easy-to-use, geographically-seamless interface for the large volume of USGS water data maintained in 48 separate NWIS databases nationwide. Data is updated in the NWIS sites on a regularly scheduled basis; real-time data is transmitted to NWISWeb several times a day. NWISWeb provides several output options: real-time streamflow, water levels and water-quality graphs, data tables and site maps; tabular output in HTML and ASCII tab-delimited files, and lists of selected sites in summary form, with reselection for details. All of the Seashore protocol ground-water data and pond-level data collected in 2000 are available on NWISWeb.

Ground-Water-Site Inventory System

The GWSI is a computer system for storage and access of ground-water data; it is networked into a nationwide database. The GWSI is an interactive system that maintains a dialog with the user through menus and prompts. The GWSI provides a vehicle to enter new sites and update existing sites in the database, as well as to retrieve and display past data in several useful formats. The GWSI system also contains over 300 descriptive elements about each site (such as well type, depth information, construction information, and land ownership).

Automated Data-Processing System

NWSI is also home to the Automated Data Processing System (ADAPS) that is used to process, store, and retrieve water data (primarily surface-water data). The interactive method of processing these data in ADAPS allows the user to assemble and set up the information needed to compute streamflows or other types of hydrologic records on a variable time basis (Dempster, 1990). All of the CACO-protocol streamflow data were processed in ADAPS and are available on NWISWeb.

Archiving procedures

After the monitoring network or project becomes inactive, all project files must be archived to ensure that data will be permanently stored and maintained in a secure and accessible environment. In general, all data used to support scientific analyses leading to conclusions in reports are archived (USGS, written commun., 1999).

In general, some of the desirable characteristics of an archival system include:

- Data are on media that can be permanently maintained
- Systematic archival procedures are established and maintained
- Archiving is for an indefinite period
- Data are readily accessible
- Data are preserved in a non-volatile state or one of extremely low volatility (that is, low vulnerability to deterioration)
- Data are known to be accurate and complete

Corrections can be made to the data, but a record of the transaction is archived
Data are indexed before archiving

In the USGS, relevant data are archived in the District archives or at a regional Federal Archives and Records Center (FARC). Most data that is to be kept indefinitely must be sent to the FARC for safekeeping. The required length of storage for specific types of hydrologic data for both the District archives and the FARC can be reviewed in table 15.

Table 15. Data to be archived and archive period
(Modified from USGS, written commun., 1999)

Type of Data	FARC Retention Time	District Disposal Date
Field Data		
Surface Water		
Current-meter discharge measurements	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Stage data	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
GPS data	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Original field observations, notes, and measurements	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Observer's notes and readings	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Field notes and observations	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Stage-device inspections	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Photographs and slides	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Field-survey notes	75 years	5 years
Computations	75 years	5 years
Level notes	75 years	5 years
Ground water		
Water-level data sheets	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Surveying records	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Geologic and hydrologic field notes	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Well records and logs	75 years	Keep in District files
Location maps	75 years	Keep in District files
Drilling logs	75 years	Keep in District files
Geologic maps	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Leveling and surveying notes	75 years	After 10 years, sent to FARC on 5-year transmittal schedule

Type of Data (Cont.)	FARC Disposal Date	District Disposal Date
Computational Data		
Station analysis	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Rating curves and tables	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Primary computation sheets	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Levels summary sheet	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
End-of-year summary	75 years	After 10 years, sent to FARC on 5-year transmittal schedule
Documentation		
Copy of published report	75 years	Send to FARC 3 years after completion of project
Project description	75 years	Send to FARC 3 years after completion of project
Key calculations	75 years	Send to FARC 3 years after completion of project
Final statistical analysis	75 years	Send to FARC 3 years after completion of project
Equipment, type, models, serial number	75 years	Send to FARC 3 years after completion of project
Permits	75 years	Send data with discontinued stations to FARC every 5 years
Sampling Protocols	75 years	Send data with discontinued stations to FARC every 5 years
Project proposal	75 years	Send data with discontinued stations to FARC every 5 years
Safety plan	75 years	Send data with discontinued stations to FARC every 5 years

Data-Analysis Techniques

Water-level and streamflow data reporting and analysis depend on the intended use of the data and may vary greatly. Often, water-resources data is simply tabulated and recorded in a paper file or electronic database. Simple tabulation is useful in determining average and extreme (minimum and maximum) conditions but does not easily reveal changes caused by seasonal and annual variation in precipitation, water use, or other hydrologic stresses (Taylor and Alley, 2001). A variety of analysis techniques, including many graphical approaches, can be used to reveal changes in the status of water resources. In addition, spatial and temporal trends in the data should be explored. Data collected under the long-term ecosystem monitoring should be analyzed for these spatial and temporal trends in order to meet the goals of the monitoring program.

Ground Water, Ponds, and Seasonal Wetlands

The most common approach to understanding trends in ground-water, pond, and wetland water levels is by use of the hydrograph. A hydrograph is a graph showing water levels at a specific location as a function of time. Hydrographs provide a visual description of the range in fluctuations, seasonal water-level variations, and the cumulative effects of short- and long-term hydrologic stresses. Water-level hydrographs can be constructed to compare recent and historical water-level data, and to present statistics for water-level measurements (Taylor and Alley, 2001). An example of three different types of hydrographs for the same protocol well TSW 89-0028 can be seen in figure 18. These data are reproduced from the USGS National online database (NWISweb) (http://waterdata.usgs.gov/nwis/gw). The data were collected by the USGS and NPS for this study protocol during the first year as documented in this report and during the second year (2000) of protocol implementation.

Hydrographs can also be used to compare sites in different regions of the study area. Figure 19 shows “current conditions” hydrographs for four wells, each located in a different flow cell in the protocol area. Each well responds differently depending on its proximity to the coast or other surface-water bodies, proximity to pumping centers, and variations in precipitation. During 1999-2000, well EGW 36 in the Nauset flow cell reached all-time monthly lows while well TSW 89 in the Pamet flow cell was at slightly less than average conditions. This statistical low could reflect less precipitation in the southernmost flow cell or could be a result of the shorter period of record at this site which does not include the drought conditions of the mid-1960s.

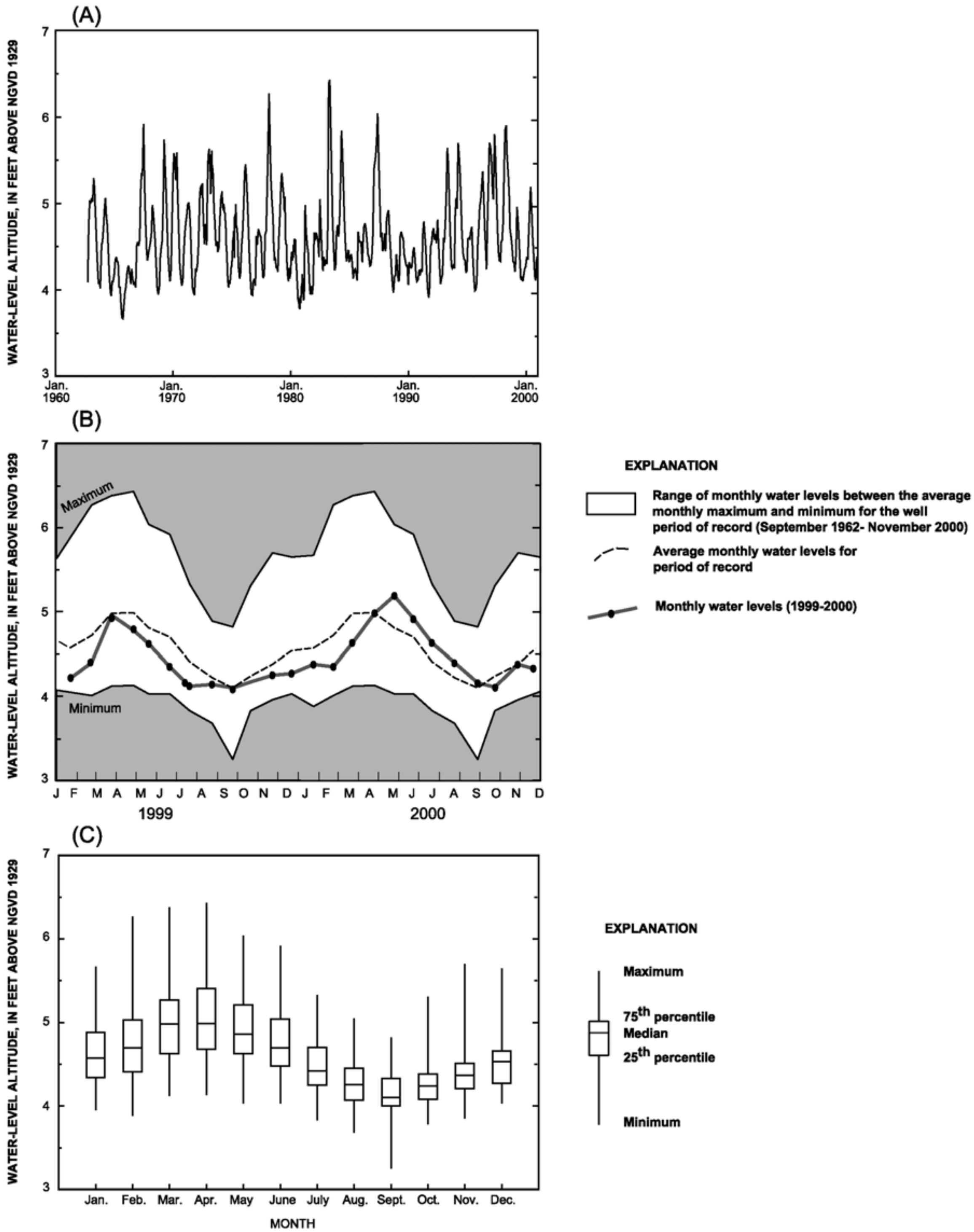


Figure 18. Three types of hydrographs for Truro well TSW 89-0028 showing (A) long-term monthly water-level measurements over a period of nearly 40 years; (B) comparison between water levels measured during the protocol measurement period to historical monthly high, average, and low water-level measurements; and (C) statistical distribution (boxplots) of water levels for each month for the period of record.

Just as hydrographs are the most common tool for analyzing temporal trends in water-level data, the water-table map is the most common tool for analyzing spatial trends in ground-water levels. A water-table map is a two-dimensional representation of a three-dimensional surface, generally a contour map that shows equal elevations of the water table. The data used to construct a water-table map are water-level elevations measured in wells screened at or near the water table during the same measurement round or snapshot. In an unconfined system like the Seashore, lakes, ponds, and streams intersect the aquifer at the water table and generally represent the water-table surface. The altitude of these surface-water features should be included in constructing the water-table map. Once all the measurements and measurement locations are plotted on a base map, contours of equal ground-water elevations can be drawn. Examples of water-table maps on Cape Cod include Savoie (1995) and LeBlanc and others (1986). Figure 20 shows a map for a portion of the Chequesset flow cell which includes lines of ground-water altitude for two dates, March 25, 1999, and January 24, 2000. The elevations used for each date are plotted at the measurement location. During the nine-month period, water levels decreased over 1 ft. As the quantity of water in the aquifer changed, the shape of the flow cell and the regional and local flow patterns changed.

