

PORTNOY 7580



Horsley & Witten, Inc.
Environmental Services

Hydrologic Evaluation of Duck and Gull Ponds

Wellfleet, MA

JUNE 1996

Submitted to:

U.S. DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
Cape Cod National Seashore
South Wellfleet, MA 02663

TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY	1
INTRODUCTION	3
DESCRIPTION OF STUDY AREA	4
Geography	4
Geology	4
General Hydrology	6
PREVIOUS INVESTIGATIONS AND DATA COLLECTION	6
STUDY APPROACH	7
DATA COLLECTION	9
Precipitation	9
Evaporation	10
Evapotranspiration	10
Ground Water Information	17
Design and Installation of Well Network	17
Water Levels	18
DATA EVALUATION AND ANALYSIS	18
Precipitation	18
Evaporation and Evapotranspiration	18
Ground Water Flow Systems	29
Duck Pond Ground Water Flow System	29
Duck Pond Conceptual Water Budget and Storage Change	38
Duck Pond Ground Water Seepage and Mini-Piezometer Tests	43
Duck Pond Short Term Aquifer Response Experiments	43
Gull Pond Ground Water Flow System	47
Gull Pond Conceptual Water Budget and Storage Change	58
Gull Pond Outlet	58
GROUND WATER MODELING	62
Conceptual Model of Ground Water Flow	62
Model Description	62
Model Approach	62
Grid and Boundary Conditions	63
Hydraulic Conductivity (K)	63
Vertical Flow (Leakance Between Layers)	63
Anisotropy	66

TABLE OF CONTENTS

	<u>Page</u>
Recharge	66
Model Calibration	66
Percent Error	67
Transient Model	67
Modeled Change in Storage	69
Duck Pond	69
Gull Pond	70
 CONCLUSIONS	 71
 RECOMMENDATIONS	 73
Gull Pond Discharge Monitoring	73
Well Network Surveying	74
Pond Surface Area Delineation	74
Additional Monitoring Wells	74
Pond Bottom Thickness and Hydraulic Conductivity	75
Further Aquifer Response Testing	75
Evaporation Monitoring	76
Precipitation Monitoring	76
Plugged Monitoring Wells	76
Future Uses of the Ground Water Models	77
 REFERENCES	 78
 APPENDIX A: Daily Precipitation at Duck and Gull Ponds	
APPENDIX B: Horsley & Witten, Inc. Boring Logs	
APPENDIX C: Model Input Files	

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Precipitation at Duck and Gull Ponds	13
2. Evaporation Measurements a Duck Pond	15
3. Evaporation Measurements at Gull Pond	16
4. Monthly Evapotranspiration Calculations for Wellfleet	20
5. Duck Pond Well Data and Water Levels	25
6. Gull Pond Well Data and Water Levels	27
7. Seepage Measurements at Duck Pond	44
8. Gull Pond Stage and Discharge Measurements	59
9. Calibration Table for Steady-State Model	68
10. Ground Water Flux for Model Layers	69
11. Comparison of Measured Versus Model Storage Change	69

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Locus Map	5
2. Site Plan Showing Well Locations-Duck Pond	10
3. Site Plan Showing Well Locations-Gull Pond	11
4. Monthly Precipitation Records at Duck and Gull Ponds from May 1994-April 1995	14
5. Monthly Evapotranspiration from May 1994-April 1995	19
6. Profile of Duck Pond-Cross Section A-A'	21
7. Profile of Duck Pond-Cross Section B-B'	22
8. Profile of Gull Pond-Cross Section A-A'	23
9. Profile of Gull Pond-Cross Section B-B'	24
10. Pond Levels	30
11. Site Plan Showing Water Table	31
12. Shallow Ground Water Levels About Duck Pond	32
13. Vertical Gradients at SE Shore of Duck Pond	33
14. Vertical Gradients at SW Shore of Duck Pond	34
15. Ground Water Elevations North of Duck Pond	35
16. Vertical Gradients at North Shore of Duck Pond	36
17. Duck Pond Ground Water Conditions (7-25-94) Cross Section A-A'	39
18. Duck Pond Ground Water Conditions (7-25-94) Cross Section B-B'	40
19. Duck Pond Ground Water Conditions (4-27-95) Cross Section A-A'	41
20. Duck Pond Ground Water Conditions (4-27-95) Cross Section B-B'	42
21. Regression Rating Curve Showing Relationship of Head Differential and Ground Water Flux in Vicinity of Well Cluster HW-13	45
22. Water Level Fluctuations in Observation Wells HW-3s, HW-3m, and HW-3d	46
23. Site Plan Showing Water Table	48
24. Shallow Ground Water Levels About Gull Pond	49
25. Gull Pond Ground Water Conditions (7-26-94) Cross Section A-A	50
26. Gull Pond Ground Water Conditions (7-26-94) Cross Section B-B	51
27. Gull Pond Ground Water Conditions (4-27-95) Cross Section A-A	52
28. Gull Pond Ground Water Conditions (7-26-94) Cross Section B-B	53
29. Ground Water Elevation on West Shore of Gull Pond	55
30. Ground Water Elevation on East Shore of Gull Pond	56
31. Ground Water Elevation on North Shore of Gull Pond	57
32. Regression Rating Curve of head differential between Gull and Higgins Pond and stream discharge from Gull Pond	61
33. Map Showing Modeling Grid and Locations of Observation Wells around Duck Pond	64
34. Map Showing Modeling Grid and Locations of Observation Wells around Gull Pond	65

EXECUTIVE SUMMARY

Horsley & Witten, Inc. (H&W) was retained by the National Park Service to conduct the initial phase of a hydrologic evaluation of Gull and Duck Ponds, two kettle ponds located in the Cape Cod National Seashore in Wellfleet, Massachusetts. H&W developed and implemented a ground water, surface water and climatological monitoring program, and developed two numerical ground water flow models to evaluate the adequacy of the monitoring program and make recommendations for continued monitoring. The final goal of the overall program, of which this is the first phase is to quantify the hydrologic budget for each pond which can then be used to evaluate water quality and biological issues associated with the ponds.

The monitoring program was designed to provide data needed to develop the water budget for each pond. A series of monitoring wells were installed and used with existing wells at Gull Pond to evaluate three dimensional ground water flow and to develop estimates of aquifer permeability. Protocols were designed and equipment prepared for monitoring of precipitation, evaporation, ground water levels and, at Gull Pond, stream outflow. Monitoring was conducted from May 1994 to April 1995 by National Park Service personnel with review by H&W.

Ground water monitoring data collected during the year indicates that ground water flows into Duck Pond on all sides and at all depths with the exception of pond discharge into the aquifer at a depth of 30 feet on the north side of the pond. Ground water flows into Gull Pond on three sides and pond water discharges to the aquifer on the north side of the pond in the vicinity of the outlet stream.

The monitoring data was used to develop three dimensional ground water flow models for each pond using the numerical model MODFLOW developed by the US Geological Survey. The models were calibrated to the average measured water level in each monitoring well. The model results were used to estimate the ground water flux into and out of each pond. This flux data was then used with other measured hydrologic parameters to estimate the water budget for each pond.

The change in storage calculated with the water budget data for Duck Pond showed a decline in water level that was not as large as the observed decline (0.96 feet calculated versus 2.21 feet observed). For Gull Pond the calculated changes in storage showed a 3.2 feet decline, whereas the actual change in pond level was only a 0.07 foot decline as it is controlled by the outlet stream. These discrepancies underline the need to continue the field monitoring for the next two years to refine the models and more accurately predict changes in pond storage. When the models are refined, they can be used to predict changes in

lake storage resulting from changing climatic conditions or changes in ground water usage.

Based on the model results and a review of the first years monitoring data, a series of recommendations have been made for continued monitoring. It is suggested that water levels, precipitation and expanded evaporation and stream discharge monitoring be continued. It is also suggested that existing survey elevations for monitoring wells be confirmed by a registered land surveyor, and vandalized monitoring wells be repaired or replaced.

It is also recommended that the full ground water drainage basin to each pond be mapped to accurately determine the land areas contributing ground water, and potentially pollutants to the pond. The existing ground water flow data suggests that near shore development can provide nutrient inputs to the pond from septic systems lawn fertilizers and road runoff. The extent of the drainage area for Gull Pond appears to be larger than the drainage area to Duck Pond based on existing data. The Gull Pond shoreline is also more developed than that of Duck Pond. The potential threat to each pond will depend on the potential for future development in each of the drainage areas.

Duck Pond may be more sensitive to pollutant and nutrient inputs from shoreline areas as the contributing area appears to be small (it does not extend far from the pond shore). There is no surface water outlet so outflow occurs only through evaporation and discharge to ground water (the extent of which needs to be refined in the remainder of this project). The pond may be acting as a nutrient sink, and over time the buildup of nutrients could begin to cause water quality problems. The next two years of monitoring will provide an increased understanding of ground water flux out of Duck Pond, allowing a more accurate determination of the effects of nutrient inputs on pond water quality.

INTRODUCTION

The National Park Service (NPS) is responsible for management of the natural resources of the Cape Cod National Seashore (CCNS). Utilization of ponds within the Seashore is controlled to provide recreational use while maintaining environmental conditions. Over utilization or inappropriate use could harm sensitive fauna and flora or degrade water quality leading to diminished value. On the other hand, under utilization would deprive the public of reasonable use of the resources of the Seashore.

Twenty kettle ponds within the Cape Cod National Seashore are a rare and distinct natural resource to be preserved for both their high recreational value to the public and their role in supporting rare plant and animal communities. Management of these resources to take advantage of their recreational values while preserving their habitats for rare plants and animals and other aquatic and aesthetic values requires sound understanding of their water budgets and the pathways for nutrients and contaminants into and about them.

A fundamental understanding of pond hydrology, specifically the interaction between pond water and the land surrounding the ponds is needed. A goal of such hydrologic description is determination of the quantities of water inflow and outflow, including underground flow. Duck and Gull Ponds were selected for description because they are typical of two common types of ponds within the Seashore and other parks managed by the NPS. Duck Pond has no surface inlets or outlets and is considered a ground water pond. Gull Pond has an outlet but no inlets and is largely dependent on interaction with ground water.

The National Park Service retained Horsley & Witten, Inc. (H&W) to develop preliminary hydrological data for each pond. Specifically, the scope of services included planning for, and installing a hydrologic data collection network for each pond, supervising the collection of hydrologic data during the first year of monitoring, and developing preliminary ground water models for each pond based on data collected over the course of the one-year monitoring period. The models were designed to represent steady-state water levels about each pond in a three-dimensional framework, estimate ground water flow into and out of the ponds, and to be used as a means of evaluating the hydrologic data. Based on the data evaluation and modeling results, recommendations regarding future monitoring needs as well as management implications for the ponds are also included in this report.

DESCRIPTION OF STUDY AREAS

Geography

The Cape Cod National Seashore is located on the sandy Cape Cod peninsula, which extends about 30 miles Eastward into the Atlantic Ocean from the rocky shores of New England (Figure 1). The peninsula trends eastward about 30 miles then takes a right angle turn and extends another 25, or so, miles to the north. The Seashore properties are located on this northern extension of the peninsula, known locally as the "Lower Cape." The climate is temperate with approximately 35 to 45 inches of annual precipitation. The many ocean and fresh water beaches, unique natural and historical character and moderately cool temperatures attract visitors from across the United States. Because of a large influx of vacationers in the summer, the population swells to between 3 and 7 times that of the winter months.

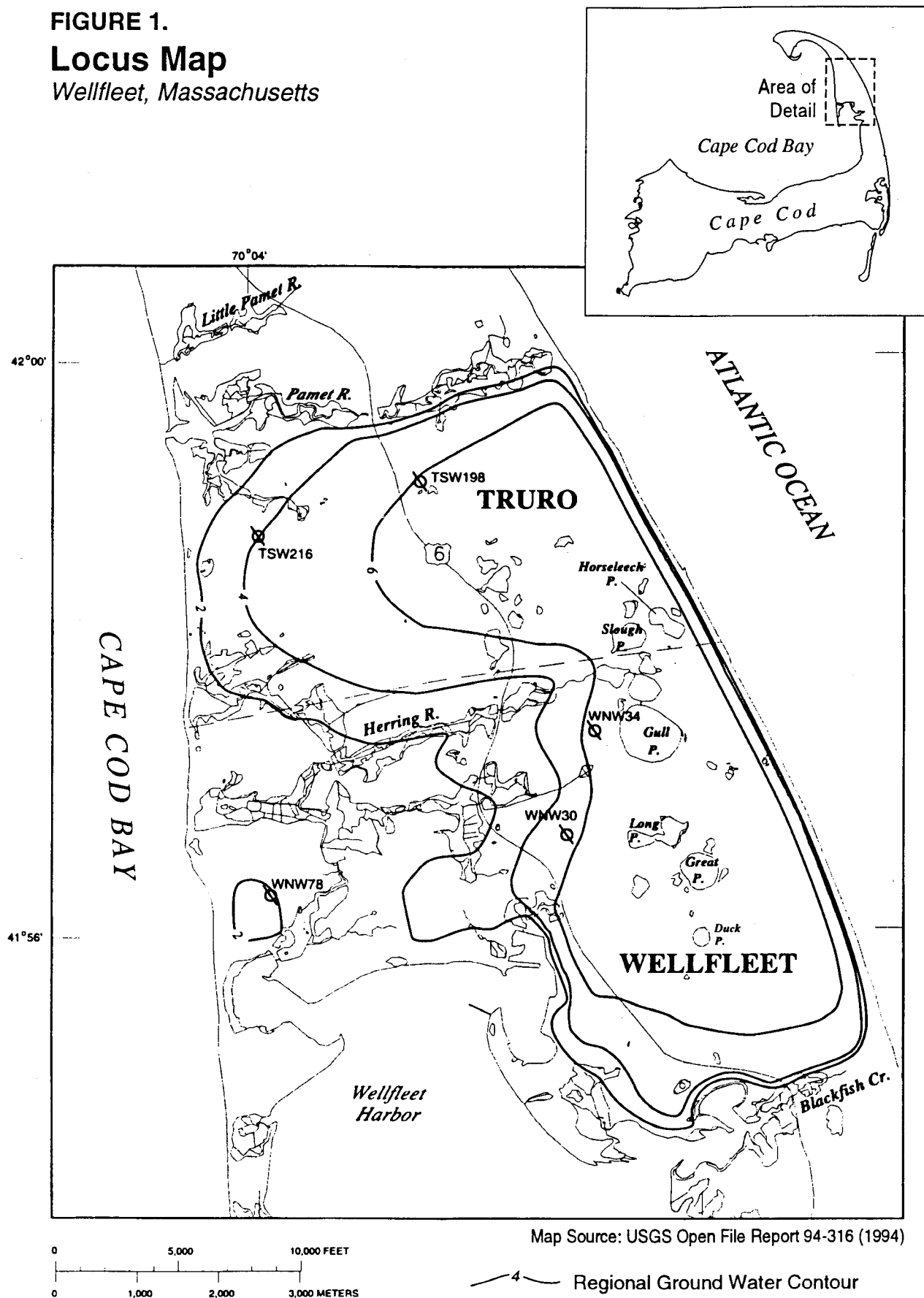
Geology

Duck and Gull Ponds and eighteen other ponds in the National Seashore are kettle hole ponds in glacial outwash deposits of Wisconsinan age. During the retreat of the glacial ice, the South Bay Lobe of ice lay to the east of what is now the National Seashore property on Cape Cod. Outwash sediments of layered unconsolidated sand, gravel and silt were deposited by meltwater streams flowing westward from the South Bay Lobe to form the lower part of Cape Cod (Oldale, 1968, 1981). Post glacial erosion by waves and deposition by long shore currents has redistributed some of the sediments that originally formed Truro, Wellfleet and Eastham to create the lands of Provincetown to the north. Geologists explain kettle holes as depressions formed by the melting of huge remnant ice blocks that had been buried in the outwash sediments. Since the continental glacier melted and sea level rose, the water table has risen above the bottoms of the kettle holes and they have partially filled with water to form kettle hole ponds.

Initially, these kettle hole ponds did not have circular shorelines, but irregular shorelines roughly reflecting the shape of the remnant ice block that was responsible for the formation of the depressions in glacial sediments. Post glacial wave action and ice push working on the shores have modified the original shore lines to the characteristic circular shapes so prominently exhibited by both Duck and Gull Ponds. Wave action moves unconsolidated sediments along the shoreline from headlands to the quieter water of bays and inlets, thereby smoothing the shoreline and causing it to become circular.

Ice push occurs as ice on the pond surface expands and pushes radially against the sediment and vegetation along the pond's shores. Ice expands because it cracks and the cracks fill with new ice and because ice expands with increasing temperature.

FIGURE 1.
Locus Map
Wellfleet, Massachusetts



These processes are still operative. For example, erosion is demonstrated by recent small land slides observed along the steep east shore of Duck Pond and deposition is demonstrated by sand clogging the small stream outlet for Gull Pond.

General Hydrology

Precipitation is the source of all fresh water on Cape Cod. Water from precipitation seeps into the sandy soils and either recharges the ground water flow system or is returned to the atmosphere by evapotranspiration. The ground water flows to streams or the ocean and the Bay where it slowly discharges.

Regional ground water contours for the area extending from southern Wellfleet to southern Truro show that the study areas are located within an elongate ground water mound (fresh water lens) which drains radially (Figure 1). Ground water in this part of Cape Cod is bounded in every direction by tidally influenced waters. The eastern and western limits of the water table are the Atlantic Ocean and Cape Cod Bay respectively. Tidal influence from the Pamet River in Truro to the north and Blackfish Creek in South Wellfleet to the south also provide natural ground water flow boundaries.

Neither pond is recharged by surface inlets. Gull Pond drains through a surface outlet northward into Higgins Pond. Duck Pond is completely isolated from other surface water bodies. Because there is no surface inflow into either pond, their sole source of recharge is a combination of direct precipitation and ground water inflow. Each pond is directly connected to the surrounding ground water and may therefore be considered a surface expression of the water table.

Ground water recharge is a function of excess precipitation over evapotranspiration, resulting in a net increase of aquifer storage. Ground water flux into and out of the ponds is controlled by gradients between pond levels and hydraulic head in the immediately joining aquifer. Pond outflow also occurs from evaporation from the pond surface and, in the case of Gull Pond, stream drainage. There are no significant ground water withdrawals in this part of Cape Cod. By using water budget data recorded during the measuring period as model input, future inputs under varying recharge conditions can be estimated.

PREVIOUS INVESTIGATIONS AND DATA COLLECTION

The geology of the Seashore area has been described by Oldale, R. N. and by Koteff, Oldale and Hartshorn in the Geologic Quadrangle map series published by the U.S. Geological Survey. The geology of Cape Cod was also summarized by Strahler, A. N. in 1966. The Hydrogeology of Cape Cod is described in "Ground Water Resources of Cape Cod, Massachusetts" (LeBlanc and others, 1986) in U.S. Geological Survey Hydrologic Atlas HA-692. Regional (large scale) numerical

ground water models have been prepared by the U.S. Geological Survey (Guswa and LeBlanc, 1985 and Masterson and Barlow, 1994). The model prepared by Masterson and Barlow is designed as a transient flow model which predicts the movement of ground water as well as ground water elevations. Estimates of aquifer hydraulic conductivity, transmissivity and ground water recharge are available from the reports describing these models. However, the cell divisions are too large for these models to be directly applied to make detailed study of the kettle hole pond hydrology needed by the NPS. Water levels in a few observation wells in and near the Seashore have been monitored by the U.S. Geological Survey and by the Cape Cod Commission, and its predecessor. Data from these observations is available from either of the two agencies.

The National Park Service (Soukup, M. A., 1977) described investigations of the limnology and management of the Cape Cod National Seashore freshwater ponds. Soukup reported a range of discharges from Gull to Higgins Ponds of from 9,000 to 73,000 cubic feet per day. Winkler (1994) analyzed lake and wetland sediment cores to determine historical changes in the Gull Pond chain and Herring River drainage, and Dowd (1984) developed a two-dimensional ground water model for Gull Pond.

At the request of the National Park Service, the U.S. Geological Survey performed a study of Gull Pond hydrology between 1977 and 1980. A network of observation wells was installed to sample lithology and monitor water levels at various depths in the aquifer about Gull Pond. As a result of this study, the U.S. Geological Survey prepared an Administrative Report "Estimated Ground-Water Flow to and from Gull Pond, Wellfleet, Massachusetts" for the National Park Service in 1980 (Ryan, B. J., 1980). Twelve shallow wells and three deep clusters of 3, 4 and 4 wells set at varying depths down to 125 feet below land surface were installed and monitored. Darcy's law was applied to estimate flows into and out of the pond. Ryan concluded that ground water inflow ranged from 25,000 to 145,000 cubic feet per day, and ground water outflow ranged from 11,000 to 13,000 cubic feet per day. Water table maps in this report show ground water flow into Gull Pond from the East, South and West, and out of the pond to the north. The availability of the network of wells installed by the U.S. Geological Survey was a significant factor in selecting Gull Pond for this study. No studies of the hydrology of Duck Pond were available and a network of observation wells had to be installed for study of that pond.

STUDY APPROACH

To generate a representative steady-state hydrologic data base and numerical models that simulate not only water levels but also the various water budget components, long term (a minimum of three years) monitoring is essential. The main goals of this study are a description of pond hydrology and determination of the water budget for each pond. Thus, the data collection and preliminary

modeling completed thus far represents phase one of this ultimate goal. As monitoring continues and more accurately represents steady-state conditions, the models may then be refined. The program of monitoring pond storage and inflows and outflows to the ponds was established to provide, at least, monthly measures for a period of three years. The selection of a three-year monitoring period is intended to permit monitoring of at least one average year, neither drought nor wet conditions. The U.S. Geological Survey's Water Resources Division customarily plans for a minimum of three years of monitoring for studies involving budget analyses, in part because there is little likelihood of three consecutive abnormal years. Indeed, the first year of monitoring for this study could not be expected to be representative of average conditions because this project started during abnormally wet conditions.

The initial first year of data collected for this study were to be evaluated with the aid of preliminary models. Based on these models, changes in the monitoring plan have been recommended for the remaining monitoring, and design and calibration of final numerical simulation models.

Data were monitored for input to the hydrologic budget for each pond. Inflow from precipitation was monitored with the daily monitoring of rain gages established at each pond. Evaporation pans were established and monitored, adjacent to each pond to provide measure of water loss to the atmosphere. The discharge through the surface outlet from Gull Pond was measured biweekly when there was flow. Pond levels were monitored biweekly to determine changes in storage in the ponds. Only underground inflow and outflow could not be measured directly. Monitoring of ground water levels about both Duck and Gull Ponds as well as monitoring of the pond levels was needed to understand the water flux between the ground and the ponds.

A series of field experiments were undertaken to develop an understanding of the ground water system and the pond to aquifer hydrologic connection. The results of the experiments may suggest modifications to the data collection program. The objectives of these experiments were to determine recharge response to precipitation and to determine pond bottom hydraulic conductivity. Data loggers and pressure transducers were used to monitor rapid water-level responses in wells tapping different depths in the aquifer and beneath different thicknesses of unsaturated zone to show response to recharge from precipitation. Small diameter mini-piezometers were driven through the pond bottom of Duck Pond in a near shore part of the pond for measurement of head gradient across the pond bottom sediments.

From interpreting hydraulic gradients and by accounting for changes in pond storage from precipitation, evaporation and surface discharge (for Gull Pond only) between the ponds and the adjacent aquifer, net ground water flux into or out of each pond was estimated. The hydrogeologic framework and the transient hydraulic head data combined with the inflow and outflow data were planned to

be used to create digital simulation models (MODFLOW) in plan and profile at each of the two ponds. These models were to be used to develop preliminary estimates of the ground water fluxes into and out of the ponds. These estimates would then be used to evaluate the water budgets for each pond. During the study it was decided to use three-dimensional models of the ponds, rather than the two-dimensional plan and profile models originally planned. Cross section representations could be generated from model output from vertical sections through the three-dimensional models. For the model inputs, aquifer hydraulic conductivities, transmissivities and storage coefficients were available from the models of previous studies (Guswa and LeBlanc, 1985 and Masterson and Barlow, 1994) as well as from interpretation of lithologic logs from the construction of the observation wells. Pond bottom hydraulic conductivity and thickness was to be simulated by calibrating vertical leakance through the pond bottom to match the measured pond levels and to also match hydraulic heads in the observation wells about the shores of the ponds. Boring logs were used to construct cross-section maps for each pond.

The resultant cross sections and maps produced by measurements and by the models calibrated to the three years of data (steady state) would then show the direction of flow between the ponds and the ground at various depths about the ponds under a range of different conditions. Model outputs will be the ground water inflow, ground water outflow, and net flux between the pond and the adjacent aquifer. Cross sections and maps will show the directions of ground water flow (in and out) with respect to pond depth and with respect to location along the pond shores for the study period.

This interim report summarizes the progress and findings after the first year of the study. It describes the preliminary model design and preliminary model calibration and recommends changes in the monitoring and data collection program.

DATA COLLECTION

Horsley & Witten, Inc. designed a data collection program for the NPS that included recording daily precipitation, weekly evaporation, and semi-monthly pond and ground water levels from monitoring well networks at Gull and Duck Ponds (Figures 2 and 3).

Precipitation

Precipitation, either directly or indirectly, provides all of the recharge to both ponds. Average annual precipitation for Wellfleet is approximately 40.4 inches/year (Leblanc et al, 1986). Rain gages were established at each pond and read by the NPS after precipitation events. The purpose of this was to obtain site-specific precipitation data for incorporation into the water budget calculations as

well as the models. Review of the data shows that after July 1994, the data for both ponds are the same for each pond and are also the same as records from the National Atmospheric Deposition Program (NADP) station. Total rainfall measured for the study period was lower than typical conditions, 36.14 inches for Duck Pond, and 37.91 inches for Gull Pond (Table 1 and Figure 4). Daily measurements provided by the NPS are shown in Appendix A.

Evaporation

Evaporation of water from the pond surfaces is a discharge from each system. Free-water evaporation pans were placed at Duck and Gull Ponds and measured weekly by the NPS for the months May - November, 1994 to measure the evaporation rate from each pond for the months when most evaporation occurs. The evaporation pans used in this study were constructed of aluminum, 4 feet in diameter, and 10 inches deep. They were elevated on wooden supports so air was free to circulate underneath each pan, and then leveled. *— why important?*

Evaporation data consisted of the change in water level in the land pan and the time between measurements (Tables 2 and 3). After noting the change in the pan water level, the NPS added water as needed to ensure there was sufficient water in the pan at the beginning of each measuring period. The NPS corrected for added water each time a measurement was made. Total precipitation which occurred between measurements was subtracted from the measured volume of water lost to evaporation to determine net evaporation rate. Land pans warm more readily than a pond, and are thus more likely than a pond to gain or lose heat through the sides and bottom, unlike a pond (Shuttleworth, 1993). Evaporation rates were multiplied by a land pan coefficient of 0.75 to account for these relative differences (Maidment, 1993). Total evaporation was approximately 28 inches for Duck Pond (Table 2) and approximately 23 inches for Gull Pond (Table 3), lower than the approximately 36 inches/year estimate for Wellfleet provided by Masterson and Barlow (1994). It should be noted that although, the evaporation pans were measured for months when most evaporation is expected to occur, the possibility exists that a small, yet significant, amount of evaporated water occurred in the late fall, winter, or early spring months.

