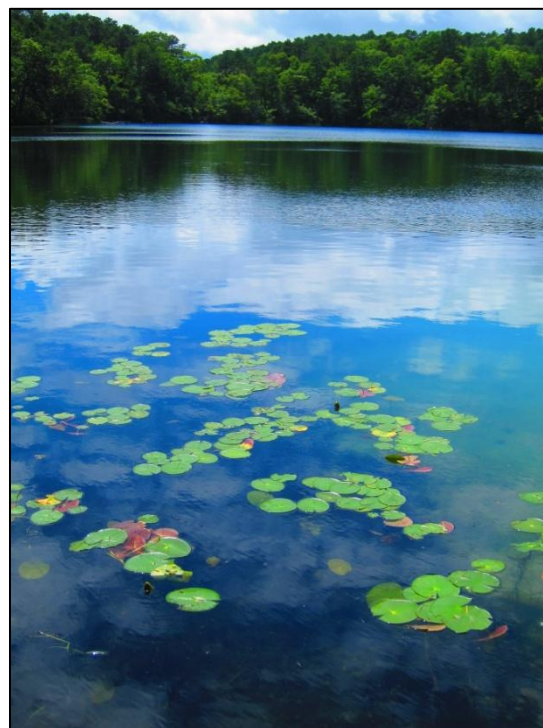


Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems

Cape Cod National Seashore

Natural Resource Report NPS/CACO/NRR—2011/469



ON THE COVER

Top left photo is a view of Pamet River at Cape Cod National Seashore; photo by J. Burkhardt.

Bottom left photo is a vernal pond at Cape Cod National Seashore; photo by K. Medeiros.

Right photo is a view of Ryder Pond, a kettle hole pond at Cape Cod National Seashore; photo by J. Barnes.

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Edited by Kelly Chapman Medeiros

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This version 1.01 of the Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems is a revision of the original USGS Open File Report 02-497 authored by Timothy D. McCobb and Peter K. Weiskel 2003. Any changes that have been made follow the Oakley et. al. 2002 standard for writing National Park Service monitoring protocols.

December 2011

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Revision History

Version numbers will be incremented by a whole number (e.g., Version 1.30 to 2.00) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g., Version 1.06 to Version 1.07) when there are minor modifications that do not affect requirements or procedures included in the protocol. Add rows as needed for each change or set of changes tied to an updated version number.

Revision History Log

Version #	Date	Revised By	Changes	Justification
1.00 (USGS Open-File Report 02-497)	2003			
1.01	Sept 2011	K. C. Medeiros	Added Revision History pages. Updated formatting and nomenclature of original USGS document. Updated Table of Contents, Figures, Tables and Appendixes. Updated Horizontal and Vertical Datum section. Extended Figure 3 from 2000 to 2010. Updated Figure and Table labels. Added text where updating of field procedures and references to SOPs and Appendixes was necessary. Separated Literature Cited.	Revised to meet Oakley, et. al., 2002 format for I&M program.

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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, this protocol is organized as follows:

Part 1: Protocol Background and Justification details the objectives of the monitoring protocol and provides justification for the recommended sampling program. 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 1 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 2: Standard Operating Procedures (SOPs) consists of five SOPs that explain the step-by-step procedures for all aspects of the long-term monitoring program, including field, data analysis, and data management.

Appendixes consists of 12 appendixes that include examples of field sheets, data collection, and justifications for why Cape Cod National Seashore has changed the network of sites for each component of the original version.

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 groundwater 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 groundwater-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 groundwater and pond levels, and rating curves between stream stage and discharge for stream flow, 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 local and global scales on coastal water resources in park units.

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

	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	4047	square meter
	acre	0.4047	hectare
Flow Rate			
	cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)

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.

All new surveys (2010 and beyond) will be measured to NAVD88 and the required vertical precision will be met by post processing RTK base station GPS files via the National Geodetic Survey (NGS) Online Positioning Service (<http://www.ngs.noaa.gov/OPUS/>). Please refer to Cape Cod National Seashore's Standard Operating Procedures for how to gain an elevation using a Real Time Kinematic GPS system.

Please also visit the NGS website for more information: <http://www.ngs.noaa.gov/>

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1. Protocol, Background, and Justification

1.1. Introduction

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 ha (44,000 ac) of uplands, ponds, wetlands, and tidal lands on lower Cape Cod, Massachusetts (Godfrey et al. 1999). The hydrologic system of lower Cape Cod consists of four distinct groundwater 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 (Figure 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 et al. 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 et al. 1999).

The purpose of this report is to establish a hydrologic monitoring protocol for 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.

1.2. 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 (Figure 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.

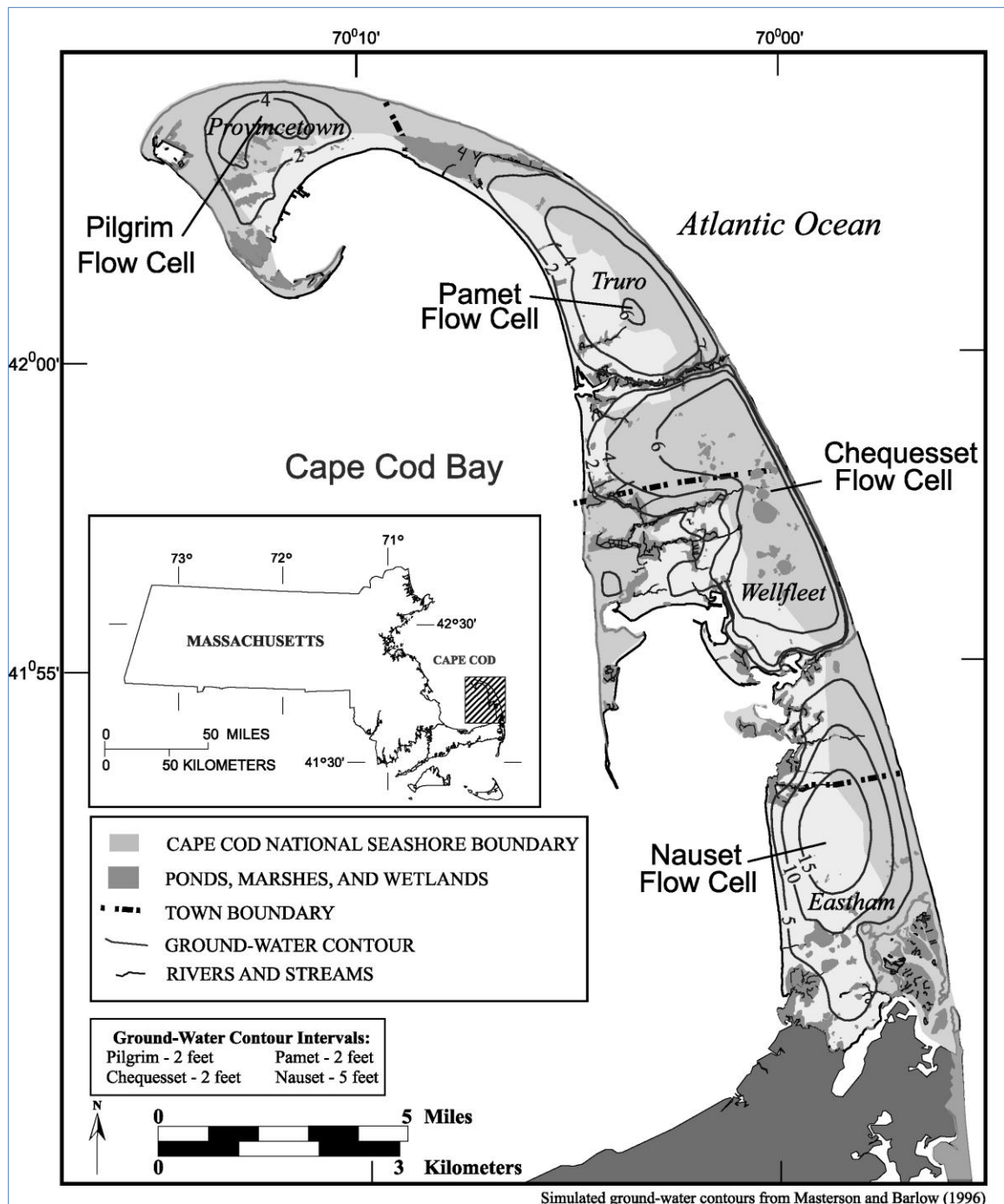


Figure 1. Hydrologic monitoring protocol area showing the Lower Cape Cod groundwater flow cells.

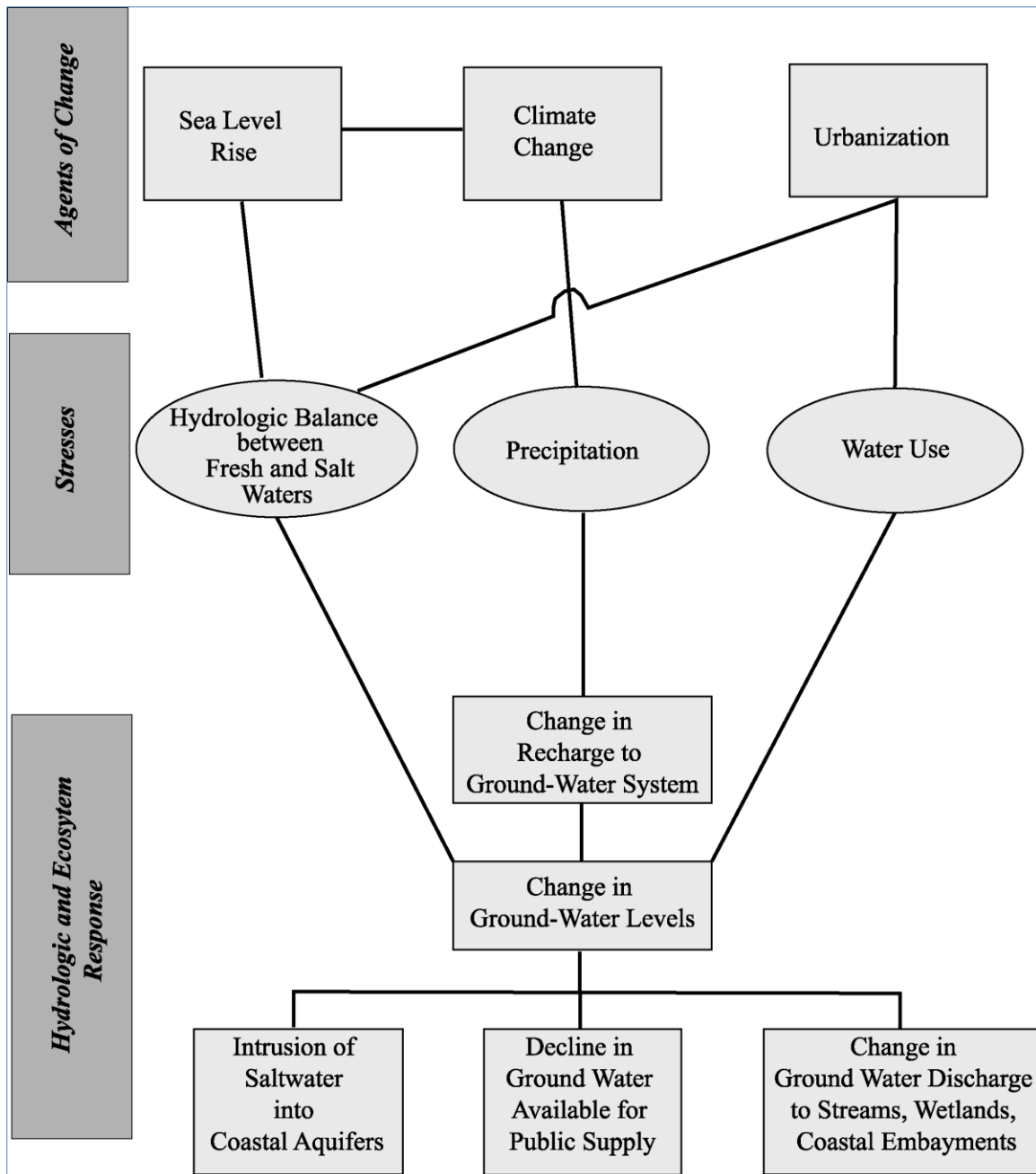


Figure 2. An example of how agents of hydrologic change can stress the hydrologic system at the Cape Cod National Seashore and cause a variety of ecosystem responses.

1.2.1. 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 2.66 mm/yr (Figure 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 into 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 saltwater and freshwater within the groundwater 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 (the flow of water in and out of a system) 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.

1.2.2. 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, well observation records show the effects of long-term climate change on the hydrologic system. For example, the 50-yr hydrograph for well TSW-1-0068 (Figure 4) shows the impact of periods of drought around 1954, 1964, and 1980 upon groundwater levels in Truro (the hydrograph also appears to show a rising trend of 2.1 mm/yr in average groundwater level, which may reflect sea-level rise). Masterson and Barlow (1996) have shown that drought-induced groundwater declines over an extended period (five years) can have a large impact on the position of the interface between saltwater and freshwater at the base of a coastal aquifer (Figure 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.

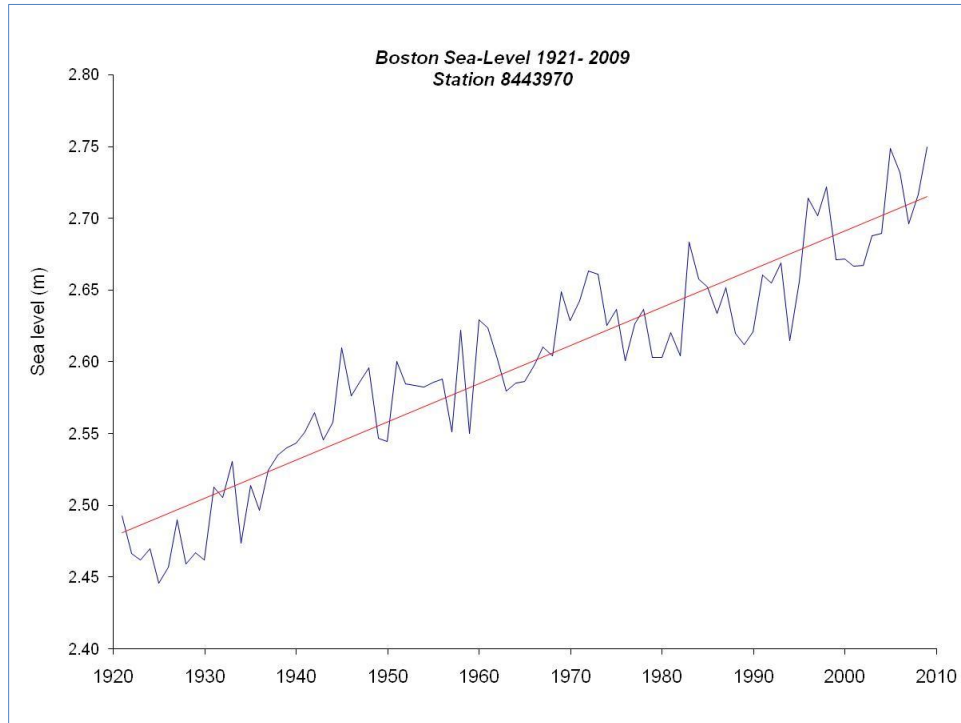


Figure 3. Annual sea-level rise rate at Boston, MA tide gage of 2.66 mm/year.

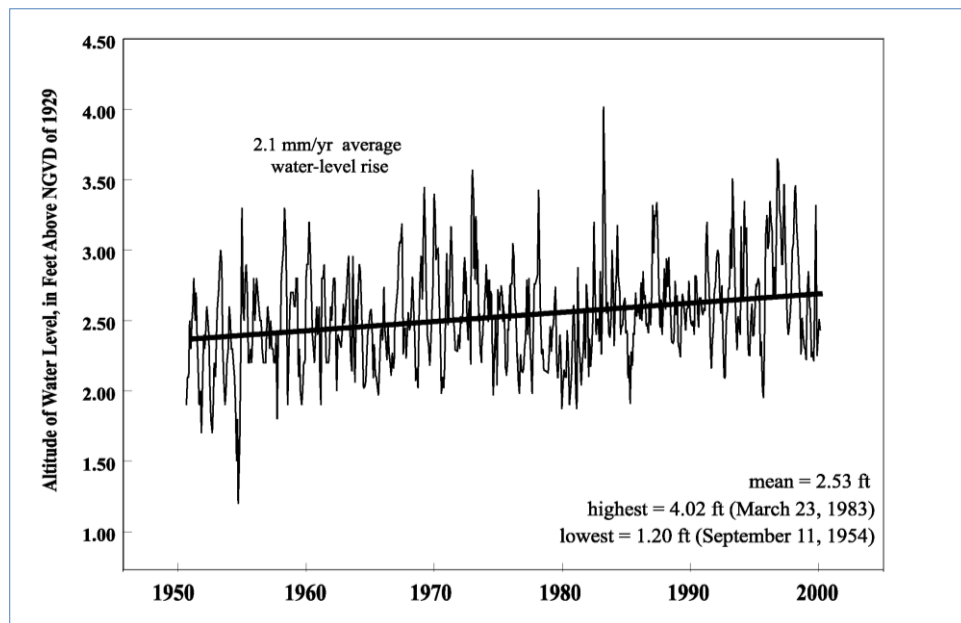


Figure 4. Long-term hydrograph of water levels in observation well TSW 1-0068 near the coast and near a water-supply well in Truro, Massachusetts.

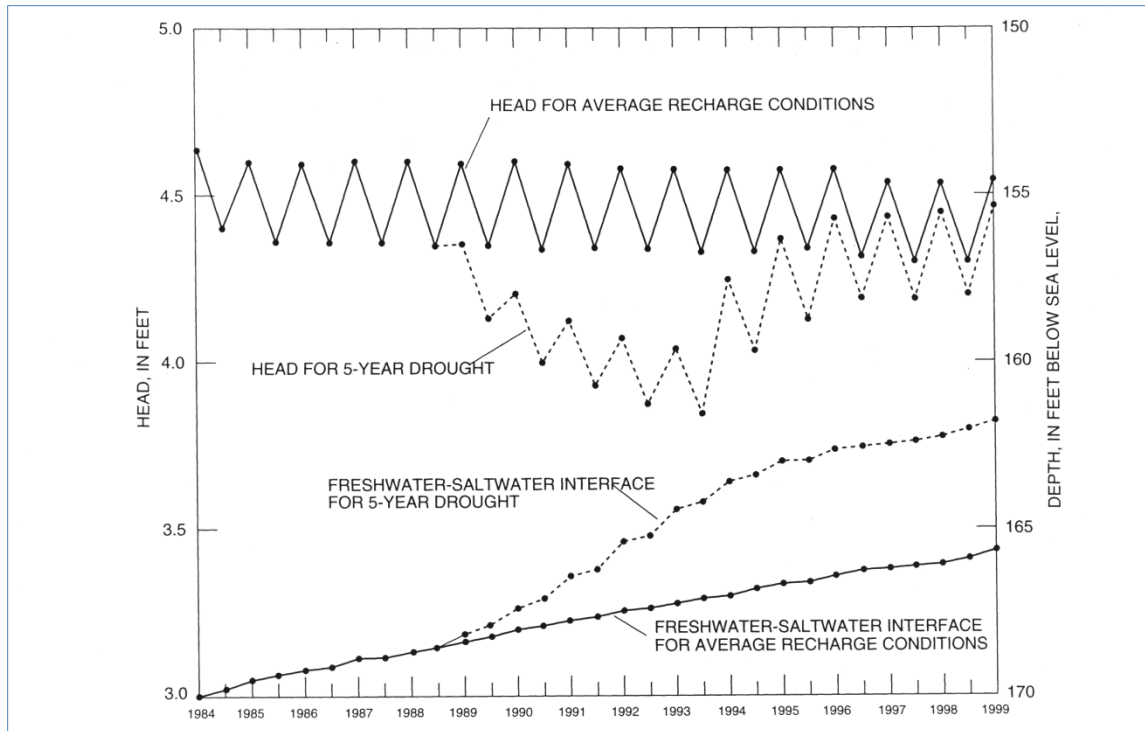


Figure 5. Model-calculated water table altitude and position of the freshwater saltwater interface at observation well TSW 90 for average recharge conditions and for simulation of a five-year drought and 1989 pumping rates, Cape Code, Massachusetts (Masterson and Barlow 1996).

Finally, it can be inferred that streams and wetland ecosystems on Cape Cod are similarly affected by declines in groundwater levels because of the close interaction between groundwater, streams, and wetland systems on the Cape (LeBlanc et al. 1986, Sobczak and Cambareri 1995, Masterson et al. 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 groundwater levels and how are they related to available climatic records?
2. Are groundwater, 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?

1.2.3. 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 groundwater 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 freshwater and saltwater at depth in the aquifer. This pumping can lead to shifts in the position of the interface between freshwaters and saltwaters and possibly cause saltwater intrusion into pumping wells (Barlow 2000, Lacombe and Carleton 1992, Spechler 1994, Luszczynski 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 saltwater and freshwater 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 saltwater 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 groundwater levels)?
3. What are sustainable, long-term rates of groundwater export from the Pamet flow cell (Figure 1) that will not cause undue change in groundwater levels?
4. What may be the effect of tidal restoration (e.g. Pamet River, Herring River) on groundwater level and streamflow?
5. What are the local drawdown effects of groundwater pumping upon vernal ponds?

1.3. Sampling Methods

Many types of sites are available in coastal systems for hydrologic monitoring. Monitoring sites can be categorized into three classes: (1) groundwater, (2) streams, and (3) ponds and wetlands. 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 groundwater 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.

1.3.1. Groundwater

Groundwater 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 groundwater 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.

1.3.1.1. Site Selection

The design of a comprehensive observation network for groundwater-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 et al. 1991) should be reviewed to identify:

- a) thickness and characteristics of saturated zones;
- b) depth to the water table;
- c) probable groundwater flow directions;
- d) presence of vertical gradients;
- e) hydrologic features and human stresses which may cause groundwater levels to fluctuate, such as water supply pumping, fluctuating river stages, and tidal influence;
- f) probable frequency of fluctuations in levels;
- g) observation wells that are available for use; and
- h) regions that lack previous water-table definition.

Site-selection criteria for groundwater level monitoring have been collected from various USGS monitoring programs with different network objectives (USGS 1980, Lapham et al. 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.

1.3.1.1.1. 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.

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 (Figure 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. The updated well network for CACO can be found in Appendix A.

***Due to the size of Table 3,
Tables 1 and 2 and Figure 6 are on the same page, following the text on the next page.***

1.3.1.2. Groundwater Monitoring Wells

Groundwater levels can be measured through a variety of methods. The use of observation wells, piezometers, and, at times, direct surfacewater measurements are acceptable means for obtaining measurements of groundwater 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 2.54 cm (1 in) in diameter and are traditionally used in geotechnical engineering applications, such as head measurements in dams and embankments (Dalton et al. 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 5-cm (2-in) diameter monitoring wells would be installed with a hollow-stem-auger drilling rig (Figure 7) and included in the network of 32 wells. Details on installation of these wells are included in SOP 1: Groundwater 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 (Figure 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, Sanders 1984).

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 ft 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 et al. 1995, Godfrey et al. 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 groundwater 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 groundwater discharge	To monitor hydrologic changes at groundwater receivers	Near kettle ponds, between flow cells, on stream shores Example: Inflow sides of all of the kettle ponds represent groundwater 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

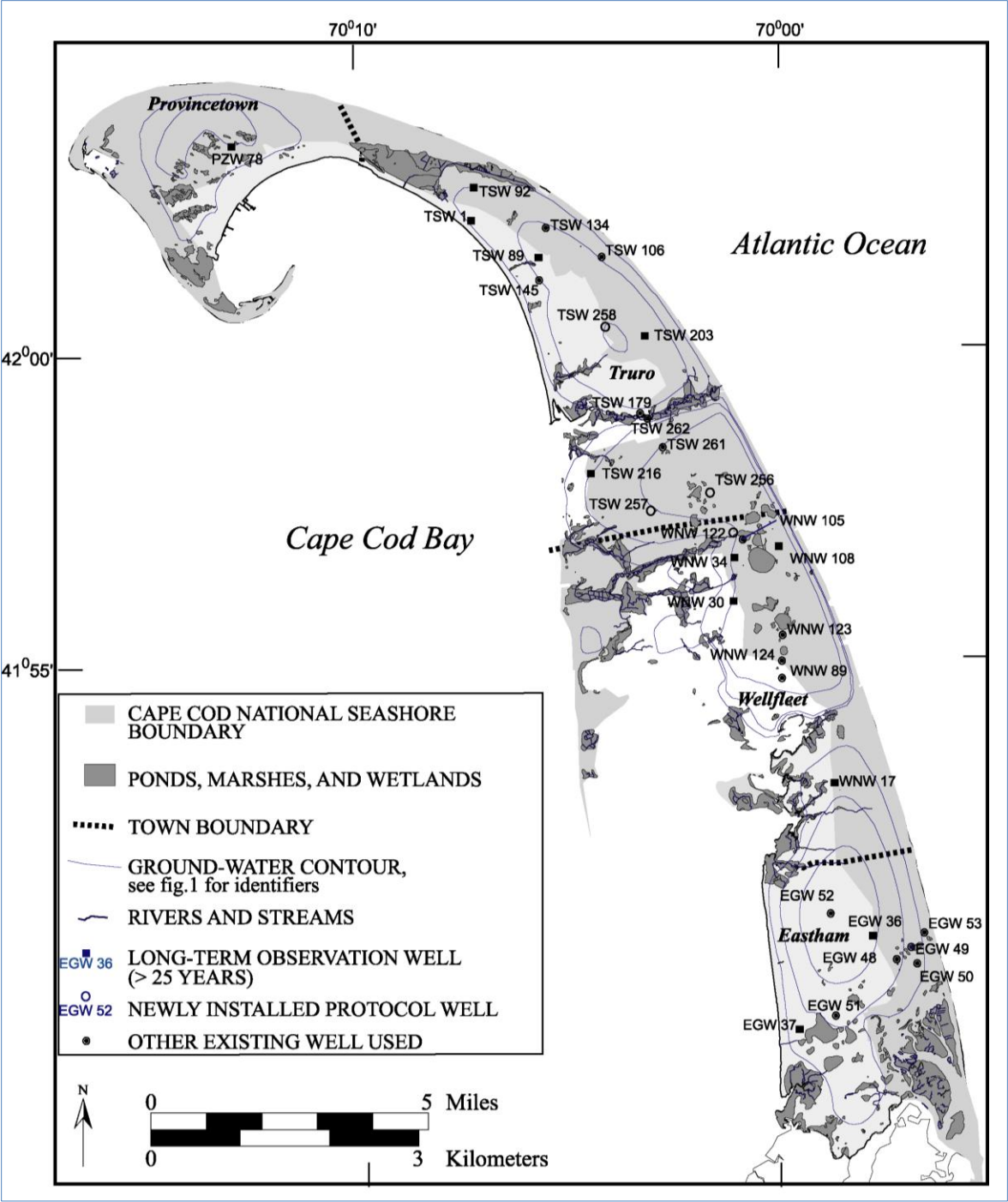


Figure 6. Recommended long-term observation-well network for monthly water-level monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore.

Table 3. Recommended well network selected for long-term monitoring at Cape Cod National Seashore. State plane coordinates are NAD83 in meters; Altitudes in feet above or (-) below NGVD29; Long-term Cape Cod Commission on long-term network; Protocol, existing wells added to network; New Protocol, newly installed wells. The number following the dash in each station nae reports the approximate depth of the well; this depth identifier is not used in Figure 6 and in text.

Station Name	Town	Flow Cell	Classification	Easting (meters)	Northing (meters)	Longitude			Latitude			Altitude of Land Surface (feet)	Stick-up from Land Surface (feet)	Top of Casing Altitude (feet)	Depth to Bottom of Screen below Land Surface (feet)	Altitude of Bottom of Screen (feet)	Diameter of Well Casting (inches)	Length of Screen (feet)
						°	ft	in	°	ft	in							
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	27.7	-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	321374.012	854615.494	41	55	45	70	00	03	65.07	2.50	67.57	68.00	-2.93	2.00	10

Table 4. Summary of well-construction methods (modified from Lapham et al. 1996).

Well construction method	Drilling fluid	Casing advance possible	Geologic materials ¹	Borehole depth	Borehole diameter ²	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	<150 ft	6-18 in	yes	yes	yes
solid-stem power auger	none	no	U; slightly indurated	<150 ft	2-10 in	can be difficult	yes	yes
power bucket auger	none	no ³	U; slightly indurated	<150 ft ⁴	18-48 in	can be difficult	yes	yes
hand auger (with / without power)	none	no ³	U	<70 ft ⁴	2-6 in	can be difficult	yes	yes
direct rotary with water-based fluid	water, mud	yes	U, R, (s)	>1,000 ft	2-36 in	yes	yes	yes
wireline rotary	water, air, foam	yes	U, R	>1,000 ft	3-6 in	yes	yes	yes
reverse rotary: with water-based fluid; with air assistance	water, mud, air, foam	yes	U, R, (s)	>2,000 ft	12-36 in	yes	yes	yes
air rotary: direct rotary air and down-the-hole air hammer; with casting driver ⁵	water, air, foam	yes	U, R	>2,000 ft	4-16 in	yes	no ⁶	yes
cable tool	water	yes	U, R	approx. 500 ft	6-8 in	yes	yes	yes
jet wash and jet percussion ⁷	water	no	U	<50 ft	2-4 in	yes	yes	yes
direct push ⁸	none	no	U	<100 ⁸ ft	0.5-4 in	no	yes	yes
vibration rig	non, water, air	yes	U, R	approx. 500 ft	4-12 ² in	yes	yes	yes

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

²Borehole 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 a diameter of 10 in or greater, borehole depth is limited to approximately 100 ft.

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

⁴Above water table only; below water table, borehole must be kept full of drilling fluid.

⁵Casing-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.

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

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

⁸Some 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.

