WATER TABLE LEVEL DATA UPDATE & DISCUSSION

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Martha's Vineyard Commission

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Introduction:

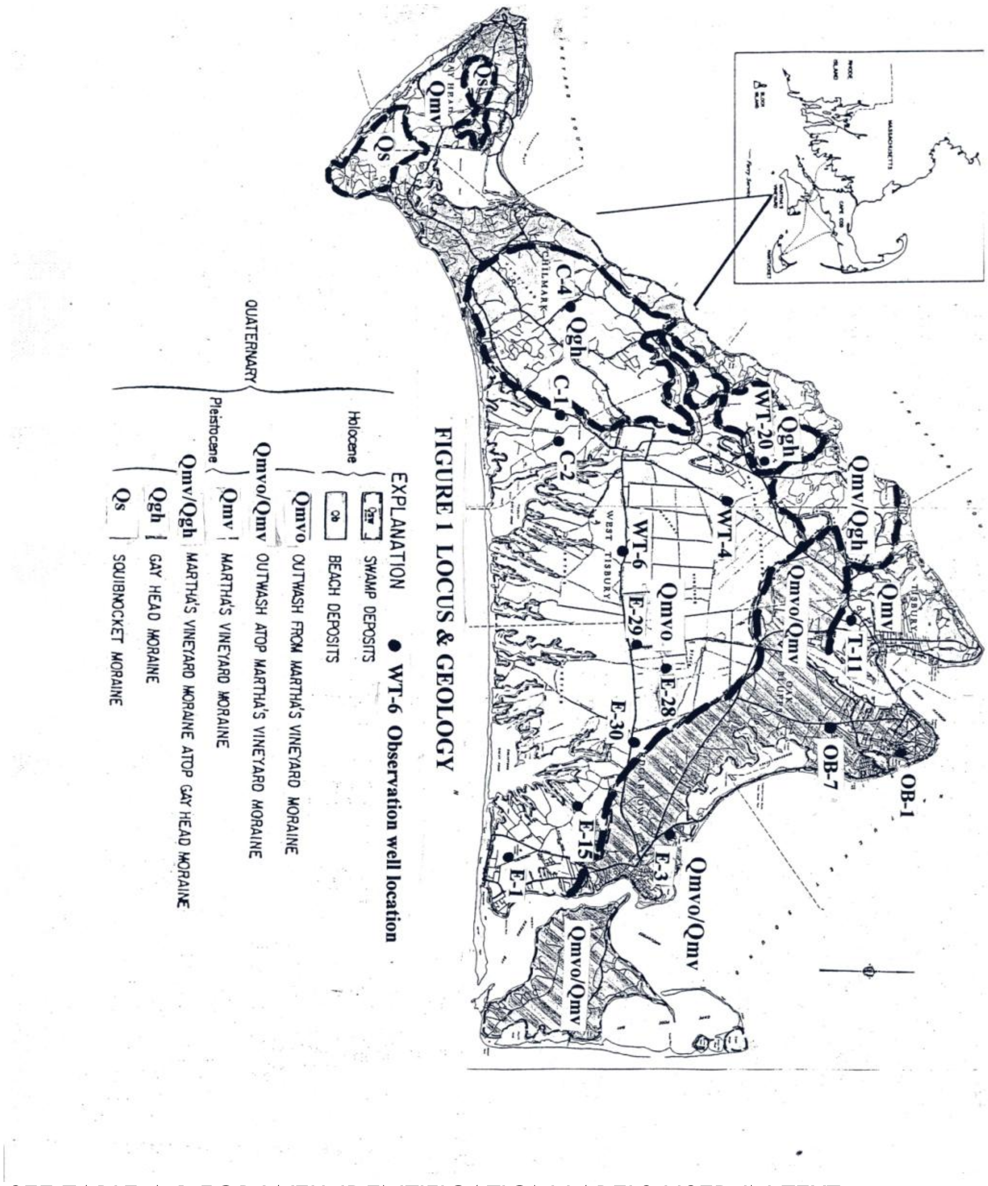
The Island has numerous monitoring wells drilled over the last 30 plus years. The wells were driven for a wide variety of reasons on behalf of numerous Boards and Commissions. For these reasons, the specifications on these wells are scattered through numerous files and in a large number of reports, most with their own well naming approach. The identifying numbers used in this report are from the USGS system and are cross-referenced with the MVC well atlas or the agency installing the well in Table A-1 in the appendix at the end of the report. Many of the observation wells now have GPS coordinates.

The purpose of this report is to summarize the data collected from 1992 through 2008 from an Island-wide network of 15 monitoring wells. The well locations discussed in this report are shown in Figure 1. Well level data is recorded in cooperation with the US Geological Survey. Most of these wells have been measured monthly since late in 1991. However, for one well (E-28 or USGS ENW-52), I have a record since late 1978. This data is included to give a historical perspective to the 17 years of data that is the primary focus of this report.

All water levels are determined by use of a chalked steel tape. Well levels are collected during the last week of each month. All measurements in the field are made to the lip of the casing or other measurement point and corrected to NGVD or other datum in the office. Repeat measurements are made at each well to check for measurement errors. Any duplicate reading that is off by more than 0.02 feet is repeated until the error is reduced to less than or equal to that distance. A standard error of plus or minus 0.02 feet is typical of the data reported here.

Most of the wells involved have been surveyed to the top of the well casing (TOC) or protective cover or street box so that precise water table elevations can be determined and compared. However, there are some wells that have not been surveyed and for which the water elevations recorded are estimates. For these wells, the relative changes in water level from month to month at these locations are exact to within the errors described above.

The wells in this survey are primarily found in the outwash plain (Qmvo) and in the eastern moraine (Qmvo/Qmv) (see Fig. 1). The collection of this data is vital to gaining a thorough understanding of the hydrology of the various water bearing formations on which we depend for our drinking water supplies and into which various contaminants are released in the disposal of wastewater, infiltration of road runoff, past disposal of solid waste and spills of various chemicals. To plan for a sustainable future source of drinking water that does not compromise either the quality of the supply or the complex interaction between ground and surface waters in our coastal ponds, we need to know as much as possible about what is "average" for the water table elevation and what range of elevations is typical during periods of excess precipitation and drought.



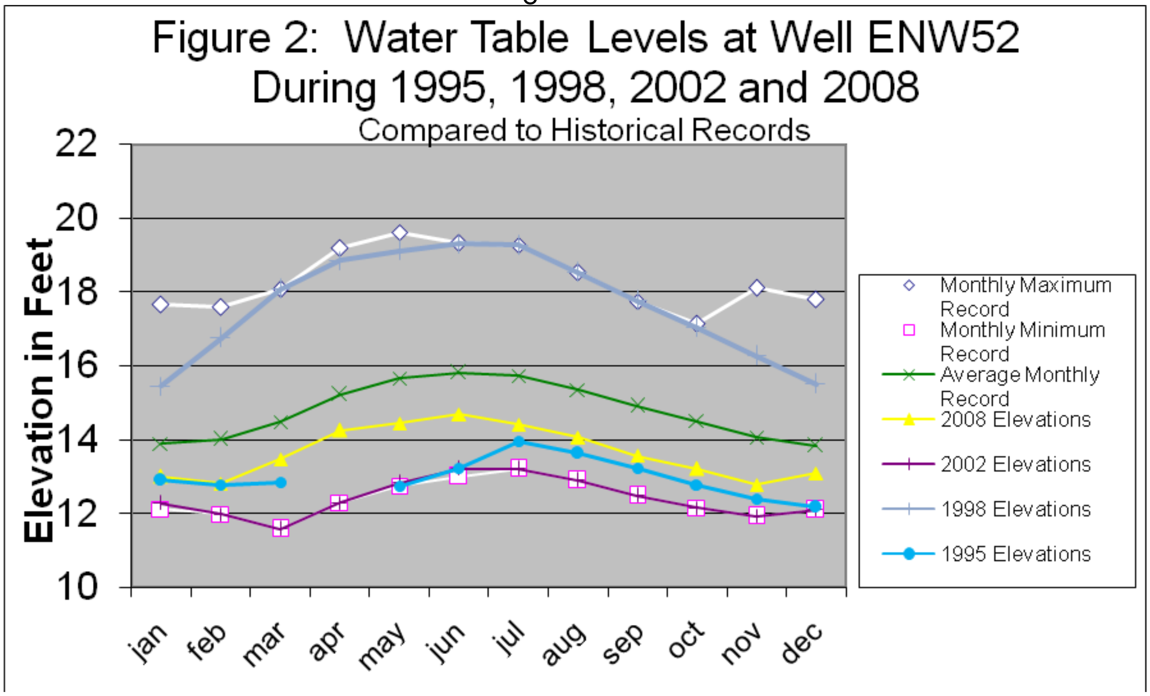
SEE TABLE A-1 FOR WELL IDENTIFICATION LABELS USED IN TEXT

Water Table Elevation Statistics:

It should be kept in mind that groundwater levels are a reflection of climate, which is known to be changing at a pace that is readily measured on a human time scale (50 to 100 years). The averages determined at this time will continue to shift but should serve for planning purposes on the same time scale.

Record levels, both minimum and maximum, have been set for a number of months during a single year that follows and builds on either a dry period or unusually high precipitation and groundwater recharge (see pre-2002 and pre-1998 rainfall data in Table 2 and compare to Figure 2 record setting years of 1996 and 2002). 2002 brought with it consecutive 24-year records for low water tables during all months except January, May and June at well

ENW52 (E-28). 2002 minimums evolved out of a dry period that began in 1999. Maximum water table elevations in this well for the month of March and the period from July through September were all set during 1998 that followed a wet period in 1996 and 1997. Selected yearly charts for this well compared to maximum, minimum and average elevations for each month are shown in Figure 2.



