CLIMATOLOGY OF LONG ISLAND RELATED TO THE "BROWN TIDE" PHYTOPLANKTON BLOOMS of 1985 and 1986

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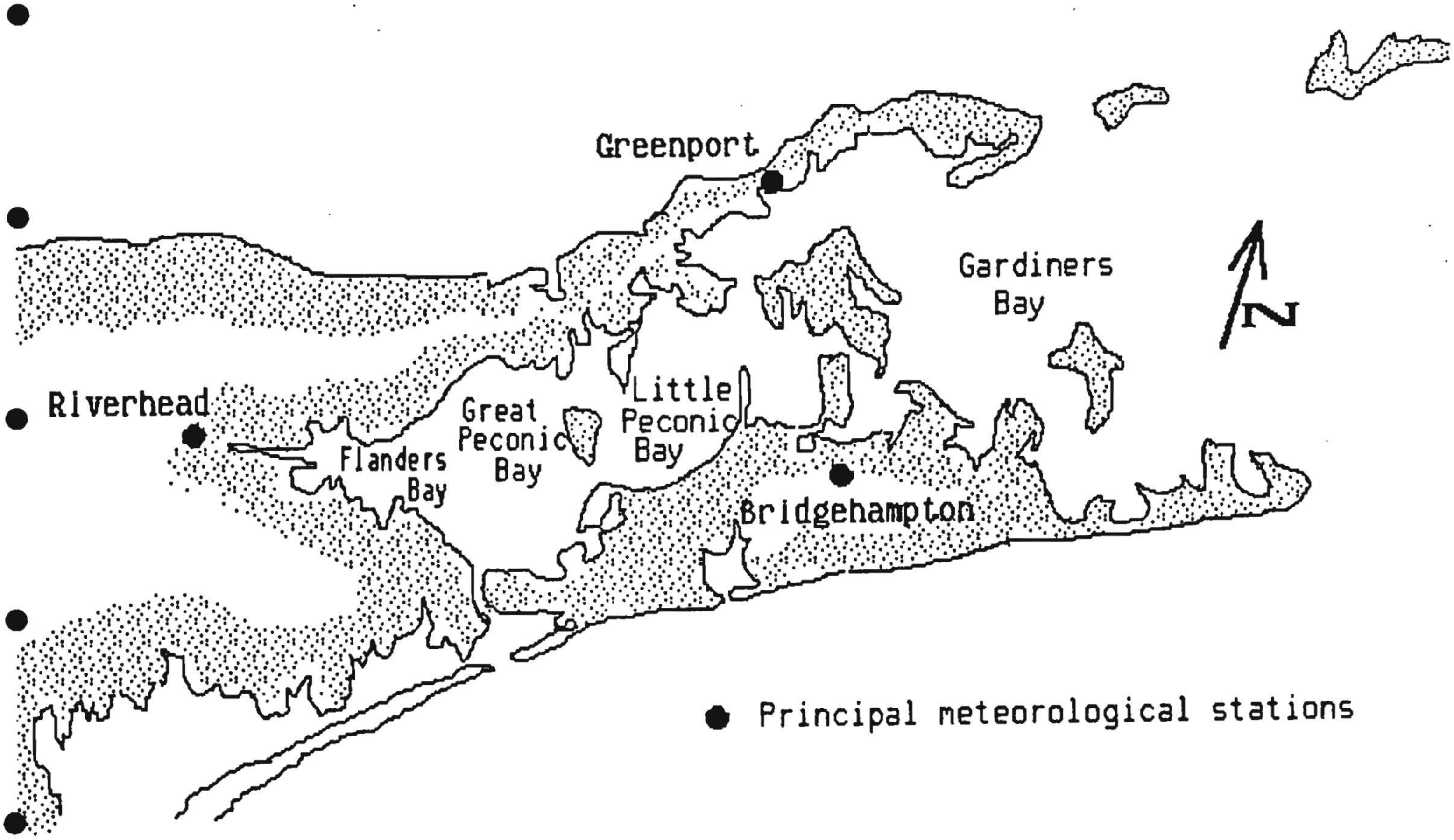

Greenport
Gardiners Bay
N
Riverhead
Great Peconic Bay
Little Peconic Bay
Flanders Bay
Bridgehampton
Principal meteorological stations

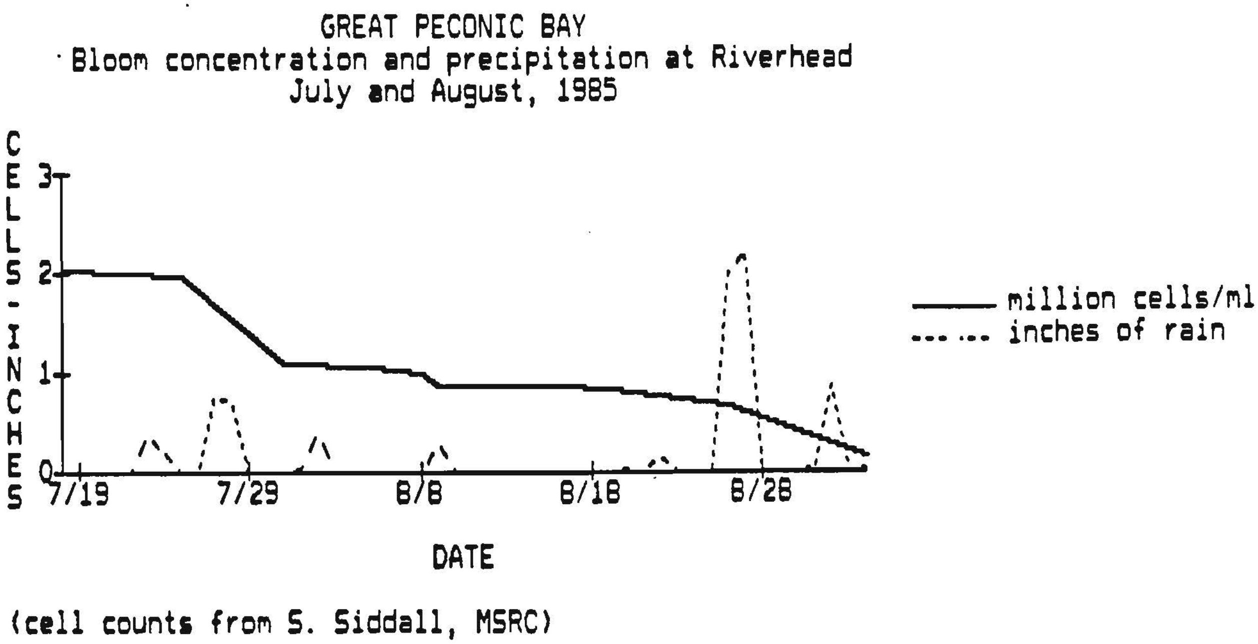
INTRODUCTION

The so-called "brown tide" phytoplankton blooms which appeared in Long Island's coastal bays in 1985 and 1986, from the Great South Bay through the Flanders-Peconic-Gardiners estuary, resulted in significant ecological and economic damage. Many bay scallops, *Argopecten irradians*, died and the 1985 landings in this important fishery were some of the lowest in the past two decades. Bay scallop larvae which were produced in 1985 and 1986 - those on which future harvests depend - were killed. Crops of cultivated oysters (*Crassostrea virginica*) died prior to harvest adding to losses of shellfish. Some species of finfish moved offshore as the blooms developed, a migration which may have affected their spawning efforts, and which took them out of reach of recreational fishermen. The dense algal blooms in waters overlying eelgrass beds (*Zostera marina*) shaded this ecologically important plant which depends on sunlight for growth and expansion. The economic losses to Suffolk County from these two consecutive summers of phytoplankton blooms have been estimated to be between two and five million dollars (J. Kahn, NYS Interagency Committee on Aquatic Resources Development "Brown Tide Conference").