Evapotranspiration

In the study area, aquifer and pond water levels rise and fall in response to precipitation and evapotranspiration (ET). ET is the total amount of water lost from the land as a result of evaporation and uptake and transpiration by plants. Evapotranspiration affects ground water recharge as plant roots draw water from the root zone that would otherwise reach the water table. Generally, as ET increases, water levels decline. Evapotranspiration is largely a function of temperature so that ET increases in the summer and consequently water levels decline in the summer. Because of this, it is important to quantify ET for an

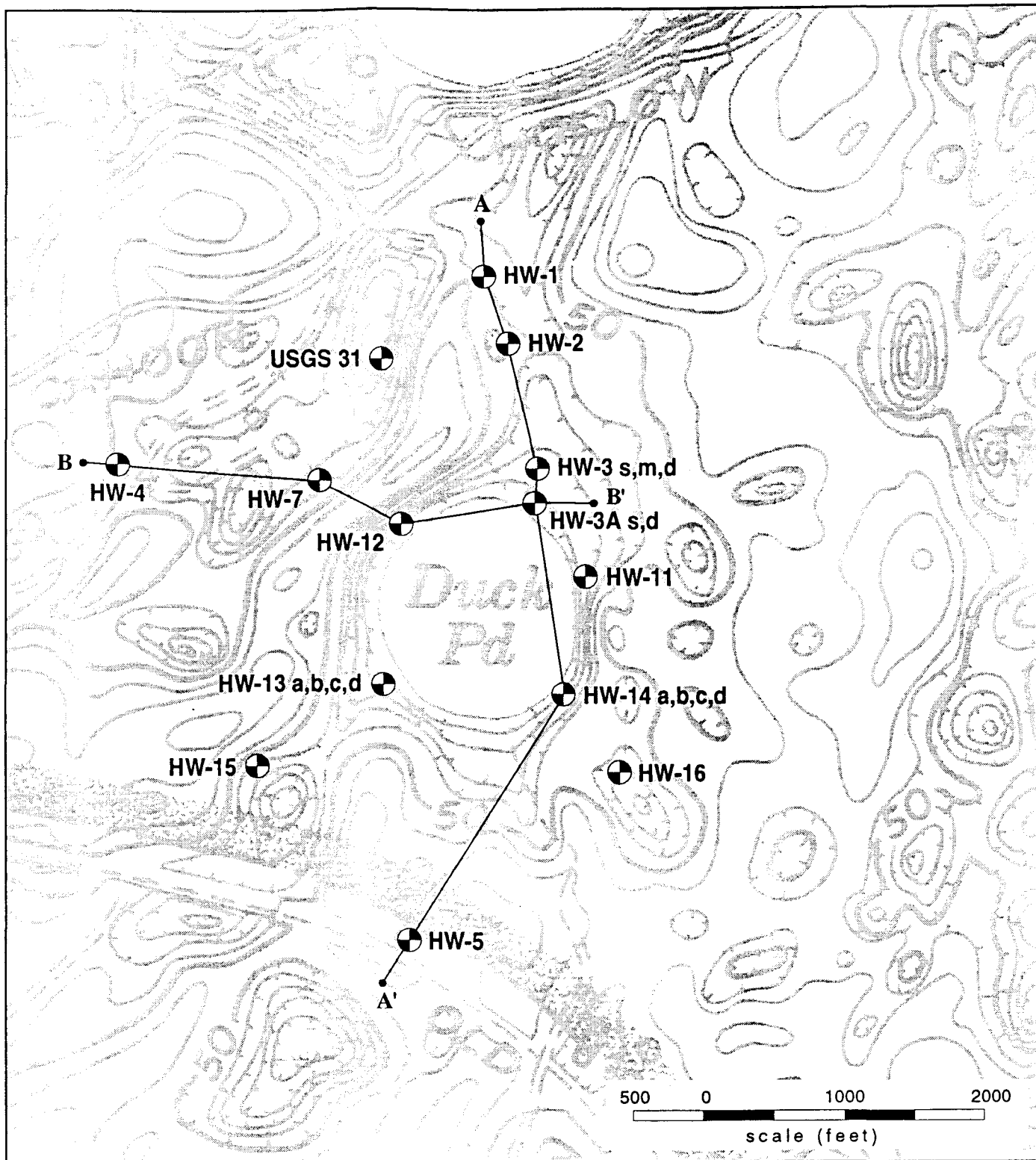


FIGURE 2.
Site Plan showing Hydrologic Data Network
Duck Pond, Wellfleet

- HW-5 Monitoring Well Location
- A —●— A' Trace of Cross Section

Source: USGS Quadrangle (Wellfleet, 1972)



Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

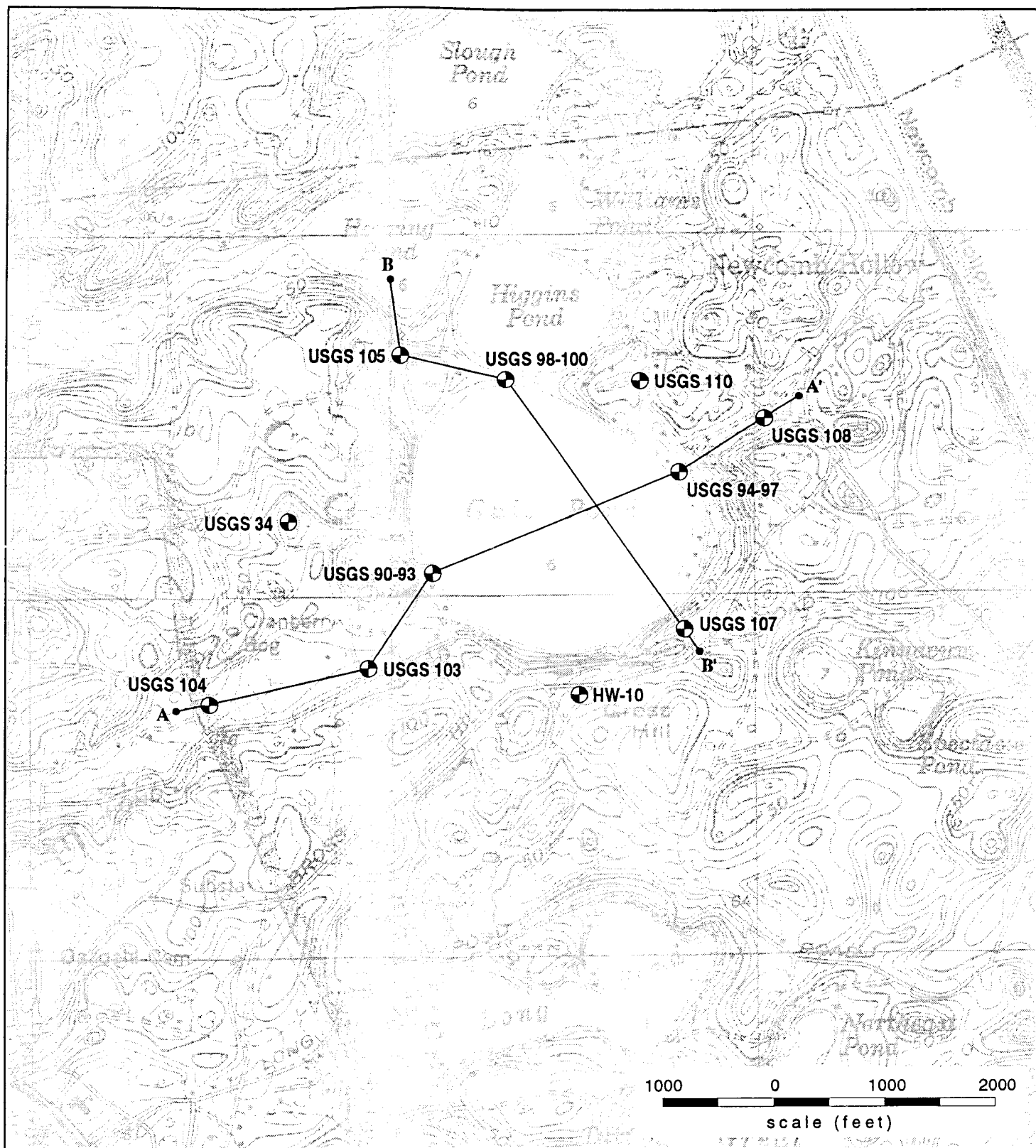


FIGURE 3.
Site Plan showing Hydrologic Data Network
Gull Pond, Wellfleet

⊕ HW-5 Monitoring Well Location

A — A' Trace of Cross Section



Source: USGS Quadrangle (Wellfleet, 1972)

Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

Table 1. Precipitation at Duck and Gull Ponds

Month	Duck Pond Precipitation (inches)	Gull Pond Precipitation (inches)
May	2	2.69
June	3.94	3.4
July	1.22	1.26
August	3.18	3.18
September	5.02	5.75
October	0.95	1.35
November	2.8	3.25
December	6.13	6.13
January	2.96	2.96
February	2.54	2.54
March	2.64	2.64
April	2.76	2.76
Annual Totals	36.14	37.91

Figure 4

Monthly Precipitation Records at Duck and Gull Pond from May 1994 - April 1995

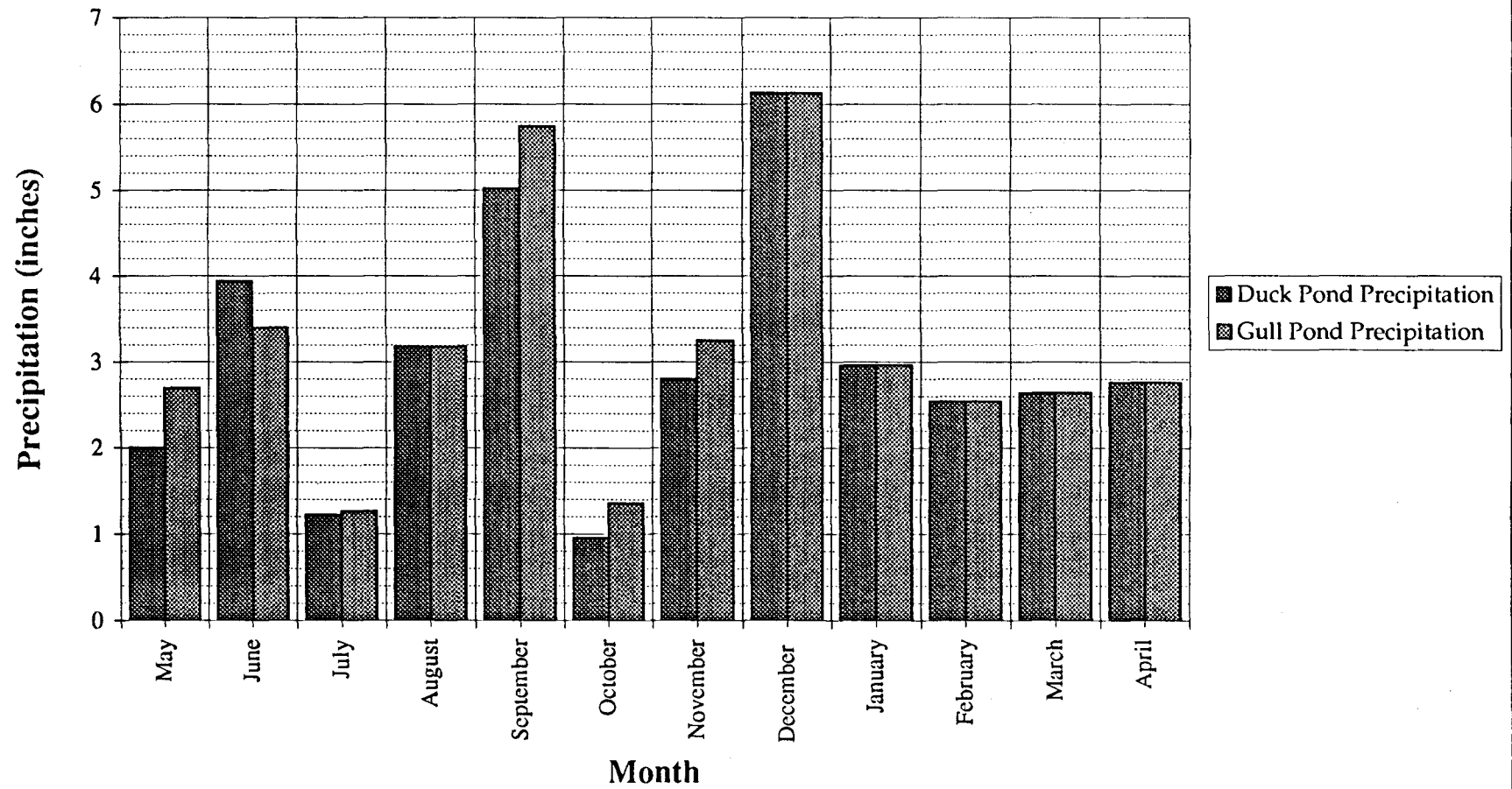


Table 2. Evaporation Measurements at Duck Pond

Date	Previous Measurement (inches)	Water Added (inches)	Current Measurement (inches)	Elapsed Time since Previous Measurement (days)	Net Water Evaporated (inches)
4-May-94			3.01		
9-May-94	3.01	2.46	5.40	5	0.08
18-May-94	2.46	1.97	3.63	9	0.80
25-May-94	1.97	1.93	1.60	7	2.30
15-Jun-94	2.21	2.80	0.00	21	5.01
29-Jun-94	2.13	0.00	2.37	14	-0.24
7-Jul-94	2.37	0.00	2.14	8	0.23
13-Jul-94	2.14	2.26	1.43	6	2.97
20-Jul-94	2.26	2.27	1.45	7	3.07
24-Jul-94	2.27	2.70	1.67	4	3.30
3-Aug-94	2.70	2.86	2.28	10	3.27
9-Aug-94	2.86	3.37	3.37	6	2.86
17-Aug-94	3.37	2.56	2.56	8	3.37
24-Aug-94	2.56	2.51	3.40	7	1.68
31-Aug-94	2.51	2.31	2.31	7	2.51
7-Sep-94	2.31	2.59	4.73	7	0.17
14-Sep-94	2.00	2.00	0.59	7	3.42
20-Sep-94	2.00	2.51	2.51	6	2.00
28-Sep-94	2.51	2.75	3.79	8	1.47
5-Oct-94	2.75	2.39	2.39	7	2.75
12-Oct-94	2.39	2.20	1.90	7	2.69
19-Oct-94	2.20	2.02	2.02	7	2.20
26-Oct-94	2.02	3.13	3.13	7	2.02
2-Nov-94	3.13	3.14	3.14	7	3.13
9-Nov-94	3.14	2.65	2.65	7	3.14

Total = 54.19

Total Precipitation During Monitoring Period = 16.50

Total Evaporated Water = 28.26

Table 3. Evaporation Measurements at Gull Pond

Date	Previous Measurement (inches)	Water Added (inches)	Current Measurement (inches)	Elapsed Time since Previous Measurement (days)	Net Water Evaporated (inches)
4-May-94			1.60		
9-May-94	1.60	2.18	3.61	5	0.16
18-May-94	2.18	1.87	2.71	9	1.34
25-May-94		1.60	1.45	7	0.14
15-Jun-94	2.01	2.25	3.80	21	0.46
1-Jul-94	1.10	0.00	2.60	16	-1.49
7-Jul-94	2.60	1.99	1.43	6	3.15
14-Jul-94	1.99	2.47	0.20	7	4.26
20-Jul-94	2.47	2.32	1.88	6	2.92
26-Jul-94	2.32	2.76	1.25	6	3.83
4-Aug-94	2.76	3.08	2.50	9	3.35
10-Aug-94	3.08	2.91	2.91	6	3.08
17-Aug-94	2.91	2.38	2.38	7	2.91
24-Aug-94	2.38	2.52	3.09	7	1.81
31-Aug-94	2.52	2.02	2.02	7	2.52
7-Sep-94	2.02	2.32	4.28	7	0.06
14-Sep-94	2.32	1.60	1.60	7	2.32
21-Sep-94	1.60	1.99	1.99	7	1.60
28-Sep-94	1.99	2.51	3.17	7	1.33
5-Oct-94	2.51	1.99	1.99	7	2.51
12-Oct-94	1.99	1.76	1.52	7	2.23
19-Oct-94	1.76	1.74	1.56	7	1.94
26-Oct-94	1.74	2.63	2.69	7	1.68
2-Nov-94	2.63	2.45	2.45	7	2.63
9-Nov-94	2.45	2.27	2.27	7	2.45

Total = 47.20

Total Precipitation During Monitoring Period = 16.50

Total Evaporated Water = 23.03

accurate water budget model. Monthly ET was calculated using the Thornthwaite method (Thornthwaite, 1944) (Figure 5 and Table 4). Calculated ET was then subtracted from monthly precipitation to determine net recharge to ground water. Total ET for the monitoring period was 22.6 inches.

Ground Water Information

Design and Installation of Well Network

H&W designed and installed an observation well network in the vicinity of Duck Pond for the purpose of determining ground water flow conditions. A similar monitoring well network established for previous study of Gull Pond was tested, evaluated and found to be representative and nearly complete. One new well had to be constructed south of Gull Pond to replace one that had been destroyed. Each well network was intended to provide adequate spatial distribution of static geologic and dynamic hydrologic information (Figures 6 through 9) to develop and calibrate the ground water models of the ponds and the adjacent aquifer.

Lithology of the glacial sediments was described from core samples and resistance to drilling during the installation of the observation wells. Lithologic logs were prepared for wells where two-foot split spoon samples were taken every five feet to the greatest depth penetrated at all sites. Inaccessibility to some well locations prohibited use of a drill-rig. At these sites, wells were installed by driving small diameter (0.5 inch) wells to the desired depth, thus preventing collection of soils samples. Appendix B is a record of soil borings for wells that were sampled.

The Duck Pond network consists of 24 observation wells (see Figure 2). Three well clusters, HW-3, HW-13, and HW-14, screened at different depths, were established around the pond periphery to monitor vertical gradients at those locations. Well cluster HW-3 consists of three wells: one screened at the water table, one screened at 30' below land surface (BLS), and one screened at 50' BLS. Well clusters HW-13 and HW-14 each consist of four wells: one screened at the water table, one screened at 20' below land surface (BLS), one screened at 50' BLS, and one screened at 70' BLS. The high water levels of the early spring of 1994 caused well cluster HW-13 to become submerged, requiring a section of PVC to be added to each well and then resurveying those wells.

The USGS previously established a network of eighteen observation wells in the vicinity of Gull Pond, including three well clusters (USGS 90-93, USGS 94-97, and USGS 98-100) around the periphery of the pond. Desmond Well Drilling installed one additional well (HW-10) to this network on the south side of Gull Pond. This location was selected because the well that previously existed there was destroyed, which left a considerable gap between USGS 107 and USGS 103 (see Figure 3).

All of the measurement reference points for water-level observations were surveyed relative to sea level (National Geodetic Vertical Datum of 1929) as a common base. From water-level measurements made every two weeks and from the lithologic data, geologic and hydrologic cross sections could be prepared to describe the framework and hydraulic conditions about the ponds.

Water Levels

The National Park Service recorded semi-monthly pond stage measurements and ground water level measurements from observation wells at Duck and Gull Ponds from May 1994 through April 1995 (Tables 5 and 6, respectively). These data were used to create graphs depicting flow directions into and out of each pond, and to provide a data base to which the models could be calibrated.

DATA EVALUATION AND ANALYSIS

Precipitation

Over the first year of water-level monitoring, ground and pond water levels fell from a historically high level (as mentioned previously) owing to change from overabundance of precipitation during antecedent conditions to slightly lower than normal precipitation during the monitoring period. Daily precipitation records for Duck and Gull Ponds indicate that precipitation amounts at the two sites only varied in the early stages of monitoring and were identical after August 1994. Because of this, it is not clear whether the data from August 1994 - April 1995 accurately represents site-specific information or whether it represents more regional information.

??
NADP
data after
Aug. 94

Evaporation and Evapotranspiration

Pan evaporation data show that significantly greater evaporation occurs at Duck Pond than at Gull Pond (28.26 inches versus 23.03 inches respectively during the monitoring period). It is not clear what may be causing more than 5 inches of water to be lost at Duck Pond than at Gull Pond. To rule out possible monitoring error and to better clarify this difference in the amount of water lost to evaporation, more monitoring data is warranted.

The Thornthwaite (1957) method for calculating ET does not require site specific information, just average monthly temperature, number of days in each month, and latitude; thus, ET calculations are the same for each pond. Total estimated ET for Wellfleet for the monitoring period was 22.61 inches.

Figure 5

Monthly Evapotranspiration from May 1994 - April 1995

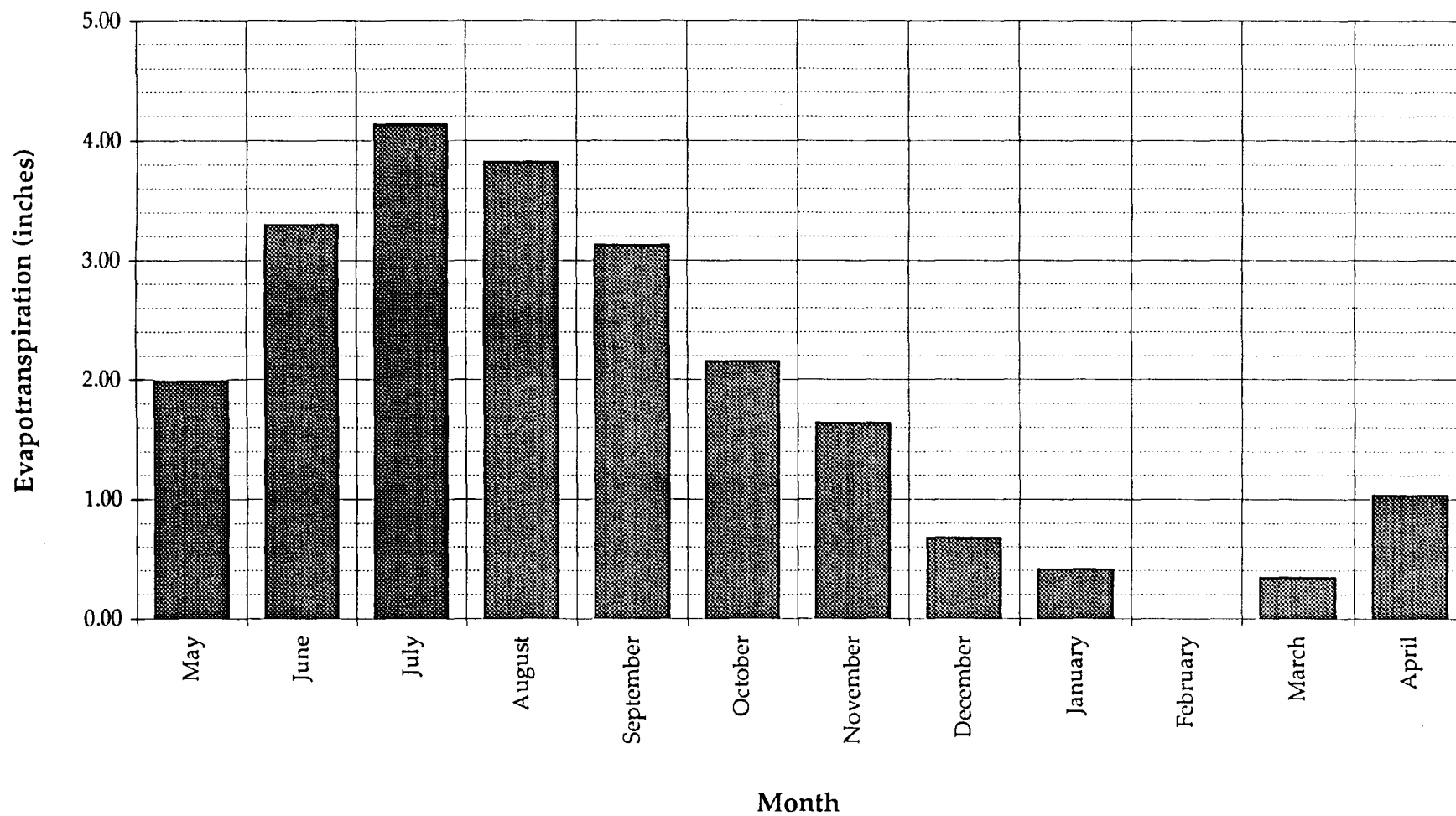
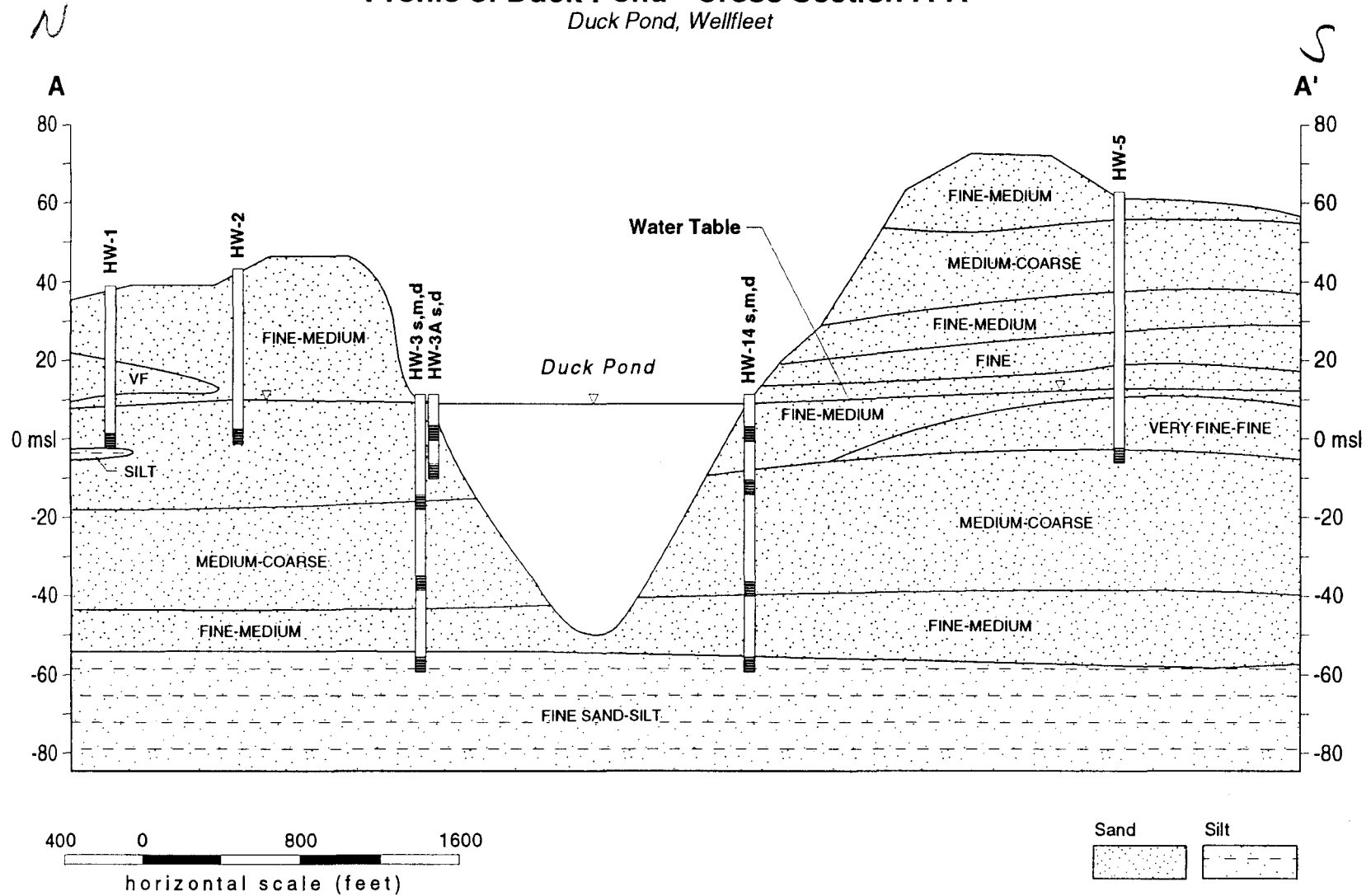


Table 4. Monthly Evapotranspiration Calculations for Wellfleet

Month	Mean Monthly Temperature (Farenheit)	Mean Monthly Temperature (Celcius)	Number of Days in month	Evapotranspiration (inches/mo)
May	52.6	11.44	31	1.98
June	63.8	17.67	30	3.29
July	70.6	21.44	31	4.13
August	68.1	20.06	31	3.82
September	62.4	16.89	30	3.13
October	54.1	12.28	31	2.15
November	49.5	9.72	30	1.64
December	40.2	4.56	31	0.67
January	37.4	3.00	31	0.41
February	31.5	0.00	28	0.00
March	36.6	2.56	31	0.34
April	43.8	6.56	30	1.03

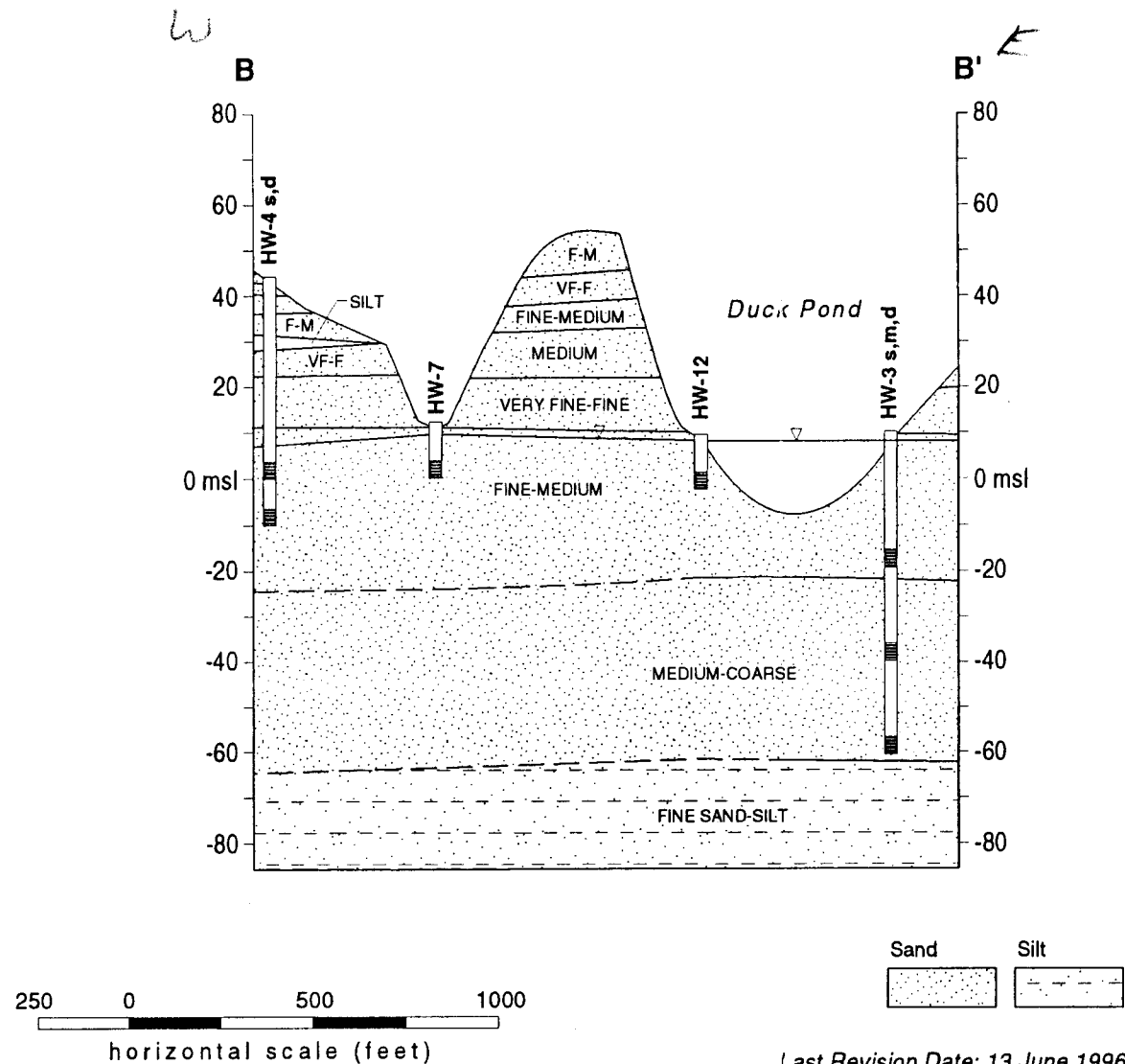
Annual Total (inches) = 22.61

FIGURE 6.
Profile of Duck Pond - Cross Section A-A'
Duck Pond, Wellfleet



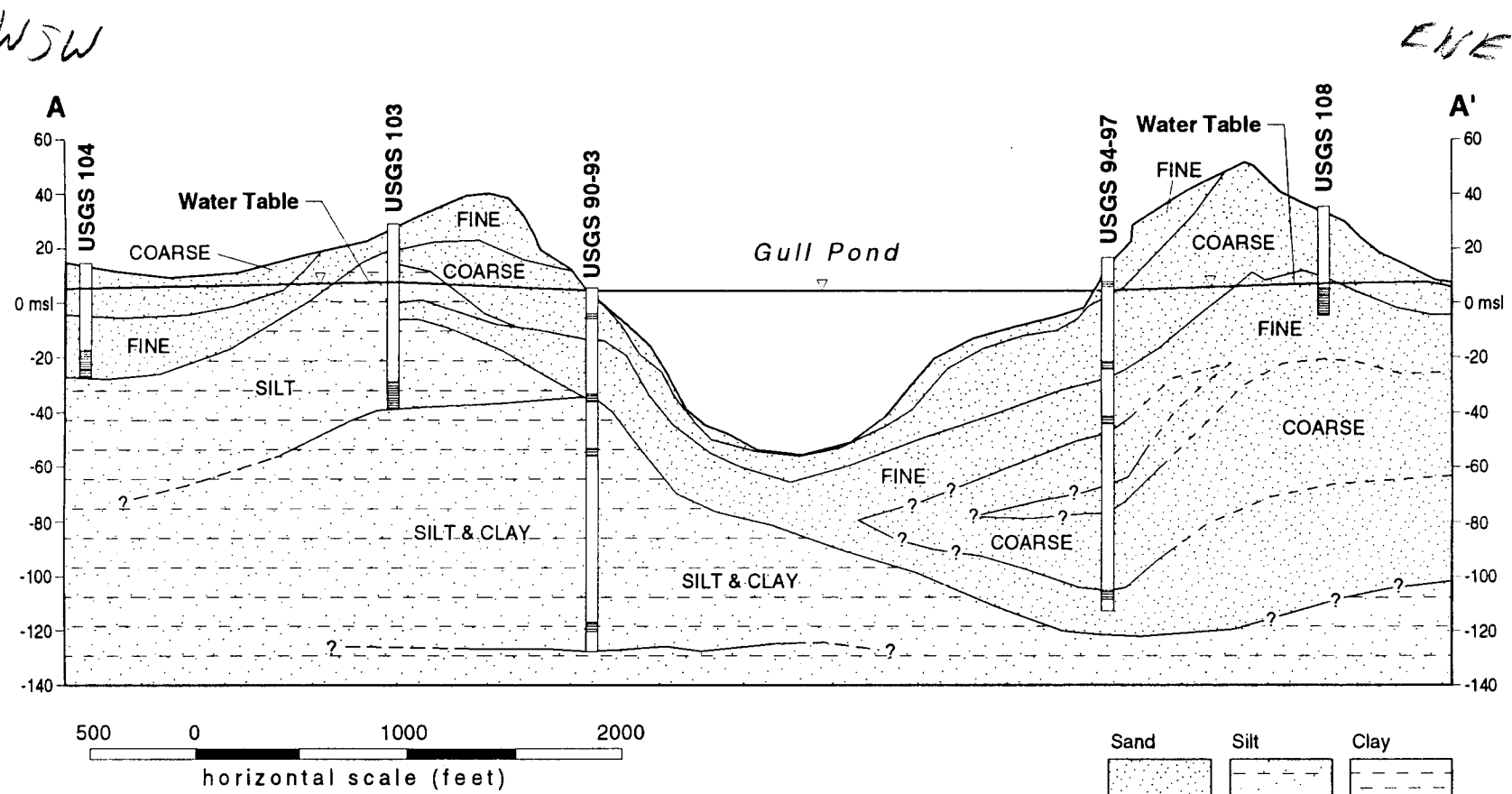
Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

