Metadata File for Waquoit Bay National Estuarine Research Reserve, Waquoit, MA (October 1995-December 1995)
Latest Update: December 16, 1999

I. Data set and Research Descriptors
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2. Entry verification:
The data are uploaded in three file formats (each to separate files identified with the same file name but with unique extensions) from the YSI 6000 data logger to a PC with the YSI 6000 data transfer software (Kermit). Two of these (PC6000 and ASCII text formats) are kept on file in the WBNERR archive. The comma delimited format data file is imported to the EXCEL spreadsheet program (version 5.0) where it is processed according to standard NERRS CDMO protocol using the CDMO Excel 5.0 macros. File size of one complete month of data each has been achieved by concatenating (and truncating if necessary) shorter files of interrupted data segments. File contents are examined for anomalies (e.g., sensor malfunction, battery failure, spurious values, etc.) by visualization of data with the program GRAPHER (ver. 1.3). Data requiring editing are noted and copies of the graphs of raw data are saved at WBNERR. Data editing to CDMO protocol is conducted in EXCEL. Missing data (data logger malfunction or maintenance periods) are represented by periods ("."). Outliers (data values not within the design range of the respective sensors except for turbidity and depth) are changed to periods. Data values recorded during deployment or retrieval (i.e., when the instrument was out of the water or in the laboratory) are also changed to periods. A record of changes is documented in the Data Anomalies section of the metadata file.

The monthly files are sent electronically by FTP to CDMO. Copies of all files are retained at the reserve.

3. Research Objectives:
The primary issue of concern for the Waquoit Bay ecosystem is the influence of

anthropogenic induced alterations by nitrogen enrichment. Waquoit Bay receives nitrogen from several sources, such as septic systems (their leachate percolates into groundwater which then enters the bay), run off from roads, run off containing domestic and agricultural fertilizer and animal waste, and atmospheric sources. This elevated nitrogen loading to the bay has resulted in eutrophic conditions that have contributed to alterations of habitats in the bay. For example, thick mats of seaweeds now cover the bottom where eelgrass meadows thrived in the 1970's. Unfortunately, there are few definitive records of bay conditions during that period, which makes it difficult to evaluate the rates of change. To facilitate future evaluation, long-term records from data loggers are being compiled to track several parameters that describe conditions in this eutrophic system. Of particular interest are measurements of dissolved oxygen and turbidity. These long-term records will facilitate evaluation of changes which may come about from a continuation of watershed alteration that result from "traditional" development (i.e., non-sewered residential areas served by private septic systems typically consisting of septic tanks and leach fields) as well as non-industrial commercial development, such as golf courses, cranberry bogs, and "mini shopping malls". The records will be useful for evaluating the efficacy of remediation efforts intended to reduce the nitrogen loading from these sources to Waquoit Bay.

One data logger, considered the "baseline" unit, is located in central Waquoit Bay at latitude 41 o 34' 00" N, longitude 70 o 31' 47" W. Logger sensors are 0.75 m above the bottom. The site has depths that typically range between 1.8 m to 2.5 m during a tide. It is well flushed by tidal currents, is sufficiently exposed to all points of the wind (i.e., only minimally influenced by shoreline features), and is adequately removed from the navigation channel to be minimally affected by boating activities. Data from this unit are considered to represent ambient environmental conditions within the bay at the time of a sample.

A second data logger, with sensors also 0.75 m above the bottom, is located in a slightly deeper basin (2.3 - 3.0 m) at the head of Waquoit Bay. More than 200 boat moorings are in this basin. During the last decade, there have been fish kills in this area, as evidenced by

sightings of dead and dying fish and shellfish along the basin's shore. Preliminary data suggest that low concentrations of dissolved oxygen that occur near dawn (daybreak hypoxia) are the cause. Oxygen levels in the bay are the lowest each day at dawn due to respiration by biota in the bay, particularly the copious quantity of seaweeds that have become exceedingly abundant due to nitrogen loading. On most days sufficient sunlight for photosynthesis usually reaches the bottom of the shallow bay and dissolved oxygen concentrations increase quickly after sunrise. However, if fog sufficiently reduces insolation, oxygen production by photosynthesis may be severely limited. If such conditions persist, fish (e.g., juvenile winter flounder, Pleuronectes americanus) and shellfish (e.g., bay scallop, Argopectin irradians) may be killed due to inadequate oxygen. Data from the northern and central basins and the WBNERR meteorological station will help us learn about the scale and dynamics of these events and their frequency of occurrence.