Concurrent with the Long Island blooms, very similar phytoplankton blooms appeared in parts of Narragansett Bay, Rhode Island and along the New Jersey coast, notably in Barnegat Bay. This regional nature of these blooms suggested that the environmental factors which promoted and maintained the blooms were also of a regional, or large-scale, nature. Long-term climatological trends and short-term meteorological events are two of the more obvious types of regional, environmental factors. Adding support to the notion that regional weather phenomena affected the blooms was the apparent inverse relationship between rainfall and phytoplankton cell concentrations observed during the decline of the 1985 bloom in the Peconic-Gardiner's estuary (see Figure 1). Local precipitation events appeared to result in reductions in cell concentrations throughout July and August, 1985.

Based on this background, the present study was proposed by the Suffolk County Department of Health Services; the Marine Sciences Research Center was requested to conduct the study with Suffolk County funding. The objective of the study was to confirm and quantify the possible relationships between existing meteorological records and observations of Long Island's phtoplankton blooms.

FIGURE 1:



APPROACH

There are basically two types of meterological data; long-term records (over decades) which indicate trends in prevailing climatology and are usually reported as monthly or even annual summaries, and short-term (annual) records which detail weather events, usually on a daily basis. Analyses of such long-term summary data are often straightforward however, given the constraints of time and money in any study, it is not possible to examine critically all available, highly-detailed, meteorological records. Therefore, the present study was restricted to:

(1) analyses of daily meteorological data for five stations surrounding the East End bays for the period January 1984 through September, 1986, and

(2) analyses of long-term, climatological data available for Long Island.

The specific data sets collected and analyzed in this study are presented in Table 1.

TABLE 1: SUMMARY OF CLIMATOLOGICAL DATA EXAMINED

1. Mean daily air temperatures from Bridgehampton, Greenport Patchogue, Riverhead and Setauket (January, 1984 through September, 1986).
2. Thirty year (1951-81) mean monthly air temperatures from Bridgehampton, Patchogue, Riverhead and Setauket.
3. Total daily precipitation from Bridgehampton, Greenport, Patchogue, Riverhead and Setauket (January, 1984 through September, 1986)
4. Mean monthly air temperatures from Brookhaven National Laboratory (1949 - 1977).
5. Mean monthly precipitation from Brookhaven National Laboratory (1949 - 1977).
6. Annual precipitation from Central Park, New York City (1826-1985).
7. Monthly Palmer Drought Hydrological Index (PDHI) from Long Island (1895 - 1985).
8. Wind (velocity X duration) from Greenport (summer months of 1984 through 1986).
9. Mean daily pyranometer data from Brookhaven National Laboratory (1984 and 1985 only).

Phytoplankton bloom data used in this study consist of station data (throughout the Flanders-Peconic-Gardiners estuary) of cell counts of the chrysophyte, *Aureococcus anorexefferens*, (E. Cosper and E. Carpenter; NYS Interagency Committee on Aquatic Resources Development "Brown Tide Conference") gathered in 1985 by the author and in 1986 by Dr. Robert Nuzzi and staff of the Suffolk County Department of Health Services. Because the blooms were nearly unialgal in their composition, counts of this single species are accurate reflections of the progress of the bloom during both years.

For purposes of statistical comparison, the blooms may be looked at in two ways.

(1) The detailed view of the blooms, where each datum is a single cell count of bloom concentration at a given point in space and time, can be compared (correlated) with the daily recordings of the short-term (1984 - 1986) meteorological data.

(2) Each of the two consecutive blooms (1985 and 1986) may be viewed as single events and compared with the monthly or annual data of the long-term climatological record (1826 - 1985).

Essentially, the frequency of the phytoplankton and weather observations dictate how the comparisons may be conducted. The higher frequency, short-term data on the progress of each bloom may be compared only with the corresponding higher frequency, short-term meteorological records. The two blooms may be compared to the lower frequency, long-term climatological record only when the blooms are treated as two single events happening in 1985 and 1986.

METHODS

Most of the climatological data were purchased from the National Climatic Data Center (NCDC, Asheville, NC) and received in printed form ("Climatological Data for New York", Vols. 96 through 98; data manually re-rentered and proofread) or as 9-track tapes (FORTRAN programs were written to read these directly). Additional climatological data was extracted from Nagle (1973, 1978) and from printouts provided by J. Tichler, Brookhaven National Laboratory. All data were analyzed on the University's Sperry 1100/82A mainframe facilities using SPSS Version 9 and on a Digital Equipment Corp. PRO/380 using the RS/1 statistical spreadsheet.

Temperature and precipitation data are presented for specific observation stations (Central Park, Riverhead, etc; see Table 2 for a complete description of station locations). Average daily temperatures were calculated as (daily minima + daily maxima)/2 as described by Karl, et al., 1986. Thirty year (1951 - 1981) mean values for daily precipitation and temperature are provided by the NCDC with time biasing corrected (differing hours of observation at different stations; see Karl et al., 1986). Summer wind data are available only for Greenport.

TABLE 2: CLIMATOLOGICAL STATION DESCRIPTIONS

Station	Latitude	Longitude	Elevation
Bridgehampton	40 57'	72 18' W	60 feet
Greenport Power House	41 6'	72 22' W	16 "
Central Park, NYC	40 47'	73 58' W	132 "
Patchogue	40 48'	73 1' W	55 "
Riverhead Research Fm	40 58'	72 43' W	100 "
Setauket	40 58'	73 6' W	40 "

The Palmer Drought Hydrological Index (PDHI), a monthly value which indicates the severity of a wet or dry period, is presented for the New York Coastal Division (NCDC #04) which is Long Island in its entirety. The index is based on the principles of a balance between moisture supply and demand. It is of particular use in estimating the state of reservoirs, runoff and groundwater effects. Man-made changes such as increased irrigation, new reservoirs and added industrial water use are not included in the computation of this index. The index usually ranges from -6 to +6 with negative values denoting dry periods and positive values indicating wet periods. PDHI values from 0 to -0.5 are normal, -0.5 to -1.0 indicate incipient drought, -1.0 to -2.0 indicate mild drought, -2.0 to -3.0 indicate moderate drought, -3.0 to -4.0 indicate severe drought and values more negative than -4.0 indicate extreme drought. Similar adjectives are associated to positive values of wet spells.

For purposes of these analyses, cosine weighted, three month running means of the PDHI and cosine weighted three year running means of the precipitation at Central Park were calculated as:

MEAN FOR MON = 0.25*(MON-1) + 0.50*(MON) + 0.25*(MON+1)

where MON = value for a given month
MON-1 = value for the preceeding month
MON+1 = value for the next month

Presentation of such a weighted running mean (linear filtering of time series data: see Anscombe, 1976) filters out some of the random variation and more clearly reveals long-term trends.

RESULTS

Graphical descriptions of the short-term meteorological record (temperature, precipitation, wind, daily radiation) are presented in Figures 2 to 13. Based on the thirty year means, there are no significant anomalies which can be associated with the initiation or maintenance of the blooms of 1985 or 1986.