FIGURE 7.
Profile of Duck Pond - Cross Section B-B'
Duck Pond, Wellfleet



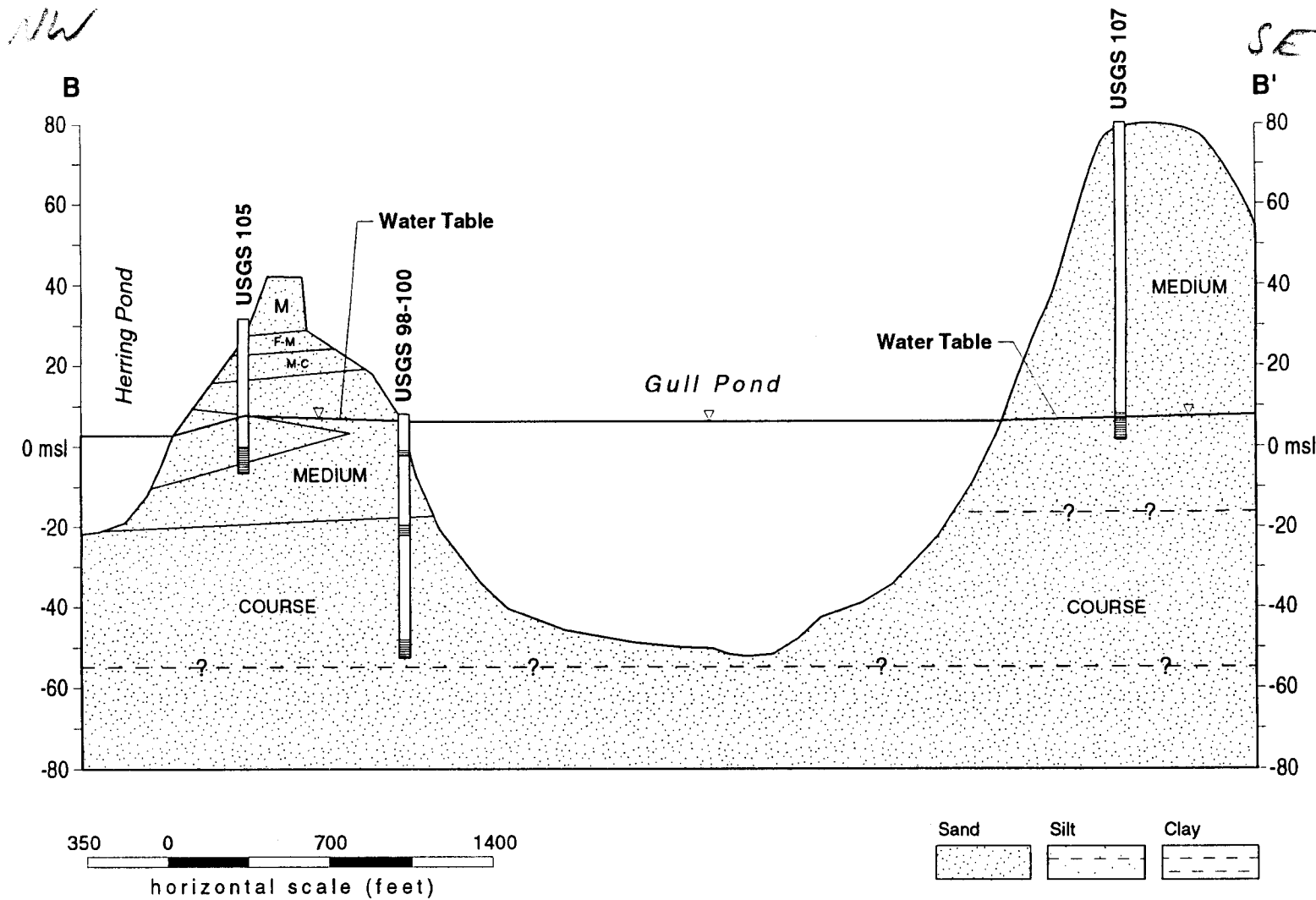
Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

FIGURE 8.
Profile of Gull Pond - Cross Section A-A'
Gull Pond, Wellfleet



Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

FIGURE 9.
Profile of Gull Pond - Cross Section B-B'
Gull Pond, Wellfleet



Last Revision Date: 26 February 1996
Horsley & Witten, Inc.

Table 5. Duck Pond Well Data and Water Levels
Water Levels expressed in feet above mean sea level

ELEVATIONS:		42.79	43.01	10.84	10.84	11.72	11.75	11.52	44.14	44.10	67.57	11.47	11.07
-------------	--	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

DATE	POND	HW-1	HW-2	HW-3As	HW-3Ad	HW-3s	HW-3m	HW-3d	HW-4s	HW-4d	HW-5	HW-7	HW-11
4-May-94	9.86	10.35	10.53						8.00	7.88	10.48	10.63	9.86
18-May-94		10.50	10.68			10.09	10.85	10.69	8.24	8.10	10.69	10.80	10.17
15-Jun-94	10.27	10.51	10.73	10.64	10.64				8.08	7.90	10.72	10.86	10.17
1-Jul-94	10.15	10.44	10.74	10.56	10.55				8.10	7.92	10.67	10.73	10.06
14-Jul-94	9.99	10.31	10.53	10.40	10.39	9.97	10.69	10.54	7.90	7.64		10.57	10.24
25-Jul-94	9.79	10.14	10.35	10.21	10.22	9.80	10.52	10.34	7.79	7.53	10.37	10.39	9.77
9-Aug-94	9.68	9.98	10.17	10.07	10.03	9.58	10.35	10.18	7.70	7.55	10.21	10.21	9.61
2-Sep-94	9.38	9.67	9.85	9.75	9.75	9.27	10.08	9.90	7.40	7.22	9.83	9.91	9.31
15-Sep-94	9.29	9.57	9.72	9.66	9.63	9.13	9.94	9.79	7.38	7.26	9.97	9.76	9.16
29-Sep-94	9.17	9.50	9.62	9.53	9.54	9.01	9.84	9.67	7.40	7.30	9.02	9.64	8.97
12-Oct-94	8.88	9.31	9.41	9.23	9.23	8.78	9.59	9.42	7.49	7.04	9.28	9.42	8.79
26-Oct-94	8.76	9.15	9.25	9.12	9.12	8.47	9.40	9.26	7.08	6.98	9.09	9.24	8.64
8-Nov-94	8.50	8.99	9.10	8.91	8.91	8.31	9.21	9.06	6.95	6.74	8.91	9.08	8.44
21-Nov-94	8.41	8.78	8.86	8.77	8.76	8.16	9.07	8.89	6.75	6.58	8.71	8.92	8.29
7-Dec-94	8.15	8.66	8.72	8.66	8.66	8.00	8.95	8.80	6.76	6.67	8.52	8.79	8.17
19-Dec-94	8.04	8.56	8.61	8.50	8.49	7.87	8.81	8.64	6.68	6.58	8.36	8.67	8.01
4-Jan-95	8.15	8.69	8.69	8.53	8.53	7.93	8.84	8.69	6.69	6.58	8.32	8.80	8.03
19-Jan-95	8.04	8.57	8.59	8.43	8.41	7.83	8.74	8.57	6.63	6.55	8.24	8.62	7.93
1-Feb-95	7.85	8.53	8.56	8.31	8.31	7.80	8.64	8.48	6.67	6.58	8.20	8.58	7.83
13-Feb-95	8.02	8.50	8.51	8.27	8.26	7.76	8.60	8.44	6.64	6.59	8.11	8.54	7.80
2-Mar-95	7.84	8.44	8.48	8.23	8.23	7.74	8.56	8.40	6.65	6.68	8.10	8.50	7.76
13-Mar-95	7.80	8.44	8.46	8.23	8.21	7.73	8.55	8.39	6.58	6.52	8.10	8.48	7.76
28-Mar-95	7.70	8.40	8.42	8.16	8.16	7.71	8.50	8.33	6.72	6.75	8.09	8.45	7.71
11-Apr-95	7.70	8.34	8.37	8.11	8.10	7.65	8.44	8.28	6.56	6.48	8.04	8.40	7.66
27-Apr-95	7.64	8.31	8.33	8.08	8.06	7.60	8.40	8.24	6.59	6.52	8.02	8.36	7.62

AVERAGE WL:	8.71	9.23	9.33	9.06	9.05	8.46	9.30	9.14	7.18	7.05	9.09	9.37	8.71
-------------	------	------	------	------	------	------	------	------	------	------	------	------	------

Table 5. Duck Pond Well Data and Water Levels
Water Levels expressed in feet above mean sea level

ELEVATIONS:	11.30	10.60	13.85	13.93	14.20	10.94	14.49	14.79	14.73	15.85	19.78	21.24
-------------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

DATE	HW-12	HW-13a	HW-13b	HW-13c	HW-13d	HW-14a	HW-14b	HW-14c	HW-14d	HW-15	HW-16	HW 31
4-May-94	10.33	10.04				10.09				11.10	10.49	11.97
18-May-94	10.60	10.31				10.37				11.21	10.64	12.17
15-Jun-94	10.65	10.40	10.45	10.47	10.48	10.49	10.52	10.52	10.55	11.20	10.64	11.94
1-Jul-94	10.67	10.34	10.39	10.41	10.40	10.40	10.42	10.44	10.46	11.10	10.58	12.12
14-Jul-94	10.10	10.18	10.21	10.23	10.25	10.23	10.23	10.29	10.26	10.91	10.46	11.92
25-Jul-94	9.97	9.97	9.99	10.06	10.02	10.04	10.04	10.08	10.07	10.74	10.31	11.74
9-Aug-94	9.86	9.70	9.88	9.91	9.89	9.90	9.92	9.91	9.91	10.55	10.11	11.59
2-Sep-94	9.55	9.51	9.55	9.59	9.51	9.58	9.57	9.57	9.57	10.17	9.74	11.27
15-Sep-94	9.42	9.41	9.38	9.39	9.39	9.47	9.46	9.46	9.45	10.03	9.61	11.14
29-Sep-94	9.31	9.32	9.30	9.35	9.28	9.36	9.35	9.35	9.35	9.91	9.45	11.04
12-Oct-94	9.03	9.01	8.98	9.03	9.00	9.09	9.08	9.06	9.06	9.70	9.22	10.82
26-Oct-94	8.89	8.87	8.84	8.58			8.92	8.99	8.42		9.22	
8-Nov-94	8.68	8.68	8.66	8.62	8.65	8.73	8.70	8.71	8.70	9.34	8.85	10.48
21-Nov-94	8.53	8.54	8.49	8.52	8.49	8.61	8.57	8.56	8.57	9.17	8.66	10.33
7-Dec-94	8.43	8.44	8.39	8.40	8.38	8.49	8.46	8.46	8.45	9.00	8.48	
19-Dec-94	8.27	8.28	8.25	8.24	8.23	8.33	8.30	8.29	8.33	8.87	8.35	
4-Jan-95	8.30	8.31	8.27	8.29	8.25	8.35	8.32	8.32	8.32	9.18	8.32	10.25
19-Jan-95	8.19	8.19	8.15	8.16	8.14	8.24	8.22	8.22	8.21	8.96	8.26	DRY
1-Feb-95	8.07	8.07	8.04	8.05	8.04	8.13	8.10	8.10	8.10	8.87	8.20	DRY
13-Feb-95	8.04	8.06	8.01	8.03	8.00	8.09	8.06	8.06	8.06	8.85	8.14	DRY
2-Mar-95	7.99	8.00	7.96	8.00	7.96	8.06	8.02	8.03	8.03	8.80	8.10	DRY
13-Mar-95	7.98	7.99	7.94	7.95	7.94	8.04	8.01	8.00	8.01	8.78	8.10	DRY
28-Mar-95	7.93	7.93	7.90	7.92	7.89	7.98	7.96	7.95	7.94	8.75	8.07	DRY
11-Apr-95	7.86	7.85	7.83	7.85	7.83	7.94	7.90	7.89	7.90	8.69	8.01	DRY
27-Apr-95	7.84	7.83	7.79	7.83	7.79	7.89	7.86	7.86	Plugged	8.64	8.00	DRY

AVERAGE WL:	8.98	8.93	8.81	8.82	8.81	9.00	8.87	8.87	8.90	9.69	9.12	
-------------	------	------	------	------	------	------	------	------	------	------	------	--

Table 6. Gull Pond Well Data and Water Levels
Water Levels expressed in feet above mean sea level

Well Elevations:			68.21	17.39	10.79	10.79	10.76	10.79	9.29	9.3	9.32
------------------	--	--	-------	-------	-------	-------	-------	-------	------	-----	------

DATE	HIGGINS POND	GULL POND	HW-10	USGS 34	USGS 90	USGS 91	USGS 92	USGS 93	USGS 94	USGS 95	USGS 96
4-May-94	6.815	6.955		9.72	9.19	9.12	8.38	8.31	6.96	6.94	6.96
18-May-94	6.84	7.16	8.25	9.65	9.31	9.25	8.48	8.5	7.06	7.02	7.08
15-Jun-94	7.09	7.09	8.13	9.47	9.28	9.22	8.58	8.58	7.13	7.11	7.12
1-Jul-94	6.95	7.01		9.29	9.11	9.05	8.35	8.34	6.99	6.96	7.24
14-Jul-94	6.95	7.01	7.98	9.17	8.93	8.87	8.13	8.12	6.85	6.81	6.84
26-Jul-94	6.62	6.77	7.86	9.03	8.83	8.76	8.03	8.03	6.75	6.73	6.81
10-Aug-94	6.62	6.79	7.76	8.78	8.77	8.72	8.05	8.06	6.76	6.75	6.81
1-Sep-94	6.79	6.65	7.55	8.42	8.69	8.65	8.08	8.09	6.75	6.74	6.8
14-Sep-94	6.72	6.83	7.45	8.27	8.62	8.59	8.13	8.12	6.82	6.8	6.83
28-Sep-94	6.775	6.805	7.44	8.16	8.64	8.6	8.12	8.13	6.8	6.79	6.85
13-Oct-94			7.28	7.97	8.57	8.43	7.91	7.91	6.62	6.61	6.68
27-Oct-94	6.68	6.73	7.11	7.82	8.47	8.44	8	7.99	6.71	6.67	6.74
9-Nov-94	6.605	6.705	7.11	7.72	8.45	8.38	7.94	7.94	6.65	6.64	6.71
23-Nov-94	6.67	6.74	6.95	7.62	8.42	8.4	8.02	8.03	6.71	6.7	6.77
7-Dec-94	6.87	6.9	6.93	7.56	8.54	8.51	8.24	8.26	6.88	6.87	6.93
20-Dec-94	6.82	6.87	6.89	7.51	8.51	8.48	8.2	8.2	6.87	6.86	6.93
3-Jan-95	7.03	6.87	7	7.7	8.73	8.72	8.43	8.45	7.08	7.05	7.13
18-Jan-95	6.98	7.14	6.99	7.7	8.73	8.71	8.5	8.5	7.12	7.12	7.18
1-Feb-95	7.05	7.25	6.96	7.74	8.64	8.61	8.27	8.29	6.97	6.95	7.03
13-Feb-95	7	6.96	6.92	7.74	8.62	8.59	8.25	8.27	6.94	6.93	6.98
1-Mar-95	6.85	6.96	6.93	7.79	8.65	8.62	8.39	8.39	6.98	6.97	7.03
13-Mar-95	6.875	6.965	6.95	7.8	8.64	8.6	8.29	8.29	6.97	6.94	7
29-Mar-95	6.79	6.89	6.93	7.81	8.6	8.56	8.23	8.21	6.91	6.89	6.96
11-Apr-95	6.75	6.9	6.89	7.79	8.56	8.54	8.22	8.22	6.89	6.88	6.94
27-Apr-95	6.75	6.89	6.9	7.8	8.56	8.52	8.18	8.18	6.88	6.86	6.93
AVERAGE WL:	6.84	6.91	7.32	8.30	8.74	8.70	8.22	8.22	6.88	6.86	6.93

Table 6. Gull Pond Well Data and Water Levels
 Water Levels expressed in feet above mean sea level

Well Elevations:	9.06	7.86	8.35	8.32	25.23	18.89	29.34	73.11	39.84	57.75
-------------------------	------	------	------	------	-------	-------	-------	-------	-------	-------

DATE	USGS 97	USGS 98	USGS 99	USGS 100	USGS 103	USGS 104	USGS 105	USGS 107	USGS 108	USGS 110
4-May-94	6.92	6.98	6.88	6.9	9.33	8.36	7.02	8.83	9.2	6.96
18-May-94	7.05	7.08	7.04	7.06	9.47	8.51	7.13	8.9	9.07	7.07
15-Jun-94	7.1	7.12	7.06	7.1	9.27	8.3	7.12	8.77	8.97	6.94
1-Jul-94		6.99	6.95	6.97	9.2	8.14	7.03	8.7	8.72	6.88
14-Jul-94	6.83	6.82	6.76	6.77	9.07	8.24	6.83	8.59	8.58	6.72
26-Jul-94	6.75	6.75	6.67	6.66	8.94	7.85	6.73	8.5	8.46	6.73
10-Aug-94	6.78	6.73	6.67	6.72	8.8	7.67	6.73	8.39	8.25	6.67
1-Sep-94	6.75	6.79	6.69	6.73	8.47	7.39	6.72	8.22	7.91	6.56
14-Sep-94	6.84	6.82	6.76	6.79	8.4	7.36	6.75	8.11	7.75	6.56
28-Sep-94	6.8	6.76	6.81	6.84	8.32	7.3	6.83	8.02	7.59	6.59
13-Oct-94	6.62	6.65	6.61	6.63	8.08	7.1	6.63	7.87	7.44	6.43
27-Oct-94	6.68	6.72	6.68	6.71	7.63	7.05	6.68	7.79	7.33	6.45
9-Nov-94	6.65	6.67	6.62	6.65	7.96	6.99	6.64	7.68	7.23	6.43
23-Nov-94	6.71	6.74	6.68	6.7	7.8	6.91	6.7	7.62	7.13	6.46
7-Dec-94	6.88	6.92	6.87	6.89	7.83	6.92	6.86	7.59	7.04	6.58
20-Dec-94	6.88	6.92	6.86	6.89	7.81	6.85	6.86	7.55	6.96	6.61
3-Jan-95	7.08	7.11	7.07	7.08	8.15	7.05	7.13	7.6	7.06	6.83
18-Jan-95	7.15	7.11	7.02	7.06	8	6.97	7.07	7.6	7.19	6.85
1-Feb-95	6.98	6.99	6.93	6.97	7.98	7.05	6.99	7.57	7.26	6.76
13-Feb-95	6.96	6.97	6.92	6.93	7.96	6.98	6.95	7.54	7.31	6.73
1-Mar-95	6.99	7	6.93	6.96	7.91	6.97	6.96	7.55	7.35	6.73
13-Mar-95	6.97	6.98	6.93	6.96	7.87	6.99	6.98	7.57	7.36	6.76
29-Mar-95	6.92	6.92	6.85	6.89	7.95	7.02	6.92	7.55	7.39	6.7
11-Apr-95	6.9	6.89	6.82	6.84	7.83	6.91	6.86	7.53	7.4	6.66
27-Apr-95	6.89	6.89	6.82	6.85	7.94	6.94	6.86	7.54	7.34	6.67
AVERAGE WL:	6.87	6.89	6.84	6.86	8.38	7.41	6.88	8.03	7.78	6.70

Ground Water Flow Systems

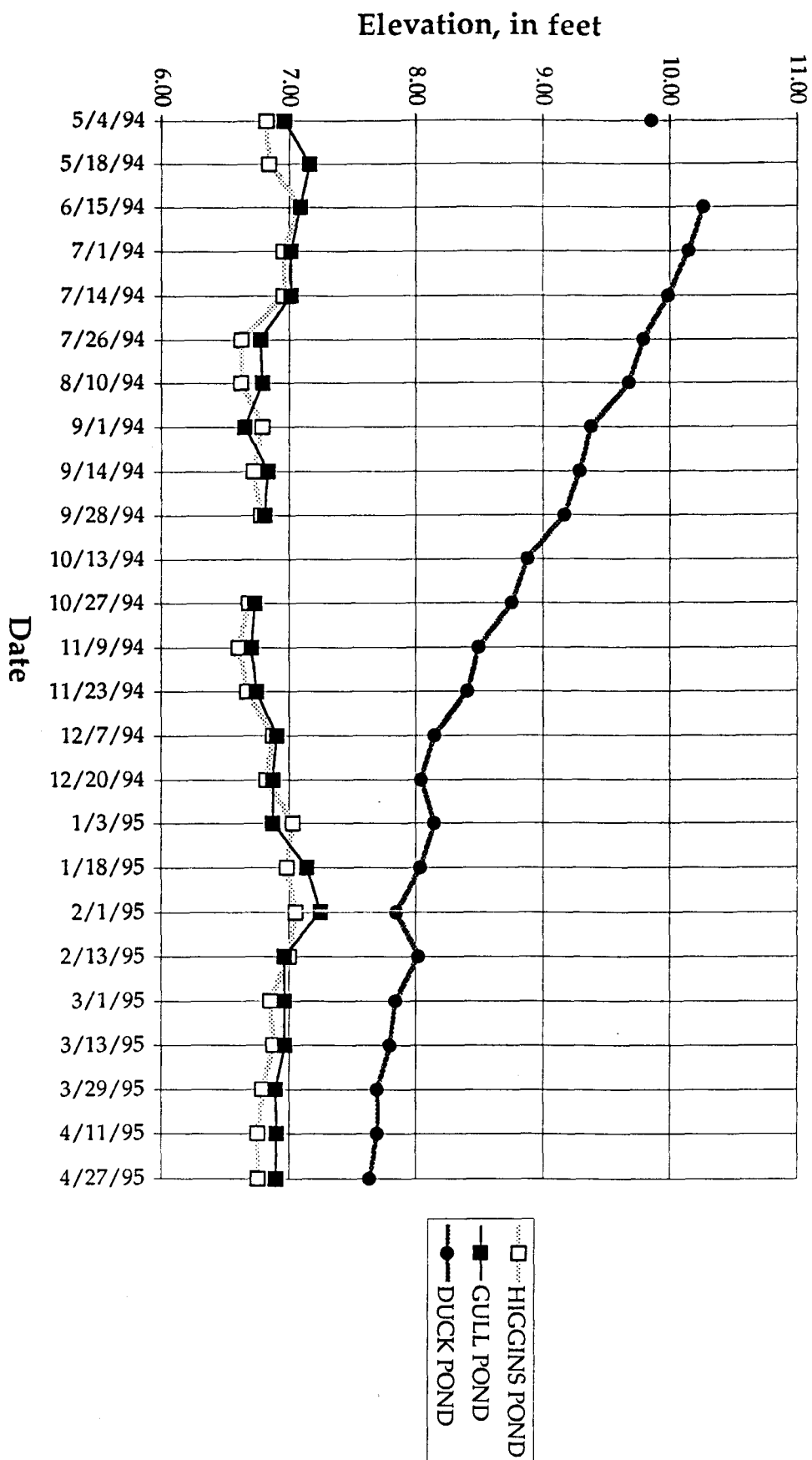
Gull and Duck Ponds are hydrologically different. Water level data collected over the course of the study period, May 1994 to April 1995, showed that the water level in Duck Pond declined about 2.8 feet, while the water level in Gull Pond remained about the same (Figure 10). This difference is caused by the presence of a surface outlet at Gull Pond and the land locked conditions (no outlet) at Duck Pond. The surface outlet from Gull to Higgins Pond and the Herring River act as an relief valve which limits the build up of water storage in Gull Pond. Duck Pond, however, interacts only with the atmosphere and ground water, and its level reflects significant changes in water storage. The changes in the level of Duck Pond are generally coincident with changes in levels in ground water in the surrounding aquifer (Table 5). For this reason, Duck Pond might be described as a ground water pond. While ground water levels about Gull Pond acted similarly to ground water levels about Duck Pond, only Duck Pond levels reflected the changes in ground water level. Each pond's ground water flow system is discussed in greater detail below.

Duck Pond Ground Water Flow System

Average water level data collected during the study period for Duck Pond wells suggest inflow occurs from every direction (Figure 11). Water levels also showed an overall decline over the May 1994 to April 1995 period. Only twice, January 4 and February 13 1995, did the biweekly measurements show a water-level increase. All the rest of the measurements for Duck Pond showed declines (Figure 10). Prior to June 1994, a few scattered measurements show a general rise of water levels. Shallow ground water levels about the pond were consistently higher than the pond level throughout the period, demonstrating that shallow ground water always flowed into the pond (Figures 12 through 16). Water levels at greater depth in the aquifer system, about 30, 50 and 70 feet below pond level, varied from place to place. While deep wells southeast and southwest of the pond consistently showed ground water gradients and, therefore, flow toward the pond (Figures 13 and 14), the 30-foot deep well at the north shore of the pond showed gradients from the pond into the ground (Figure 16).

At the north side of Duck Pond, a barrier beach has blocked off a bay of the original pond, and that bay has filled with sediment, forming a wetland with a thin soil of low permeability. Water entering this wetland becomes perched above the soil and trapped behind the dam of the barrier beach. The water then slowly seeps through the sandy beach into Duck Pond and downward through the mucky soil into the ground water flow system, or is evaporated and transpired into the atmosphere. Along a north-south section (Figure 16) this wetland forms a high point, or divide, in the shallow ground water system between flow to the south into Duck Pond and to the north away from Duck Pond. Observation wells HW-3s, HW-3m, and HW-3d, located in this wetland,

... so the wetland is perched ?