Since 2002, the water table has varied around the average value without real extremes for each month over the survey period. The record for 2008 is summarized in Table 1 where the "Departure from Average" values for each month are given for all wells that are regularly measured. The departure is determined by subtracting 2008 elevation for each month from the average elevation for that month. The 2008 elevations are almost all negative indicating that the water table at most wells was below average for most of the year. Exceptions include CNW36 that is located in Chilmark near Tisbury Great Pond where the elevation of the water table is affected by the elevation of the Pond.

In these statistics, note that the range of the extremes is most for wells in the interior (XEW39 and ENW52) where it is 5 to 7 feet and least for wells nearer to the shore (CNW36 and ENW60) where the difference is 2 feet or less. These ranges are the extremes for each month over a number of years. A similar pattern was noted by Delaney on **an annual basis** who concluded that the water table fluctuated less than 5 feet during a given year in areas where the water table stood more than 15 feet above the NGVD datum (that is about 15 feet above sea level) and less than 3 feet where the water table was less than 5 feet above NGVD (Delaney, 1980). This phenomenon is in part the result of the groundwater flow in the elevated part of the aquifer having a larger vertical component than is found nearer to the shore. The hydraulic gradient in these areas is lower than it is nearer to the shorelines where the aquifer is constantly discharging water. The result is that the recharging water piles up and when there is no recharge, the continuing discharge drops the water table by a greater amount.

TABLE 1: MONITORING WELL STATISTICS- 1992 to 2008										
					All values are in feet relative to the National Geodetic Vertical Datu					
Well # >>>	CNW36(c2)	ENW52 (e28	ENW60(e1)	ENW81(e3)	E30	OBW36(ob7)	TOW18(t11)	XEW38(wt6)	XEW39(wt4)	E15
Well Elevation	23.8	32.5	20.9	14.8	28.9	43.9	113.8	48.9	76.7	22.95
SEE COMMENTS										
Average elevations-Feet	updated to '08									
jan	5.87	13.90	4.43	6.21	8.60	5.15	7.64	13.66	22.83	6.03
feb	6.19	14.01	4.43	6.40	8.84	5.30	7.57	13.74	22.70	6.56
mar	6.64	14.47	4.72	6.72	9.09	5.53	7.62	14.08	22.60	6.82
apr	6.22	15.23	4.79	6.79	9.89	6.05	8.01	14.92	23.50	7.07
may	5.93	15.67	4.47	6.60	9.75	5.83	8.02	14.83	24.25	6.87
jun	5.71	15.81	4.21	6.15	9.54	5.67	7.84	14.85	24.33	6.75
jul	5.15	15.73	3.89	5.68	8.85	5.11	7.83	14.59	24.77	6.24
aug	4.72	15.34	3.74	5.31	8.43	4.86	7.73	14.23	24.63	5.58
sep	4.76	14.92	3.80	5.70	8.14	4.74	7.70	13.89	24.16	5.57
oct	4.91	14.51	3.82	5.78	8.08	4.78	7.73	13.59	23.59	5.42
nov	4.93	14.07	4.01	5.92	8.09	4.86	7.69	13.43	23.40	5.42
dec	5.50	13.84	4.35	6.07	8.36	5.07	7.71	13.50	22.86	5.81
MONTHLY MAX Over Record		updated to 2007								
	CNW36(c2)	ENW52 (e28	ENW60(e1)	ENW81(e3)	E30	OBW36(ob7)	TOW18(t11)	XEW38(wt6)	XEW39(wt4)	E15
jan	7.02	17.66	5.68	7.30	10.05	6.60	9.05	15.89	26.19	7.22
feb	7.71	17.59	5.90	7.73	10.51	6.95	9.04	16.04	26.73	7.80
mar	8.14	18.07	5.71	7.91	10.73	7.57	9.35	16.88	27.07	8.48
apr	7.81	19.19	5.45	7.64	11.37	7.71	9.80	17.35	27.75	8.15
may	6.80	19.61	4.92	7.25	11.22	7.26	9.91	17.12	28.92	7.91
jun	6.94	19.32	5.14	7.14	11.13	6.97	10.01	17.58	29.39	7.78
jul	5.84	19.26	4.58	6.57	10.44	6.28	9.82	17.15	30.38	7.44
aug	5.70	18.52	4.48	6.36	9.81	5.83	9.83	16.57	29.99	6.55
sep	7.58	17.74	6.41	7.21	9.38	6.45	9.66	16.02	29.37	8.15
oct	7.66	17.14	6.42	7.84	9.20	7.28	9.42	15.95	28.60	8.69
nov	5.98	18.10	4.92	7.46	9.20	7.13	9.03	16.20	27.85	8.17
Dec	6.75	17.79	5.47	7.37	9.49	6.81	9.01	15.90	26.43	7.51
MONTHLY MIN Over Record		updated to 2007								
	CNW36(c2)	ENW52 (e28	ENW60(e1)	ENW81(e3)	E30	OBW36(ob7)	TOW18(t11)	XEW38(wt6)	XEW39(wt4)	E15
jan	5.01	12.13	3.91	5.64	7.44	4.27	6.83	12.27	19.90	5.25
feb	5.37	11.98	3.87	5.22	7.54	4.24	6.78	12.19	20.19	5.52
mar	5.19	11.59	3.86	5.82	7.56	4.43	6.73	11.88	20.32	5.73
apr	5.05	12.30	3.85	5.81	8.23	4.47	6.69	12.20	19.99	5.95
may	4.34	12.74	3.86	5.81	8.33	4.42	6.49	12.54	20.23	5.21
jun	5.02	13.01	3.64	5.23	8.28	4.38	6.43	12.80	20.49	5.67
jul	4.24	13.21	3.45	4.25	7.62	3.98	6.04	12.47	20.72	5.51
aug	3.70	12.90	3.30	4.60	7.21	3.81	5.94	12.07	20.59	5.05
sep	3.66	12.48	3.37	4.35	7.02	3.89	6.09	11.82	20.33	4.88
oct	3.73	12.15	3.41	5.16	7.00	4.07	6.17	11.69	20.18	4.69
nov	4.18	11.94	3.42	5.28	7.45	4.01	6.27	11.63	19.85	4.69
Dec	4.17	12.10	3.43	5.32	7.31	4.12	6.49	12.17	19.53	4.65
Departure from Historical Average: By Month for 2008										
	CNW36(c2)	ENW52 (e28	ENW60(e1)	ENW81(e3)	E30	OBW36(ob7)	TOW18(t11)	XEW38(wt6)	XEW39(wt4)	E15
jan	0.01	-0.89	-0.30	-0.61	-0.68	-0.55	0.01	-0.50	-0.03	-0.40
feb	0.28	-1.19	0.00	-0.25	-0.60	-0.43	-0.05	-0.48	-0.34	-0.41
mar	-0.59	-0.99	0.03	-0.35	0.06	0.03	0.00	-0.13	-0.42	0.10
apr	-0.91	-0.98	-0.64	-0.29	-0.54	-0.66	-0.38	-0.85	-0.68	-0.59
may	0.22	-1.23	-0.06	-0.21	-0.64	-0.33	-0.33	-0.73	-1.13	-0.28
jun	0.00	-1.12	-0.58	-0.40	-0.84	-0.53	-0.41	-0.69	-0.93	-0.73
jul	-0.20	-1.31	-0.16	-0.18	-0.66	-0.29	-0.67	-0.75	-1.29	-0.48
aug	0.21	-1.27	-0.22	-0.40	-0.57	-0.15	-0.37	-0.70	-1.42	-0.13
sep	0.35	-1.35	-0.05	0.02	-0.56	-0.19	-0.31	-0.59	-1.36	-0.12
oct	0.49	-1.30	-0.08	-0.10	-0.68	0.25	-0.22	-0.49	-1.22	-0.36
nov	0.52	-1.29	-0.08	0.07	-0.58	0.11	-0.16	-0.63	-1.50	-0.37
dec	0.84	-0.75	0.50	0.28	-0.03	0.46	-0.33	-0.16	-1.15	0.16

Precipitation & Groundwater Recharge:

The National Weather Service has maintained a weather observer station in Edgartown since 1946. For the period from 1946 through 1975, precipitation averaged 45.82 inches per year. An evaluation of precipitation records during the 1951 to 1998 period increased the average slightly to 46.94 inches. On the Vineyard, rainfall is fairly evenly distributed through the year, being somewhat higher in the months of November through May and lower during June through October (with the exception of August which can be a wet month).

The loss of water to the air from plant's respiration and by evaporation (evapotranspiration) is greatest during the growing season (roughly May through September). The annual evapotranspiration was estimated at 23.7 inches and the excess precipitation recharge to the groundwater annually was estimated at 22.2 inches (Delaney, USGS, 1980). The data is summarized in Table A-2 and Figure A-1in the Appendix. The recharge estimate has recently been revised by the Massachusetts Estuaries Project to 28.7 inches to better reflect the increased average precipitation and reconcile with observed water table response (Howes et al, 2008).

Groundwater recharge is focused in the winter and spring portion of the year when plant uptake and evaporation are lowest. The water table elevation rises to an annual high point in spring or early summer. During the summer through fall period, nearly none of the precipitation falling recharges to the groundwater, causing the water table level to decline as groundwater continues to flow toward its discharge point at the shore. Occasionally, early fall hurricanes will produce recharge in late summer.

