

TABLE OF CONTENTS

I. INTRODUCTION 1

 I.1 THE MASSACHUSETTS ESTUARIES PROJECT APPROACH 14

 I.2 SITE DESCRIPTION 18

 I.3 NITROGEN LOADING 25

 I.4 WATER QUALITY MODELING 26

 I.5 REPORT DESCRIPTION 27

II. PREVIOUS STUDIES RELATED TO NITROGEN MANAGEMENT 29

III. DELINEATION OF WATERSHEDS 36

 III.1 BACKGROUND 36

 III.2 NANTUCKET HARBOR CONTRIBUTORY AREAS 36

**IV. WATERSHED NITROGEN LOADING TO EMBAYMENT: LAND USE, STREAM
 INPUTS, AND SEDIMENT NITROGEN RECYCLING 40**

 IV.1 WATERSHED LAND USE BASED NITROGEN LOADING ANALYSIS 40

 IV.1.1 Land Use and Water Use Database Preparation 41

 IV.1.2 Nitrogen Loading Input Factors 45

 IV.1.3 Calculating Nitrogen Loads 48

 IV.2 ATTENUATION OF NITROGEN IN SURFACE WATER TRANSPORT 54

 IV.2.1 Background and Purpose 54

 IV.2.2 Surface water Discharge and Attenuation of Watershed Nitrogen: Stream
 Discharge to Quaise, Polpis and Head of the Harbor portions of the Nantucket
 Harbor System 56

