

# Science Summary

## Nutrient and Hydrodynamic Studies of Great, Green and Bournes Ponds

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**Purpose of Summary:** What follows is a detailed summary of the nutrient related water quality studies performed for the Town of Falmouth Nitrogen Offset Program and Horsley & Witten Inc. This summary contains the information as to approach, methodologies, and major results detailed in the following sections.

**Report Overview:** The present report is part of the N-Offset Program to remediate nitrogen loading to Great, Green and Bournes Ponds. Task 1 focuses on evaluating the distribution and loading intensity of the various nitrogen sources within the watersheds of Great, Green and Bournes Ponds. Task 2 describes the results of pond flushing studies and details the hydrodynamic modeling which formed the basis for the water quality modeling presented in Task 3. The results of the water quality modeling (Task 3) indicates which of which land areas and sources play the greatest role in the current (and future) nitrogen degradation of these salt ponds. Later reports from the N-Offset Program utilize the water quality model for evaluation of nitrogen management alternatives (engineering and regulatory) for selection of the most cost effective approaches to pond restoration.

**The Problem:** Nutrient related water quality decline represents one of the most serious threats to the ecological health of our nearshore coastal waters. Coastal salt ponds and embayments, because of their shallow nature and large shoreline area, are generally the first indicators of nutrient pollution from terrestrial sources. By nature these systems are highly productive environments, but nutrient over-enrichment of these systems world-wide is resulting in the loss of their aesthetic, economic, and commercially valuable attributes.

Each embayment system maintains a capacity to assimilate watershed nitrogen inputs without degradation. However, as loading increases a point is reached at which that capacity is exceeded and nutrient related water quality degradation occurs. As nearshore coastal salt ponds and embayments are the primary recipients of nutrients carried via surface and groundwater transport from terrestrial sources, it is clear that activities within the watershed (often miles from the water body itself) can have chronic and long lasting impacts on these fragile coastal environments. These estuaries have algal growth limited by nitrogen availability.

Almost all of Falmouth's coastal ponds along the south shore are near or beyond their ability to assimilate additional nutrients without impacting their ecological health. This process results from the increasing levels of nutrients, primarily nitrogen, entering from their surrounding watersheds. The increase in nutrient loads results from changing land-use, as fields and forestland are converted to residential development. In general, nutrient overfertilization is

Within the present study Great, Green and Bournes Ponds are all experiencing nutrient related water quality declines. All 3 ponds are showing nitrogen levels above the Falmouth Nutrient Bylaw. Green Pond is currently in the advanced stages of eutrophication and exhibits poor ecological health from the headwaters into the Lower Pond region. The upper region of Great Pond shows poor nutrient related water quality. The nitrogen levels in the upper arm of Great Pond and Perch Pond have typically exceeded 0.75 mg N/L throughout the 1990's, with even higher levels in Perch Pond. The large lower portion of Great Pond continues to maintain moderate-to-high water quality. While Bournes Pond maintains relatively high water quality throughout most of its reach, it is clearly nutrient enriched. Of the ponds monitored on Falmouth's southern shore, Bournes Pond is generally in the best health.

**History:** The Town of Falmouth, Massachusetts, has long recognized the potential threat of nutrient over-enrichment of its coastal salt ponds and embayments. In the mid-1980's the Town enacted an innovative Nutrient Overlay By-law that tied watershed development to water quality within the adjacent embayment. The goal was to keep nitrogen concentrations in the receiving systems below thresholds that were projected to cause water quality shifts. A water quality monitoring program, Falmouth Pondwatch, was established to provide on-going nutrient related embayment health information in support of the By-law. These approaches were primarily initiated for planning as development within coastal watersheds progressed. Falmouth's Planning Department has continued to enhance its tools for gauging future nutrient effects from changing land-uses. The GIS database used in the present study is part of that continuing effort. Unfortunately, monitoring has documented that most regions within the Town's coastal ponds are currently showing water quality declines and are beyond the limits set by the By-law.

More recently, an additional source of nitrogen to three of the salt ponds on the south shore has been cause for concern. A plume of nitrogen rich groundwater was discovered approaching Green Pond and possibly Great Pond and Bournes Pond. The plume emanated from the Massachusetts Military Reservation's wastewater treatment facility which discharged secondarily treated effluent to rapid infiltration beds near the southeastern corner of MMR from 1936 through 1995. Although a new facility has come on-line which now discharges to Cape Cod Canal waters, decades of nitrogen discharge is still moving through groundwater towards Falmouth's coastal ponds. Since the plume, Ashumet Valley Wastewater Plume, would ultimately be discharging to already nitrogen-overloaded ecosystems, nitrogen remediation of plume waters was considered. Since The Ashumet Valley wastewater plume contains a large volume of contaminated water but at relatively low nitrogen levels, nitrogen removal is technically difficult and inefficient.