Massachusetts is currently moving out of a dry period that extends back through 2007 as indicated by the Palmer Z index (see Appendix Figure A-2). In response, the water table at well ENW52 was below average for each month during 2008 after dropping below the average in October 2007 (Table 1). During 2006, the water table was above the average elevation on the back of the generally above normal precipitation in 2003 through 2006.

The low water table level in 2002 at the time of the last report resulted from significant deficits in precipitation (see Table 2) during 1999 through 2002. Despite large amounts of precipitation during November and December 2002 that brought that year's total up to near average, the preceding deficit led to record low water-table stands in well ENW52 (E-28) for most months.

TABLE 2: Annual Precipitation and Departure from Average

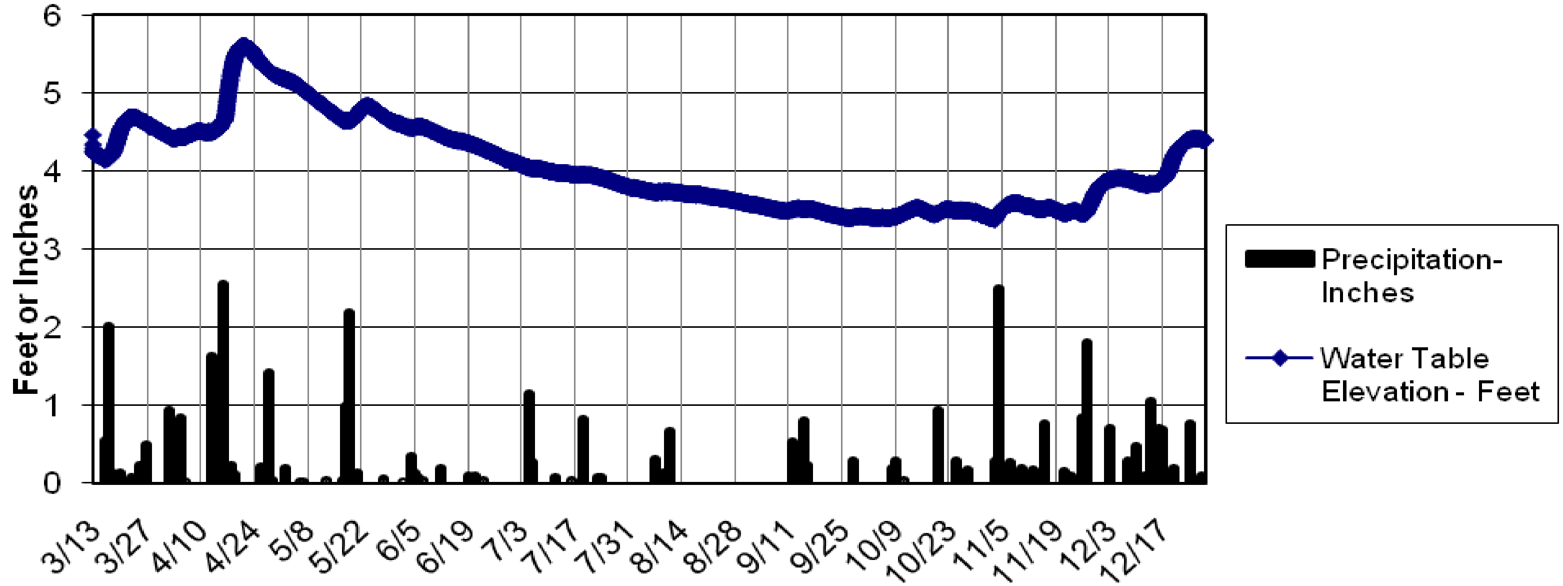
YEAR	TOTAL PRECIPITATION inches	DEPARTURE FROM AVERAGE (46.94") inches	Running Average Two-Year Departure from the Average
1990	44.7	-2.24	
1991	47.6	+0.66	-0.79
1992	43.8	-3.14	-1.24
1993	44.1	-2.84	-2.99
1994	45.3	-1.64	-2.24
1995	42.0	-4.94	-3.29
1996	61.6	+14.66	+4.86
1997	49.1	+2.16	+8.41
1998	47.5	+0.56	+1.36
1999	40.5	-6.44	-2.94
2000	42.3	-4.64	-5.54
2001	42.39	-4.55	-4.6
2002	46.68	-0.26	-2.41
2003	50.01	+3.07	+1.41
2004	42.58	-4.36	-0.65
2005	48.85	+1.91	-1.23
2006	50.98	+4.04	+2.98
2007	44.40	-2.54	+0.75
2008	45.57	-1.37	

Rainfall Data provided by Mark Lovewell, NWS Weather Observer, for Edgartown

The Water table response to precipitation is generally seasonal occurring when the loss of moisture to the air by evapotranspiration is lowest during late winter and spring. In order to evaluate changes in the aquifer over the period covering times of recharge and discharge, a Global WL15 water level logger was placed in well ENW60 (E1) in March 2007 and set to record the water table level over the pressure transducer at 1 hour intervals. The device was removed in December 2007 and the record provides the basis for Figure 3.

At this location, the water table is about 12 feet below grade. The soil type is Katama sandy loam that typically has 16 inches of sandy loam over sand and loamy coarse sand (less than 5% clay). Percolation rates are indicated at 2 to 20 inches per hour (USDA, 1986). This implies that rainfall should reach and recharge the groundwater within a few days following a rain event. In Figure 3, following precipitation on 13 April of 1.6 inches and 16 April of 2.5 inches, the water table increases in response by 1.1 feet over the period from18 to 22 April.

Figure 3: Precipitation and Water Table Response: Katama Airpark, 2007



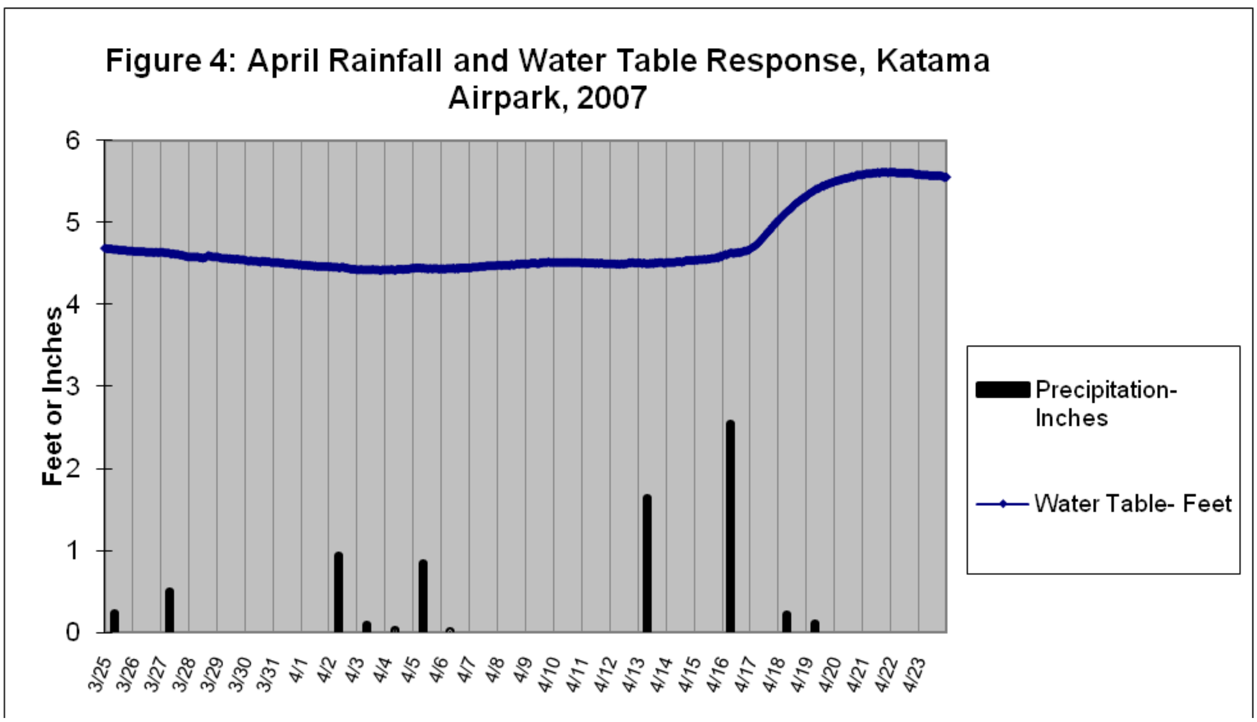
To better illustrate the lag between precipitation and recharge, the graphics are expanded for this period in Figure 4.
In this figure, the vertical lines are about 12:45 a.m. on the date indicated. The rainfall records are typically collected in the morning of the date indicated reflecting the preceding 24 hours and are placed accordingly on this chart.

The water table shows a slight drop between March 25 and April 10 and no significant change in elevation from 10 April to 14 April. By the 15th it is up but by only 0.025 feet. The water table then proceeds to increase as follows:

- 0.08 feet on both the 16th and 17th and
- Jumps by 0.35 feet by the 18th and
- Up by another 0.29 feet by the 19th.
- On the 20th it has increased another 0.17 feet from which point it only increases slightly through the 22nd.

Prior to the 13 April rain, there were rain events of 0.9and 0.8 inches on 2 April and 5 April but there was no substantial response in the water table during the following 10 days indicating that precipitation was ineffective at recharging the water table. This rainfall may have replenished soil moisture or was largely lost to evaporation. The relative stability of the water table over the period from March 25 to April 16 indicates that the increase in the water table elevation discussed is almost certainly the result of the 2 rain events on the April 13 and 16.