FIGURE 2: BRIDGEHAMPTON recent precipitation record

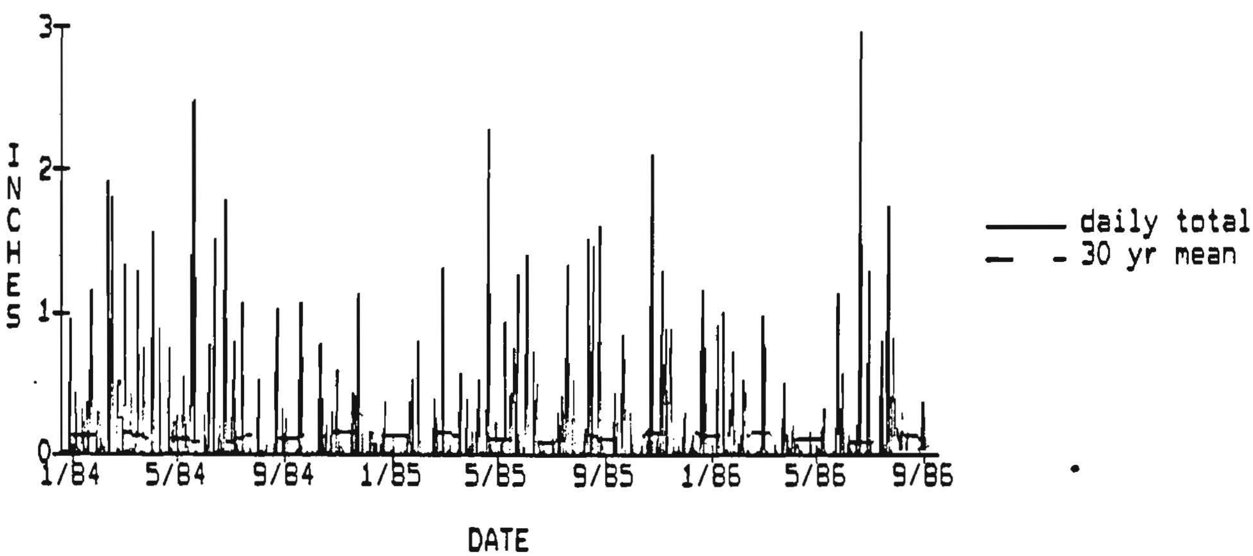
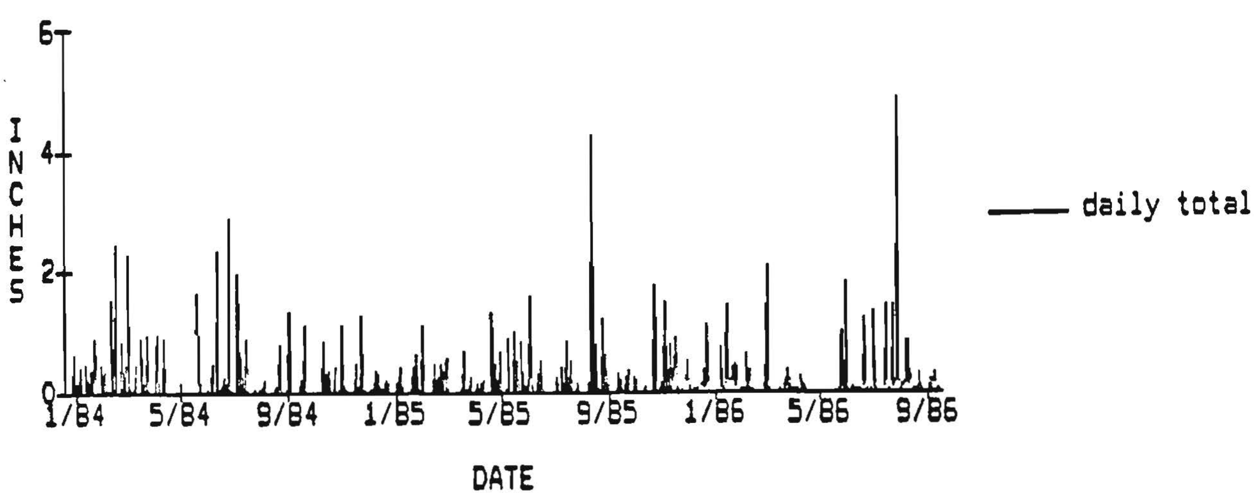


FIGURE 3: GREENPORT recent precipitation record



[No long term ppt records exist for Greenport]