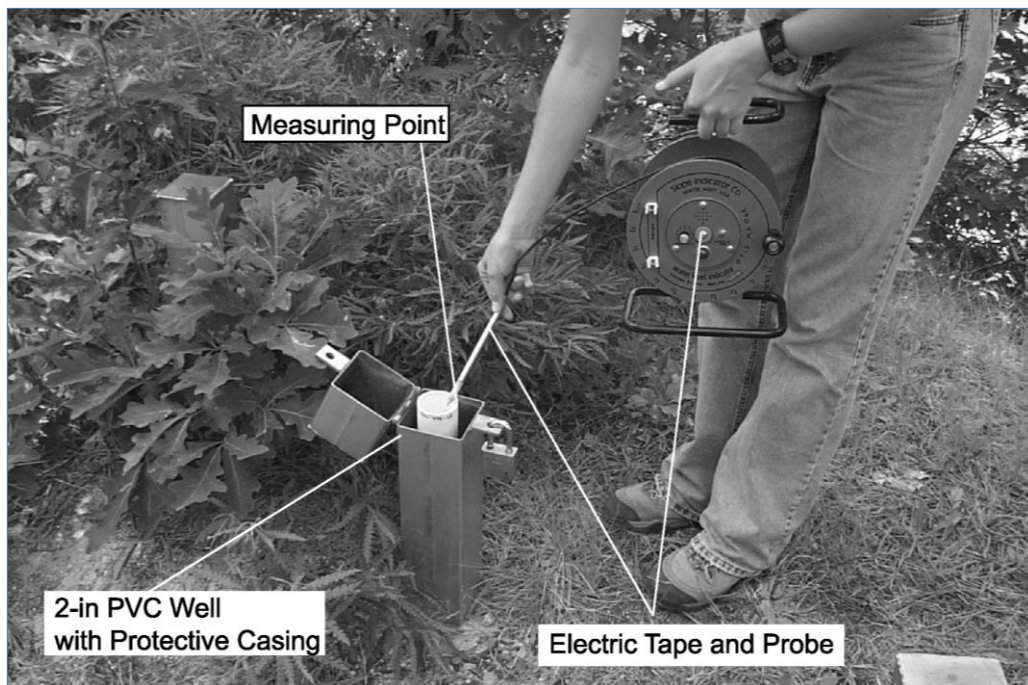


Figure 8. Hydrologic technician measuring water level in an observation well. Protective casing, 2-in. PVC well, locking cap, measuring point, and electric measuring tape shown.

1.3.1.3. Sampling Program

A comprehensive program to monitor groundwater-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.

1.3.1.3.1. 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 groundwater 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 (Figure 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 4.89 m (16.06 ft) above sea level (EGW 52 in the Nauset flow cell), to a minimum of 0.67 m (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 0.13-0.20 ft in the Nauset flow cell, 0.14-0.16 ft in the Chequesset flow cell, and 0.19-0.25 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 groundwater 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 freshwater levels.

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 et al. 1999a).

Table 5. Observed monthly water table altitudes for the long-term Cape Code National Seashore network, February 23, 1999-January 24, 2000.

Station name	Top of casing elevation	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
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

Altitudes in feet above or below (-) NGVD 29.

--- Site not measured or not yet installed.

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

U – Distributed spatially in the upper (top) portion of the flow cell.

I – Distributed spatially in the middle portion of the flow cell.

L – Distributed spatially in the lower (bottom) portion of the flow cell.

1.3.1.3.2. Frequency

Sampling frequency is determined by 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 one- to two-day period with no hydrologic events, such as precipitation, during the measurement period.

The CACO pilot monitoring program allowed for monthly measurements of groundwater levels. One person accomplished this round over a period of one to two 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 one-month

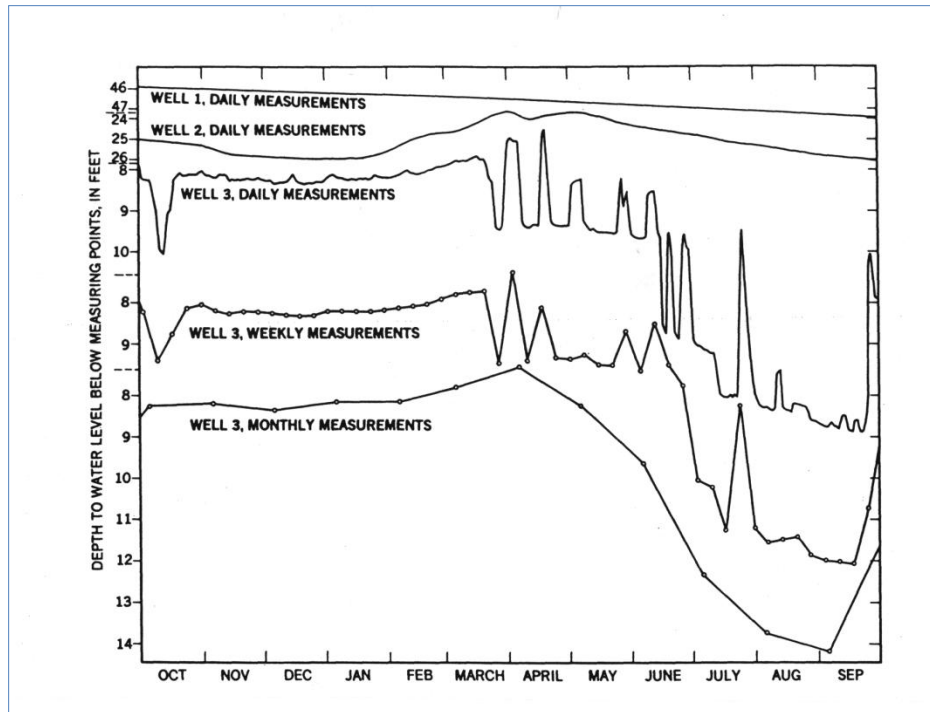


Figure 9. Graphs showing different types of water-level fluctuations in three observation wells and a comparison between the graphs plotted for daily, weekly, and monthly water levels in the same observation well (U.S. Geological Survey 1980).

period ranged from 0 to 0.85 ft throughout the monitoring area. The total monthly average change over the one-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 groundwater levels to seasonal and climatic trends, then an increase in sampling frequency may be warranted.

Changes that CACO has made to the recommended network of groundwater level wells and the other components of this protocol can be found in Appendixes A through D. The final network of wells as of fall of 2010 are also included.

1.3.2. Streamflow

Streamflow is essential to biota in estuarine ecosystems of the Seashore. Streamflow monitoring is needed to calibrate and verify groundwater flow models, to detect change in response to human-induced factors such as altered land use and groundwater 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 section 1.3.2.3.2. *Frequency*). On Cape Cod, a substantial percentage of water in the groundwater 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 (R. S. Socolow, USGS, written communication, 2000). Standard methods of stream-gaging are described by Rantz et al. (1982) and in the USGS publication series Techniques of Water-Resources Investigations (Carter and Davidian 1968, Davidian 1964, Kilpatrick and Schneider 1983).

1.3.2.1. 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 et al. 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 et al. 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 et al. (1982) are presented in Table 7.

Rarely will all criteria be satisfied in streamflow site selection. Similar to groundwater 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:

- a) Straight alignment;
- b) Exposed consolidated rock as opposed to alluvium;
- c) Banks subject to overflow;
- d) Steep banks for confined flow;
- e) Divided channels;
- f) Possible variable backwater effect from a tributary or confluent stream or from a reservoir; and
- g) Potential sites for discharge measurement by current meter.

Table 7. Specific site criteria for an ideal stream-gaging station (modified from Rantz et al. 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 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

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 et al. 1982).

Based on these criteria, four partial-record gaging sites along two streams were selected for pilot monitoring (Figure 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 Road). 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 ~ 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 reasons listed above, it was decided that additional sites should be selected so that all substantial flow-cell outflow from streamflow could be measured. Concurrent groundwater 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. The final eight streamflow-gaging sites recommended for measurement at the Seashore are shown in Table 8b and Figure 11. 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.

Four of the recommended sites were measured in 2009 on a weekly or biweekly basis in order to gain as much data as we could for each of the sites to begin to develop a rating curve.

Continuous HOBOTM water level loggers (Onset Computer Corp.) were deployed in tidally influenced sites in Pamet River (Corn Hill and Castle Road) in winter of 2010 for approximately one week at an interval of five minutes in order to better estimate the sampling window where the most freshwater surface flow would be most accurately quantified (Appendix D).

It was determined that Pamet River at Castle Road would be sampled two and a half hours after predicted low (using Provincetown tides: <http://www.boatma.com/tides/>) and the Pamet River at Corn Hill Road would be measured three hours after predicted low. The Fresh Brook and Hatches Creek sites were not monitored specifically to determine the time of measurement; however, there is data from Fresh Brook throughout the summer of 2010 that can and will be used to analyze the streamflow data that was collected at that site. It was determined that these two sites would be measured at predicted low tide (using Wellfleet tides: <http://www.boatma.com/tides/>).

These sampling efforts resulted in a re-evaluation of the recommended streamflow network in the fall of 2010. Each station was visited and it was decided that all eight would be measured weekly (or as close to weekly as possible due to tides) for two years with continuous water level loggers deployed within the stream reaches. One station, Salt Meadow in Truro was added to the network; this station will hopefully quantify the amount of freshwater input to the East Harbor coastal lagoon system that is so important to the Seashore. Currently, it is being naturally blocked by a sand bar due to prevailing winds and sediment movement; only when this channel is open will it be suitable to measure.

1.3.2.2. Stream-Gaging Methods

1.3.2.2.1. 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 et al. 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 (USGS 1989). Table 9 includes various types of stage-measurement methods.

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 USGS Techniques of Water-Resources Investigations (TWRI) publication series entitled “Stage Measurement at Gaging Stations” (Buchanan and Somers 1982).

1.3.2.2.2. 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 et al. 1995, Figure 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 et al. (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 five 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; Socolow et al., written communication, 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 (see SOP 2).

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 et al. 1995). Discharge is usually expressed in cubic feet per second or cubic meters per second.

Table 8a. Stream-gaging stations selected for long-term monitoring at Cape Code National Seashore; four sites measured during first year of monitoring program.

Station name	Flow cell	Tidally influenced	Reference point description	Site #	Latitude	Longitude	Arbitrary reference point elevation	Field reconnaissance data					
								Date	Time	Gage height	Discharge	Specific conductance (uS/cm)	Temp. °C
Herring River at Old Kings Highway at Wellfleet, MA	Chequesset	no	top of orange mark on upstream center of bridge wall	011058793	415734	700116	8.39 ft	2/23/1999	1300	2.60 ft	0.41 ft³/s	---	---
Herring River at High Toss Road at Wellfleet, MA	Chequesset	yes	top of orange mark on downstream side of metal culvert pipe	415636070032801	415663	700328	9.99 ft	2/23/1999	1400	1.11 ft	20.66 ft³/s	---	---
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 ft	2/23/1999	1530	2.15 ft	8.77 ft³/s	---	---
Pamet River at Pamet Roads Connector at Truro, MA	Pamet/Chequesset	yes	top of orange mark at top edge of concrete headwall over culvert	415939070030201	415939	700302	9.99 ft	9/23/1999	0900	1.97 ft	6.23 ft³/s	---	---

Table 8b. Stream-gaging stations selected for long-term monitoring at Cape Code National Seashore; final eight sites recommended for long-term monitoring program.

Station name	Flow cell	Tidally influenced	Reference point description	Site #	Latitude	Longitude	Arbitrary reference point elevation	Field reconnaissance data					
								Date	Time	Gage height	Discharge	Specific conductance (uS/cm)	Temp. °C
Herring River at Herring Pond Outlet at Wellfleet, MA	Chequesset	no	top of aluminum I-beam at footbridge	415748070005901	415748	700059	9.99 ft	9/26/2000	1432	8.24 ft	0.22 ft³/s	148	17.6
Herring River at Old Kings Highway at Wellfleet, MA	Chequesset	no	top of orange mark on upstream center of bridge wall	011058793	415734	700116	8.39 ft	9/26/2000	1325	5.82 ft	0.22 ft³/s	147	15.9
Herring River at Bound Brook Island Road at Wellfleet, MA	Chequesset	yes	top of orange mark on upstream headwall of culvert	415714070032501	415714	700325	9.99 ft	9/27/2000	1245	7.26 ft	4.06 ft³/s	210	---
Hatches Creek at West Road at Eastham, MA	Nauset	yes	top of orange mark at center of upstream end culvert pipe	415238069593601	415238	695936	9.99 ft	9/27/2000	0844	9.65 ft	0.09 ft³/s	189	12.7
Fresh Brook at Route 6 at South Wellfleet, MA	Nauset	yes	top of orange mark on large rock at right upstream-side culvert	415326069591601	415326	695916	9.99 ft	9/27/2000	0945	8.80 ft	0.79 ft³/s	1361	14.2
Little Pamet River at Corn Hill Road at Truro, MA	Pamet	yes	top of orange stake in streambed, 20 ft downstream of headwall	415957070044201	415957	700442	9.99 ft	9/28/2000	0832	9.87 ft	1.48 ft³/s	4000	14.2
Pamet River at Castle Road at Truro, MA	Pamet/Chequesset	yes	top of orange mark on upstream corner of large granite block 20 ft downstream	415937070030201	415937	700302	9.99	9/28/2000	0932	8.68 ft	6.65 ft³/s	1170	13.7
Pole Dike Creek at Bound Brook Island Road at Wellfleet, MA	Chequesset	yes	top of orange mark on center of upstream side of culvert	415653070024001	415653	700240	9.99 ft	9/27/2000	1201	---	---	---	---

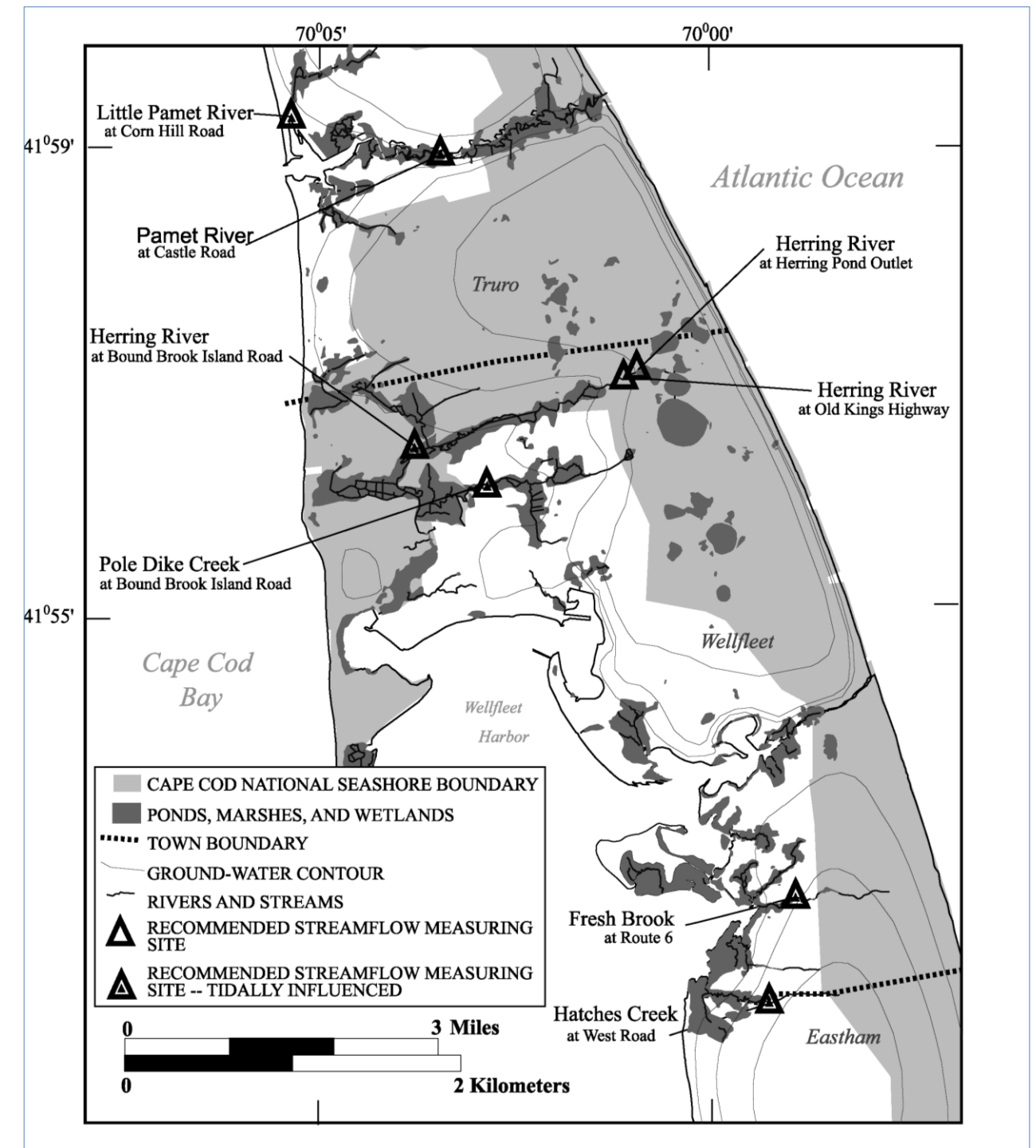
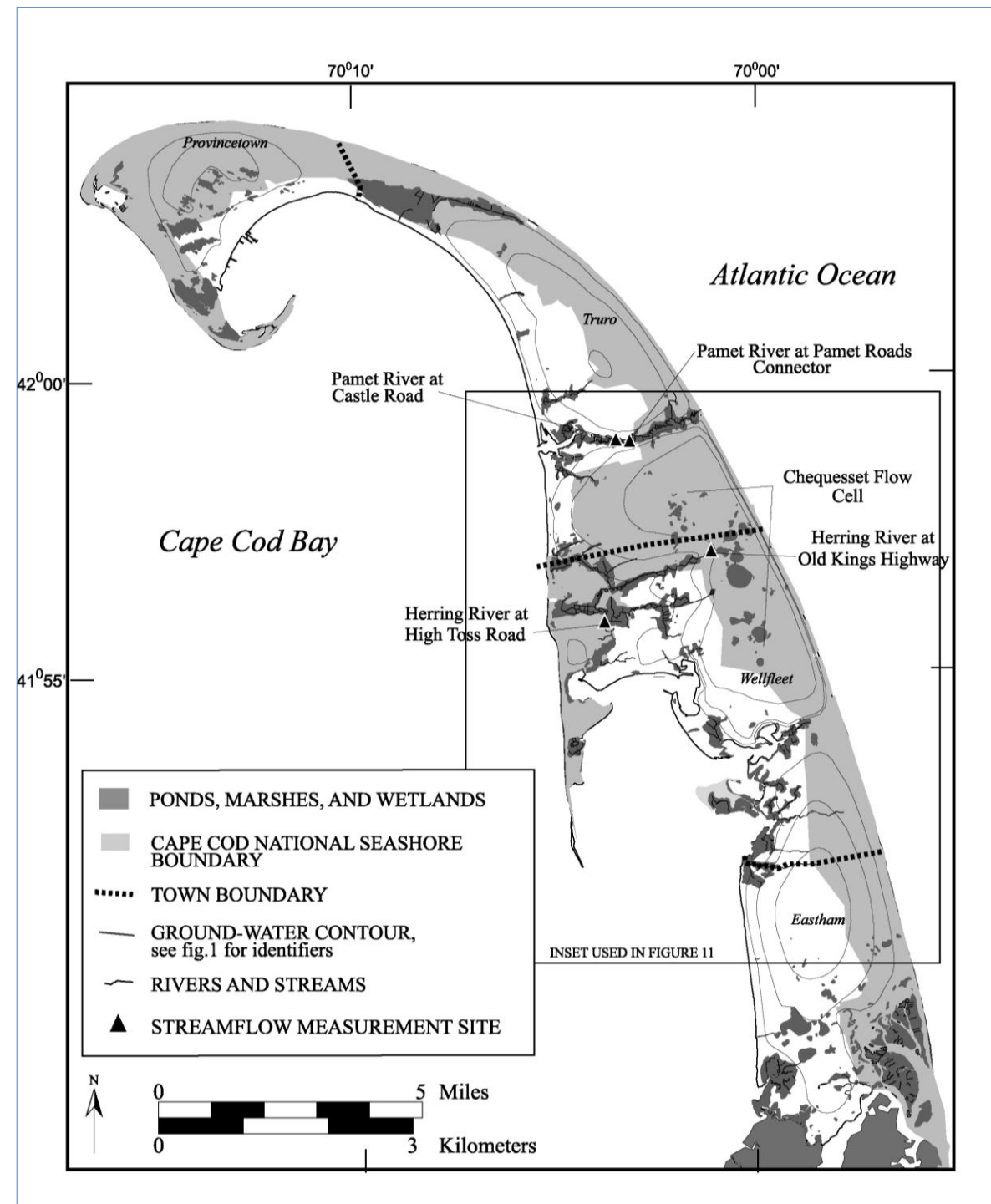


Figure 10. Selected sites for long-term monthly streamflow monitoring through the first year of monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. Final recommended network shown in figure 11.

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.

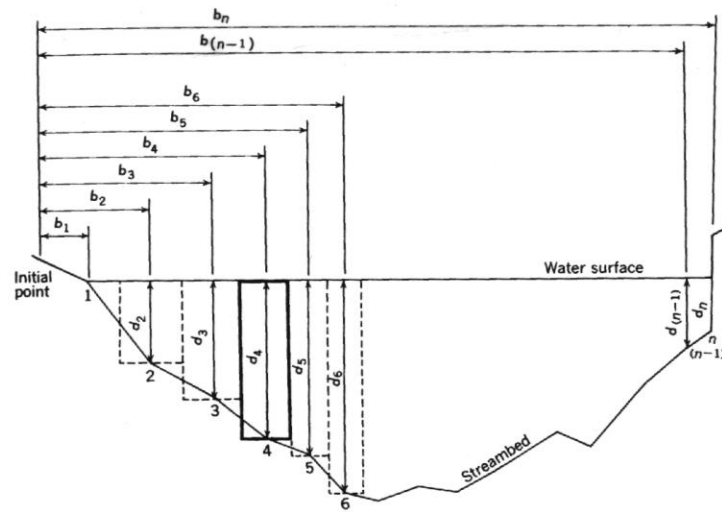
Table 9. Methods of measuring stage (recording and non-recording).

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

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

Date	011058793 Herring River at Old Kings Hwy, 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 Connect. 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

--- site not measured.



EXPLANATION

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

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

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

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 et al. 1982).

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 (Davidian 1964, Carter and Davidian 1968, Rantz et al. 1982, 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 (USGS 1985).

Table 11. Configuration and recommended velocity and depth ranges for USGS current meters (USGS 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 et al., USGS, written communication, 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 (Figure 10). Water depths dictated the use of a Rickley Hydrologic-brand (model 6205) pygmy current meter with headset (Figure 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 et al. 1982) and methods involving portable weirs and flumes (Kilpatrick and Schneider 1983).

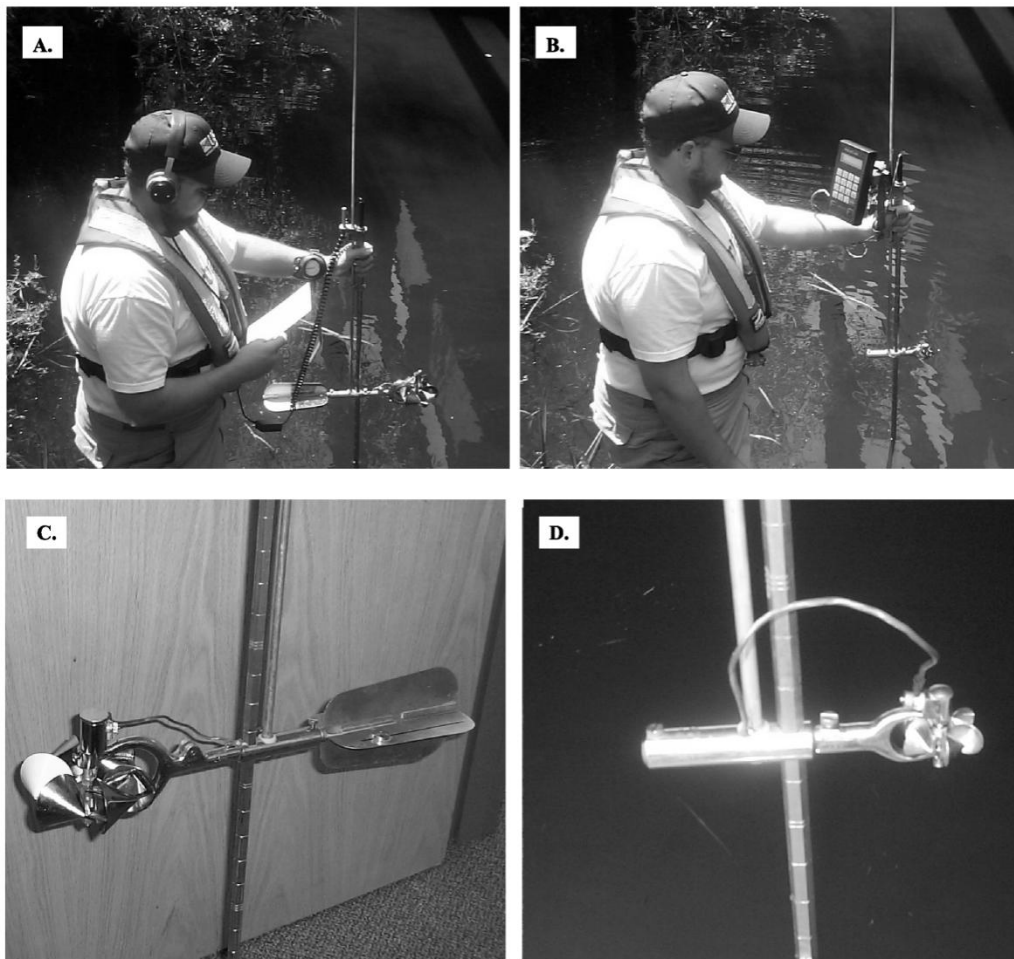


Figure 13. Streamflow-measurement equipment includes: A. Type AA current meter with headset and stopwatch; B. Pygmy current meter with automated digitizer; C. Type AA current meter on a wading rod; and D. a Pygmy current meter on a wading rod.

1.3.2.3. 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.

1.3.2.3.1. Spatial Distribution

As project objectives dictate, the goal of stream 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. 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 in flow between the two stations, which are less than 650 ft apart, ranged from 0.9 to 3.8 ft³/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 ft³/s during summer low-flow periods to 21.5 ft³/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 (Figure 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 (Figure 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 down-gradient (at Bound Brook Island Road) of the original site.

1.3.2.3.2. 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 et al. 1982). Any deviations from the general procedures for Cape Cod National Seashore may be seen in SOP 2.

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 (Figure 11). For this reason, the six tidally influenced streams were measured about two 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). A slight increase in stage (0.20 ft) over a 1-month period resulted in a $1.26 \text{ ft}^3/\text{s}$ increase in flow (over 300 percent) at the Herring River station (011058793). Three months later, between May and June, a significant decrease in stage (0.40 ft) resulted in a $0.61 \text{ ft}^3/\text{s}$ decrease in flow (98 percent). As with groundwater at the Seashore, streamflow changes rapidly as a reflection of recharge to and withdrawals from the aquifer system.

1.3.3. 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 groundwater 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.

1.3.3.1. 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 groundwater 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 et al. 1999b).

Considerations for site selection of ponds and lakes in the protocol area were typical of groundwater 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, Figure 14). Please see Appendix A for an updated network of ponds, lakes, and wetlands. Typical ponds at the Seashore are permanently flooded glacial kettle holes that range in area from 1.2–109 acres and depth from 6–60 ft. Wetlands and intermittent vernal pools typically range in size from 15–100 ft. Rim Lake, the only brackish lake in the region, was once a saltwater bay that has been subjected to natural and anthropogenic alterations to form a eutrophic, shallow, brackish lake of over 127 acres.

1.3.3.2. 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 et al. 1999b).

Staff gages (Figure 15A) and various forms of graduated stakes are the most common devices for monitoring pond water level (Rantz et al. 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 (Figure 15B) is a simple, low-cost device that connects an onshore measuring standpipe to the water body through an intake pipe (Rantz et al. 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 et al. 1982). Pressure transducers usually have a fixed orifice tube beneath the water surface that is connected to a continuous gas source (Figure 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 data logger.

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

Site	Town	Flow cell	Type	Easting#	Northing#	Latitude			Longitude			Altitude at top of casting	Water level below top of casting	Water level date	Altitude water level
						°	ft	in	°	ft	in				
Duck Pond	Wellfleet	Chequesset	kettle pond	307564.257	867546.118	41	55	56	70	00	06	13.90 ft	4.26 ft	12/19/2000	9.64 ft
Dyer Pond*	Wellfleet	Chequesset	kettle pond	323603.971	856484.240	41	56	23	70	00	35	12.63 ft	4.99 ft	12/19/2000	7.64 ft
Great Pond	Truro	Chequesset	kettle pond	321890.394	858336.733	41	58	25	70	01	21	14.19 ft	6.19 ft	12/19/2000	8.00 ft
Great Pond	Wellfleet	Chequesset	kettle pond	324304.907	854614.279	41	56	26	70	00	12	12.64 ft	4.84 ft	12/19/2000	7.80 ft
Gull Pond	Wellfleet	Chequesset	kettle pond	324133.631	856493.519	41	57	25	70	00	14	12.24 ft	5.35 ft	12/19/2000	6.89 ft
Herring Pond	Wellfleet	chequesset	kettle pond	323350.656	856479.816	41	57	43	70	00	43	11.58 ft	5.06 ft	12/19/2000	6.52 ft
Long Pond*	Wellfleet	Chequesset	kettle pond	323386.864	858362.697	41	56	36	70	00	46	14.41 ft	6.65 ft	12/19/2000	7.76 ft
Ryder Pond	Truro	Chequesset	kettle pond	321949.981	860220.008	41	57	54	70	01	48	11.99 ft	4.82 ft	12/19/2000	7.17 ft
Snow Pond*	Truro	chequesset	kettle pond	322479.361	860229.163	41	58	09	70	01	44	11.58 ft	3.77 ft	12/19/2000	7.81 ft
E-9	Eastham	Nauset	vernal pool	327665.627	847145.134	41	51	03	69	57	46	18.76 ft	8.31 ft	12/19/2000	10.45 ft
Little Bennett Pond	Provincetown	Pilgrim	wetland	312047.803	867615.856	42	03	32	70	12	04	10.31 ft	4.86 ft	07/31/2000	5.45 ft
Pilgrim Lake *	Provincetown	Pilgrim / Chequesset	brackish lake	324054.518	858374.383	42	03	52	70	08	49	5.36 ft	4.48 ft	12/19/2000	0.88 ft

*Siphon gages were installed at these sites 09/21/1999 to supplement the network as a special initiative project of the USGS Massachusetts/Rhode Island District.