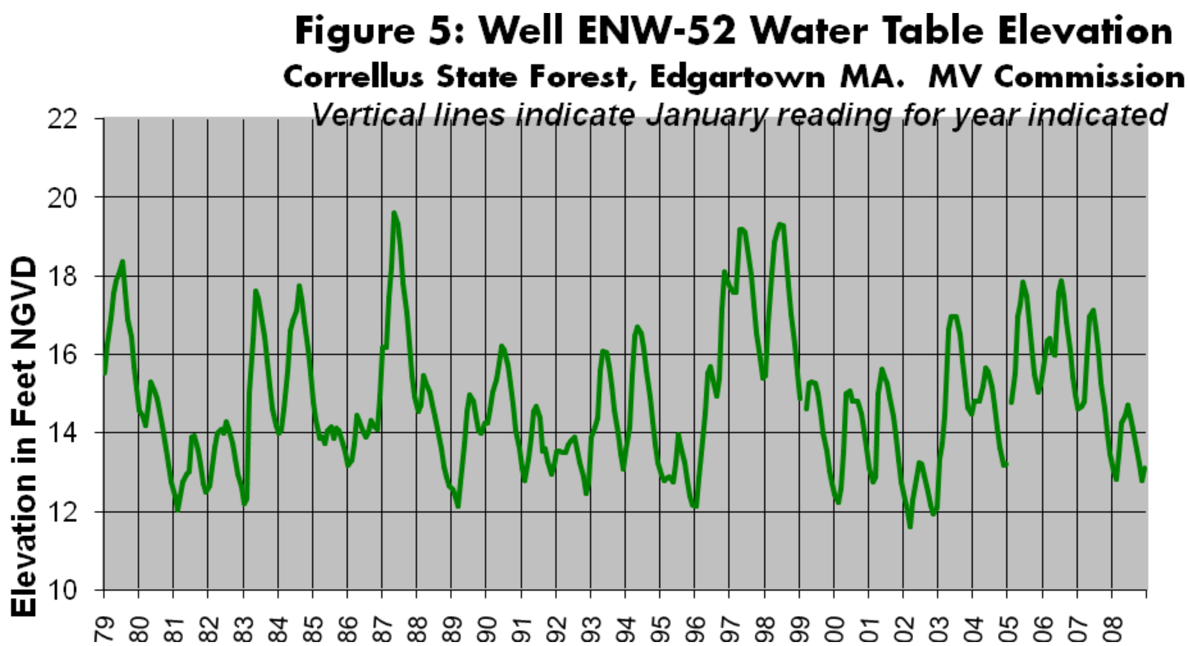
This suggests that the leading edge of the recharge reached the water table by16 April or 4 days after the first precipitation event with the bulk of the recharge occurring 5 to 6 days after the two rain events. Given an estimate of 30% porosity in the sediment, the 1.1 foot rise in the water table requires about 4 inches of water that is nearly all of the precipitation in those two events.



From the high point attained on April 22 of 5.62 feet, the water table begins a general decline that continues until the low point of the record is reached about 27 September at 3.4 feet elevation

(Figure 3). This decline in elevation results from a lack of recharge over the growing season and the continuous discharge of the water table to Herring Creek and the Atlantic Ocean to the south of this well. The indication is that, over this period, the water table dropped 0.014 feet per day (about 0.2 inches) without recharge. The water table is cut by the east to west Herring Creek over a distance of 4700 feet along Atlantic Drive. A block of the aquifer 4700 feet on a side dropping 0.014 feet would discharge approximately 300,000 cubic feet per day.

As discussed, the average water table position is a reasonable reflection of the departure of the year's precipitation from the annual average within the setting of recent previous years' precipitation and resulting water table level. For example, during the years 1992 through 1995 and 1999 through 2002 when annual precipitation was below average (Table 2) the water table is at low stands. This is illustrated in Figure 5 where during those years the water table at well ENW52 makes a spring peak that is below 17 feet. When a wet cycle began in 1996, the water table made a double peak in response to the excess rainfall (17.35 inches above average from August through October) and the highest level for the year was reached in November. Near record spring water table levels followed in both 1997 and 1998.



Summary of Seasonal Water Level Fluctuations:
In response to the rainfall-evapotranspiration cycle (Figure A-1, Appendix), recharge to the groundwater typically occurs during the late winter and spring and not during the late summer and fall. The recharge is superimposed on groundwater discharge that is relatively constant at least within a given year and the result is that the water table rises in late winter and spring and declines through the summer and fall. The timing and amount of precipitation during the time of least evapotranspiration (i.e. winter/spring) will usually determine the timing and maximum level of the water table in late spring for most years.

As discussed in a previous report (Wilcox, 1996), an examination of the data collected for 18 wells monitored on a monthly basis from 1991 through 2001 indicated that the high water tables were found most often during the March through May period (about 60 percent). Only rarely (13 times out of 149 data sets examined) did the highest water table for the calendar year occur between September and November (as was the case in 1996 in response to an unusually wet August through October).

On Cape Cod, 30 percent of the maximum annual water level elevations were recorded in the month of April and 67 percent occurred from February through May. "Water level was at an annual maximum most frequently in April in 10 of the 13 wells and in January, March and May in the remaining three." (Frimpter, USGS Report 80-1008)

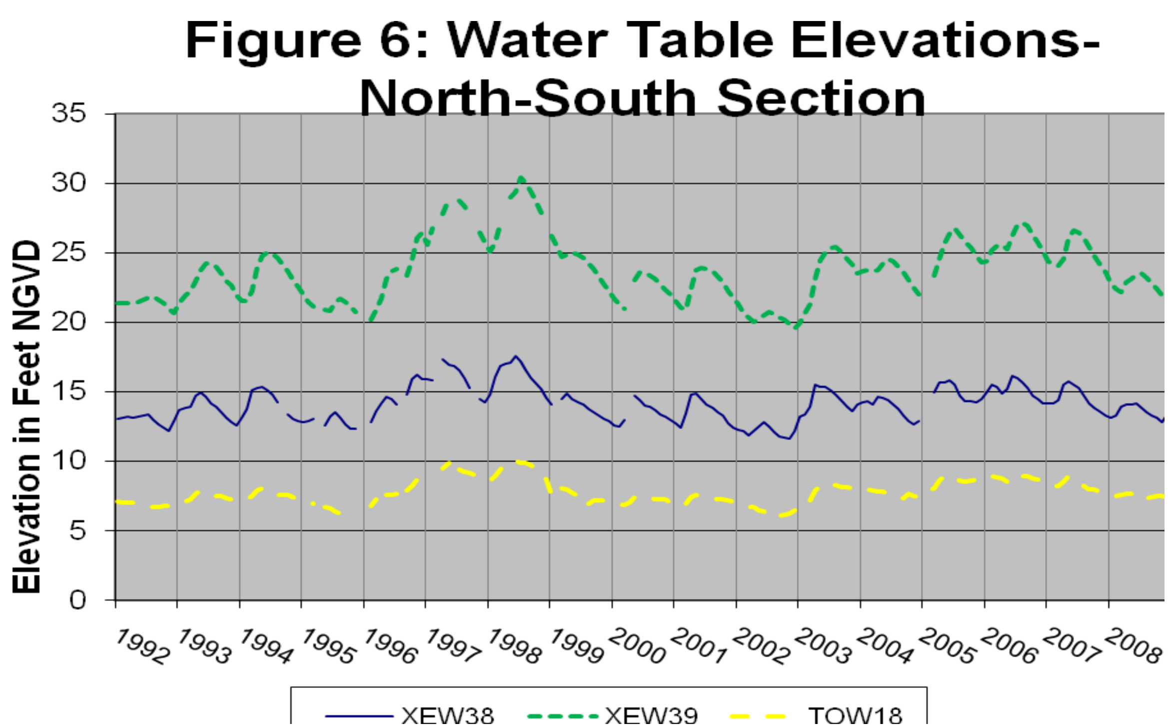
On the Vineyard, the lowest water tables for the year occurred most often in December and around 90 percent of the time during the period from September through February but only 1 time in 149 records during the March through May time period.

This data was reviewed on a calendar-year basis and there might be some slight shift if viewed from a growing season or rain cycle basis – either using the standard water year beginning in October or with the time of lowest water table in December. However, it seems certain that the generalizations made above would continue to hold.

Observation Well Data for the Outwash Plain
Most of the wells regularly surveyed are located in the outwash deposits from the Wisconsin glaciation (Qmvo in Figure 1). This geological deposit consists of layered sand and gravel that extends to well below sea level. A deep boring at the location of well ENW52 by the USGS (Hall et al, 1980) provides the primary basis for our current knowledge of this deposit. The primary aquifer was identified to a depth of about 70 feet below NGVD. At that point a thin, silty sand was encountered (~20 feet) that separated the Primary from the Secondary aquifer. This lower deposit continues to a depth of about 150 feet below NGVD. The Secondary aquifer was determined to be a poor aquifer containing high levels of iron. Hall (1980) described the upper 100 feet of the entire outwash deposit as medium to coarse white sand with scattered pebbles similar to outcrops of other Pleistocene strata. Since this stratigraphic study, the silty layer separating the two aquifers has been found to be discontinuous elsewhere in the outwash plain. All outwash wells reported here are completed within the Primary Aquifer.

The highest groundwater elevations in the outwash aquifer are centered on the area between the intersection of Old County and State Road, Indian Hill Road and the landfill in West Tisbury. Groundwater flows outward primarily toward the north and south and to a more limited extent toward Oak Bluffs and Edgartown where it is drawn from supply wells or discharges into coastal ponds. The majority of flow is toward the direction of greatest change in head (drop in water table elevation) that is toward the nearest ponds that are Tashmoo to the northeast, Tisbury Great Pond to the south and Lagoon Pond to the east-northeast. Lesser flow is toward the other south shore ponds that are further to the east. To protect existing and future water supplies, the Town of West Tisbury created a zoning overlay water resource protection district in this area with restrictions on uses that might adversely impact water quality.