FIGURE 4: PATCHOGUE recent precipitation record

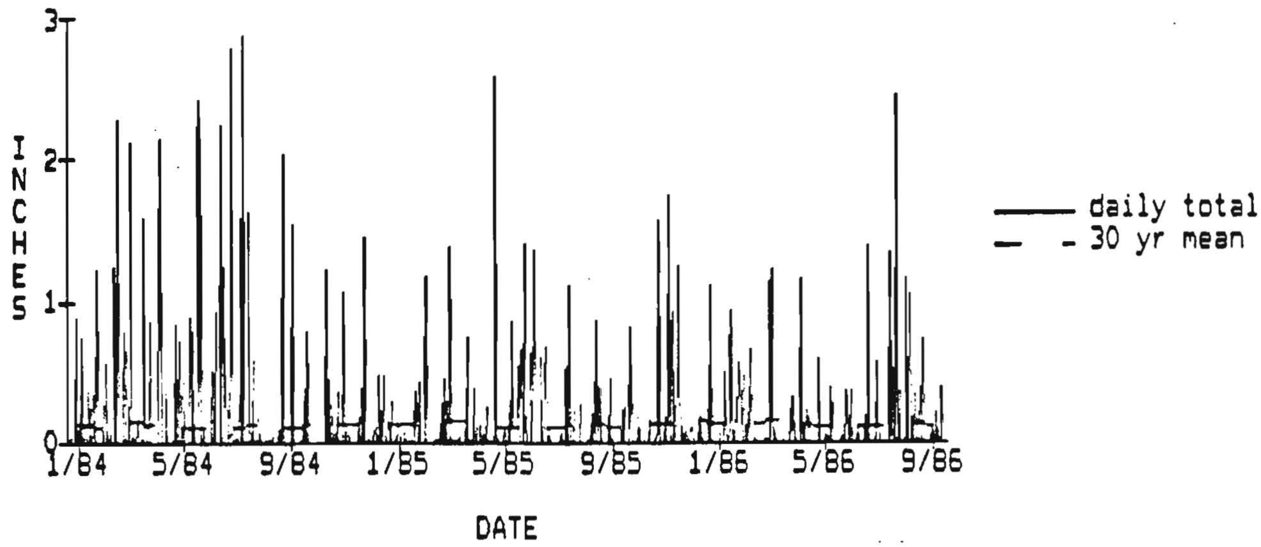


FIGURE 5: RIVERHEAD recent precipitation record

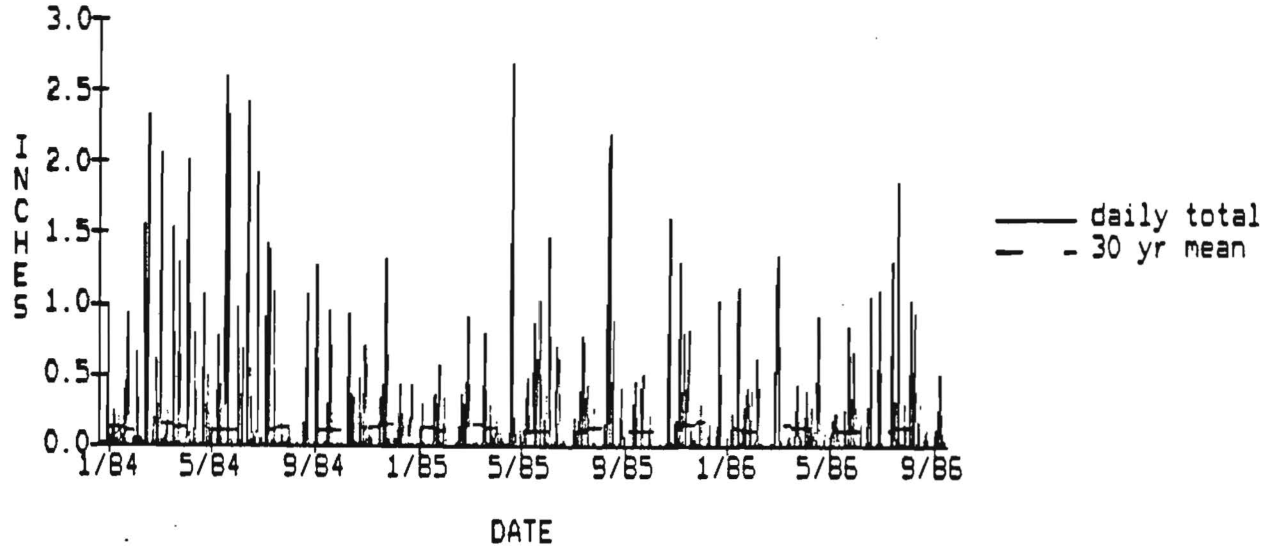


FIGURE 6: SETAUKET recent precipitation record

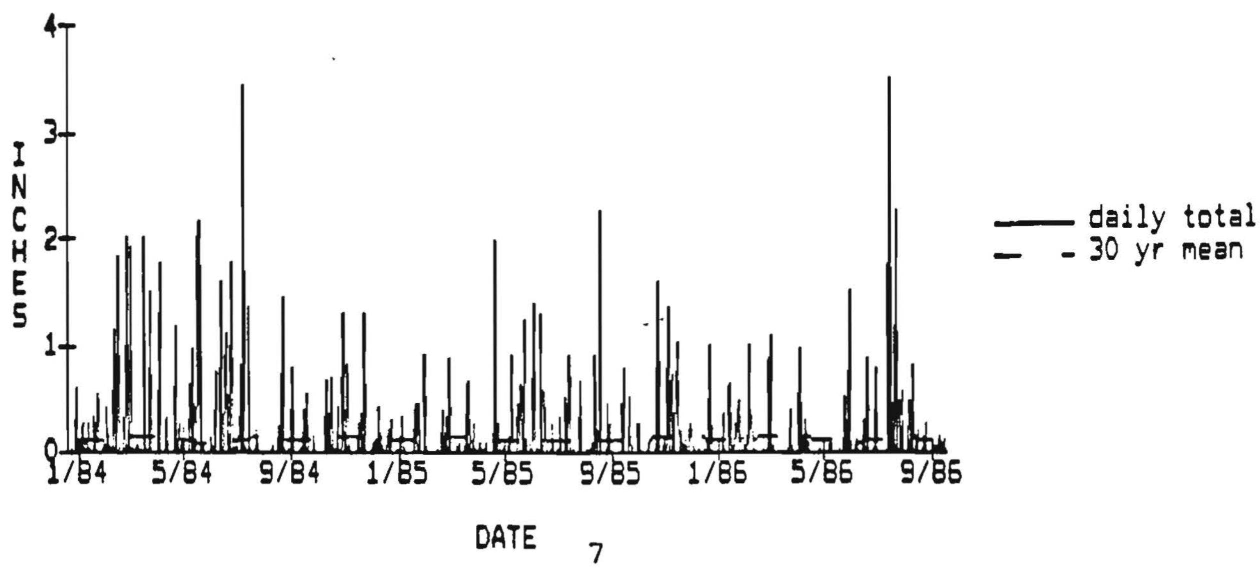


FIGURE 7: BRIDGEHAMPTON recent temperature records

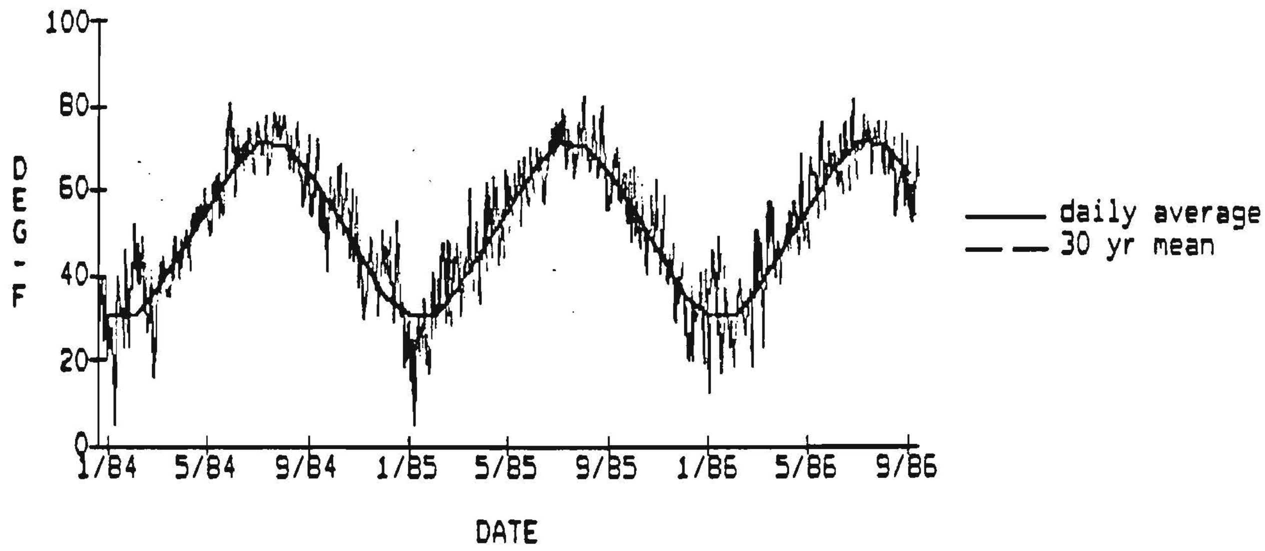
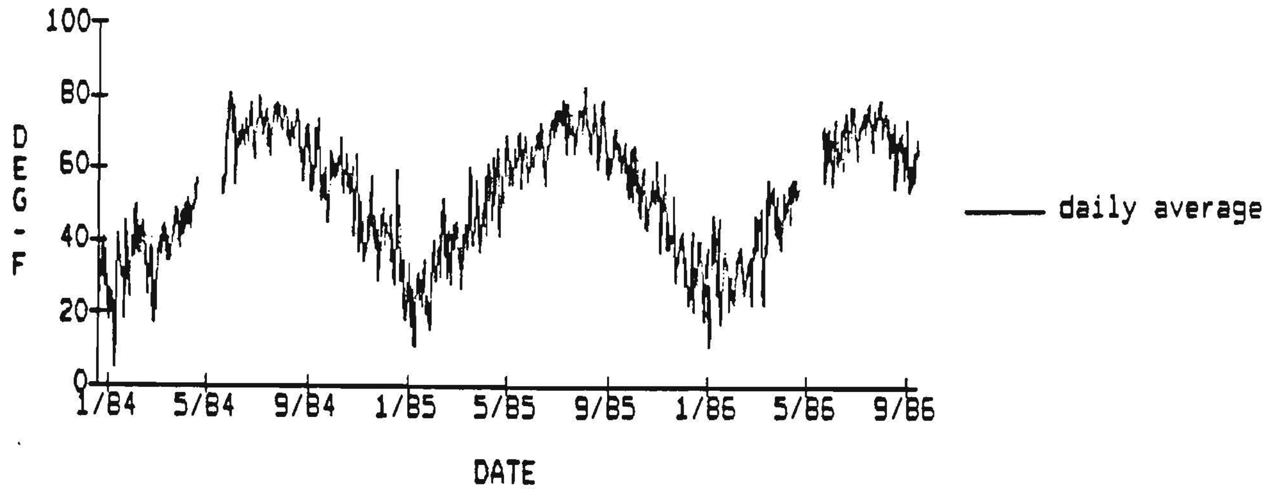


FIGURE 8: GREENPORT recent temperature records



(no long term mean temperature data exists for Greenport)