A simple analysis of the change in flow patterns over time can be done by means of using a gradient analysis of water-level elevations measured in three wells. The three-point triangulation method (Fetter, 1994) can be used to estimate the magnitude and direction of horizontal hydraulic gradients in an unconfined aquifer by fitting a planar surface to three vertical measurement elevations to approximate the curved surface of the water table (McCobb and others, 1999a). The slope and direction of the planar surface can be calculated with basic trigonometry and yields estimates of the gradient (fig. 21). Table 16 summarizes the results for wells EGW 36, EGW 52, and EGW 51 at CACO; the three wells are located near the center of the Nauset flow cell in Eastham, MA (fig. 6). The average gradient magnitude and direction over an 11-month monitoring period ($n = 11$) was 0.00080 (L/L) and 140.3 degrees east of true north, respectively. The gradient results are consistent with the general observations from the water-table map discussed earlier. This simple analysis quantifies the changes in magnitude and direction of the horizontal component of the hydraulic gradient for a specific region of interest. In this area of the Nauset flow cell extending from the top of the water-table mound southeastward towards Nauset marsh, the range in gradient magnitude and direction over this 1-year period was 0.00021 (L/L) and 15.1 degrees, respectively, for an average fluctuation in water-level elevation of 1.48 ft.

A numerical ground-water-flow model is a sophisticated tool that can be used to analyze the flow system in a variety of ways. Numerical models rely upon the solution of basic flow equations (Darcy's Law) to represent conditions in the ground-water system. Hydrologic data collected (both streamflow and water levels) provide the initial and boundary conditions of the flow problem. Hydrologic-data snapshots are used to calibrate these models at different water-level conditions. Examples of flow models at CACO include LeBlanc (1982) and Masterson and Barlow (1996).

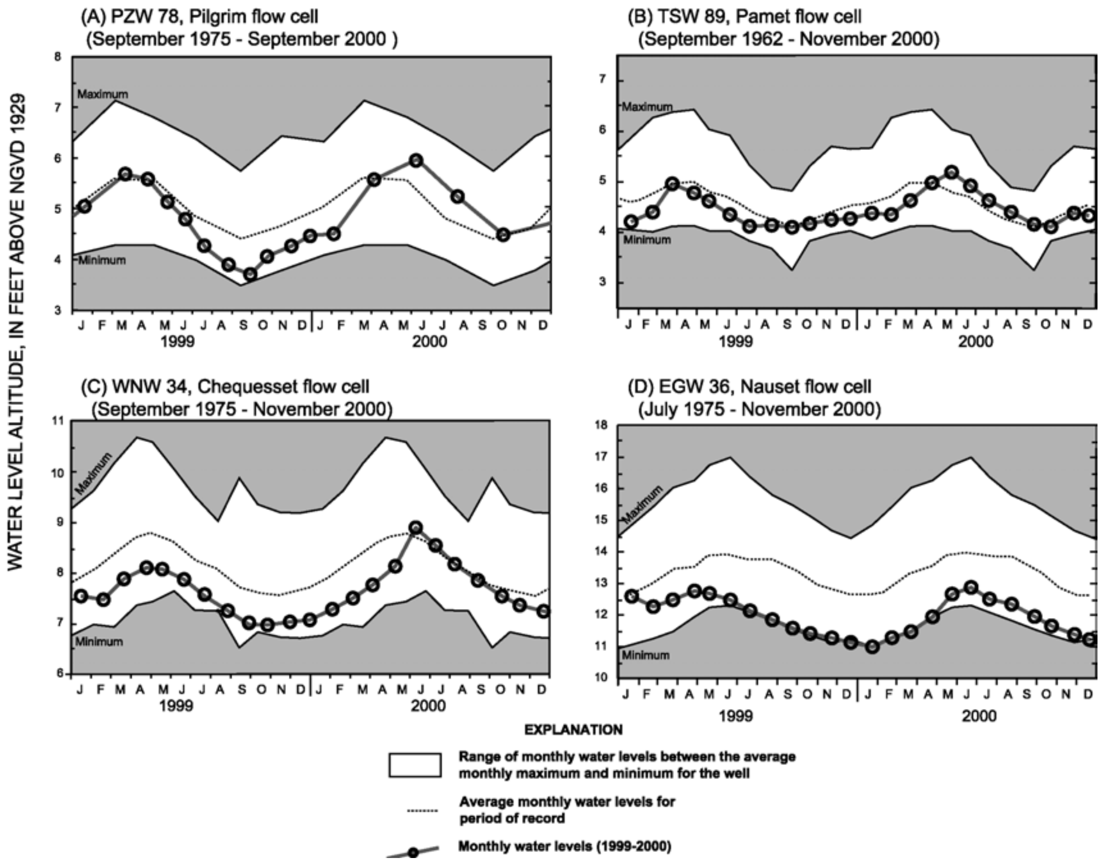


Figure 19. Current conditions hydrographs for four protocol wells from different Lower Cape Cod ground-water-flow cells. Vertical scales and lengths of record vary.

Table 16. Results of horizontal hydraulic-gradient analysis based on water levels measured in wells EGW 52, EGW 51, and EGW 36 for the protocol period.

Date	Gradient magnitude, in feet per feet	Gradient direction, in degrees east of true north	Altitude of well EGW 36, in feet above NGVD29
3-25-99	0.00071	140.45	12.48
4-13-99	0.00073	143.01	12.72
5-21-99	0.00081	143.42	12.68
6-21-99	0.00083	144.08	12.47
7-21-99	0.00078	147.46	12.13
8-24-99	0.00077	145.82	11.85
9-23-99	0.00092	138.42	11.58
10-23-99	0.00085	136.87	11.41
11-23-99	0.00080	137.15	11.27
12-22-99	0.00079	133.89	11.13
1-24-00	0.00077	132.40	10.99
average	0.00080	140.27	11.88
range	0.00021	15.06	1.48

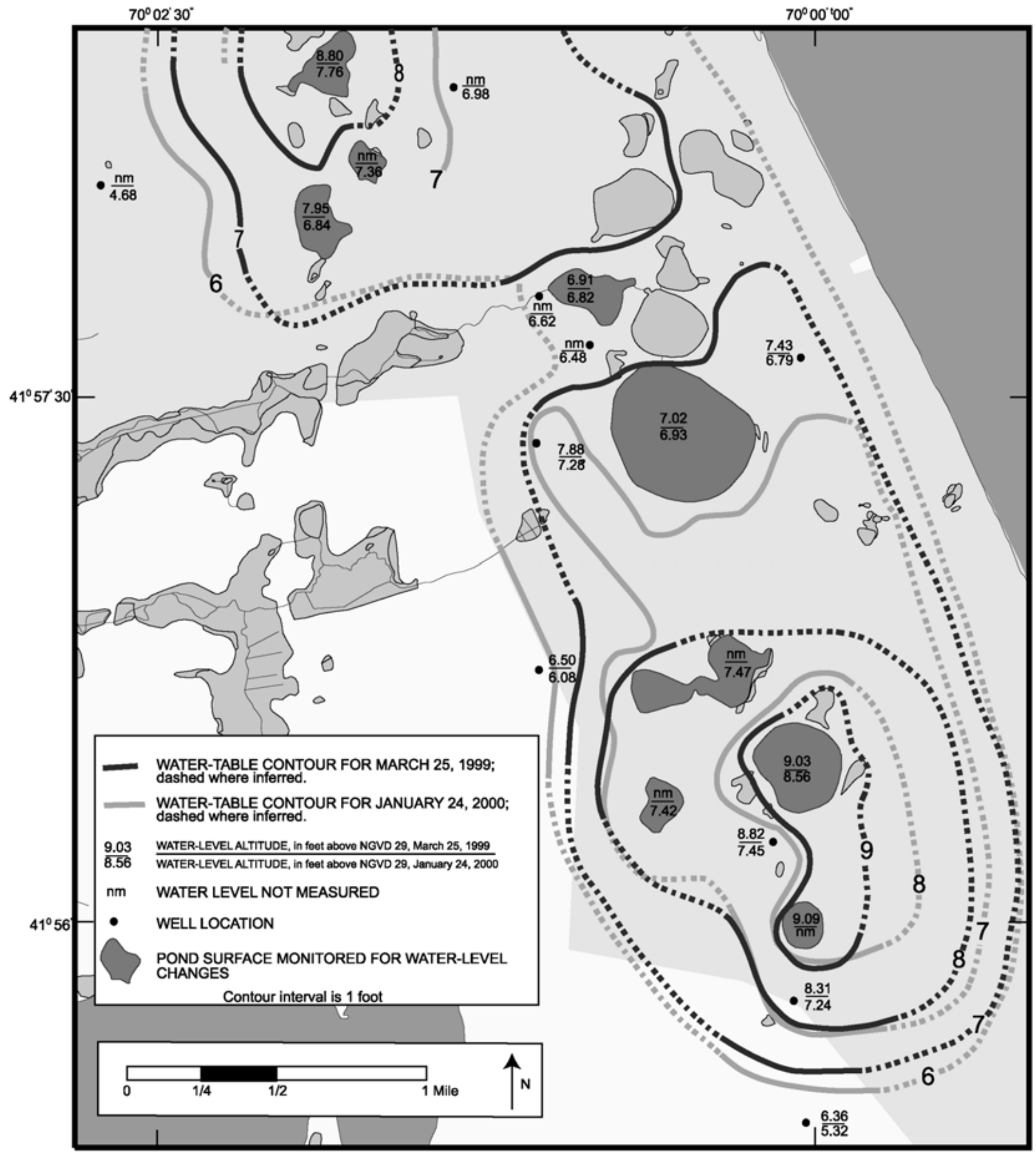
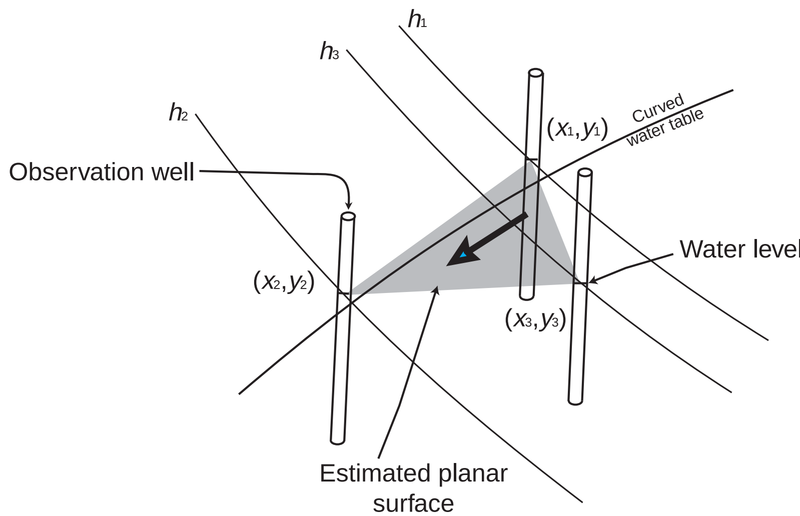


Figure 20. An example of a water-table map for an area near the top of the Chequesset flow cell for two different measurement dates.



$$\text{Magnitude} = [(dh/dx)^2 + (dh/dy)^2]^{1/2} \text{ (in feet/feet), and} \quad (1)$$

$$\text{Direction} = \arctan[(dh/dx)/(dh/dy)] \text{ (in degrees),} \quad (2)$$

Where

dh/dx	is $1/2A\,[h_1(y_2\text{-}y_3) + h_2(y_3\text{-}y_1) + h_3(y_1\text{-}y_2)]$,
dh/dy	is $1/2A\,[h_1(x_3\text{-}x_2) + h_2(x_1\text{-}x_3) + h_3(x_2\text{-}x_1)]$,
A	is $[x_2y_3 - x_3y_2 + x_3y_1 - x_1y_3 + x_1y_2 - x_2y_1]/2$,
x_i	is x coordinate of the location of well i, relative to a common datum
y_i	is y coordinate of the location of well i, relative to a common datum,
h_i	is measured hydraulic head in well i, relative to a common datum, and
i	is the well number.