#State plane coordinates are NAD83 in meters.

Altitudes are in feet above NGVD 29.

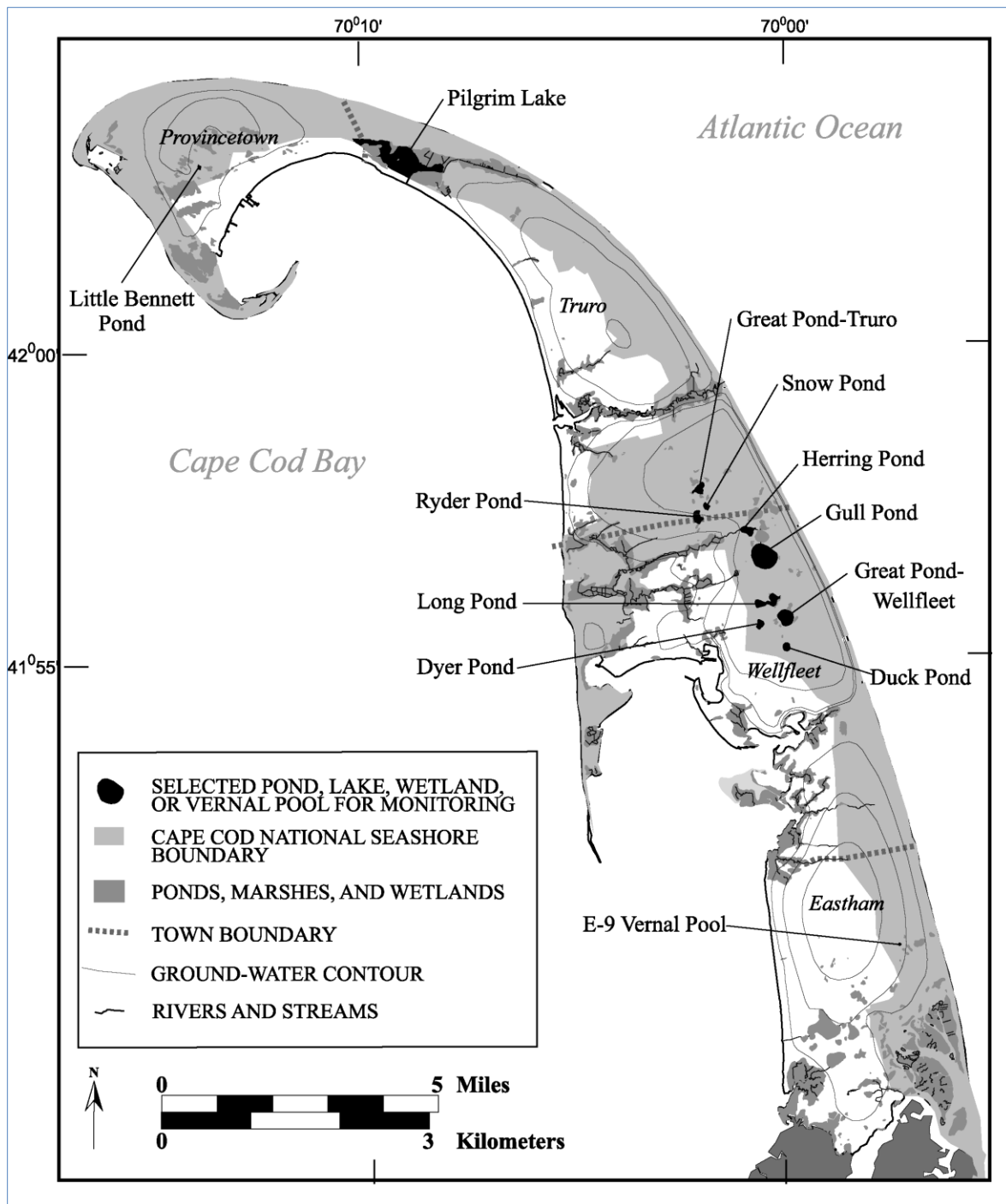


Figure 14. Recommended ponds for long-term monthly water-level monitoring as part of the Long-Term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore.

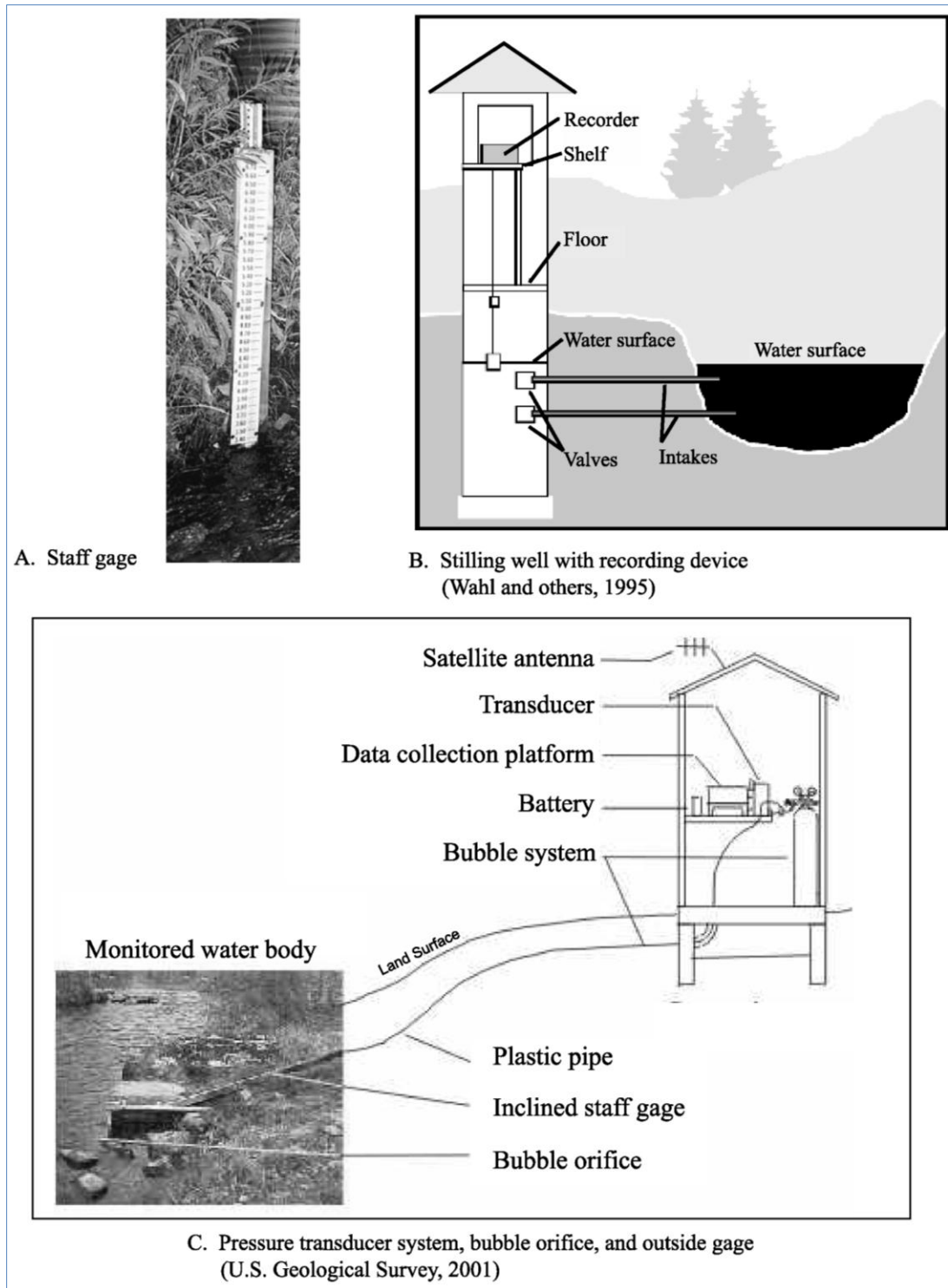


Figure 15. Photographs and schematic diagrams of stage monitoring devices including: A. staff gage; B. stilling well; and C. pressure-transducer system.

A siphon gage for the measurement of pond levels (Figure 16) was recently designed, tested, and documented (McCobb et al. 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 groundwater 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 thereby 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 six of 12 months during the pilot test period), the siphon gage here required periodic recharging as water levels became measurable.

The siphon gage method was last used to collect data in 2005. The siphon gages became more of a maintenance effort than a monitoring effort. It was determined that measuring the pond water stage was as accurate as using the siphon gages (Table 13). The difference was tolerable for our standard of measure for this protocol data analysis. Cape Cod is currently using a pond stage leveling method to gain accurate water level measurements for ponds, lakes, and wetlands (see SOP 3).

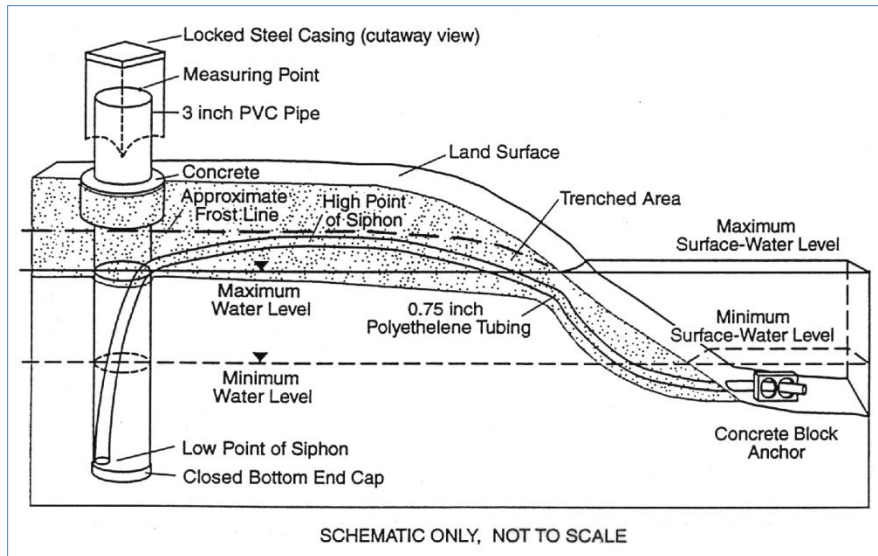


Figure 16. Schematic construction diagram of a siphon gage for monitoring pond levels (McCobb et al. 1999a).

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

1.3.3.3. 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.

1.3.3.3.1. Spatial Distribution

The spatial distribution of pond-level measurements is dictated by the ponds' locations in the aquifer system. Like sites for groundwater 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, pond levels provide an excellent reflection of the local water table due to the unconfined aquifer conditions. As with groundwater 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 (East Harbor, 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 East Harbor ranged from 0.64–1.17 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 six 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 groundwater 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 one-year monitoring period is given in Table 14. All surface-water bodies were measured during each sampling round.

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 (Figure 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 Pond's 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.

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

Station name	Top of casting elevation	Water level altitude [#]											
		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

[#]Water level altitudes in feet above NGVD 29

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

1.3.3.3.2. *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 direction and to provide calibration data for groundwater models.

At the Seashore, unconfined conditions dictate that each kettle pond closely represents the local groundwater 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 groundwater monitoring. The year-long data set shows monthly changes in elevation, ranging from 0.00–0.57 ft. An example of the importance of monitoring changes over a one-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° with an increase in elevation resulting in a more northwesterly flow path. The gradient magnitude is almost two and a half 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.

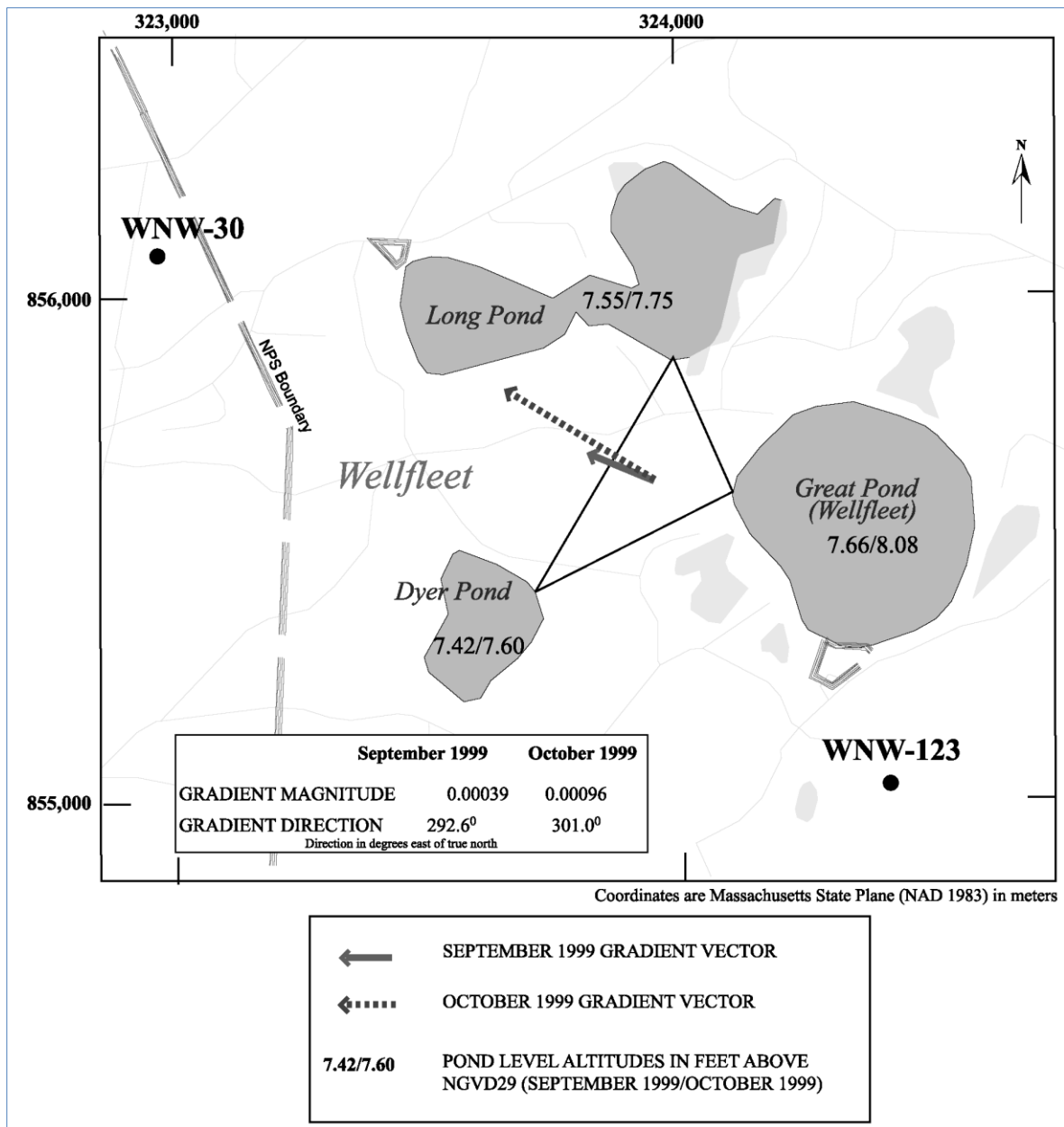


Figure 17. Comparison of hydraulic-gradient estimations among three ponds over a one-month period (September 1999 to October 1999).

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2. Standard Operating Procedures

2.1. SOP 1. Groundwater Level Monitoring

Revision History Log:

Version #	Date	Revised By	Changes	Justification
1.00 (USGS Open-File Report 02-497) Version 1.00 May 2002	2003			
1.01	Sept 2011	K. C. Medeiros	Separated SOP from others in original version. Updated Tables 15, 16, and 17. Added information about CACO datum standards and what instrumentation that we use currently. Updated equipment and supply lists. Added data entry and management procedures.	Revised to meet Oakley, et. al., 2002 format for I&M program.

A 32-well groundwater 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).

2.1.1. General Well Installation Procedures

2.1.1.1. Equipment and Supplies

Table 15. Required equipment and supplies for site clearing and monitoring well installation.

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

2.1.1.2 General Procedures

1. Select observation-well site on the basis of monitoring-program objectives and established selection criteria. Consult with an experienced hydrologist to confirm the suitability of potential sites.
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 groundwater 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, 2002).
 - 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, site sketch, and a well lithologic log at sites where sediment samples are collected (Appendixes E and F).

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 (Figure 8).
15. Clearly marked the MP with a permanent marker or notch at the top of the PVC casing (Figure 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 water level measurements, below).

2.1.2. Determination of Well Measuring-Point Elevation

2.1.2.1. Equipment and Supplies

Table 16. Required equipment for reference-point leveling.

<i>Leveling Equipment</i>	<i>Purpose</i>
Leveling Equipment	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
Real Time Kinematic GPS	To determine vertical elevation of well MP
Cell Phone	To protect personnel
Orange Vest	To protect personnel

2.1.2.2. General Procedures

NOTE: Geodetic datum MUST be documented for all elevations! Cape Cod National Seashore uses meters or feet NAVD88 as a standard measure of elevation for all sites and currently uses Trimble R8 GNSS RTK receivers to gain accurate elevations of benchmarks and measuring points.

Elevation surveys should be tied to current NGS benchmarks calculated at current horizontal datums (NAD83, epoch 2005) and the vertical datum NAVD88 or to current CACO elevation backbone benchmark sites based on minimum 4-hour static RTK occupations corrected via NGS Online Positioning Service (OPUS). All elevation surveys should include additional check shots on known reference benchmarks. Step by step procedures and an explanation of geodetic datums can be found on the NOAA National Geodetic Survey website: <http://www.ngs.noaa.gov/>

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 G) 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.

2.1.3. 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:

1. 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. *NOTE: Geodetic datum MUST be documented for all elevations! Cape Cod National Seashore uses feet NAVD88 as a standard measure of elevation for all sites.*
2. Town name
3. Latitude and longitude
4. UTM XY coordinates
5. Altitude of land surface
6. Length of casing stick-up from the land surface to the top of the MP
7. Total depth of the hole
8. Depth to the bottom of the screen
9. Length of the screen
10. Altitude of the measuring point
11. A description of the well site with directions and a well-site sketch map (Appendix F)

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

2.1.4. Water-level Measurements

2.1.4.1. Equipment and Supplies

Table 17. Required equipment for water level measurements.

<i>Water-level Measurement Equipment and Supplies</i>	<i>Purpose</i>
Well Keys	To determine vertical elevation of well MP
Pipe wrenches, 18" and 36"	To hold level stable
Water-level tape	To provide vertical "ruler" in 0.01-ft increments
Sounding tape with weight	To assist in keeping stadia rod level
Water-level field sheet	To record level information
Cell Phone	To protect personnel
Orange Vest	To protect personnel

2.1.4.2. General Procedures

Before travelling to each groundwater level well, the field personnel MUST have reviewed the Cape Cod National Seashore Long-Term Ecosystem Monitoring Program's Safety Standards and Procedures for Monitoring Projects-Version 3 (Y:\I&M_Program\Programmatic_SOPs) as well as review the powerpoint presentation on vehicle safety (Y:\Natural_Resources_Div\SAFETY\SAFETY_MODULES_POWERPOINT). Knowledge of how to properly use a 4 wheel drive vehicle is a necessity in order to travel to most of the well network sites.

Water-level measurements are a routine aspect of hydrologic monitoring. The determination of the water-table elevation, and subsequently of the groundwater-flow direction, flow rate, hydraulic gradient, and location of groundwater 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 pre-printed waterproof datasheets. Required data include personnel collecting measurements, weather conditions, well name, date of measurement, time of measurement, and depth to water from MP.
2. Electric Tape Method:
 - a. Turn on the electric-tape sensor (Heron Dipper-T water level meter) and slowly lower the probe down the well (Figure 8).
 - b. 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.
 - c. Read the graduated line at the MP position and record on datasheet. The depth below MP is a direct measurement (no correction required).
 - d. Slowly lower the probe down the well again and confirm measurement written in field notebook.
3. 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 an electric tape. . If the measurements are off by >0.01 ft (0.35 cm), remove tape completely, dry off head and re-measure until two consecutive measurements are 0.01 ft (0.35 cm) different.

For each measurement round (at CACO – monthly) the following information must be recorded on the field sheet (Appendix G):

- Weather conditions
- Personnel involved
- Date and time of measurement
- The method (including instrument identification) used
- Depth to water from the MP (in hundredths of a foot)
- Any correction factor for the tape being used

Notes should also 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. Any new field sketches should be scanned and added to the archive available

and on file at the CACO Headquarters and the U.S. Geological Survey Massachusetts-Rhode Island District office.

2.1.5. Data Entry and Management

2.1.5.1. General Procedures

1. All measurements MUST be entered into the spreadsheet the same day as they were taken.
2. The raw Groundwater Level Data should be entered into the existing Excel 2007 spreadsheet. The RAW spreadsheet has been set up to mimic the field data sheet (Figure 18). It can be found on the following network drive:

Y:\I&M_Projects\Physical_Resources\Hydrology\HYDROLOGYDATA\DATA\RAWHYDRODATA\Observation Wells

MONITORED WELLS DEPTH TO WATER									
Town	Flow Cell	Meas. Pt. (ft)	Latitude	Longitude	Northing	Easting	Well Id	Location Note	
Truro	Chapasset	26.15					TSW-247	Lombard Hollow	
Eastham	Nauset	55.13					EGW-36	Nauset	
Eastham	Nauset	19.16					EGW-48	C1	
Eastham	Nauset	13.49					EGW-49	C2	
Eastham	Nauset	21.51					EGW-40	C3	
Eastham	Nauset	12.81					EGW-43	R32	
Eastham	Nauset	23.86					EGW-41	Goemast Residence	
Wellfleet		15.77					WNW-30	Old Long Pond Road	
Wellfleet	Chapasset	42.79					WNW-34	Golf Pond Access	
Wellfleet	Chapasset	67.57					WNW-123	Garrison	
Wellfleet	Chapasset	8.00					WNW-124	Pur Line	
Wellfleet	Chapasset	28.84					WNW-89	Paines campground	
Wellfleet	Chapasset	10.41					WNW-108	Tomhole	
Truro	Chapasset	57.51					WNW-122	HR-1	
Truro	Chapasset	41.20					TSW-246	Mitro	
Truro	Panmet	131.48					TSW-242	C6	
Truro	Panmet	103.13					TSW-241	NW-24 - dump	
Truro	Panmet	28.32					TSW-240	Quail Ridge	
Truro	Panmet	59.16					TSW-216	Old County	
Truro	Panmet	54.53					TSW-203	Lensbrook	
Truro	Panmet	71.40					TSW-134	off HeadoftheLedge Rd.	
Eastham	Nauset	14.89					TSW-106	Highland Golf	
Provincetown	Pilgrim	9.33					EGW-60	Salt Pond (VC)	
Wellfleet	Chapasset	44.14					EGW-79	On Hatches Harbor Rd	
							HW-4s	Dog Park	

Figure 18. Screen capture of current RAW data spreadsheet.

3. Groundwater level data is collected on a monthly basis. There is a separate workbook for each year and each tab within that workbook contains:
 - a. the raw data entered from the field sheet
 - b. a column with the stick up (ft) of each individual well measuring point
 - c. a column with the measuring point elevation (ft-NGVD29)
 - d. a column that calculates the depth of water below ground surface using the raw depth to water (ft) and the stick up (ft) of measuring point
 - e. a column that calculates the water level (ft-NGVD29) using the raw depth to water (ft) and the measuring point elevation (ft-NGVD29)
(NOTE: Elevations will be measured using RTK instrumentation during low canopy season in order to gain the best satellite reception. The current elevations in ft-NGVD29 will be updated when this data is post processed and will be documented in ft-NAVD88).
4. Save file using the following naming convention:
RAW_GroundwaterWellData_MonthYearofEntry_PersonnellInitials.xlsx
 (example: **RAW_GroundwaterWellData_Jan2011_KCM.xlsx**)
5. A photocopy of the field data sheet and an electronic backup copy should be made each month after the raw data is entered. The raw file is protected as *Read Only*.
6. A WORKING FILES workbook has been set up to include data from all years. This includes depth of water level (ft below ground surface) on *Tab1: ft_below_ground_surface* and water level (ft-NGVD29) on *Tab2: ft-NGVD29*
 - a. Copy the three columns from the RAW workbook
 - b. Navigate to the WORKING FILES workbook
 - c. Paste Special and click on Values to paste only the values found in RAW columns not the calculations
 - d. Update the chart
 - e. Save the workbook with the following naming convention:
WORKING_GroundwaterWellData_MonthYearofEntry_PersonnellInitials.xlsx
 (example: **WORKING_GroundwaterWellData_Jan2011_KCM.xlsx**)

The WORKING FILES workbook can be found:

Y:\I&M_Projects\Physical_Resources\Hydrology\HYDROLOGYDATA\DATA\WORKINGHYDRODATA\Observation Wells

7. An electronic backup copy should be made each month after the working file workbook has been updated.

2.1.6. References

- Bennett, G.D., 1976, Introduction to groundwater hydraulics, a programmed text for self-instruction: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter B2, 172 p.
- Driscoll, F.G., ed., 1986, Groundwater and wells (2nd ed.): St. Paul, Minnesota, Johnson Filtration Systems, 1089 p.
- Kennedy, E.J., 1990, Levels at streamflow gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A19, 31 p.
- Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Groundwater data-collection protocols and procedures for the National Water-Quality Assessment Program: Selection, installation, and documentation of wells, and collection of related data: U.S. Geological Survey Open-File Report 95-398, 79 p.
- Nielsen, D.M., and Schalla, Ronald, 1991, Design and installation of groundwater monitoring wells in Nielsen, D.M., ed., Practical handbook of groundwater monitoring: Chelsea, Michigan, Lewis Publishers. 239-331.
- Sanders, P. J., 1984, New Tape for Ground Water Measurements: Ground Water Monitoring Review, v. 4, no. 1, p. 38-42.
- Stallman, R.W., 1971, Aquifer-test design, observation, and data analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter B1, 26 p.
- U.S. Geological Survey, 2002, U.S. Geological Survey Occupational Safety and health Program Requirements Handbook SM 445-2-H, accessed January 20, 2002, at URL <http://www.usgs.gov/usgs-manual/handbook/hb/445-2-h.html>.

2.2. SOP 2. Streamflow Measurements

Revision History Log:

Version #	Date	Revised By	Changes	Justification
1.00 (USGS Open-File Report 02-497) Version 1.00 May 2002	2003			
1.01	Sept 2011	K. C. Medeiros	Separated SOP from others in original version. Updated Table 18 and added Figures 19, 20, 21 and 22. Added information about datum standards and current instrumentation. Updated equipment and supply lists. Added field methods. Added data entry and management procedures.	Revised to meet Oakley, et. al., 2002 format for I&M program.

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).

2.2.1. Reference-point Establishment and Leveling

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 (Rantz and others, 1982) such as the National Geodetic Datum of 1988 (NAVD88). 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). *NOTE: Geodetic datum MUST be documented for all elevations! Cape Cod National Seashore uses meters or feet NAVD88 as a standard measure of elevation for all sites.*

2.2.1.1. Equipment and Supplies

You can find the required equipment for reference point leveling in Table 16 in SOP 1: Groundwater Level Monitoring.

2.2.1.2. General Procedures

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. For example, bridge culverts were used as stable reference structures for several CACO stream gage sites.
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 and obvious enough to a novel observer.
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 H.

2.2.2. Stage and Discharge Measurements

Discharge measurements are recorded by field personnel on pre-printed waterproof field sheets (Appendix H). 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 needed at each site visit include:

- a. Observer
- b. Date
- c. Time
- d. Weather conditions
- e. Gage-height readings at start time
- f. Gage-height readings at end time (only for tidally influence sites)
- g. Distance along the cross section from initial point (or width of stream section)

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

- a. Calculated total discharge
- b. Mean gage height
- c. Width
- d. Area
- e. Velocity

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

2.2.2.1. Equipment and Supplies

Table 18. Required equipment for conducting streamflow monitoring

<i>Streamgaging Equipment</i>	<i>Purpose</i>
Personal Floatation Device	To protect personnel
Wading rod	To measure depth and meter height setting
Pygmy meter	To measure streamflow
Aquacalc Pro	To record meter rotations
Tagline	To measure cross-section length and position
2 PVC Posts	To anchor tagline
Discharge field sheet	To record measurement
Electric Well Tape	To measure groundwater level in nearby observation wells
Gloves	To protect personnel
Brush cutter	To clear brush or debris from section and shore
Mallet (optional)	to secure PVC posts
Hip waders	To protect personnel
Chest waders	To protect personnel
Orange Safety Vest	To protect personnel
Digital Camera	To document site conditions
GPS	To locate site location
Cell phone	To protect personnel
Copy of discharge rating	To check that measurement is within 5% of curve
Site sketch	To find measurement section
Extra 9V and AA batteries	Spare for Aquacalc and GPS units
Vehicle with safety equipment (i.e cones)	To protect personnel

2.2.2.2. General Procedures

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

1. A safety check of the measurement area must be made prior to working on the stream. Some hazards include deteriorating culverts, soft stream bottom substrates and eroding stream embankments
2. Pre-measurement observations and notes are made on the field sheet and must include:
 - a. Initials and last name of all field-party members
 - b. Date
 - c. Time of arrival at site
 - d. Type of meter
 - e. Flow conditions
 - f. Weather conditions
 - g. Description of the stream-channel control
3. For automatic digital-calculation devices, the datalogger should be prepared with pertinent information including:
 - a. Site name
 - b. Meter type
 - c. Correct meter settings
 - d. Correct time and date.

NOTE: The AquaCalc Pro uses the midsection method that is used by the United States Geological Survey and is well documented in the Geological Survey Water Supply Paper 2175 (Rantz et al, 1982).

4. Make sure all equipment is working properly
5. Perform spin test of pygmy meter (pygmy meter should be able to spin for 60 sec without stopping)
6. Make sure that the AquaCalc Pro is recording revolutions before collecting measurements
7. Measure the stream stage by recording the distance from an established overhead reference point before beginning cross sectional measurements and record on field sheet. If there is an observational groundwater well near the stream site, it is a good idea to also record water level as well. Two sites at CACO have wells located near the stream bed and data are collected on the field sheets for these two sites.
8. Clear anything that needs to be cleared from section
9. String tagline across section (Fig 19). 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 on field sheet.