Pond Levels

Figure 10

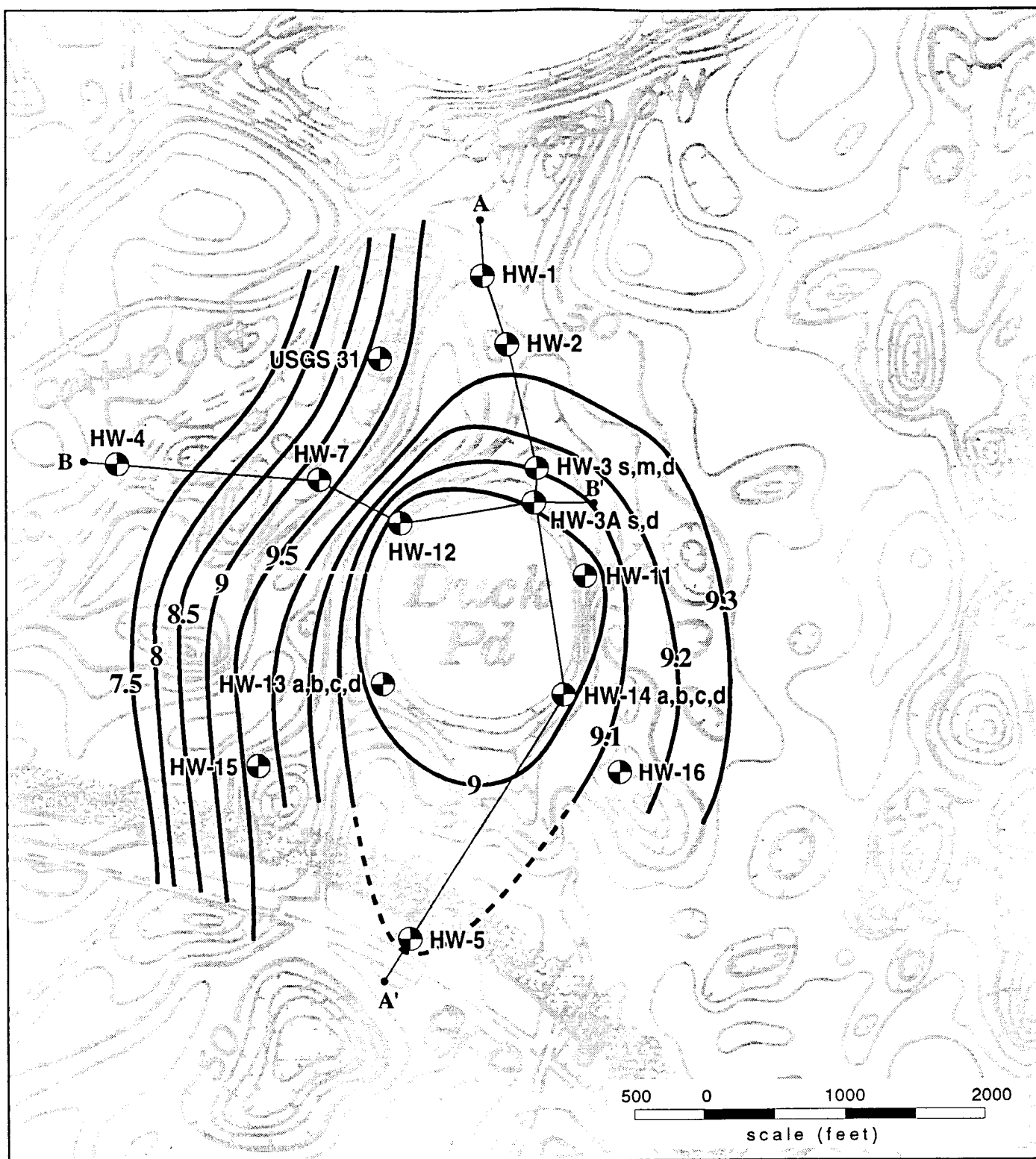
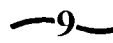
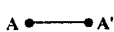
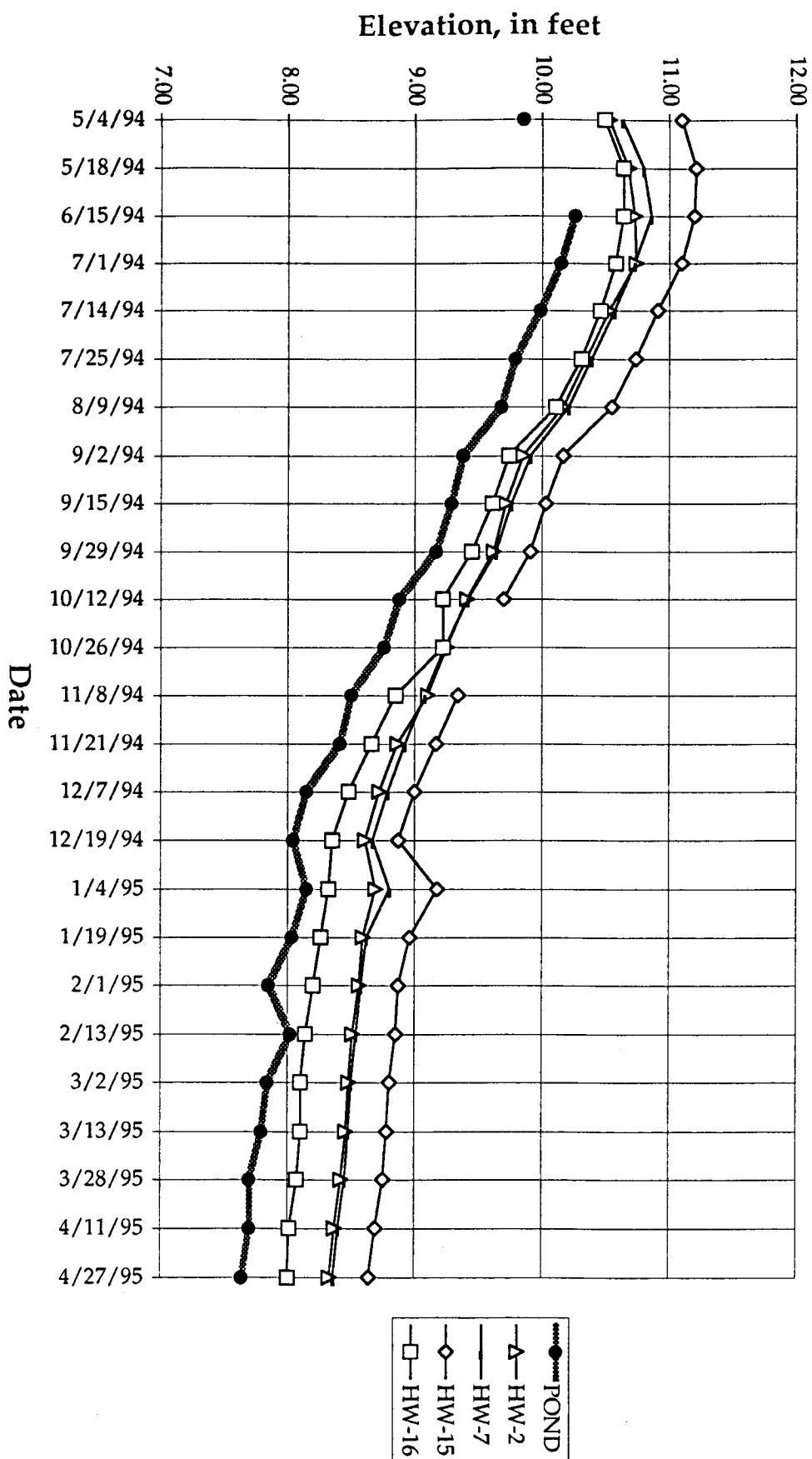


FIGURE 11.
Site Plan showing Water Table
Duck Pond, Wellfleet

-  Water Table Contour
-  HW-5 Monitoring Well Location
-  Trace of Cross Section

Source: USGS Quadrangle (Wellfleet, 1972)

Last Revision Date: 13 June 1996
Horsley & Witten, Inc.



Shallow Ground-Water Levels about Duck Pond

Figure 12

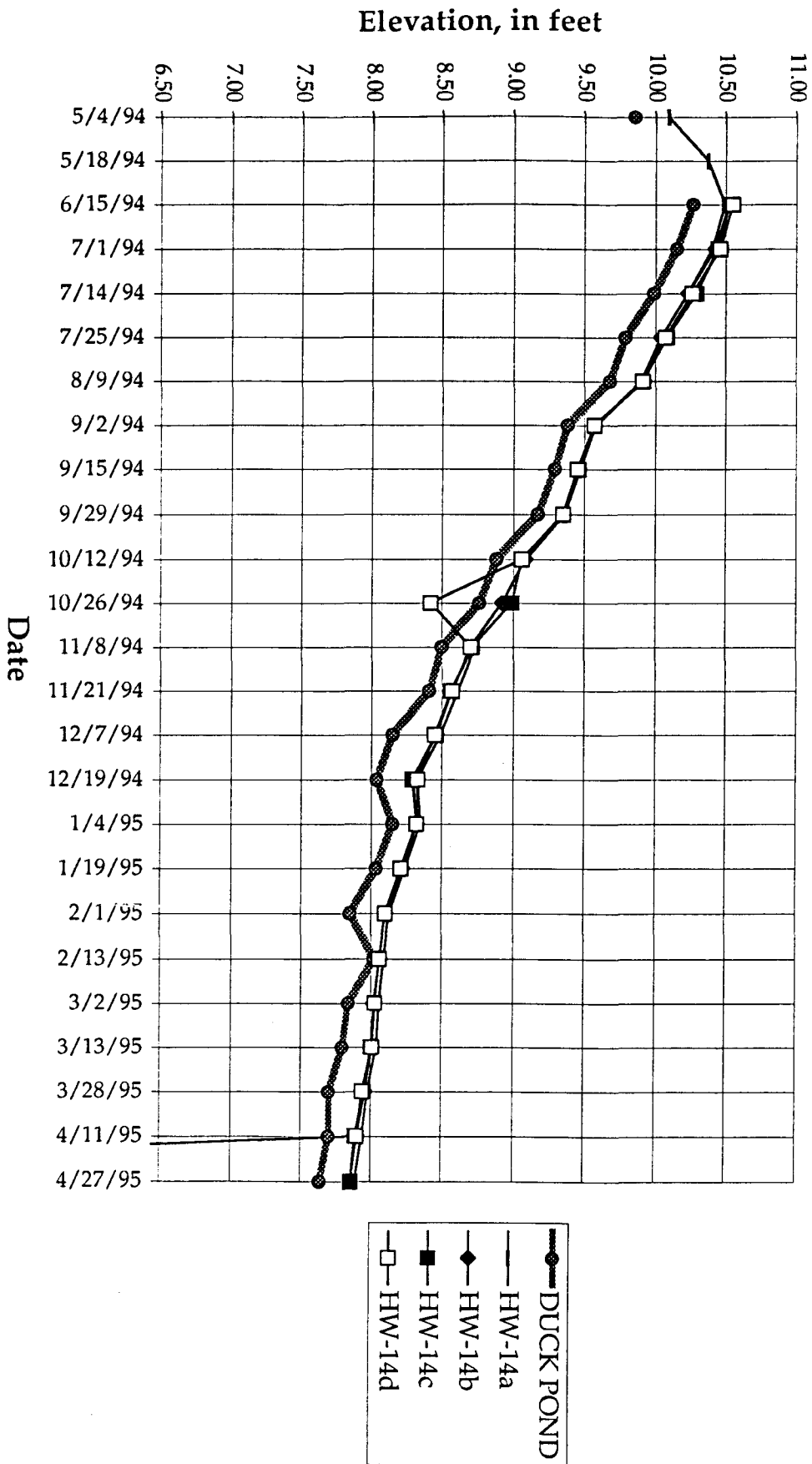
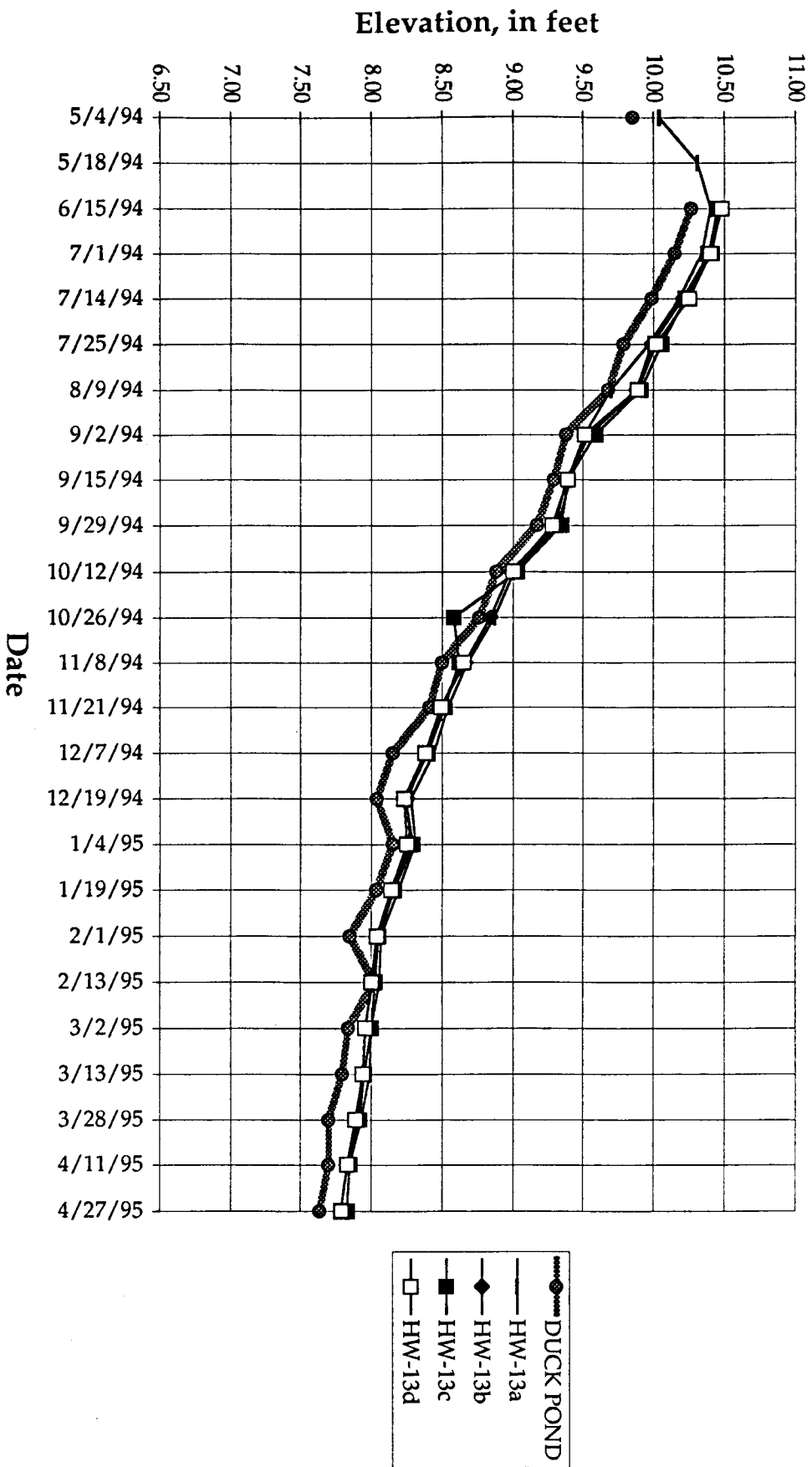


Figure 13

Vertical Gradients at SE Shore of Duck Pond



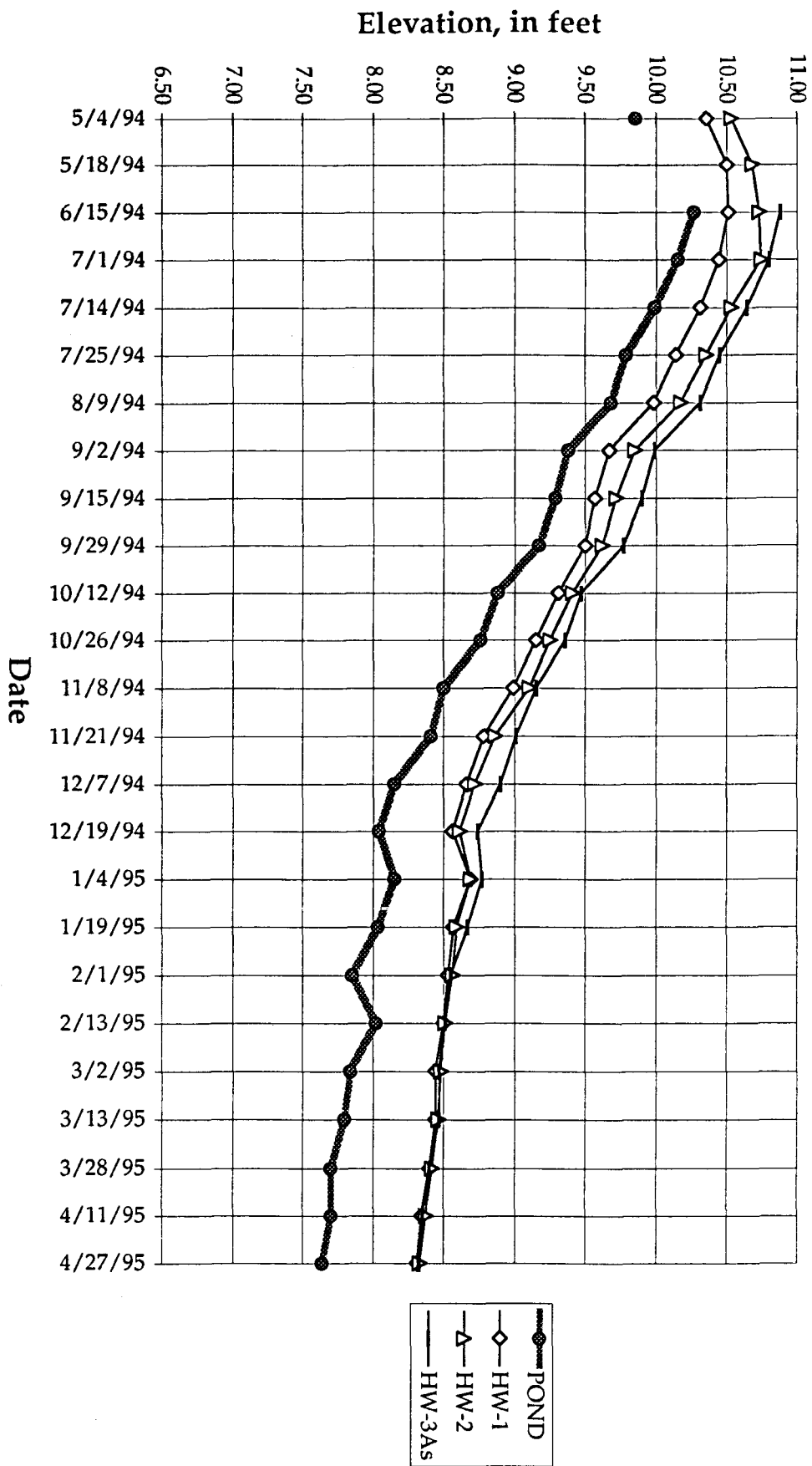


Figure 15

Ground-Water Elevations North of Duck Pond

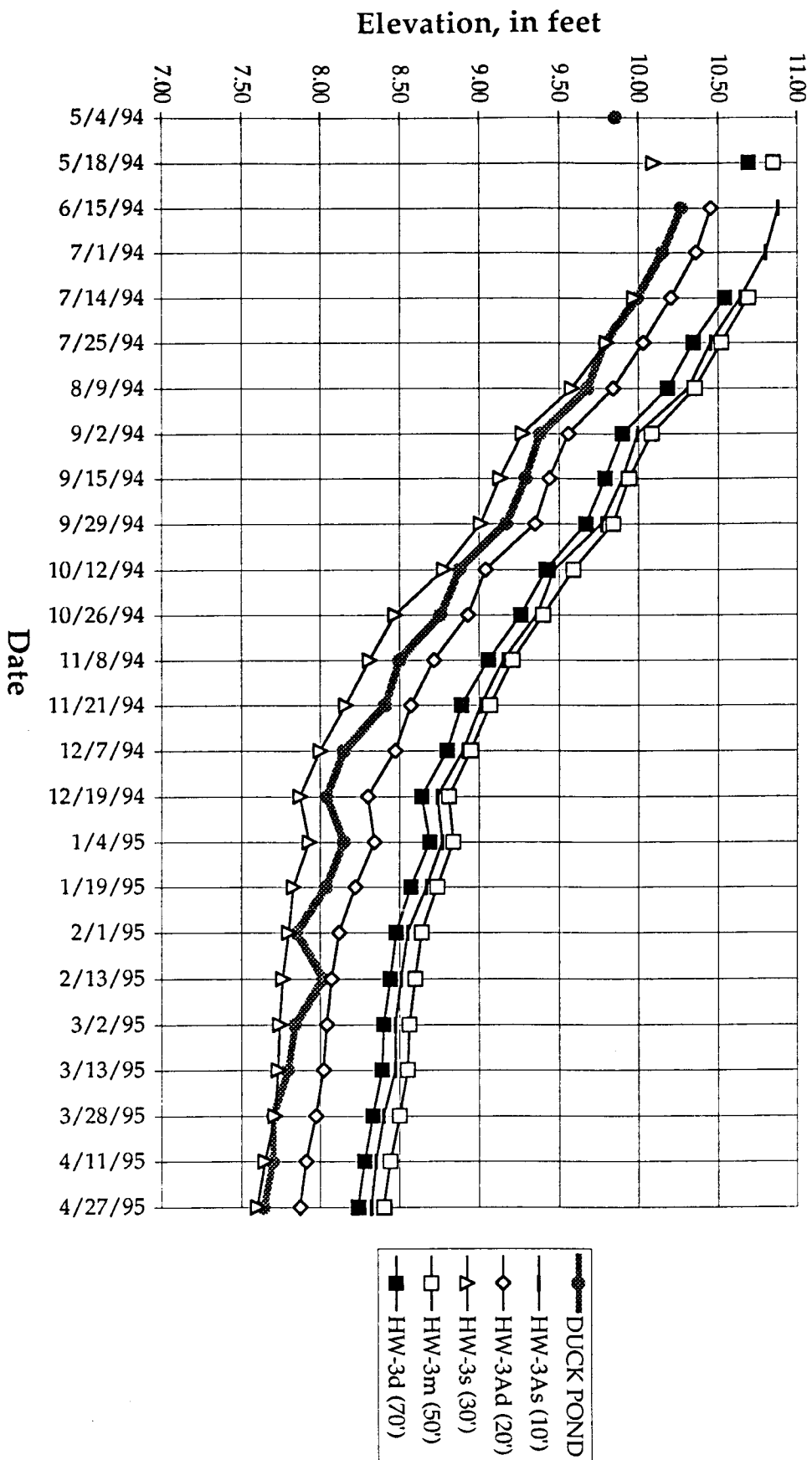


Figure 16

Vertical Gradients at North Shore of Duck Pond

had been finished in lock boxes flush with land surface in order to preserve wilderness-like visual character of the site. Water levels in this wetland were so high in the spring, soon after construction of the wells, that surface water submerged the tops of the well casings. In order to prevent surface water from flowing into the wells when the plugs were removed to make water-level measurements, extension pipes had to be added to the top of the casings. Indeed, initial installation of shore line monitoring wells at Duck Pond had to be postponed because the beaches of Duck Pond were drowned by pond water. The changing water level conditions, seen in the first year, will be useful later in the project for calibrating models to transient conditions. Vertical gradients at both the southeast and southwest shores of the pond are very small, suggesting either very little vertical flow or very little resistance to vertical flow or both. At the north end of Duck Pond the ground water flow system is complex. Shallow ground water gradients from the 10- and 20-foot levels are toward the pond, but at the 30-foot depth the gradient is generally from the pond toward the aquifer. Additionally, the gradients are upward from the 50-foot level into the 30-foot level while there is a slight downward gradient from the 50-foot level to the 70-foot level. These complex gradients on the north end of the pond assume that the resurveying that was done for well cluster HW-13 is correct, and independent, confirmatory surveying of this and all other clusters is recommended (see Recommendations Section). These gradients are maintained for high ground water levels as well as low ground water levels. The gradients converging on the 30-foot level from above and below are pronounced (nearly 1 foot per 20 feet of vertical separation). Because there are no confining layers indicated in the lithologic logs of these wells, these strong gradients are interpreted as indicative of a significant volume of ground water flow, rather than significant resistance to flow. Profile maps constructed from boring logs and water level data depict the ground water gradients for Duck Pond (Figures 17 through 20). These gradients are interpreted to indicate that the aquifer at about 30 feet deep in this location is highly permeable and acting as an underground drain carrying ground water away from the vicinity of Duck Pond. It was initially assumed that low permeability pond bottom sediments at depths of 30 feet in the pond would probably act as a seal preventing direct hydraulic connection, thereby making it unlikely that a large volume of water flows directly from Duck Pond into this drain. However, the NPS recently reported that highly permeable sands in Duck Pond extend to a depth of 43 feet where the pond bottom sediments change to less permeable organic mud (J. Portnoy, Pers. Comm, 1996). The permeable nature of the bottom sediments below the 30-foot depth thus enables outflow to occur in this region of the pond.

resurvey
needed

The northward drainage is interpreted as being a consequence of the variation of permeability in the glacial sediments in the vicinity of this north-south trending line of kettle hole ponds in Wellfleet and Truro. During glacial melting, it is highly likely that abundant runoff between the kettle hole low points would have deposited coarse grained and highly permeable stream bottom sediments along the stream courses connecting the ponds. Now, these underground river

(How does permeable
channel flow to the pond?)

deposits may form shallow but highly conductive drainage channels for ground water discharge. Water levels in HW-4s and HW-4d located about 1,000 feet west of Duck pond also exhibit anomalously low water levels also suggesting potential drainage to the west (Table 5). The presence of such highly permeable channels affecting the underground drainage about these ponds was not anticipated and if determination of the directions of flow away from the pond is needed, then, additional exploration to locate the permeable channel(s) would be needed. The presence of highly permeable zones near these ponds is also suggested by the observation that many of the public supply wells elsewhere on Cape Cod have been located in valleys and near kettle hole ponds partly because the aquifer is more permeable in those locations.

Duck Pond Conceptual Water Budget and Storage Change

The water budget for Duck Pond is rather simple because there are no surface water outlets. Inflow is from precipitation directly on the pond surface and ground water recharge. Outflow is from evaporation and ground water discharge and the pond level changes in response to changes in pond storage. The hydrologic budget for Duck Pond may be described as:

$$(PPT_i + GW_i) - (EVAP + GW_o) = +/- \Delta Store$$

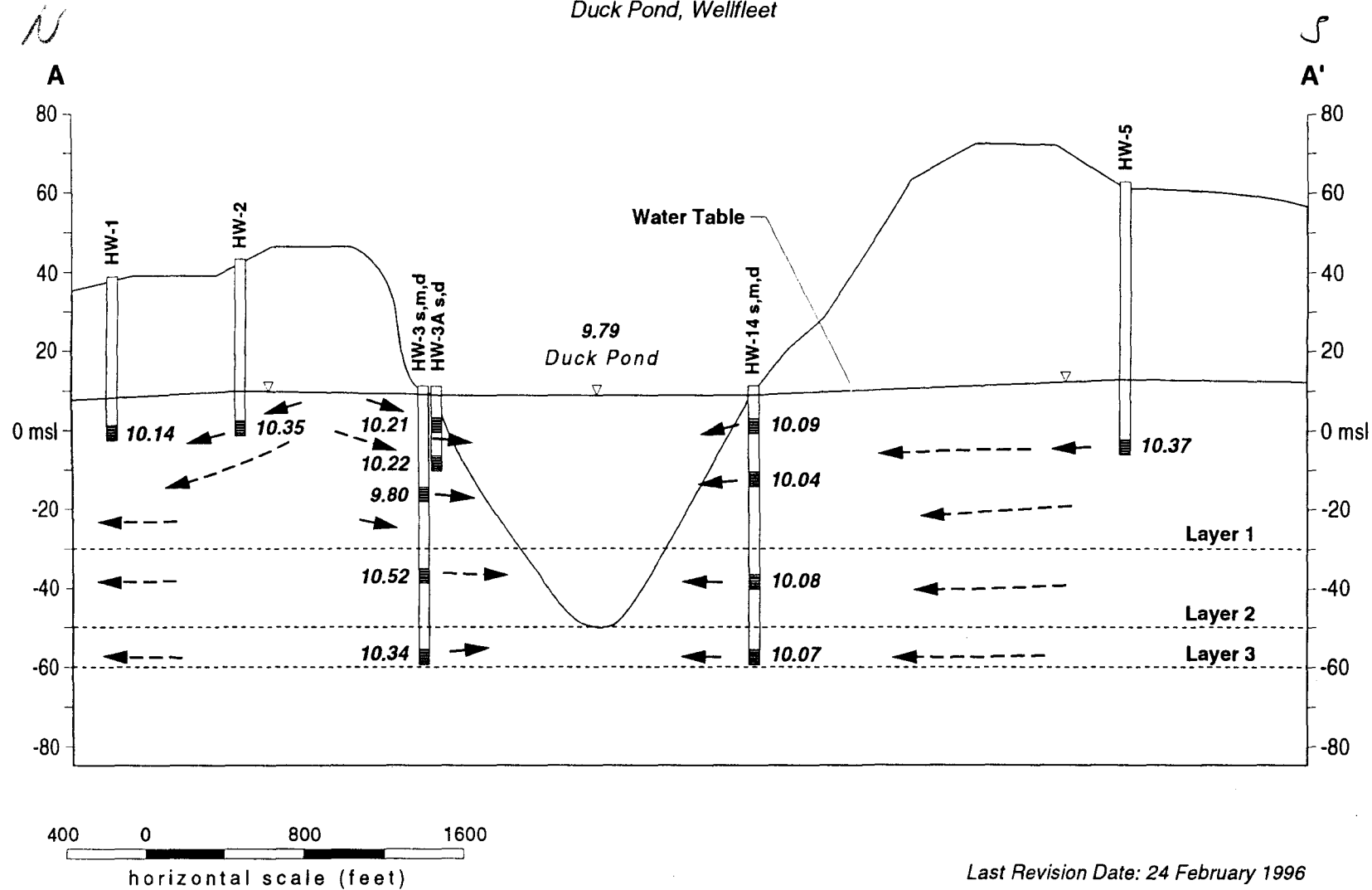
where: PPT_i = Precipitation inflow
 GW_i = Ground-Water inflow
 $EVAP$ = Evaporation from pond surface
 GW_o = Ground-Water outflow
 $\Delta Store$ = Change in Pond Storage

Computation of change in pond storage for comparison with measured changes in pond storage provide a check on the balance. As noted in the previous section on ground water flow system, there was very little ground water outflow from Duck Pond in the first year of monitoring due to the water table being at higher elevations than the pond.

Storage change was determined by multiplying the average surface area of the pond by the drop in pond stage that occurred over the course of the study period. The periphery of Duck Pond was digitized from the USGS 1:25000 Wellfleet Quadrangle map. The surface area of the resulting polygon was determined to be 450,910 ft². The approximate 2.8 foot drop in pond stage over the course of the study period equates to a loss of approximately 1,263,000 ft³ of water released from storage. This computation assumes that the pond surface area remains constant during this stage change. In fact, the periphery of the pond waxes and wanes with changes in stage.