 IV.3 BENTHIC REGENERATION OF NITROGEN IN BOTTOM SEDIMENTS 59

 IV.3.1 Sediment-Watercolumn Exchange of Nitrogen 59

 IV.3.2 Method for determining sediment-watercolumn nitrogen exchange 60

 IV.3.3 Rates of Summer Nitrogen Regeneration from Sediments 62

V. HYDRODYNAMIC MODELING 67

 V.1 INTRODUCTION 67

 V.2 GEOMORPHIC AND ANTHROPOGENIC EFFECTS TO THE ESTUARINE SYSTEM .. 69

 V.2.1 Inlet Stabilization 69

 V.2.2 Inlet Processes and Shoreline Change Analysis 70

 V.2.3 Inlet Management Implications 72

 V.3 DATA COLLECTION AND ANALYSIS 73

 V.3.1 Bathymetry Data Collection 73

 V.3.2 Tide Data Collection and Analysis 74

 V.2.3 ADCP Data Analysis 82

 V.4 HYDRODYNAMIC MODELING 88

 V.4.1 Model Theory 88

 V.4.2 Model Setup 88

 V.4.2.1 Grid generation 89

 V.4.2.2 Boundary condition specification 89

 V.4.2.3 Calibration 89

 V.4.2.3.1 Friction coefficients 91

 V.4.2.3.2 Turbulent exchange coefficients 91

 V.4.2.3.3 Marsh porosity processes 92

V.4.2.3.4 Comparison of modeled tides and measured tide data 92

V.4.2.4 ADCP verification of the Nantucket Harbor system 95

V.4.2.6 Model Circulation Characteristics 97

V.5 FLUSHING CHARACTERISTICS 101

VI. WATER QUALITY MODELING 105

VI.1 DATA SOURCES FOR THE MODEL 105

VI.1.1 Hydrodynamics and Tidal Flushing in the Embayments 105

VI.1.2 Nitrogen Loading to the Embayments 105

VI.1.3 Measured Nitrogen Concentrations in the Embayments 105

VI.2 MODEL DESCRIPTION AND APPLICATION 106

VI.2.1 Model Formulation 107

VI.2.2 Water Quality Model Setup 108

VI.2.3 Boundary Condition Specification 108

VI.2.4 Model Calibration 109

VI.2.5 Model Salinity Verification 111

VI.2.6 Build-Out and No Anthropogenic Load Scenarios 112

VI.2.6.1 Build-Out 114

VI.2.6.2 No Anthropogenic Load 117

VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH 121

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS 121

VII.2 BOTTOM WATER DISSOLVED OXYGEN 122

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS 131

VII.4 BENTHIC INFAUNA ANALYSIS 143

VIII. CRITICAL NUTRIENT THRESHOLD DETERMINATION AND DEVELOPMENT OF WATER QUALITY TARGETS 150

VIII.1. ASSESSMENT OF NITROGEN RELATED HABITAT QUALITY 150

VIII.2. THRESHOLD NITROGEN CONCENTRATIONS 155

VIII.3 DEVELOPMENT OF TARGET NITROGEN LOADS 157

IX. REFERENCES 162

LIST OF FIGURES

Figure I-1. Major component basins of the Nantucket Harbor Estuary assessed by the Massachusetts Estuaries Project relative to nutrient related habitat health and nitrogen management planning. The Harbor exchanges tidal waters with Nantucket Sound through a single jettied inlet. Freshwaters enter from the watershed primarily through direct groundwater discharge and a series of small, short streams draining wetlands and 1 small surface water discharge (Mill Brook to Polpis Harbor).2

Figure I-2. Simplified map of ice sheet front relative to Nantucket (after Oldale 1985). The southern line indicates a position for the formation of the Nantucket Moraine. A more southerly maximum terminal extension is not shown. The northern stand of the retreating ice sheet was important to the formation of harbor area sediments, moreover there is evidence of glacial lake-bed deposits in Polpis Harbor and a pro-glacial lake in the harbor area.3

Figure I-3. Generalized distribution of surficial glacial deposits on Nantucket (after Oldale 1985). Extensive deposits of sandy outwash are the result of several depositional events stemming from different ice-front positions. Many of the freshwater and saltwater wetlands in the Polpis Harbor area occur in areas of patchy ice contact (uplands) deposits and fine grained, glacial lake-bed deposits of lower hydraulic conductivity. Coatue and Great Point are marine deposits formed as sea level rose post-glaciation and which are continually being reworked by coastal processes.4

Figure I-4. Nantucket Harbor bathymetric map as determined from surveys conducted in 1990-1991. Contours are in feet.6

Figure I-5. Hypometric curve of Nantucket Harbor based on bathymetry survey conducted in 1990-1991. Nearly 60 percent of the harbor area is less than 10 feet in depth.7

Figure I-6. Map of Nantucket Harbor depicting component sub-basins based on work previously undertaken and presented in 1997 Nantucket Harbor study.8

Figure I-7. Nantucket Harbor component sub-basins: A) relative volumes, B) relative surface areas. Head of the Harbor is the largest component sub-basin in the Nantucket Harbor system based on both volume and surface area.9

Figure I-8. Massachusetts Division of Marine Fisheries map of designated shellfish growing area NT2 (Nantucket Harbor West) depicting closed area NT2.2. 10

Figure I-9. Massachusetts Division of Marine Fisheries map of designated shellfish growing area NT4 (Polpis Harbor) depicting closed area NT4.1. 11

Figure I-10. Massachusetts Estuaries Project Critical Nutrient Threshold Analytical Approach. Section numbers refer to sections in this MEP report where the specified information is provided. 18

Figure I-11. Sediment distribution by grain size in Nantucket Harbor (after Lidz, 1965).20

Figure I-12. Distribution of sediment organic carbon in Nantucket Harbor as determined from >300 samples collected throughout Nantucket Harbor (courtesy D. Schlezinger and B. Howes).21

Figure I-13. Distribution of sediment organic carbon throughout Nantucket Harbor as adapted from an earlier study by Lidz, 1965. Methodological differences allow only qualitative comparisons to percentages presented in Figure I-12.23

Figure III-1. Watershed and sub-watershed delineations for the Nantucket Harbor estuary system. Sub-watersheds to embayments were selected based upon the functional estuarine sub-units in the water quality model (see section VI).37