Figure 21. Schematic diagram of a three-point triangulation for hydraulic-gradient analysis [Modified from McCobb and others, 1999a].

Streamflow

It is common to develop an empirical relation between stream discharge and stream stage called a rating curve. A rating curve for a stream allows stage measurements to be converted to streamflow measurements without a time-consuming streamflow measurement. On a rating curve, stage versus discharge (for the same measurement time) is plotted at different stage heights throughout the historical fluctuation in stage (Kennedy, 1984). Rating curves often take many years of data collection to develop and can shift over time as stream-channel conditions change. An example of a rating curve for a Cape Cod stream can be seen in figure 22. The Quashnet River station is a continuous-record station (011058837) located on Western Cape Cod in Mashpee, Massachusetts. Stage has been measured continuously and discharge periodically at the Quashnet River station since October 1988. The rating curve for the period of record has been developed on the basis of monthly measurements. The measurements made during the protocol period are plotted and numbered on the rating curve.

Another type of hydrograph is the stage hydrograph. The stage of a pond or stream like that for ground-water levels can be plotted over time. The surface-water stages can also be plotted with ground-water levels to show their relation. Figure 23 shows stage hydrographs for the Herring River station (011058793) near Wellfleet, MA, for Herring Pond, and for well WNW 122 near the head of the Herring River at the Herring Pond outlet. This figure shows the relation between the stages of Herring Pond and the Herring River, and heads in a nearby monitoring well. The Herring River flows from Herring Pond, so the pond is always at a higher water level (hydraulic head). The level in well WNW 122 varied throughout the protocol period, but generally was at a level between the pond and stream. When some pond levels were high, however, the well level was higher than the pond; this difference indicates local ground-water flow towards the pond.

For design or regulatory purposes, it may be necessary to know how often the discharge of a stream meets or exceeds a given value (Fetter, 1994). Duration curves are an analytical tool created by ranking the discharge data from greatest to least. The chance that a given flow will be equaled or exceeded, expressed as a percentage, is determined by the equation:

$$P = 100(m) / (n + 1),$$

Where m = serial rank, and
n = the number of data values.

Figure 24 is an example of a duration curve for the Quashnet River (station 011058837) on Western Cape Cod for water years 1989 to 2000. This plot shows, for example, that at this site, discharge exceeds 20 ft^3/sec (0.57 m^3/sec) about 17 % of the time. This information can be critical in determining the adequacy of streamflow to meet biological and ecological requirements.

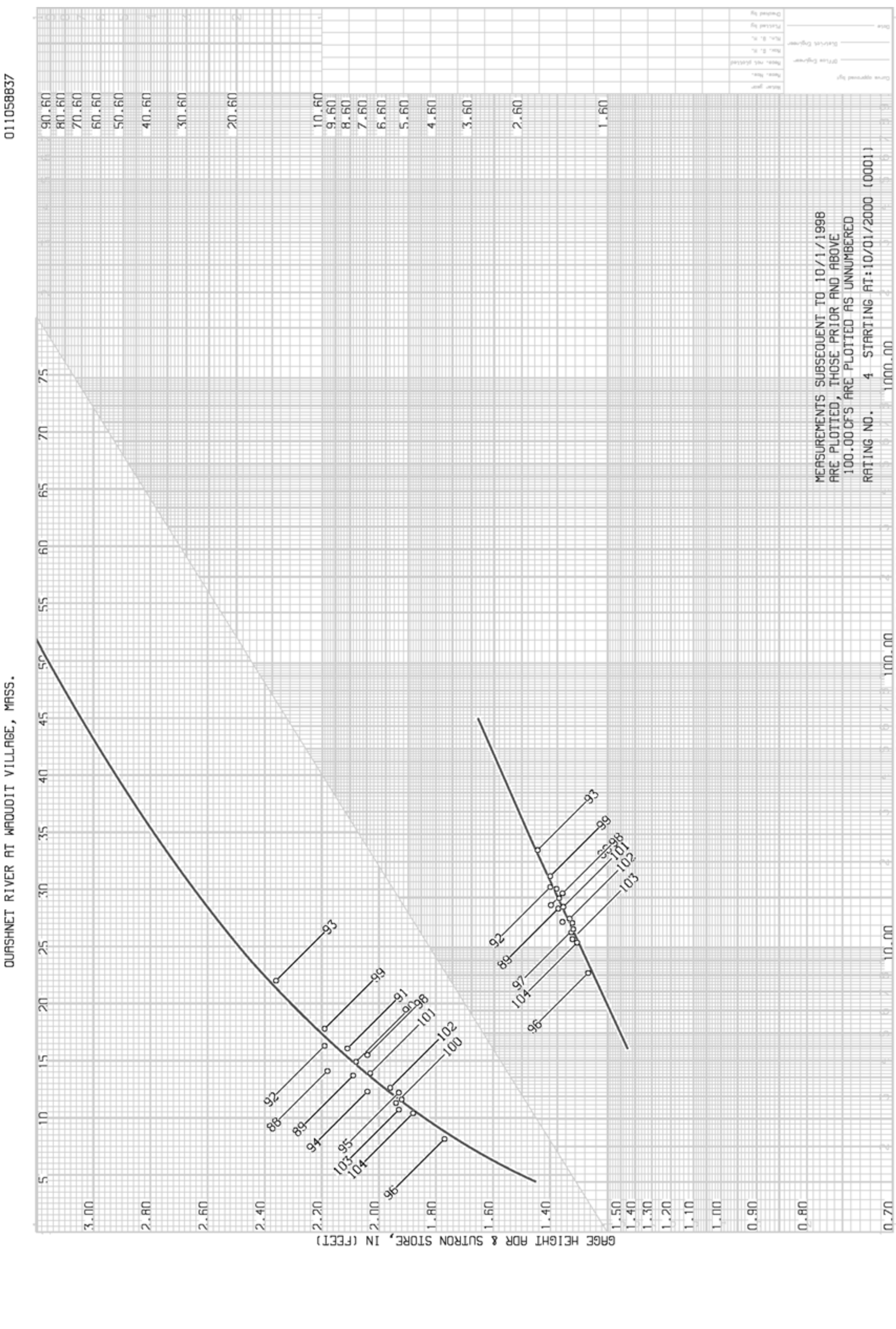


Figure 22. An example of a discharge-rating curve for the Quashnet River stream-gaging station (011058837), Cape Cod, Mass., for the protocol measurement period.

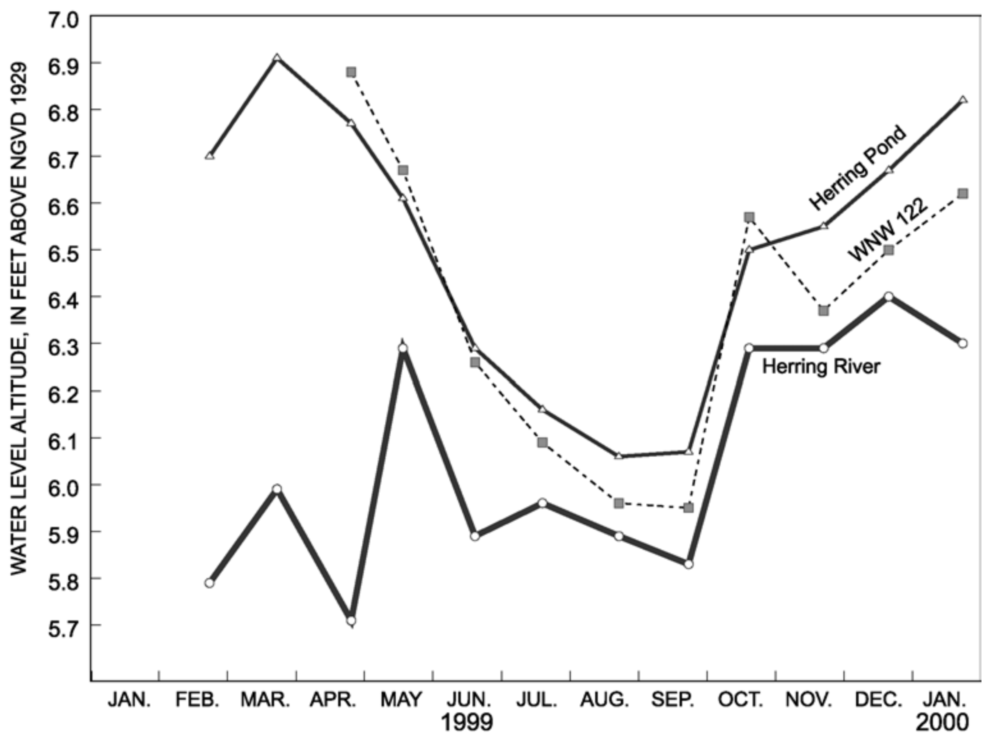


Figure 23. An example of a stage hydrograph for the Herring River stream-gaging station (011058793) near Wellfleet, Mass., Herring Pond, and well WNW 122 near the head of the Herring River for the protocol-monitoring period.