FIGURE 9: PATCHOGUE recent temperature records

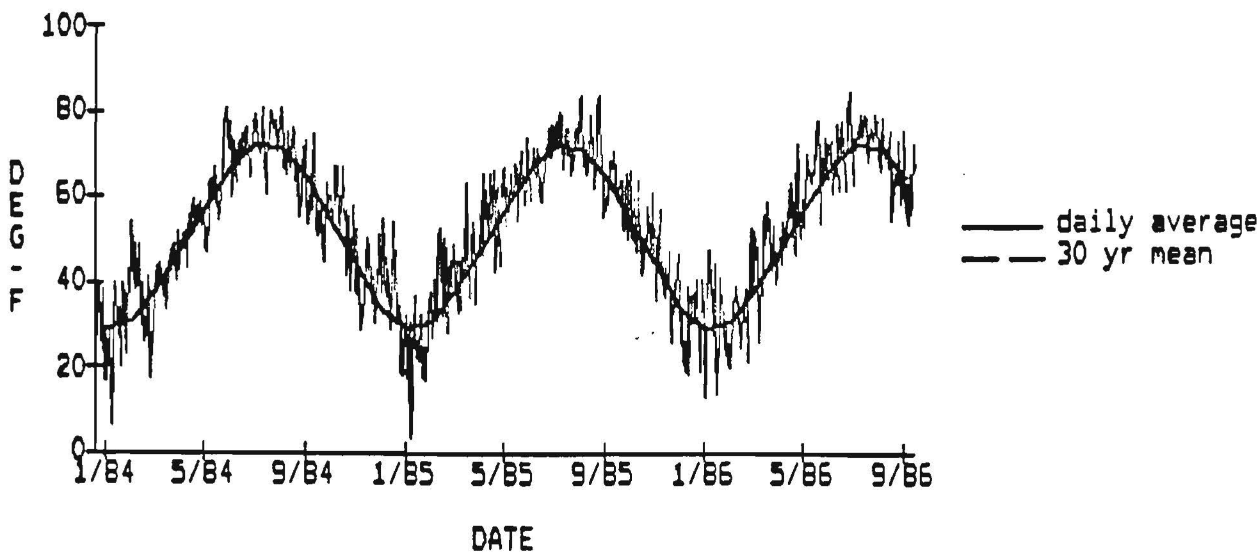


FIGURE 10: RIVERHEAD recent temperature records

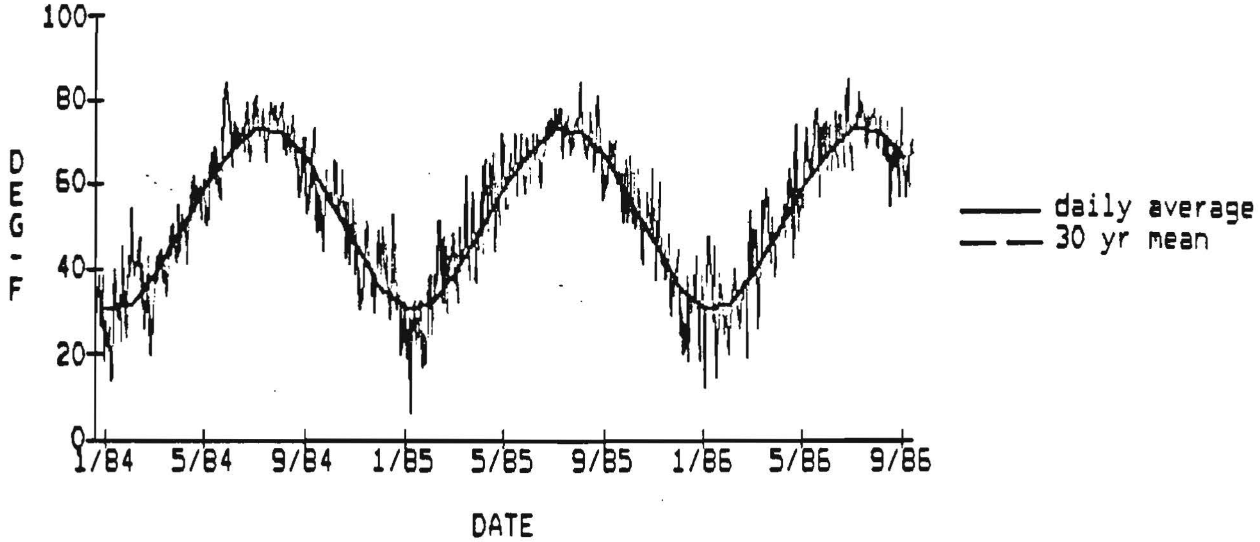


FIGURE 11: SETAUKET recent temperature record

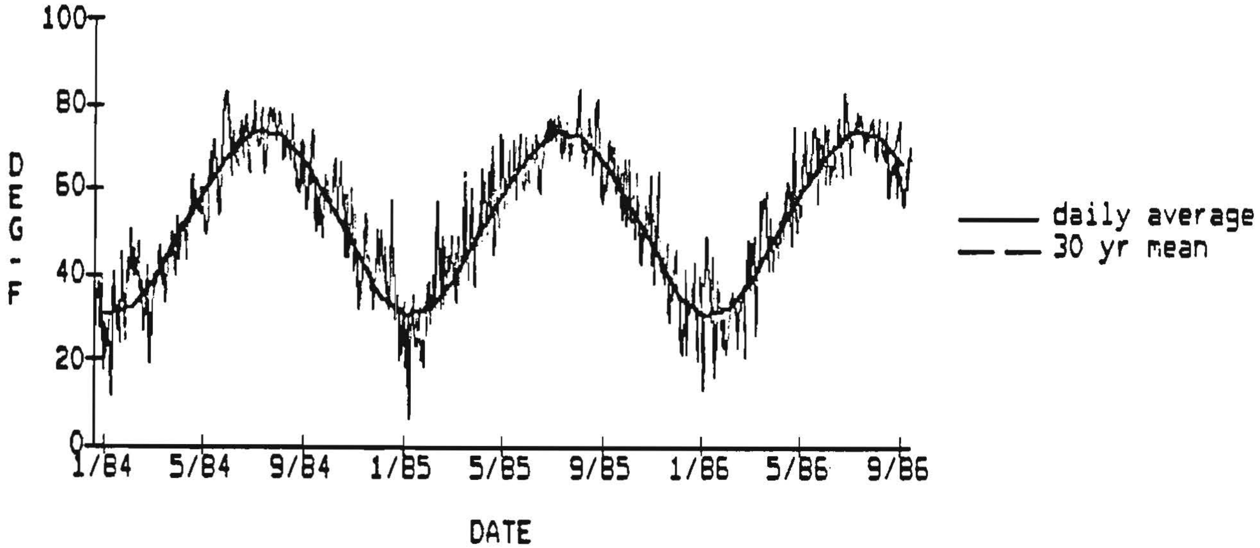
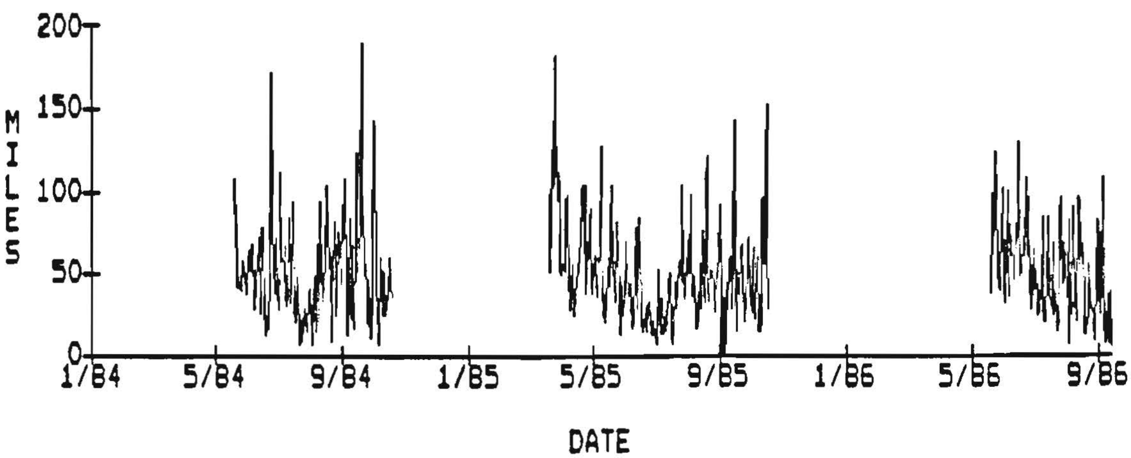
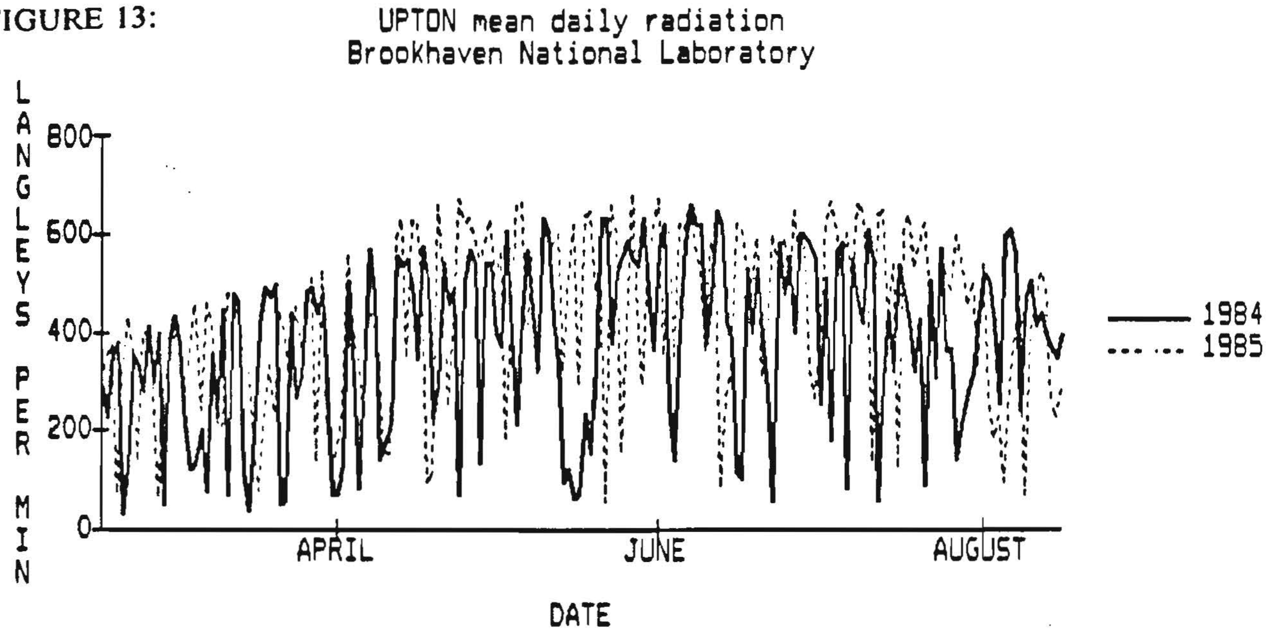