Another parameter of direct interest at WBNERR is turbidity. Since the mid 1970's, the major primary producer of the Waquoit Bay ecosystem has shifted from eelgrass to macroalgae. The seaweed dominated system relies on the energy subsidy of eutrophication (in this case nitrogen) to sustain its prolific productivity. But it has been hypothesized that eventually, shifts in trophic energy flow through the "artificially sustained" ecosystem will alter the delicate equilibrium that supports the proliferation of seaweeds. This may result in an increase in phytoplankton abundance which would decreases the amount of light reaching the benthic algae, causing it to die. This would release nutrients that would further fuel the growth of phytoplankton until the system is no longer dominated by seaweed. An increase in phytoplankton concentration would result in an increase in ambient turbidity levels that would be detectable by moored data logger instruments. Thus, long-term records of turbidity will be extremely valuable should such a scenario occur. However, this important parameter is also affected by weather (wind and rain), land use, hydrography, and boating. Understanding how these variables influence turbidity is a topic of ongoing research by staff at the reserve.

4. Research methods

There are two sampling sites. One is in the central portion of the bay and is considered to provide baseline measurements of "ambient" conditions. A second data logger is deployed in the mooring basin at the head of Waquoit Bay. This logger monitors the dynamics of daybreak hypoxia that is prevalent in this area of the bay.

The data loggers at the two sites in Waquoit Bay record measurements of temperature, specific conductivity, salinity, dissolved oxygen, turbidity, water level, and pH at thirty minute intervals during deployment periods of roughly two weeks. The sampling season is generally from March to December. However, this is dependent on weather, the amount of ice on the bay, and the operational availability of the boat that serves as tender for the loggers.

Each PC6000 data logger is anchored with a 75 pound mooring to which two lines are attached. One line is for a surface float that marks the location. The other line is shorter and terminates at a smaller float; line length is such that the float remains submerged throughout tidal changes. The data logger is attached to this line in a vertical manner so that the sensors (pointing downward) are suspended 75 cm from the bottom. This system was chosen to minimize opportunities for vandalism. Unfortunately, because the data logger tender is small, handling the weight of the mooring can exceed the limits of safety for data logger deployment/retrieval operations on windy days. As such, data logger field operations are limited to "fair weather". This contingency may result in interruptions in data collection that exceed those required for routine maintenance and calibration schedules, particularly when staffing levels are low.

During colder months, continuous operations are limited to about two weeks due to limited battery life. In the warmer months, particularly June - September, biofouling of the sensors also limits continuous operation to about two weeks even though battery performance during this period would allow longer deployments.

After a deployment, each logger is brought back to the laboratory for post calibration check, data downloading, instrument and sensor cleaning, and calibration. These procedures are

carried out according to the methods described in the YSI Operating Manual. Salinity sensors were calibrated with reference seawater that had been previously analyzed with a Guildline salinometer at the Woods Hole Oceanographic Institution. Oxygen calibration was performed with the aid of a laboratory grade barometer. pH sensors were calibrated with 7.0 and 10.0 pH standard solutions (2-point calibrations). Turbidity standard solutions were prepared from formazin dilutions that were checked with a LaMotte Model 600 turbidity meter (calibrated with a 2-point calibration using LaMotte turbidity standards). Temperature sensors were not calibrated.

During the summer months, oxygen membranes were changed during each maintenance period (an operation so noted in metadata file Section 13). During colder months, when biofouling is less of a concern, membranes may have been used for two deployments. When membranes were reused, they were cleaned with the water jet from a Water Pick dental instrument. If a membrane was replaced, calibration was not done until the membrane had been in place for at least 24 hours. Final calibration was done immediately prior to instrument deployment.

5. Site location and character:
The Waquoit Bay National Estuarine Research Reserve (WBNERR) is located in the northeastern United States on the southern shore of Cape Cod, Massachusetts. About 8,000 people maintain permanent residency in Waquoit Bay's drainage area, which covers parts of the towns of Falmouth, Mashpee, and Sandwich. During summer months, the population swells 2-3 fold.

WBNERR is representative of shallow coastal lagoons that occur from Cape Cod to Sandy Hook, New Jersey. WBNERR is within the Virginian biogeographic province, on the transitional border (Cape Cod) between the Virginian and the more northern Acadian biogeographic province.