After evaluation of the plume remediation possibilities, an agreement was reached between MMR/AFCEE and the Town of Falmouth for management of nitrogen loading to the three salt ponds (Great, Green and Bournes Ponds) which could potentially receive plume nitrogen upon discharge. An innovative approach was developed whereby the Department of Defense would grant funding to the Town for nitrogen reduction, not of the Ashumet Valley Plume, but of other more readily addressed sources within the pond watersheds. Since all nitrogen inputs to the embayments impact ecological health regardless of the source, focussing on the more readily treatable sources (septic systems, fertilizers etc) should allow for a higher level and more rapid reduction in total nitrogen loading than merely treating the Ashumet Valley Plume. The Nitrogen Offset Program was established with \$8.5 million for nitrogen source reductions within the

watersheds of the three salt ponds potentially receiving MMR wastewater nitrogen through the Ashumet Valley Plume.

**Site Description:** The three salt ponds being examined for nitrogen management, Great, Green and Bourne Ponds are estuaries with focused freshwater inputs at the headwaters and tidal exchange of marine waters from Vineyard Sound (tide range of approximately 0.5 m or 1.6 ft) at their southern inlets. Perch Pond is a tributary to Great Pond and is predominantly influenced by the water quality of the much larger Great Pond through tidal exchange. The three main ponds are similar in length, but show a range of widths that result in their differing surface areas. Great/Perch Pond is the largest at 109 hectares (1 ha = 2.47 acres) with Bourne (62 ha) and Green (53 ha) being about half as large.

The watersheds to Great/Perch, Green and Bourne Ponds are primarily in the Town of Falmouth (approximately 84% of the watersheds are within the Town limits). In fact, the watersheds to these salt ponds encompass about 27% of the total Town land area, 9,632 acres (this study) vs. 29,698 acres (Falmouth Planning Office, 1997). The small areas of the Ponds' upper watersheds are in the Towns of Bourne and Sandwich, but are nearly completely in conservation land or are part of the Massachusetts Military Reservation. Based upon land-use and the watersheds being predominantly in Falmouth, it appears that nitrogen management for Pond restoration can be fully conducted within the Town of Falmouth.

## **Task 1: Evaluation of Nutrient Loadings to Great, Green, and Bourne Ponds, Falmouth, MA**

Annual nitrogen loading to each of the ponds was determined using a standardized watershed loading model approach which has been calibrated under “real-world” conditions. The present study is part of the N-Offset Program and focuses on evaluating the distribution and loading intensity of the various nitrogen sources within the watersheds of Great, Green and Bourne Ponds. Total annual nitrogen loading from each watershed or sub-watershed to the receiving salt pond is a combination of nitrogen loading to groundwater or surface water (generally also via an initial groundwater step) pathways minus any attenuation (removal) which occurs during transport.

**Watershed Nitrogen Loading:** Watershed boundaries were determined by groundwater modeling USGS (West Cape Model) in cooperation with the Air Force Center for Environmental Excellence. Present and future nitrogen loadings to Green Pond from the surrounding watershed were estimated from measured land-use and regionally determined source specific nitrogen loading rates. Enumeration of the nutrient sources within each watershed area was based upon aerial photography and assessors information, as detailed in the Town of Falmouth’s GIS database. Complete land-use analysis was conducted using each of the Town’s GIS databases with the comparison of results used as verification

Nitrogen loading rates were based primarily upon measured loads to the groundwater from each land-use type within each watershed. Terrestrial inputs by land-use (source strength terms) were based upon both available published studies, regional studies and site-specific data collected by CMAST coastal scientists.

Total annual nitrogen loading from each watershed or sub-watershed to the receiving salt pond is a combination of nitrogen loading to groundwater or surface water (generally also via an initial groundwater step) pathways minus any attenuation (removal) which occurs during transport. Annual nitrogen loading to each of the ponds was determined using a standardized watershed loading model approach which has been calibrated under “real-world” conditions. Current and future annual nitrogen to groundwater within each watershed was calculated from a land-use loading model, where component sources were summed within each watershed.

Not all of the nitrogen that enters the groundwater enters the receiving salt ponds. Some of the nitrogen may be denitrified during transport under anaerobic conditions, such as in the upper portion of the Ashumet Valley Wastewater Plume. However, the major mechanism for nitrogen interception in coastal watersheds is after discharge to surface water systems: ponds, lakes, rivers, streams, and wetlands. After entering surface waters, biological uptake and transformation results in a high degree of nitrogen attenuation (removal through burial or denitrification). Estimates of retention of nitrogen during passage through ponds and streams were verified using direct measurements of surface waters entering each pond.