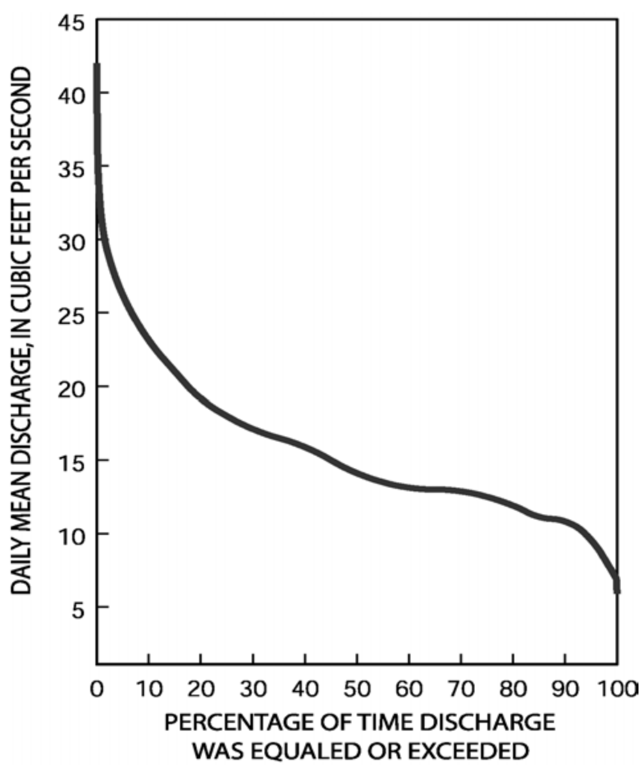


Figure 24. Flow-duration curve of daily mean discharge at the Quashnet River stream-gaging station (011058837) on western Cape Cod for water years 1989-2000.

EQUIPMENT LISTS

Ground-Water Equipment and Supplies

The required equipment for site clearing, monitoring-well installation, reference-point leveling, and water-level measurements is listed in table 17.

Streamflow-Measurement Equipment

The required equipment for measuring streamflow and determining reference-point elevation is listed in table 18.

Pond and Seasonal Wetlands

The required equipment for installing, operating, and maintaining a siphon gage and determining reference-point elevation is listed in table 19.

Table 17. Required equipment for site clearing, monitoring-well installation, reference-point leveling, and water-level measurements.

Installation Equipment and Supplies	***Purpose***
Shovel	To clear augered material, fill hole
Hoe	To mix concrete
Iron Rake	To finish grade site
Concrete mixing bucket	To mix concrete
5-gallon water bucket	To hold water needed for concrete
Rags	To clean equipment
Hard Hat	To protect personnel
Gloves	To protect personnel
Eye protection	To protect personnel
Steel-toed boots	To protect personnel
Wooden stakes	To pre-mark site
Flagging tape	To pre-mark site or trail to site
Brush clippers	To clear land
Chainsaw	To clear land
Gasoline/oil	To fuel equipment
Chain bar oil	To lubricate equipment
Chaps	To protect personnel
Helmet with face shield	To protect personnel
Hacksaw	To trim well casing
File	To trim well casing
Permanent marker	To label well with name and MP
GPS unit	To survey well location
Installation Equipment and Supplies (cont.)	***Purpose***
Clipboard	To protect field sheet and provide surface
Field sheets (construction/site sketch)	To record field notes
Protective well casing	To protect well from contact and access
Lock	To protect public and equipment
Concrete (60 lbs/well)	To secure protective casing
PVC casing, end point	To plug bottom of well
PVC casing, 10 ft, sch. 40	To construct well
PVC screen, 2.5 ft, 0.010-in. slot	To provide openings through which water flows in and out of well
Sand/gravel filter pack	To surround well screen with material that allows unrestricted flow
Well seal material	To stop vertical movement of water around well casing

Leveling Equipment	***Purpose***
Level	To determine vertical elevation of well MP
Tripod	To hold level stable
Stadia Rod	To provide vertical "ruler" in 0.01-ft increments
Rod level	To assist in keeping stadia rod level
Level note field sheet	To record level information

Water-level Measurement Equipment and Supplies	***Purpose***
Well keys	To provide well access
Pipe wrenches, 18" and 36"	To open wells
Water-level tape	To measure water-level
Sounding tape with weight	To sound well depth
Water-level field sheet	To record water levels

Table 18. Required equipment for conducting streamflow monitoring and determining reference point elevation.

Streamgaging Equipment	***Purpose***
Personal Floatation Device	To protect personnel
Wading rod	To measure depth and meter height setting
AA standard meter	To measure streamflow
Pygmy meter	To measure streamflow
Headset or Current Meter Digitizer	To record meter rotations
Tagline	To measure cross-section length and position
Discharge field sheet	To record measurement
Clipboard	To protect field sheet
Gloves	To protect personnel
Weed wacker (manual)	To clear algae or weeds from section
Brush cutter	To clear brush or debris from section and shore
Hip waders	To protect personnel
Chest waders	To protect personnel
Cell phone	To protect personnel
Copy of discharge rating	To check that measurement is within 5% of curve
Site sketch	To find measurement section
Vehicle with blinking beacon light	To protect personnel
Bridge crane (when ness.)	To support cable, weights, and meter
Bridge weights (when necessary)	To stabilize meter on bridge measurements
Bridge cable	To hang meter and weights from bridge

Leveling Equipment	***Purpose***
Level	To measure level
Tripod	To hold level stable
Stadia rod	To provide vertical "ruler" in 0.01-ft increments
Rod level	To assist in keeping stadia rod level
Leveling field sheet	To record leveling information

Table 19. Required equipment for installing, operating, and maintaining a siphon gage, and determining reference-point elevation.

Siphon Gage Installation Equipment	*Purpose*
Personal Floatation Device	To protect personnel
Shovel	To clear augered material, fill hole
Hoe	To mix concrete
Iron Rake	To finish grade site
Concrete mixing bucket	To mix concrete
5-gallon water bucket	To mix concrete and clean equipment
Rags	To clean equipment
Hard Hat	To protect personnel
Gloves	To protect personnel
Eye protection	To protect personnel
Steel-toed boots	To protect personnel
Wooden stakes	To pre-mark site
Flagging tape	To pre-mark site or trail
Brush clippers	To clear land
Chain saw	To clear land
Gasoline/oil	To fuel equipment
Chain bar oil	To lubricate equipment
Chaps	To protect personnel
Helmet with face shield	To protect personnel
Hacksaw	To trim well casing
File	To trim well casing
Permanent marker	To label well name and MP

Siphon Gage Installation Equipment	*Purpose*
Clipboard	To protect field sheet, provide surface
Gloves	To protect personnel
Brush cutter	To clear land
Hip waders	To access the pond
Chest waders	To access the pond
Cell phone	To protect personnel and provide communication
Pick axe	To trench siphon line
Cordless drill and bits	To drill siphon tube hole
Silicone sealant	To seal siphon tube hole in well
Gasoline pump	To jet siphon tube on pond-bottom
Reducing coupling	To creates jet
Jet wand	To provide handle for jet
200-ft flexible fire hose	To transport jetted water
Hose intake screen	To prevent pump from sucking up debris
Siphon Supplies	***Purpose***
PVC casing, 3-in., sch. 40	To construct standpipe
PVC, 3-in. bottom plug	To plug bottom of standpipe
Protective casing	To protect well from contact and access
Lock	To protect public and equipment
¾” polyethylene tubing	To connect standpipe to pond
Concrete block	To anchor tubing to bottom of pond
X-large cable ties	To anchor tubing to bottom of pond

Leveling Equipment	***Purpose***
Level	To make level measurement
Tripod	To hold level stable
Stadia rod	To provide vertical “ruler” in 0.01-ft increments
Rod level	To assist in keeping stadia rod level
Leveling fieldsheet	To record notes

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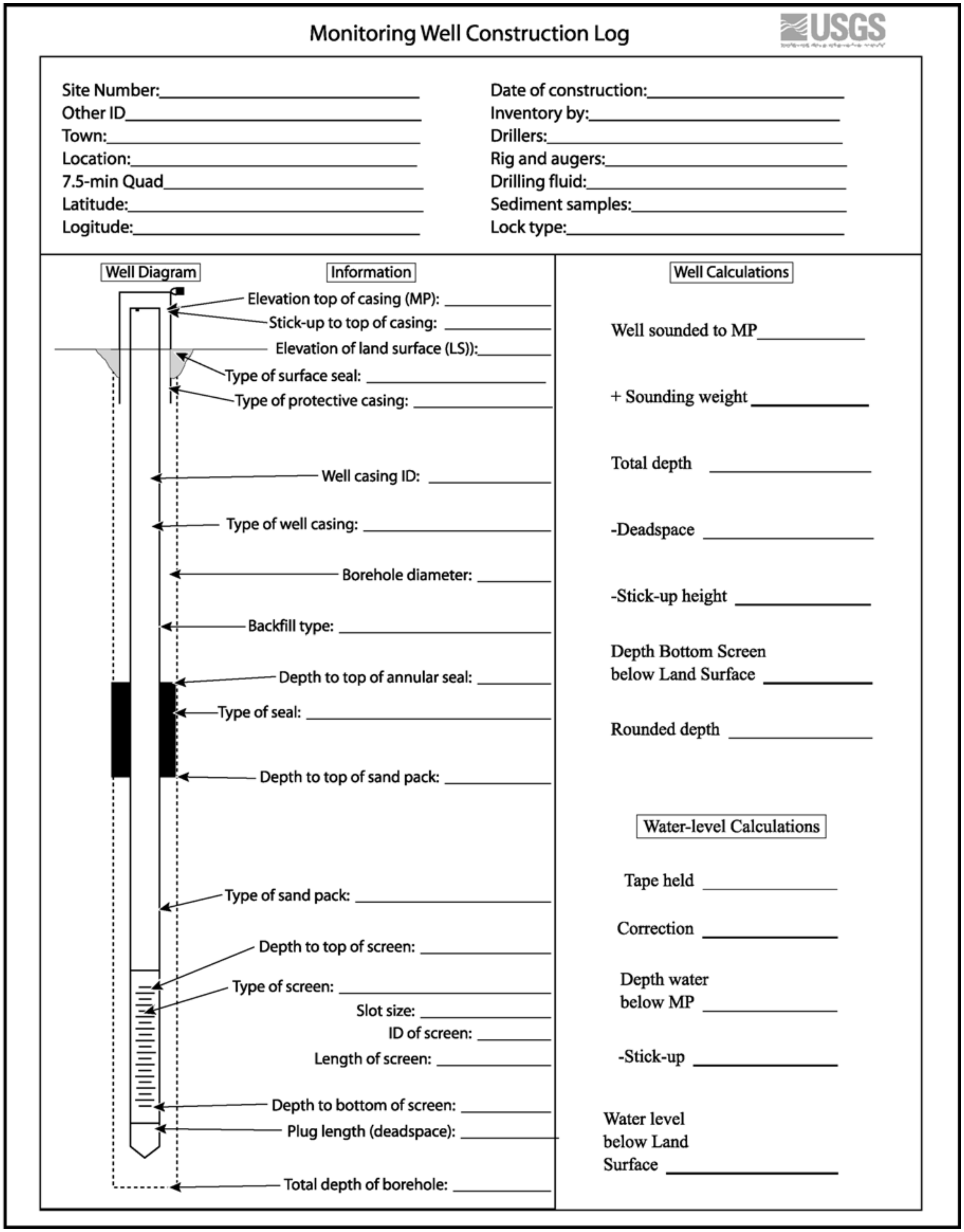


Monitoring Well Construction Log

USGS

Site Number:________________
Other ID________________
Town:________________
Location:________________
7.5-min Quad________________
Latitude:________________
Logitude:________________