FIGURE 12; GREENPORT recent wind record (in miles = velocity X duration)



(wind records are not made during winter months)

FIGURE 13:


UPTON mean daily radiation
Brookhaven National Laboratory
LANGLEYS PER MIN
800
600
400
200
0
APRIL
JUNE
AUGUST
DATE
1984
1985

The long-term climatological record of precipitation at Central Park (1826 to 1985) is presented in Figure 14. The period 1966 - 1967 was one of the driest periods on record for this observation station while the following decade was one of the wettest. Central Park was dry in 1984 and has been relatively wet since. Central Park, however, is not part of the New York Coastal Division of Long Island, and the long-term PDHI data (Figure 15) for Long Island tells a very different story.

FIGURE 14: Annual precipitation - Central Park, NY
Three year running mean

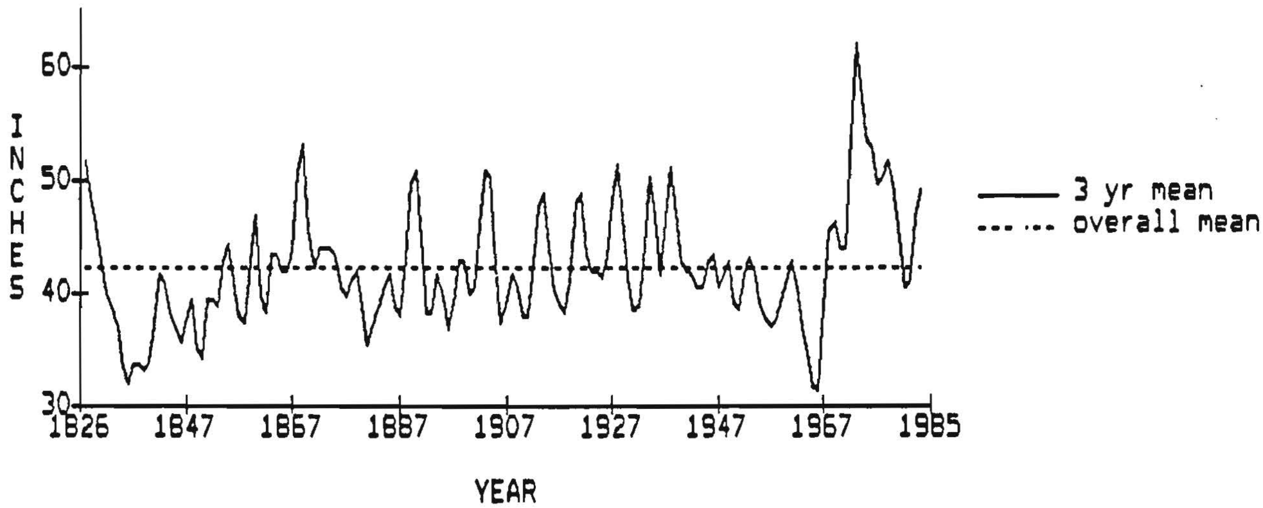
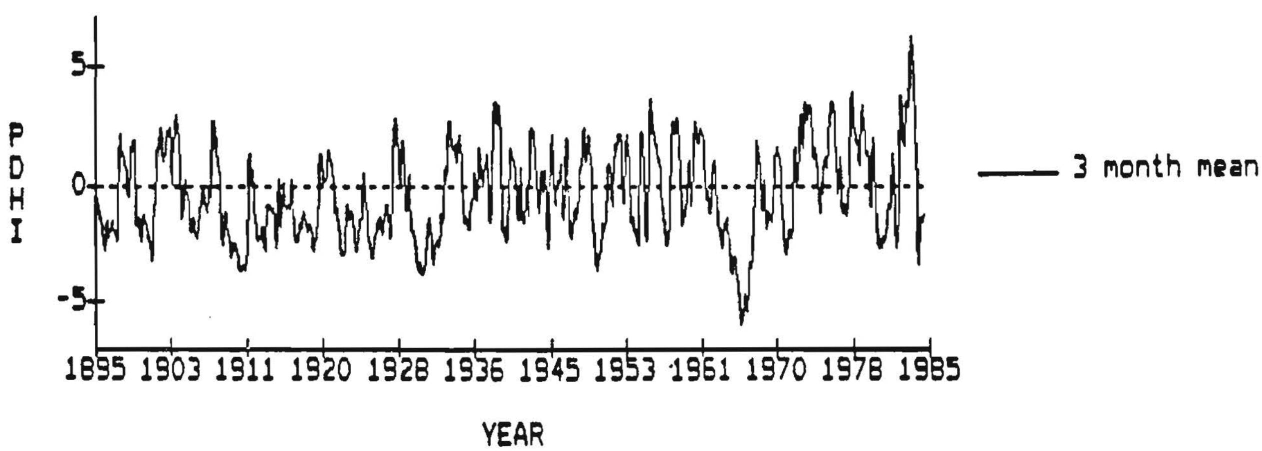
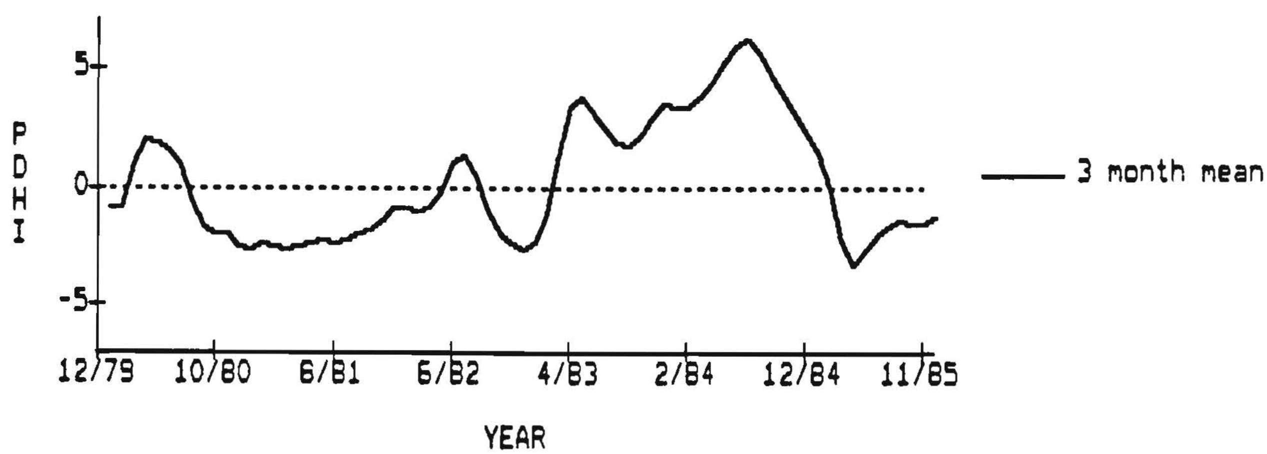