**Conclusions from Watershed Nitrogen Loading Study:** While the results of the watershed N loading analysis are primarily for parameterizing the embayment water quality model (Task 3), the analysis revealed several important factors relating to N sources and potential remediation. The analysis had 5 major findings relating to the N-Offset Program goals of nitrogen management for restoration of Great, Green and Bourne Ponds:

- Septic systems are the major single source of nitrogen to each of the salt ponds.

- The Ashumet Valley Wastewater Plume will only discharge to Great and Green Ponds. This plume will increase the N loading from the upper watershed over current conditions by 5% and 10%, for Great and Green Ponds, respectively. However, it will only increase the total N loading (upper and lower watersheds) to these salt ponds by 2% and 3%, for Great and Green Ponds, respectively.
- At maximum build-out and full discharge of the Ashumet Valley Wastewater Plume, total nitrogen loads from their watersheds are projected to increase over current conditions by 16% for Great Pond, 13% for Green Pond and 21% for Bourne Pond.
- Nitrogen loading from the lower watersheds accounts for most of the total N load to Great Pond-59%, Green Pond-70% and Bourne Pond-79%.
- Since most of the nitrogen loading is concentrated in the lower portions of the watersheds, which have little natural attenuation of nitrogen during transport to the salt ponds, engineered nitrogen remediation efforts should focus on these areas.

## **Task 2: Two-Dimensional Hydrodynamic Modeling of Great, Green, and Bournes Ponds, Falmouth, MA**

**Overview:** In general, water quality studies of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system. Estuarine hydrodynamics control a variety of coastal processes including tidal flushing, pollutant dispersion, tidal currents, sedimentation, erosion, and water levels. This section summarizes the development of hydrodynamic models for three coastal Ponds: Great Pond, Green Pond, and Bournes Pond. For each Pond, a calibrated hydrodynamic model was used to quantify water movement through each estuary. The tidal flushing results when coupled with the nitrogen loading data from Task 1 form the basis for the quantitative evaluation of water quality presented in Task 3.

Estuarine water quality is dependent upon the nutrient and pollutant loading and the processes which help flush nutrients and pollutants from the estuary (e.g., tides and biological processes). Relatively low nutrient and pollutant loading and efficient tidal flushing are indicators of high water quality. The ability of an estuary to flush nutrients and pollutants is proportional to the volume of water exchanged with a high quality water body (i.e. Vineyard Sound). Several embayment-specific parameters influence tidal flushing and the associated residence time of water within an estuary. For Great, Green, and Bournes Ponds, the most important parameters are: tide range, inlet configuration, the size, shape and depth of each estuary, and longshore transport of sediment.

**Flushing Model Description:** This study of Great, Green, and Bournes Ponds utilized a state-of-the-art computer model to evaluate tidal circulation and flushing. The particular model employed was the RMA-2V model developed by Resource Management Associates for the U.S. Army Corps of Engineers. It is a two-dimensional depth averaged model that solves momentum and flow continuity equations over several tidal cycles. The model is widely accepted and tested for analyses of estuaries or rivers. Applied Coastal staff members have utilized RMA-2V for numerous flushing studies on Cape Cod, including West Falmouth Harbor, Popponesset Bay, and the Pleasant Bay estuary.

Three types of boundary conditions were employed for the RMA-2V model: 1) "slip" boundaries (land boundaries where flow is parallel to shore), 2) freshwater inflow, and 3) tidal elevation boundaries. Based on field measurements, freshwater recharge was specified at the north end of each Pond. A tidal boundary condition was specified seaward of the inlet to each Pond. Tidal elevation measurements provided the required data. The rise and fall of the tide in Vineyard Sound is the primary driving force for estuarine circulation. After developing the finite element grids, and specifying boundary conditions, the model for each Pond was calibrated. Numerous model simulations were required (20+) for each estuary, specifying a range of friction and eddy viscosity coefficients, to calibrate the model.

The rate of pollutant/nutrient loading and the quality of water outside the estuary both must be evaluated in conjunction with water residence times to obtain a clear picture of water quality. Efficient tidal flushing (low residence time) is not an indication of high water quality if pollutants and nutrients are loaded into the estuary faster than the tidal circulation can flush the system. Neither are low residence times an indicator of high water quality if the water flushed into the estuary is of poor quality. Advanced understanding of water quality was obtained from the calibrated hydrodynamic model by extending the model to include pollutant/nutrient dispersion. The water quality model provided a valuable tool to evaluate the complex mechanisms governing estuarine water quality in the Great Pond, Green Pond, and Bournes Pond systems.