Date of construction:________________
Inventory by:________________
Drillers:________________
Rig and augers:________________
Drilling fluid:________________
Sediment samples:________________
Lock type:________________

Well Diagram / **Information**

Elevation top of casing (MP): ________
Stick-up to top of casing: ________
Elevation of land surface (LS)):________
Type of surface seal: ________
Type of protective casing: ________
Well casing ID: ________
Type of well casing: ________
Borehole diameter: ________
Backfill type: ________
Depth to top of annular seal: ________
Type of seal: ________
Depth to top of sand pack: ________
Type of sand pack: ________
Depth to top of screen: ________
Type of screen: ________
Slot size: ________
ID of screen: ________
Length of screen: ________
Depth to bottom of screen: ________
Plug length (deadspace): ________
Total depth of borehole: ________

Well Calculations

Well sounded to MP________
+ Sounding weight ________
Total depth ________
-Deadspace ________
-Stick-up height ________
Depth Bottom Screen below Land Surface ________
Rounded depth ________

Water-level Calculations

Tape held ________
Correction ________
Depth water below MP ________
-Stick-up ________
Water level below Land Surface ________

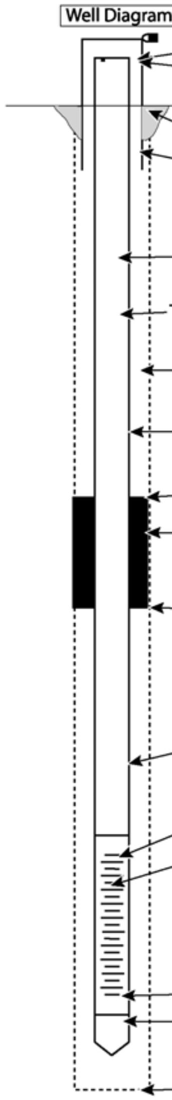
Appendix 1a. Example of a monitoring-well construction log.

Monitoring Well Construction Log

USGS

Site Number:	TSW 257-0035	Date of construction:	09-08-1999
Other ID	Lombard Hollow Site	Inventory by:	T. McCobb
Town:	Truro, MA	Drillers:	G. Berwick and D. Kraemer
Location:	In Lombard Hollow, 0.5 mi from Rt. 6	Rig and augers:	USGS-NH, CME-75 w/3.25" ID HSA
7.5-min Quad	Wellfleet, MA	Drilling fluid:	Town of Truro water
Latitude:	415808	Sediment samples:	None collected
Logitude:	0700243	Lock type:	USGS #2640

Well Diagram



Information

Elevation top of casing (MP):	27.09'
Stick-up to top of casing:	1.63'
Elevation of land surface (LS)):	25.46'
Type of surface seal:	Concrete
Type of protective casing:	4" sq. galv. steel
Well casing ID:	2.00"
Type of well casing:	Sch. 40 PVC, flush-joint, threaded
Borehole diameter:	6"
Backfill type:	Ambient sand
Depth to top of annular seal:	N/A
Type of seal:	No seal
Depth to top of sand pack:	N/A
Type of sand pack:	N/A
Depth to top of screen:	32.58'
Type of screen:	Sch. 40 slotted screen
Slot size:	0.010"
ID of screen:	2.00"
Length of screen:	1.97'
Depth to bottom of screen:	34.55'
Plug length (deadspace):	0.64'
Total depth of borehole:	36'

Well Calculations

Well sounded to MP	36.56
+ Sounding weight	0.26
Total depth	36.82
-Deadspace	0.64
-Stick-up height	1.63
Depth Bottom Screen below Land Surface	34.55
Rounded depth	35

Water-level Calculations

Tape held	21.89
Correction	-----
Depth water below MP	21.89
-Stick-up	1.63
Water level below Land Surface	20.26

Appendix 1b. Monitoring-well construction log for well TSW 257-0035.

N

Detail of Well Layout

Well Site Sketch

Site Number:____________________________

Date of installation:________________________

Land owner:______________________________

Contact number:___________________________

Lock number:_____________________________

Key holder:______________________________

USGS 7.5-min Quad:_______________________

Latitude:________________________________

Longitude:_______________________________

Protective casing:__________________________

Well stickup:______________________________

Well location description:____________________

____

____

____

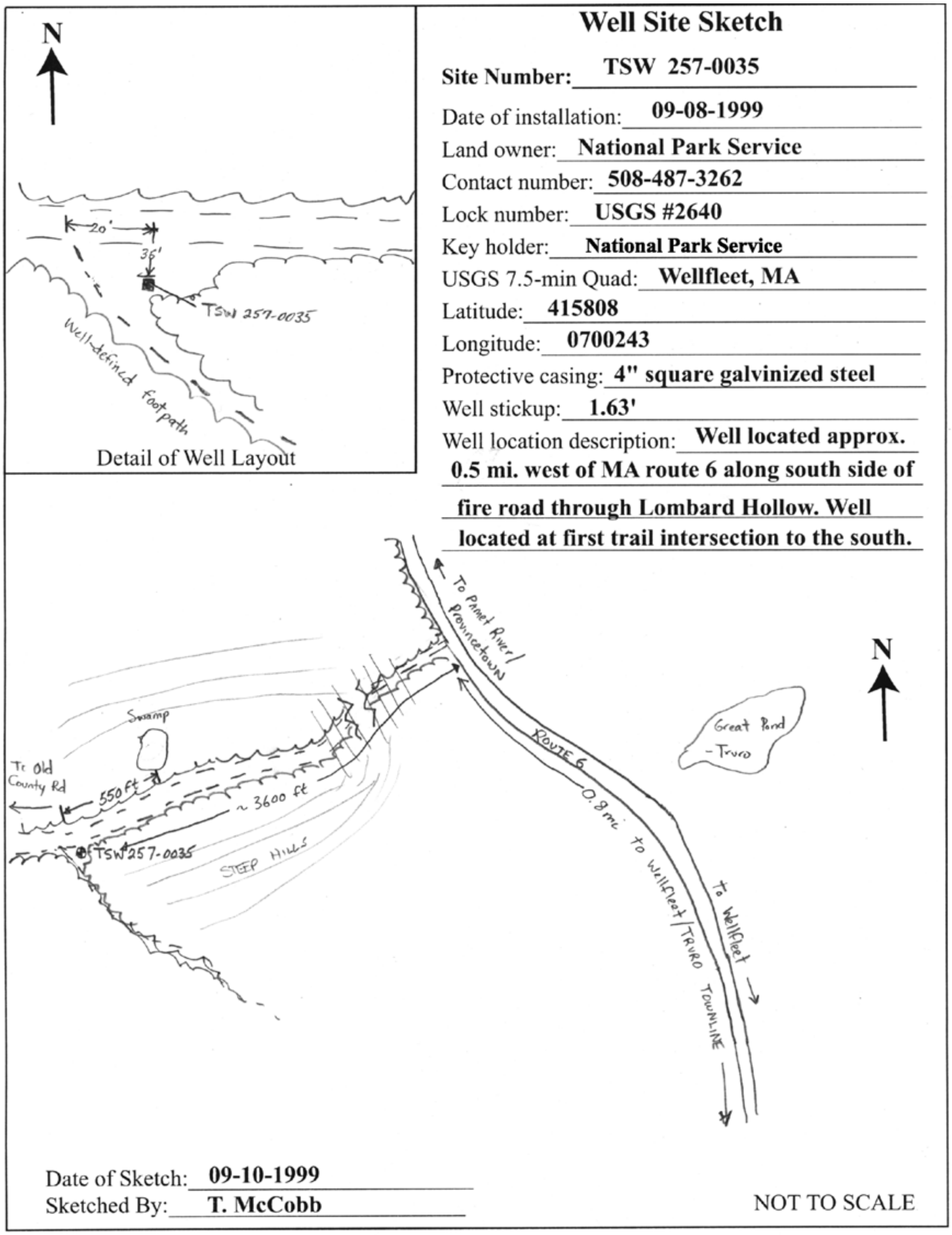
N

Date of Sketch:________________________

Sketched By:__________________________

NOT TO SCALE

Appendix 2a. Example field sheet for a well site sketch map



Well Site Sketch

Site Number: TSW 257-0035

Date of installation: 09-08-1999

Land owner: National Park Service

Contact number: 508-487-3262

Lock number: USGS #2640

Key holder: National Park Service

USGS 7.5-min Quad: Wellfleet, MA

Latitude: 415808

Longitude: 0700243

Protective casing: 4" square galvinized steel

Well stickup: 1.63'

Well location description: Well located approx. 0.5 mi. west of MA route 6 along south side of fire road through Lombard Hollow. Well located at first trail intersection to the south.

Date of Sketch: 09-10-1999

Sketched By: T. McCobb

NOT TO SCALE

Appendix 2b. Sketched location map for well TSW 257-0035

RECORD OF WELL CONSTRUCTION

BOREHOLE DATA: **WELL SITE:**

BOREHOLE DIAMETER: ____________ inches (or centimeters);

TOTAL DEPTH OF BOREHOLE: _____ feet (or meters);

APPROXIMATE DEPTH TO WATER: _______________ feet (or meters)

Illustrate thickness and types of lithologic materials

land surface

DESCRIPTION OF GEOLOGIC MATERIALS				FROM	TO	THICKNESS
LITHOLOGY	SORTING	COLOR	WET OR DRY	feet (or meters)	feet (or meters)	feet (or meters)

Appendix 3a. Example of a lithologic construction log field sheet

RECORD OF WELL CONSTRUCTION

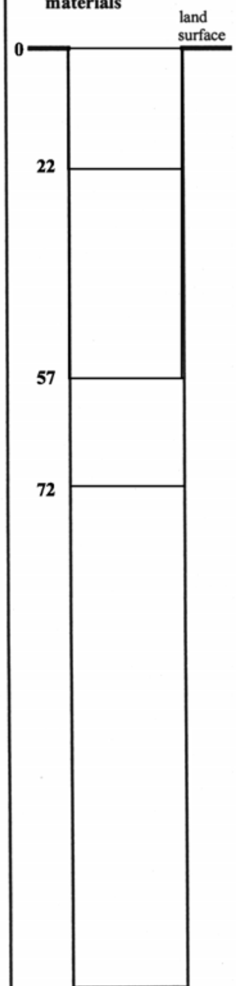
BOREHOLE DATA: **WELL SITE: EGW-36**

BOREHOLE DIAMETER: **6** inches (or centimeters);

TOTAL DEPTH OF BOREHOLE: **72** feet (or meters);

APPROXIMATE DEPTH TO WATER: **44** feet (or meters)

Illustrate thickness and types of lithologic materials



DESCRIPTION OF GEOLOGIC MATERIALS				FROM	TO	THICKNESS
LITHOLOGY	SORTING	COLOR	WET OR DRY	feet (or meters)	feet (or meters)	feet (or meters)
Sand, medium to coarse, gravel and cobbles	---	**Brown**	**Dry**	**0**	**22**	**22**
Sand, medium to coarse, gravel	---	**Brown**	**Dry/Wet**	**22**	**57**	**35**
Sand, coarse	---	**Brown**	**Wet**	**57**	**72**	**15**