Like many embayments located on glacial outwash plains, Waquoit Bay is shallow, fronted by prominent barrier beaches (i.e., those of South Cape Beach State Park and Washburn Island),

and is backed by salt marshes and upland forests. Two narrow, navigable inlets, reinforced with granite jetties, have been constructed through two barrier beaches to connect Waquoit Bay with Nantucket Sound to the south. A third shallow and generally unnavigable inlet opened through the Washburn Island barrier beach during Hurricane Bob in August 1991. It has not been reinforced and its fate remains uncertain.

The eastern shore of uninhabited Washburn Island, with its low, steep bluffs and forested uplands, forms the western boundary of the reserve. However, tidal waters enter and leave the bay proper (and the Reserve) via the so-called Seapit and Eel rivers, which funnel tidal flows along the western shore of Washburn Island, through Eel Pond and ultimately to Nantucket Sound.

Dense housing developments cover the two peninsulas that form the western shore of the two rivers. Although the developments are outside of the Reserve boundaries, nitrogen in discharges from their septic systems (which flows ultimately into the bay via groundwater) and in fertilizer run-off from their lawns has significant effects on the functioning of the Waquoit Bay ecosystem complex. The impacts of these effects have been a subject of study at the Reserve since its designation (1988). An outcome of this research has been the delineation of subwatersheds within the overall drainage area for Waquoit Bay, of which WBNERR is a small part. This knowledge allows robust experimental designs (e.g., substitution of space for time) which augment results from work done within and near to the Reserve.

At the northern end of the Bay, an area comprising a separate subwatershed, coastal bluffs of glacial till rise 30 feet above sea level, the highest land within the Reserve. Adjacent to the bluffs, the northern basin of the bay is its deepest area (2.3 m mean low water), albeit much of the remainder of the bay is only slightly shallower (roughly 1.6 m). The NB data logger is located within this basin. Bourne, Bog, and Caleb ponds are freshwater kettle hole ponds on the northern-most shore of the bay. As components of the same sub-watershed, they have a common albeit minor freshwater outflow into the bay's northern basin via a narrow channel

through a brackish marsh. Although this flow is small, over the centuries it has created a significant delta of coarse sand that overlies much finer sediments found at comparable offshore distances elsewhere. The source of this sand is the sandy beach through which this fresh water discharge must travel.

To the east and south, land in other subwatersheds surrounds several salt and freshwater ponds, including Hamblin and Jehu Ponds, brackish salt ponds that are connected to the Bay by the tidal waters of Little and Great rivers, respectively. The shorelines of the ponds are developed with residences that are occupied both seasonally and year round. Hamblin Pond and Little River are components of one subwatershed, and Jehu Pond and Great River are elements of a separate subwatershed. Further south lies Sage Lot Pond. It is in the least developed subwatershed which also contains the barrier beach and salt marsh ecosystem of the reserve's South Cape Beach State Park. To the east of Sage Lot Pond and within the same subwatershed, lies the highly brackish Flat Pond. It receives minimal tidal flows of salt water from Sage Lot Pond through a narrow, excavated channel. The preponderance of the input to Flat Pond is groundwater and run off, both of which are likely affected (e.g., nutrients, pesticides, bacteria) by an adjacent golf course and near-by upper-scale residential development.

The largest source of freshwater to Waquoit Bay is the Quashnet/Moonakis River. (Although named "river", this and the reserve's Childs River are more appropriately described as "rivulets".) A component of yet another subwatershed, it originates in Johns Pond situated north of the bay and traverses forests, cranberry bogs, residential areas, and the Quashnet Valley Golf Course before entering the bay near the southern "boundary" of the northern basin. ("Quashnet" applies to that portion of the river within the town of Mashpee, and "Moonakis" refers to the brackish estuary at the river's mouth, lying in the town of Falmouth. Quashnet will be used hereafter to refer to the entire river.) Although the "baseline" data logger is roughly in the middle of the bay, it is also in the course of the discharge plume of the river. The plume is only detectable by the CB data logger during high water flows. The

Quashnet River is the only component of the Waquoit Bay estuary system that has sufficient numbers of coliform bacteria to cause it to be closed to shellfishing. The source(s) of this bacteria is unknown. The Quashnet River delivers significantly less nitrogen to Waquoit Bay than does the Childs River, which lies to the west and originates in Johns Pond.

The Childs River is the second largest input of freshwater to the Bay. A component of another subwatershed, it runs through densely developed residential areas. The Childs River subwatershed receives the highest nitrogen loading and is the largest nitrogen contributor to the Waquoit Bay system of all the subwatersheds.