Figure III-2. Comparison of 1990 HWH and current Nantucket Harbor watershed and subwatershed delineations.38

Figure IV-1. Land-use in the Nantucket Harbor watershed. The watershed is completely contained within the Town of Nantucket. Land use classifications are based on assessors’ records provided by the town.42

Figure IV-2. Distribution of land-uses within the subwatersheds and whole watershed to Nantucket Harbor. Only percentages greater than or equal to 3% are shown.44

Figure IV-3. Parcels, Parcelized Watersheds, and Developable Parcels in the Nantucket Harbor watersheds.50

Figure IV-4 (a-c). Land use-specific unattenuated nitrogen load (by percent) to the (a) overall Nantucket Harbor System watershed, (b) Head of the Harbor subwatershed, and (c) Polpis subwatershed. “Overall Load” is the total nitrogen input within the watershed, while the “Local Control Load” represents only those nitrogen sources that could potentially be under local regulatory control.52

Figure IV-4 (d-e). Land use-specific unattenuated nitrogen load (by percent) to the (d) Quaise subwatershed, and (e) Town subwatershed. “Overall Load” is the total nitrogen input within the watershed, while the “Local Control Load” represents only those nitrogen sources that could potentially be under local regulatory control.53

Figure IV-5. Location of major streams discharging to the Nantucket Harbor embayment system in relation to associated freshwater wetlands. Most of the streams are short and act primarily as “drains” for groundwater and conduits of stormwater runoff. Courtesy of Nantucket Harbor Study.57

Figure IV-6. Average nutrient concentrations for 11 streams discharging to Nantucket Harbor. Nitrate (NO₃) and particulate organic nitrogen (PON) constitute almost all of the bio-active nitrogen pool. The high level of N in stream 6 was primarily due to high nitrate possibly from wastewater. However, stream 6 did not have a commensurately high N load as the volumetric discharge was very small. Courtesy of Nantucket Harbor Study.59

Figure IV-7. Nantucket Harbor embayment system sediment sampling sites (red symbols) for determination of nitrogen regeneration rates.61

Figure IV-8. Conceptual diagram showing the seasonal variation in sediment N flux, with maximum positive flux (sediment output) occurring in the summer months, and maximum negative flux (sediment up-take) during the winter months.64

Figure V-1. Topographic map detail of Nantucket Harbor, Nantucket Island, Massachusetts.68

Figure V-2. A portion of the U.S.G.S. 1890 map showing Nantucket Harbor. This map depicts the condition of this inlet prior to the installation of jetties.70

Figure V-3. Recommended navigation improvements for Nantucket Harbor, based on the 1941 U.S. Army Corps of Engineers plan.71

Figure V-4. Historical shoreline change rates (1955-2003) in the area of Nantucket Harbor.73

Figure V-5. Transects from the bathymetry survey of the Nantucket Harbor markers show the locations of the three tide recorders deployed for this study.74

Figure V-6. Plot of interpolated finite-element grid bathymetry of the Nantucket Harbor system, shown superimposed on 2003 aerial photos of the system locale. Bathymetric contours are shown in color at three-foot intervals.....75

Figure V-7. Plots of observed tides for the Nantucket Harbor system, for the 31-day period between August 30 and September 30, 2004. The top plot shows tides offshore Nantucket Harbor inlet, in Nantucket Sound. Tides recorded in the Harbor at Brant Point, Polpis Harbor, The Creeks and in Consu Pond are also shown. All water levels are referenced to the **North American Vertical Datum** of 1988 (NAVD 88).....76

Figure V-8. Plot showing two tide cycles tides at three stations in the Nantucket Harbor system plotted together. Demonstrated in this plot is the minor frictional damping effect caused by flow restrictions at the inlets. The damping effects are seen only as a lag in time of high and low tides from Nantucket Sound. The time lag of low tide between the Sound and Prince Cove in this plot is 50 Minutes.77