Appendix 3b. Lithologic construction log for long-term well EGW-36

9-276
(Rev. 7-67)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Station Number

LEVEL NOTES

Stream____________________

Locality____________________

Party____________________ Date______________, 19____

STATION	B. S.	HT. INST.	F. S.	ELEVA-TION	REMARKS

No._____of_____sheets________Comp. by__________Chk. by__________

☆ GPO 1984 O-452-826

Appendix 4a. Example field sheet for leveling of well and stage measuring points

9-276
(Rev. 7-67)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Station Number Duck Pond

LEVEL NOTES

Stream Duck Pond Siphon gage

Locality Cape Cod National Seashore, Wellfleet, MA

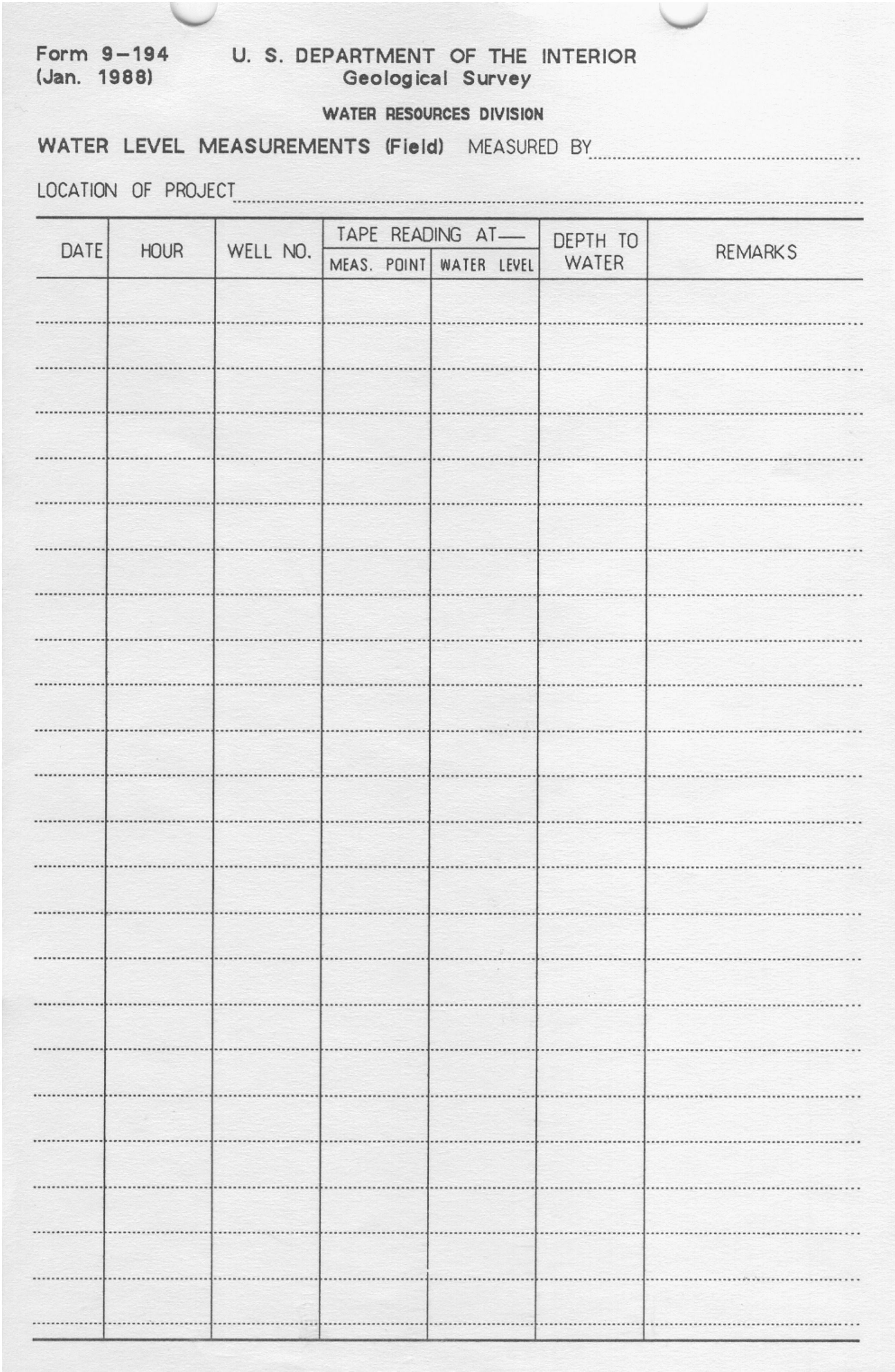
Party McCobb, Gwilliam Date 11-18, 1999

STATION	B. S.	HT. INST.	F. S.	ELEVATION	REMARKS
HW13	6.180	16.782		10.602	Known MP
Gage MP			2.883	13.899	
Duck Pond	7.125	16.411	7.496	9.286	Rock at shoreline
Gage MP			2.520	13.891	
HW13			5.824	10.587	diff = -0.005
					corr = +0.002
				Duck Pond elevation = 9.288	

No.___of___sheets___ Comp. by___ Chk. by___

☆ GPO 1984 O-452-826

Appendix 4b. Leveling notes from Duck Pond, Wellfleet, MA



Form 9–194
(Jan. 1988)

U. S. DEPARTMENT OF THE INTERIOR
Geological Survey

WATER RESOURCES DIVISION

WATER LEVEL MEASUREMENTS (Field) MEASURED BY ....

LOCATION OF PROJECT ....

DATE	HOUR	WELL NO.	TAPE READING AT—		DEPTH TO WATER	REMARKS
			MEAS. POINT	WATER LEVEL		

Appendix 5a. Example of a water-level measurement field sheet

9-194
November 1949

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Electric Tape #1

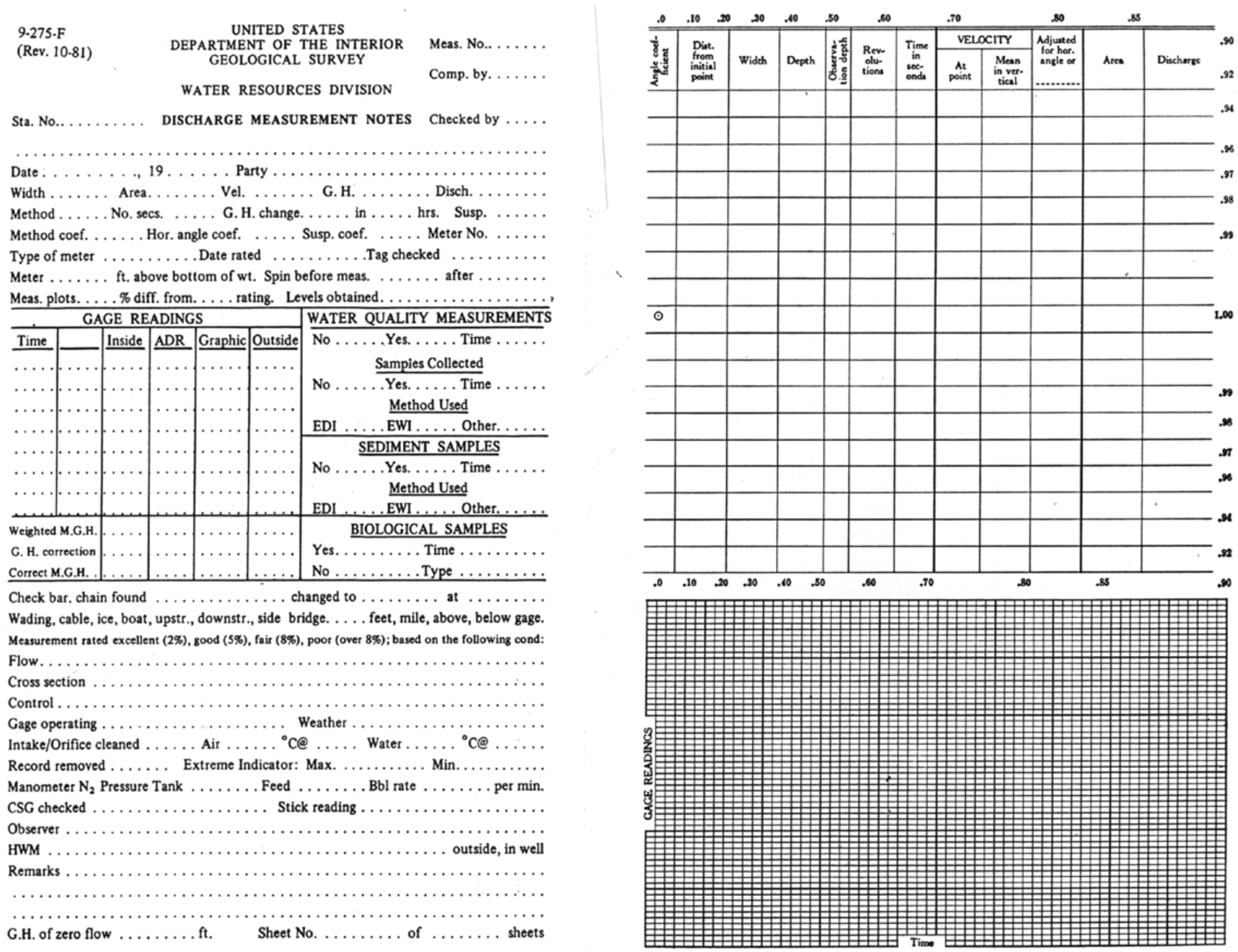
WATER LEVEL MEASUREMENTS (Field) Measured by E. Gwilliam (NPS)

Location of Project Cape Cod National Seashore

DATE 2000	HOUR	WELL NO.	TAPE READING AT— Meas. point	TAPE READING AT— Water level	DEPTH TO WATER	REMARKS
1/24	0740	EGW-36	44.14	—	44.14	
1/24	0746	EGW-37	19.16	—	19.16	
1/24	0758	EGW-48	15.18	—	15.18	
1/24	0809	EGW-49	36.58	—	36.58	
1/24	0822	EGW-50	10.53	—	10.53	
1/24	0830	EGW-51	6.42	—	6.42	
1/24	0900	EGW-52	46.11	—	46.11	
1/24	0940	EGW-53	7.91	—	7.91	
1/24	1549	PZW-78	13.18	—	13.18	
1/24	1100	TSW-1	14.29	—	14.29	
1/24	1109	TSW-89	12.25	—	12.25	
1/24	1120	TSW-92	59.20	—	59.20	
1/24	1123	TSW-106	67.81	—	67.81	
1/24	1131	TSW-134	49.97	—	49.97	
1/24	1139	TSW-145	4.75	—	4.75	
1/24	1148	TSW-179	5.67	—	5.67	
1/24	1200	TSW-203	23.65	—	23.65	
1/24	1206	TSW-216	100.27	—	100.27	
1/24	1209	TSW-256	50.53	—	50.53	
1/24	1240	TSW-257	22.07	—	22.07	
1/24	1258	TSW-258	125.40	—	125.40	
1/24	1305	TSW-261	33.58	—	33.58	
1/24	1312	TSW-262	2.04	—	2.04	

U.S. GOVERNMENT PRINTING OFFICE: 16—83878p-1

Appendix 5b. Water-level measurement field sheet for CACO wells during January 2000.