**Pond Flushing:** Since freshwater inflow is negligible (based on measurements between November 1998 and March 1999, surface flow into the estuaries ranges from 0.7 to 19.8 cubic feet per second) in comparison to the tidal exchange through each inlet, the primary mechanism controlling estuarine water quality within Great, Green, and Bournes Ponds is tidal circulation. A rising tide in Vineyard Sound creates a slope in water surface from the ocean into the estuary. Consequently, water flows into (floods) the estuary. Similarly, the estuary drains into Vineyard Sound on an ebbing tide. This exchange of water between the estuary and the ocean is defined as tidal flushing. The calibrated hydrodynamic model is a tool to evaluate quantitatively tidal flushing of the Ponds, and was used to compute flushing rates (residence times) and tidal circulation patterns.

Although the three Ponds are relatively shallow (large portions of each Pond are less than 4 feet deep at mean tide level), the small tide range reduces the tidal prism, thereby increasing the water residence times. The relatively short system residence times for all three Ponds indicates that the inlets from Vineyard Sound to each Pond do not significantly retard tidal flow. Based on the tidal constituent analysis tidal attenuation along the length of each Pond is negligible. The inlets at Great and Green Ponds cause less than 10 minutes of phase lag (based on  $M_2$  tidal constituent). The only significant damping within the three Ponds is through the inlet at Bournes Pond, where the inlet alone causes more than a one-hour phase lag between Vineyard Sound and lower Bournes Pond.

The tidal analysis revealed that all three Ponds indicate flood dominated tidal flows (higher velocities on flood than ebb tides). Typically, flood-dominance is an indicator of an estuary's tendency to trap and accumulate sediment. A simplified explanation of this complex phenomena is stronger flood currents have the energy to drag suspended sediment into the system, whereas weaker ebb flows do not have sufficient energy to suspend and flush these sediments. Sand entering each inlet causes shoaling within the inlet throat. The primary sediment source to each of the three Ponds is the predominant west-to-east littoral drift along Falmouth's beaches with smaller contributions from bottom sand in the estuary, bank erosion and runoff, and biological decay. Since each inlet is jettied, this build-up of sand periodically will require dredging. To reduce "recycling" of sand, dredged material usually should be placed on the downdrift (east) side of the inlet. Within the three coastal ponds studied sedimentation was not having a major impact on the overall ability of the estuaries to exchange water with Vineyard Sound. However, some localized effects were evident (e.g. Perch Pond and Bournes Pond).

**Conclusions from the Flushing Study:** While the hydrodynamic modeling is the foundation for the water quality modeling in Task 3, it also produced information on the flushing characteristics throughout Great, Green and Bournes Ponds. The major hydrodynamic findings are summarized below:

- All of the ponds studied may be considered rapidly flushing systems, based upon their measured residence times. However, each pond shows signs of ecological stress, indicative of poor water quality. Therefore, the levels of nutrient loading likely controls water quality within the embayments (especially the upper portions of each pond) to a greater degree than the hydrodynamic characteristics of each pond.
- The relatively low residence time of upper Bournes Pond in comparison to upper Great Pond and upper Green Pond is due to natural water depth. Due to the shallow depths of upper Bournes Pond, the ratio of average depth to tide range is a lower and a greater

percentage of water is exchanged with lower Bournes Pond every tidal cycle.

- Tides propagate from Vineyard Sound into each estuary, with little attenuation or amplitude damping and tides in all three ponds have flood-dominant characteristics. Therefore, each pond inherently tends to accumulate sediment. Maximum currents within each estuary occurred within the inlets. Maximum flood currents were approximately 4.5, 2.9, and 7.0 feet per second for Great, Green, and Bournes Ponds, respectively. The stronger tidal currents in Bournes Pond inlet may be responsible for decreased shoaling within the inlet channel, as well as the significant shoals north (flood shoal) and south (ebb shoal) of the entrance.
- The greatest tide attenuation occurs in Bournes Pond. The restricted inlet causes a tide lag of approximately one-hour. Engineering improvements (dredging and or widening of the inlet) could reduce this tide lag and improve tidal flushing of Bournes Pond, however, modifications may not be necessary due to the relatively short residence time. Tide attenuation through Great Pond inlet and Green Pond inlet were negligible suggesting that improvements to these inlets will have a negligible impact on estuarine water quality. Although engineering improvements to the Bournes Pond inlet may significantly improve tidal exchange. Although tidal amplitude damping was greatest across Bournes Pond inlet, the limited water depth of this pond produced the lowest overall residence time (0.64 days). System residence times for the upper ponds (8.4 days, 2.2 days, and 1.6 days for Great, Green, and Bournes Ponds, respectively) indicated reduced flushing of these areas.
- Since each inlet is jettied, this build-up of sand periodically will require dredging. To reduce “recycling” of sand, dredged material should be placed on the downdrift (east) side of the inlet. The natural west-to-east littoral drift will continue to supply sediment to the updrift beaches of each inlet. In addition to beach sediment, secondary sediment sources include bottom sand in the estuary, bank erosion and runoff, and biological decay. Although these sources may create flushing/water quality problems at certain locations within each Pond, they should not have a major impact on the overall ability of the estuaries to exchange water with Vineyard Sound.