Figure V-9. Example of an observed astronomical tide as the sum of its primary constituents.79

Figure V-10. Plot showing the comparison between the measured tide time series (top plot), and the predicted astronomical tide (middle plot) computed using the 23 individual tide constituents determine in the harmonic analysis of the Brant Point gauge data. The residual tide shown in the bottom plot is computed as the difference between the measured and predicted time series ($r=m-p$).81

Figure V-11. Color contour plots of along-channel and cross-channel velocity components for transect line run between Brant Point and First Point, measured at 11:52 on Sep 23, 2004 during the period of maximum ebb tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo (MASS GIS) of the survey area. A tide plot for the survey day is also given.83

Figure V-12. Color contour plots of along-channel and cross-channel velocity components for transect line run between Brant Point and First Point, measured at 17:56 on September 23, 2004 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo (MASS GIS) of the survey area. A tide plot for the survey day is also given.84

Figure V-13. Color contour plots of along-channel and cross-channel velocity components for transect line run First Point and Shimmo, measured at 11:58 on September 23, 2004 during the period of maximum ebb tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo (MASS GIS) of the survey area. A tide plot for the survey day is also given.....85

Figure V-14. Color contour plots of along-channel and cross-channel velocity components for transect line run First Point and Shimmo, measured at 18:02 on September 23, 2004 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo (MASS GIS) of the survey area. A tide plot for the survey day is also given.....86

Figure V-15. Color contour plots of along-channel and cross-channel velocity components for transect line run across the jetty tips of the Harbor entrance, measured at 17:37 on September 23, 2004 during the period of maximum flood tide currents. Positive along-channel currents (top panel) indicate the flow is moving into the estuary, while positive cross-channel velocities (middle panel) are oriented 90° clockwise of positive along-channel. Lower left plot shows scaled velocity vectors projected onto a 1994 aerial photo (MASS GIS) of the survey area. A tide plot for the survey day is also given.87

Figure V-16. Plot of hydrodynamic model grid mesh for the Nantucket Harbor estuarine system of Nantucket Island, Massachusetts. Color patterns designate the different model material types used to vary model calibration parameters and compute flushing rates.90

Figure V-17. Comparison of model output and measured tides for the TDR location offshore the inlet to Nantucket Harbor, in Nantucket Sound. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.....92

Figure V-18. Comparison of model output and measured tides for the TDR location at Brant Point. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.....93

Figure V-19. Comparison of model output and measured tides for the TDR location in Polpis Harbor. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.....93

Figure V-20. Comparison of model output and measured tides for the TDR location at the Head of the Harbor. The top plot is a 50-hour sub-section of the total modeled time period, shown in the bottom plot.....94

Figure V-21. Comparison of measured volume flow rates versus modeled flow rates (top plot) through the Nantucket Harbor Inlet between Brant Point and First Point, over a tidal cycle on September 23, 2004. Flood flows into the inlet are positive (+), and ebb flows out of the inlet are negative (-). The bottom plot shows the tide elevation offshore the Harbor Inlet. ($R^2=0.99$, $E_{RMS}=3,100 \text{ ft}^3/\text{sec}$).....96

Figure V-22. Comparison of measured volume flow rates versus modeled flow rates (top plot) in Nantucket Harbor between First Point and Shimmo, over a tidal cycle on September 23, 2004. Flood flows into the inlet are positive (+), and ebb flows out of the inlet are negative (-). The bottom plot shows the tide elevation offshore the Harbor inlet. ($R^2=0.98$, $E_{RMS}=3,200 \text{ ft}^3/\text{sec}$).97

Figure V-23. Example of hydrodynamic model output for a single time step where maximum ebb velocities occur for this tide cycle. Color contours indicate velocity magnitude, and vectors indicate the direction of flow.....99

Figure V-24. Example of hydrodynamic model output for a single time step where maximum ebb velocities occur for this tide cycle. Color contours indicate velocity magnitude, and vectors indicate the direction of flow..... 100