9-275-F
(Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

Meas. No. . . . . . .
Comp. by. . . . . . .

Sta. No. . . . . DISCHARGE MEASUREMENT NOTES Checked by . . . . .

Date . . . ., 19 . . . . . . Party . . . .
Width . . . . Area. . . . . Vel. . . . . G. H. . . . . Disch. . . . .
Method . . . . . . No. secs. . . . . . G. H. change. . . . . . in . . . . . hrs. Susp. . . . . . .
Method coef. . . . . . . Hor. angle coef. . . . . . Susp. coef. . . . . . Meter No. . . . . . .
Type of meter . . . . .Date rated . . . . .Tag checked . . . .
Meter . . . . ft. above bottom of wt. Spin before meas. . . . . after . . . .
Meas. plots. . . . . % diff. from. . . . . rating. Levels obtained. . . . .

GAGE READINGS					
Time		Inside	ADR	Graphic	Outside
Weighted M.G.H.					
G. H. correction					
Correct M.G.H.					

WATER QUALITY MEASUREMENTS
No . . . . . .Yes. . . . . . Time . . . . . .
Samples Collected
No . . . . . .Yes. . . . . . Time . . . . . .
Method Used
EDI . . . . .EWI . . . . . Other. . . . . .

SEDIMENT SAMPLES
No . . . . . .Yes. . . . . . Time . . . . . .
Method Used
EDI . . . . .EWI . . . . . Other. . . . . .

BIOLOGICAL SAMPLES
Yes. . . . . Time . . . .
No . . . . .Type . . . .

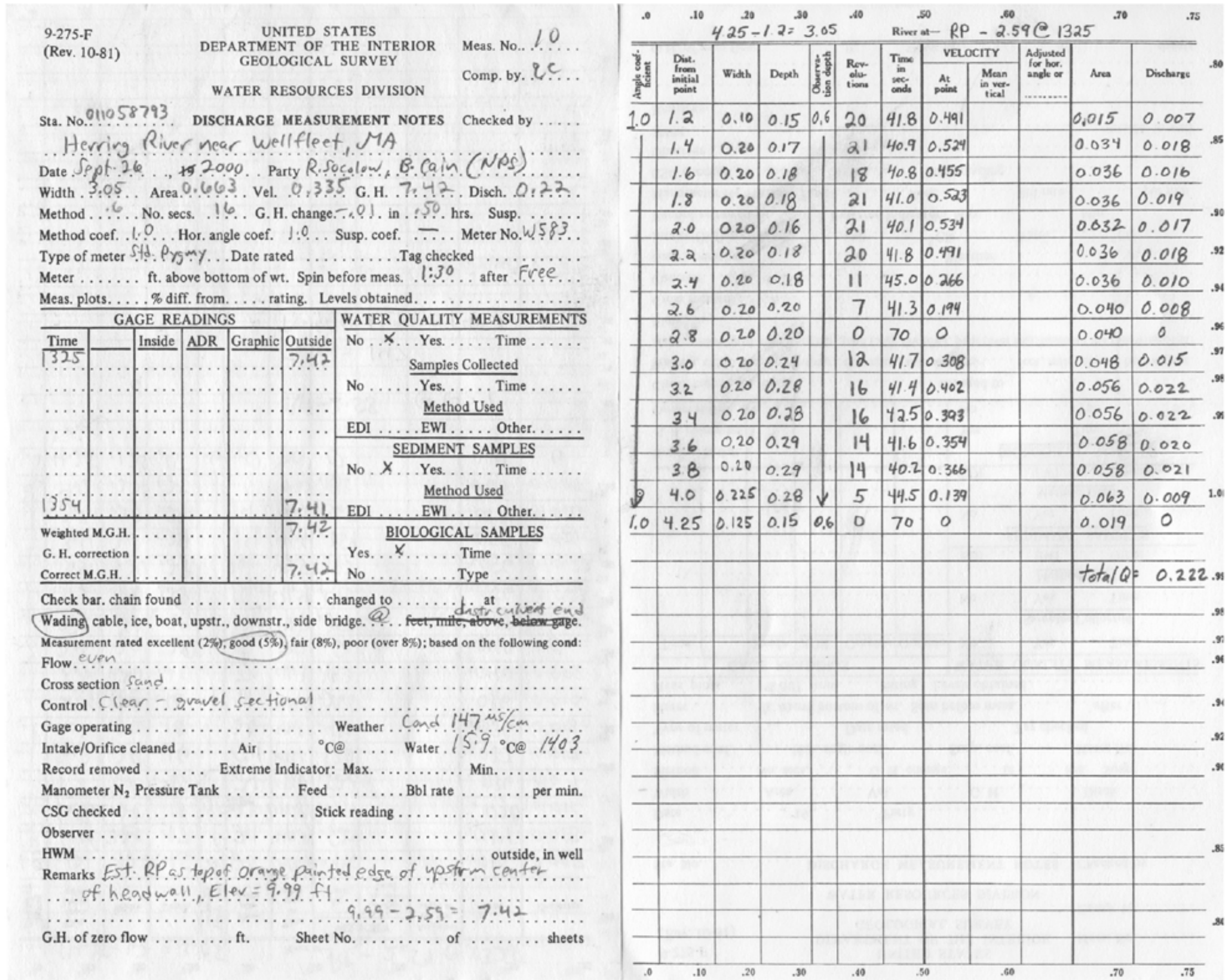
Check bar. chain found . . . . changed to . . . . at . . . .
Wading, cable, ice, boat, upstr., downstr., side bridge. . . . . feet, mile, above, below gage.
Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:
Flow. . . . .
Cross section . . . .
Control . . . .
Gage operating . . . . Weather . . . .
Intake/Orifice cleaned . . . . . . Air . . . . . . °C@ . . . . . Water . . . . . . °C@ . . . . . .
Record removed . . . . Extreme Indicator: Max. . . . . Min. . . . .
Manometer N_2 Pressure Tank . . . . Feed . . . . Bbl rate . . . . per min.
CSG checked . . . . Stick reading . . . .
Observer . . . .
HWM . . . . outside, in well
Remarks . . . .
G.H. of zero flow . . . . ft. Sheet No. . . . . of . . . . sheets

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Adjusted for hor. angle or	Area	Discharge

GAGE READINGS

Time

Appendix 6a. Example of a USGS discharge measurement field sheet



9-275-F
(Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

Meas. No. 10
Comp. by. RC

Sta. No. 011058793 DISCHARGE MEASUREMENT NOTES Checked by

Herring River near Wellfleet, MA

Date Sept 26, 2000 Party R. Socolow, B. Cain (NPS)

Width 3.05 Area 0.663 Vel. 0.335 G. H. 7.42 Disch. 0.222

Method .6 No. secs. 16 G. H. change -.01 in :50 hrs. Susp.

Method coef. 1.0 Hor. angle coef. 1.0 Susp. coef. — Meter No. W583

Type of meter Std. Pygmy Date rated Tag checked

Meter ft. above bottom of wt. Spin before meas. 1:30 after Free

Meas. plots % diff. from rating. Levels obtained

GAGE READINGS

Time	Inside	ADR	Graphic	Outside
1325				7.42
1354				7.41
Weighted M.G.H.				7.42
G. H. correction				
Correct M.G.H.				7.42

WATER QUALITY MEASUREMENTS

No X Yes Time

Samples Collected

No Yes Time

Method Used

EDI EWI Other

SEDIMENT SAMPLES

No X Yes Time

Method Used

EDI EWI Other

BIOLOGICAL SAMPLES

Yes X Time

No Type

Check bar, chain found changed to at

Wading, cable, ice, boat, upstr., downstr., side bridge @ dist current end feet, mile, above, below gage.

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:

Flow even

Cross section sand

Control Clear - gravel sectional

Gage operating Weather Cond 147 uS/cm

Intake/Orifice cleaned Air °C@ Water 15.9 °C@ 1403

Record removed Extreme Indicator: Max. Min.

Manometer N_2 Pressure Tank Feed Bbl rate per min.

CSG checked Stick reading

Observer

HWM outside, in well

Remarks Est. RP as top of orange painted edge of upstrm center of headwall, Elev = 9.99 ft

9.99 - 2.59 = 7.42

G.H. of zero flow ft. Sheet No. of sheets

4.25 - 1.2 = 3.05 River at — RP - 2.59 @ 1325

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	Velocity At point	Velocity Mean in vertical	Adjusted for hor. angle or	Area	Discharge
1.0	1.2	0.10	0.15	0.6	20	41.8	0.491			0.015	0.007
	1.4	0.20	0.17		21	40.9	0.524			0.034	0.018
	1.6	0.20	0.18		18	40.8	0.455			0.036	0.016
	1.8	0.20	0.18		21	41.0	0.523			0.036	0.019
	2.0	0.20	0.16		21	40.1	0.534			0.032	0.017
	2.2	0.20	0.18		20	41.8	0.491			0.036	0.018
	2.4	0.20	0.18		11	45.0	0.266			0.036	0.010
	2.6	0.20	0.20		7	41.3	0.194			0.040	0.008
	2.8	0.20	0.20		0	70	0			0.040	0
	3.0	0.20	0.24		12	41.7	0.308			0.048	0.015
	3.2	0.20	0.28		16	41.4	0.402			0.056	0.022
	3.4	0.20	0.28		16	42.5	0.393			0.056	0.022
	3.6	0.20	0.29		14	41.6	0.354			0.058	0.020
	3.8	0.20	0.29		14	40.2	0.366			0.058	0.021
	4.0	0.225	0.28		5	44.5	0.139			0.063	0.009
1.0	4.25	0.125	0.15	0.6	0	70	0			0.019	0
										total Q =	0.222

Appendix 6b. Discharge measurement field sheet from Herring River near Wellfleet, MA, September 2000.