Figure 19. Technician setting tagline and stream section with automated AquaCalc Pro and pygmy meter setup.

10. 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. The widest site at Cape Cod National Seashore is approximately 20 feet across so the minimum number of measurements is 20. For the remainder of the sites which are much 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 ($3 \text{ ft} / 2.5 \text{ in} = 14.4 \text{ measurements}$). For narrower streams, the maximum number of vertical measurements will be taken that will be allowed by the specifications of the instrument being used.
11. Determine total depth of streambed and determine whether you will need to perform a one point (0.6) or two-point (0.2 and 0.8) method (Figure 20).

12. Starting at the LEW (left edge of water):
 - a. Navigate to **Sections** AquaCalc Pro (Figure 20)
 - b. Choose a blank Section ID and then press **New** (soft key)
 - c. Enter the Section Information in Section Setup screen
 - d. Ensure Meter ID is set to #2 PYGMY std2
 - e. Press **Measure**
 - f. Press **Esc** key – screen will display Vertical 1 as *Water Edge*
 - g. Press **New Vertical**
 - h. Enter new vertical distance
 - i. Press **Enter**
 - j. Press **Stream Depth**
 - k. Enter depth
 - l. Press **Enter**
 - m. Adjust rod to correct depth (<2.5 ft deep, 0.6, >2.5 ft deep, 0.2 and 0.8)
 - n. Press **Measure**
 - o. Repeat by pressing **New Vertical** for each new vertical across section
 - p. At the end of section, press **New Vertical** and enter vertical distance
 - q. Press **Edge** ending at REW
13. Repeat all steps at each site
14. Perform a spin test of pygmy meter and store properly with travel pin
15. Leave the tagline in position in case the section needs re-measuring
16. Review Section Totals for each measurement section and record on field sheet (Appendix I). The AquaCalc Pro calculates the width, area, velocity and discharge for each section. If not using an automated instrument, calculate the width (usually constant per measurement), area (width × Depth), and discharge (Q) per measurement (Velocity x Area). Calculate the total discharge by summing the discharges across the entire width of the stream ($Q_{\text{total}} = q_1 + q_2 + \dots + q_n$).
17. Make sure to look at 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. At Cape Cod National Seashore, each site has been chosen so that the flow conditions are perpendicular to the tag line. The coefficient remains as 1.00.
18. At the end of the measurement, record the end time and the tagline readings for the right and left edges of water on the field sheet. Example: 1105, 10.0 ft, LEW; 1225, 42.5 ft, REW.
19. Read and record stage measurement again from the established reference point (bridge, staff gage) to check for sudden changes in stage during measurement.
20. *NOTE: CACO is in the process of developing rating curves for the streams, and they should be available by end of 2012.* 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.

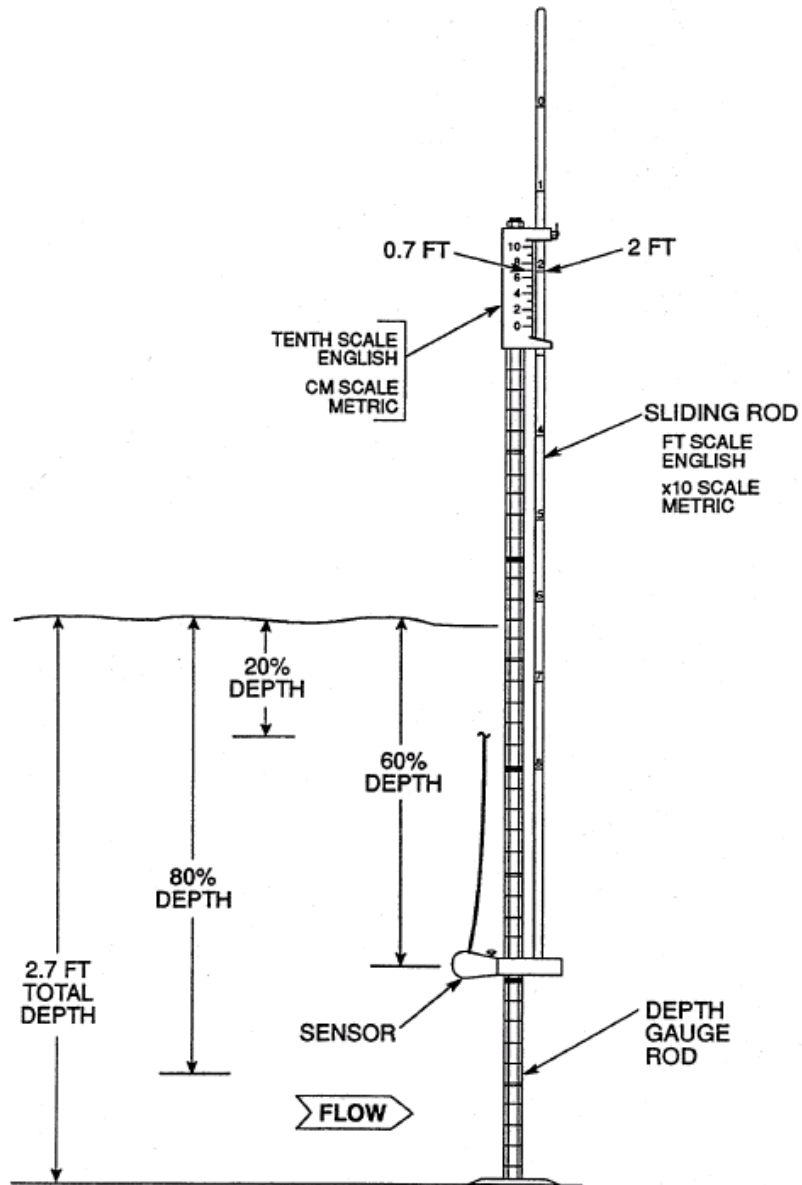


Figure 20. Top setting wading rod with examples of percent flow at 0.6, 0.2 and 0.8 depths (Shearer and Moore, 2010).



Figure 21. AquaCalc Pro keypad and display.

2.2.3. Data Entry and Management

2.2.3.1. General Procedures

2.2.3.1.1. Raw Field Sheets

1. All measurements **MUST** be entered into the workbook the same day as they are taken.
2. All data **MUST** be downloaded from the AquaCalc Pro the same day as they are recorded.
3. The raw streamflow data should be entered into the existing Excel 2007 spreadsheet. The RAW spreadsheet has been set up to mimic the field data sheet (Figure 22). It can be found at:
Y:\I&M_Projects\Physical_Resources\Hydrology\HYDROLOGYDATA\DATA\RAWHYDRODATA\Streamflow
4. Streamflow data is collected weekly and some sites biweekly. There is a separate workbook for each month that contains two tabs: *Tab1: Raw Data* - the raw data from the field sheet and *Tab 2: TotalQ* – the total discharge data for that month.

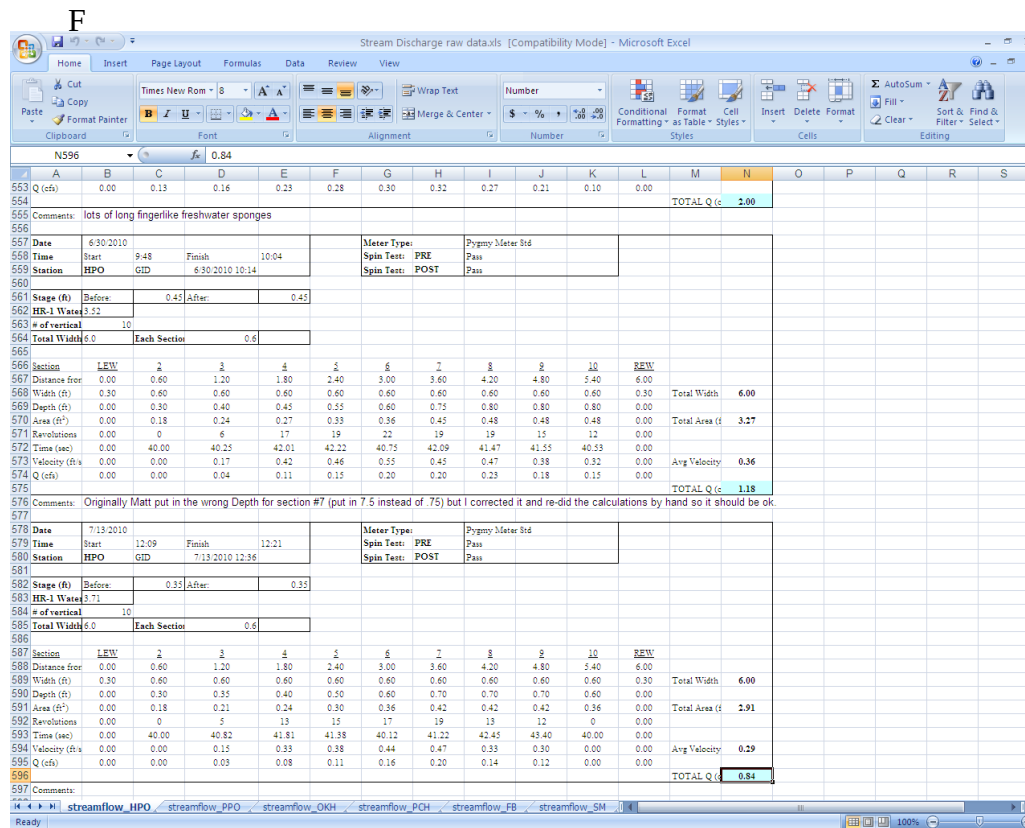


Figure 22. Screen capture of the current RAW streamflow data spreadsheet.

5. Save file using the following naming convention:
RAW_Streamflow_SiteID_MMDDYYofCollection_PersonnelInitials.xlsx
 (example: RAW_Streamflow_PPO_011511_KCM.xlsx)
6. A photocopy of the field data sheet and an electronic backup copy should be made each month. The raw files are protected as *Read Only*.
7. A WORKING FILES workbook has been set up to include the total discharge data from all sampling years and days.
 - a. Copy the total discharge columns from the RAW workbook *Tab 2: TotalQ*
 - b. Navigate to the WORKING FILES workbook
 - c. Paste Special and click on Values to paste only the values found in RAW columns
 - d. Update the chart
 - e. Save the workbook with the following naming convention:
WORKING_Streamflow_SiteID_MMDDYYofCollection_PersonnelInitials.xlsx
 (example: WORKING_Streamflow_PPO_011511_KCM.xlsx)

The WORKING FILES workbook can be found at:

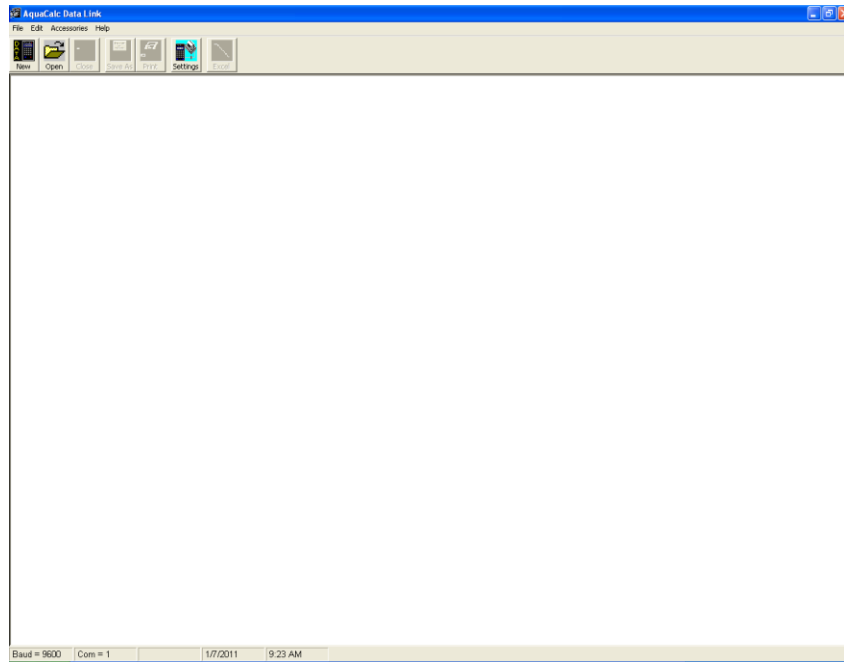
Y:I&M_Projects\Physical_Resources\Hydrology\HYDROLOGYDATA\DATA\WORKINGHYDRODATA\Streamflow

8. An electronic backup copy should be made each month after the working file workbook has been updated.

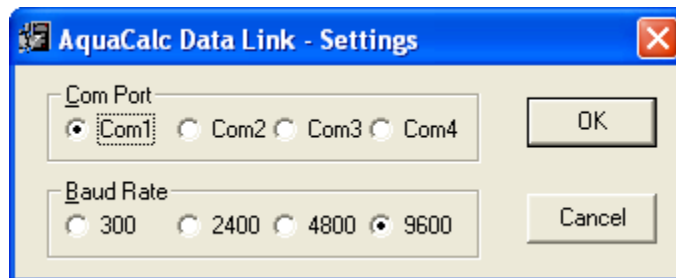
2.2.3.1.2. Downloading Data from AquaCalc Pro to PC

NOTE: Data must be downloaded the same day as it was collected!

1. Connect the Aquacalc Pro to the serial communications port of your computer using the provided data cable.
2. Start the DataLink Program (start menu-> Aquacalc Data Link)

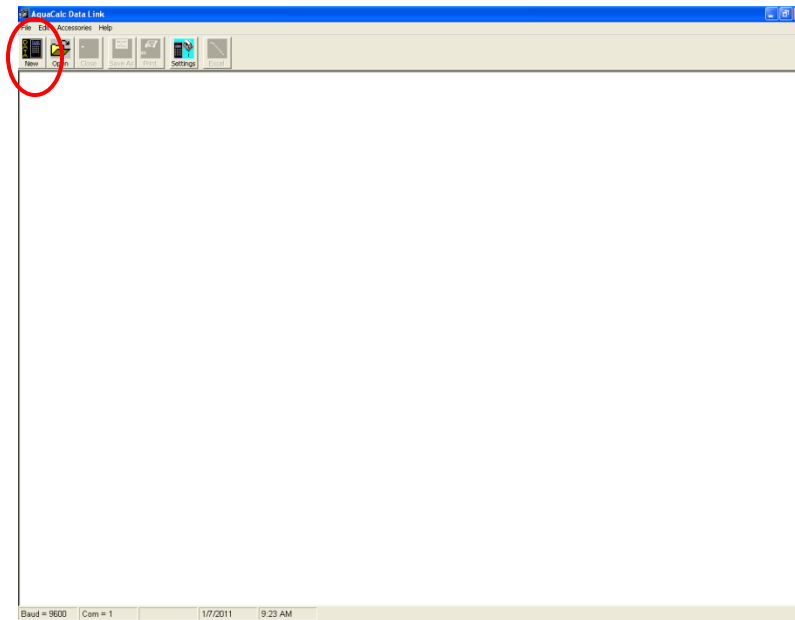


3. Click the Settings button to bring up the Settings Dialog Box

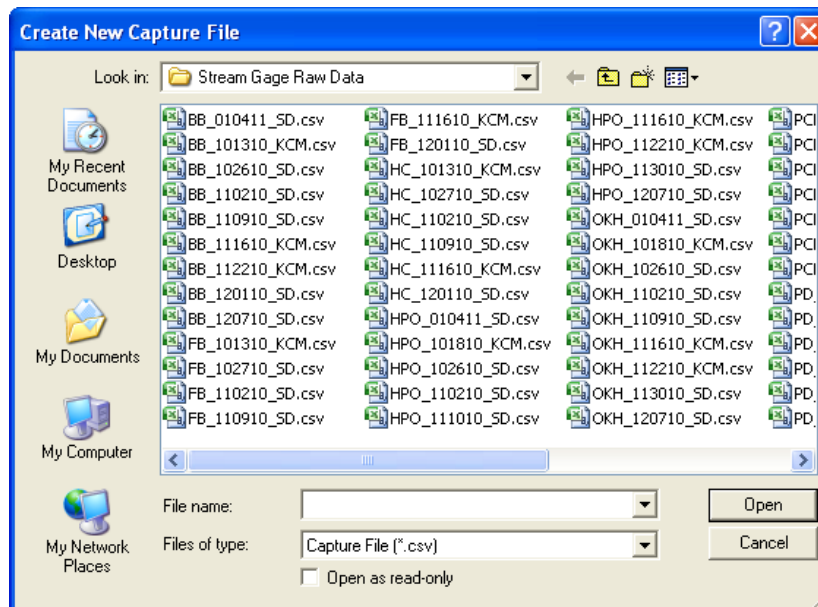


4. Choose the appropriate communications port and baud rate. The baud rate you choose must match the baud rate you set in the Aquacalc Pro in the System Preferences screen. The default Com Port is Com1 and the default baud rate is 9600.
5. Turn the Aquacalc Pro on

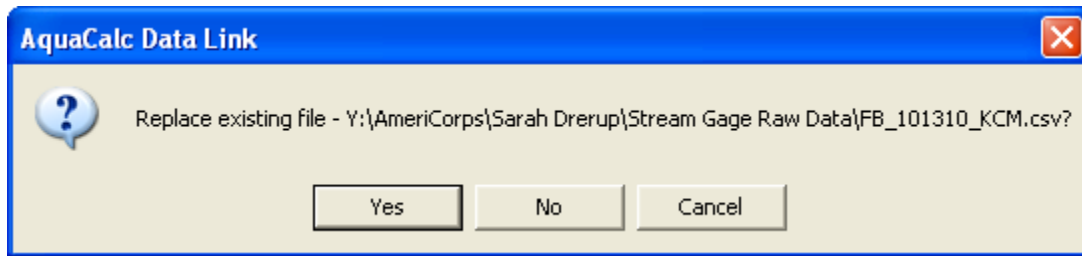
6. Select the new button from the tool bar in DataLink



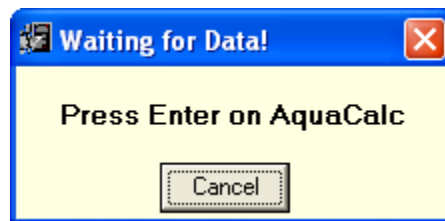
7. When the Create New Capture File comes up save the file as an .csv in the following format: site name_date.csv (ex: HPO112309.csv) This should be saved here:
Y:\I&M_Projects\Physical_Resources\Hydrology\HYDROLOGY DATA\DATA\STREAM GAGE DATA\AQUACALC PRO DOWNLOADED DATA_RAW
8. Hit Open



9. When it asks create this file? Hit Yes



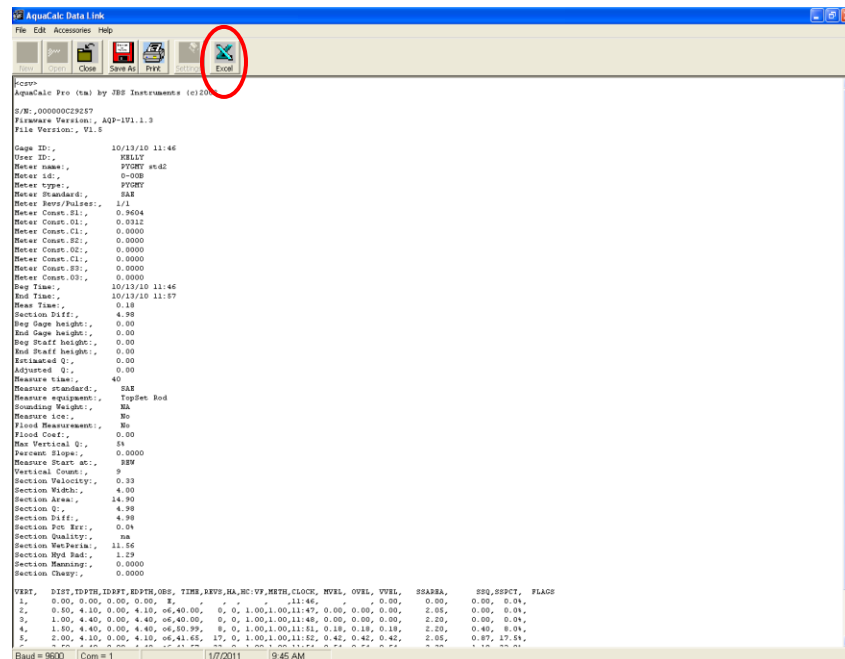
10. When the Waiting for Data box comes up hit cancel. Do NOT hit enter on Aquacalc Pro.



11. On AquaCalc Pro press #2 (Sections). Choose the section you wish to upload and hit **Enter**. This will take you back to the Main Menu.

12. On the Main Menu press #3 (Download Section). The data should appear on the DataLink screen

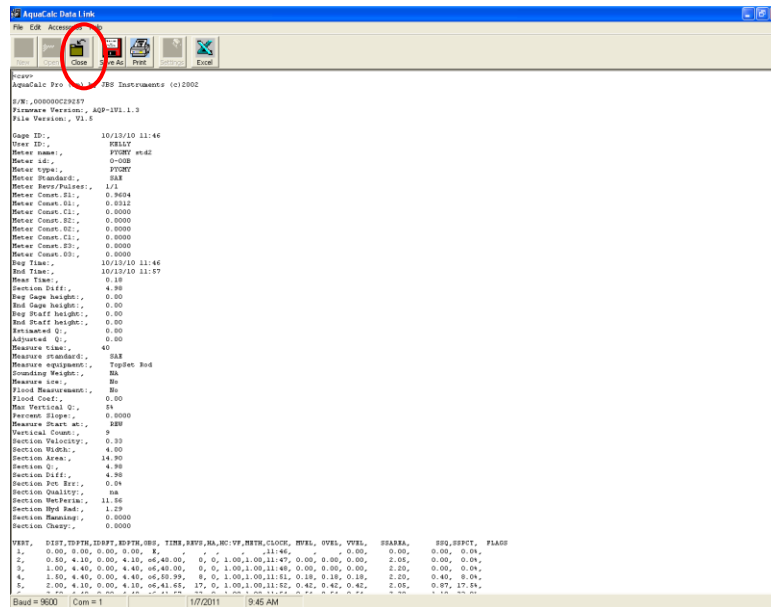
13. Click the Excel button on the tool bar in DataLink



14. Save the file as an .xlsx file here:

Y:\I&M_Projects\Physical_Resources\Hydrology\HYDROLOGY DATA\DATA\STREAM GAGE DATA\AQUACALC PRO DOWNLOADED DATA_EXCEL

15. Press Close button on the Tool Bar in DataLink.



16. Repeat steps 6 through 15 for each Section you wish to download from the Aquacalc Pro.

17. Before deleting the files from the Aquacalc Pro make sure that all of the files transferred successfully to the PC.

18. Check by opening all of them up in their current format.

19. Once you are sure that the files transferred and saved successfully, delete all of the files off of the AquaCalc Pro.

2.2.2.1.4. Deleting Files from AquaCalc Pro

1. Navigate to Main Menu on AquaCalc Pro by pressing **Menu**.
2. **Press #2 (Sections)** to get the list of Sections that were collected that day.
3. Press the # of the section you wish to delete.
4. Press soft button **Delete**.
5. A *Warning! All Data in the selected section will be permanently deleted!* message will appear.
6. Press soft button **Yes Continue**.
7. Repeat steps 3 through 6 until all files are deleted.

2.2.4. References

- Kennedy, E.J., 1984, Discharge ratings at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A10, 59 p.
- Rantz, S.E., and others, 1982, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, 2 v., 631 p.
- Shearer, J., and C. Moore. 2010. Southwest Alaska Freshwater Flow System Monitoring Protocol Standard Operating Procedures, Southwest Alaska Network. Natural Resource Report NPS/AKR/SWAN/NRR—2010/XXX. National Park Service, Fort Collins, Colorado. SOP 5: page 91.
- Socolow, R. S. U.S. Geological Survey, pers. commun., 1999. USGS ER NE WRD, 10 Bearfoot Road, Northborough, MA 01532. USGS Massachusetts-Rhode Island District Office.
- Socolow, R. S. U.S. Geological Survey, pers. commun., 2000. USGS ER NE WRD, 10 Bearfoot Road, Northborough, MA 01532. USGS Massachusetts-Rhode Island District Office.

2.3. SOP 3. Water-level Measurements in Ponds and Seasonal Wetlands Siphon Gage Method

Revision History Log:

Version #	Date	Revised By	Changes	Justification
1.00 (USGS Open-File Report 02-497) Version 1.00 May 2002	2003			
1.01	Sept 2011	K.C.Medeiros	Separated SOP from others in original version. Updated Tables 19, 20, 21. Added information about CACO datum standards and current instrumentation. Updated equipment and supply lists. Added procedures for pond stage field work and worker training. Added data entry and management procedures.	Revised to meet Oakley, et. al., 2002 format for I&M program.

2.3.1. Siphon Gage Installation

2.3.1.1. Equipment and Supplies

Table 19. Required equipment for installing, operating, and maintaining a siphon gage.

Siphon gage installation supplies & equipment	Purpose
personal flotation 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, to 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
clipboard	to protect field sheets, to provide writing surface
brush cutter	to clear land
hip waders	to access the bond
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 create jet
jet wand	to provide handle for jet
200-ft flexible firehose	to transport jetted water
hose intake screen	to prevent pump from sucking up debris
Siphon supplies	Purpose
PVC casing, 3-inch, schedule 40	to construct standpipe
PVC, 3-inch bottom plug	to plug bottom of standpipe
protective casing	to protect well from contact and access
lock	to protect public and equipment
¾-inch polyethylene tubing	to connect standpipe to pond
concrete block	to anchor tubing to bottom of pond
extra-large cable ties	to anchor tubing to bottom of pond

2.3.1.2. General Procedures

1. Select desired site location based on site-selection criteria, including consultation with a hydrologist.
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 side 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.

2.3.2. Reference Point and Pond Leveling

2.3.2.1. Equipment and Supplies

You can find the required equipment for reference point and pond leveling in Table 16 in SOP 1: Groundwater Level Monitoring.

2.3.2.2. General Procedures

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

2.3.3. Specific Data Collected at Each Siphon/Pond Site

Prior to implementation of the monitoring network, information on each monitoring station must be obtained and a master information sheet created. *NOTE: Geodetic datum MUST be documented for all elevations! Cape Cod National Seashore uses meters or feet NAVD88 as a standard measure of elevation for all sites.* This information must include:

1. Site identification – for example: Great Pond at Truro, MA
2. Town name
3. Latitude and longitude position
4. UTM XY coordinates
5. Altitude of land surface at standpipe
6. Length of casing stick-up from the land surface to the top of the MP
7. Total depth of the standpipe
8. Altitude of the measuring point
9. A description of the site with directions and a site-sketch map (Appendix F)
10. An estimated range in pond fluctuation (noting the range of dates over which the estimated range was derived).

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

2.3.4. Measurement Procedure for Siphon Gage Method

NOTE: CACO is currently not using this procedure for long-term monitoring of ponds and seasonal wetlands. Data collected until 2005 was measured using the following methods. At that time, Table 13 was used as a comparison and the difference between the Siphon Gage Pond Elevation and the Surveyed Pond Elevation was well within our data standards. Please see 2.3.5 for pond level procedure currently used.

2.3.4.1 Equipment and Supplies

Table 20. Required equipment and supplies for measuring pond and seasonal wetland water level using the siphon gage method.

<i>Siphon Gage Measurement Equipment and Supplies</i>	<i>Purpose</i>
Siphon Gage Keys	To provide well access
Water-level tape	To measure water-level
1 L plastic bottle filled with water for each site	To siphon tube
5 gallon bucket	To flush siphon tube if larger quantity needed
Siphon-Gage field sheet	To record water levels
Hip or Chest waders	To protect personnel
Cell phone	To protect personnel
Orange safety vest	To protect personnel

2.3.4.2. General Procedures

1. The functionality of the siphon must be determined by measuring the water level at least two times with an electric tape sensor (example: Heron Dipper T water level meter).
2. Using the Electric Tape Method (as in SOP 1):
 - a. Turn on the electric-tape sensor (Heron Dipper-T water level meter) and slowly lower the probe down the well (Figure 8).
 - b. 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
 - c. Read the graduated line at the MP position and record on datasheet. The depth below MP is a direct measurement (no correction required).
 - d. Slowly lower the probe down the well again and confirm measurement written in field notebook
3. After the initial readings, add a 1 liter slug of water to the standpipe and make sure that the water level in the gage returns to the pond level.
4. 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.
5. If the level is not repeated, add a 3-ft extension standpipe or use a 5 gallon bucket to force more water through the top of the siphon gage and add enough water to fill the extension pipe, completely flushing the system. Each measurement and the amount of purge water added should be documented on the field sheet.
6. Allow enough time for equilibration, and repeat steps 2 and 3 until the values are comparable.

For each measurement round at each site (at CACO – monthly), the following information must be recorded on pre-printed waterproof field sheet (Appendix J):

1. Weather conditions
2. Personnel involved
3. Date and time of measurement
4. The method (including instrument identification) used
5. Depth to water from the MP (in hundredths of a foot)
6. Any correction factor for the tape being used

Notes should be taken of the status of siphon-gage (i.e. maintenance issues, changes to the site layout, and any damage to the siphon gage) (Kennedy, 1990; McCobb and others, 1999b). Any new field sketches should be created and inserted as an appendix to the protocol if features such as roads and trees in the vicinity of the well change.

2.3.5. Measurement Procedure for Pond Stage Method

Pond water levels are monitored at 10 ponds and seasonal wetlands monthly (NOTE: the 10 primary ponds documented in the Kettle Pond Water Quality Monitoring Protocol are measured on a bi-weekly basis during the monitoring season to document major seasonal and annual hydrologic changes that could affect water chemistry and biota and are not the same 10 that are monitored in this protocol (Table 12). An auto-level is used to determine pond surface elevation by differential leveling from local benchmarks. The use of siphon gages was discontinued in 2005 due to difficulties in maintenance. NOTE: The siphon gages established at each of the 10 ponds and wetlands are now used as permanent benchmarks for all 10 of the ponds monitored in this protocol (Appendix B).