Another, albeit smaller, source of freshwater is the discharge of Red Brook through brackish marshlands into Hamblin Pond. Additional freshwater enters the bay elsewhere through groundwater seepage, precipitation and the flows of small brooks. A significant groundwater flow enters the eastern end of the mooring basin at the head of the bay. There is relatively little surface water runoff entering directly into the bay due to the high percolation rates of Cape Cod's coarse, sandy soils.

Data loggers are located at two sites in Waquoit Bay. Site 1 (identified as "Central Basin" or CB) is located at 41o 34' 00" N, longitude 70 o 31' 47" W. It is the reference site for the WBNERR data logger water quality monitoring program. An instrument will be moored at this site for the long term in order to collect baseline measurement of "ambient" conditions within Waquoit Bay. This information will be considered to represent an integration of the general conditions within the bay. The site is well flushed by tides, is 1.8-2.5 m deep, and is in an area that is minimally disturbed by routine activities on the bay (e.g. boat traffic, shellfishing, etc.). The Central Basin region was once covered by eelgrass (Zostera marina). This plant that has all but disappeared from the bay in the last two decades and has been replaced by seaweed, predominantly Cladophora vagabunda, Gracilaria tikvahiayae, and Enteromorpha sp.. The CB site is southwest of the mouth of the Quashnet River. The stream's freshwater discharge into Waquoit Bay is typically 5-10 ft3 /s. The resultant

discharge plume at these low flows has an undetectable influence on salinity at the CB site.
However, unusually high precipitation events or occasional releases of impounded water at an
upstream cranberry bog can significantly increase flow to > 30 ft3 /s. The stream's discharge
plume from these events results in slight reductions in salinity at CB. High precipitation is
most common in the spring although summer and fall are when rains from tropical
disturbances may occur. Discharges from cranberry bogs typically occur in the fall (harvest
time) and after the coldest periods of winter; they are likely to be brief events.

A second data logger is deployed in the basin at the head of Waquoit Bay (Northern Basin or
NB), at latitude 41 o 34' 44" N, longitude 70 o 31' 58" W. The basin is slightly deeper (2.3 -
3.0 m) and less mixed than the central basin reference site (CB). Knowledge of the degree of
mixing at the two sites was originally derived from measurements made by reserve staff (CB
site) and from data obtained by the reserve's volunteer water quality monitoring group the
Waquoit BayWatchers who have collected depth profiles of Waquoit Bay water quality since
1993. The NB data logger, with sensors at 0.75 m above the bottom, monitors the hourly,
daily, weekly, and seasonal dynamics of daybreak hypoxia that is prevalent in this area of the
bay.

6. Data collection period
Data collection in the central and northern basin of Waquoit Bay began October 11, 1995
and continued until December 15, 1995.

7. Associated researchers and projects
None to report.

8. Variable sequence, range of measurements, units, resolution, and accuracy:

YSI 6000 datalogger

Variable Name	Range of Measurements(units)	Resolution	Accuracy
Date	1-12, 1-31, 00-99 (Mo,Day,Yr)	1 month, 1 day, 1 year	NA
Time	0-24, 0-60, 0-60 (Hr, Min, Sec)	1 hr, 1 min, 1s	NA
Temp	-5 to 45	0.01 C	+/-0.15C
SpCOND	0-100 (mS/cm)	0.01mS/cm	+/-0.5% of reading + 0.001 mS/cm
Salinity	0-70 Parts per thousand (ppt)	0.01ppt	+/-1.0% of reading or 0.1 ppt (whichever is greater)

DO 0-200 (% air Saturation) 0.1% @air saturation +/-2% @air sat.
DO 200-500 (% air Saturation) 0.1% @air saturation +/-6% @air sat.
DO 0-20 (mg/l) 0.01mg/l +/-0.2mg/l
DO 20-50 (mg/l) 0.01mg/l +/-0.6mg/l
Depth (shallow) 0-9.1 (m) 0.001m +/-0.018m
pH 2-14 units 0.01units +/-0.2units
Turb 0-1000 NTU 0.1NTU +/-5% of reading
or 2 NTU (whichever is greater)
Data columns are separated by tabs.

9. Coded variable indicator and variable code definitions
The file names are labeled according to site identifier code, month, year (e.g., cb1095).
Identifier codes are: nb = northern basin site in Waquoit Bay, cb = central basin site in
Waquoit Bay. The central basin site is the sp-called "reference" site.