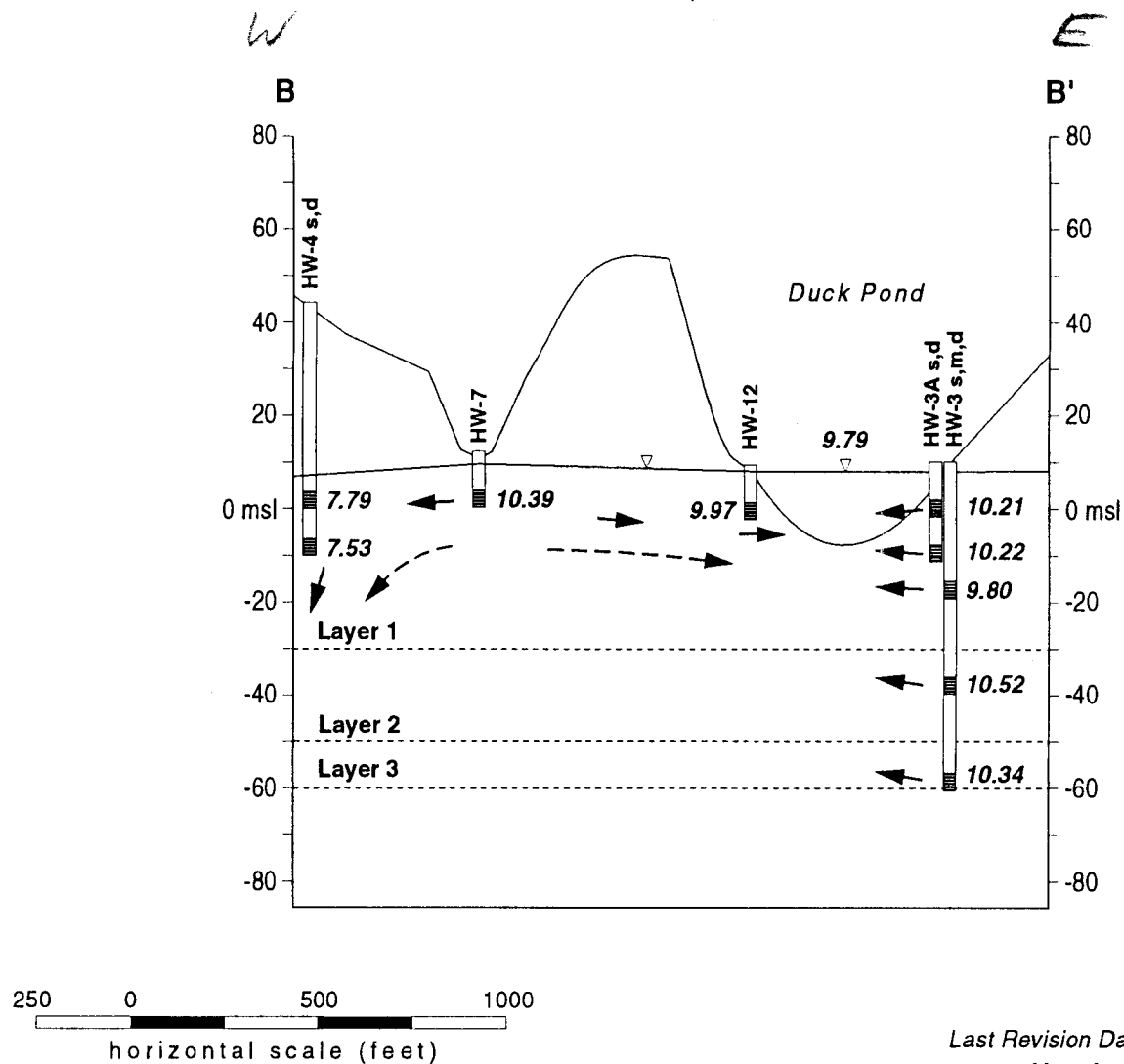
FIGURE 17.
Duck Pond Ground Water Conditions (7-25-94) - Cross Section A-A'

Duck Pond, Wellfleet



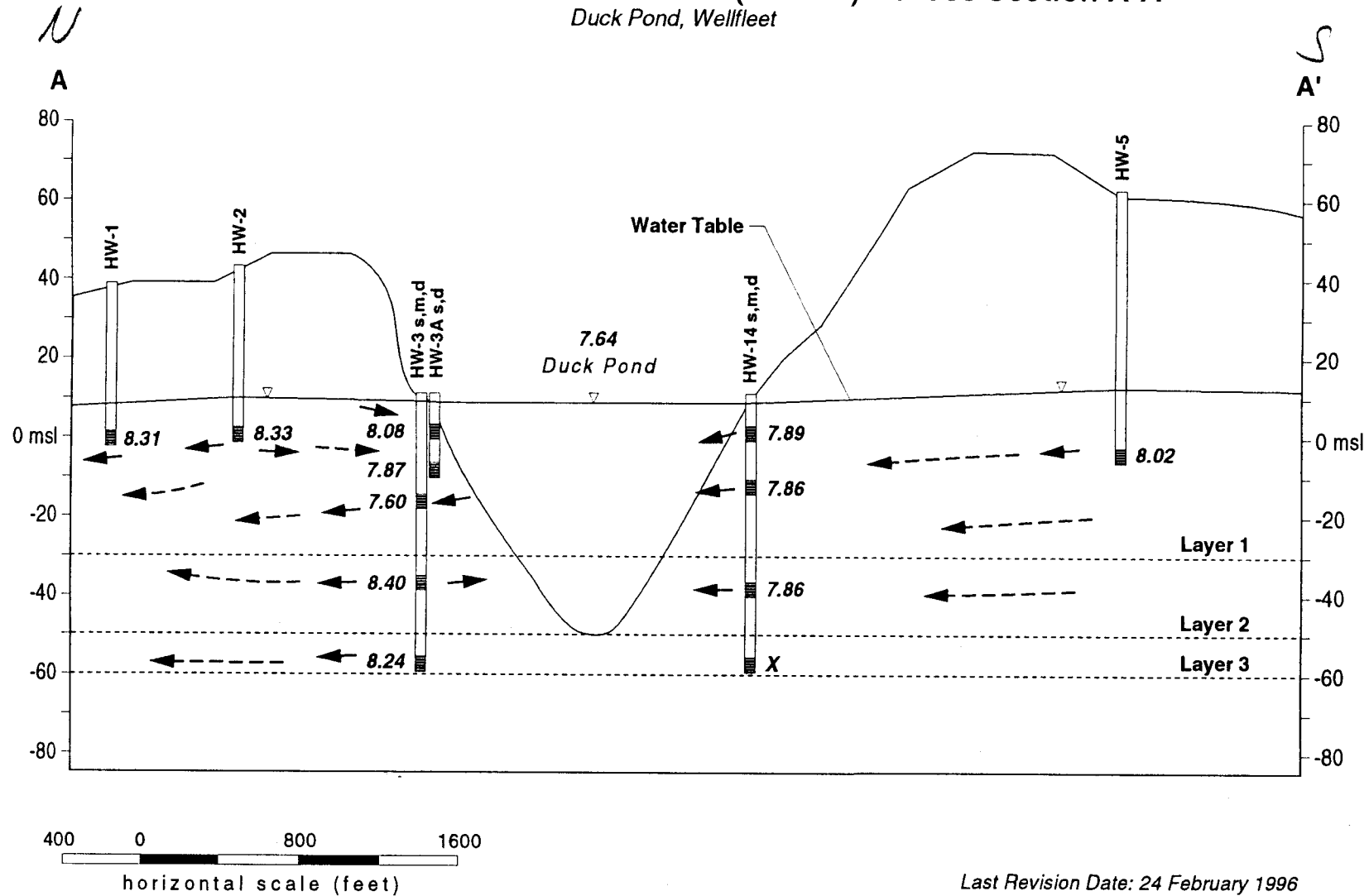
Last Revision Date: 24 February 1996
Horsley & Witten, Inc.

FIGURE 18.
Duck Pond Ground Water Conditions (7-25-94) - Cross Section B-B'
Duck Pond, Wellfleet



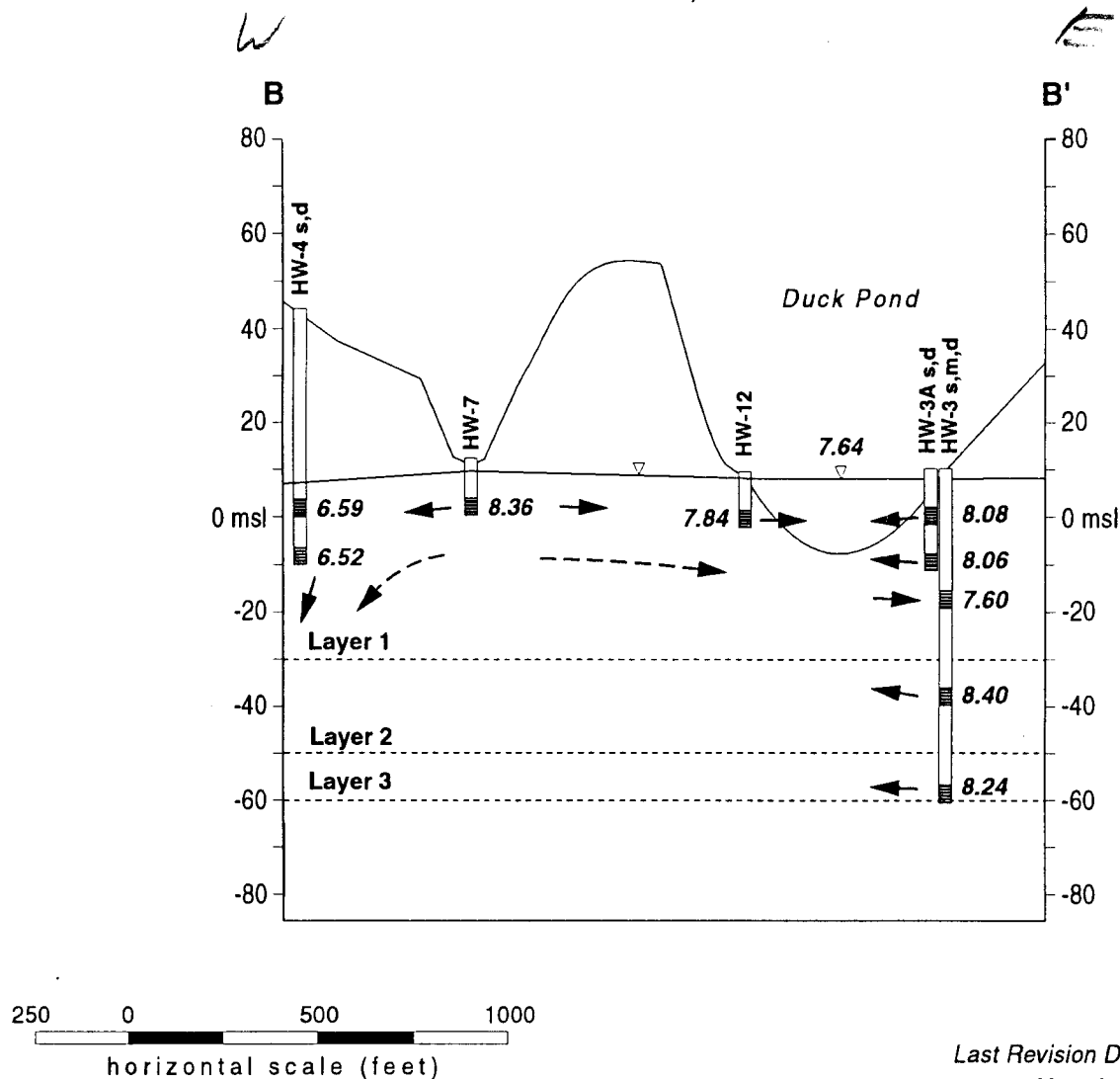
Last Revision Date: 14 June 1996
Horsley & Witten, Inc.

FIGURE 19.
Duck Pond Ground Water Conditions (4-27-95) - Cross Section A-A'
Duck Pond, Wellfleet



Last Revision Date: 24 February 1996
Horsley & Witten, Inc.

FIGURE 20.
Duck Pond Ground Water Conditions (4-27-95) - Cross Section B-B'
Duck Pond, Wellfleet



A small ephemeral inlet from the wetland north of the pond is quantitatively included with ground water inflow for this study. A very small amount of overland flow may enter the pond from the pond shore during very wet conditions and heavy precipitation, but virtually all precipitation falling on the sandy permeable land surface is either evapotranspired or conducted into the ground as ground water recharge.

Duck Pond Ground Water Seepage and Mini-Piezometer Tests

Water exchange through the peripheral lacustrine sediments of Duck Pond and the underling aquifer was evaluated through the use of seepage meters and mini-piezometers. H&W constructed five seepage meters for this monitoring. Monthly ground water seepage measurements were taken from August 1994 - April 1995 in the vicinity of the HW-13 well cluster (Table 7). Seepage meters were placed where seepage is most likely - every five feet along a twenty-five foot transect on near-shore lake bottom sediments extending perpendicular from the lake shore into the pond. The difference between pond level and the hydraulic head of underlying aquifer (measured in the mini-piezometer) represents the hydraulic gradient at the pond periphery. These data were intended to be used to evaluate whether the pond gained or lost water at the time of each test. Seepage inflow rates were compared to measured head differentials at the time of the measurements for linear regression analysis. Only inflow was observed with this monitoring, which is consistent with observed gradients (Table 5). As pond levels dropped during the study periods, the two seepage meters nearest the pond shore were completely exposed to air. Thus, these locations contain an incomplete record of water seepage. Average annual inflow from the three seepage meters which remained submerged were 4.3, 4.9, and 23.7 cubic feet. The objective of these experiments was to attempt to construct a relationship between observed gradient and seepage rates (similar to the discharge rating curve for the Gull Pond stream). The rating curve (Figure 21) shows poor correlation ($R^2=.08$). Therefore, it cannot be considered suitable as a indicator of seepage rates at those locations.

- Size (area)
of seepage
channel?
- Direction of
seepage?

Duck Pond Short Term Aquifer Response Experiments

As an experiment, data loggers and pressure transducers were used to monitor rapid water-level responses in wells tapping different depths in the aquifer at a pond. Water levels were recorded every 30 minutes in wells HW-3s at 30 feet deep, HW-3m at 50 feet deep, and HW-3d at 70 feet deep adjacent to Duck Pond from about noon on June 14, 1994 to about 9 AM on July 5, 1994. Two rapid rises in water level were recorded in all three wells at about 12 noon on June 27, 1994 and about 6 PM on June 28, 1994 (Figure 22). These responses are interpreted as response to precipitation from intense rain storms of short duration which occurred on these dates (Table 1). Comparison with the precipitation records for the rain gages at Duck and Gull ponds (Table 1) were not completely satisfactory.

Table 7. Seepage Measurements at Duck Pond
Seepage expressed in cubic feet per day

DATE	DP-5		DP-10		DP-15		DP-20		DP-25	
	Stage (ft)	Seepage (cfd)	Stage (ft)	Seepage (cfd)	Stage (ft)	Seepage (cfd)	Stage (ft)	Seepage (cfd)	Stage (ft)	Seepage (cfd)
18-Aug-94	0.05	0.004	0.04	0.003	0.05	0.004	0.06	0.004	0.05	0.003
20-Sep-94	0.04	0.008	0.05	0.014	0.045	0.015	0.04	0.015	0.035	0.172
16-Oct-94	0.03	0.027	0	0.032	0.05	0.031	0.08	0.034	0.07	0.152
27-Nov-94	x	x	0.01	0.016	0	0.006	0.03	0.009	0.11	0.061
11-Dec-94	x	x	0	0.006	0	0.002	0.01	0.006	0	0.023
11-Feb-95	x	x	frozen	0.000	frozen	0.006	frozen	0.000	frozen	0.061
25-Mar-95	x	x	0.01	0.029	0	0.032	0	0.025	0.01	0.050
16-Apr-95	x	x	x	x	0.02	0.005	0	0.006	0	0.034
7-May-95	x	x	x	x	0.01	0.004	0	0.022	0	0.029

x = no data recorded due to exposure of seepage meter to air

Figure 21

Regression Rating Curve showing relationship of Head Differential and Ground
Water Flux in the vicinity of Well Cluster HW-13

$R^2 = 0.08$

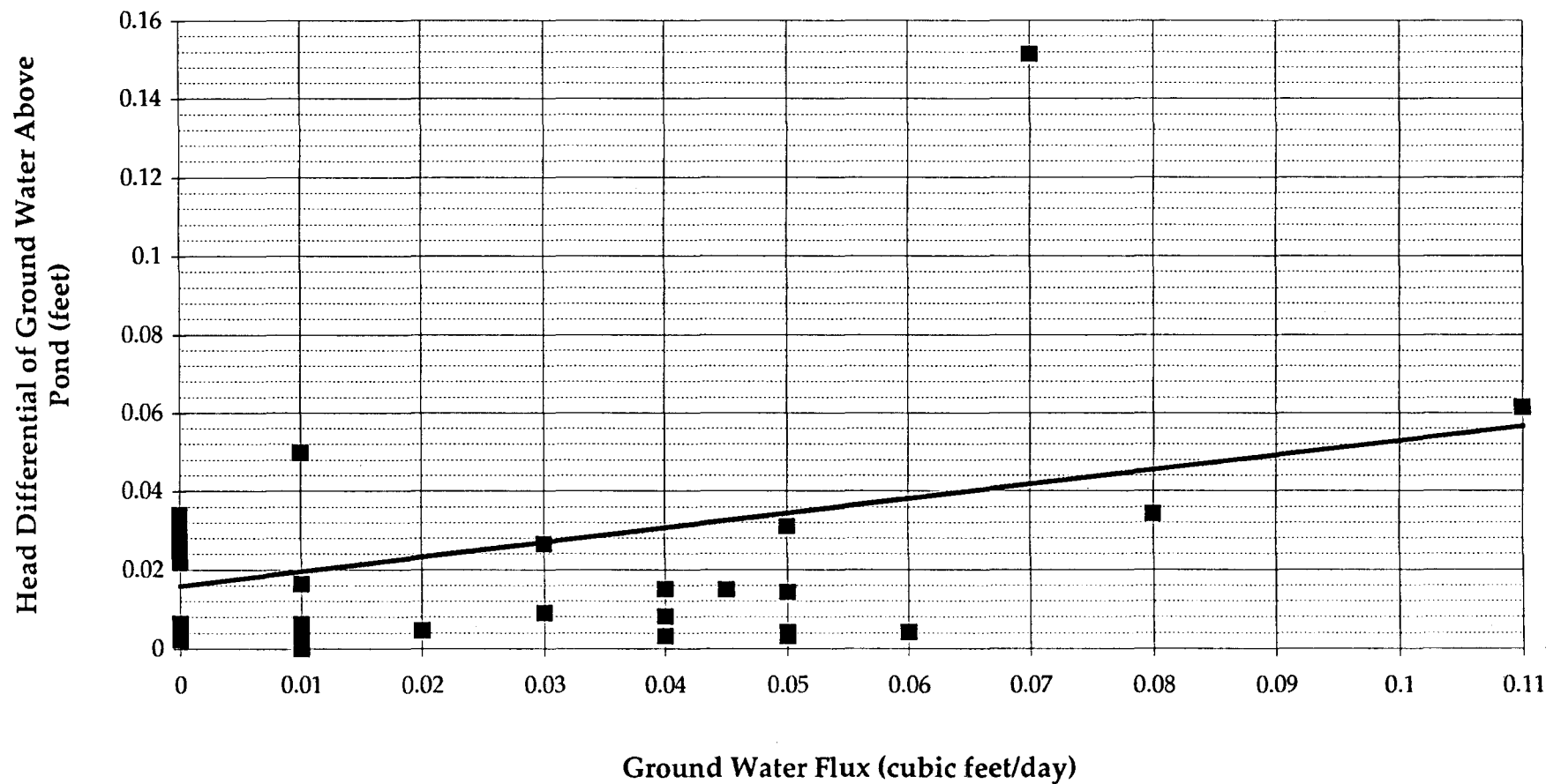
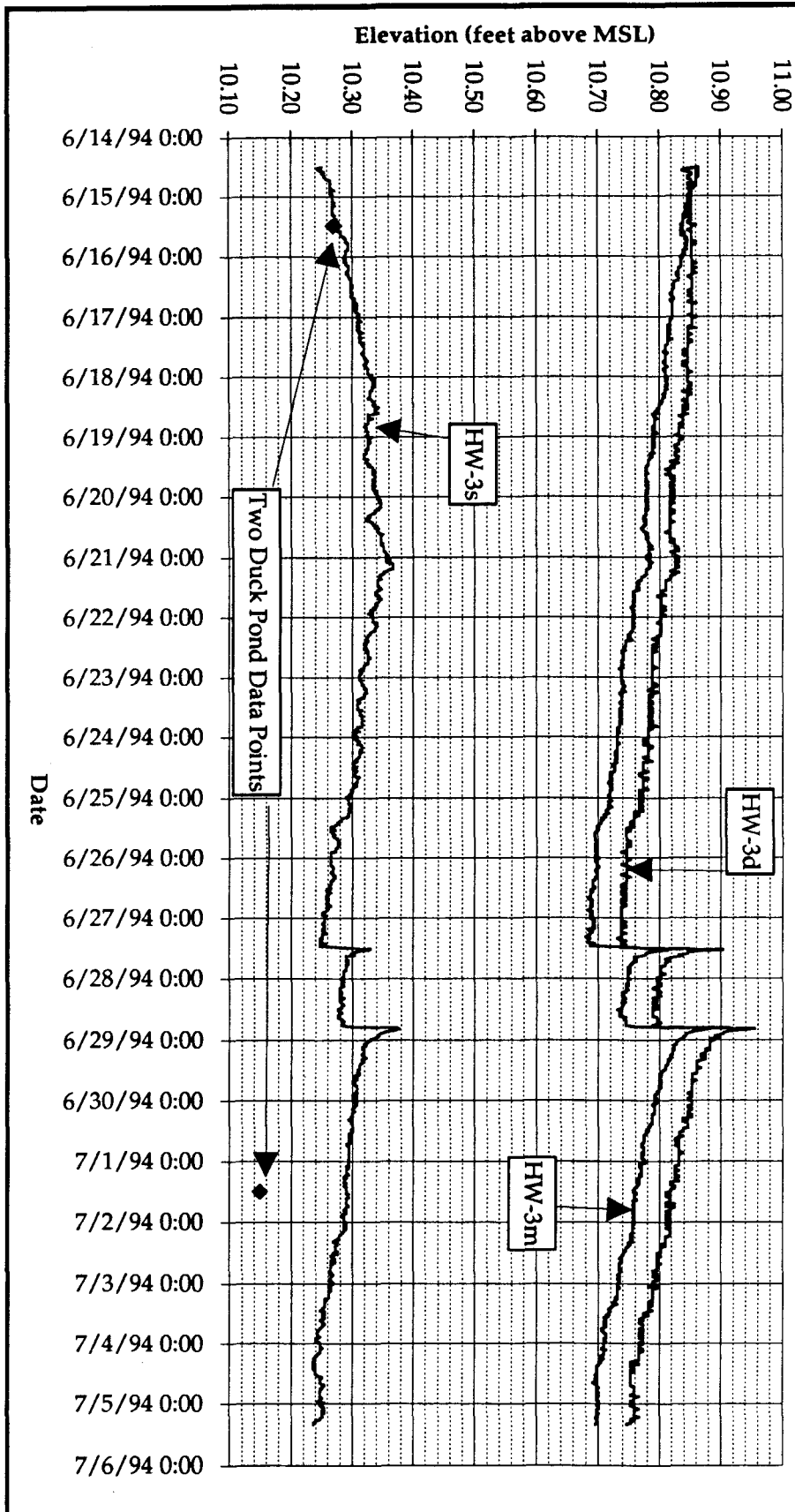


Figure 22
Water Level Fluctuations in Observation Wells HW-3s, HW-3m, and HW-3d from 14 June to 6 July 1994



The precipitation record for Duck Pond showed no precipitation on June 27 or 28, but 0.89 inches on June 29 and 1.1 inches on June 30. The precipitation record for Gull Pond showed no precipitation on June 27, but 0.95 inches on June 28 and 1.05 inches on June 29th and no precipitation on June 30th. Although there seems to be some discrepancy in the dates, there were two separate storms yielding slightly less and then slightly more than 1 inch on successive days. Even though the dates are incorrect, the volumes seem rather consistent and useful for water budgeting purposes.

Most important is the observation that water levels deep in the aquifer at the 50- and 70-foot depths responded rapidly to the precipitation. The response is that of an artesian or confined system in which the pressure of the accumulation of overlying water is almost instantly transmitted to the lower layers. Secondly, the magnitude of initial response in the deeper wells at 50 and 70 feet is nearly twice that in the well at 30 feet deep. This response is somewhat like the response of a hydraulic brake system where an application of pressure to a brake pedal is instantly transmitted to brake pads pressing on a brake disk. Since the deeper response is greater than the shallow response, the deep response can not be entirely due to the immediately overlying increase of water weight. This greater response is attributed to water level increase in Duck Pond rather than recharge to the immediately overlying aquifer. Furthermore, the die-off of the initial pressure over a few hours after the initial spikes (Figure 22) indicates that the pressure system is leaky.

Gull Pond Ground-Water Flow System

Ground water gradients about Gull Pond are toward the pond from the west, south and east, and are away from the pond to the north (Figures 23 and 24). Wells USGS-105 and USGS-110 to the north of Gull Pond have lower levels than the pond indicating ground water flow from the pond toward the north. All of the other wells (excluding well clusters discussed separately) about the pond have water levels higher than the pond, indicating ground water flow toward the pond. Figures 25 through 28 depict this flow-through dynamic. However, well HW-10, located to the south of the pond, shows water levels higher than pond levels during high water-level conditions and water levels equal to the pond level during low water-level conditions, suggesting that under some conditions there may be very little water exchange between the pond and the ground at the south side of the pond. There are two measurements which show a reversal of gradient at well HW-10, which may indicate brief periods of outflow. Additional future water-level data under different conditions are expected to provide greater insight into the flow directions at the south side of the pond. From a more regional perspective, the gradient from the area north of Long Pond is toward HW-10 and if there is a flat gradient between Gull Pond and HW-10, ground water discharge will have to go east or, more likely, west from somewhere between Gull, Great, Long, and Duck Ponds. There is not yet evidence to confirm or to refute this supposition.

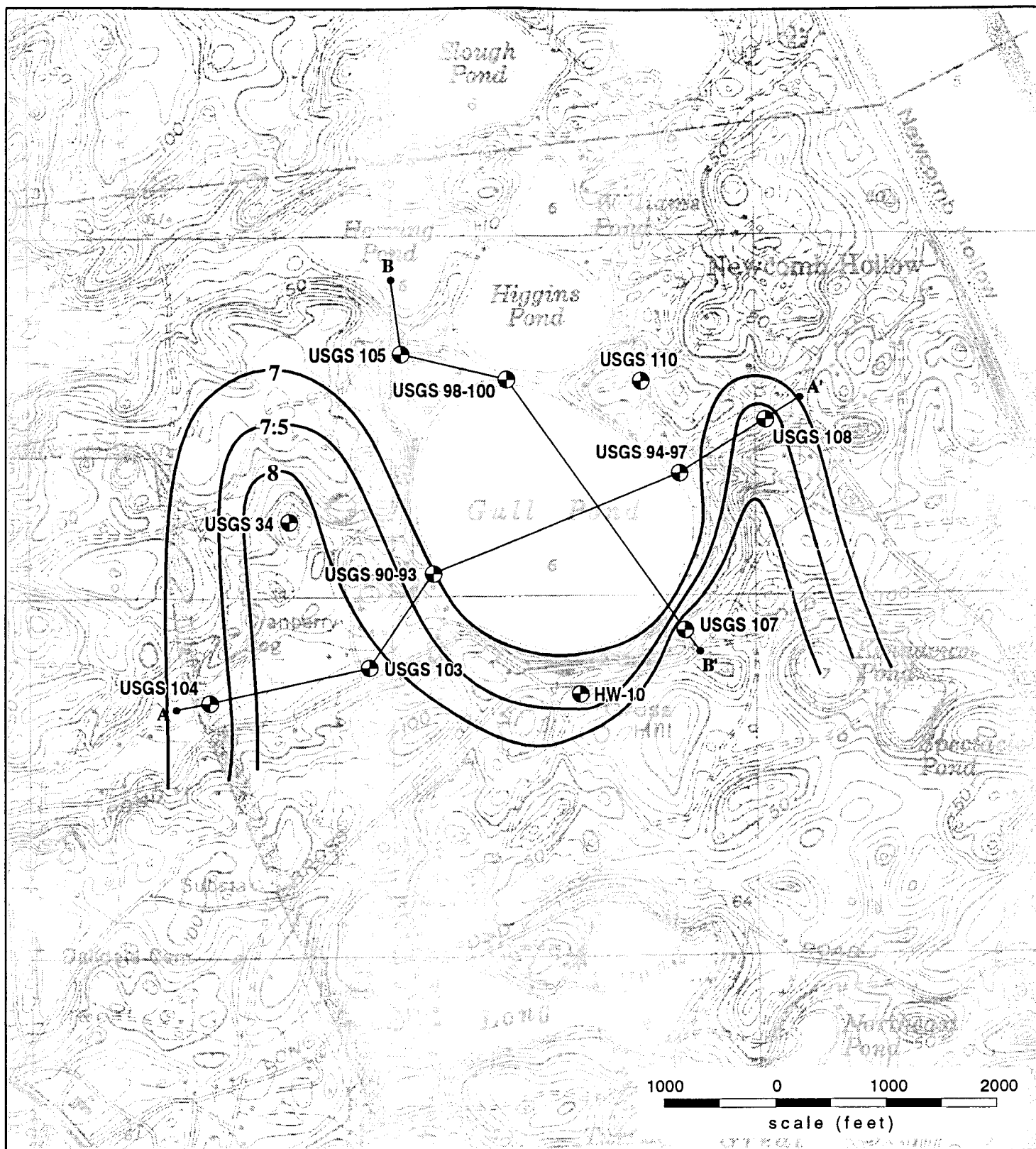
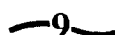
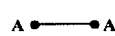


FIGURE 23.