FIGURE 15: Long term Palmer Drought Hydrological Index
for Long Island (three month running mean)



According to the PDHI from 1895 to 1985, Long Island's driest period was 1966-67, its wettest period was from 1983-84 and as the first bloom in 1985 appeared, Long Island was under conditions of moderate to severe drought. Figure 16 presents the same PDHI data for 1980 through 1985 in more graphical detail. Moderate drought conditions persisted through October, 1986 (R. Hyne, National Climatic Data Center, personal communication). The association of the 1985 bloom event with these drought conditions is the only direct evidence that can be gleaned from this long-term record, however such a relationship could be coincidental, cannot be statistically validated and does not clearly identify the specific, underlying environmental mechanisms which link drought to the initiation or maintenance of blooms. This relationship does, however, lead to speculation that precipitation, and hence terrestrial runoff or groundwater effects, has some impact on blooms in these coastal embayments.

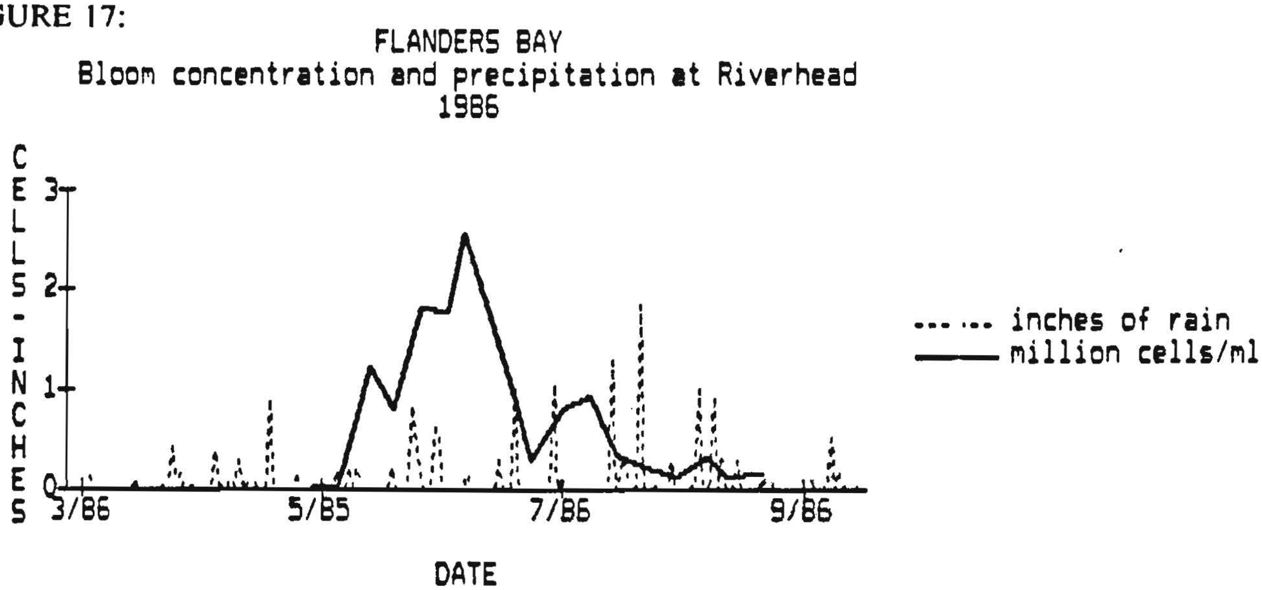
FIGURE 16: Recent Palmer Drought Hydrological Index for Long Island (three month running mean)



Figures 17 through 20 graphically present the relationship between the development and decline of the 1986 bloom and local precipitation records. For each water body, the closest meteorological observation station was used as the source of precipitation data. While the bloom began to develop at slightly different times in the four bays (with a general west to east progression from Flanders, Great Peconic, Little Peconic and Gardiners bays: R. Nuzzi, New York State Interagency Committee on Aquatic Resources Development, "Brown Tide Conference"), nearly all stations showed a first, dramatic reduction in cell concentration 7 to 14 days after two widespread rain events in June. The extent of the delay between rainfall and changes in cell concentration raises some important questions about the mechanisms by which precipitation might lead to reductions in the bloom.

Precipitation will enter the system as terrestrial runoff or groundwater. It is important to note that the deep groundwater forced into the marine system following a precipitation event is not the same water which fell as precipitation. Rainfall will hydrostatically force older groundwater of potentially different qualilty into the system. As either runoff or groundwater, precipitation should enter the marine system in no more than 3 to 4 days considering the soil types and topography of Long Island's eastern forks (H. Bokuniewicz and G. Zarillo, MSRC, personal communications), yet the bloom did not respond to rainfall for 7 to 14 days. It is possible that the bloom organism does not respond quickly to such changes, and it is also possible that the meteorological fronts which spawned these rain events indirectly affected the bloom through changes in water quality brought about over a longer period of time, *e.g.*, shift in tidal flushing, introduction of higher salinity waters from Long Island Sound, *etc.* The indirect effects of meteorological events on sea level changes and flushing rates in the estuary are possible causes of the reduction in cell concentrations. A preliminary examination of tidal elevation records from West Sayville for 1981-1986 (M. Vieira, personal communcations) supports the hypothesis that important changes in flushing rates occurred in 1985 and 1986.