10. Data anomalies
The instruments were not considered operational at WBNERR until October 11, 1995.
Review of data sets from the first three months of instrument use revealed that not all
sensors were consistently fully operational due to improper calibration and/or equipment set
up. When data values were clearly wrong they were discarded. Also, loggers occasionally took
readings during transport to or from the mooring site. These values, as well as those obtained
when the instruments were in the lab, were discarded.

During all three months, the dissolved oxygen values from the Central Basin data logger were
occasionally higher than expected, given our understanding of the study sites at the time.
This unexpected result is discussed in section 13.

There are several unexplainable spikes in the CB oxygen data. The amplitude of these spikes
is insufficient to render them as "outliers" but the cause of this instability in the data is
considered to be unlikely of biological origin (bubbles in the sensor?). These data have been
retained.

For the remaining variables in the data sets, the anomaly record is as follows:

October 1995:
Dissolved oxygen data (both concentration and saturation) during 10/11/95 14:00:00 to
16:30:00 were inexplicably high (actually increased until 16:30:00 when sunlight was

diminishing and oxygen concentrations ought to have been following suit). At 17:00:00
oxygen levels precipitously declined to values that were typical for that time of day
throughout the remainder of the month (10.5 mg/l or 135 % saturation). Because sensor
response was normal after 17:00:00, problem was attributed to a temporary condition that
caused a malfunction for the first few hours of data logging. Affected data were discarded. Ph
values during 10/11/95 14:00:00 to 10/12/95 06:30:00 were inexplicably low. The problem
was
apparently temporary because sensor output eventually exhibited "normal" behavior after a
"start up" period of instability. Sensor output during this time was judged to be meaningless
and data were discarded. Data collected after instability ceased were retained.

November 1995: none to report

December 1995:
Central Basin:
Specific conductivity and salinity data for the entire month were erroneous due to improper
calibration
of the sensor. The data were meaningless and were discarded.
North Basin:
Specific conductivity and salinity data for the entire month were erroneous due to improper
calibration
of the sensor. The data were meaningless and were discarded.
11. Missing data
No turbidity probes were available for the year 1995. Therefore, no turbidity was collected.

October 1995:
Central Basin
No data until 10/11/95 13:30:00 when logger was placed in service. No Ph data from
10/11/95 14:00:00 to 10/12/95 06:30:00 due to sensor instability during this period.
Dissolved oxygen data (both concentration and saturation) during 10/11/95 14:00:00 to
16:30:00 were inexplicably high (sensor malfunction) and were discarded. Logger was returned
to lab for servicing at 10/31/95 16:00:00; data for the month ended then. No salinity data
10/11 1400-1630.

North Basin
No data until 10/11/95 14:00:00 when logger was placed in service. No pH data for the entire

month due to sensor malfunction.
No data after 10/31/95 16:00:00 when the instrument was removed for servicing.

November 1995:
The data loggers were kept in the laboratory until November 13. During this time reserve
personnel received factory supported training and the instruments received a thorough
calibration check. The loggers were redeployed on November 13.
Central Basin:
No data until 11/13/95 16:30:00 when logger was deployed.
No data after 11/27/95 08:30:00 when logger was removed for servicing.

North Basin:
No data until 11/13/95 16:00:00 when logger was deployed.
No data after 11/27/95 09:00:00 when logger was removed for servicing.

December 1995:
Central Basin:
Specific conductivity and salinity data were discarded due to improper calibration of sensor.
No data after 12/15/95 09:30:00 when instrument was pulled for the winter due to ice in
Waquoit Bay (it was freezing over).

North Basin:
Specific conductivity and salinity data were discarded due to improper calibration of sensor.
No data after 12/15/95 09:30:00 when instrument was pulled for the winter due to ice in
Waquoit Bay (it was freezing over).

12. Other remarks/notes
A surprising finding from this initial deployment is the larger variability in the diel changes of
dissolved oxygen levels in the Central Basin (CB). It was assumed that because the Northern
Basin (NB) was less well mixed than CB, oxygen levels at logger depth would change more at
NB during the course of a 24 hour period. The opposite was the case. This was considered to
be a result of the greater volume of water in the north basin area which provided a larger
reservoir of dissolved oxygen than was available at the CB location. As a result, diel oxygen
flux was greater at CB.

It has subsequently been learned (in 1998) that a persistent lateral front exists in the vicinity
of the CB mooring site. This front is apparently due to current flow patterns in the Waquoit
Bay estuary. Salinity and temperature values may vary several units across the front. Wind

forcing and tidal forces influence the position of the front and it may migrate through the CB
deployment area several times during a month. This causes variation within the "reference"
data set that may otherwise be unexplained.