Site Plan showing Water Table

Gull Pond, Wellfleet

-  Water Table Contour
-  HW-5 Monitoring Well Location
-  A—A' Trace of Cross Section

Source: USGS Quadrangle (Wellfleet, 1972)

Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

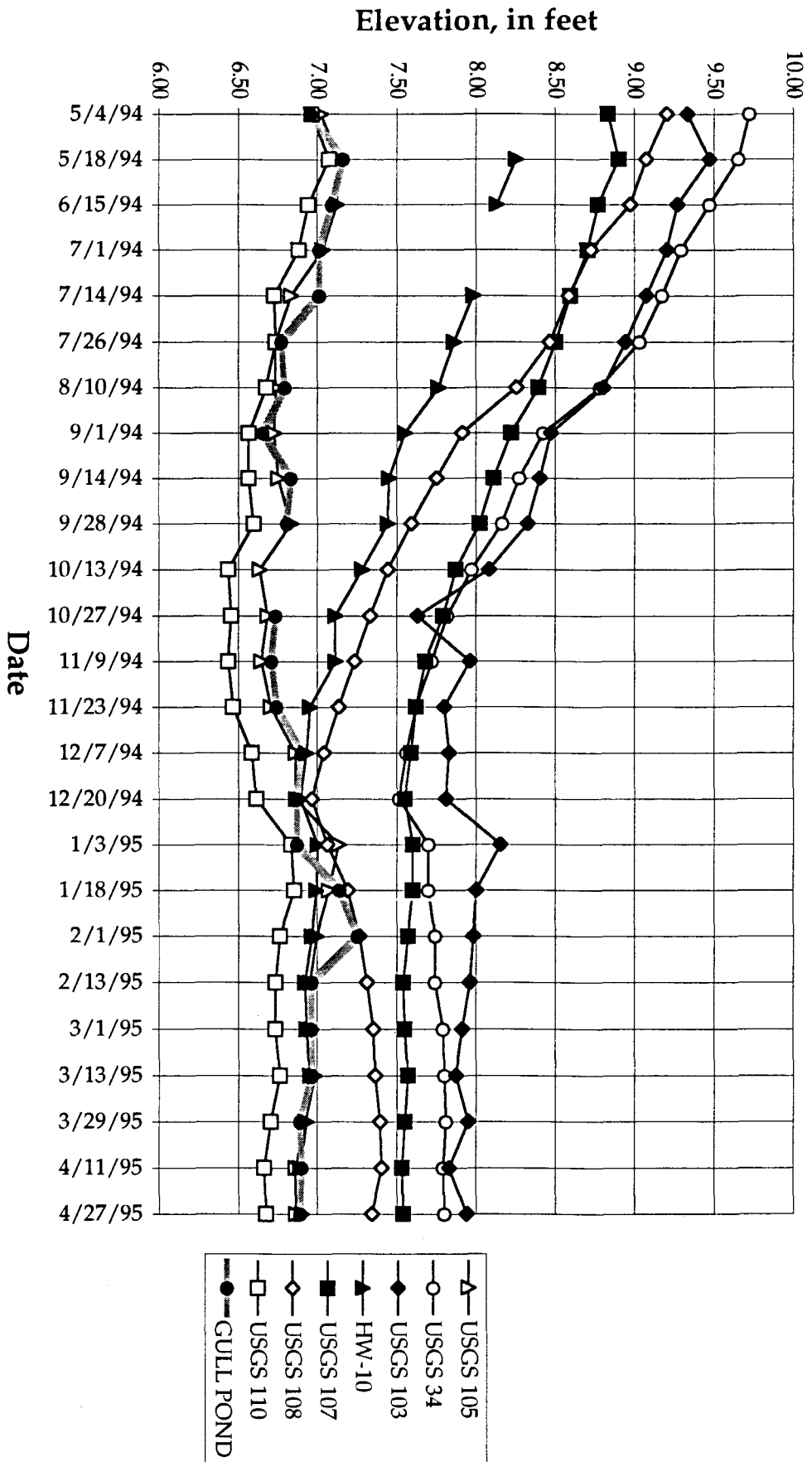
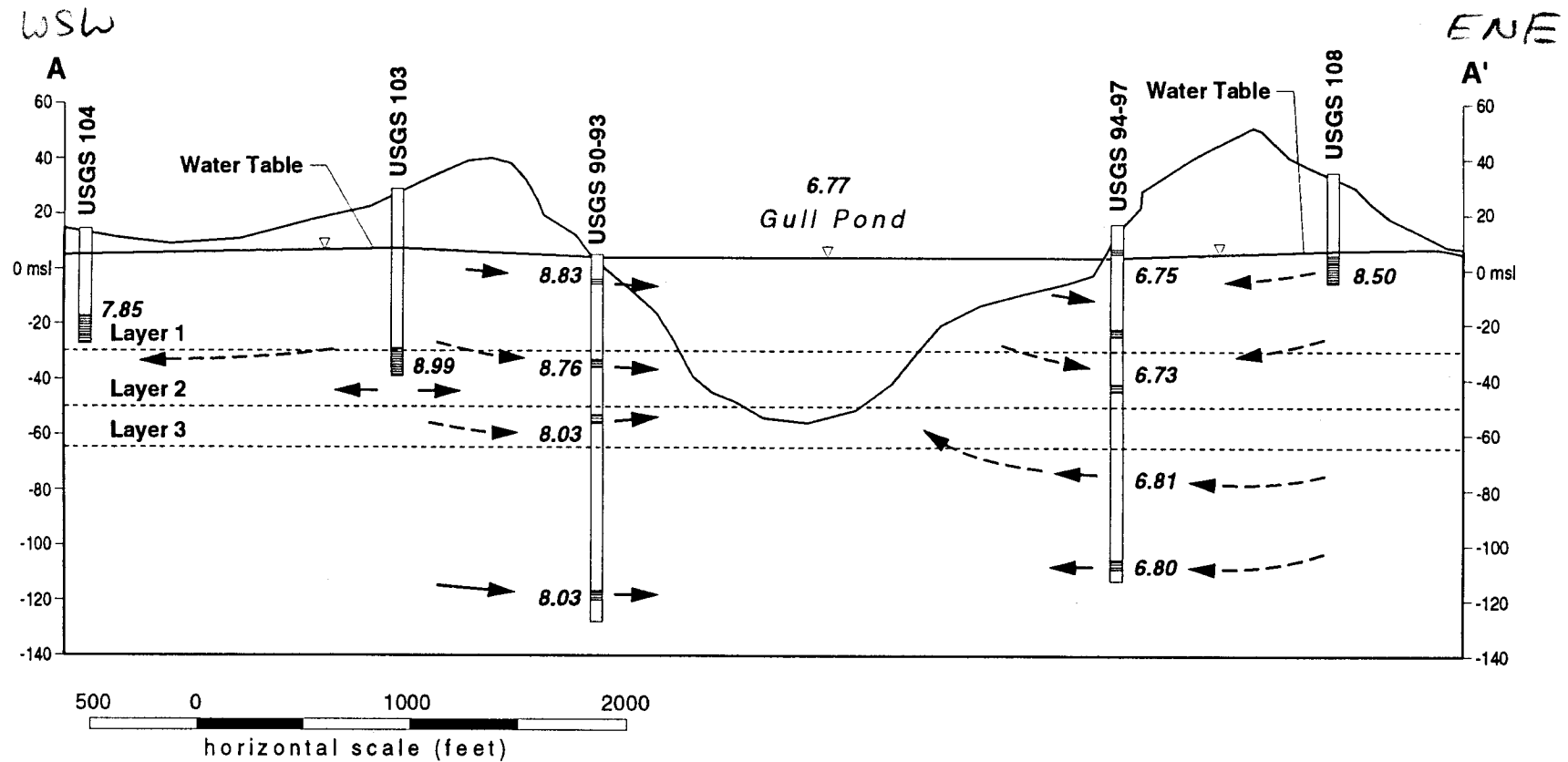


Figure 24

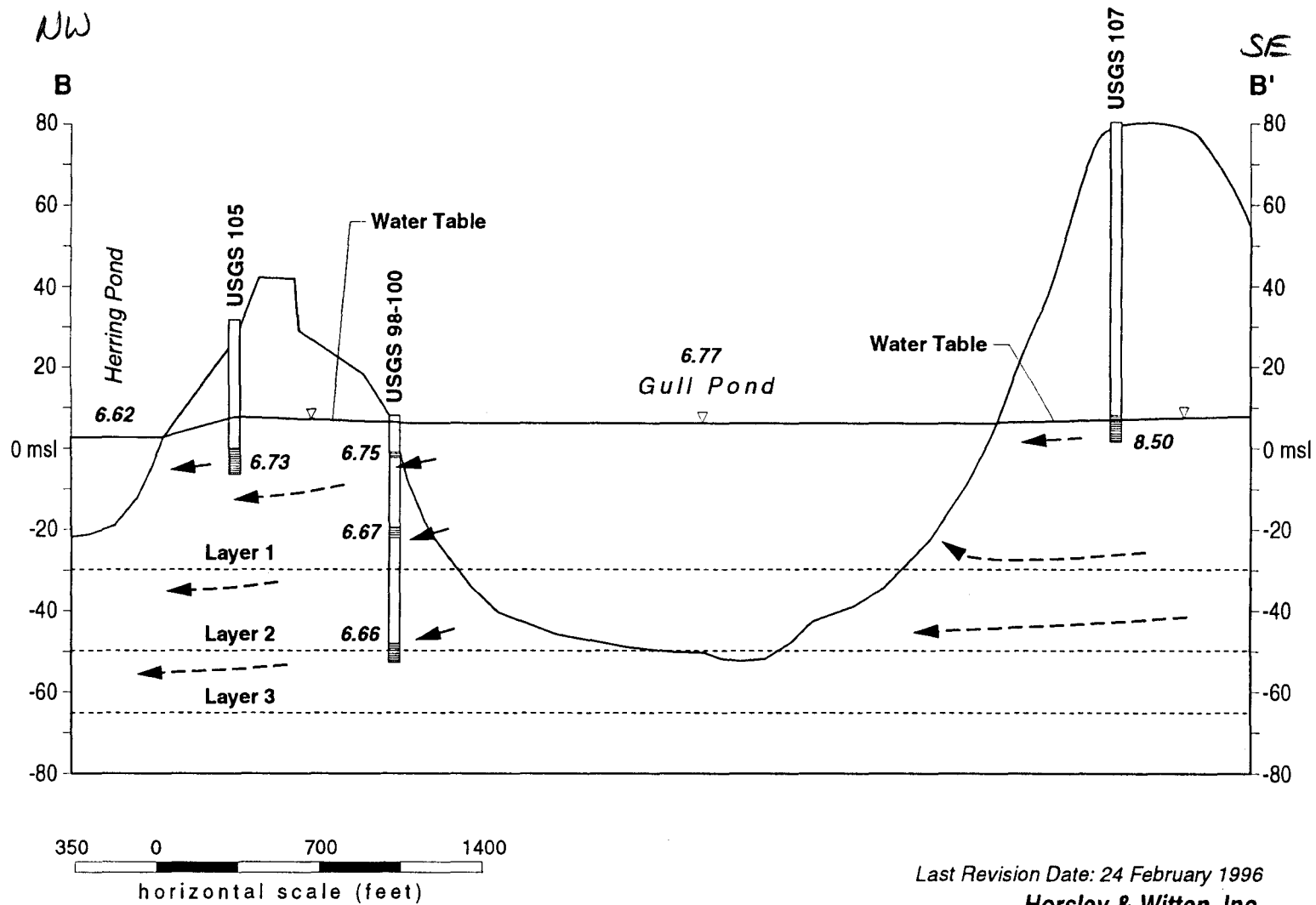
Shallow Ground-Water Levels about Gull Pond

FIGURE 25.
Gull Pond Ground Water Conditions (7-26-94) - Cross Section A-A'
Gull Pond, Wellfleet



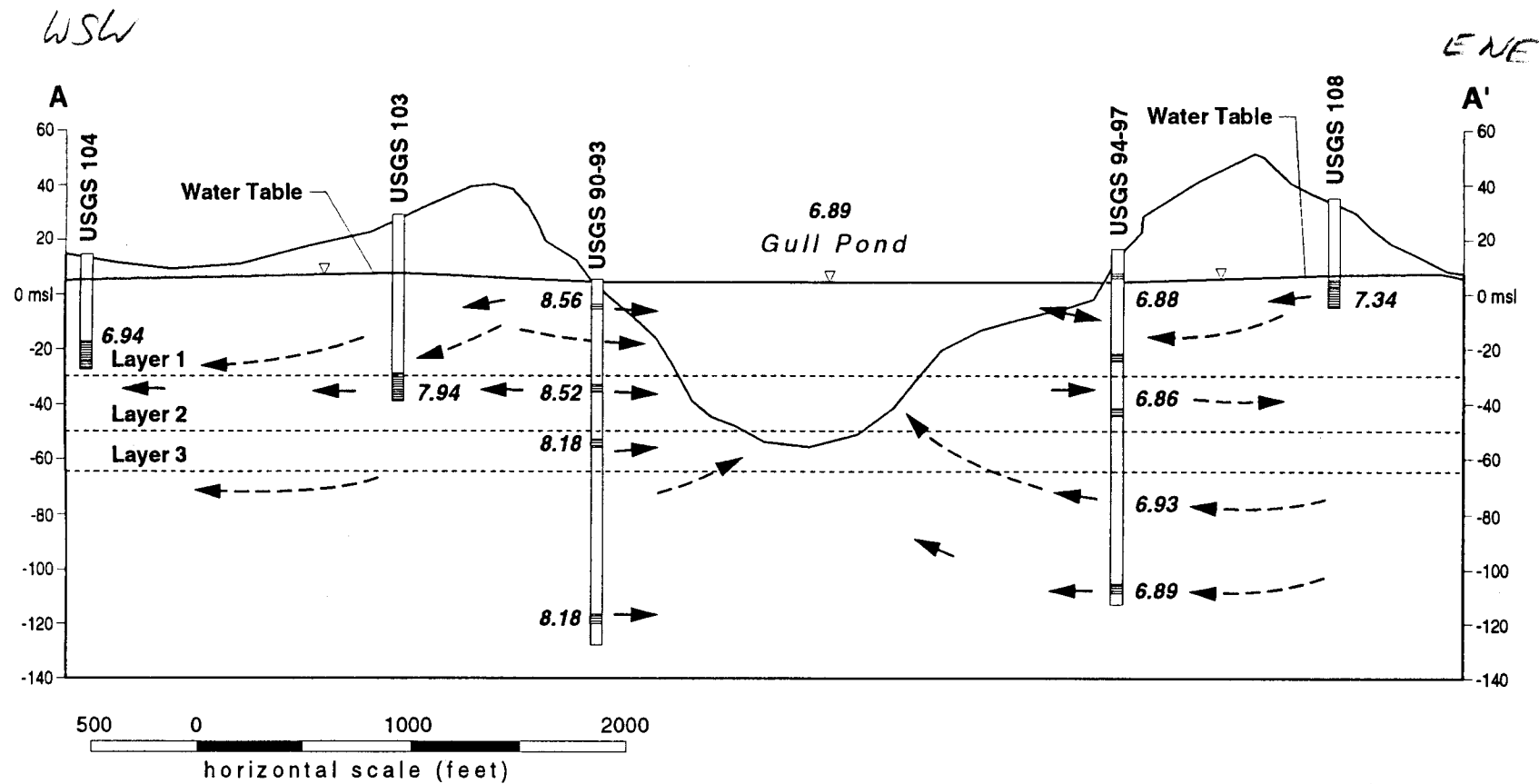
Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

FIGURE 26.
Gull Pond Ground Water Conditions (7-26-94) - Cross Section B-B'
Gull Pond, Wellfleet



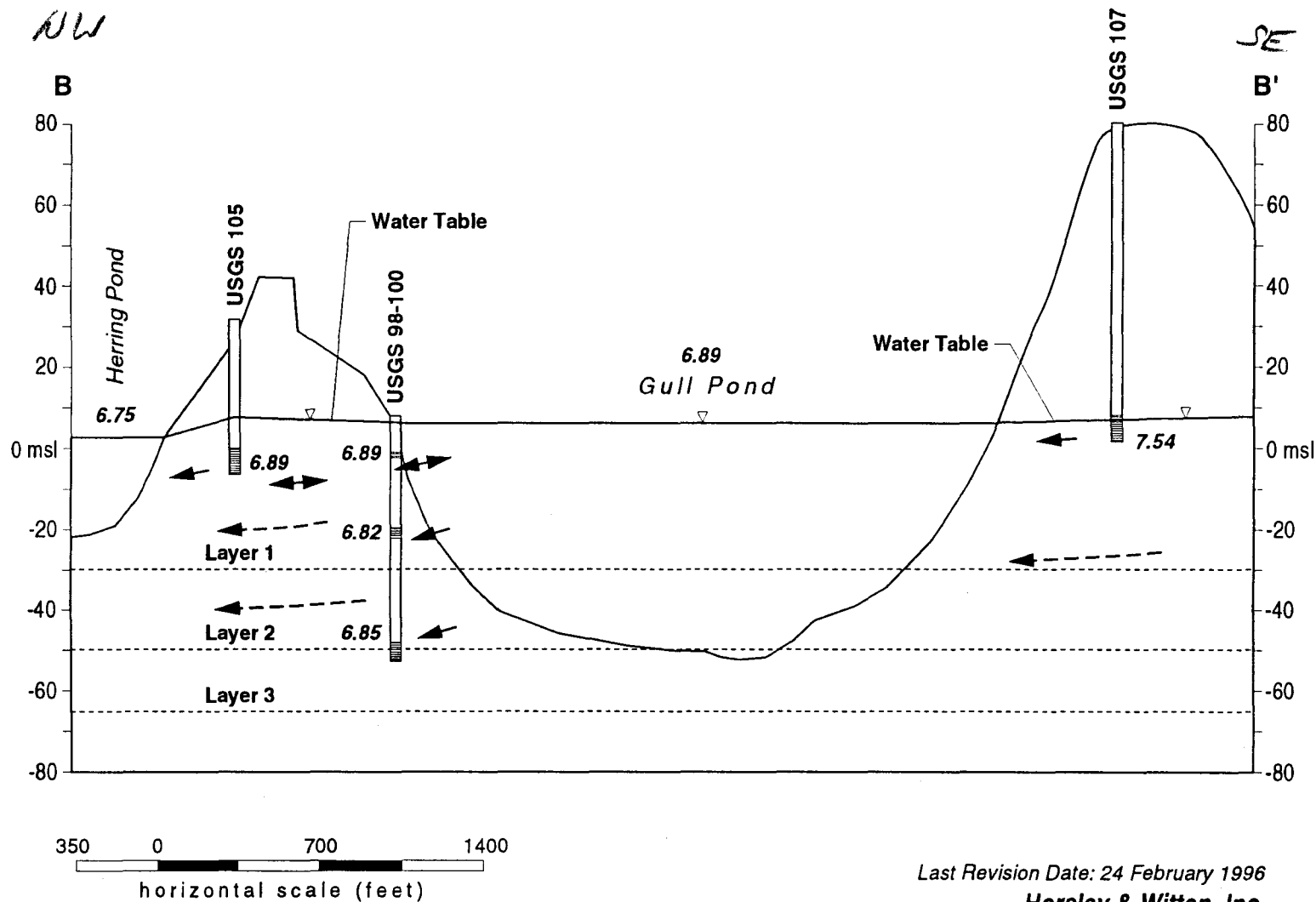
Last Revision Date: 24 February 1996
Horsley & Witten, Inc.

FIGURE 27.
Gull Pond Ground Water Conditions (4-27-95) - Cross Section A-A'
Gull Pond, Wellfleet



Last Revision Date: 13 June 1996
Horsley & Witten, Inc.

FIGURE 28.
Gull Pond Ground Water Conditions (4-27-95) - Cross Section B-B'
Gull Pond, Wellfleet



Over the entire period of monitoring, May 1994 to April 1995, there was a pronounced gradient of about one to two feet from all depths in the aquifer into the pond on the west side (Figure 29). The vertical gradient at a cluster of wells at the shore shows a downward gradient from the shallow aquifer to the deeper aquifer. Along the western shore of the pond ground water is consistently moving into the pond. Because the vertical gradient is downward from the shallow to the deeper aquifer at this location, the deeper flow system may tend to be less well connected to the pond. Fine grained sediments at depth on the west side of the pond as shown in the cross section (Figure 8) most likely preclude significant ground water interchange with the pond from deeper parts of the aquifer. Subsequent model analyses may confirm or refute this conjecture.

reduced pressure?

Along the east shore of Gull Pond, water levels from a cluster of wells at different depths indicates flow both into and out from the pond under different conditions (Figure 30). This appears to be a transition location where small changes in levels cause changes in flow direction. Generally, flow seems to be from the pond to the aquifer at relatively shallow depths. On the other hand, at about 50 and 100 feet deep there appears to be a consistent upward gradient at the site, so that deeper wells have higher water levels than the pond. This upward gradient on the discharge side of the pond suggests that the pond is less well connected to the deeper zones of the aquifer than the shallow zones. The interpretation is consistent with the expectation that less permeable bottom sediments would be thicker and less conductive in the deeper portions of the pond. Water from the deeper aquifer and from the pond flows through the shallow aquifer toward the north as is the case at the north shore of Duck Pond. Land to the north of this well cluster does not contribute water or, potentially, nutrients or other contaminants to Gull Pond.

conflicts with observed GW discharge and the cluster north of this cluster.

Along the north shore of the pond a cluster of wells at different depths on the narrow tombolo sand bar were monitored. At this site gradients were most commonly from the pond into the aquifer and from the shallow aquifer to the deeper aquifer (Figure 31). Some measurements indicate a slight gradient from the shallow aquifer into the pond. A pronounced gradient is not expected at this location because little surface water gradient occurs across the narrow sandy tombolo between the two ponds (Figure 10).

Within the regional ground water flow system Gull Pond acts as a surface drain, somewhat like a giant spring. Ground water flows into the pond from the west, south and south east, while surface water and some ground water flows northward out of the pond (Figure 29) and pond storage remains relatively constant. For example, from 1974 to 1982 Gull Pond stage ranged over only 1.48 feet (Letty, D. F., 1984). While increases of ground water inflow can result from increased recharge from precipitation, rapidly compensating increases of surface outflow keep the pond level from rising significantly. On the other hand, the

Figure 29

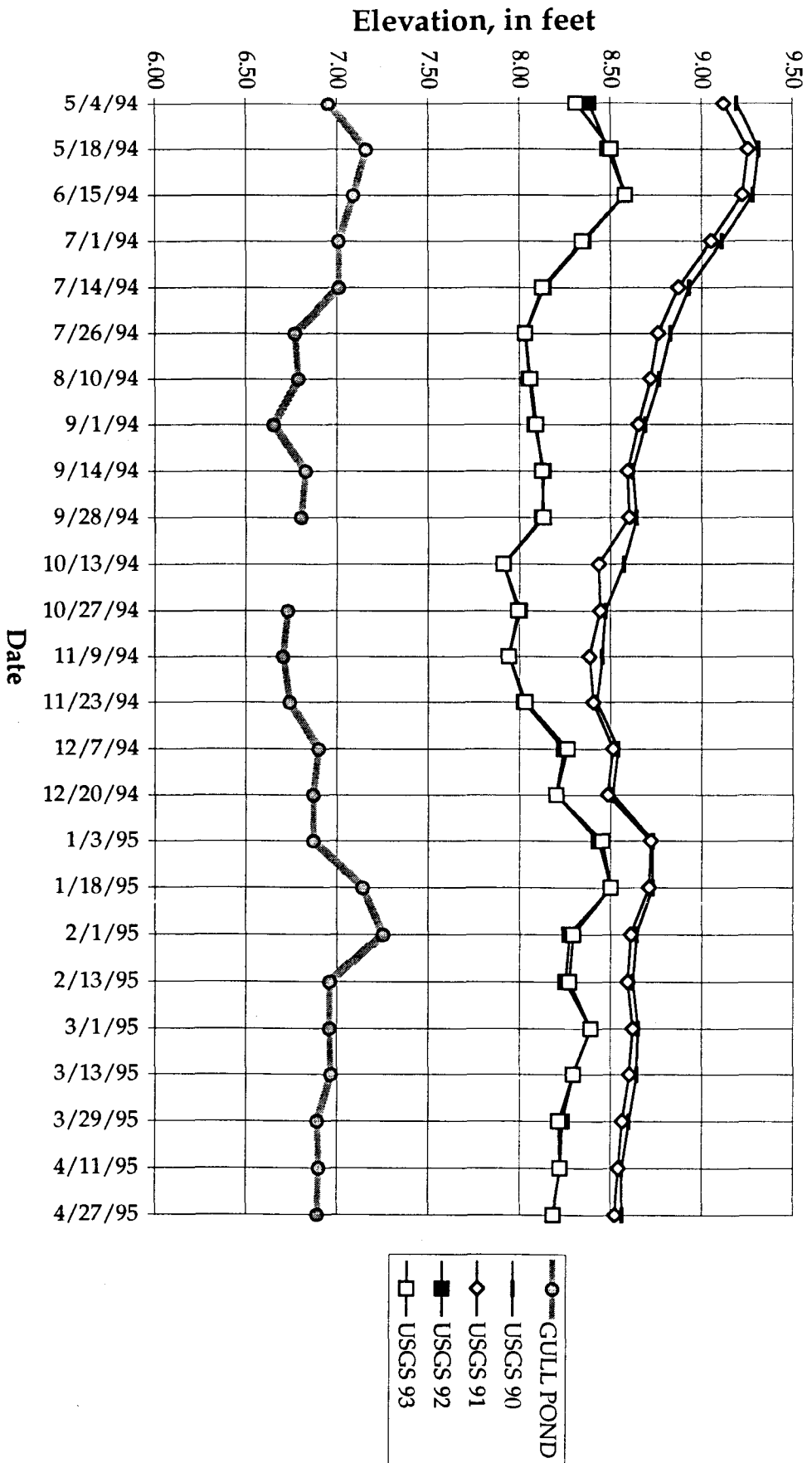
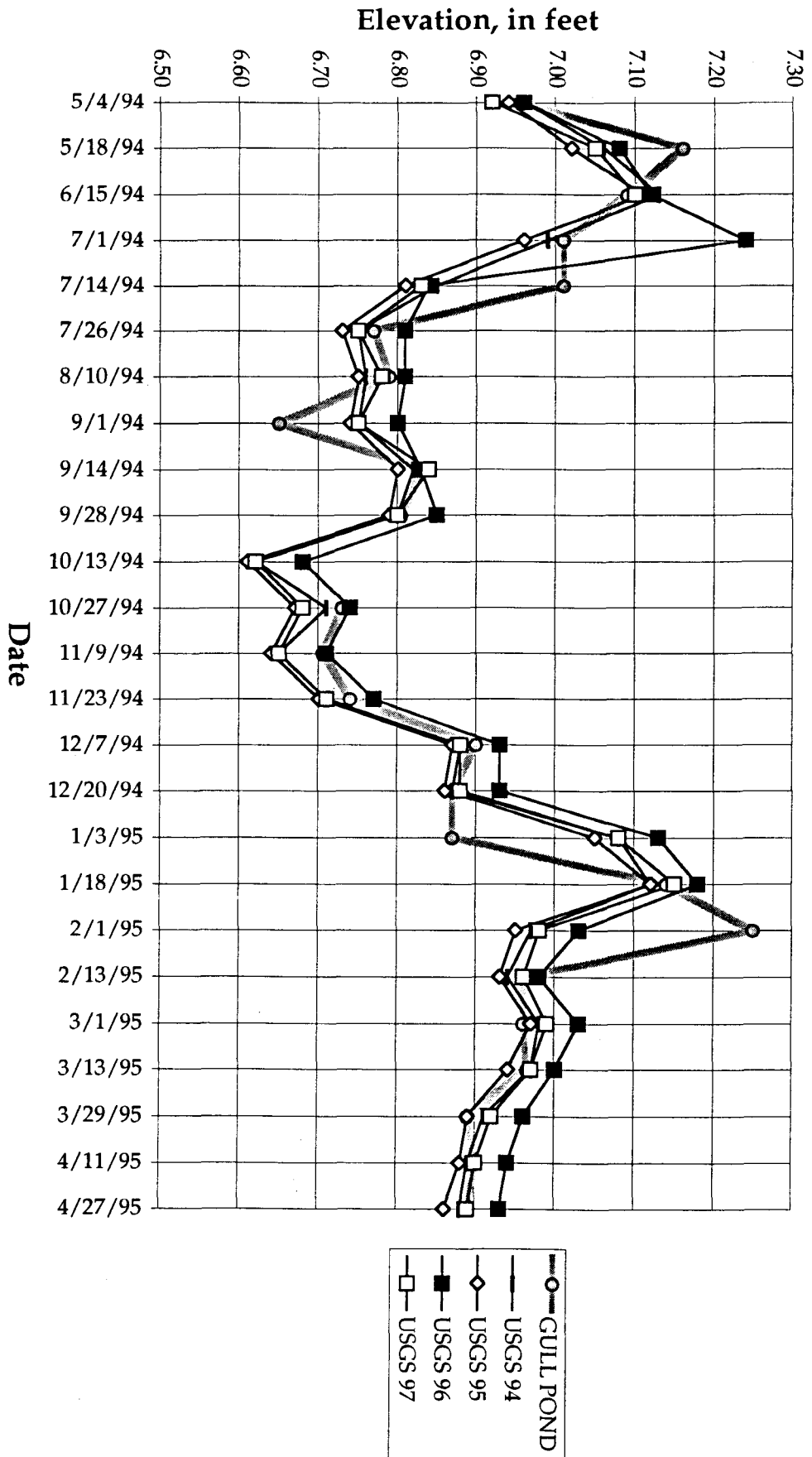
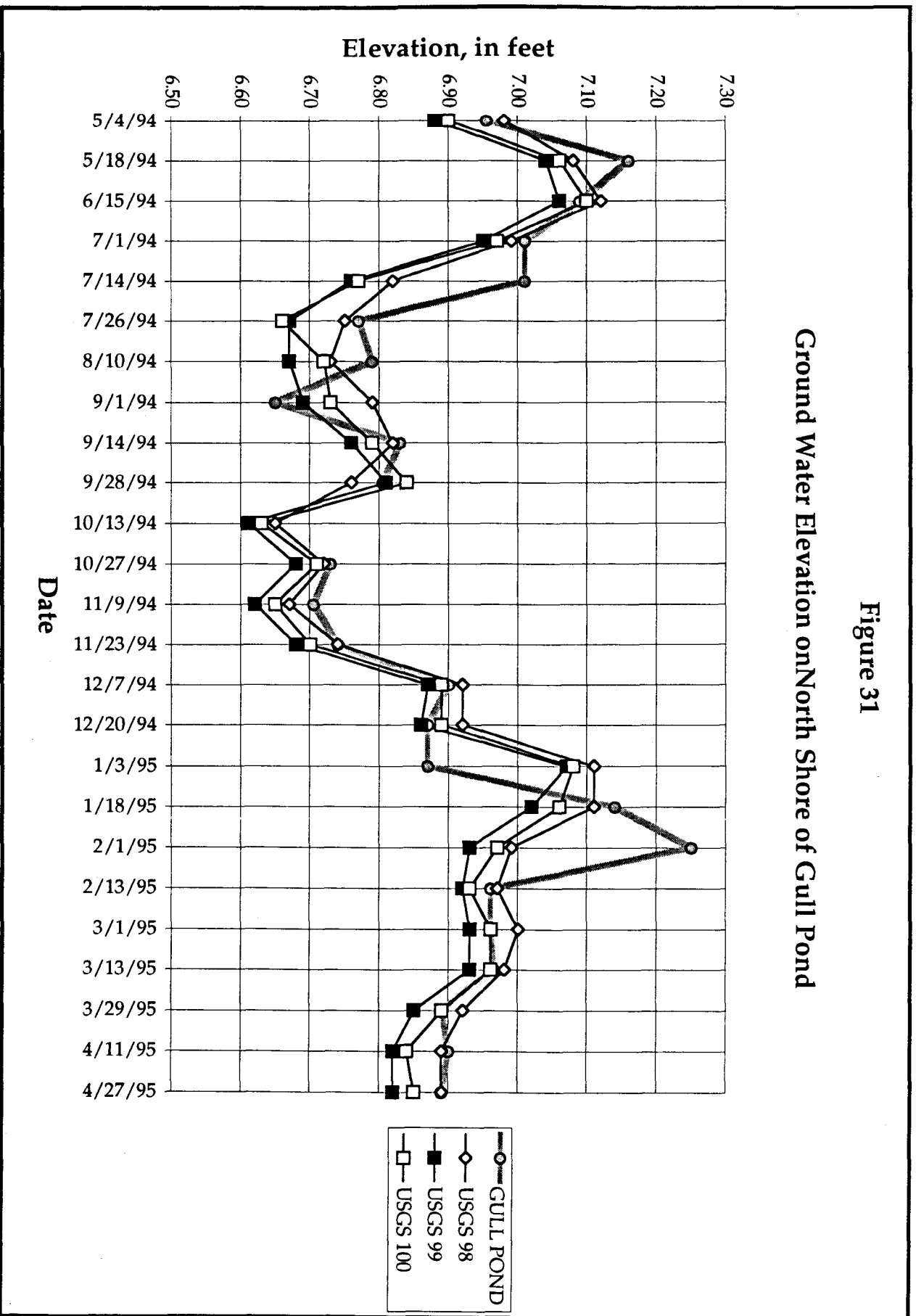


Figure 30

Ground Water Elevation on East Shore of Gull Pond





surface stream ceases to flow in the warm summer months when evaporation is sufficient to match or exceed ground water inflows, and pond storage can be depleted causing lowering of the pond level.