In Figure 6, the annual water table levels are plotted for three wells that occur in a north to south profile. Well TOW18 is the northernmost well at an elevation of 113.8 feet in Tisbury near the DPW office and barn. Well XEW39 is at an elevation of 76.7 feet and is located on Old County Road in West Tisbury north of the School. This well is situated in that portion of the aquifer where the groundwater stands near the highest elevations. Well XEW38 is the southern most well at an elevation of 48.9 feet and is found on the West Tisbury-Edgartown Road near the Magid Development pond. See Figure 1 for well locations. The distance between well TOW18 and XEW39 is about 17,000 feet indicating an increase in water table elevation of about 1 foot per 1000 feet. The drop down from XEW39 to XEW38 is at a rate of about 0.9 feet per 1000 feet.



Clearly the range of water table levels is greatest for XEW39 (water table above 15 feet elevation) and least for well TOW18 (water table elevation near 5 feet). Precise average annual elevations and range of water table levels are found in Table 1.

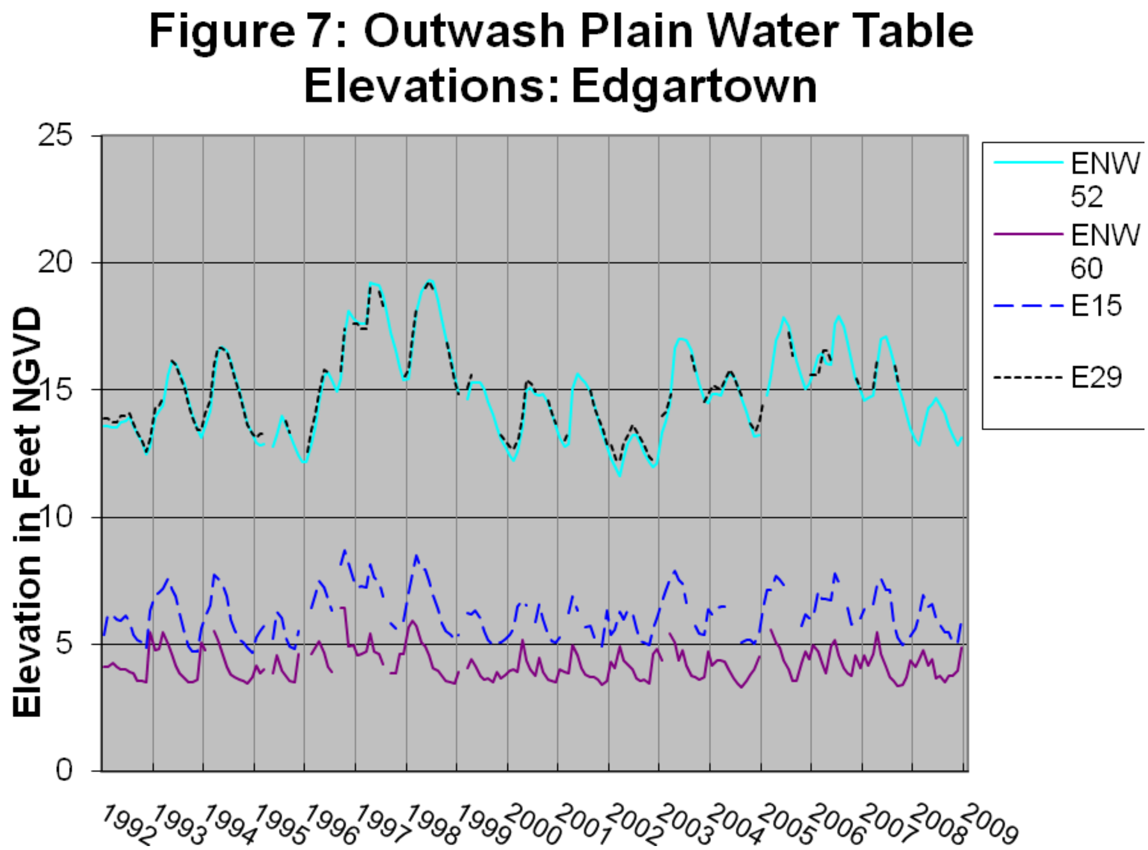
In Figure 6, the vertical year marker lines are for January of each year. The lowest stand of the water table for the calendar year usually occurs between October of one year and February of the next year. One notable exception is the spring of 1995 when the water table dropped through May as there was a shortfall of over 6 inches of rain during the January through April period. The highest water table level typically occurs in June or July for well XEW39 (WT-4) and in June for XEW38 (WT-6). The later annual maximum at XEW39 may be partly a function of the 20 extra feet that recharge must travel to reach the aquifer at that location. There may also be differences in permeability that affect the rate of downward infiltration. Frimpter (1980) also concluded that the greater the depth to the water table below grade, the later the water level reaches the annual maximum.

Different rates of percolation may account for the annual maximum water table level in well TOW18 (T-11) occurring at the same time as the other wells despite the depth to water at T-11 being almost 40 feet greater than at XEW39 and 65 feet greater than at well XEW38.

It is also clear in Figure 6 that, despite a much higher ground elevation at well TOW18, the groundwater elevation is substantially higher at XEW39 (by about 20 feet). The groundwater flow is from the high elevation area around well XEW39 toward both the Tisbury well to the north and toward XEW38 to the south. Despite its ground elevation, proximity to groundwater discharge points at the Lagoon and the Harbor (4000 feet) and Tashmoo (2500 feet) increases the rate of flow and probably influences the lower water table elevation at well T-11.

In Figure 7, the elevations of the water table are plotted for four wells in Edgartown that comprise a northwest to southeast section across the aquifer. Well ENW60 (E-1) is at the southeast end of the Katama Airpark runways at a ground elevation of about 17 feet (top of casing is 20.9 feet). Well E-15 is on Meetinghouse Road about 1500 feet from Edgartown Great Pond at a ground elevation of about 22.95 feet. Well ENW52(E-28) is in the State Forest at the bottom of a dry valley at elevation 32.5 while E-29 is along Airport Road just north of the West Tisbury -Edgartown Road intersection at elevation 46.7. The annual timing of the peak water table level is close for all four of these wells however ENW52 and E-29 reach a peak a month after the others.

The plots of wells ENW52 and E-29 are remarkably similar despite a difference in ground elevation of 14 feet. Both water table elevation and range are virtually the same. If ENW52 is compared with well ENW60 at about 15 feet lower elevation, there is no such similarity in water table elevation. The narrow frost bottom in which ENW52 is found does not affect the water table, as does the regional decline in the water table elevation from these wells to well ENW60 located near the Katama Airpark. This demonstrates that limited scale topographic features may not have great effect on the water table. The water table elevations are a reflection of the regional change in level (e.g. that from XEW39 to E-29 and on to ENW60) rather than a small-scale feature like the dry valley feature at well ENW52.



West Tisbury:
The monthly levels for two wells, XEW39 and XEW38, (WT4 and WT6) are summarized in Figure 6. Well XEW38 is situated on the Edgartown Road at an elevation of 48.9 feet and well XEW39 is located toward the north end of Old County Road at 76.7 feet. The correlation between depth to groundwater and timing of spring water-table high stands is demonstrated by these wells. That is: the greater the depth to the water table below grade, the later the water table reaches its annual maximum. Table 1 indicates that, on average, the water table is highest in April in well XEW38 (shallow well) and in July in XEW39 (deeper). From Figure 6, we see the maximum for XEW38 is reached during May in 1993 and 1994, while in XEW39, at a higher elevation, it is apparently in June and July in 1993, and June in 1994. This may be the result of recharging rainwater taking longer to reach the deeper water table (rate is estimated at 1/2 foot per day- K. Healy, personal communication) and possibly differences in permeability.

Wells situated in and around the highest part of the aquifer were surveyed for water table elevation in 1996 to establish the groundwater flow pattern in this area. The elevations at each of 7 wells were plotted on the USGS quad sheet and distances and rate of decrease in elevation determined between wells. This was then interpolated to locate whole number water table elevations between pairs of wells and water table contours drawn. The results are shown in Figure 8. From the water table configuration, the drainage divide for groundwater flowing toward Tisbury Great Pond was established as shown by the bold dash-dot line for the date surveyed. It is possible that there are small seasonal differences in the location of the divide shown.