### **Task 3: Water Quality Analysis of Great, Green, and Bournes Ponds, Falmouth, MA**

**Overview:** The best mechanism to integrate the effects of nitrogen inputs from land with outputs via tidal exchanges is through numerical modeling of flows coupled to quantitative nitrogen input data. The water quality model was calibrated based on existing information and then used to predict levels of total nitrogen within the various sections of Great, Green, and Bournes Ponds. Predicting future nitrogen distributions and concentrations is a useful process for assessing potential changes to the ponds as a result of development. However, predictions need to be interpreted within the constraints of the model. Since the forecast was based on the existing conditions within Great, Green, and Bournes Ponds, major changes in the biological systems which control nitrogen processing (e.g. a change from phytoplankton to macroalgal production), or physical features which control hydrodynamics (e.g. channel configurations) will invalidate the results. To evaluate these scenarios, additional model analysis is required. The calibrated hydrodynamic (Task 2) and water quality (this section) models will serve as the basis for evaluating various nitrogen reduction strategies, as well as potential engineering modifications to improve tidal circulation, in ongoing studies by Horsley and Witten, Inc.

**Water Quality Model Description:** Evaluation of upland nitrogen loading (Task 1) provides important “boundary conditions” for water quality analyses of Great, Green, and Bournes Ponds; however, a thorough understanding of estuarine circulation is required to accurately determine nitrogen concentrations within each salt pond. Therefore, water quality modeling of tidally influenced estuaries must include a thorough evaluation of the hydrodynamics of the estuarine system (Task 2). Once the hydrodynamics of an estuary system are understood, computations regarding the related coastal processes become relatively straightforward extensions to the hydrodynamic modeling. The spread of pollutants may be analyzed from tidal current information developed by the numerical models. A water model was used to examine the potential impacts of nitrogen loading into three “finger ponds” along Falmouth’s south shore (Great, Green, and Bournes Ponds) and that resulting from existing and future natural, as well as anthropogenic sources.

Estimates for the dispersion coefficients required by the water quality model were determined by evaluating natural dispersion of salt within each pond. Salinity measurements during slack and/or ebbing tide conditions along the central axes of Great, Green, and Bournes Ponds provided the basis for dispersion estimates. Since salt is a conservative constituent (the only source is Vineyard Sound and there are no sinks); therefore, measurement of salt in combination with an analysis of freshwater inflow allows determination of dispersion/diffusion along the longitudinal axis of each pond.

Using dispersion relationships from the salinity study, the water quality model and the hydrodynamic models were then integrated in order to generate estimates regarding the spread of total nitrogen from the site-specific hydrodynamic properties. The distributions, strengths and discharge locations of nitrogen loads from watershed sources were determined from land-use analysis (coupled with direct measures) and the volume and locations of freshwater inflows. Almost all nitrogen entering the three ponds is transported by freshwater, predominantly groundwater. Estimates of the volume discharge and mean nitrogen concentration of entering waters to the various planning areas were used as the watershed sources in the water quality model. Concentrations in Vineyard Sound source waters were taken from Falmouth Pondwatch data. Measurements of current nitrogen distributions throughout harbor waters (from Pondwatch) were used to validate the water quality model (under existing loading conditions). In addition, the effects of increased nitrogen loading associated with projected build-out conditions

were evaluated within the context of increased pond nitrogen levels.

**Nitrogen Thresholds:** Since the nitrogen levels in receiving waterbodies increase gradually in the incremental development of coastal watersheds, their health undergoes the gradual decline with cultural eutrophication. The gradual ecological changes within systems like Falmouth’s coastal ponds, take the form of increasing phytoplankton production and epiphyte production and reducing light penetration. These processes reduce the habitat quality for eelgrass, but during initial stages of these processes or in “borderline” cases, eelgrass beds persist. At higher nitrogen levels, eelgrass beds will become less dense and will begin to disappear from the deeper areas. At even higher nitrogen levels, the beds will disappear, but there are still diverse and productive benthic communities. These systems are characterized by higher nitrogen concentration, periodic moderate blooms of phytoplankton, and oxygen concentrations that show some moderate depletion. At higher N levels these blooms become more frequent and animal communities become significantly effected.