In an evaluation of this portion of the protocol, it was determined that it was a much better use of resources to gain a pond stage elevation that could be obtained using an auto-level method than taking those same resources and time in maintaining and fixing damaged and vandalized siphon gages.

2.3.5.1. Equipment and Supplies

Table 21. Required equipment and supplies for measuring pond stage

<i>Pond Stage Measurement Equipment</i>	<i>Purpose</i>
2 field workers	Need to collect accurate level
Siphon Gage Keys	To provide well access
Level	To measure level
Tripod	To hold level stable
Pond Stage Field Sheet	To record water levels
Knee Boots or Hip Waders	To protect personnel
Sledge Hammer	To break through ice
Cell Phone	To protect personnel
2 Orange Safety vests	To protect personnel

2.3.5.2. General Procedures

2.3.5.2.1. Training

In order to perform these field measurements, each field worker must be trained in using all of the equipment necessary to get accurate pond stage elevations. It is essential that each worker can perform each of the jobs, holding and reading the stadia rod as well as operating the leveling equipment (tripod and level). Each of these jobs requires knowledge of how to accurately read the stadia rod. Elevation markings differ between rods and each level may have its own unique handling requirements. This is why the following training session **MUST** be completed. A temporary benchmark (BM) and a separate location of unknown elevation has been set up outside in the field at the North Atlantic Coastal Lab (NACL) at the Cape Cod National Seashore. Each of the stadia rods and levels have their own unique ID number that are located on each piece of equipment and will need to be noted on the Pond Stage Field Sheet (Appendix J). The worker must become familiar with which equipment he/she is using in order to know if the measurements will be in feet or meters and that the correct sequence of numbers are being recorded. Each field worker must complete a reading with the level at least 3 times simultaneously with a trained staff member and the readings must not be more than 0.005 m (0.016 ft) off of the each other. If the measurements fall outside of this range, the worker will need to perform the test again. Three people are needed for this training (one of the three must be trained in taking level measurements).

To begin, the trained staff person reviews how to read the stadia rod and how to set up leveling equipment in the field.

1. Trainee sets up leveling equipment:
 - a. Place tripod on ground in location where both benchmark and location of unknown elevation are visible.
 - b. Adjust tripod legs until feet are firmly seated and the base of tripod is roughly level.
 - c. Place auto level on tripod so that leveling screws line up with legs of tripod.
 - d. Attach auto level to tripod using tripod mounting screw.
 - e. Adjust leveling screws to center bubble in bubble vial.
 - f. Rotate auto level and check to make sure it is level in all directions. Use vial sighting prism and readjust leveling screws if necessary.
2. Begin taking measurements
 - a. 2nd staff member holds the stadia rod steady and level on top of the benchmark.
 - b. Trainee lines up optical sight on auto level with rod. Use eyepiece and focusing knob to focus crosshair on rod.
 - c. Record height at which crosshair intersects stadia rod on field sheet. This is the backsight (BS). Care must be taken to accurately read the elevation from the stadia rod.
 - d. After the height is recorded, re-read where the crosshair intersects the stadia rod and confirm that you have recorded the measurement accurately.
 - e. Trained staff member repeats steps 2b,c and d.
 - f. 2nd staff member places the stadia rod onto the unknown elevation marker. Make sure that the rod is as vertical as possible.

- g. Trainee lines up optical sight on auto level with rod. Use eyepiece and focusing knob to focus crosshair on rod.
- h. Record height at which crosshair intersects stadia rod on field sheet. This is your foresight (FS). Care must be taken to accurately read the elevation from the stadia rod.
- i. After the height is recorded, re-read where the crosshair intersects the stadia rod and confirm that you have recorded the measurement accurately.
- j. Trained staff member repeats steps 2h, i, and j.
3. Steps 1 and 2 are repeated three times.
4. If the measurements are not within 0.005 m (0.016 ft) of each other, the test needs to be repeated.
5. All feet on level are brought down to original position and stored.

2.3.5.2.2. Field Measurements

1. Field worker sets up leveling equipment:
 - a. Place tripod on ground in location where both benchmark and location of unknown elevation are visible.
 - b. Adjust tripod legs until feet are firmly seated and the base of tripod is roughly level.
 - c. Place auto level on tripod so that leveling screws line up with legs of tripod.
 - d. Attach auto level to tripod using tripod mounting screw.
 - e. Adjust leveling screws to center bubble in bubble vial.
 - f. Rotate auto level and check to make sure it is level in all directions. Use vial sighting prism and readjust leveling screws if necessary.
2. Begin taking measurements
 - a. First worker opens the cap of the steel casing.
 - b. First worker holds the stadia rod steady and level on the top of the edge of the steel casing (Figure 23).

(NOTE: If the PVC on the inside of the siphon well casing is used as the benchmark measuring point (MP), you MUST indicate this on the field sheet- Table?? are known MP elevations for both the PVC and steel casing benchmarks for reference).



Figure 23. Stainless steel well casing as benchmark for pond stage measurements.

- c. Second worker line up optical sight on auto level with rod. Use eyepiece and focusing knob to focus crosshair on rod.
 - d. Record height at which crosshair intersects stadia rod on field sheet. This is the backsight (BS). Care must be taken to accurately read the elevation from the stadia rod.
 - e. After the height is recorded, re-read where the crosshair intersects the stadia rod and confirm that you have recorded the measurement accurately.
 - f. First worker places the stadia rod into a shallow (~0.1m) point in the pond visible to the worker operating the auto level. Make sure that the rod does not sink into sediment while the measurements are being recorded. *(NOTE: If ice is present, break through and place stadia rod to the bottom as usual and measure WE where the water intersects the rod NOT where the ice surface intersects. If you cannot break through the ice, no measurement should be taken!)*
 - g. Second worker line up optical sight on auto level with rod. Use eyepiece and focusing knob to focus crosshair on rod.
 - h. Record height at which crosshair intersects stadia rod on field sheet. This is your foresight (FS). Care must be taken to accurately read the elevation from the stadia rod.
 - i. After the height is recorded, re-read where the crosshair intersects the stadia rod and confirm that you have recorded the measurement accurately.
 - j. First worker reads level at which water intersects stadia rod (WE). This is the instrument height (HI).
3. Use formula to determine unknown elevation.

$$(BS + BM) - (FS - WL) = \text{Pond stage elevation m-MSL (Figure 21)}$$

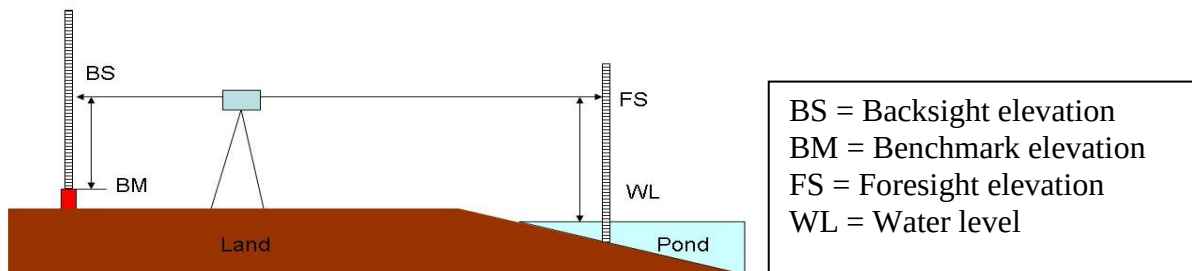


Figure 24. Diagram of the procedure for gaining a pond stage measurement using a known benchmark.

2.3.6. Data Entry and Management

2.1.5.1. General Procedures

1. All measurements **MUST** be entered into the spreadsheet the same day as they were taken.
2. The raw Pond Stage Data should be entered into the existing Excel 2007 spreadsheet. Currently the RAW Pond Stage Data is entered into a spreadsheet containing data from both this protocol as well as the Kettle Pond Water Quality Monitoring Protocol. It can be found:

Y:\I&M_Projects\Aquatic_Ecology\Kettle_Ponds_Water_Quality\Data\2010_KPWQ\Pond_Stage_Data_2010.xlsx

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1																				
2	Duck	1/11/2011	10:35 AM	4.24	0.75		2.545	0.075	2.47	2.52			Secondary Ponds							
3	Duck	2/23/2011	9:37 AM	4.24	0.54		2.21	0.07	2.14	2.04			Higgins**	4/14/2011	3.73	0.515	0.515	2.215	0.15	
4	Duck	3/16/2011	12:20 PM	4.24	0.8		2.415	0.1	2.315	2.73			Higgins**		3.73		0			
5	Duck	4/19/2011	12:43 PM	4.24	0.79		2.24	0.4	1.84	3.19							0			
6	Duck	4/22/2011	8:20 AM	4.24					0	4.24	13.30		Williams***	4/14/2011	3.73	0.515	0.515	2.215	0.15	
7	Duck	5/9/2011	3:35 PM	4.24					0	4.24	13.90		Williams***	8/19/2011	3.73		0			
8	Duck	5/17/2011	8:05 AM	4.24					0	4.24	12.70		Williams***		3.73		0			
9	Duck	5/20/2011	10:39 AM	4.24	0.765		2.205	0.08	2.125	2.88							0			
10	Duck	6/2/2011	10:40 AM	4.24					0	4.24	9.35		Kinnecum***	4/8/2011	3	1.16	1.16	2.13	0.155	
11	Duck	6/15/2011	11:44 AM	4.24	0.76		2.215	0.11	2.105	2.90	8.30		Kinnecum***	8/17/2011	3	1.215	1.215	2.16	0.1	
12	Duck	7/11/2011	11:30 AM	4.24	0.685		2.065	0.11	1.955	2.97	6.18		Kinnecum***	8/23/2011	3	1.215	1.215	2.16	0.1	
13	Duck	8/15/2011	10:48 AM	4.24	0.165		1.77	0.1	1.67	2.74							0			
14	Duck	8/17/2011	9:45 AM								4.10		Northeast*	4/7/2011	3.85	1.7	1.7	1.725	0.1	
15	Duck	8/24/2011	10:00 AM								4.40		Northeast*	8/15/2011	3.85	1.633	-0.315	1.68	0.1	1.97
16	Duck												Northeast*	8/17/2011						
17	Duck																0			
18	Duck												Southeast*	4/7/2011	3.85	1.78	1.78	1.795	0.1	
19	Duck												Southeast*	8/15/2011	3.85	1.915	-0.055	1.93	0.1	1.97
20	Duck												Southeast*	8/17/2011						
21	Duck																0			
22																				
23													Turtle*	4/7/2011	3.85	0.855	0.855	1.855	0.1	
24	Dyer	3/11/2011	11:05 AM	3.85	0.65		1.98	0.1	1.88	2.65			Turtle*	8/15/2011	3.85	1.575	-0.395	1.96	0.1	1.97
25	Dyer	2/23/2011	9:00 AM	3.85	0.81		1.905	0.1	1.805	2.86			Turtle*	8/17/2011						
26	Dyer	3/15/2011	11:58 AM	3.85	0.95		1.975	0.1	1.875	2.93							0			
27	Dyer	4/19/2011	1:51 PM	3.85	0.87		1.83	0.1	1.73	2.99			Horseleech****	4/29/2011	3	0.895	0.895	2.035	0.105	
28	Dyer	4/22/2011	10:20 AM	3.85							7.90		Horseleech****	5/21/2011	3					
29	Dyer	5/6/2011	9:48 AM	3.85	0.835		1.825	0.16	1.665	3.02	8.95		Horseleech****		3					
30	Dyer	5/17/2011	9:38 AM	3.85							8.55						0			
31	Dyer	5/20/2011		3.85	0.965		1.885	0.1	1.785	3.03			Slough****	4/20/2011	3	1.41	1.41	1.93	0.1	
32	Dyer	6/16/2011	12:27 PM	3.85					0	3.85	8.60		Slough****	8/16/2011	3	1.14	1.14	1.77	0.025	
33	Dyer	6/27/2011	11:00 AM	3.85	0.665		1.505	0.1	1.405	3.11	7.03		Slough****	8/22/2011	3					
34	Dyer	7/13/2011	1:27 PM	3.85	0.905		1.9	0.1	1.8	2.98	5.35						0			
35	Dyer	8/15/2011	12:46 PM	3.85	0.835		1.97	0.1	1.87	2.82			Round (west)****	4/20/2011						
36	Dyer	8/18/2011	11:40 AM								6.25		Round (west)****	8/19/2011						
37	Dyer	8/24/2011	8:20 AM								5.40		Round (east)****							
38	Dyer												Round (east)****	4/20/2011	3					
39	Dyer																0			
40	Dyer																0.86	3.025	0.1	
41	Dyer																			
42	Dyer																			
43	Dyer																			
44	Dyer																			
45																				
46																				
47	Great_T	3/11/2011	11:55 AM	4.32	0.495		2.205	0.1	2.105	2.71										
48	Great_T	2/23/2011	10:26 AM	4.32	0.24		1.85	0.1	1.75	2.81										

Figure 25. Screen capture of current RAW pond stage spreadsheet.

3. Pond Stage data is collected on a monthly basis. There is one spreadsheet for all years starting in 2010 and all sampling dates. This spreadsheet includes:
 - a. the raw data entered from the field sheet
 - b. a column calculating the final pond water level (m-NGVD29)

(NOTE: Elevations will be measured using RTK instrumentation during low canopy season in order to gain the best satellite reception. The current elevations in ft-NGVD29 will be updated when this data is post processed and will be documented in ft-NAVD88).

4. Save file as POND_STAGE_2011.xlsx

5. A photocopy of the field data sheet and an electronic backup copy should be made each month after the raw data is entered. The raw file is protected as *Read Only*.
6. A WORKING FILES workbook has not been set up to date.
7. Once established, an electronic backup copy should be made each month after the working file workbook has been updated.

2.3.7. References

Kennedy, E.J., 1990, Levels at streamflow gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A19, 31 p.

McCobb, T.D, LeBlanc, D.R., and Socolow, R.S., 1999b, A siphon gage for monitoring surface-water levels: Journal of the American Water Resources Association, v. 35, no. 5, p. 1141-1146.

2.4. SOP 4. Data Management

Revision History Log:

Version #	Date	Revised By	Changes	Justification
1.00 (USGS Open-File Report 02-497) Version 1.0 May 2002	2003			
1.01	Sept 2011	K. C. Medeiros	Separated SOP from others in original version. Added site safety plan location. Added file organization and archiving procedures. Added Table 22 and updated Table 23. Added figures and procedures for current data storage and management procedures.	Revised to meet Oakley, et. al., 2002 format for I&M program.

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 be obtained from the Massachusetts-Rhode Island District of the U.S. Geological Survey (Northborough, MA). 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 Appendixes E-K.

Well Installation (from construction log – Appendix E)

An example of a completed construction log (well TSW 257-0034) can be reviewed in Appendix E.

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 G)

An example of a completed water level field sheet (month of January 2000) can be reviewed in Appendix G.

Raw Data Required:

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 field sheet* – Appendix H) An example of a completed discharge field sheet (Herring River, 011058793, 9/26/2000) can be reviewed in Appendix H.

Raw Data Required:

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	

Pond, Lake, Wetland Water-Level Measurements (from *pond water level measurement field sheet* – Appendix J)

Raw Data Required:

Project name	Measurement personnel
Date	Time of each measurement
Well name	Depth to water from MP (siphon)
Water-level method (siphon or pond stage)	Meter or tape used
Tape correction, if needed	Final depth to water from MP (siphon)
Auto-level and Rod ID (pond stage)	Weather conditions
Ice conditions	MP location (PVC or casing)

2.4.1. 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

2.4.1.1. 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 (Appendix A)
2. Safety information including site-safety plan: *Cape Cod National Seashore Long-Term Ecosystem Monitoring Program's Safety Standards and Procedures for Monitoring Projects-Version 3*
Y:I&M_Program\Programmatic_SOPs
3. Photographs of relevant features of the site-network area (Appendix A)
4. Permission and permit documentation for sampling and installation of equipment (MA-RI USGS District Archives).

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. Typically if ASCII files are not created, .csv files are created for archiving purposes.

A general Hydrology Data folder is set up that includes separate data folders for the three monitoring components of the long-term monitoring protocol, groundwater level, streamflow and pond and wetland water level data. Each of those is separated into raw and working files. The raw data files for all components are *Read Only* so that they cannot be manipulated. They are also saved as .csv files for archiving purposes. A new filename is created with the new date that the latest data was entered and the initials of the technician who entered it (example: **GWLEVEL_DATA_NOV2010_KCM.xlsx**). For the automated streamflow data that is measured by the Aquacalc Pro, the data files are named using the Site ID initials, the date that the data was collected and the initials of the field technician (example: **PD_101510_KCM.xlsx**). The pond water level data is entered into a spreadsheet under the general Hydrology folder but also entered into the Kettle Pond Water Quality Monitoring Protocol spreadsheet for future analysis. This data is treated the same as the groundwater level data.

The following screen captures illustrate the general file organization structure of all of the raw and working Hydrologic Data:

The screenshot shows a Windows Explorer window with the following details:

- Address Bar:** Y:\BAM_Projects\Physical_Resource\Hydrology\HYDROLOGY DATA\DATA
- Left Pane (Tree View):**
 - Documents_for_review
 - Dune Shack EA
 - Dune Shack_EA_01_Classes
 - General BAF
 - BAF Program
 - Aquatic Ecology
 - CACO Vegetation Map 2000
 - Climate Change
 - Coastal_Forests
 - Coastal_HealthIndex
 - Cover_Type_Mapping
 - Data Management
 - Dune_Grassland_Vegetation
 - Dune_Slack_Wetlands
 - Forested_Wetland_Pools
 - MP Species
 - Physical Resources
 - Dune_Slack_Wetlands
 - DNE
 - ENE
 - Geomorphic_Shoreline_Change
 - GUT PROFILES - TP
 - GW Quality
 - HORSESHOE CRABS_M0_2011_FMES
 - Hydrology
 - Avenacos
 - Applied Hydrogeology CD
 - AQUACROSS
 - Climate Change Analysis Presentati
 - EASTMAP_VETELS
 - ECONOMY Software
 - Elevation Worksheets
 - Geospatial Datacube Interbar
 - GIS Projects
 - Groundwater_Quality
 - HYDRO DATA
 - HR_WetlandWade
 - HYDRO PROTOCOLS
 - HYDROLOGY DATA
 - DATA
 - Backup
 - Data Requests
 - DataToArchive
 - CAL_Hydro_Data
 - RAW HYDRO DATA
 - SITE PROFILE INFORMATION
 - WORKING HYDRO DATA

- Right Pane (File List):**

Name	Size	Type	Date Modified
Backup		File Folder	11/14/2009 2:52 PM
Data Requests		File Folder	12/29/2010 11:24 AM
DataToArchive		File Folder	9/13/2009 10:22 AM
CAL_Hydro_Data		File Folder	12/29/2010 11:26 AM
RAW HYDRO DATA		File Folder	1/7/2011 10:30 AM
SITE PROFILE INFORMATION		File Folder	12/29/2010 11:26 AM
WORKING HYDRO DATA		File Folder	12/29/2010 12:47 PM
- Status Bar:** 7 objects (Disk free space: 144 GB), 0 bytes, Local Internet

2.4.1.3. 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 Groundwater 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 groundwater, 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 groundwater data and pond-level data collected in 2000 are available on NWISWeb. Table 22 lists the groundwater level data that are available on NWIS. Note that these are wells that have been or continue to be monitored by the Cape Cod Commission.

Table 22. Groundwater level data that are currently available on NWIS.

Site Number	Site Name	Period of Record		
		Begin Date	End Date	# Levels
415125069581501	MA-EGW 36	7/22/1975	11/30/2010	382
414959069595001	MA-EGW 37	7/22/1975	8/24/2004	160
420355070112302	MA-PZW 78	9/30/1975	11/30/2010	217
420239070062001	MA-TSW 1 TRURO, MA	8/30/1950	7/27/2007	714
420206070045901	MA-TSW 89 TRURO, MA	9/24/1957	11/30/2010	634
420313070061901	MA-TSW 92	6/18/1964	11/30/2010	240
420206070034001	MA-TSW 106	5/19/1970	12/19/2000	69
420233070044601	MA-TSW 134	5/30/1972	12/19/2000	99
420145070045901	MA-TSW 145	5/31/1972	12/19/2000	26
415940070025701	MA-TSW 179	5/7/1973	9/30/2007	187
420051070024805	MA-TSW 203	9/25/1973	11/30/2010	247
415843070035901	MA-TSW 216	7/21/1975	6/20/2007	167
415821069591601	MA-TSW 256-0061	9/23/1999	12/19/2000	15
415808070024301	MA-TSW 257-0034	9/8/1999	12/19/2000	16
420107070122801	MA-TSW 258-0135	9/23/1999	12/19/2000	13
415705070025101	MA-TSW 261-0053	10/21/1999	12/19/2000	13
415933070024501	MA-TSW 262-0010	11/23/1999	12/19/2000	13
415353069585401	MA-WNW 17 WELLFLEET, MA	11/29/1962	11/30/2010	571
415638070011501	MA-WNW 30	9/30/1975	6/20/2007	171
415722070010001	MA-WNW 34	9/30/1975	11/30/2010	405
415528070000302	MA-WNW 89	2/23/1999	12/19/2000	22
415738070004801	MA-WNW 105	3/30/1978	12/19/2000	59
415732070000401	MA-WNW 108	4/4/1978	11/30/2010	339
415747070010001	MA-WNW 122-0015	3/24/1999	12/19/2000	20
415609070000101	MA-WNW 123-0042	3/23/1999	12/19/2000	22
415545070000301	MA-WNW 124-0068	3/23/1999	12/19/2000	22

2.4.1.3.1. Ground Water Site Inventory System

The GWSI is a computer system for storage and access of groundwater 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).

2.4.1.2.2. 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 collected for protocol development were processed in ADAPS and are available on NWISWeb. *Data from 2000 through present are currently unavailable on ADAPS but are stored locally at CACO.*

2.4.2. Data Archiving Procedures

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 - <http://ma.water.usgs.gov/> or at a regional Federal Archives and Records Center (FARC) - www.archives.gov/frc. 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 23. All data at CACO are physically archived in fire safe cabinets in the form of field sheet copies, field notebooks and CD/DVDs. The electronic back ups are in .csv format. Each file is documented with an archival sheet (Appendix L). All electronic data are backed up on a local server and tapes as well as monthly portable hard drive backups that are stored out of the building.

Table 23. Data to be archived and archive period (Modified from USGS, pers. 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
Groundwater		
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 - MA-RI
Location maps	75 years	keep in district files - MA-RI
Drilling logs	75 years	keep in district files - MA-RI
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
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

2.4.3. References

- Dempster, G.R., compiler, 1990, National water information system user's manual--volume 2, chapter 3. Automated data processing system: U.S. Geological Survey Open-File Report 90-116, version 90.1, variously paged.
- Fetter, C.W., 1994, Applied hydrogeology (3d ed.): Upper Saddle River, New Jersey, Prentice-Hall, 691 p.
- U.S. Geological Survey, 1999, pers. commun. USGS ER NE WRD, 10 Bearfoot Road, Northborough, MA 01532. USGS Massachusetts-Rhode Island District Office.

2.5. SOP 5. Data Analysis Techniques

Revision History Log:

Version #	Date	Revised By	Changes	Justification
1.00 (USGS Open-File Report 02-497) Version 1.0 May 2002	2003			
1.01	Sept 2011	K. C. Medeiros	No changes to text or content, only to format.	Revised to meet Oakley, et. al., 2002 format for I&M program.

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.

2.5.1. Groundwater, Ponds and Seasonal Wetlands

The most common approach to understanding trends in groundwater, 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 26. 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.

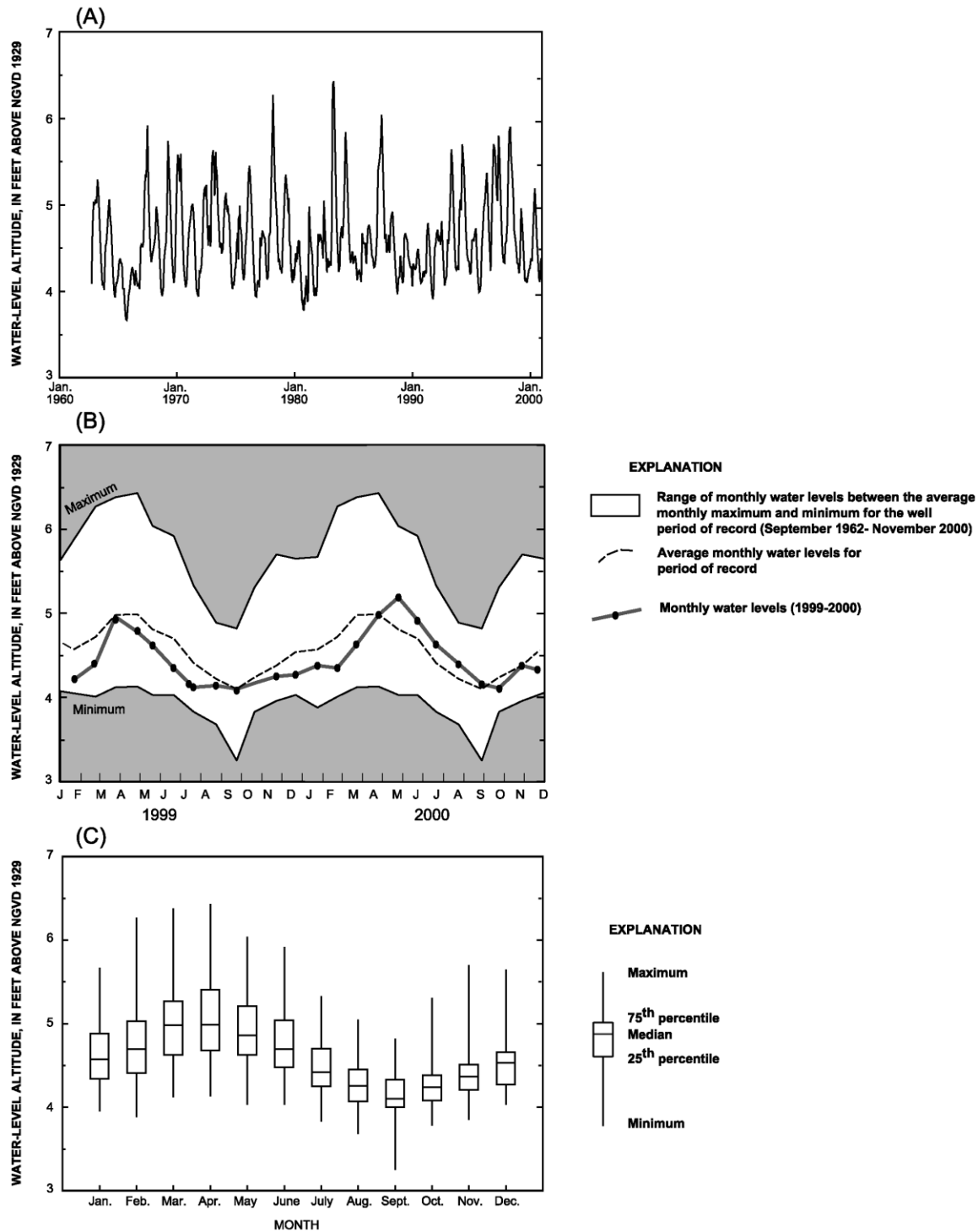


Figure 26. Three types of hydrographs for Truro well TSW 89-0028 showing: (A) long-term monthly water-level measurements over a period of nearly 40 years; (B) comparison between water levels measured during the protocol measurement period to historical monthly high, average, and low water-level measurements; 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 groundwater 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 groundwater elevations can be drawn. Examples of water-table maps on Cape Cod include Savoie (1995) and LeBlanc and others (1986). Figure 28 shows a map for a portion of the Chequesset flow cell which includes lines of groundwater 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. 29). Table 24 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 groundwater-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 groundwater 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).

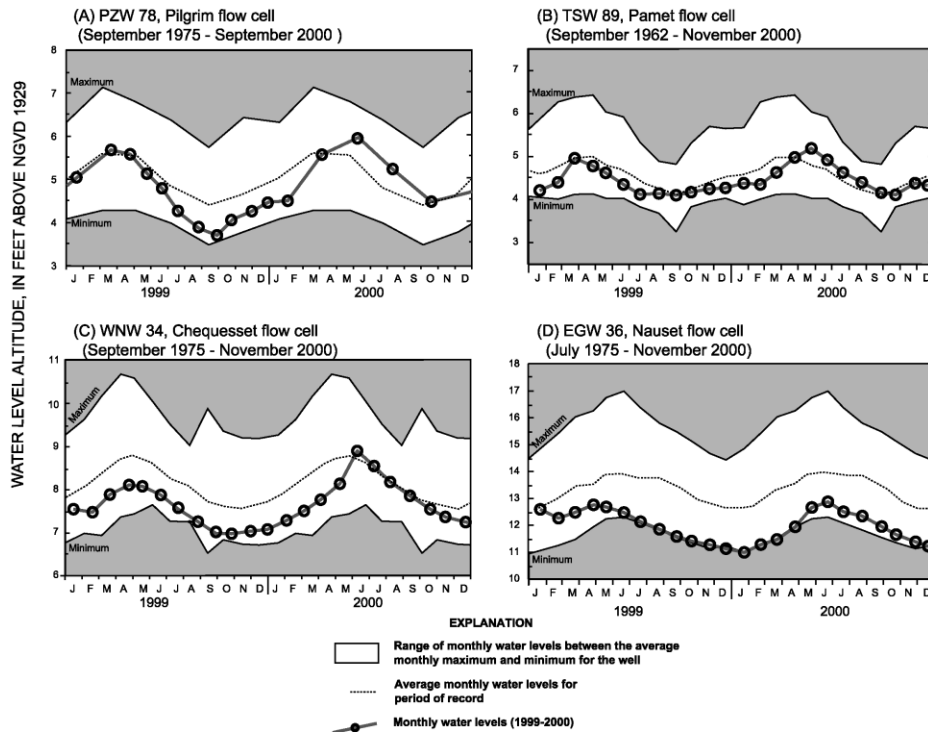


Figure 27. Current conditions hydrographs for four protocol wells from different Lower Cape Cod groundwater-flow cells. Vertical scales and lengths of record vary.