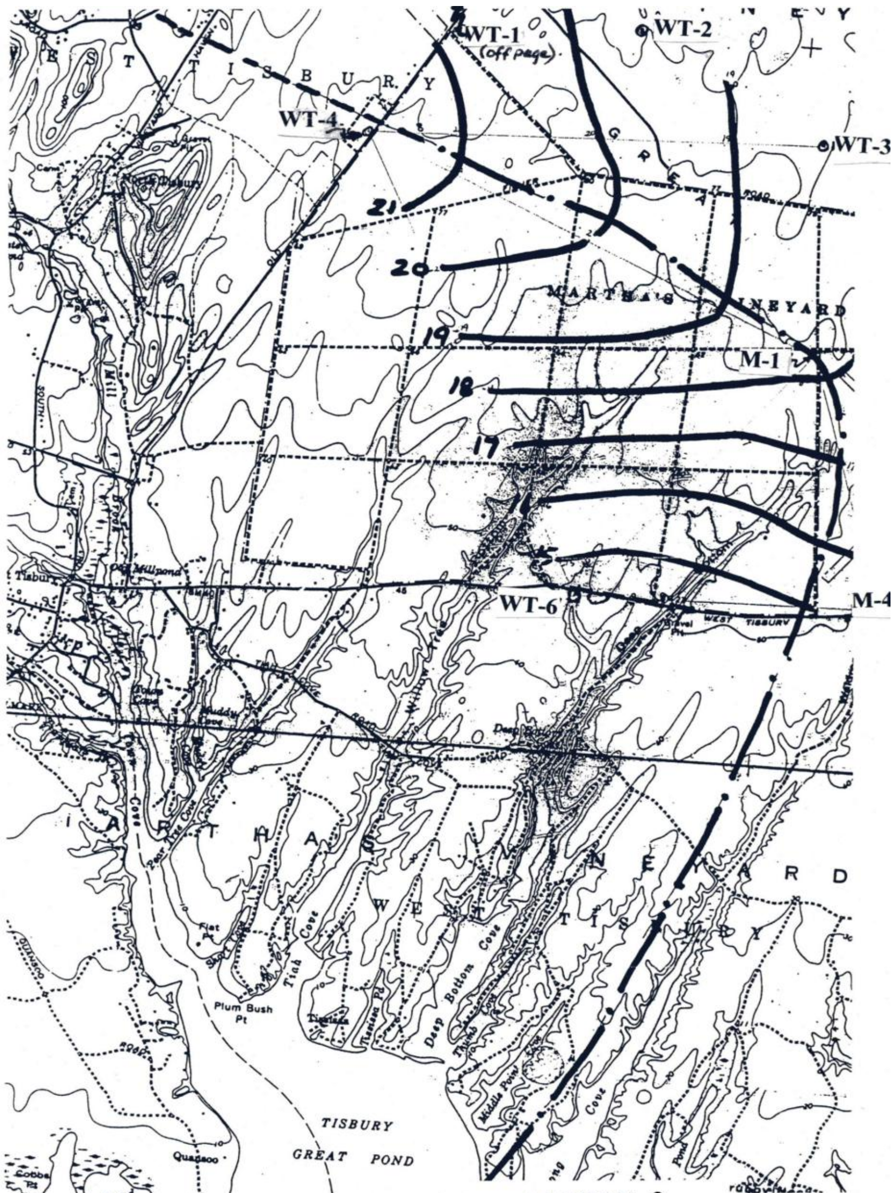


FIGURE 8

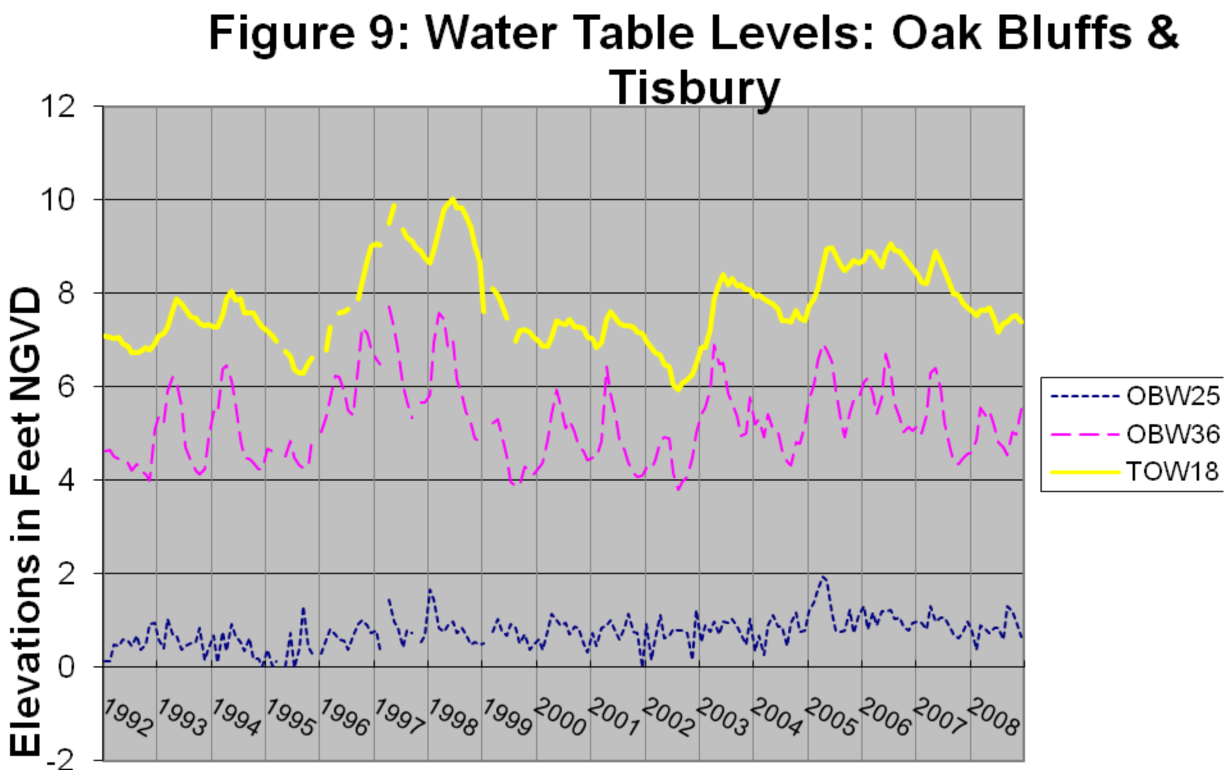
GROUNDWATER CONTOURS & TISBURY GREAT POND WATERSHED DIVIDE
Based on Measuremnts Taken from 9 Wells on April 29, 1996

Approximate Scale 1" = 1977' Eleveations in Feet Above MSL

Oak Bluffs and Tisbury:

The monthly elevations from the wells monitored are plotted in Figure 9. These portions of the Island consist of outwash sand and gravel over sandy glacial till. Well OBW25 (OB-1) is situated near the Harbor, a constant head boundary, and fluctuates over a narrow range of elevations. Being near the Harbor, it is also subject to some tidal influence that causes the curve to be rougher than the others in response to the propagation of tidal signals through the groundwater.

Wells near a constant head boundary like OBW25 on Oak Bluffs Harbor generally exhibit less annual range than wells that are sited further into the upland (OBW36). TOW18 is at an elevation of 113 feet with a finished depth of about 113 feet. This well is located at the Town DPW building and shows relatively little annual fluctuation in the water table. This may be a reflection of its position near the groundwater divide with constant head boundaries to the east (Lagoon Pond at 4000 feet), to the north (the Harbor at about 4000 feet) and west (Tashmoo at 2500 feet.



Despite their elevation differences, the average monthly high point in TOW18 and OBW36 occur in April (Table 1). The lowest average water table elevation is in August for both wells. Due to its proximity to the Harbor (about 100 feet), tidal influence affects the data for well OBW25.

Edgartown Outwash Groundwater Contours:
A survey of observation wells in Edgartown was made in 1997 (Wilcox, 1999) for the purpose of establishing the groundwater divide on the east and north sides of the Edgartown Great Pond watershed. A total of 25 observation wells surveyed in to NGVD were used to establish the range of water table elevations throughout the area north and east of the Great Pond. Interpolation as described for Tisbury Great Pond was performed and the resulting contour map is shown in Figure 10. Complications to the placement of this divide include public well withdrawals near the margins of the watershed such as the Machacket well and Lily Pond well that may effect the area contributing groundwater to the Great Pond by varying amounts due to their water withdrawal.