The results of three methodologies to determine nitrogen thresholds for embayments are shown in Table 1. The values which are used in the present study (CMAST/Applied Coastal, column 3) are the synthesis of data from the Cape Cod Commission and Buzzards Bay Project/MCZM, as well as comparative results from the Coalition for Buzzards Bay Monitoring Program with site-specific information from the Falmouth Pondwatch Program on Great, Green and Bourne Ponds. In addition, information on eelgrass distribution and fish kills was developed from Pondwatch data. The rationale for each of the classifications of nitrogen based water quality thresholds is detailed in the complete Task 3 report.

<b>Table 1:</b> Nitrogen thresholds and coastal water classifications used in the present study. Threshold values are site-specific. Abbreviations: CCC – Cape Cod Commission, BBP/MCZM – Buzzards Bay Project/ Massachusetts Coastal Zone Management, ND – not determined. Values are concentrations of total nitrogen (mg/L) within the water column of Great, Green, or Bourne Ponds.					
Classification of N based water quality	Trophic classification	CMAST/ Applied Coastal	CCC	BBP/MCZM	Mass Classification (310 CMR 4.05(4))
Excellent	Oligo to Mesotrophic	< 0.30	ND	ND	
Good	Oligo to Mesotrophic	0.30 – 0.39	< 0.34	< 0.39	SA
Moderate Impairment	Mesotrophic	0.39 – 0.50	0.34 – 0.39	0.39 – 0.44	SB
Significant Impairment	Eutrophic	0.50 – 0.70	ND	ND	
Severe Degradation	Hyper-Eutrophic	> 0.70	ND	ND	
(a) suitable for shellfish harvesting without depuration, (b) excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation, (c) excellent aesthetic value.					
(a) suitable for shellfish harvesting with depuration, (b) habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation, (c) consistently good aesthetic value.					

**Evaluation of Pond Health Evaluation:** It appears from the nitrogen thresholds that the entirety of Great and Perch Ponds, Green Pond, and all but the most southerly section of Bourne Pond are currently showing “Significantly Impaired” nutrient related water quality conditions. Therefore, nitrogen management of these systems must be aimed at restoration, not protection or maintenance of existing conditions. The ultimate cause of the nitrogen overload to these systems is the increase in nitrogen inputs to the upper and lower watershed from changing land-use over the past century. The shift from pasture-land or forest to residential development with on-site disposal of wastewater, represents nearly a 10-fold increase in nitrogen loading on a per area basis. The year-round population of Falmouth has increased more than 5-fold from the 1930 census to today, with most of this increase being in the watersheds of the Town’s coastal ponds. The population of Cape Cod has increased 6-fold since 1920. In 1920, all of Cape Cod supported the same population that lives year-round in Falmouth today.

The issue for Falmouth is how to manage the nitrogen loading from the shift in land-use, thereby obtaining a moderate level of ecological health within the coastal salt ponds. It will not be possible to establish “high quality” estuarine conditions throughout these ponds, even if all septic loading is removed. The present and projected nutrient related water quality of the ponds is outlined below:

*Great Pond:* There is a strong gradient in nitrogen level and health in Great Pond, with highest nitrogen and lowest environmental health in the headwaters of Great and Perch Ponds and lowest nitrogen and greatest health near the inlet to Vineyard. Both of these upper arms to Great Pond are presently showing “Severely Degraded” water quality and “Hyper-Eutrophic” conditions. Eelgrass is absent from these regions and periodic fish kills have been reported, resulting from oxygen depletion. Upper Great Pond periodically shows macro-algal accumulations. Perch Pond exhibits higher nitrogen levels than its adjacent source waters primarily due to the shoaling of its short inlet to central Great Pond. Perch Pond is showing increasing nitrogen levels.

The main basin of Great Pond results is showing moderate quality based upon nitrogen and oxygen analysis. The high nitrogen levels within the main basin have not degraded other portions of the system to the levels observed in neighboring Green Pond. Due to the oxygen conditions, Great Pond still supports highly productive shellfish beds and small areas of eelgrass. Scallops were observed within the pond in 1998.

Analysis of future build-out of the Great Pond watershed show increases in nitrogen loading to the pond of approximately 16%. This future build-out will not noticeably affect the two upper arms (Perch Pond and the marine portion of the Coonamessett River), because both are already Hyper-Eutrophic. Similarly, within the main basin there will be little detectable change in water quality or health. The major effect will be movement of the 0.6 mg N/L contour toward the inlet.

It appears from the modeling that removing wastewater nitrogen loading would result in dramatic improvements to the health of almost the entire Great/Perch Pond System. The largest improvement is not in the small tributary systems, but in the main basin. Under these conditions, benthic animal populations should improve and eelgrass beds expand. Phytoplankton production should remain sufficiently high to sustain a productive shellfishery, which should expand with increased habitat availability. It is possible that scallops would return to the lower portion of this system (they were reported in 1998).