Figure V-25. Time variation of computed flow rates at two channel transects in the Nantucket Harbor system. Positive flow indicated flooding tide, while negative flow indicates ebbing tide..... 100

Figure V-26. Close-up of Nantucket Harbor, showing output from the hydrodynamic model at a single time step, where a recirculation eddy (or gyre) has set up on the south side of Brant Point. 101

Figure VI-1. Estuarine water quality monitoring station locations in the Nantucket Harbor estuary system. Station labels correspond to those provided in Table VI-1..... 107

Figure VI-2. Comparison of measured total nitrogen concentrations and calibrated model output at stations in the Nantucket Harbor system. Station labels correspond with the MEP IDs provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed concentration for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate \pm one standard deviation of the entire dataset 110

Figure VI-3. Model total nitrogen calibration target values are plotted against measured concentrations, together with the unity line. Computed correlation (R^2) and error (rms) for the model are also presented..... 111

Figure VI-4. Contour plot of average total nitrogen concentrations from results of the present conditions loading scenario, for the Nantucket Harbor system. 112

Figure VI-5. Comparison of measured and calibrated model output at stations in Nantucket Harbor. Stations labels correspond with those provided in Table VI-1. Model output is presented as a range of values from minimum to maximum values computed during the simulation period (triangle markers), along with the average computed salinity for the same period (square markers). Measured data are presented as the total yearly mean at each station (circle markers), together with ranges that indicate \pm one standard deviation of the entire dataset..... 113

Figure VI-6. Model salinity target values are plotted against measured concentrations, together with the unity line. RMS error for this model verification run is 0.65 ppt or 2.03% of measurements. 113

Figure VI-7. Contour Plot of modeled salinity (ppt) in the Nantucket Harbor system..... 114

Figure VI-8. Contour plot of modeled total nitrogen concentrations (mg/L) in the Nantucket Harbor system, for projected build-out scenario “A” loading conditions..... 117

Figure VI-9. Contour plot of modeled total nitrogen concentrations (mg/L) in the Nantucket Harbor system, for projected build-out scenario “B” loading conditions. 118

Figure VI-10. Contour plot of modeled total nitrogen concentrations (mg/L) in Nantucket Harbor, for no anthropogenic loading conditions..... 120

Figure VII-1. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System (Schlezinger and Howes, unpublished data). Rates vary \sim 7 fold from winter to summer as a result of variations in temperature and organic matter availability..... 123

Figure VII-2. Aerial Photograph of the Nantucket Harbor system on the island of Nantucket showing locations of Dissolved Oxygen mooring deployments within each of the main basins, conducted by the Nantucket Harbor Study (1997)..... 124

Figure VII-3. Rate of oxygen consumption ($\text{mmol m}^2 \text{d}^{-1}$) within the bottom sediments and overlaying 1 meter of water. These data indicate that Head of the Harbor and Polpis Harbor are the most susceptible to oxygen depletion resulting from a brief period of water column stratification. At these rates of consumption, only 24 hours would be required to remove half the oxygen in a stratified water column that is initially at full oxygen saturation thus creating a stressful environment for infauna..... 127

Figure VII-4. Bottom water record of dissolved oxygen at the Polpis Harbor station, Summer 1992..... 129

Figure VII-5. Bottom water record of dissolved oxygen in the deeper waters of the Quaise Basin (Pocomo Mooring - M2), Summer 1992..... 130

Figure VII-6. Bottom water record of Dissolved Oxygen at the Head of the Harbor (Wauwinet) station, Summer 1992..... 130

Figure VII-7. Bottom water record of Dissolved Oxygen at the Harbor Channel station, Summer 1992. Calibration samples represented as red dots. 131

Figure VII-8. Distribution of eelgrass (*Zostera Marina*, hatched area) within Nantucket Harbor. The extensive eelgrass beds located outside the Harbor are not shown..... 132