Gull Pond Conceptual Water Budget and Storage Change

The hydrologic budget for Gull Pond is relatively simple, but somewhat different from that for Duck Pond. Because Gull Pond has a surface outlet there is little change in storage in the Pond, but surface outflow is relatively large. Like Duck Pond, inputs occur from precipitation directly on the pond surface and from ground water inflow. A small amount of overland flow may enter from the pond shore during very wet conditions, but virtually all precipitation falling on the sandy permeable land surface is either evapotranspired or conducted into the ground as ground water recharge. Outputs occur from evaporation, ground water outflow, and stream discharge. As mentioned before, Gull Pond had an historical range of water level from 1974 to 1982 of only 1.48 feet. Because storage changes are small in Gull Pond, the measurement of stream discharge is essential for the pond's hydrologic balance. The hydrologic budget for Gull Pond may be expressed as:

$$(PPTi + GWi) - (EVAP + GWo) +/- \Delta Store = SWo$$

where: PPTi = Precipitation inflow
 GWi = Ground-Water inflow
 EVAP = Evaporation from pond surface
 GWo = Ground-Water outflow
 SWo = Surface-Water outflow
 Δ Store = Change in Pond Storage

The measured pond stage can be used to compute a measured change in pond storage for comparison with estimated storage changes computed with models using this budget. Based on the measured water level data, the .07 foot decline in Gull Pond indicates a loss of 316,000 ft³ of water released from storage during the study period. This is based on a pond surface area of 4,519,324 square feet as digitized from the USGS 1:25000 Wellfleet Quadrangle map.

Gull Pond Outlet

Gull Pond discharges through a short stream into Higgins Pond which subsequently drains into the Herring River and Cape Cod Bay. A tombolo, or sand bar, formed by wave action on the two ponds separates the two ponds except for the short stream. The NPS recorded semi-monthly discharge measurements from the stream that flows from Gull Pond into Higgins Pond from May 1994 - April 1995 (Table 8). The water level in Gull Pond ranged over only 0.6 feet (Table 6). During the first year of measurement the water levels measured in

Table 8. Gull and Higgins Pond Stages and Gull Pond Discharge Measurements

Date	Gull Pond Stage (feet above MSL)	Higgins Pond Stage (feet above MSL)	Head Differential between Ponds (ft)	Measured Discharge (cfd)	Elapsed Time since last Measurement (days)	Discharge Since Previous Measurement (cfd)
4-May-94	6.955	6.815	0.14	142,406	7	443,919*
18-May-94	7.16	6.84	0.32	187,860	14	1,993,684
20-May-94				128,740	2	375,720
25-May-94				156,798	5	643,700
15-Jun-94	7.09	7.09	0	168,182	21	3,292,758
1-Jul-94	7.01	6.95	0.06	178,979	16	2,690,912
14-Jul-94	7.01	6.95	0.06	48,258	13	2,326,727
11-Aug-94	6.79	6.62	0.17	22,692	28	1,351,224
1-Sep-94	6.65	6.79	-0.14	22,553	21	476,532
14-Sep-94	6.83	6.72	0.11	83,933	13	293,189
28-Sep-94	6.805	6.775	0.03	101,928	14	1,175,062
13-Oct-94				36,224	15	1,528,920
27-Oct-94	6.73	6.68	0.05	45,245	14	507,136
9-Nov-94	6.705	6.605	0.1	17,205	13	588,185
7-Dec-94	6.9	6.87	0.03	55,149	28	481,740
20-Dec-94	6.87	6.82	0.05	35,340	13	716,937
3-Jan-95	6.87	7.03	-0.16	94,953	14	494,760
19-Jan-95	7.14	6.98	0.16	132,339	16	1,519,248
2-Feb-95	7.25	7.05	0.2	37,200	14	1,852,746
14-Feb-95	6.96	7	-0.04	37,154	12	446,400
2-Mar-95	6.96	6.85	0.11	67,620	16	594,464
15-Mar-95	6.965	6.875	0.09	59,939	13	879,060
29-Mar-95	6.89	6.79	0.1	45,384	14	839,146
11-Apr-95	6.9	6.75	0.15	44,129	13	589,992
27-Apr-95	6.89	6.75	0.14	63,417	16	706,064

Annual Total Discharge (cf)= 26,808,225

* Based on 7 days between 4/27 and 5/4

Gull Pond are almost always higher than those measured in Higgins Pond and the surface flow, if any, is northward from Gull Pond to Higgins Pond. Generally, the level of Higgins Pond was between .05 and .15 feet lower than Gull Pond (Table 6). The NPS noted that the stream was dry (no discharge occurred) at several times during the monitoring period. However, these dates were not recorded. Therefore, this report assumes that discharge occurred throughout the monitoring period (Table 8).

Stream discharge data was forwarded to H&W for regression analysis to determine correlation between Gull Pond level and discharge (rating curve). The purpose of a rating curve is to establish a relationship between these parameters such that future pond stage readings can be used to determine the volume of surface water discharging from Gull Pond. Two rating curves were evaluated. The first (included in the Draft Final Report) plotted Gull Pond stage versus measured stream discharge. The coefficient of distribution (R^2) for this relationship is 0.199, a poor correlation between pond stage and stream discharge. The second rating curve (Figure 32) plots the head differential between Gull Pond and Higgins Pond versus stream discharge, and has a corresponding R^2 value of 0.048.

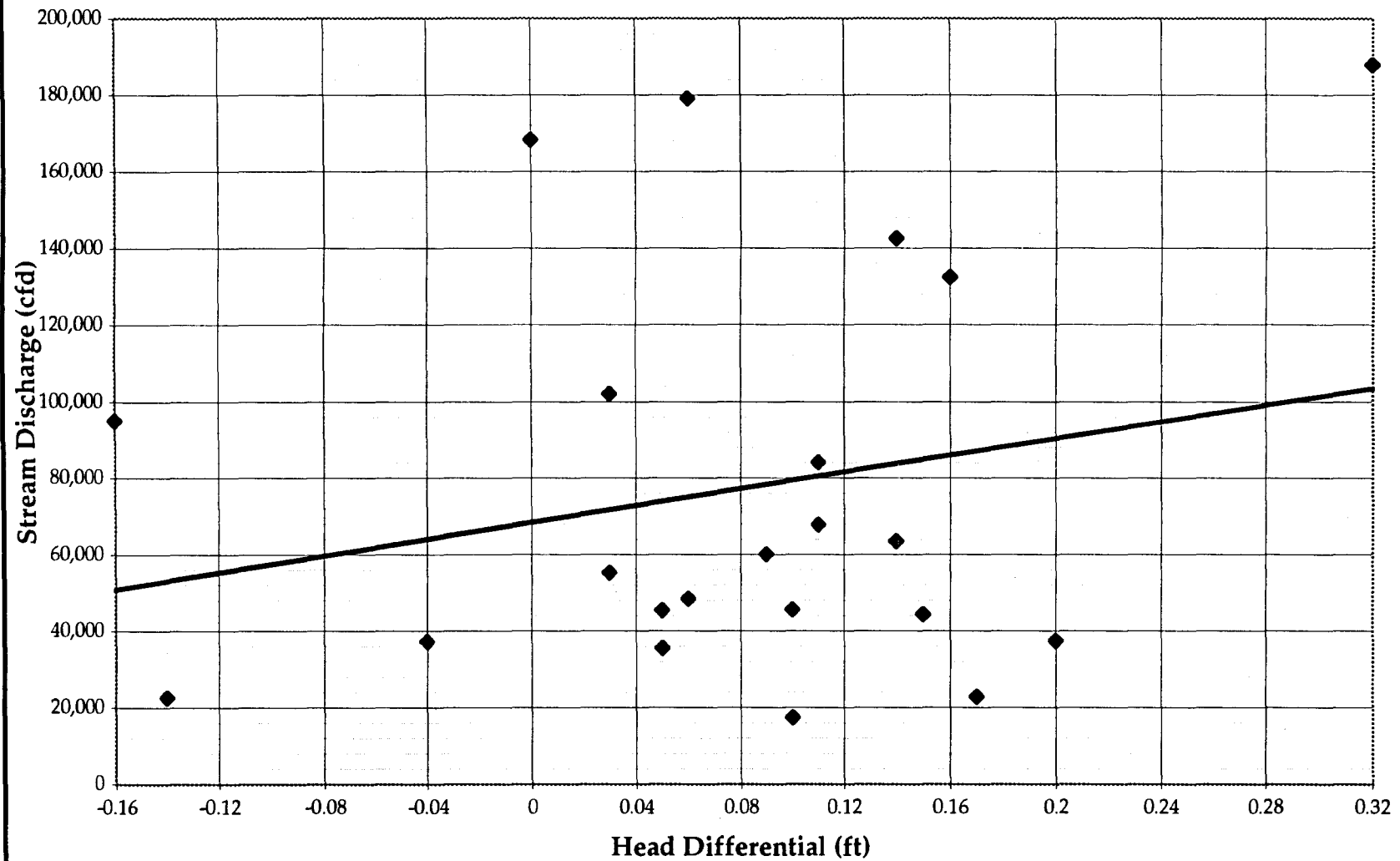
On September 1, 1994, January 3, 1995, and February 13, 1995, the water-level measurements indicate that the level of Higgins Pond was higher than Gull Pond, yet stream discharge measurements still indicate flow from Gull Pond toward Higgins Pond (Tables 6 and 8). Because of wind and wave, action water levels are not the same across the ponds. Water becomes higher on the downwind sides of the ponds than on the upwind sides because the wind pushes the pond water. Pond stage measurements were taken near the connecting stream on both sides of the tombolo and represented the north side of Gull Pond and the south side of Higgins Pond, not subjected to the same fetch for wind effects. When observations in one pond are at the downwind shore, observations in the other pond are at the upwind shore. These wind effects vary widely from day to day with wind direction, velocity and duration. It was not possible to develop a reliable stage to discharge rating for the stream discharge through the small stream connecting the two ponds in part because of wind driven water-level effects.

One of the requirements for stream gaging is selecting a gaging site conducive to measuring representative flow. It is important that the morphology of the stream bed remains relatively undisturbed for the duration of the study period because in order to analyze data through regression analysis, all factors other than discharge and pond stage should be constant.

On several occasions during the study period the NPS observed that the stream bed had been dredged. The NPS noted that local fisherman may be responsible for this alteration. On other occasions currents (long shore currents) have

Figure 32

Regression Rating Curve of head differential between Gull and Higgins Pond and Stream
Discharge from Gull Pond ($R^2=0.048$)



deposited sediment and temporarily choked off the small stream. The poor correlation between pond levels and discharge therefore is likely due, in part, to these man-made changes in stream bed configuration. When dredging occurs, the stream is then capable of carrying water from a lower pond depth, causing a large initial loss of water from Gull Pond before sedimentation begins replacing the lost material. The changes in gradient between Gull and Higgins Ponds mentioned previously may also affect stage/discharge relationship in the stream.

Isn't gradient driving discharge?

GROUND WATER MODELING

Conceptual Model of Ground Water Flow

Water enters the subsurface system at each pond primarily through precipitation, which infiltrates through an unsaturated zone into the saturated zone and becomes ground water. Precipitation is distributed with respect to space and time. Other sources of recharge to ground water include seepage from Duck and Gull Pond and, in the case of Duck Pond, a small wetland. After water has entered the saturated zone, it flows toward areas of lower hydraulic potential. Ground water flows perpendicular to lines of equal hydraulic head.

Model Description

The three-dimensional, block-centered finite difference code, MODFLOW (McDonald and Harbaugh, 1988) was used for this study to simulate the hydrologic system of the aquifer around each pond. The three-dimensional systems for both Duck and Gull Ponds were simulated as three two-dimensional layers of porous material, each with different hydrologic properties. The models were then used to further analyze the hydrologic data collected over the course of study period.

Model Approach

Fourteen model simulations were run for each pond. The first was a steady-state scenario designed to predict water levels over a period of 10,000 days assuming an average annual precipitation of 40.4 inches/year over this period (average conditions). The second was also a steady-state simulation, but for this case, the model was run to evaluate the water table response over the study period (365 days) based on measured precipitation and evaporation data collected during the study period. The remaining 12 model simulations represent transient scenarios for each month beginning in May 1994. Data entered into the models for this study are based on the initial 10,000 day steady state conditions and on monthly measured field data and hydrogeologic information. Repetitive model simulations were run, and the steady-state output was compared to measured data and hydraulic conductivity, vertical leakance and recharge rates were adjusted in order to calibrate the model.

Grid and Boundary Conditions

The outwash aquifer surrounding each pond was subdivided into cells using a variably spaced grid extending from the Atlantic coast to Cape Cod Bay. The grid for the Duck Pond area consists of 50 columns and 35 rows and 3 layers. The Gull Pond model area consists of 50 columns, 40 rows, and 3 layers. Grid spacing is finest around the ponds (Figures 33 and 34). Coastal cells were selected as constant head cells, and set equal to 0.01 feet. The rows that define the limits of the grid to the north and south were selected as no-flow boundaries because these areas are sufficiently outside of the study area such that extending them would have negligible effect. Cells within the model boundary (active cells) were assigned values of hydraulic conductivity, storage coefficient, vertical leakance, thickness, and recharge. Cells outside the model boundary (inactive cells) were assigned values of zero for these parameters. By using a multi-layered model, hydrogeologic changes which occur at depth can be represented.

The eastern and western limits of the grid (cells along the coasts of the Atlantic ocean and Cape Cod Bay) were modeled as constant heads, as were Great Pond and Long Pond because they are located sufficiently far from the study ponds. Cells containing the Herring River were also modeled as constant heads to simulate the surface water gradient toward Cape Cod Bay. Cells for Duck, Gull, Higgins, and Herring Ponds were modeled as active cells, free of constraint in order to allow water levels for those ponds to fluctuate according to variations in model inputs. Cells located beyond the shores of the Atlantic Ocean and Cape Cod Bay were modeled as no-flow cells (inactive cells).

Hydraulic Conductivity (K)

Hydraulic conductivity for pond cells was 999,999 ft/day; thus flow through and about those cells takes place with negligible resistance. Hydraulic conductivity values for the glacial deposits were based on field data from aquifer pump tests as well as from interpretation of soil borings. Initial values of K were derived from previous USGS models (Guswa and LeBlanc, 1985 and Masterson and Barlow, 1994). Hydraulic conductivity for aquifer cells initially ranged from 1 ft/day to 420 ft/day. Variations of K over the grid area were confirmed during model calibration. Hydraulic conductivity values are provided in Appendix C (a diskette containing model input files).

Vertical Flow (Leakance Between Layers)

Vertical conductance in the aquifer system was simulated as leakance between model layers. Vertical leakance was calculated by dividing the difference in thickness between adjoining layers and the average horizontal hydraulic conductivity of those layers. Adjustments were made to values of vertical

leakance during model calibration for areas where measured gradients were greater than modeled gradients. Values of vertical leakance used in the models are provided in Appendix C.

Anisotropy

No site-specific data were available for this study regarding anisotropy. Both models were initially run assuming isotropic conditions, as noted in the previous Draft Final Report. Subsequent communication with the USGS confirmed that an anisotropy of 10:1 is representative of the glacial outwash deposits for this part of Cape Cod (J. Masterson, personal communication, 1995). Thus both models were run with an assumed 10:1 anisotropy. Anisotropy was incorporated into the vertical conductance term.

Recharge

Recharge was assigned only to cells in the first layer. For aquifer cells, recharge was determined by subtracting evapotranspiration from average monthly precipitation. Recharge to pond cells was determined by subtracting evaporation measured from the evaporation pans from average monthly precipitation. Except for the Gull Pond outlet, it was assumed for this study that surface runoff is negligible.

For the first steady-state model simulation (10,000 days) an average recharge rate of 18 inches/year was used for cells outside the pond and 12.4 inches/year for pond cells (Masterson and Barlow, 1994). Recharge for the second steady-state simulation (365 days) was based on precipitation and evaporation records measured by the NPS during the monitoring period. The second steady-state model was initially run using recharge rates of 15.8 inches/year for glacial outwash cells and 10.4 inches/year for pond cells. Recharge for the transient simulations were also based on measured monthly precipitation, estimated ET, and measured pan evaporation. Transient recharge rates were determined by subtracting monthly evaporation and/or ET from precipitation measured for each month.

less due to ST evaporation?

Model Calibration

For this phase of the modeling, average water levels for the one year monitoring period were used as initial calibration targets. Water budget parameters such as ground water flux and stream outflow are intended to be used as additional calibration targets for the second phase of modeling once a more comprehensive steady-state data base is compiled. Once calibrated, the model was then run for 12 successive months beginning with May 1994, although the model was not calibrated to transient conditions. It is anticipated that with a more comprehensive data set (i.e., three years of data) the transient models will provide a more accurate accounting of monthly water fluxes.

Calibrating the model required numerous simulations to be executed, with modeled output compared to measured data. Model inputs were adjusted within a reasonable range such that residual water levels for the 365 steady-state run closely matched the field data. In areas where no soil borings were collected, hydraulic conductivities and vertical leakance were initially assumed to be the same as similar areas for which data was available. They were then adjusted within what H&W believed to be a reasonable range in order to calibrate the model. Recharge to aquifer cells was slightly increased during model calibration from the initial estimate of 15.8 to 17.5 inches/year. For cells in the immediate vicinity of the pond, a modeled water level difference of 0.5' was deemed an acceptable margin of error for model calibration (Table 9). For cells beyond the immediate vicinity of the pond, H&W calibrated the model as close to the same standard (0.5 ft) as was possible within the limits of the aquifer characteristics. The areas which required the greatest scrutiny were the cells immediately surrounding the ponds. Initial model output showed Duck and Gull Ponds at the highest points on the water table, on the ground water divide between ocean waters. While this condition is approximately true in a regional sense, local gradients from the aquifer to the ponds exist. Thus, for successive model runs, aquifer characteristics were adjusted on a basis of modeled steady-state comparisons of water level output with measured water levels.

Differences between simulated and measured parameters indicate where model refinement was needed. The process of adjusting model parameters continued until the output approximated measured levels. In order for the modeled output to be considered to be within an acceptable level of tolerance, modeled steady-state water levels had to be within 0.5' of average measured levels. Once the modeled output approximated the measured head values in the ponds and the observation wells, the model was determined to be calibrated.

Percent Error

MODFLOW calculates a percent error for each model execution. This value is an indicator of how accurately inputs and outputs are balanced for the active cells in each layer in the grid at the end of each model time-step. Percent error for both steady-state model runs at Duck Pond was 0.74. Percent error for both steady-state Gull Pond model runs was 1.95.

Transient Model

The preliminary models for each pond were designed to generate transient predictions in addition to steady-state predictions. While this was done for each pond, only the steady-state model output was evaluated during model

Table 9. Steady-State Calibration Table

WELL I.D.	Measured Water Level	Modeled Water Level	Difference
Duck Pond	8.71	8.72	-0.01
HW-1	9.23	9.2	0.03
HW-2	9.33	9.29	0.04
HW-3As	9.06	8.98	0.08
HW-3Ad	9.05	8.98	0.07
HW-3s	8.46	9.09	-0.63
HW-3m	9.30	9.08	0.22
HW-3d	9.14	9.08	0.06
HW-4s	7.18	7.93	-0.75
HW-4d	7.05	7.93	-0.88
HW-5	9.09	8.69	0.40
HW-7	9.37	8.61	0.76
HW-11	8.71	8.79	-0.08
HW-12	8.98	9.04	-0.06
HW-13a	8.93	8.72	0.21
HW-13b	8.81	8.72	0.09
HW-13c	8.82	8.52	0.30
HW-13d	8.81	8.5	0.31
HW-14a	9.00	8.73	0.27
HW-14b	8.87	8.73	0.14
HW-14c	8.87	8.45	0.42
HW-14d	8.90	8.45	0.45
HW-15	9.69	8.5	1.19
HW-16	9.16	8.69	0.47

Higgins Pond	6.84	7.08	-0.24
Gull Pond	6.91	7.09	-0.18
HW-10	7.32	7.67	-0.35
USGS 34	8.30	7.39	0.91
USGS 90	8.74	8.28	0.46
USGS 91	8.70	8.28	0.42
USGS 92	8.22	8.1	0.12
USGS 93	8.22	8.05	0.17
USGS 94	6.88	7.03	-0.15
USGS 95	6.86	7.03	-0.17
USGS 96	6.93	6.93	0.00
USGS 97	6.87	6.94	-0.07
USGS 98	6.89	7.08	-0.19
USGS 99	6.84	7.08	-0.24
USGS 100	6.86	7.09	-0.23
USGS 103	8.38	8.1	0.28
USGS 104	7.41	8.21	-0.80
USGS 105	6.88	6.78	0.10
USGS 107	8.03	7.62	0.41
USGS 108	7.78	6.24	1.54
USGS 110	6.70	6.79	-0.09

calibration. Further calibration of the steady-state models with 3 years of data will enable the models to produce reliable estimates of transient monthly inflow/outflow.

Modeled Change in Storage

ZONE BUDGET (Harbaugh, 1993), a computer program that interfaces with MODFLOW output, was used to determine ground water flux for each pond across cells representing the pond aquifer boundaries for each modeled layer (Table 10).

Table 10. Ground Water Flux for Model Layers				
Layer Number	Duck Pond Inflow (cfy)	Duck Pond Outflow (cfy)	Gull Pond Inflow (cfy)	Gull Pond Outflow (cfy)
1	356240	5,840	22,189,445	23,813,330
2	714,690	1,825,000	12,898,005	12,500,155
3	24,455	1,095	14,471,520	6,592,265
Totals	1,095,385	1,831,935	49,558,970	42,905,750

Modeled ground water flux data were saved for cells at the periphery of each pond, and summed for each grid layer. By adding the flux values together, composite fluxes for each pond were determined. The flux data were then used with precipitation, evaporation, and surface water flux to determine the change in storage for each pond (Table 11).

Table 11. Comparison of Measured versus Model Storage Change							
Hydrologic Budget Equation: $PPT_i + (GWi - GWo) - SWo - EVAP = +/- (Storage\ Change)$							
Pond	Measured Precip. (PPTi) (cubic feet)	Modeled Ground Water Flux* (GWi-GWo) (cubic feet)	Measured Stream Discharge (-SWo) (cubic feet)	Measured Evap. (-EVAP) (cubic feet)	Calculated (Storage Change) (cubic feet)	Measured (Storage Change) (cubic feet)	Difference (Cubic feet)
Duck	1,358,000	-737,000	0	1,052,000	-431,000	-1,263,000	832,000
Gull	14,311,000	6,653,000	26,808,225	8,660,000	-14,506,225	-316,000	-14,027,000

Duck Pond

Modeled ground water flux at Duck Pond is consistent with measured water levels. The first layer indicates net inflow into the pond at the top layer, net outflow from the pond from layer 2, and net inflow from layer 3. However,

while the measured change in pond level for the study period was a loss of 2.2 feet, the modeled change in storage represents a loss of only 0.96 feet in pond level.

Thus, the model is overpredicting the volume of water recharging Duck Pond relative to the volume of water discharging from Duck Pond. One or a combination of factors may be responsible for this discrepancy, including possible underestimation of the volume of water lost to pond surface evaporation, although there is no conclusive evidence to the contrary, and greater pond outflow. The model is shown to predict net inflow from the bottom layer, consistent with observed water levels in wells adjacent to the pond. It was assumed for this preliminary modeling that the bottom sediments of Duck Pond acted as a low permeability layer through which water exchange is unlikely. However, these results suggest that leakance through the pond bottom sediments may be occurring. In order for the model to predict a drop in pond storage that reflects what was measured, there must be a significant component of relative outflow (i.e. greater outflow, less inflow, or, more likely a combination of both) from the pond that is as yet not represented. Loss of water through the pond bottom was not observed during the monitoring period. However, studies have shown that significant amounts of water may be transmitted from the pond to the aquifer through pond bottom sediments despite observed inflow gradients from deep wells located on the periphery of a pond (Winter, 1981, Pfannkuch and Winter, 1984). It is also possible that the model may also be underestimating the net volume of water lost from the model's second layer. Increased discharge through this layer would counter-balance the large inputs modeled from the first layer. One other factor that may be influencing these results may be an incomplete record of evaporation. Since evaporation represents a discharge from the system, any unaccounted for losses during the months between November and May will translate into greater inflow relative to outflow.

? They mean
"Here's no evidence
for underestimation?"

Gull Pond

Inputs to Gull Pond consist of net ground water flux and precipitation. Annual precipitation and ground water inflow account for most of the water entering Gull Pond, and annual outputs from Gull Pond are evaporation and stream discharge (Table 10). There is a net decrease of approximately 14,506,225 ft³ of water from Gull Pond which equates to an approximate pond stage decrease of 3.2 feet over the monitoring period. This represents a discrepancy between what was measured versus what was modeled.

In this case, it could be that the model is underpredicting the contribution of ground water inflow, although modeled inflow is in general agreement with estimations provided by Ryan (1980). Another possibility for this storage decrease may be an overestimating of stream discharge. Measured stream discharge from Gull Pond for the monitoring period approached record high

levels compared to previous measurements (Soukup, 1977) despite the fact that it was during a low precipitation year. Further discharge monitoring will provide the basis for confirming or refuting this assertion.

CONCLUSIONS

Devising management and protection plans for the hydrologic and ecological systems that occur at Duck and Gull Ponds, and other similar kettle hole ponds in the Cape Cod National Seashore, depend on reliable water budget information gained over a period of time which may be considered representative of normal hydrologic conditions. Although the monitoring period may not be considered representative of normal conditions, much has been learned about the behavior of these two ponds from the monitoring data collected during the study period.

Numerical models were developed for Duck and Gull Ponds to simulate hydrologic conditions measured over a period of one year, and thereby estimate the contribution of ground water flux to overall water budgets for each pond. These models were used to evaluate the monitoring data collected during the study period in terms of additional monitoring needs. In each case, flow directions about each pond are accurately represented.

Evaporation data may not completely represent steady-state conditions. Although evaporation was monitored for what is generally considered the growing season, there may be a significant component of evaporation (or sublimation) occurring for the months between November and April. This information, if significant, could be used to further calibrate the models.

The Duck Pond model predicts a loss of 431,000 ft³ of water from pond storage, which equates to a pond stage drop of 0.96 feet over the course of the monitoring period. The calculated storage loss and drop in pond stage are less than the actual storage loss of approximately 1,263,000 ft³ and the measured 2.22 foot drop in pond stage. Further monitoring will provide more representative steady-state values allowing better refinement of the model.

In Gull Pond, the measured 0.07 foot decrease in Gull Pond level equates to a loss of approximately 316,000 ft³, whereas the model predicts a loss of pond storage of 14,506,225 ft³ and a decrease in overall pond stage of 3.21 feet. At this point, it is not clear whether the model needs further adjustment in order to match this storage change or whether the stream outflow measurements overestimate the volume of water leaving the pond. As previously mentioned, there were three occasions when Gull Pond outflow was measured despite the fact that water level data indicate its stage was lower than Higgins Pond. Moreover, despite low precipitation measured during the course of the monitoring period, the total measured stream outflow over the one-year period nearly equates to the

1 ?

maximum estimated daily discharge rate (Soukup, 1977) extrapolated to a one-year period. The inherent uncertainty associated with these conditions plus the fact that dredging of the channel occurred during the monitoring period underscores the need for further monitoring. Further monitoring should better constrain this essential component of the Pond's water budget, and thus confirm or refute data collected to date and improve the reliability of the rating curve and the model predictions.

*Shoreway
discharge*

The significant ground water inflow at Duck and Gull Ponds makes them vulnerable to water quality impacts from land uses that occur within their recharge areas. Depending on upgradient land uses, ground water discharging to surface water bodies may be susceptible to contamination from a variety of sources. Duck Pond appears to be sufficiently geographically isolated, and generally upgradient, from potentially harmful land uses. However, this should not preclude the need for long term water quality monitoring along the Duck Pond shore. Gull Pond, which exists within an area of considerably more localized development, is more susceptible to anthropogenic influences from nearby land uses. Fifty-eight percent of the total ground water inflow to Gull Pond is derived from the upper layer. In view of this, there is a continued need to monitor the ground water quality at this pond.

*Where are these data tabulated?
ie. layer-specific discharge for
both ponds.*

RECOMMENDATIONS

Gull Pond Discharge Monitoring

It is recommended as an essential effort that monitoring of the outflow from Gull Pond be upgraded. Measurement of the outflow from Gull Pond is essential to determining the water budget including ground water inflow and outflow for the pond. Analysis of the first year of biweekly measurements has shown that a simple correlation between measured discharge and pond stage from a single measurement point on the shore of the pond does not produce a meaningful stage/discharge rating curve that can be used to estimate discharge from measurement of stage. Therefore, the common stream gauging methods employed by the U.S. Geological Survey would not be effective for this location. As explained previously in this report, wind effects may be responsible, in part, for the apparent lack of correlation. The simplest and most cost-effective approach to obtaining accurate discharge data through the Gull Pond outlet is by frequent measurement. More exotic and expensive measurements requiring construction to channel the outlet through a canal or flume instrumented with velocity measurement devices that measure the distortion of sound waves traveling through water, the Doppler effect, could be designed and installed.

For the continued monitoring at this site, however, we recommend discharge measurement with the Malcomb Pirny meter every seven days. Each measurement would be taken to represent the flow over seven days, 3.5 days before and 3.5 days after the measurement. By making measurements this frequently, the chances of misrepresenting flow because of one day wind conditions would be considerably reduced and tend to be averaged out. Furthermore, it is important to record period of no flow, as not doing so creates erroneously high estimates of the volume of discharged water.

It is further recommended as a desirable effort that a series of daily measurements be made to measure the effects of strong, steady winds in different directions and calm conditions for the purpose of understanding the relationship between wind and discharge which, along with wind direction, velocity and duration measurements, could possibly be employed to estimate influence on the stage discharge relationship. Successful demonstration of this approach would reduce the need for frequent discharge measurement for this study and provide a technique that could be transferred to application at other pond studies. As part of this research, wind velocity and direction would have to be recorded hourly. Also, wind driven effects on the surface of the pond would be determined. If it may be assumed that wind effects cause the distortion of the pond surface to be analogous to tilting of a planar surface, then three stage measurements made at the same time at three points equidistant along the shore of the pond could be used to define the attitude of the plane of the surface of the pond and to calculate the elevation of the center point (median) on the assumed planar surface of the pond. This investigation might have significant application

in the study of other pollutant and biological factors for the pond, as well as leading to better understanding of pond dynamics and the stage/discharge rating.

Well Network Surveying

It is recommended as an essential effort that measurement of the precise elevations of the measurement reference points used for this study be performed by an impartial, independent and highly reliable agent. The interpretations and analyses in this study are highly dependent on small differences of water level elevations (hundredths of a foot) measured at distant map locations (thousands of feet apart). Several instances where levels are not as one might anticipate are described in this report. These aberrations require somewhat more complicated and less direct interpretive explanation than expected by those doing the research and most assuredly by peer reviewers. In order to assure the credibility of the final analysis of this project, it is essential that water levels be independently verified or corrected.