*Green Pond:* There is a strong gradient in nitrogen levels and environmental health within Green Pond, with highest nitrogen at the estuarine headwaters (approximately 1 mg N/L) and decreasing concentrations to a low in the boat basin between the bridge and the inlet (approximately 0.5 mg N/L). As a result of high watershed nitrogen loading, Green Pond is currently showing Severe Degradation ( $N > 0.7 \text{ mg/L}$ ) over the entire upper two-thirds of its length. All eelgrass is absent in this region. There are macro-algal accumulations that smother shellfish and other bottom-dwelling animals. Large phytoplankton blooms ( $> 20 \mu\text{g/L}$  Chlorophyll a) are typical of summer conditions. These blooms result from the high nutrient availability and cause low watercolumn transparency (secchi depth  $< 1$  meter) and oxygen depletions to stressful levels ( $< 4 \text{ mg/L}$ ).

The lower third of Green Pond supports “Significantly Impaired” waters just north of the bridge, grading to “Moderately Impaired” waters in the lower boat basin. Above the bridge eelgrass is absent, while below the bridge some small patches remain. This region of the Pond (near the bridge) supports large concentrations of quahogs and soft-shell clams. These shellfish are likely benefiting from the high phytoplankton production from the upper pond. Chlorophyll a levels within this region are typically  $\leq 10 \mu\text{g/L}$ , half (or less) than the upper pond.

Under future projected build-out, nitrogen loading to this Pond will increase by about 14%; however, the zone of “Severely Degraded” water quality ( $< 0.7 \text{ mg N/L}$ ) is not projected to expand toward the south significantly. The major change, projected from the water quality modeling, will be the movement into the boat basin, south of the bridge, of the “Significantly Impaired” quality waters. Therefore, a further decline of the best quality portion of the Green Pond System will occur. Removal of all wastewater loads from the Green Pond watershed (not achievable) would result in major improvements to the health of Green Pond, primarily in the lower reaches. The upper third of the pond would still support “Severely Degraded” water quality and “Hyper-Eutrophic” conditions. However, the middle third of the Pond would improve to a level of “Significant Impairment”, which should support some ecological resources (including shellfish) and improved aesthetics. However the lower third of the pond should greatly improve in ecological health as this portion of the pond still supports some (stressed) aquatic resources. North of the bridge, conditions would shift to “Moderate Impairment”, which will support relatively healthy benthic animals and shellfish communities. In addition, water quality in the boat basin would improve to a level capable of supporting eelgrass beds.

The modeling and health evaluations indicate that increasing nitrogen levels associated with build-out will result in further degradation of Green Pond, primarily to the remaining resources in the southern third of the pond. In contrast, decreasing nitrogen loading over present conditions should result in improved conditions, primarily in the southern two-thirds of the pond, with the potential true restoration of health in the lower basin.

*Bournes Pond:* Bournes Pond is the least nitrogen loaded of the three ponds evaluated (Chapter 1). As a result, it currently supports regions with the highest water quality within the three systems. In addition, the nitrogen plume from the former Massachusetts Military Reservation Wastewater Treatment Facility (now closed) is not projected to enter this system. The Town owns significant acreage of conservation land on the western side of the pond. Bournes Pond is also the only pond that has restricted tidal exchange with Vineyard Sound, primarily due to periodic sedimentation of the inlet and the narrow/shallow inlet channel.

Bournes Pond shows a strong horizontal gradient in nitrogen and health resulting from the distribution of its watershed nitrogen inputs and the exchanges with the high quality waters of

Vineyard Sound. The headwaters of the pond, including the northerly third of the pond (marine reach of Bournes Brook), are currently showing “Severely Degraded” water quality and “Hyper-Eutrophic” conditions, similar to upper Green and Great Ponds. The high nitrogen levels are associated with moderate to high chlorophyll a concentrations and moderate to high oxygen depletions. Water transparency within all but the most northerly reaches is sufficient to support benthic plant production. Although conditions within the upper tributary fall within the “Hyper-Eutrophic” classification, most of the area is near the threshold to “Eutrophic” or “Significant Impairment” status.

Most of the lower portion of Bournes Pond (more than half of the surface area) can be considered “borderline” between “Significant Impairment” and “Moderately Impaired” (or Mesotrophic and Eutrophic). This can be seen in the modest chlorophyll a levels (<5µg/L), moderate oxygen depletions (not below 4 mg/L), and moderate to poor water column transparencies. This region of the pond supports shellfish beds and does not appear to accumulate significant amounts of macro-algae. The southern portion of the lower basin might support eelgrass.