Figure VII-9. Distribution of macro-algal cover within Nantucket Harbor. The highest coverage was found along the shore of Coatue where nutrients were lowest. The distribution is consistent with patterns of water circulation..... 135

Figure VII-10. Percent of bottom area (0-100m) covered by macroalgae or eelgrass measured by shoreline survey of Nantucket Harbor during late summer/fall 1994. *Polysiphonia* and *Codium* were the predominant macroalgae encountered..... 136

Figure VII-11. Eelgrass bed distribution within the Nantucket Harbor System. The 1951 coverage is depicted by the dark green outline (hatched area) inside of which circumscribes the eelgrass beds. The analysis of the 1951 aerial photography determined that the image quality for large areas of the Harbor was not sufficient to confidently assess the presence of eelgrass except for a small area confined to the inlet of the Harbor and Polpis Harbor. In the composite photograph, the light green outline depicts the 1995 eelgrass coverage and the yellow outlined areas circumscribe the eelgrass coverage in 2001. The 1995 and 2001 areas were mapped by MassDEP. All data was provided by the MassDEP Eelgrass Mapping Program..... 137

Figure VII-12. Eelgrass bed distribution within the Nantucket Harbor System. The 1951 coverage is depicted by the dark green outline (hatched area) inside of which circumscribes the eelgrass beds. The analysis of the 1951 aerial photography determined that the image quality for large areas of the Harbor was not sufficient to confidently assess the presence of eelgrass except for a small area confined to the inlet of the Harbor and Polpis Harbor. In the composite photograph, the light green outline depicts the 1995 eelgrass coverage and the yellow outlined areas circumscribe the eelgrass coverage in 2001. The 1995 and 2001 areas were mapped by MassDEP. All data was provided by the MassDEP Eelgrass Mapping Program..... 138

Figure VII-13. Eelgrass bed distribution within the Nantucket Harbor System. The 1951 coverage is depicted by the dark green outline (hatched area) inside of which circumscribes the eelgrass beds. In the composite photograph, the light green outline depicts the 1995 eelgrass coverage and the yellow outlined areas circumscribe the eelgrass coverage in 2001. The 1995 and 2001 areas were mapped by MassDEP. All data was provided by the MassDEP Eelgrass Mapping Program..... 139

Figure VII-14. Eelgrass bed distribution within the Nantucket Harbor System. The 1951 coverage is depicted by the dark green outline (hatched area) inside of which circumscribes the eelgrass beds. The analysis of the 1951 aerial photography determined that the image quality for large areas of the Harbor was not sufficient to confidently assess the presence of eelgrass except for a small area confined to the inlet of the Harbor and Polpis Harbor. In the composite photograph, the light green outline depicts the 1995 eelgrass coverage and the yellow outlined areas circumscribe the eelgrass coverage in 2001. The 1995 and 2001 areas were mapped by MassDEP. All data was provided by the MassDEP Eelgrass Mapping Program..... 140

Figure VII-15. Eelgrass bed distribution within the Nantucket Harbor System. The 1951 coverage is depicted by the dark green outline (hatched area) inside of which circumscribes the eelgrass beds. In the composite photograph, the light green outline depicts the 1995 eelgrass coverage and the yellow outlined areas circumscribe the eelgrass coverage in 2001. The 1995 and 2001 areas were mapped by MassDEP. All data was provided by the MassDEP Eelgrass Mapping Program..... 141

Figure VII-16. Location of sampling stations for summer 1992 (August) and spring 1994 (May) benthic infaunal surveys within Nantucket Harbor and Nantucket Sound..... 144

Figure VII-17. Number of individuals per 0.04 m² of benthic animal species representative of pristine, intermediate and stressed environmental conditions. Numbers of bars represent number of species present at each station. Note the shift from pristine to intermediate conditions between the lower and upper portions of the Harbor. 145