Table 24. 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 foot	Gradient direction, in degrees east of true north	Altitude of well EGW 36, in feet above NGVD29
3/25/1999	0.00071	140.45	12.48
4/13/1999	0.00073	143.01	12.72
5/21/1999	0.00081	143.42	12.68
6/21/1999	0.00083	144.08	12.47
7/21/1999	0.00078	147.46	12.13
8/24/1999	0.00077	145.82	11.85
9/23/1999	0.00092	138.42	11.58
10/23/1999	0.00085	136.87	11.41
11/23/1999	0.0008	137.15	11.27
12/22/1999	0.00079	133.89	11.13
1/24/2000	0.00077	132.4	10.99
average	0.0008	140.27	11.88
range	0.00021	15.06	1.48

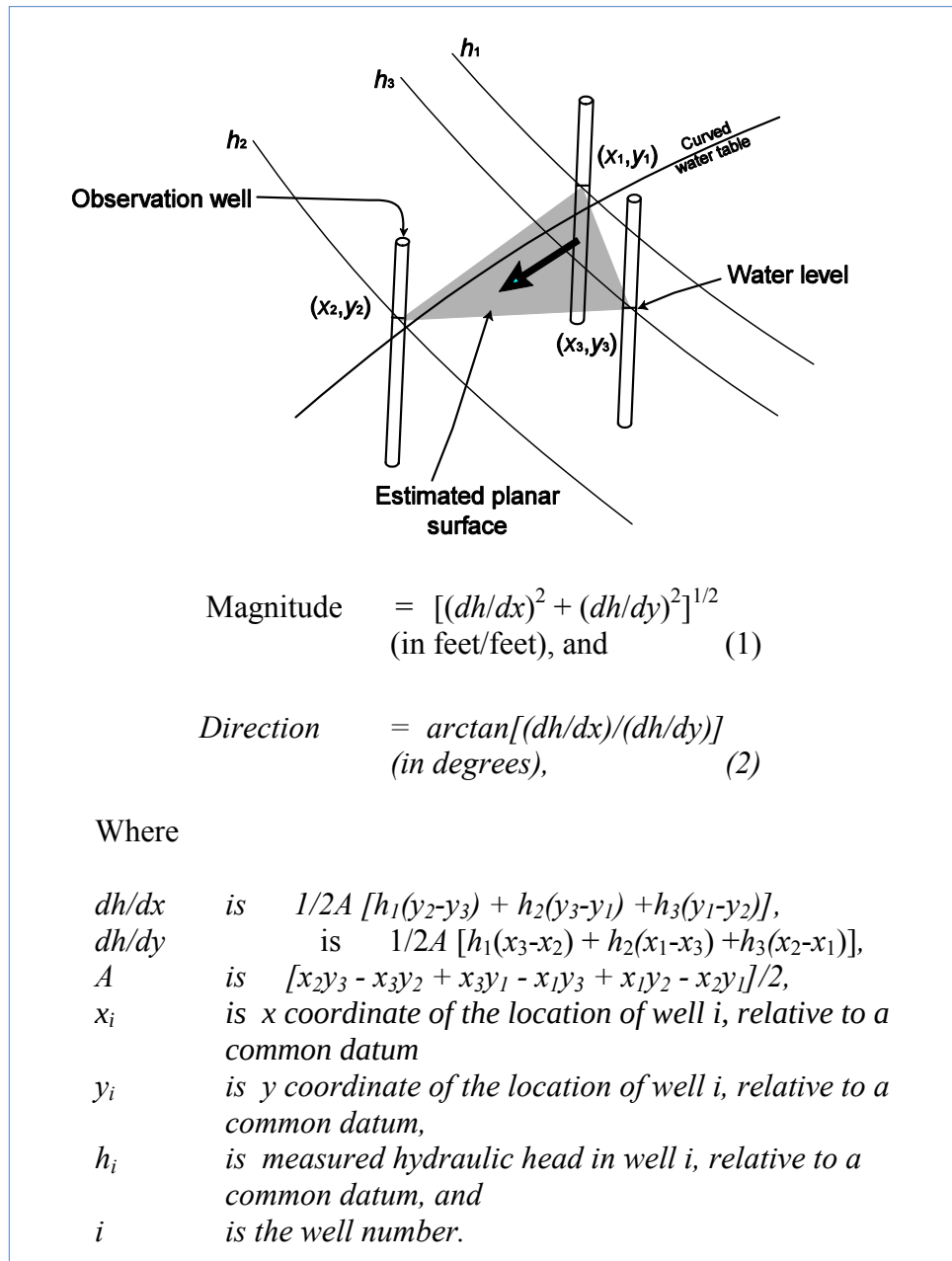


Figure 29. Schematic diagram of a three-point triangulation for hydraulic-gradient analysis (modified from McCobb and others, 1999a).

2.5.2. 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 30. 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 groundwater levels can be plotted over time. The surface-water stages can also be plotted with groundwater levels to show their relation. Figure 31 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 groundwater 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 32 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 ft³/sec (0.57 m³/sec) about 17 % of the time. This information can be critical in determining the adequacy of streamflow to meet biological and ecological requirements.

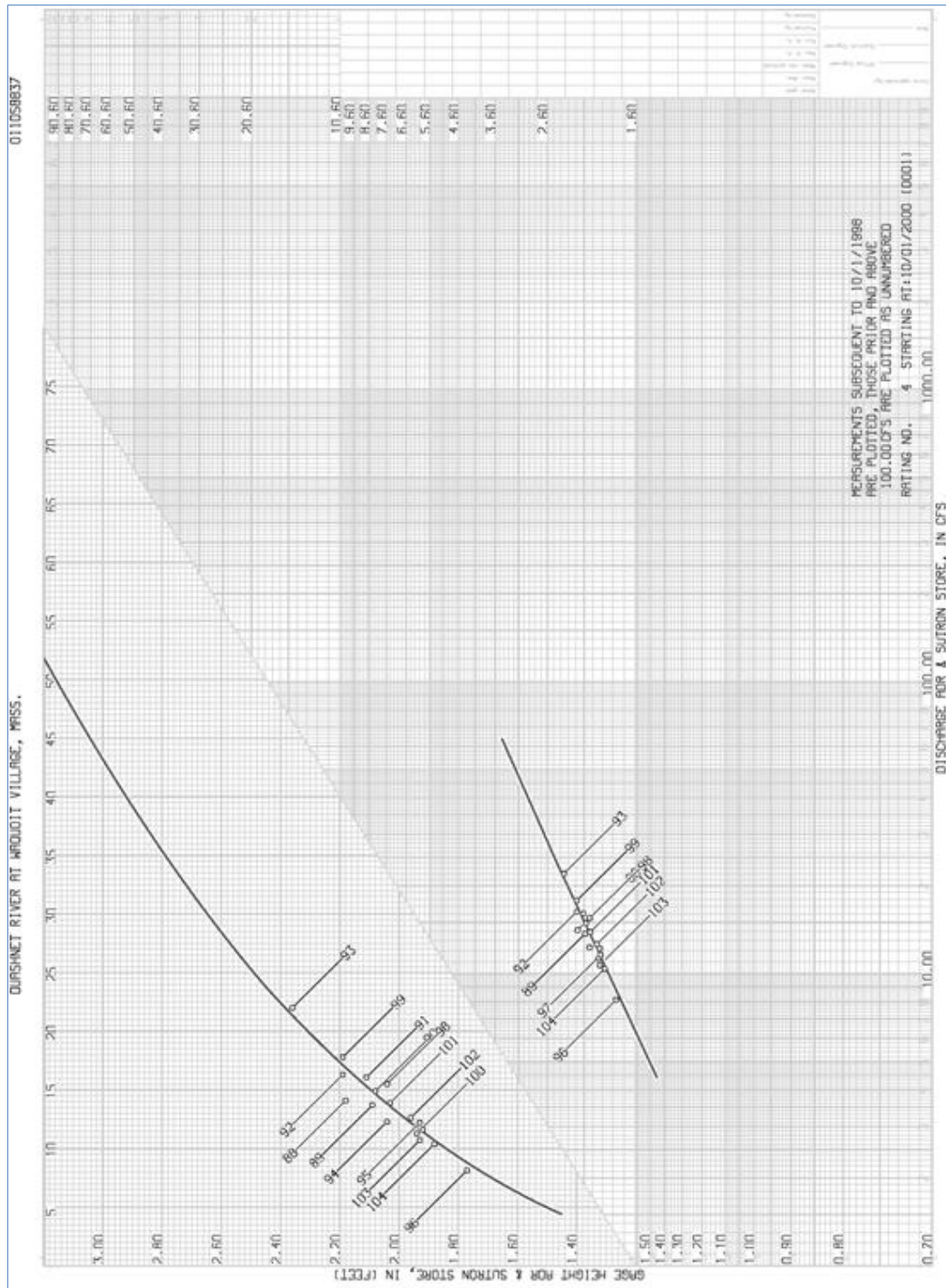


Figure 30. An example of a discharge-rating curve for the Quashnet River stream-gaging station (011058837), Cape Cod, Mass., for the protocol measurement period.

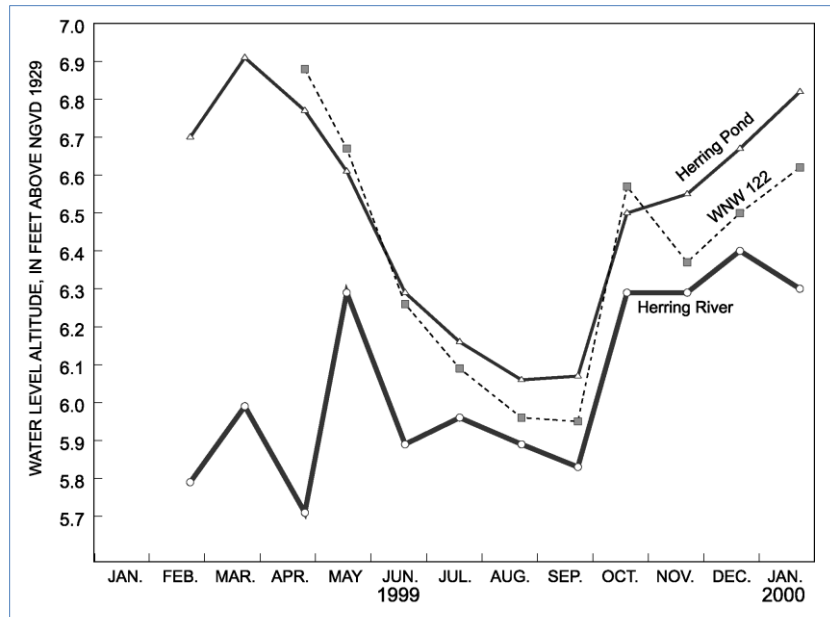


Figure 31. An example of a stage hydrograph for the Herring River stream-gaging station (011058793) near Wellfleet, Mass., Herring Pond, and well WNW 122 near the head of the Herring River for the protocol-monitoring period.

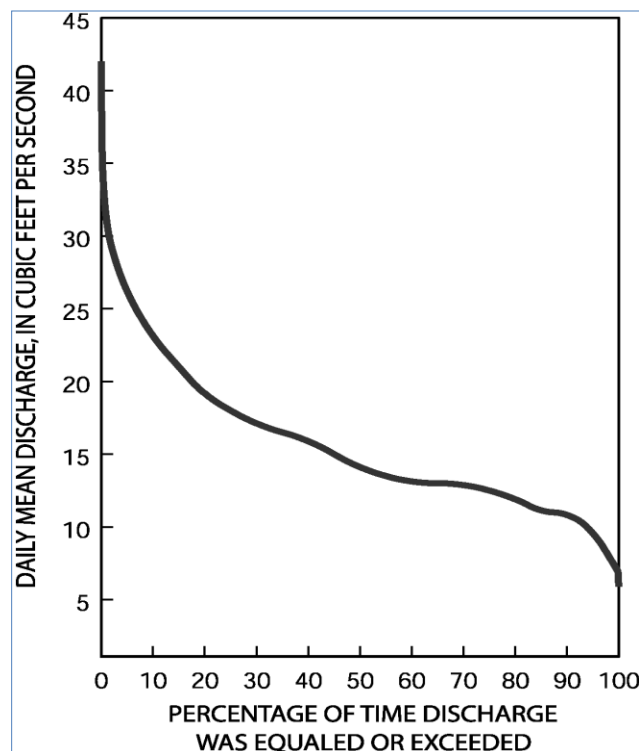


Figure 32. Flow-duration curve of daily mean discharge at the Quashnet River stream-gaging station (011058837) on western Cape Cod for water years 1989-2000.

2.5.3. References

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- Taylor, C.J., and Alley, W.M., 2001, Groundwater-level monitoring and the importance of long-term water-level data: U.S. Geological Survey Circular 1217, 68 p.

Appendixes

Revision History Log:

Version #	Date	Revised By	Changes	Justification
1.00 (USGS Open-File Report 02-497) Version 1.00 May 2002	2003			
1.01	Sept 2011	K. C. Medeiros	Consolidated existing appendixes. Added Appendixes for justification of new network of sites. Added sample field sheets for current field visits.	Revised to meet Oakley, et. al., 2002 format for I&M program.

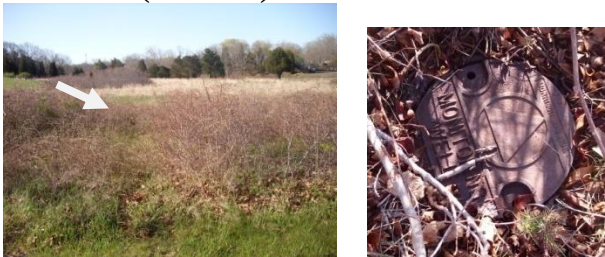
Appendix A. Current groundwater level, streamflow, and pond stage network for CACO after re-evaluation in Fall 2010 (including photos, directions, and maps).

Table A-1. Table of current groundwater well networks after re-evaluation in fall 2010.

Well ID	Station Name	Flow Cell	MP (ft-NGVD-29)	X	Y
TSW 257	Lombard	Cheq	26.75	413413.582100000000	4646851.849999990000
WNW-30	Old Long Pond	Cheq	15.77	415426.674500000000	4644061.308000000000
EGW-51	Goemaat	Nauset	23.86	418007.632900000000	4632282.995000000000
EGW-60	Salt Pond	Nauset		419145.813700000000	4632228.211000000000
EGW-48	C1	Nauset	19.16	420032.015100000000	4633668.525999990000
EGW-49	C2	Nauset	13.49	420577.722300000000	4634013.544999990000
EGW-50	C3	Nauset	51.51	420839.540600000000	4633802.444000000000
EGW-36	Nauset	Nauset	55.13	419434.615700000000	4634356.602000000000
WNW-89	Paines	Cheq	8	417025.815899999000	4641877.989000000000
WNW-124	Powerline	Cheq	67.57	416954.097699999000	4642462.227000000000
HW-4s	DogPark	Cheq			
WNW-123	Garrison	Cheq	42.79	417012.415299999000	4643220.583999990000
WNW-105	Tombolo	Cheq	28.84	416112.539899999000	4645906.469999990000
WNW-122	HR-1	Cheq	10.41	415760.115899999000	4646217.669999990000
TSW-256	Mitre	Cheq	57.51	415189.094500000000	4647312.439000000000
TSW-282	C6	Cheq		415516.769399999000	4648827.939000000000
TSW-261	Dump	Cheq	41.2	413923.226800000000	4648681.281999990000
TSW-258	Quail Ridge	Pamet	131.48	412235.395399999000	4652217.980999990000
TSW-216	Old County	Pamet	103.13	411698.329700000000	4647962.372999990000
TSW-134	Head of Meadow	Pamet	54.53	410683.325300000000	4655079.061999990000
TSW-106	Golf	Pamet	71.4	412206.206799999000	4654262.893000000000
PT-5	off Provincelands Rd	Pilgrim	9.33	399384.21853798700	4657661.25659342000

GROUNDWATER LEVEL WELL DIRECTIONS

(Current 2010 network; diagonal black line indicates well was deleted from network)

Lombard (Truro) 	Off Route 6 Take right onto dirt road (almost looks like its paved) before telephone pole 4906/mile marker 105 (Dirt road is before Round Pond West & George Nilson Rd) ...Follow straight (past first intersection) past bog on right... Well on left at intersection in silver casing (read from PVC)
Goemaat (Eastham) 	To get out of the woods Go Left at Fork after the well. Go straight and then at the top go Left. At next fork go Right down a hill. At next fork go Left uphill. Go Right onto George Nilson Road out of the woods then go Right onto Route 6. Off Route 6 Take right onto Great Pond Road in Eastham...follow and go through stop sign...take right onto Great Pond Place...Goemaat residence in back yard...white PVC low to ground
Salt Pond (Eastham) 	Take left off Route 6 to front of SPVC...low well cover all the way to the left (read from PVC). Hint: Go into the brush about 5 feet to the Left of the tree that is in front of all the bushes. It is about 2-3 feet in from the very back of all the bushes. Hard to Find.
R32 (Eastham) 	Take right out of SPVC and follow Doane road all the way past Coast Guard beach...After the White Stop sign on the Right hand side of the road take a Right into that dirt driveway (bathhouse at top of hill)...walk down into valley on trail and around to the left...There will be a small rusty pipe after the first pile of dead logs in the trail.

Nauset (Eastham)  	Turn Right back onto Doane Rd. Take left at stop sign at Nauset Light onto Cable Rd...follow to the end of road past Nauset High School. Take a left onto Nauset Road and immediately pull to the left hand side...Walk along Nauset Rd ~34 paces from Nauset Regional High School sign to sewer grate, well is ~12 paces into woods from sewer grate, under fallen tree (read from larger pipe)
C1 (Eastham)  	Follow Nauset Road until you hit Seaside Drive on right (usually a decorated sign pole)...take left onto Fire Road across the street from Seaside Ave...well off to right by E9 (large well cover...read from PVC)
C2 (Eastham)  	Follow Fire Road until it turns left to a camp...park at camp and walk the trail to the Right. At the top of the hill at T go Left down to the bottom of the hill...read from PVC
C3 (Eastham)  	Take a left onto the dirt road from C2 and follow road until you see the Fire Road gate...tree marked where well cover is located on ground on the right side under a fallen tree...well about 2 feet in from side of the road...read from PVC
Marconi (Wellfleet)  	Go back out to Nauset Road. Take a Right onto Route 6 and Drive towards Marconi Beach...Take a R at Marconi... turn off on first Fire Road turnoff on right...well down to the left right past the gate

Paine's Camp (Wellfleet)		In Wellfleet, off of Route 6, take a right onto Old County Road and stop at Paine's Campground on the right. After entrance (there is a gate) take a right onto dirt road following until you reach the gated Keep Out sign. Walk down this road ~20 paces till you reach the red post. Turn here, walk down the hill to well house and measure first well that you see (lowest one...read from top of pipe)
Powerline (Wellfleet)		From Paine's turn right onto Old County and take a right onto a dirt road to the powerlines (it will be your next road)...cross the powerlines and take a left onto the road (sand access road)...well will be in blue casing on right near US Boundary marker, ~54 paces before pole 158 and ~40 paces before pole #102...(read from PVC)
HW-4s (Wellfleet)		From powerline follow and take right onto dirt road with Fire Road gate across (CA-10)- stay straight until you see a pull off for the old Firing Range (now the new Dog Park)...across from pull off will be two blue well casings. You will need the key for the Master lock...this is the well that you need to measure...it has a HOBO water level instrument deployed.
Garrison (Wellfleet)		From HW-4s follow road and go through the next Fire Road gate...this will bring you out to Cahoon Hollow Road...take a right about 500 yards up the road into the Garrison property (metal gate)...well will be in blue casing (about 2 feet in from the edge of the road) on the right of the access after wood pile...read from PVC
Old Long Pond Road (Wellfleet)		Off Route 6 take right at Wellfleet Fire Station onto Lawrence Rd...Take left onto old Long Pond Road (dirt road) ...house #115 down to left across from garage under a bunch of trees...orange flagging low lying like "Nauset" well

Gull Pond Access (Wellfleet) 	Off Route 6 take right onto Gull Pond Road...take left onto Schoolhouse Rd...Park right after split rail fence and walk up path to the left...orange tape down to the right into the woods
Tombolo(Wellfleet) 	Continue on Schoolhouse Rd on the dirt road portion...At the first fork take a Right....Drive about 100 feet and where the road splits again stop....well is under the dead tree off to the right about 5-6 feet in.
HR-1(Wellfleet)	Go back the way you came and take a Right onto Gull Pond Access Road..Take a Right onto Route 6. Take a Right onto Black Pond Road across from Pamet Point Road(dirt road) follow this road for about 5 minutes until you come to a parking area on Right at the beginning of Herring Pond...well is down path to the left, rusty metal pipe, read from pipe)
Mitre (Truro) 	Off Route 6 traveling North take unmarked road right after Truro town line, take a right onto Collins Road...follow and take right towards the mitre site (first paved gated fire road w/ caution flags on gate)...open gate, well will be on your right up the access road <0.1m...locked with DA-1 in silver casing...read from marked measuring point
C6 (Truro) 	Take a Right on Collins Road...first Fire Road on right with blue well casing outside...DO NOT MEASURE THIS WELL...unlock gate and follow Fire Road straight all the way until you hit a T. The well will be in a blue well casing on the left...read from PVC

Dump (Truro) 	Take a Right onto Collins Road next Fire Road will be on left...Follow fire road all the way past the sand pit on the left...pull off at first sign of road off to left...walk 100 yards down the path to your left and the well will be in blue well casing on the left...the one closest to the road that's unlocked...read from PVC
Old County Road-Truro 	Take a Right back onto Collins Road and go back to Route 6. Take a Right onto Route 6...Off of Route 6, take left onto Prince Valley Road...follow all the way to end and take a right onto Old County road... pass the Pine Grove cemetery sign...first right from Prince Valley road past this sign...down dirt road...left at fork...well right off the dirt road on the left about 2 feet in.
Longnook (Wellfleet) 	Off of Route 6, take right onto Longnook Road and the turnoff to the right where the first No Parking sign is... walk down path and to the left ...orange flagging
Quail Ridge (Truro) 	Off Route 6 heading N take a right onto Whitmanville followed by a right onto Quail Ridge Road...follow all the way to end the road and then take a right to the end of the cul de sac. Park there and walk up the dirt path past the house on the left...well is across from clearing in a silver well casing locked with a DA-1...read from PVC
Head of Meadow (N.Truro) 	Off Route 6 take right at Head of the Meadow sign...pull off on the third pull off to the right at the split rail fence...follow the path and head straight...at end when you reach clear sand, take a right and follow until you hit a little path/clearing on left...well will be rusty metal pipe to the left...read from pipe

Pilgrim Heights (N.Truro) 	Off Route 6 take right into Pilgrim Heights parking lot...follow around to the end of the second parking lot and park in the last space...follow path to left and will be a big metal casing to the left...measure from top of pipe
North Maintenance (Provincetown)  	Off Route 6 take right at first set of lights towards Race Point on Race Point Road...Approx 3 miles take a right into North District Maintenance ...take left up to Pearsall's and park in the parking lot by the split rail fence and walk down the path and off to the right –marked by orange flagging
PT-5 (Provincetown)  	Go back out past the maintenance area and take a right onto Race Point Rd...follow and take your first left past the Visitor's Center...once on this Road, the well will be down at the bottom of the first hill on the right in a blue well casing...stone gravel pull off...read from PVC
Clover- (N.Truro)  	Head back towards the Lab from PT-5 and take the Lighthouse/Golf Course exit off of Route 6. Take a Left off of the exit and park at the little bus terminal immediately to your left. The well will be in the middle of the field in front of you. Difficult to find in summer months.
Golf (N.Truro)	Park at the Highland Golf Course... You can either use a golf cart or walk to well house at the second fairway...low large metal well under the pine tree next to well house...read from top of pipe

Table A-2. Table of current ponds, lakes and wetlands network after re-evaluation in Fall 2010.

Station ID	Type	Flow Cell	MP (ft- NGVD-29)	X	Y
East Harbor	Coastal Lagoon	Pilgrim/Cheq	5.36	405105.41371931000	4657589.21211385000
Little Bennett	Wetland	Pilgrim	10.31	400614.51819999900	4657032.33600000000
Ryder	Kettle Pond	Cheq	11.99	414616.03529999900	4646410.76400000000
Gull	Kettle Pond	Cheq	12.24	416831.28149999900	4645554.86699999000
Great Wellfleet	Kettle Pond	Cheq	12.64	416801.41869999900	4643661.21399999000
Dyer	Kettle Pond	Cheq	12.63	416355.48340000000	4643592.74700000000
Duck	Kettle Pond	Cheq	13.9	416941.92950000000	4642730.59999999000
Herring	Kettle Pond	Cheq	11.58	416174.23479999900	4646068.43400000000
Great Truro	Kettle Pond	Cheq	14.19	414431.41680000000	4647366.99000000000
E9	Vernal Pool	Nauset	18.76	420052.57260000000	4633666.41899999000

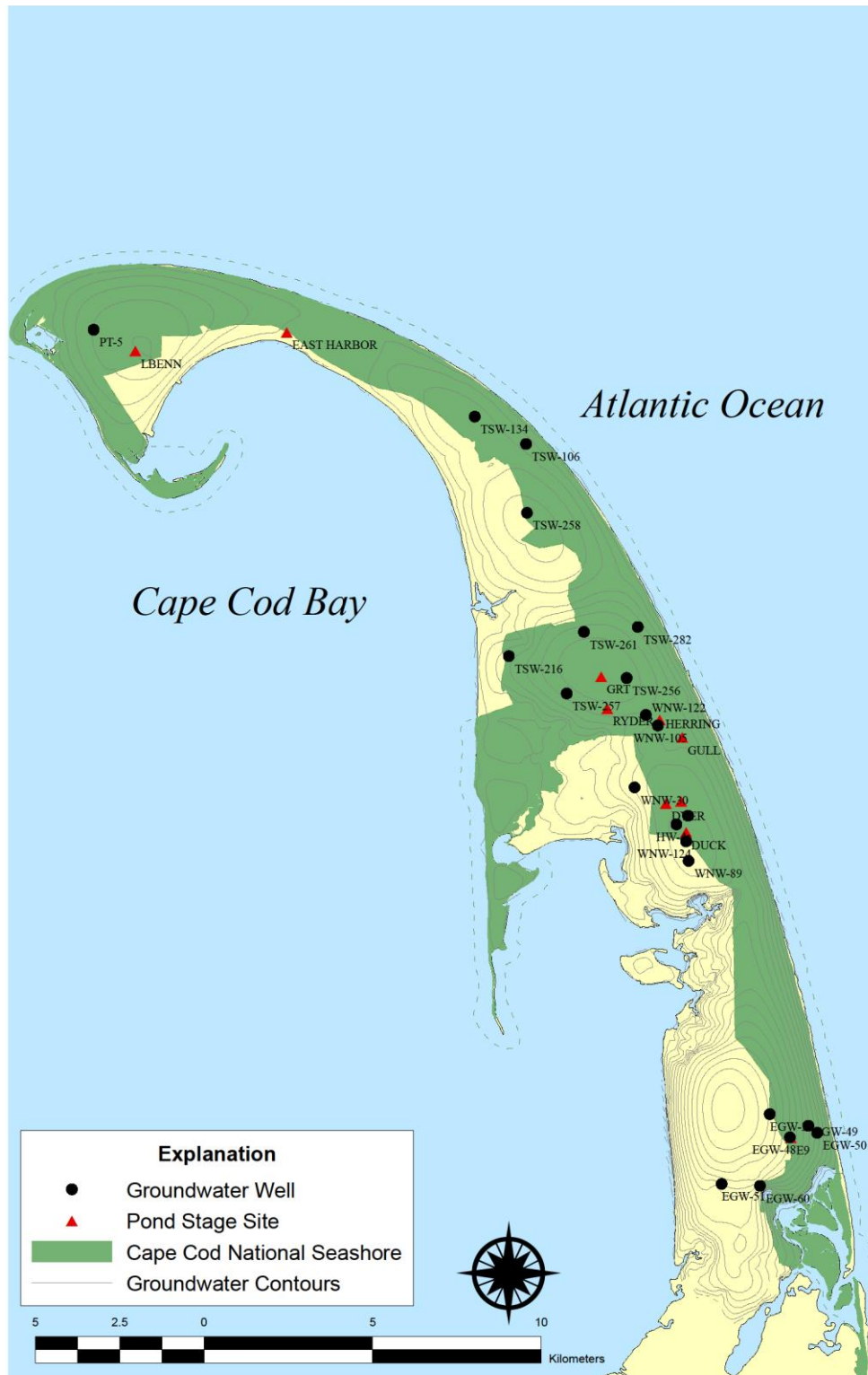


Figure A-1. Groundwater well and pond stage network after re-evaluation in Fall 2010 (a subset of original recommended network shown in Figures 6 and 14).

Table A-3. Table of current streamflow site network after re-evaluation in fall 2010.

Station Name		Station ID	Flow Cell	Tidally Influenced	X	Y
Herring River at Herring Pond Outlet, Wellfleet MA		HR-HPO	Chequessett	No	415788	4646212
Herring River at Old Kings Highway, Wellfleet MA		HR-OKH	Chequessett	No	415408	4646035
Herring River at Bound Brook Island Road, Wellfleet MA		HR-BB	Chequessett	Yes-micro	412231	4645031
Pole Dike Creek at Bound Brook Island, Wellfleet MA		HR-PD	Chequessett	Yes-micro	412399	4645178
Pamet River at Castle Road, Truro MA		PR-PPO	Pamet/Chequessett	Yes	413006	4649609
Little Pamet River at Corn Hill Road, Truro MA		PR-CH	Pamet	Yes	410700	4650246
Fresh Brook at Route 6, S. Wellfleet MA		FB	Nauset	Yes	418095	4638097
Hatches Creek at West Road, Eastham MA		HC	Nauset	Yes	417552	4636531
Salt Meadow, Truro MA		SM	Pamet	No	407612	4656708



Figure A-2. Map of streamflow stations after re-evaluation in fall 2010.

STREAM GAGING SITE PROFILES

FRESH BROOK (FB)

Directions from Lab: Follow Route 6 south until you reach two “Beach Accessory Souvenir” stores on either side of the highway. Turn left and park in the east store parking lot (the one with the big jack-o-lantern ball in the front). Walk along the guard rail and look for a path on the right down the bank to the stream. The site is 10 feet after the sharp right bend in the river upstream of the culvert.