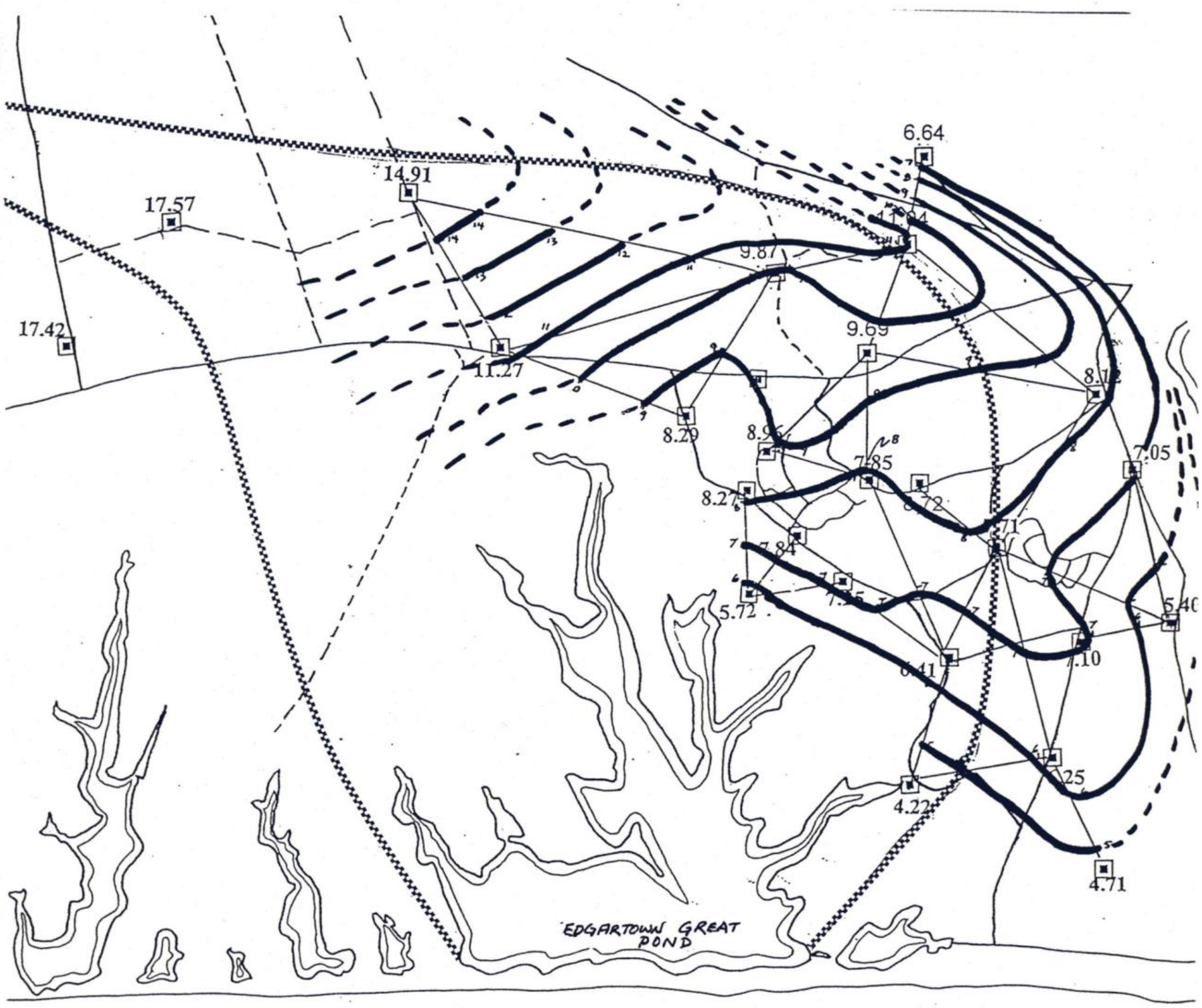
FIGURE 10

EDGARTOWN GREAT POND WATERSHED

INTERPOLATION OF RAW DATA

WITH GROUNDWATER CONTOURS & WATERSHED DIVIDE

MARTHA'S VINEYARD COMMISSION



Crunching the Numbers:
The following section, Implications of Data from the Outwash Plain is meant as a first approximation interpretation of the well data collected. The estimates derived from the observation well data indicate that the groundwater supply in the outwash plain is abundant and should not become a growth-limiting factor in terms of available volume in the foreseeable future. The picture in the western moraine is less clear and, it is possible, that large, irrigated landscapes here could lead to water supply problems as the area overlying the isolated aquifers found there is built up.

Implications of the Data from the Outwash Plain Aquifer:
This section has been updated to reflect the new estimate of annual recharge provided by the Mass Estuaries Project (Howes et al, 2008).

The area defined by the outwash plain is the primary reservoir for present day and future water supplies. All public supply wells except for the seasonal Menemsha water supply are located in this aquifer. The outwash plain (Qmvo) is shown in Figure 1 as mapped by Dr. Clifford Kaye, US Geological Survey. The area mapped by Kaye as Qmvo/Qmv was believed initially to be a sandy morainal deposit but is now thought of as a collapsed head of outwash. The total area of outwash plain aquifer is about 29558 acres. In this estimate, I included as potential usable outwash plain aquifer the area above the 15-foot ground elevation. This was measured by planimeter to determine the area of this portion of the aquifer. An area of this size receiving recharge at the average annual rate of 28.7 inches per year will gain an average of 3 billion cubic feet or 22 billion gallons per year. The annual discharge at the coast is adjusted to the recharge rate varying from wet years to dry years so that the aquifer is in a dynamic equilibrium. This means that there may be short term excesses or deficits of recharge so that the water table as a whole may be somewhat higher or lower but, over time, the water table moves up and down within a range that we think of as average conditions.

The primary aquifer (Hall, 1980) extends to an estimated depth of 70 feet below Mean Sea Level. The water table elevation around observation well XEW39 is about 25 to 30 feet above MSL implying a total thickness of the primary aquifer in this area of 100 feet (Note: the water table high point is further to the northwest of XEW39). A rough estimate of the volume of the aquifer can be made by assuming that the aquifer is a wedge shaped 3-D volume that is 35883 feet on a side and 100 feet thick tapering to zero thickness at the 15-foot elevation. The volume of this figure is 64.38 billion cubic feet. With an average porosity of 30%, the water volume contained in the primary aquifer is about 19.3 billion cubic feet of water or 144.5 billion gallons. This estimate should be conservative on the low side. Annual recharge is about 15% of the total volume of the primary aquifer (the previous estimate based on the old recharge figure was 12 %).

The quantity of water drawn from the aquifer for domestic use on an annual basis is on the order of 1 to 1.5 billion gallons per year. (This number is an **estimate** based on the assumption that private well water use is roughly equal to the 700 to 750 million gallons of water drawn each year by the three municipal supplies.) If the four existing golf courses plus approximately 150 acres of irrigated row crops and small fruits are added, an additional 150 million gallons are withdrawn each year. Total annual extraction of water on the Island as a whole is estimated at 1.2 to 1.7 billion gallons. Of the domestic use portion, a large percentage (as much as 75%) is returned to the aquifer through septic systems. Much of what is "lost" is irrigation water that either evaporates in the air or is drawn in by the plants and transpired into the air as water vapor.

In comparing the annual recharge and total volume of the main aquifer to annual demand, the Up-Island area should be excluded from this estimate as the connection between the aquifer(s) in the moraine is unknown but most of these aquifers are probably not related to the outwash plain aquifer. About 13 percent of the 15000 housing units on the Vineyard are in Chilmark and Aquinnah. If the annual water use estimate is reduced by this percentage, the annual extraction from the outwash plain aquifer alone ranges from 1 to 1.5 billion gallons. The amount returned to that aquifer today by wastewater disposal systems is about 700 million to 1 billion gallons of the total drawn out each year. At the present time, we draw about 0.9 percent of the total main aquifer volume for water supply uses (but we return all but about 0.3%).

From year to year, the aquifer may contain more or less water depending on the amount of recharge that has occurred. An estimate of the natural aquifer volume variation can provide guidance on appropriate limits to water consumption. Well XEW39 (WT-4) near the highest point in the outwash aquifer displays a large variation in monthly water table levels over the years. The data from 1995 through 2002 for this well is shown in Table 3.

Table 3: Well XEW39 Range of Aquifer Elevations

Month	1995	1996	1997	1998	1999	2000	2001	2002	**Range**
Jan	21.95		25.58	25.09	26.19	21.67	21.48	21.27	**4.24**
Feb	21.45	20.19	26.73	25.67		21.3	21.07	20.63	**6.54**
Mar	21.14	20.84		27.07	24.70	20.98	20.84	20.32	**6.75**
Apr		21.67	27.75		24.86		22.36	19.99	**7.76**
May	20.85	23.09	28.85	28.92	24.99	23.00	23.69	20.23	**8.69**
Jun	20.77	23.63		29.39	24.80	23.58	23.90	20.49	**8.90**
Jul	21.46	23.8	28.71	30.38	24.62	23.59	23.77	20.72	**9.66**
Aug	21.64		28.34	29.99	24.22	23.35	23.65	20.59	**9.4**
Sep	21.41	23.32	27.66	29.37	23.77	23.07	23.24	20.33	**9.04**
Oct	21.1	24.41		28.6	23.27	22.70	22.86	20.18	**8.42**
Nov	20.75	26.02	26.43	27.85	22.71	22.30	22.22	19.85	**8.00**
Dec		26.43	25.72		22.19	21.98	21.75		
Average									**7.95**

The data indicates that the difference between the highest and lowest water table elevation for each month over this period has averaged nearly 8 feet. This period includes extreme high (1998) and low (2002) water table levels (see Figure 6). To be conservative on the low side, I used a 6-foot elevation change to calculate the difference in aquifer volumes. The difference in the volume of water represented by this 6-foot wedge over the area of the outwash plain is about 8.7 billion gallons of water. This volume is calculated as a wedge shape volume 6 feet thick and tapering to zero over the dimensions used for estimating the total aquifer volume. This change in volume would be that seen in the outwash aquifer from the high stand in 1998 (30.4 feet) to the spring, 2001, low stand (23.9feet). The 6-foot difference in aquifer volume between the high spring stand and low spring levels is nearly 6% of the total volume of the aquifer. For comparison, an 8-foot wedge would contain about 11.6 billion gallons of water (8% of the total aquifer volume).

In planning for growth limits based on water use, an important question is: what is the safe yield of the aquifer? The safe yield of an aquifer is the amount of water that can be drawn from it on an annual basis without having an undesirable effect. One obvious undesirable effect to avoid would be drawing salt water into the near shore portions of the aquifer which might impact private wells or, if enough water was drawn from a given public well, into the town well itself. This could happen under extreme water consumption conditions because it is the pressure of the fresh water aquifer that determines the location of the interface between fresh and salt groundwater. Removal of large amounts of fresh water reduces this pressure and causes the interface between fresh and saline groundwater to move inland. Salt-water intrusion into more than a small, localized area is not likely to occur under foreseeable conditions because extraction and loss is such a small portion of the entire aquifer volume.

A more subtle definition of safe yield is the amount of water that could be drawn from the aquifer without compromising the volume of fresh groundwater that seeps into coastal ponds and gives them their unique estuarine character. In trying to address the question of what is the safe yield for our aquifer, one approach may be to assume that some percentage of the observed range of aquifer volumes from driest to wettest years could be consumed without pushing the system outside of the range of annual discharge volumes that currently enters our coastal ponds. This points to an annual maximum consumption limit of some amount **less** than 8.7 billion gallons per year (the 6% estimate of the natural range of aquifer volume multiplied by the 144 billion gallons in the outwash aquifer).