STANDARD RATING TABLE NO. 2 FOR AA CURRENT METERS (6/99)
EQUATION: V = 2.2048 R + 0.0178 (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND Revolutions									Seconds
	3	5	7	10	15	20	25	30	40	
40	0.183	0.293	0.404	0.569	0.845	1.12	1.40	1.67	2.22	40
41	0.179	0.287	0.394	0.556	0.824	1.09	1.36	1.63	2.17	41
42	0.175	0.280	0.385	0.543	0.805	1.07	1.33	1.59	2.12	42
43	0.172	0.274	0.377	0.531	0.787	1.04	1.30	1.56	2.07	43
44	0.168	0.268	0.369	0.519	0.769	1.02	1.27	1.52	2.02	44
45	0.165	0.263	0.361	0.508	0.753	0.998	1.24	1.49	1.98	45
46	0.162	0.257	0.353	0.497	0.737	0.976	1.22	1.46	1.94	46
47	0.159	0.252	0.346	0.487	0.721	0.956	1.19	1.43	1.89	47
48	0.156	0.247	0.339	0.477	0.707	0.936	1.17	1.40	1.86	48
49	0.153	0.243	0.333	0.468	0.693	0.918	1.14	1.37	1.82	49
50	0.150	0.238	0.326	0.459	0.679	0.900	1.12	1.34	1.78	50
51	0.147	0.234	0.320	0.450	0.666	0.882	1.10	1.31	1.75	51
52	0.145	0.230	0.315	0.442	0.654	0.866	1.08	1.29	1.71	52
53	0.143	0.226	0.309	0.434	0.642	0.850	1.06	1.27	1.68	53
54	0.140	0.222	0.304	0.426	0.630	0.834	1.04	1.24	1.65	54
55	0.138	0.218	0.298	0.419	0.619	0.820	1.02	1.22	1.62	55
56	0.136	0.215	0.293	0.412	0.608	0.805	1.00	1.20	1.59	56
57	0.134	0.211	0.289	0.405	0.598	0.791	0.985	1.18	1.57	57
58	0.132	0.208	0.284	0.398	0.588	0.778	0.968	1.16	1.54	58
59	0.130	0.205	0.279	0.391	0.578	0.765	0.952	1.14	1.51	59
60	0.128	0.202	0.275	0.385	0.569	0.753	0.936	1.12	1.49	60
61	0.126	0.199	0.271	0.379	0.560	0.741	0.921	1.10	1.46	61
62	0.124	0.196	0.267	0.373	0.551	0.729	0.907	1.08	1.44	62
63	0.123	0.193	0.263	0.368	0.543	0.718	0.893	1.07	1.42	63
64	0.121	0.190	0.259	0.362	0.535	0.707	0.879	1.05	1.40	64
65	0.120	0.187	0.255	0.357	0.527	0.696	0.866	1.04	1.37	65
66	0.118	0.185	0.252	0.352	0.519	0.686	0.853	1.02	1.35	66
67	0.117	0.182	0.248	0.347	0.511	0.676	0.840	1.01	1.33	67
68	0.115	0.180	0.245	0.342	0.504	0.666	0.828	0.991	1.31	68
69	0.114	0.178	0.241	0.337	0.497	0.657	0.817	0.976	1.30	69
70	0.112	0.175	0.238	0.333	0.490	0.648	0.805	0.963	1.28	70
	3	5	7	10	15	20	25	30	40	

STANDARD RATING TABLE NO. 2 FOR AA CURRENT METERS (6/99)
EQUATION: V = 2.2048 R + 0.0178 (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND Revolutions									Seconds
	50	60	80	100	150	200	250	300	350	
40	2.77	3.33	4.43	5.53	8.29	11.04	13.80	16.55	19.31	40
41	2.71	3.24	4.32	5.40	8.08	10.77	13.46	16.15	18.84	41
42	2.64	3.17	4.22	5.27	7.89	10.52	13.14	15.77	18.39	42
43	2.58	3.09	4.12	5.15	7.71	10.27	12.84	15.40	17.96	43
44	2.52	3.02	4.03	5.03	7.53	10.04	12.55	15.05	17.56	44
45	2.47	2.96	3.94	4.92	7.37	9.82	12.27	14.72	17.17	45
46	2.41	2.89	3.85	4.81	7.21	9.60	12.00	14.40	16.79	46
47	2.36	2.83	3.77	4.71	7.05	9.40	11.75	14.09	16.44	47
48	2.31	2.77	3.69	4.61	6.91	9.20	11.50	13.80	16.09	48
49	2.27	2.72	3.62	4.52	6.77	9.02	11.27	13.52	15.77	49
50	2.22	2.66	3.55	4.43	6.63	8.84	11.04	13.25	15.45	50
51	2.18	2.61	3.48	4.34	6.50	8.66	10.83	12.99	15.15	51
52	2.14	2.56	3.41	4.26	6.38	8.50	10.62	12.74	14.86	52
53	2.10	2.51	3.35	4.18	6.26	8.34	10.42	12.50	14.58	53
54	2.06	2.47	3.28	4.10	6.14	8.18	10.23	12.27	14.31	54
55	2.02	2.42	3.22	4.03	6.03	8.04	10.04	12.04	14.05	55
56	1.99	2.38	3.17	3.95	5.92	7.89	9.86	11.83	13.80	56
57	1.95	2.34	3.11	3.89	5.82	7.75	9.69	11.62	13.56	57
58	1.92	2.30	3.06	3.82	5.72	7.62	9.52	11.42	13.32	58
59	1.89	2.26	3.01	3.75	5.62	7.49	9.36	11.23	13.10	59
60	1.86	2.22	2.96	3.69	5.53	7.37	9.20	11.04	12.88	60
61	1.83	2.19	2.91	3.63	5.44	7.25	9.05	10.86	12.67	61
62	1.80	2.15	2.86	3.57	5.35	7.13	8.91	10.69	12.46	62
63	1.77	2.12	2.82	3.52	5.27	7.02	8.77	10.52	12.27	63
64	1.74	2.08	2.77	3.46	5.19	6.91	8.63	10.35	12.08	64
65	1.71	2.05	2.73	3.41	5.11	6.80	8.50	10.19	11.89	65
66	1.69	2.02	2.69	3.36	5.03	6.70	8.37	10.04	11.71	66
67	1.66	1.99	2.65	3.31	4.95	6.60	8.24	9.89	11.54	67
68	1.64	1.96	2.61	3.26	4.88	6.50	8.12	9.74	11.37	68
69	1.62	1.94	2.57	3.21	4.81	6.41	8.01	9.60	11.20	69
70	1.59	1.91	2.54	3.17	4.74	6.32	7.89	9.47	11.04	70
	50	60	80	100	150	200	250	300	350	

Appendix 7. Standard rating table No. 2 for AA current meters (USGS, 1999a)

STANDARD RATING TABLE NO. 2 FOR PYGMY CURRENT METER (6/99)
EQUATION: V = 0.9604 R+ 0.0312 (R=revolutions per second)

Seconds	VELOCITY IN FEET PER SECOND Revolutions														
	3	5	7	10	15	20	25	30	40	50	60	80	100	150	200
40	0.103	0.151	0.199	0.271	0.391	0.511	0.631	0.752	0.992	1.23	1.47	1.95	2.43	3.63	4.83
41	0.101	0.148	0.195	0.265	0.383	0.500	0.617	0.734	0.968	1.20	1.44	1.91	2.37	3.54	4.72
42	0.100	0.146	0.191	0.260	0.374	0.489	0.603	0.717	0.946	1.17	1.40	1.86	2.32	3.46	4.60
43	0.098	0.143	0.188	0.255	0.366	0.478	0.590	0.701	0.925	1.15	1.37	1.82	2.26	3.38	4.50
44	0.097	0.140	0.184	0.249	0.359	0.468	0.577	0.686	0.904	1.12	1.34	1.78	2.21	3.31	4.40
45	0.095	0.138	0.181	0.245	0.351	0.458	0.565	0.671	0.885	1.10	1.31	1.74	2.17	3.23	4.30
46	0.094	0.136	0.177	0.240	0.344	0.449	0.553	0.658	0.866	1.08	1.28	1.70	2.12	3.16	4.21
47	0.093	0.133	0.174	0.236	0.338	0.440	0.542	0.644	0.849	1.05	1.26	1.67	2.07	3.10	4.12
48	0.091	0.131	0.171	0.231	0.331	0.431	0.531	0.631	0.832	1.03	1.23	1.63	2.03	3.03	4.03
49	0.090	0.129	0.168	0.227	0.325	0.423	0.521	0.619	0.815	1.01	1.21	1.60	1.99	2.97	3.95
50	0.089	0.127	0.166	0.223	0.319	0.415	0.511	0.607	0.800	0.992	1.18	1.57	1.95	2.91	3.87
51	0.088	0.125	0.163	0.220	0.314	0.408	0.502	0.596	0.784	0.973	1.16	1.54	1.91	2.86	3.80
52	0.087	0.124	0.160	0.216	0.308	0.401	0.493	0.585	0.770	0.955	1.14	1.51	1.88	2.80	3.73
53	0.086	0.122	0.158	0.212	0.303	0.394	0.484	0.575	0.756	0.937	1.12	1.48	1.84	2.75	3.66
54	0.085	0.120	0.156	0.209	0.298	0.387	0.476	0.565	0.743	0.920	1.10	1.45	1.81	2.70	3.59
55	0.084	0.119	0.153	0.206	0.293	0.380	0.468	0.555	0.730	0.904	1.08	1.43	1.78	2.65	3.52
56	0.083	0.117	0.151	0.203	0.288	0.374	0.460	0.546	0.717	0.889	1.06	1.40	1.75	2.60	3.46
57	0.082	0.115	0.149	0.200	0.284	0.368	0.452	0.537	0.705	0.874	1.04	1.38	1.72	2.56	3.40
58	0.081	0.114	0.147	0.197	0.280	0.362	0.445	0.528	0.694	0.859	1.02	1.36	1.69	2.51	3.34
59	0.080	0.113	0.145	0.194	0.275	0.357	0.438	0.520	0.682	0.845	1.01	1.33	1.66	2.47	3.29
60	0.079	0.111	0.143	0.191	0.271	0.351	0.431	0.511	0.671	0.832	0.992	1.31	1.63	2.43	3.23
61	0.078	0.110	0.141	0.189	0.267	0.346	0.425	0.504	0.661	0.818	0.976	1.29	1.61	2.39	3.18
62	0.078	0.109	0.140	0.186	0.264	0.341	0.418	0.496	0.651	0.806	0.961	1.27	1.58	2.35	3.13
63	0.077	0.107	0.138	0.184	0.260	0.336	0.412	0.489	0.641	0.793	0.946	1.25	1.56	2.32	3.08
64	0.076	0.106	0.136	0.181	0.256	0.331	0.406	0.481	0.631	0.782	0.932	1.23	1.53	2.28	3.03
65	0.076	0.105	0.135	0.179	0.253	0.327	0.401	0.474	0.622	0.770	0.918	1.21	1.51	2.25	2.99
66	0.075	0.104	0.133	0.177	0.249	0.322	0.395	0.468	0.613	0.759	0.904	1.20	1.49	2.21	2.94
67	0.074	0.103	0.132	0.175	0.246	0.318	0.390	0.461	0.605	0.748	0.891	1.18	1.46	2.18	2.90
68	0.074	0.102	0.130	0.172	0.243	0.314	0.384	0.455	0.596	0.737	0.879	1.16	1.44	2.15	2.86
69	0.073	0.101	0.129	0.170	0.240	0.310	0.379	0.449	0.588	0.727	0.866	1.14	1.42	2.12	2.81
70	0.072	0.100	0.127	0.168	0.237	0.306	0.374	0.443	0.580	0.717	0.854	1.13	1.40	2.09	2.78
	3	5	7	10	15	20	25	30	40	50	60	80	100	150	200

Appendix 8. Standard rating table No. 2 for Pygmy current meters (USGS, 1999b)