Streambed Type: Mud and Organic – Much of the stream bed is comprised of mud and organic debris including leaves and sticks. The stream features several sharp turns and several fallen trees impeding flow.

GPS Coordinates: X 418095 Y 4638097

Images:



Fresh Brook Culvert



Fresh Brook Looking Downstream

HATCHES CREEK (HC)

Directions from Fresh Brook: Turn left on Route 6, heading south, and make the next right onto West Road. Follow West Road past the Massasoit Hills Trailer Park and park just before Parkingtonhouse Road on the right. Site is about 20 feet up West Road off to the right. Access the creek at the culvert and the site is about 15 feet downstream.

Streambed Type: Mud – The streambed is primarily mud with a layer of leaves and other organic debris.

GPS Coordinates: X 417555 Y 4636531

Images:



Hatches Creek from the Road



Hatches Creek looking upstream



Hatches Creek looking downstream



Hatches Creek Channel

POLE DIKE (PD)

Directions from Hatches Creek: Get back on Route 6 and head north. Turn left onto Main Street and continue onto West Main Street past the Transfer Station. West Main Street turns into Pole Dike Road and park at the pull off on the right just before a Herring River sign. The site is the downstream (left) side of the culvert. Take the reading as close to the culvert as possible.

If leaving from the Lab: Turn left onto Old Truro Road/Cole's Neck Road and make a left onto Pole Dike Road. The pull off will be on your left.

Streambed Type: Mud – Streambed is primarily mud with organic debris.

GPS Coordinates: X 413423 Y 4644522

Images:



Pole Dike Site looking downstream from the culvert.



Looking down at the Pole Dike Culvert

BOUND BROOK (BB)

Directions from Pole Dike: Head northwest on Pole Dike Road and continue onto Bound Brook Road. Park in the pull off located on the left side of the road just before Bound Brook Island Road (before Atwood Higgins House sign). The site is the upstream side of the culvert near the fire hydrant. Take the reading as close to the culvert as possible.

Streambed Type: Mud – Streambed is primarily mud with organic debris.

GPS Coordinates: X 412402 Y 4645175

Images:



Looking down at the Bound Brook Culvert



Looking downstream of Bound Brook Culvert



Bound Brook Culvert

OLD KING’S HIGHWAY (OKH)

Directions from Lab: Follow Route 6 South and take a left onto Black Pond Road after the “Welcome to Wellfleet” sign. Follow Black Pond Road until you come to an intersection where there is a brown and white “Private Homes” sign and a homemade sign that has a number and “OKH” on it. Take a right here and park. Walk to the culvert and access the stream on the downstream (right) side. The site is about 200 feet downstream between two fallen trees.

If you are coming from Bound Brook: Follow Old County/Bound Brook Road and take a right onto Pamet Point Road. Go straight across Route 6 onto Black Pond Road.

Streambed Type: Gravel and Sand – The stream bed has a sand base with a top layer of coarse gravel.

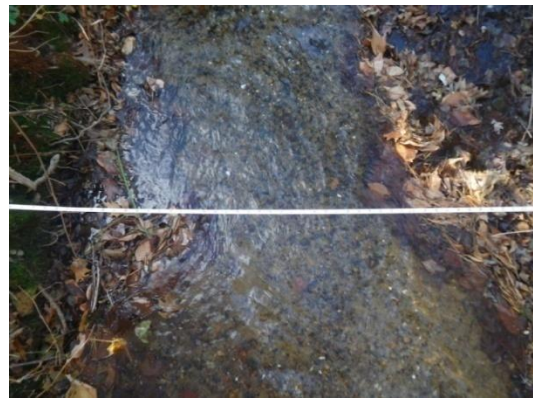
The channel is straight but low flow leads to small riffles over the gravel throughout the stream.

GPS Coordinates: X 415408 Y 4646035

Images:



Old Kings Highway looking downstream



Old Kings Highway Channel



Old Kings Highway Culvert

HERRING POND OUTLET (HPO)

Directions from Old Kings Highway: Follow Black Pond Road east (right) until the cleared parking area in front of Herring Pond on the right. Pull all the way in to the right. Park here and walk down the path that's on the right corner of the parking lot. The water is about 50 feet from the beginning of the path. The staff gage is to the left attached to the small footbridge, the observation well is about 30 feet on the path from the stream (it will be a small brown metal pipe to your left in the bushes) and the site is about 50 feet downstream from the bridge to the right. Streambed Type: Sand and Mud– The stream bed is primarily sand and mud with scattered gravel. The channel is straight with laminar flow throughout. GPS Coordinates: X 415782 Y 4646203

Images:



Herring Pond Outlet Looking Upstream



Herring Pond Outlet Channel



Herring Pond Outlet Culvert and Bridge

PAMET RIVER POST OFFICE (PPO)

Directions from Herring Pond Outlet: From Route 6, take a right off the Truro Town Center exit. Make another right onto South Pamet Road and another right onto Truro Center Road. On the left is the Truro Post Office, park in the parking lot. Access the river by the culvert near the east end of the post office parking lot and the site is about 100 feet downstream.

Streambed Type: Mud and Sand – The stream bed is a mixture of sand and mud. *Phragmites australis* is the primary vegetation on both stream banks. Tidally influenced, the stream is only accessible two hours after low tide.

GPS Coordinates: X 413006 Y 4649609

Images:



Pamet River Post Office looking downstream



Pamet River Post Office Culvert

PAMET RIVER CORN HILL (PCH)

Directions from the post office: take a left out of the parking lot onto Truro Center Road. Take the next left onto Castle Road. Follow this road until the triangle and stay left to go on Corn Hill Road. You will park on the left at the hairpin turn where there is a small cottage with maroon trim and lots of “No Parking” signs. If someone is there and asks, just tell them what you are doing and will only be 15 minutes. Access the site over the sand where it says “No Shellfishing” and the site is about 30 feet downstream of the culvert.

Streambed Type: Sand- The streambed is sand with a few scattered rocks.

GPS Coordinates: X 410700 Y 4650246

Images:



Pamet River Corn Hill looking upstream



Pamet Corn River Hill looking downstream



Pamet River Corn Hill Gate

SALT MEADOW (SM)

Directions from the Lab: Salt Meadow is located on the Northeastern side of East Harbor. Follow Route 6 north and turn right onto High Head Road. Follow this road over a tidal stream until you reach a fork. Take a left down the dirt road to stay on High Head Road and follow until you see a clearing on the left (a boat access). Access the site from here and turn right. The site is about 50 feet from the access.

Streambed Type: Sand – The streambed is sand and the source has been blocked with sediment leading to no flow.

GPS Coordinates: X 407612 Y 4656708

Image:



Salt Meadow looking downstream when river is flowing

Appendix B. 2006 Review of the Long-term Hydrologic Monitoring Protocol for Coastal Systems.

In 2006, an internal review of the groundwater well network and ponds network of the Long-term Hydrologic Monitoring Protocol was conducted. The following is the document that resulted from this review. This document has been included in order to provide a complete history of the evolution of this protocol.

Cape Cod National Seashore Evaluation of Long-term Hydrologic Monitoring Protocol for Coastal Systems 2006 Review.

Hydrologic Monitoring Protocol Review
Kelly Chapman
January 2006

Long-term hydrologic monitoring at Cape Cod National Seashore is guided by a protocol developed by USGS¹ in 2003. A significant portion of this protocol involves monitoring ground water levels at a network of wells and ponds in order to address the following questions:

Sea-Level Rise

- 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?*

Climatic Change

- 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?*

¹ McCobb, T. and P. Weiskel. 2003. Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems. USGS, Northborough, MA. 94pp.

Urbanization

- 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?*

Over the years, minor changes have been made to the protocol to cope with non-functional wells, vandalism, maintenance problems, and the data needs of short-term projects. In addition, other studies and monitoring projects have expanded our need for long-term ground-water data beyond what was anticipated when the protocol was designed. In 2005 and 2006, we reviewed the network to verify that:

- we are collecting the data we need, particularly in support of other long-term monitoring projects;
- we are not collecting data that is no longer needed; and
- the monitoring network is accurate and well documented.

To establish a final network of observation wells, the process began by collecting the GPS locations of all of the wells and siphon gages that were being measured by National Park Service (NPS) staff. Some of the other wells in the existing network were noted as being monitored by the Cape Cod Commission (CCC). The GPS locations for these were sent to us by the CCC staff. All of the wells and siphon gages that were in the existing network (Tables B-1 and B-2), whether measured by NPS staff or CCC staff were then plotted on a map and examined by the Natural Resources Staff at CACO, with focus on how each site contributed to answering the previously listed questions.

Table B-1. Existing observation well network selected for long-term hydrologic monitoring at CACO (McCobb and Weiskel, 2003).

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 is not)

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)
BGW 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
BGW 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

Table B-2. Existing siphon gage network selected for long-term hydrologic monitoring at CACO (McCobb and Weiskel, 2003)

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
Lins Benzen 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

After careful review, it was determined that the wells that were being monitored by the CCC staff would be added to the well network that NPS staff would include in their monthly monitoring field days. After this was determined, a revised map and corresponding table were prepared. Those wells and siphon gages that were questionable and needed to be looked at more thoroughly were highlighted for review. The seven observation wells and four ponds that needed review are as follows:

- Kennedy
- Gristmill
- Salt Pond
- EGW-52
- TSW-262
- Gull-NEW
- C6
- Snow Pond
- Long Pond
- Dyer Pond
- Pilgrim Lake.

Three of the observation wells (Kennedy, Gristmill and Salt Pond) have been measured since October 2004. John Colman, a hydrologist at USGS had originally asked if the staff could measure these three wells monthly (due to the commuting hassle from his office in Northborough). Each well has an associated MLS ground water quality well system adjacent to it and the data collected is essential for future ground water quality work. However, at this time it was decided that Salt Pond was the only well that would be added to the final long-term monitoring network (Table B-3). In January 2006, the data from these wells were plotted (Figure B-1). Kennedy was not added because the data that will be collected at Salt Pond would show a representative change similar to that at the Kennedy site. Gristmill was not added because it was outside of the flow cells that CACO staff is looking at for long term monitoring. Any data related to Salt Pond has great significance to current ongoing monitoring questions from a number of protocols and projects. The data collected from this site will be instrumental in many future projects as well.

Four of the other observation wells were examined to determine whether they should continue to be monitored. The well identified as EGW-52 (located at the Captain's Quarters Motel) was never located. It has been measured in the past but field notes and technician recollection indicate that it might be directly tied into the Motel's septic field and the data would be of little use. Another attempt to find this well will be implemented in the January 2006 sampling period. However, if it is not found, the well will be removed from the network. The well identified as TSW-262 (off of Pamet Road) has not been monitored since 2003. An attempt was made in 2003 to pump the well but the field technician noted that a "sulfidic slime" with a strong hydrogen sulfide odor was hindering measurements at this site. This well has been removed from the network.

The remaining two wells identified as Gull-NEW and C6 were closely looked at and it was decided that C6 would remain in the network while Gull-NEW would not. It wasn't necessary

because Gull Pond stage measurements were being collected “next door”. It was determined that C6 was important to continue due to its location within the flow cell and there are very few wells in the area surrounding C6. Finally, it was suggested by Natural Resource staff that PT-5 (on Provincelands Road in Provincetown) should be added to the well network. PT-5 is an existing well that was established in 2000 to collect data to develop a hydrologic model for the Lower Cape. More long-term data would be useful in this area. Natural Resource staff is in hopes to get a good baseline data set for a future study to better understand the hydrologic dynamics of the Provinceland Dune system.

Four of the twelve siphon gage sites (Snow, Long, Dyer Ponds and Pilgrim Lake) were installed to supplement the network as a special initiative project of the USGS-MA and the Rhode Island District. It was determined that the only two sites that would be useful to keep in the network would be Dyer Pond and Pilgrim Lake. Dyer Pond data are important because the water body has the potential to be impacted by future well water withdrawal by the Town of Wellfleet. Long term monitoring will be able to indicate any significant changes. Pilgrim Lake data is essential to the ongoing East Harbor restoration project. Long-term data from the northwest cove will be important. It might also be interesting to look at the impact that the culvert may have, if any, to the stage of the water body.

In conclusion, most of these changes were implemented in the December 2005 sampling period, however the wells that were being measured by the CCC staff have not been located in the field and PT-5 has not been measured. A final map will be produced that will illustrate the locations of all of the wells in the final long-term monitoring network (Figure B-2). Hopefully, this revised network of wells will be implemented fully by February 2006.

Table B-3. Final observation well and pond stage network selected in 2006 for long-term hydrologic monitoring at CACO by Natural Resource Staff.

Station ID	Town	Flow Cell	Site Description	Type of well	Xcoord	Ycoord	Long	Lat
TSW-257	Truro	Chequesset	Lombard	Observation Well	413413.582050438	4646851.84385439	-70.0443923	41.3689050
EGW-36	Eastham	Nauset	Nauset	Observation Well	419434.61570217	4634356.60153521	-69.9706238	41.8570173
EGW-48	Eastham	Nauset	C1	Observation Well	420032.015085421	4633668.52640985	-69.9633405	41.8508814
EGW-49	Eastham	Nauset	C2	Observation Well	420577.722258852	4634013.54525032	-69.9568138	41.8540434
EGW-50	Eastham	Nauset	C3	Observation Well	420839.540558042	4633802.44424597	-69.9536318	41.8521686
EGW-53	Eastham	Nauset	R32	Observation Well	420366.368127278	4634426.64314363	-69.9521803	41.8578027
EGW-51	Eastham	Nauset	GPS-T (goeasat)	Observation Well	418007.632943927	4632282.93534139	-69.9875320	41.8381968
EGW-52	Eastham	Nauset	GPS-27	Observation Well				
WNW-123	Wellfleet	Chequesset	HW-1 (garrison)	Observation Well	417012.415317989	4643220.5838973	-70.0010535	41.9365912
WNW-124	Wellfleet	Chequesset	HW-5 (pwrline)	Observation Well	416954.097674376	4642462.2270427	-70.0016500	41.9297558
WNW-89	Wellfleet	Chequesset	Paines	Observation Well	417025.815889386	4641877.38875082	-70.0007029	41.9245020
GULL NEW	Wellfleet	Chequesset	Gull Test Well	Observation Well	416313.358654786	4645346.88757102	-70.0024758	41.9557296
WNW-105	Wellfleet	Chequesset	Tombolo	Observation Well	416112.533867797	4645306.47013324	-70.0122834	41.9606834
WNW-122	Wellfleet	Chequesset	HR-1	Observation Well	415760.115344583	4646217.67002549	-70.0165861	41.9634483
TSW-256	Truro	Chequesset	Mitre	Observation Well	415189.094538867	4647312.43933106	-70.0236338	41.9732457
C6	Truro	Chequesset	C6	Observation Well	415516.763439545	4648827.9330735	-70.0198973	41.9869284
TSW-261	Truro	Chequesset	MW-2d (dump)	Observation Well	413923.226781057	4648681.28218936	-70.0391103	41.9854352
TSW-262	Truro	Chequesset	TLF-005	Observation Well				
TSW-258	Truro	Pamet	Quail Ridge	Observation Well	412235.395437268	4652217.98129748	-70.0600109	42.0170374
TSW-134	Truro	Pamet	Head of Meadow	Observation Well	410683.325316508	4655079.06243729	-70.0731891	42.0426869
TSW-145	Truro	Pamet	Sawyer Grove	Observation Well				
TSW-106	Truro	Pamet	Highland Golf	Observation Well	412206.206820443	4654262.8930631	-70.0606634	42.0355087
Kennedy	Eastham	Nauset	Kennedy	Observation Well				
Gristmill	Eastham	Nauset	Gristmill	Observation Well				
Salt Pond	Eastham	Nauset	Salt Pond	Observation Well				
PT-5	Provincetown	Pilgrim	Provincelands Rd	Observation Well				
EGW-37	Eastham	Nauset	Wiley Park	Observation Well				
PZW-78	Provincetown	Pilgrim	Behind ND Maint	Observation Well				
TSW-1	Truro	Pamet	Knowles Crossing Wellfield	Observation Well				
TSW-89	Truro	Pamet	Highland Rd/Rte 6 Clover	Observation Well				
TSW-179	Truro	Pamet	100 yds N of Pamet Road	Observation Well				
TSW-203	Truro	Pamet	Longnook Rd	Observation Well				
TSW-216	Truro	Chequesset	Old County Road	Observation Well				
WNW-17	Wellfleet	Nauset	Marconi Beach Rd	Observation Well				
WNW-30	Wellfleet	Chequesset	Old Long Pond Rd	Observation Well				
WNW-34	Wellfleet	Chequesset	Off Gull Pond Landing Rd	Observation Well				
WNW-108	Wellfleet	Chequesset	Aunt Sally's Bottom Rd	Observation Well				
E9	Eastham	Nauset	E9	Pond Stage	420052.572551936	4633666.4187279	-69.9630926	41.8508645
Duck Pond	Wellfleet	Chequesset	Duck Pond	Pond Stage	416941.929471084	4642730.6002855	-70.0018346	41.9321713
Dyer Pond	Wellfleet	Chequesset	Dyer Pond	Pond Stage	416355.483389915	4643592.74686846	-70.0030295	41.9338733
Great Pond (W)	Wellfleet	Chequesset	Great Pond (W)	Pond Stage	416801.418701072	4643661.21356251	-70.0036605	41.9405370
Gull Pond	Wellfleet	Chequesset	Gull Pond	Pond Stage	416831.281472137	4645554.8663303	-70.0035678	41.9575332
Herring Pond	Wellfleet	Chequesset	Herring Pond	Pond Stage	416174.234731043	4646068.43422194	-70.0115681	41.9621485
Long Pond	Wellfleet	Chequesset	Long Pond	Pond Stage	416138.845188316	4643955.58752504	-70.0109704	41.9431242
Ryder Pond	Truro	Chequesset	Ryder Pond	Pond Stage	414616.035305901	4646410.76403225	-70.0304185	41.9650640
Snow Pond	Truro	Chequesset	Snow Pond	Pond Stage	414853.525045654	4646830.19171507	-70.0275412	41.9688674
Great Pond (T)	Truro	Chequesset	Great Pond (T)	Pond Stage	414431.416785391	4647366.93037816	-70.0327852	41.9736551
Pilgrim Lake	Truro	Pamet	Pilgrim Lake	Pond Stage				
Little Bennett Pond	Provincetown	Pilgrim	Little Bennett Pond	Pond Stage	400614.51824418	4657032.33605964	-70.2011546	42.0530671

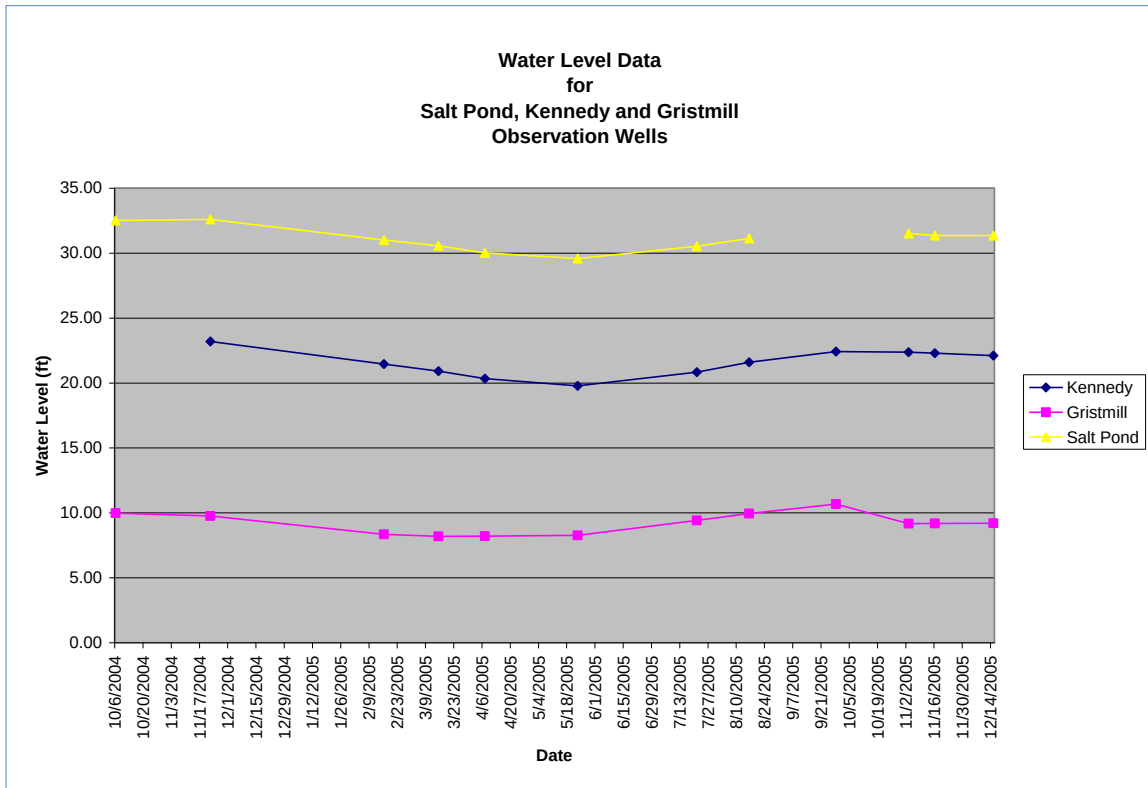


Figure B-1. Salt Pond, Kennedy and Gristmill water level data to determine which to keep in the long-term monitoring well network in 2006.

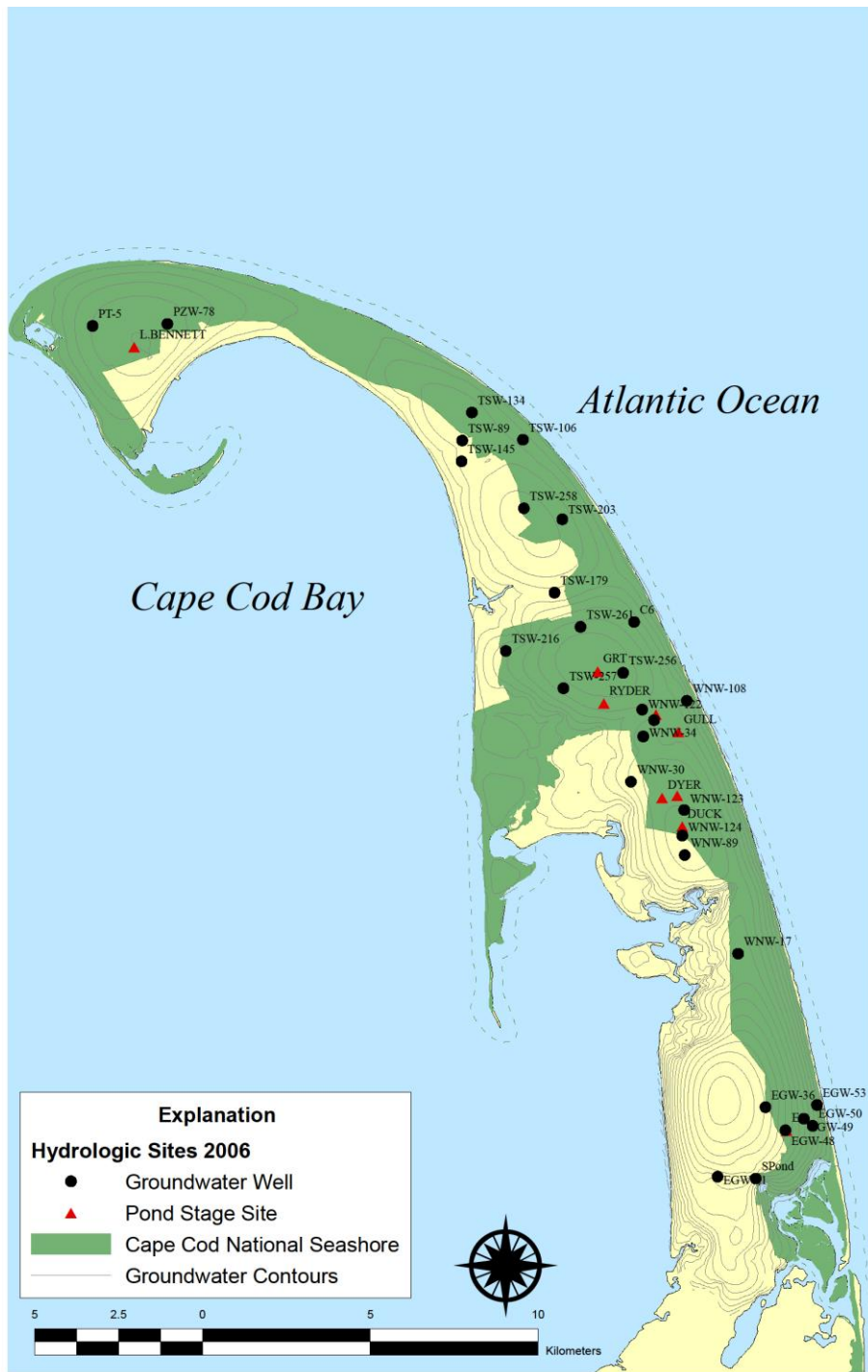


Figure B-2. Final long-term hydrologic monitoring network map at CACO for 2006.

Review of siphon gage technique for measuring pond stage.

All twelve ponds, including Pilgrim Lake, were monitored using the siphon gage technique since 2000. The misconception was that the siphon wells provided an inexpensive, easy to maintain data collection method that was well suited for kettle ponds that are subject to large changes in shoreline position. For most sites, the siphon gage provided accurate, reliable monthly data at the inception of this protocol. However, it was found that siphon wells were too high maintenance and many sites required return visits to repair siphon tubes disturbed by users of the ponds. Some ponds developed a slow siphon response due to organic rich pond bottom sediments that clogged the tubing intake. The vernal pool E-9 was intermittently dry and the siphon gage required periodic recharging as water levels became measurable.

As a result of reviewing the pros and cons of keeping the siphon gage method, it was clear, even in the original protocol development, that the siphon gage only reflected a difference of 0.01 and 0.03 ft in comparison to the surveyed pond levels. With these conditions, it was decided that pond stage elevation would replace the siphon gage method for collecting long-term data for pond and lake levels within the Seashore.

Currently, pond stage (surface water level) is measured at ten kettle ponds on a monthly basis to document major seasonal and annual hydrologic changes. Two of these twelve have been eliminated from the network and now the ten ponds (E-9, Duck Pond, Dyer Pond, Great Ponds (W and T), Gull Pond, Herring Pond, Ryder Pond, Pilgrim Lake and Little Bennett Pond) are measured using a surveying method with an auto-level to determine pond surface elevation by differential leveling from local benchmarks. The local benchmarks (known elevations) are the actual PVC pipe or top of the siphon gage metal casing at each pond that has siphon gages. The ponds are still measured monthly, within two to three days of collecting static water levels from the network of observation wells.

A Standard Operating Procedure for measuring pond stage will be developed by the end of February 2006 and will be an addendum to the Hydrologic Protocol Review. Furthermore, a comparison of the siphon gage data and pond stage data will be revisited to assess the accuracy of the long-term measurements.

Appendix C. Comparison of network groundwater level data collected by both CACO and Cape Cod Commission.

The groundwater level network that was reviewed in 2006 was monitored through the Fall 2010. In 2010, the well network was again reviewed. Data from the wells that were being monitored by both the NPS and the Cape Cod Commission in this 4 year time span were analyzed and the following was the result of this review.

In 2007, nine of the network observation wells were added to the monthly measurements as a result of a change in the well network for the Cape Cod Commission (CCC). These nine were not being measured because the CCC was measuring them monthly and making that data available on the USGS NWIS. The CCC eliminated two of the nine wells that both organizations were measuring. CACO continued to measure all nine through the fall of 2010. At that time, the data that CACO and the CCC collected were plotted and it was determined that CACO was no longer going to continue to monitor the wells that were in the CCC network. Correspondence was sent out to the CCC so that they were aware of this and if they were to choose to remove any of these wells from their network that they would communicate that to CACO so that they could be continued to be monitored in the long-term. Figures C-1 and C-2 illustrate why it is unnecessary to take duplicate readings of these wells. The network of ponds, lakes and wetlands have remained the same since 2007 (Appendix A).

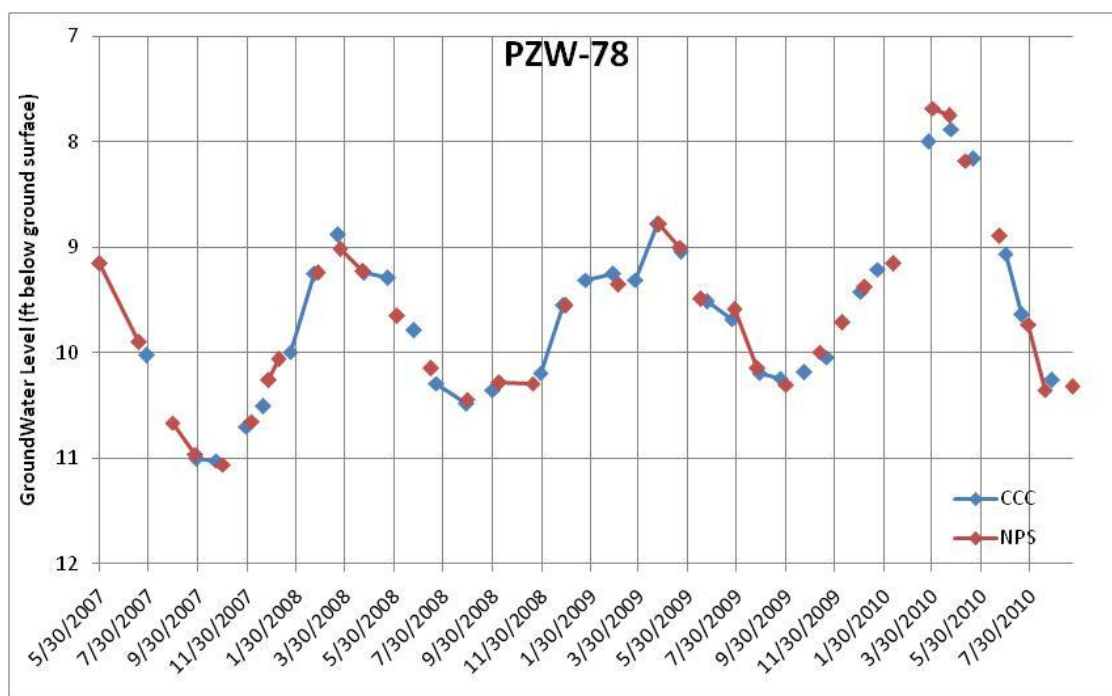


Figure C-1. Water level data in feet below ground surface from CACO and CCC at well PZW-78 located behind the North District Maintenance Building in Provincetown, MA.