In 1991, DEM prepared a forecast of water needs for towns that have public water supply. The three down island municipal water supplies were projected to require about one third more water for the year 2010 than they used in 1990. If this percentage increase were to hold across private and public water uses, an annual withdrawal of some 2 billion gallons appears to be likely in 2010. Of this, all but about 0.6 billion gallons would be returned to the aquifer as treated wastewater.

The USGS projected municipal water needs through the year 2020 (USGS, 1994). Total water demand for municipal supplies on an annual basis was projected to be 1.94 billion gallons per year at that time. This implies a total water extraction that is in the range of 3.5 to 4 billion gallons per year. If somewhere around 70 percent is returned to the aquifer, the annual loss of water from the aquifer is 1 to 1.2 billion gallons or about 12 to 15 percent of the observed volume change from conditions between wet years (1998) and dry years (2001). From these rough estimates, it appears that projected water use is compatible with maintaining aquifer levels within the range observed over the past 11 years with some room for estimation errors.

Conclusions:

The changes in the water table that are the basis of this report represent a geologically short-term picture of the average conditions in the aquifer. Changes in climate may alter rainfall and recharge patterns and thereby alter our concept of what is average aquifer behavior.

Over the past sixteen years, the water table fluctuations have been monitored on a monthly interval at 11 observation wells. Over this time frame, the water table reaches its highest levels in late spring to early summer and reaches a low point in late fall through early winter. The annual water table range seen in wells that are in isolated aquifers in the western moraine and in perched water tables is greater than that observed in wells in the outwash plain aquifer. Observation wells near constant head boundaries such as a pond or the ocean fluctuate very little.

The highest part of the outwash aquifer is found in the area between County Road and State Road around the Up Island Supermarket to the landfill in West Tisbury. This part of the aquifer contributes groundwater to all of the down island towns.

Chappaquiddick has a separate aquifer that is not connected to the main aquifer and is only replenished by rain falling on that island. The aquifer includes at least two sub-aquifers, that at Chappy Point and that found at Cape Pogue. The Chappy Point aquifer experiences annual saltwater intrusion that is caused by the combined effects of relatively high demand in a small area and the normal seasonal decline in water table during the summer months.

Annually the amount of water recharging the outwash plain aquifer is around 22 billion gallons and may be even greater if there is recharge either from runoff out of the western moraine or if portions of the western moraine aquifer connect to the outwash plain aquifer. The projected usage by 2020 is estimated at 4 billion gallons of which nearly 3 billion gallons would be returned via septic systems or wastewater treatment facilities. A possible limit to water consumption is derived from the estimated difference in aquifer volume from wet to dry years. This change in volume of the outwash aquifer is estimated at 8.7 billion gallons. The projected 2020 water removed and not returned to the aquifer (about 1 billion gallons) is about 12 percent of the natural aquifer volume change observed from wet to dry years.

It appears from the data collected that the primary concerns about water supply on the Vineyard fall into three areas:

- Overuse of small aquifers in the western moraine primarily due to large turf plantings (given that 3 acres zoning continues in place).
- Extraction of large volumes of water to irrigate commercial scale turf plantings.
- Isolated areas where water extraction by private wells is focused near the shore leading to salt water intrusion.

Beyond these issues that are related to the amount of groundwater available, there are concerns about localized areas in the groundwater polluted by chemical spills or leakage, landfill leachate or by disposal of sewage. Current zoning and health board bylaws, landfill capping and sewage treatment plant effluent standards largely address these concerns as far as human health. The impact on coastal ponds of the nitrogen disposed into the groundwater with wastewater is a serious threat to their sustainability and must be addressed.

Acknowledgements:
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APPENDIX

Table A-1

	A	B	C	D	E	F	G	H
1	**USGS Number**	**MVC Well Number**	**Other Number**	**Elevation**	**Depth**			
2				**Top of Casing**		**Location**	**Condition**	
3				**Feet**	**Feet**			
4		C-1	Fenner Dug Well	~ 28	19	South Road roadside, Chilmark		
5	CNW 36	C-2		23.8	23	Quansoo Road, Chilmark		
6		C-3	MVC-6	~ 24	33	Quansoo Road, Chilmark		
7	CNW-35	C-4	C-101	223.23	50	Tabor House Road at landfill, Chilmark		
8	ENW-60	E-1		20.9	23.1	Katama Air Park Edgartown		
9	ENW-81	E-3	LP-9	14.77	15	Beach Rd. at Oakdale, Edgartown		
10		E-7	LP-13	39.02	35	North of MSPCA, Edgartown	destroyed	
11		E-15	STP-15	22.95	23	Meeting House Rd., Edgartown		
12		E-16	E-102	31.41	58	Machacket Rd. at landfill, Edgartown		
13	ENW-82	E-25	EWC6-87	34.4	85	West Tisbury Rd., Edgartown	destroyed	
14	ENW-52	E-28		32.52	35	State Forest, Edgartown		
15		E-29	B	46.7	?	Airport Rd., Edgartown		
16		E-30	MVC-3	28.9	87	Bold Meadow, West Tis. Rd. Edgartown		
17	OBW-25	OB-1		~8.9	18.9	East Chop Drive, Oak Bluffs		
18	OBW-36	OB-7		43.9	54.5	Tradewinds Airport, Oak Bluffs		
19		OB-10	104-R	85.83	109	Landfill, Oak Bluffs		
20		OB-11	101	69.7	83	DPW driveway, Oak Bluffs		
21		T-1	T&B 1	52.59	53	West Chop Woods, Tisbury		
22		T-2	TOW-3	~ 40	?	Causeway Rd., Tisbury	destroyed	
23	TOW-18	T-11	W-2	113.84	112.5	Near DPW , Tisbury		
24		WT-1	MVC-4	96.21	?	Old County Rd. at Briarwood. West Tis.		
25	XEW-39	WT-4		76.7	64.2	Old County Rd. at Evergreen. West Tis.		
26	XEW-38	WT-6	MVC-5	48.9	40	Edgartown Rd., West Tis.		
27		WT-20		~ 110	> 100	Cardinal Way, West Tis.		
28								

TABLE A-2: MONTHLY RAINFALL VS. EVAPORATION & TRANSPIRATION

Based on Data Collected by the New England Climatic Service

	Rain 1946-1975 Record Inches	Rain 1951-1998 record Inches	Evapotranspiration USGS
January	3.67	3.96	0
February	4.12	3.75	0
March	4.03	4.39	0.6
April	4.28	4.22	1.3
May	4.25	3.82	2.35
June	2.65	3.22	4.1
July	2.63	3	4.25
August	4.43	4.2	4.45
September	3.56	3.6	3.8
October	3.39	3.83	1.85
November	4.4	4.51	1
December	4.41	4.44	0
	45.82	**46.94**	**23.7**

Figure A-1: Precipitation versus Evapotranspiration

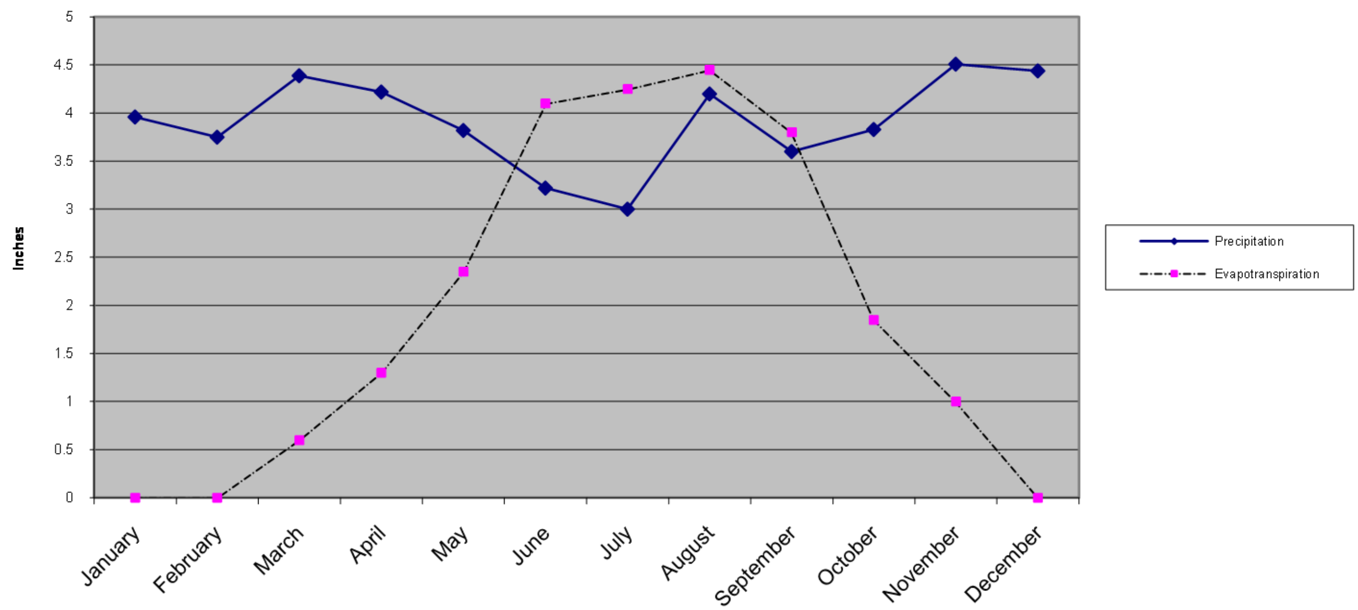

Figure A-2