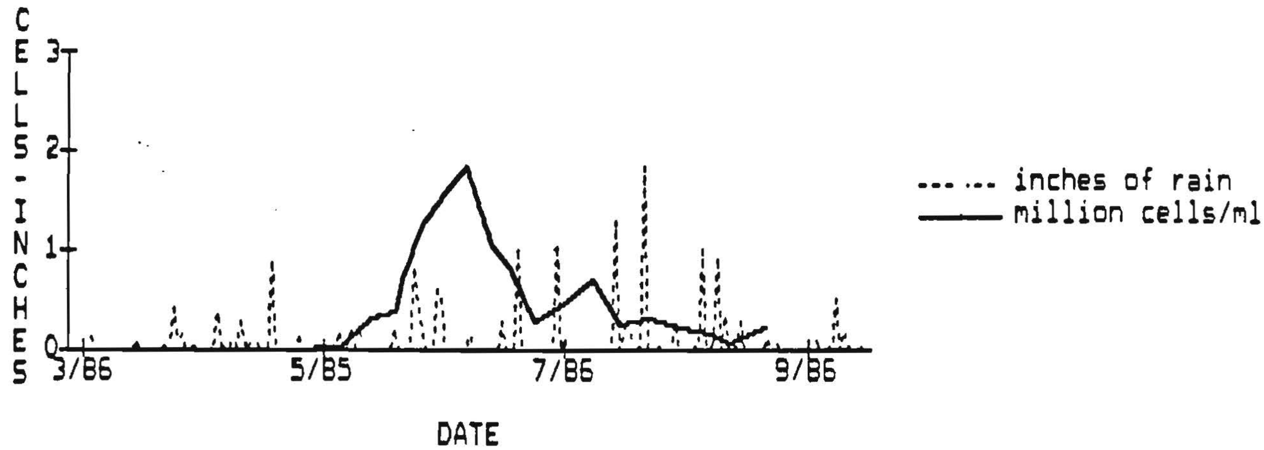
FIGURE 17:



(cell counts from R. Nuzzi, Suffolk County)

FIGURE 18:

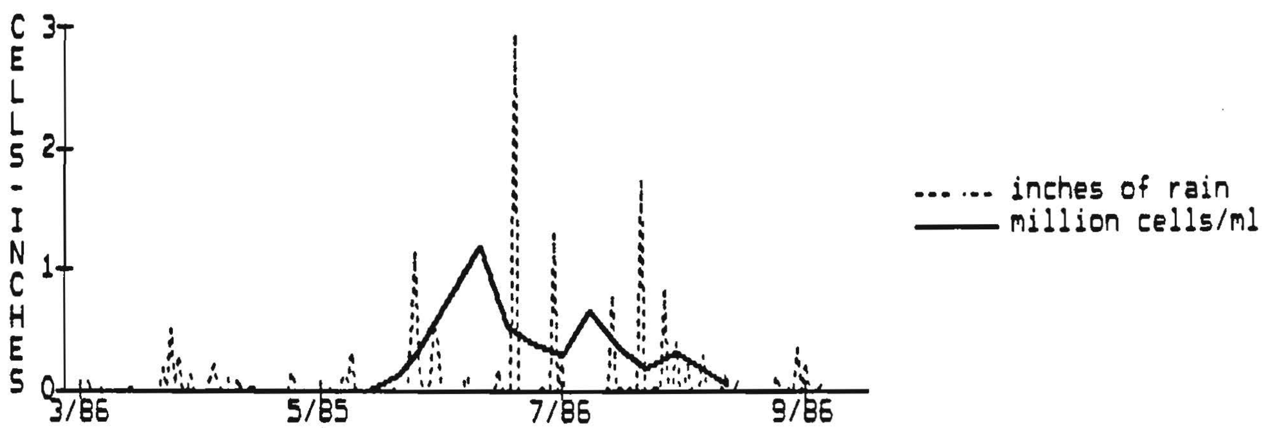
GREAT PECONIC BAY
Bloom concentration and precipitation at Riverhead
1986



(cell counts from R. Nuzzi, Suffolk County)

FIGURE 19:

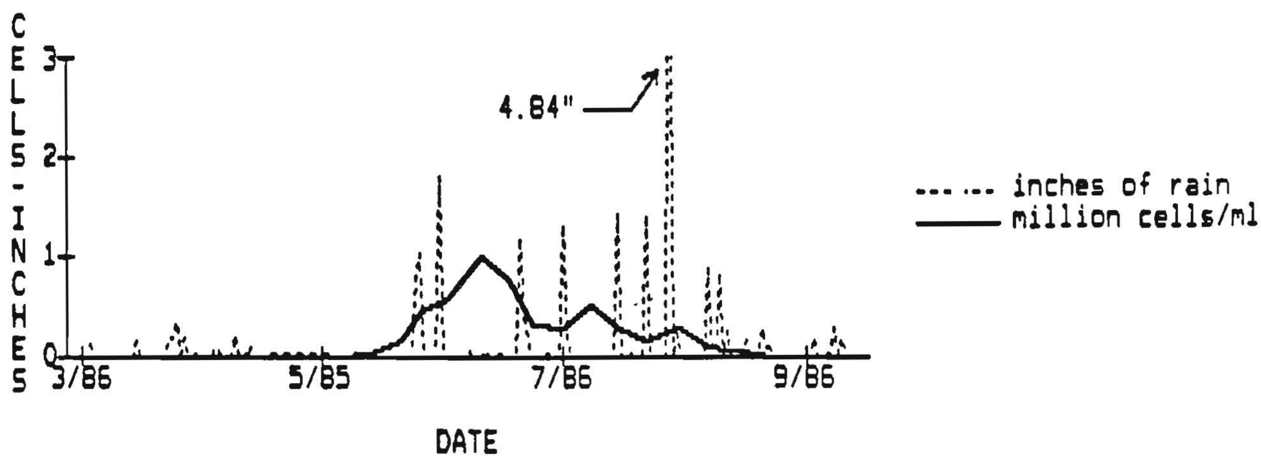
NORTHWEST HARBOR
Bloom concentration and precipitation at Bridgehampton
1986



(cell counts from R. Nuzzi, Suffolk County)

FIGURE 20:

ORIENT HARBOR
Bloom concentration and precipitation at Greenport
1986



(cell counts from R. Nuzzi, Suffolk County)

Table 3 presents the results of a series of statistical analyses describing the correlations between cell concentration and local precipitation over the 4 days preceeding the sampling of the bloom. Four days was chosen in view of the estimated length of time required for runoff and groundwater to enter and affect water quality in the estuary.

Table 3: CORRELATIONS
between CELL CONCENTRATION and PRECIPITATION
(over four days preceeding phytoplankton sample)

Phytoplankton station	Precipitation record	correlation coefficient, r	coefficient of determination, r^2
ALL DATA (July 8, 1985 through September 4, 1986):			
Flanders Bay	Riverhead	-0.134	0.018
Great Peconic Bay	Riverhead	-0.084	0.007
Orient Harbor	Greenport	-0.101	0.010
Northwest Harbor	Bridgehampton	-0.053	0.003
DATA from 1986 BLOOM PERIOD ONLY (May 19, 1986 through September 4, 1986):			
Flanders Bay	Riverhead	0.361	0.131
Great Peconic Bay	Riverhead	0.451	0.203
Orient Harbor	Greenport	0.175	0.031
Northwest Harbor	Bridgehampton	-0.014	0.0002
Little Peconic Bay	Riverhead	0.368	0.135
E/S Shelter Island	Bridgehampton	0.081	0.006
W/S Shelter Island	Bridgehampton	-0.096	0.009
W/S Gardiners Island	Bridgehampton	-0.266	0.071

Very weak, negative correlations exist between cell concentration and precipitation when all available data are considered. Rainfall tended to reduce cell concentrations. However, the hypothesis being tested states that rainfall reduces the cell concentrations of the bloom, which assumes that the bloom is already in progress, or substantially developed, thus the analysis is more properly restricted to those date between May 19, 1986 and September 4, 1986, during which time the bloom was known to exist at the stations sampled. These correlations are much stronger and for the most part, positive (rainfall led to an increase in cell concentration) with the excpetion of the W/S Gardiners Island station compared to the rather distant precipitation data for Bridgehampton. From this work, it appears that rainfall does not reduce cell concentrations, however it must be emphasized that the coefficients of determination for all of these correlations are extremely low. Rainfall accounts for relatively little of the variances in cell concentration, but this might be expected for this is a purely statistical correlation which must, for lack of information, ignore the probably complex environmental links between rainfall and phytoplankton growth.

Taken together, however, the climatological, meteorological and phytoplankton data leave open (but certainly do not prove) the interesting possiblity that such blooms develop only under conditions of drought and are initiated by the rare precipitation event during the otherwise dry period.

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