Figure VII-18. Distribution of high, moderate and low benthic habitat quality areas based on summer 1992 and Spring 1994 infaunal surveys. Areal coverage incorporated data from visual diver surveys, sediment type and organic matter content as well as basin configuration..... 147

Figure VII-19. Aerial photograph of the Nantucket Harbor system showing location of benthic infaunal sampling stations (red symbol). Infaunal samples collected in the fall of 2003..... 148

Figure VIII-1. Contour plot of modeled total nitrogen concentrations (mg/L) in the Nantucket Harbor system, for threshold “A” loading conditions. 160

Figure VIII-2. Contour plot of modeled total nitrogen concentrations (mg/L) in the Nantucket Harbor system, for threshold “B” loading conditions. 161

LIST OF TABLES

Table I-1. Nantucket Harbor sub-basin morphometry summarizing basin areas and volumes.8

Table III-1. Daily groundwater discharge from each of the sub-watersheds to the Nantucket Harbor Estuary.39

Table IV-1. Primary Nitrogen Loading Factors used in the Nantucket Harbor MEP analyses. General factors are from MEP modeling evaluation (Howes & Ramsey 2001). Site-specific factors are derived from Barnstable data. *Data from MEP lawn study in Falmouth, Mashpee & Barnstable 2001.49

Table IV-2 (a-b). Nantucket Harbor Nitrogen Loads. (a) presents nitrogen loads based on current conditions including removal of wastewater nitrogen loads from the watershed by current connections to the municipal sewer system. (b) presents nitrogen loads based on the connection of all existing and buildout properties within the sewer district to the municipal sewer system and the removal of their wastewater nitrogen loads from the watershed. All values are kg N yr⁻¹.51

Table IV-3. Rates of net nitrogen return from sediments to the overlying waters from within each of the component basins of the Nantucket Harbor System. These values are combined with the basin areas to determine total nitrogen mass in the water quality model (see Chapter VI). Measurements represent July-August rates. Shallow samples were collected at depths <8' and deep at >10'.66

Table V-1. Tide datums computed from a 28-day period from the tide records collected in the Nantucket Harbor system. Datum elevations are given relative to NAVD 88.78

Table V-2. Major tidal constituents determined for gauge locations in Nantucket Harbor, September 30 through October 30, 2004.79

Table V-3. M₂ tidal constituent phase delay (relative to Nantucket Sound) for gauge locations in the Nantucket Harbor system, determined from measured tide data.80

Table V-4. Percentages of Tidal versus Non-Tidal Energy for stations in Nantucket Harbor, September 2004.80

Table V-5. Manning's Roughness coefficients used in simulations of modeled sub-embayments. These embayment delineations correspond to the material type areas shown in Figure V-16.91

Table V-6. Tidal constituents for measured water level data and calibrated model output, with model error amplitudes, for the Nantucket Harbor system, during modeled calibration time period.95

Table V-7. Correlation statistics between modeled and measured total flow rates at the ADCP transects used in the model verification of the Nantucket Harbor model.97

Table V-8. Embayment mean volumes and average tidal prism during simulation period.103

Table V-9. Computed System and Local residence times for embayments in the Nantucket Harbor system.104

Table VI-1. Measured data and modeled Nitrogen concentrations for the Nantucket Harbor estuarine system used in the model calibration plots of Figures VI-2 and VI-3. All concentrations are given in mg/L N. "Data mean" values

are calculated as the average of the separate yearly means. Data represented in this table were collected in the summers of 1988 through 1990 and 1992 through 1994 by the Woods Hole Oceanographic Institute (WHOI), and between 1992 and 2005 by the Town of Nantucket Marine Department..... 106

Table VI-2. Sub-embayment and surface water loads used for total nitrogen modeling of the Nantucket Harbor system, with total watershed N loads, atmospheric N loads, and benthic flux. These loads represent **present loading conditions** for the listed sub-embayments. 109