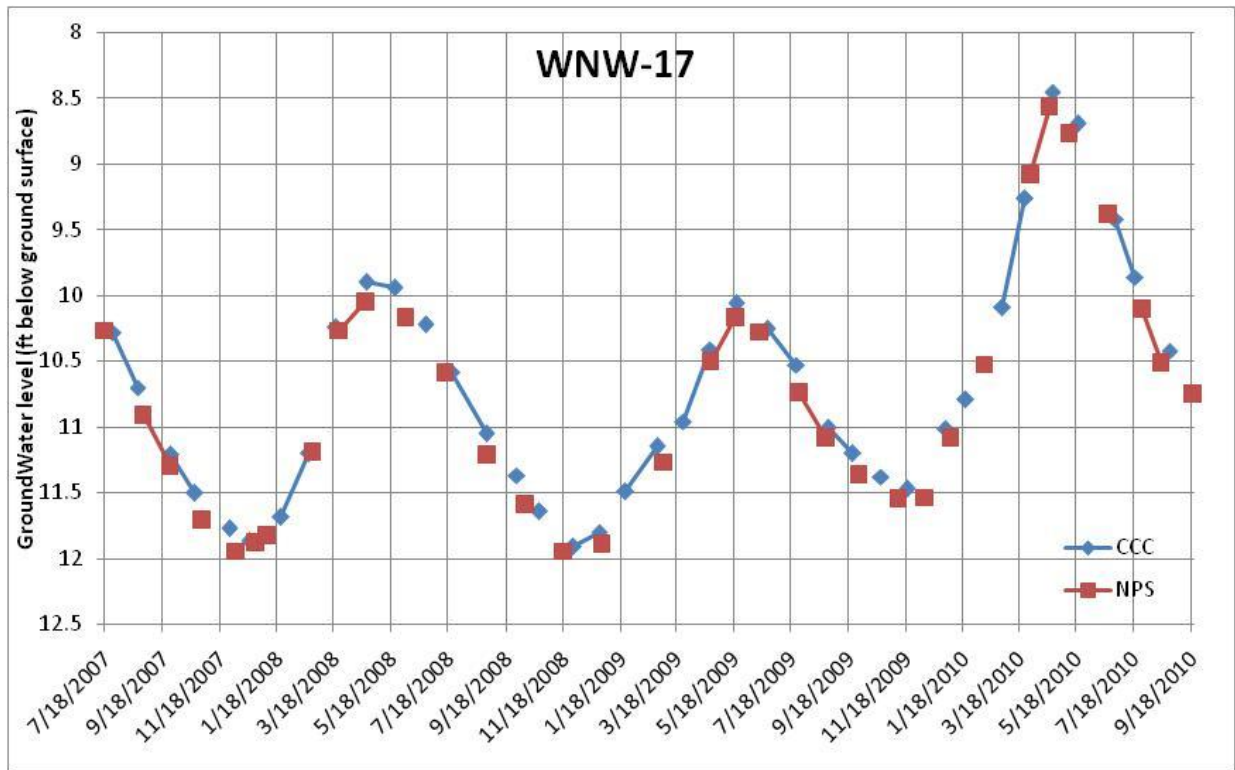


Figure C-2. Water level data in feet below ground surface from CACO and CCC at well WNW-17 located off of Marconi Site Road in South Wellfleet, MA.

Appendix D. Water level data from Pamet River streamflow sites to determine sampling window for measuring streams.

Four of the recommended sites were measured in 2009 on a weekly or biweekly basis in order to gain as much data as we could for each of the sites to begin to develop a rating curve. Continuous water level loggers (HOBO) were deployed in the tidally influenced sites in Pamet River (Corn Hill and Castle Road) in the winter 2010 for approximately a week at an interval of 5 minutes (Figures D-1 and D-2) in order to better estimate the sampling window where the most freshwater surface flow would be most accurately quantified.

It was determined that Pamet River at Castle Road would be sampled 2 hours 20 minutes after predicted low (using Provincetown tides: <http://www.boatma.com/tides/>) and the Pamet River at Corn Hill Road would be measured 3 hours and 10 minutes after predicted low.

The Fresh Brook and Hatches Creek sites were not monitored with continuous loggers to determine the time of measurement however there is data from Fresh Brook throughout the summer of 2010 that can and will be used to analyze the streamflow data that was collected at that site. Based on observation it was determined that these two sites would be measured at predicted low tide (using Wellfleet tides: <http://www.boatma.com/tides/>) with Hatches having a larger sampling window.

These sampling efforts resulted in a re-evaluation of the recommended streamflow network in the fall of 2010 (Appendix A). Each station was visited and it was decided that all eight would be measured weekly (or as close to weekly due to tides) for two years with continuous water level loggers deployed within the stream reaches. One station, Salt Meadow in Truro was added to the network. This station will hopefully quantify the amount of freshwater input to the East Harbor coastal lagoon system that is so important to the Seashore. Flow has been naturally blocked by a sand bar due to prevailing winds and sediment movement. Only when this channel is open will it be suitable to measure.

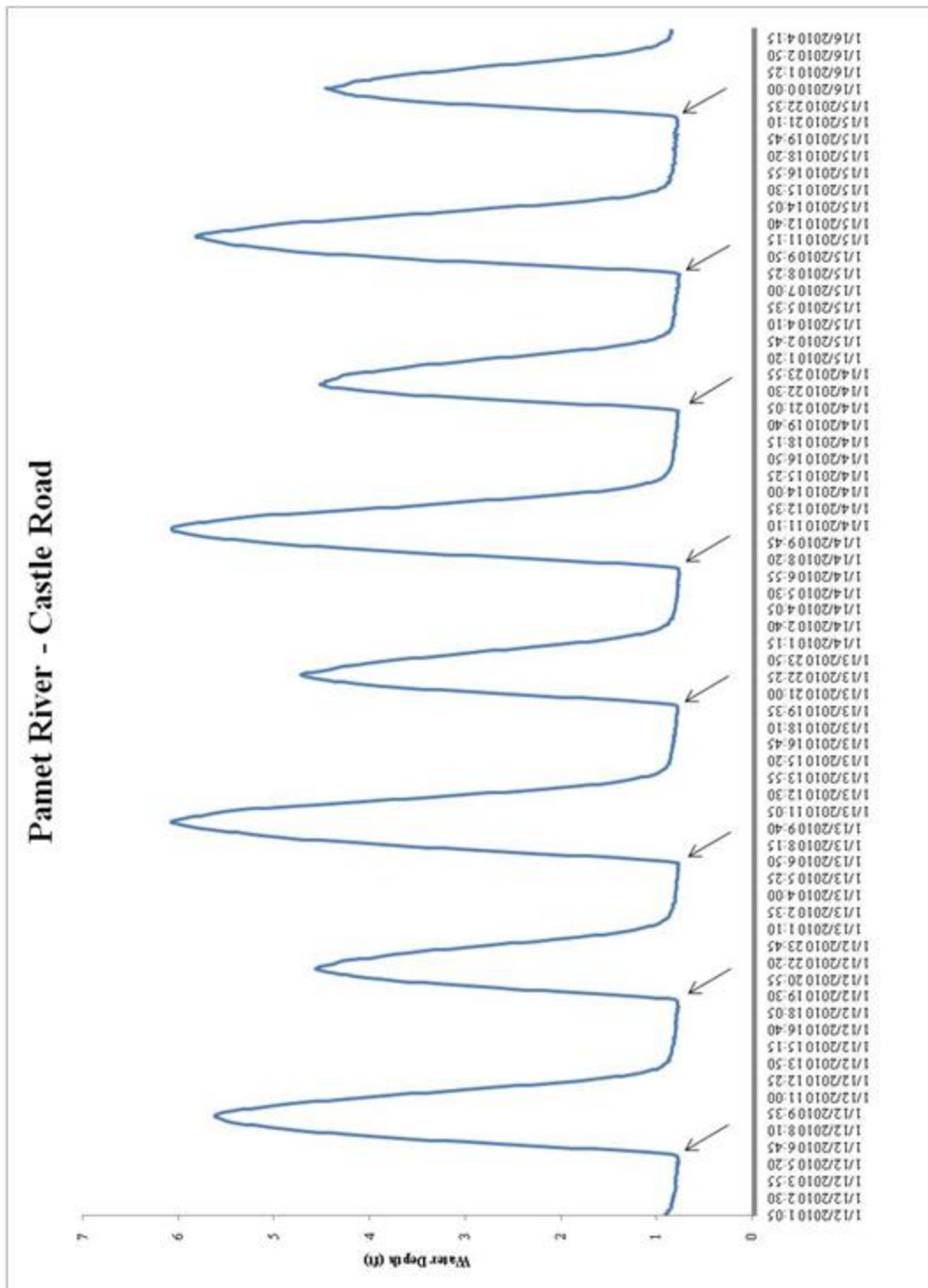


Figure D-1. Water level data from Pamet River Castle Road streamflow site. Arrows indicate time of maximum surface water flow conditions for measurements (~2 hours, 20 minutes after predicted low).

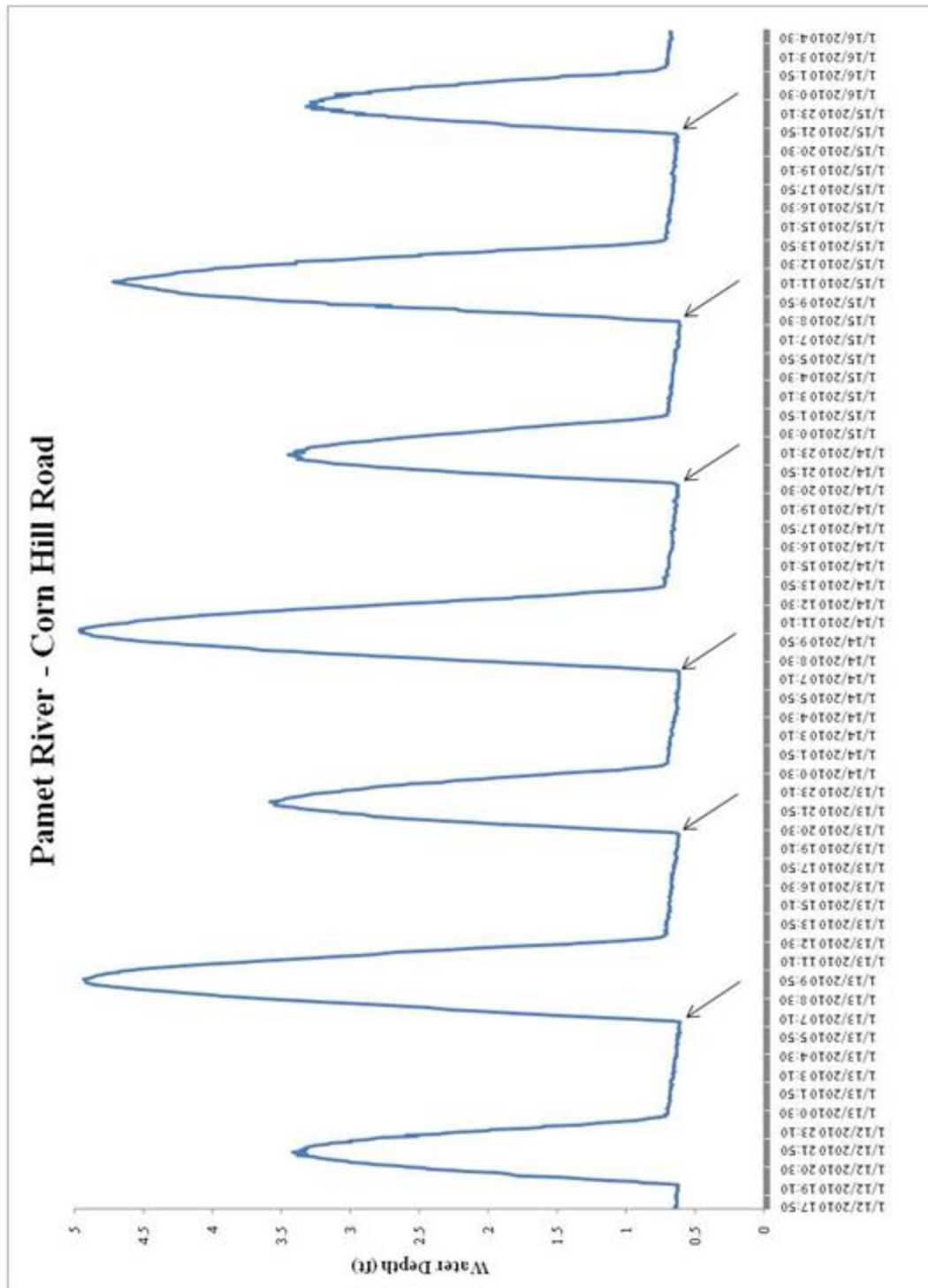


Figure D-2. Water level data from Pamet River Corn Hill Road streamflow site. Arrows indicate time of maximum surface water flow conditions for measurements (~3 hours, 10 minutes after predicted low).

Appendix E. Log sheets for monitoring well construction.

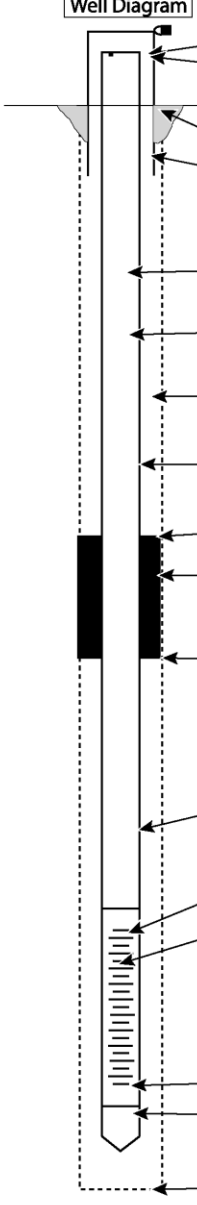
Monitoring Well Construction Log		
Site Number: _____ Other ID: _____ Town: _____ Location: _____ 7.5-min Quad: _____ Latitude: _____ Longitude: _____	Date of construction: _____ Inventory by: _____ Drillers: _____ Rig and augers: _____ Drilling fluid: _____ Sediment samples: _____ Lock type: _____	
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: _____

Figure E-1. Example of a monitoring well construction log.

Monitoring Well Construction Log



Site Number: **TSW 257-0035**
 Other ID: **Lombard Hollow Site**
 Town: **Truro, MA**
 Location: **In Lombard Hollow, 0.5 mi from Rt. 6**
 7.5-min Quad: **Wellfleet, MA**
 Latitude: **415808**
 Longitude: **0700243**

Date of construction: **09-08-1999**
 Inventory by: **T. McCobb**
 Drillers: **G. Berwick and D. Kraemer**
 Rig and augers: **USGS-NH, CME-75 w/3.25" ID HSA**
 Drilling fluid: **Town of Truro water**
 Sediment samples: **None collected**
 Lock type: **USGS #2640**

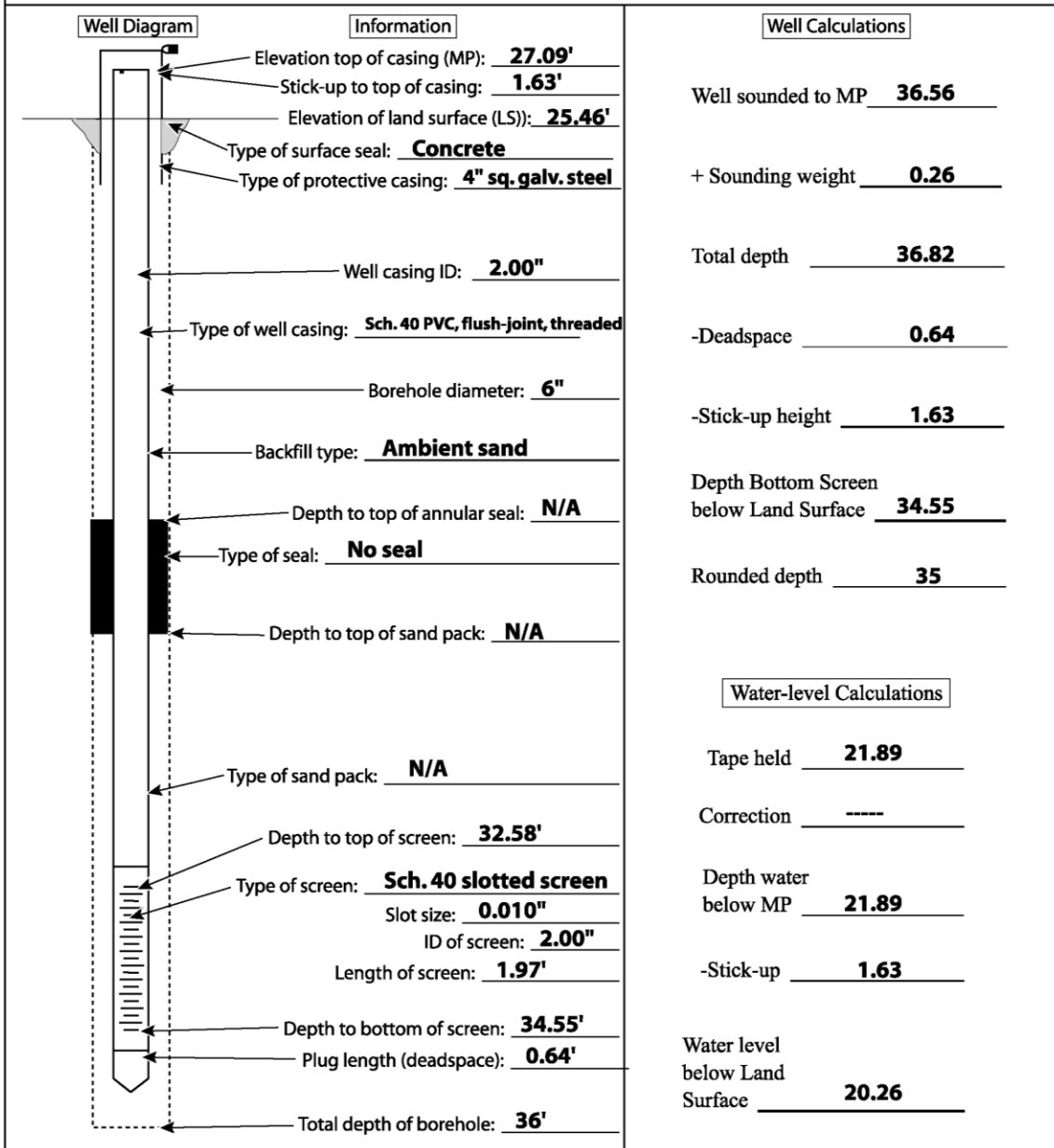


Figure E-2. Monitoring-well construction log for well TSW 257-0035.

Appendix F. Sample field sheets for well site sketch maps.

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
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Figure F-1. Example field sheet for a well site sketch map.

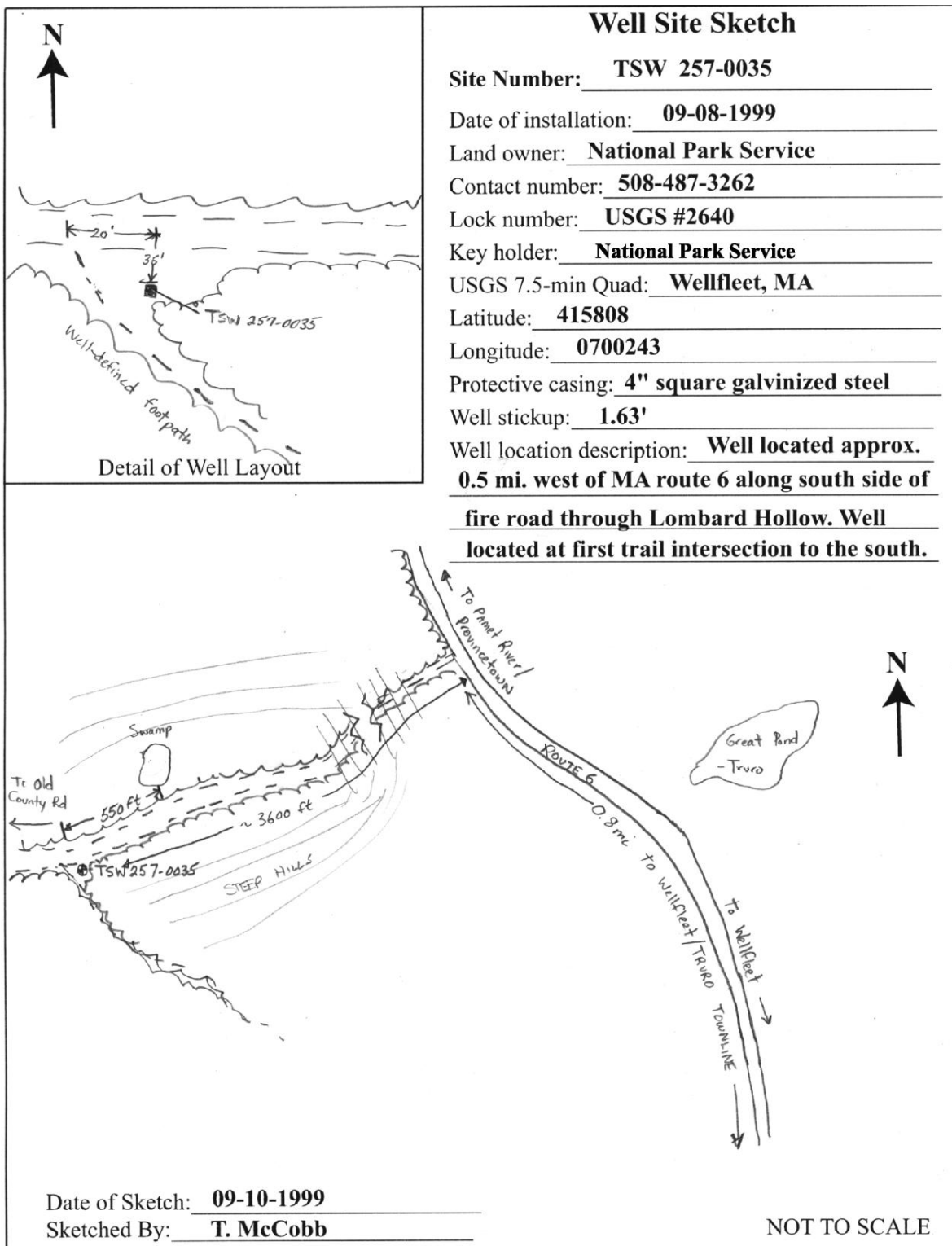


Figure F-2. Sketched location map for well TSW 257-0035.

Figure G-1. Example of a water-level measurement field sheet.

Figure G-1. 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—		DEPTH TO WATER	REMARKS
			Meas. point	Water level		
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: 16-63878p-1

Figure G-2. Water-level measurement field sheet for CACO wells during January 2000.

WATER-LEVEL FIELD SHEET									
KCM_Dec 2010									
Measured By: _____ Water Level Meter Used: <i>Heron Instruments Dipper-T</i> Weather: _____ Other: _____									
Date	Time	Depth to Water (ft)	Well Id	Meas.Pt. (ft)	Location Note	Town	Flow Cell	Remarks	
			TSW-257	26.75	Lombard Hollow	Truro	Cheq		
			WNW-30	15.77	Old Long Pond Road	Wellfleet	Cheq		
			EGW-51	23.86	Goenaat Residence	Eastham	Nauset		
			EGW-60		Salt Pond (VC)	Eastham	Nauset		
			EGW-48	19.16	C1	Eastham	Nauset		
			EGW-49	13.49	C2	Eastham	Nauset		
			EGW-50	51.51	C3	Eastham	Nauset		
			EGW-36	55.13	Nauset	Eastham	Nauset		
			WNW-89	8.00	Paines campground	Wellfleet	Cheq		
			WNW-124	67.57	Pwr Line	Wellfleet	Cheq		
			HW-4s		Dog Park	Wellfleet	Cheq		
			WNW-123	42.79	Garrison	Wellfleet	Cheq		
			WNW-105	28.84	Tombolo	Wellfleet	Cheq		
			WNW-122	10.41	HR-1	Wellfleet	Cheq		
			TSW-256	57.51	Mitre	Truro	Cheq		
			TSW-282		C6	Truro	Cheq		
			TSW-261	41.20	MW-2d -- dump	Truro	Cheq		
			TSW-258	131.48	Quail Ridge	Truro	Pamet		
			TSW-216	103.13	Old County	Truro	Pamet		
			TSW-134	54.53	off HeadoftheMeadow Rd.	Truro	Pamet		
			TSW-106	71.40	Highland Golf	Truro	Pamet		
			PT-5	9.33	On Hatches Harbor Rd	Provincetown	Pilgrim		
Notes: _____									Entered by: _____ Date Entered: _____

Figure G-3. Current groundwater level field sheet for CACO (2010).

Appendix H. Sample field sheets for stream discharge measurements.

UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY WATER RESOURCES DIVISION									
9-275.F (Rev. 10-81)									
DISCHARGE MEASUREMENT NOTES									
Sta. No.	Date		Party	Meas. No.		Comp. by		Checked by	
	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.						
	Meas. plots	% diff. from	rating	Levels obtained					
WATER QUALITY MEASUREMENTS									
Time	Inside	ADR	Graphic	Outside	No	Yes	Time		
					No	Yes	Time		
					No	Yes	Time		
					EDI	EWI	Other		
					Method Used				
					No	Yes	Time		
					EDI	EWI	Other		
					Method Used				
					No	Yes	Time		
					EDI	EWI	Other		
					Method Used				
					No	Yes	Time		
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					Method Used				
					No	Yes	Time		
					EDI	EWI	Other		
					Method Used				
					No	Yes	Time		
					EDI	EWI	Other		
	</								

Figure H-2. Discharge measurement field sheet from Herring River near Wellfleet, MA , September 2000.

KCM - Dec 2010

WADING STREAM DISCHARGE FIELD SHEET

Station ID: _____ GID: _____

Measured by: _____

Date: _____

Time Start: _____ Time Finish: _____

Meter Type: *Sid Pygmy w/AquaCalc* Other: _____

Method: 0.6 0.2/0.8 Method Coeff. 1.0 Horiz. Angle Coeff. 1.0

Spin Test (Before): Pass / Fail Spin Test (After): Pass / Fail

(spins for at least 60 sec CClockwise)

Stage Before (ft): _____ Stage After (ft): _____

Tidally Influenced: Yes / No

HR-1 Well Level (ft): _____

of Verticals _____

Section	LEW	2	3	4	5	6	7	8	9	10	REW
Distance from LEW (ft)											
Width (ft)											
Depth (ft)											
Area (ft ²)											
Revolutions											
Time (sec)											
Velocity (ft/sec)											
Q (discharge, cfs)											
Section Totals:	Total Width (ft) _____ Total Area (ft ²) _____ Velocity (ft/sec) _____ Meas. Q (cfs) _____										

Observations: _____

Data Entry Information:
 Entered by: _____ Date Entered: _____
 Data Downloaded: _____ Date Downloaded: _____

Figure H-3. Current wadeable stream discharge field sheet for CACO (2010).

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

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		

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			

Appendix J. Current field sheet for pond stage measurements (2010).

POND STAGE FIELD SHEET					KCM-Dec 2010		
Date: _____							
Method: Pond Stage		Other: _____					
Auto Level ID: _____		Stadia Rod ID: _____		ft / m			
Auto Level Reader: _____				Rod Holder: _____			
Weather: _____							
Ice**: Yes No							
Site ID	Time	BS	FS	WE	Measurement	PVC*	Remarks
East Harbor					PVC*/ Casing	Inner / Outer	
L. Bennett					PVC*/ Casing	Inner / Outer	
Ryder					PVC*/ Casing	Inner / Outer	
Gull					PVC*/ Casing	Inner / Outer	
Great W					PVC*/ Casing	Inner / Outer	
Dyer					PVC*/ Casing	Inner / Outer	
Duck					PVC*/ Casing	Inner / Outer	
Herring					PVC*/ Casing	Inner / Outer	
Great T					PVC*/ Casing	Inner / Outer	
E9					PVC*/ Casing	Inner / Outer	
Observations:					Data Entry Information: Entered By: _____ Date Entered: _____		
<i>** If YES to ice -- break through and place stadia rod at the bottom as usual and measure WE to where the water intersects the stadia rod NOT where ice surface intersects.</i> <i>If you cannot break through the ice, no measurement should be taken</i>							

Figure K-1. Example field sheet for leveling of well and stage measuring points.

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Station Number

Duck Pond

LEVEL NOTES

Stream Duck Pond Siphon cage
Locality Cape Cod National Seashore, Wellfleet, MA
Party McCobb, Gwilliam Date 11-18, 19 99

[illegible]

No. _____ of _____ sheets _____ Comp. by _____ Chk. by _____

☆ GPO 1984 O-452-826

Figure K-2. Leveling notes from Duck Pond, Wellfleet, MA.

Appendix L. Data archive hard copy record for original field data sheets.

FIELD NOTEBOOK /FIELD DATA RECORD FOR ORIGINAL HARDCOPY DATA

- Please prepare a sheet for each item stored in fireproof file
- Please label the cover of each item with an abbreviated code as follows:
PROTOCOL/PROJECT/YEAR/NOTEBOOK NUMBER/INITIALS
PLEASE PROVIDE THE FOLLOWING IN BRIEF:

Protocol/Project:

Keywords:

Geographic area:

Start and End Dates of content:

Protocol/Project Principle Investigator:

Other observers/data collectors:

Instrumentation used:

Field or Lab data?

List types of data (e.g. counts, % cover, GPS points, elevations, etc.)

Description of the notebook or datasheets (e.g. yellow rite in the rain, looseleaf in a binder, etc).

Directory structure to electronic version of data (e.g.
biolabserver\I&M_Projects\Aquatic_Ecology.... Etc)

Date of electronic archive of this data

Archive format type

Alternate physical location of electronic archive

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 609/111726, December 2011

National Park Service
U.S. Department of the Interior



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