Pond Surface Area Delineation

It is recommended as a highly desirable effort that measurements of pond storage changes be made more precise by using pond surface areas measured from aerial photography or from a global positioning system (GPS) for different (high and low) pond stages. Changes in pond storage are part of the water budget equation for each pond. For this report, pond areas were determined by digitizing the Wellfleet 1:25000 USGS Topographic Map. It is recommended that areas be determined from correct USGS aerial photographs taken for cartographic purposes and available from the EROS Data Center in Sioux Falls, South Dakota. Use of orthographic enlargements of these photographs would improve the measurement of the pond areas. Additionally, the different pond areas that would be represented by different pond elevations can be indexed to historical stage measurements available for Gull and, possibly, for Duck Pond, if pond level measurements are available for the dates of the available aerial photography. The areas of the ponds will be different between high and low stage as indicated by the apparent disappearance of beaches during high water levels. This approach would increase the precision of the calculations of volumes of storage and is dependent on the increase in precision of the measurements of area of the ponds which are multiplied by the stage changes to determine the volumes.

Additional Monitoring Wells

It is recommended that the observation well networks about the ponds be enlarged sufficiently to provide the needed data for delineation of the ground water drainage areas to the ponds. The current project was not initially designed to define drainage areas, for the ponds. Although the ground water levels adjacent to the ponds are well known, ground water levels more distant from the ponds, where the divides between drainage areas contributing to the ponds

and drainage areas contributing to other surface water bodies are located, are unavailable. Based on control points near the ponds, measured water levels suggest where the divides are likely to be (Figures 11 and 23), but these delineations are not sufficiently accurate for most management purposes. Additional observation wells drilled into the water table would have to be located, drilled, leveled and monitored in order to define the divides.

Pond Bottom Thickness and Hydraulic Conductivity

It is recommended as a highly desirable effort that the thickness and hydraulic conductivity of the pond bottom sediments that separate the ponds from the deep ground water flow system be better defined. Although the leakance of the pond bottoms can be adjusted to match observed water levels in the models, the leakance values are estimated only indirectly. The sediments from the bottom of Duck Pond have been sampled and these samples could be tested with a permeameter to determine their hydraulic conductivity. The thickness of pond bottom sediments can be determined with a depth finder (sonar-type devices) or with radar. The U.S. Geological Survey (LeBlanc, D.R., oral comm., 1995) has indicated that radar transported by boat effectively profiled pond sediments at the National Ground Water Research Site in Falmouth, Massachusetts, and the U.S. Geological Survey in Marlborough, Massachusetts, has been profiling streambed conditions with a variety of depth finders for a Statewide Bridge Scour project. Although the radar would be more expensive to use, the depth finder type tools are attenuated by depth of water and may not be capable of measuring sediment thickness below 40 feet. Duck Pond is as much as 65 feet deep. Actual measurement of the characteristics which determine leakance rates would substantiate the modeled leakance values and improve the credibility of the modeled pond/aquifer flow system.

Further Aquifer Response Testing

It is recommended that additional experiments be designed to measure the short-term water-level response at the water table to recharge events be applied. The timing of water-level rise in response to recharge from precipitation may have significant influence on the direction of ground water flow in the water table region of the aquifer. The test analyzed in this report suggests some short-term reversals of ground water flow direction. These conditions need to be better understood when trying to manage the potential flow of contaminants recharged to the water table. The rate and magnitude of recharge response at the water table may be related to the thickness of overlying unsaturated sediments and differences therefore apparently related to topography could have an influence on potential contaminant pathways into or not into a pond. The experiments should be designed to determine the timing and magnitude of water-level response to single and, therefore, similar recharge events in different locations where different unsaturated thicknesses are present. These should be coordinated with similar measurements of pond stage response to the same

events. For these measurements, it is recommended that a recording precipitation gauge be used as well. As mentioned previously, daily reading of precipitation gauges in the first year of study was not adequate for these analyses of short-term response.

Evaporation Monitoring

The measured pan evaporation seems to be less than the budget analyses would predict if evaporation was to be calculated as a residual. Attention should be given to selecting sites for the pans which are exposed to the same lengths of fetch as the ponds, and to evaporation occurring in the late fall, winter and early spring. During the first year of this study, the pans were operated only from May to November and it is likely that there was small, albeit significant to the overall budget, evaporation over the months that the pans were not in operation. The wide variability of measured evaporation rates from the two pond underscores the need to continue this site-specific monitoring to preclude reliance on assumed values. It is therefore recommended that semi-monthly evaporation monitoring continue at both sites until ice begins to form on the water surface in the pan, and resume immediately following ice-out. This approach may not capture all of the evaporation that occurs over one year, but it will greatly improve the reliability of observed values.

Precipitation Monitoring

In general, the decline in precipitation over the course of the study period caused water to be lost to ET that would have otherwise recharged the aquifer and ponds. This substantiates the need to continue to record precipitation. Moreover, since the precipitation records for the monitoring are so similar for each pond and are also identical to the NADP data, interpretation on a site-specific basis is difficult. Therefore, it is recommended that rain gages at both ponds continue to be monitored for at least one more year. If, after another year of rain gage monitoring the data continue to indicate identical trends as the NADP data, site-specific data can be replaced by NADP data. However, if another year of monitoring shows significant site-specific differences in precipitation, monitoring at both ponds should continue beyond next year.

This is very confusing. If they were identical (and they were not) it would make site-specific interp. easy!

Plugged Monitoring Wells

The NPS has noted that some observation wells have become plugged or bent (HW-13d was plugged and HW-14c is slightly bent). A review of the observation wells that have been vandalized or have failed for one reason or another should be undertaken by the NPS and measures to replace the data they provided should be evaluated and, where needed, corrective action taken.

This says nothing. We asked A+W to review situation and recommend which need replacement based on preliminary data.

Future Uses of the Ground Water Models

The year of monitoring provided a general understanding of the hydrologic systems at each pond which was critical to first developing initial conceptual models then developing numerical models. The preliminary modeling focused on calibrating the models to water levels collected during the monitoring period, or steady-state conditions. At this point the ground water models have been calibrated to these conditions, and therefore are a useful indicator of the distribution of water levels over the monitoring period. However, more annual data is need to further calibrate the model. The intent of a three year data collection period for which monthly data is collected is to generate a data base that can be considered representative of steady-state and transient conditions for these two study areas. As further data are collected, the models can be updated and refined in order to calibrate them not only to water levels that can be considered more representative of these areas, but also to water budget parameters as well. Then, as a predictor of hydrologic effects of changes in the study areas (natural or anthropogenic), these models may be used in either the steady-state or transient mode to model water levels for extreme conditions such as periods of drought or peak precipitation, or assess the effects of future pumping from water supply wells.

*Truely
calibrated?*

REFERENCES

- Chow, V.T., ed., 1964, Handbook of Applied Hydrology.
- Dowd, 1984, Modeling Groundwater Flow Into Lakes, Thesis Dissertation, Yale University.
- Frimpter, M.H., 1973, Ground-Water Management: Cape Cod, Martha's Vineyard, and Nantucket, Massachusetts: U.S. Geological Survey Open-File Report, 53 p.
- Frimpter, M.H., 1987, Massachusetts Ground-Water Resources, U.S. Geological Survey Water-Supply Paper 2275, p 249-254.
- Guswa, J. H., and Leblanc, D. R., 1985, Digital Models of Ground-Water Flow in the Cape Cod Aquifer System, Massachusetts: U.S. Geological Survey Open-File Report 2209, 112 p.
- Harbaugh, 1993, ZONEBUDGET, A Computer Program for Calculating Subregional Water Budgets Using Results from the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Model, U.S. Geological Survey.
- Hvorslev, M.J., 1951, Time Lag and Soil Permeability in Ground Water Observations, U.S. Army Corps of Engineers Waterway Experimentation Station, Bulletin 36.
- Kotteff, Carl, Oldale, R. N. and Hartshorn, J. H., 1967, Geologic map of the North Truro quadrangle, Barnstable County, Cape Cod, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-599, scale 1:24,000
- Leblanc and others, 1986, Ground-Water Resources of Cape Cod, Massachusetts, Hydrologic Atlas HA-692, U.S. Geological Survey.
- LeBlanc, D.R., J.H. Guswa, M.H. Frimpter, and C.J. Londquist. 1986. Ground water resources of Cape Cod, Massachusetts, U.S. Geological Survey Hydrologic Investigations Atlas 692, 4 sheets, scale 1:48,000.
- LeBlanc, D.R., 1995, oral communication.
- Letty, D.F., 1984, Ground-Water and Pond Levels, Cape Cod, Massachusetts, 1950-1982, USGS Open-file Report 84-719. ✖
- Maidment, David R., 1993, Handbook of Hydrology.

- Masterson and Barlow, 1994, Effects of Simulated Ground-Water Pumping and Recharge on Ground-Water Flow in Cape Cod, Martha's Vineyard, and Nantucket Island Basins, Massachusetts, U.S. Geological Survey Open-File Report 94-316.
- McDonald, H. R., & Harbaugh, A.W., 1984, MODFLOW, A Modular Three-Dimensional Finite-Difference Ground Water Flow Model, U.S. Geological Survey.
- Oldale, R. N., 1981 Pleistocene stratigraphy of Nantucket, Martha's Vineyard, the Elizabeth Islands and Cape Cod, Massachusetts, in Larson, G. J., and Stone, B. D. eds., late Wisconsinan glaciation of New England: Dubuque, Iowa, Kendall/Hunt, p. 1-34.
- Oldale, R. N., Koteff, Carl, and Hartshorn, J. H., 1971, Geologic map of the Orleans quadrangle, Barnstable County, Cape Cod, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-931, scale 1:24,000
- Oldale, R. N., 1968, Geologic map of the Wellfleet quadrangle, Barnstable County, Cape Cod, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-750, scale 1:24,000
- Oldale, R.N., 1981, Geologic History of Cape Cod, Massachusetts: U.S. Geological Survey, 23 p.
- Pfannkuch, H. O., and Winter, T. C., 1984, Effect of Anisotropy and Groundwater System Geometry on Seepage through Lakebeds, *Journal of Hydrology*, 75 (1984/1985), 213-237.
- Pfannkuch, H. O., and Winter, T. C., 1984, Effect of Anisotropy and Groundwater System Geometry on Seepage through Lakebeds, *Journal of Hydrology*, 75 (1984/1985), 213-237.
- Portnoy, J. W., 1996, personal communication.
- Ryan, B.J., 1980, Cape Cod Aquifer, Cape Cod, Massachusetts: U.S. Geological Survey Water Resources Investigations Report 80-571, 23 p.
- Soukup, M. A., 1977, Limnology and the management of the freshwater ponds of Cape Cod National Seashore, University of Massachusetts-National Park Service, Cooperative Research Unit, Report No. 35, 73p.
- Thornthwaite, C.W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Centerton, N. J., Drexel Institute of Technology, Publications in Climatology, v. 10, no. 3, 311p.

Winkler, M. G., 1994, Development of the Gull Pond Chain of Lakes and the Herring River Basin, Cape Cod National Seashore.

Winter, T. C., 1981, Effects of water-table configuration on seepage through lakebeds, *Limnol. Oceanogr.*, 26(5), 925-934.

APPENDIX A

Daily Precipitation at Duck and Gull Ponds

Appendix A. Daily Precipitation at Duck and Gull Ponds

Precipitation expressed in inches

Duck Pond Precipitation

Date	Precipitation (in)
18-May-94	1.8
20-May-94	0.05
25-May-94	0.15
15-Jun-94	1.95
22-Jun-94	trace
29-Jun-94	0.89
30-Jun-94	1.1
27-Jul-94	0.67
28-Jul-94	0.05
29-Jul-94	0.5
8-Aug-94	0.85
15-Aug-94	0.35
18-Aug-94	0.18
19-Aug-94	0.15
24-Aug-94	1.15
31-Aug-94	0.5
1-Sep-94	0.25
7-Sep-94	2.3
14-Sep-94	0.15
21-Sep-94	0.72
28-Sep-94	1.6
19-Oct-94	0.05
26-Oct-94	0.9
2-Nov-94	0.15
21-Nov-94	0.8
28-Nov-94	1.85
5-Dec-94	0.95
7-Dec-94	0.27
8-Dec-94	0.03
9-Dec-94	0.06
10-Dec-94	0.36
11-Dec-94	0.12
14-Dec-94	0.06
15-Dec-94	0.08
16-Dec-94	0.03
17-Dec-94	0.48
23-Dec-94	1.83
24-Dec-94	1.82
25-Dec-94	0.03
31-Dec-94	0.01
1-Jan-95	0.82
2-Jan-95	0.15
7-Jan-95	0.18
11-Jan-95	0.13
12-Jan-95	0.28

Gull Pond Precipitation

Date	Precipitation (in)
6-May-94	0.2
9-May-94	0.5
18-May-94	1.85
20-May-94	0.05
25-May-94	0.09
15-Jun-94	1.4
28-Jun-94	0.95
29-Jun-94	1.05
25-Jul-94	trace
27-Jul-94	0.66
28-Jul-94	0.1
29-Jul-94	0.5
8-Aug-94	0.85
15-Aug-94	0.35
19-Aug-94	0.33
24-Aug-94	1.15
31-Aug-94	0.5
1-Sep-94	0.25
7-Sep-94	2.75
14-Sep-94	0.22
21-Sep-94	0.93
28-Sep-94	1.6
5-Oct-94	0.1
19-Oct-94	0.05
26-Oct-94	1.2
2-Nov-94	0.2
22-Nov-94	1.2
28-Nov-94	1.85
5-Dec-94	0.95
7-Dec-94	0.27
8-Dec-94	0.03
9-Dec-94	0.06
10-Dec-94	0.36
11-Dec-94	0.12
14-Dec-94	0.06
15-Dec-94	0.08
17-Dec-94	0.03
18-Dec-94	0.48
23-Dec-94	1.83
24-Dec-94	1.82
25-Dec-94	0.03
31-Dec-94	0.01
1-Jan-95	0.82
2-Jan-95	0.15
7-Jan-95	0.18

Appendix A. Daily Precipitation at Duck and Gull Ponds

Precipitation expressed in inches

Duck Pond Precipitation

Date	Precipitation (in)
16-Jan-95	0.08
17-Jan-95	0.38
18-Jan-95	0.05
19-Jan-95	0.03
20-Jan-95	0.6
21-Jan-95	0.1
23-Jan-95	0.12
24-Jan-95	0.04
4-Feb-95	1.45
15-Feb-95	0.06
16-Feb-95	0.41
20-Feb-95	0.04
21-Feb-95	0.12
23-Feb-95	0.1
24-Feb-95	0.15
25-Feb-95	0.01
26-Feb-95	0.01
27-Feb-95	0.09
28-Feb-95	0.1
1-Mar-95	0.03
5-Mar-95	0.51
6-Mar-95	0.15
8-Mar-95	0.02
9-Mar-95	0.81
11-Mar-95	0.03
17-Mar-95	0.75
18-Mar-95	0.02
21-Mar-95	0.12
23-Mar-95	0.08
24-Mar-95	0.1
31-Mar-95	0.02
7-Apr-95	0.11
9-Apr-95	0.06
10-Apr-95	0.59
13-Apr-95	0.09
14-Apr-95	0.26
19-Apr-95	1.14
21-Apr-95	0.26
28-Apr-95	0.25

Gull Pond Precipitation

Date	Precipitation (in)
11-Jan-95	0.13
12-Jan-95	0.28
16-Jan-95	0.08
17-Jan-95	0.38
18-Jan-95	0.05
19-Jan-95	0.03
20-Jan-95	0.6
21-Jan-95	0.1
23-Jan-95	0.12
24-Jan-95	0.04
4-Feb-95	1.45
15-Feb-95	0.06
16-Feb-95	0.41
20-Feb-95	0.04
21-Feb-95	0.12
23-Feb-95	0.1
24-Feb-95	0.15
25-Feb-95	0.01
26-Feb-95	0.01
27-Feb-95	0.09
28-Feb-95	0.1
1-Mar-95	0.03
5-Mar-95	0.51
6-Mar-95	0.15
8-Mar-95	0.02
9-Mar-95	0.81
11-Mar-95	0.03
17-Mar-95	0.75
18-Mar-95	0.02
21-Mar-95	0.12
23-Mar-95	0.08
24-Mar-95	0.1
31-Mar-95	0.02
7-Apr-95	0.11
9-Apr-95	0.06
10-Apr-95	0.59
13-Apr-95	0.09
14-Apr-95	0.26
19-Apr-95	1.14
21-Apr-95	0.26
28-Apr-95	0.25

Annual Totals: 36.14

37.91

APPENDIX B

Horsley & Witten, Inc. Boring Logs

BORING LOG

Boring No. HW-1
Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hollow Stem Auger
Ground Water: _____

Date: 29 September 1993
Completion Depth: 42'
Location: 1,100' north of Duck Pond
Inspector: B. Morgan

Date: 29 September 1993
Depth, ft.: 33*
*to ground

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	f ⁺ /m SAND, trace f gravel f ⁺ /m SAND	ss-1 ss-2	24/15 24/15	1/1/2/3 2/2/2/4	cemented water box with clay seal	
10	f ⁺ /m SAND	ss-3	24/16	2/3/4/5		
15	f/m ⁺ /trace c SAND	ss-4	24/16	1/3/3/5		
20	vf/f ⁺ /m SAND, some silt	ss-5	24/23	5/9/10/12	2" dia. threaded PVC casing	
25	vf/f ⁺ SAND	ss-6	24/22	6/6/6/6		
30	f/m SAND	ss-7	24/15	6/6/6/9		
35	f/m ⁺ SAND	ss-8	24/19	3/4/3/4		
40	f/m ⁺ /c SAND	ss-9	24/14	4/5/9/7		
45	12" f/m ⁺ /c SAND, 12" silt/clay BOH 42'	ss-10	24/24	5/9/12/15	2', 0.010 slot, sch 40, PVC screen with point	
50						
55						
60						
65						
70						

Proportions used:

trace (tr) 0-10%
little (li) 10-20%
some (so) 20-35%
and 35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium
f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

Boring No. HW-3s
Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hollow Stem Auger
Ground Water: Date

Date	Depth, ft.
28 September 1993	1.5' *
* to ground	

[illegible]

Proportions used:

Abbreviations:

f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

BORING LOG

Boring No. HW-2
Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hollow Stem Auger
Ground Water: Date

Date: 28 September 1993
Completion Depth: 42'
Location: 600' north of Duck Pond
Inspector: B. Morgan

Date	Depth, ft.
28 September 1993	32*
*to ground	

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	f ⁺ /m SAND	ss-1	24/16	1/1/1/1	cemented water box with	
	f ⁺ /m SAND	ss-2	24/16	3/3/3/4	clay seal	
10	f ⁺ /m SAND	ss-3	24/16	3/4/5/5		
15	f ⁺ /m SAND	ss-4	24/15	3/3/3/4	2" dia. threaded PVC casing	
20	f/m ⁺ SAND	ss-5	24/15	3/6/6/7		
25	f/m ⁺ /trace c SAND	ss-6	24/15	4/6/9/10		
30	f/m ⁺ /trace c SAND	ss-7	24/14	9/16/23/16		
35	f ⁺ /m/trace c SAND	ss-8	24/16	4/6/11/10		
40	f ⁺ /m SAND, tr f gravel	ss-9	24/22	4/6/8/10		
45	f/m ⁺ SAND, tr f gravel	ss-10	24/16	5/6/5/6	2', 0.010 slot, sch 40,	
	BOH 42'				PVC screen with point	

Proportions used:

trace (tr)	0-10%
little (li)	10-20%
some (so)	20-35%
and	35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium

f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

Boring No. HW-3As
Sheet 1 of 1

Date: 30 September 1993
Completion Depth: 10'
Location: North end of Duck Pond
Inspector: B. Morgan

Date	Depth, ft.
30 September 1993	2.5' *
* to ground	

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	no samples taken due to well being located 50' from HW-3d				cemented water box----- with clay seal	
10	BOH 10'				1.25" dia. threaded galvanized--- casing	
15					2', 0.010 slot, stainless----- steel screen with point	
20						
25						
30						
35						
40						
45						
50						
55						
60						
65						
70						
75						
80						
85						
90						
95						
100						
105						
110						
115						
120						
125						
130						
135						
140						
145						
150						
155						
160						
165						
170						
175						
180						
185						
190						
195						
200						

trace (tr)	0-10%
little (li)	10-20%
some (so)	20-35%
and .	35-50%

f = fine
m = medium
c = coarse
f/m = fine to medium

f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

Boring No. HW-3Ad
Sheet 1 of 1

Boring No. HW-3Ad
Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hand Driven
Ground Water: Date

Date: 30 September 1993
Completion Depth: 20'
Location: North end of Duck Pond
Inspector: B. Morgan

Date	Depth, ft.
30 September 1993	2.5' *
* to ground	

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	no samples taken due to well being located 50' from HW-3d				cemented water box-----	
10					with clay seal	
15					1.25" dia. threaded galvanized--	
20					casing	
25					2', 0.010 slot, stainless-----	
30	BOH 20'				steel screen with point	
135						
40						
45						
50						

Proportions used:

trace (tr)	0-10%
little (li)	10-20%
some (so)	20-35%
and	35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium

f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

BORING LOG

Boring No. HW-4s
Sheet 1 of 1

Project:	Hydrology of Gull & Duck Ponds	Date:	1 October 1993
Client:	National Park Service	Completion Depth:	44'
Boring Contractor:	Desmond Well Drilling	Location:	1,000' west of Duck Pond
Boring Equipment:	Hollow Stem Auger	Inspector:	B. Morgan
Ground Water:	Date	Depth, ft.	
	<u>1 October 1993</u>	<u>35' *</u>	
	<u>*to ground</u>		

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	no samples taken due to well being located 3' from HW-4d				cemented water box-----	
10					with clay seal	
15						
20					2" dia. threaded PVC casing-----	
25						
30	BOH 44'					
35						
40						
45					2', 0.010 slot, sch 40,-----	
50					PVC screen with point	

Proportions used:

trace (tr) 0-10%
little (li) 10-20%
some (so) 20-35%
and 35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium
f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

BORING LOG

Boring No. HW-4d

Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hollow Stem Auger
Ground Water: _____

Date: 29 September 1993
Completion Depth: 54'
Location: 1,000' west of Duck Pond
Inspector: B. Morgan

Date: 29 September 1993
Depth, ft.: 38*
*to ground

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	f+/m SAND vf/f+/m SAND	ss-1 ss-2	24/18 24/16	1/1/1/1 3/3/3/4	cemented water box with clay seal	
10	f/m+ SAND	ss-3	24/18	4/4/4/5		
15	f SAND	ss-4	24/22	4/6/6/5		
20	vf SAND, silt, clay	ss-5	24/21	4/3/5/6	2" dia. threaded PVC casing	
25	f/m+/trace c SAND	ss-6	24/16	3/5/7/8		
30	vf+/f SAND	ss-7	24/18	5/10/11/12		
35	vf+/f SAND, some silt	ss-8	24/20	10/16/22/23		
40	vf+/f SAND, some silt	ss-9	24/19	11/13/25/24		
45	vf/f+ SAND	ss-10	24/19	7/13/12/16		
50	vf/f+/m SAND, some silt/clay	ss-11	24/24	6/12/20/20		
55	vf/f+/m SAND BOH 54'	ss-12	24/13	4/16/30/30	2', 0.010 slot, sch 40, PVC screen with point	
60						
65						
70						

Proportions used:

trace (tr) 0-10%
little (li) 10-20%
some (so) 20-35%
and 35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium

f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

BORING LOG

Boring No. HW-3d
Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hollow Stem Auger
Ground Water: _____

Date: 27 September 1993
Completion Depth: 70'
Location: North end of Duck Pond
Inspector: B. Morgan

Date: 27 September 1993
Depth, ft.: 1.5*
*to ground

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	f/m+ SAND f/m+/trace c SAND	ss-1 ss-2	24/17 24/16	1/1/3/6 2/4/4/7	cemented water box with clay seal	
10	f/m+/trace c SAND	ss-3	24/16	2/2/3/5		
15	f/m+/trace c SAND	ss-4	24/16	1/1/1/1		
20	f+/m/c SAND, tr f gravel	ss-5	24/24	1/3/4/5	2" dia.threaded PVC casing	
25	f+/m/trace c SAND	ss-6	24/18	5/5/6/7		
30	m/c SAND, tr f gravel	ss-7	24/11	3/4/7/8		
35	m/c SAND, tr f gravel	ss-8	24/18	3/6/10/10		
40	m/c SAND, tr f gravel	ss-9	24/19	5/6/10/10		
45	m/c SAND, tr f gravel	ss-10	24/20	3/4/8/10		
50	f/m+ SAND, bottom 2" silt,clay	ss-11	24/21	3/8/20/20		
55	f/m+/c SAND, tr silt & clay	ss-12	24/10	5/5/5/5		
60	12' f SAND, silt, clay	ss-13	24/24	3/2/3/2		
65	12' f/m+/c SAND f SAND, silt	ss-14	24/19	5/9/13/15		
70	f SAND, silt BOH 70'	ss-15	24/24	3/5/7/10	2', 0.010 slot, sch 40, PVC screen with point	

Proportions used:

trace (tr) 0-10%
little (li) 10-20%
some (so) 20-35%
and 35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium
f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

Boring No. HW-3m
Sheet 1 of 1

Boring No. HW-3m
Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hollow Stem Auger
Ground Water: Date

Date: 27 September 1993
Completion Depth: 50'
Location: North end of Duck Pond
Inspector: B. Morgan

Date	Depth, ft.
27 September 1993	1.5' *
* to ground	

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	no samples taken due to well being located 1' from HW-3d				cemented water box-----	
10					with clay seal	
15						
20					2" dia. threaded PVC casing-----	
25						
30						
35						
40						
45						
50	BOH 50'				2", 0.010 slot, sch 40, PVC screen with point-----	
55						
60						
65						
70						
75						
80						
85						
90						
95						
100						

Proportions used:

trace (tr)	0-10%
little (li)	10-20%
some (so)	20-35%
and	35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium

f/c = fine to coarse

v = very
+ = more
- = less

H&W, Inc.

BORING LOG

Boring No. HW-5
Sheet 1 of 1

Project:	Hydrology of Gull & Duck Ponds	Date:	30 September 1993
Client:	National Park Service	Completion Depth:	68'
Boring Contractor:	Desmond Well Drilling	Location:	1,000' south of Duck Pond
Boring Equipment:	Hollow Stem Auger	Inspector:	B. Morgan
Ground Water:	Date <u>30 September 1993</u> Depth, ft. <u>57*</u>		
	<u>*to ground</u>		

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
5	f ⁺ /m SAND	ss-1	24/13	1/1/2/2	cemented water box with-----	
	f ⁺ /m SAND	ss-2	24/16	4/4/5/5	clay seal	
10	m ⁺ /c SAND	ss-3	24/13	4/7/8/10		
15	m ⁺ /c SAND	ss-4	24/16	4/5/9/12		
20	m ⁺ /c SAND	ss-5	24/14	4/8/11/18	2" dia.threaded PVC casing-----	
25	m ⁺ /c SAND	ss-6	24/14	5/8/10/12		
30	f/m SAND	ss-7	24/15	8/14/14/13		
35	f/m SAND	ss-8	24/15	7/19/26/18		
40	f SAND	ss-9	24/15	7/15/17/15		
45	f SAND	ss-10	24/18	8/10/12/12		
50	f/mSAND,bottom 1" vf sand/silt	ss-11	24/22	3/6/13/15		
55	f ⁺ /m SAND	ss-12	24/14	3/7/11/12		
60	vf/f SAND, silt, clay	ss-13	24/22	6/7/11/12		
65	vf/f SAND	ss-14	24/24	1/2/5/6		
70	vf/f SAND	ss-15	24/18	4/6/10/6	2', 0.010 slot, sch 40,-----	
	BOH 68'				PVC screen with point	

Proportions used:

trace (tr) 0-10%
little (li) 10-20%
some (so) 20-35%
and 35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium
f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

BORING LOG

Boring No. HW-7
Sheet 1 of 1

Project: Hydrology of Gull & Duck Ponds
Client: National Park Service
Boring Contractor: Desmond Well Drilling
Boring Equipment: Hollow Stem Auger
Ground Water: Date

Date: 1 October 1993
Completion Depth: 13'
Location: 700' west of Duck Pond
Inspector: B. Morgan

Date	Depth, ft.
1 October 1993	3' *
* to ground	

[illegible]

Proportions used:

trace (tr)	0-10%
little (li)	10-20%
some (so)	20-35%
and	35-50%

Abbreviations:

f = fine
m = medium
c = coarse
f/m = fine to medium

f/c = fine to coarse
v = very
+ = more
- = less

H&W, Inc.

BORING LOG

Boring No. HW-10

Sheet 1 of 1

Project: National Seashore-Ponds

Client: Nature Conservancy

Boring Contractor: Desmond Well Drilling, Inc.

Boring Equipment: Hollow Stem Auger

Ground Water: Date 5 April 1994 Depth, ft. 60.6 Below Land Surface

Date: 5 April 1994

Completion Depth: 68.6 ft.

Elevation: N/A

Inspector: H. Frank

Depth (feet)	Description	Sample Number	Penetra./ Recovery	Blow Count	Comments	Well Details
0					Standing Road Lock Box	
	F-M-C Brown Sand	HW-10.1	16"	4-4-4-4	1 ft. Concrete Seal	
5						
	F-M-C Brown Sand	HW-10.2	15"	4-6-7-9		
10						
	F-M-C Light Brown Sand	HW-10.3	13"	3-4-6-7		
15						
	F-M-C Light Beige Sand, some Gr & rock fragments	HW-10.4	13"	9-12-19-26		
20						
	M-C Light Brown Sand, SoF gravel	HW-10.5	15"	5-7-11-16		
25						
	F-M-C Brown Sand coarsening up	HW-10.6	16.5"	14-21-23-24		
30						
	F-M-C Brown Sand	HW-10.7	15.5"	10-16-16-23	68.5 ft. Threaded PVC Riser	
35						
	M-C Light Brown Sand	HW-10.8	15"	10-18-19-20		
40						
	VF-F-M Brown Sand, So VF-F Orange sand	HW-10.9	18"	16-25-27-36	2 ft. Bentonite Seal	
45						
	VF-F Beige Sand, coarsening up to M-C Brown sand	HW-10.10	15"	5-13-24-36	Native Backfill	
50						
	GY/BR Si & So Cl, VF-F BR Sand	HW-10.11	18"	9-19-29-45		
55						
	F-M-C Light Brown Sand, So VF Gr	HW-10.12	15"	12-22-33-42	Static Water Level	
60						
	F-M-C Red Sand	HW-10.13	24"	6-17-30-42	2 ft. .010 slot PVC Screen	
65						
70					Bottom of Hole	

Proportions used:

trace (tr) 0-10%
 little (li) 10-20%
 some (so) 20-35%

Abbreviations:

f = fine
 m = medium
 c = coarse
 f/c = fine to coarse
 v = very
 + = more

H & W, Inc

APPENDIX C

Model Input Files