Table VI-3. Values of longitudinal dispersion coefficient, E, used in calibrated RMA4 model runs of salinity and nitrogen concentration for the Nantucket Harbor estuary system. 110

Table VI-4. Comparison of sub-embayment watershed loads used for modeling of present, build-out (scenarios “A” and “B”), and no-anthropogenic (“no-load”) loading scenarios of the Nantucket Harbor system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms..... 114

Table VI-5. **Build-out scenario “A”** sub-embayment and surface water loads used for total nitrogen modeling of the Nantucket Harbor system, with total watershed N loads, atmospheric N loads, and benthic flux..... 115

Table VI-6. **Build-out scenario “B”** sub-embayment and surface water loads used for total nitrogen modeling of the Nantucket Harbor system, with total watershed N loads, atmospheric N loads, and benthic flux..... 115

Table VI-7. Comparison of model average total N concentrations from present loading and the **build-out scenario “A”**, with percent change, for the Nantucket Harbor system. The sentinel threshold station is in bold print..... 116

Table VI-8. Comparison of model average total N concentrations from present loading and the **build-out scenario “B”**, with percent change, for the Nantucket Harbor system. The sentinel threshold station is in bold print..... 116

Table VI-9. **“No anthropogenic loading”** (“no load”) sub-embayment and surface water loads used for total nitrogen modeling of the Nantucket Harbor system, with total watershed N loads, atmospheric N loads, and benthic flux..... 118

Table VI-10. Comparison of model average total N concentrations from present loading and the no anthropogenic (“no load”) scenario, with percent change, for the Nantucket Harbor system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). The sentinel threshold station is in bold print..... 119

Table VII-1. Number of days during deployment of in situ sensors that bottom water oxygen levels were below various benchmark oxygen levels. 125

Table VII-2. Percent occurrence and percent coverage of various macrophyte species present in Nantucket Harbor..... 134

Table VII-3. Changes in eelgrass distribution throughout the Nantucket Harbor system from 1995 to 2001. 1951 imagery was unsuitable to resolve presence or absence of eelgrass in the harbor. Data provided by Charlie Costello, DEP Eelgrass Mapping Program..... 143

Table VII-4. Benthic infaunal community data (Fall 2003) for the Nantucket Harbor system by component sub-embayment (Head of Harbor, Quaise Basin, Town Basin, Polpis Harbor). Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the

community allow comparison between locations (Samples represent surface area of 0.0625 m²). Station ID's refer to Figure VII-19..... 146

Table VIII-1. Summary of Nutrient Related Habitat Health within the Nantucket Harbor Estuarine System on Nantucket Island within the Town of Nantucket, MA., based upon assessment data presented in Chapter VII. The bilobate Polpis Harbor is an enclosed sub-system tributary to the Quaise basin. 152

Table VIII-2. Comparison of sub-embayment watershed **septic loads** (attenuated) used for modeling of present and threshold loading scenarios of the Nantucket Harbor system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface), benthic flux, runoff, or fertilizer loading terms. 158

Table VIII-3. Comparison of sub-embayment **total watershed loads** (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Nantucket Harbor system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms..... 158

Table VIII-4. Threshold "A" sub-embayment loads used for total nitrogen modeling of the Nantucket Harbor system, with total watershed N loads, atmospheric N loads, and benthic flux 158

Table VIII-5. Threshold "B" sub-embayment loads used for total nitrogen modeling of the Nantucket Harbor system, with total watershed N loads, atmospheric N loads, and benthic flux 159

Table VIII-6. Comparison of model average total N concentrations from present loading and the threshold scenario, with percent change, for the Nantucket Harbor system. Loads are based on atmospheric deposition and a scaled N benthic flux (scaled from present conditions). The threshold stations are shown in bold print (Sta. 2.1 is **SMAST 2A**, Sta. 4 is **Town 6** and **SMAST 4**, see Table VI-1)..... 159