Future build-out of the watershed under current conditions is projected to increase nitrogen loading to Bournes Pond by approximately 13%. While this is a relatively small increase in loading, it will affect the pond health. Within the upper pond tributary, the zone of “Severe Degradation” will expand only slightly towards the inlet and concentrations in Israels Cove will increase slightly. The major change will be the loss of the “Moderately Impaired” waters in the lower pond, with a shift in status to “Significant Impairment” or “Eutrophic” conditions. As this basin currently maintains the highest quality waters and supports the most healthy systems, this shift would represent a significant alteration of overall pond habitat quality. Removal of all wastewater loads from the Bournes Pond watershed would result in dramatic improvements to the health of almost the entire Bournes Pond System, in a manner similar to Great Pond. Removing all wastewater nitrogen would shift almost the entire pond to “Significantly Impaired” status or better. Almost the entire lower basin would only be “Moderately Impaired” and, therefore, be supportive of diverse animal populations with some eelgrass beds likely. Macro-algal accumulations would not be expected to be prevalent in any portions of the pond.

**Conclusions of Nutrient Related Water Quality Modeling Studies:** The water quality modeling and the evaluation of ecological health had six major findings relating to the N-Offset Program goals of nitrogen management for restoration of Great, Green and Bournes Ponds:

The upper reaches of each of the Great, Green and Bournes Ponds are currently showing poor nutrient related water quality as a result of nitrogen loading from the upper and lower watersheds. While the lower portions of each pond support at least moderate quality waters, only lower Bournes Pond exhibits a good level of environmental quality. The severely degraded environmental health of the upper portions of each of the Ponds is manifested in high chlorophyll a levels (>10 µg/L and typically >20 µg/L), periodic oxygen depletions to less than 4 mg/L, low water column transparency, and high nitrogen concentrations (>0.7 mg N/L). The nutrient overloaded nature of these systems is consistent with (a) the loss of eelgrass, (b) periodic fish kills due to oxygen depletion, and (c) periodic appearance of macro-algae. Each of the three ponds have total nitrogen concentrations above the levels set by the Falmouth Nutrient Overlay By-law. Since each of these coastal ponds show signs of degraded water quality, steps should be taken to limit additional nitrogen loading.

- The effects of nitrogen loading to each of the Ponds were based upon threshold nitrogen concentrations for the water column. These levels ranged from “Excellent Quality” where nitrogen levels average less than 0.30 mg N/L, “Good Quality” environments were associated with nitrogen levels between 0.30-0.39 mg N/L, “Moderately Impaired” was associated with levels from 0.39-0.50 mg N/L, systems were deemed “Significantly Impaired” at levels from 0.50-0.70 mg N/L, and “Severely Degraded” (hyper-eutrophic) above 0.70 mg N/L. These levels were determined from site specific data and thresholds developed by the Cape Cod Commission and Buzzards Bay Project.
- Removing all nitrogen from on-site septic disposal of wastewater from the watersheds of each Salt Pond results in a significant lowering of nitrogen levels in both upper (Great: 23%-31%, Green: 27%, Bournes: 15%-17%), and lower (Great:17%-22%, Green:17%-23%, Bournes: 10%). However, even the removal of all wastewater nitrogen is insufficient to fully restore the Ponds to a high level of nutrient related health. Approximately the upper (northern) half of Green, Great and Bournes Ponds would remain moderately to highly degraded by nutrient over-fertilization due to the low flushing rates and nitrogen loading associated with non-wastewater sources and natural inputs. However, it appears that there would be a notable reduction in the present significantly impaired areas in each of the three Ponds. The effect would be that the lower basins of each Pond would be support nitrogen levels of less than 0.5 mg N/L, which would be a significant improvement in ecological health.
- Under current zoning and on-site wastewater disposal practices, nitrogen loading to the Ponds at full build-out of the watersheds will increase by only 13%-16%. However, this modest increase in nitrogen loading is projected to reduce the remaining better water quality regions within the lower reaches of each pond. Within Great Pond the <0.6 mg N/L zone will be reduced by about half, currently the entire pond is >0.5 mg N/L. The present moderately impaired lower basin (below the bridge/causeway) in Green Pond is project to see a rise in nitrogen to >0.5 mg N/L over about 40% of the lower basin area. Bournes Pond, which currently has the lowest level of relative nitrogen loading and concurrently the highest water quality (primarily in the lower reaches), will see a relatively small shift primarily near the inlet. This small concentration shift is sufficient to move this region from moderately impaired to significantly impaired, and therefore may represent an important ecological shift. However, as the model had the most difficulty within this zone (only in Bournes Pond), the extent of the increase is difficult to gauge.
- In addition to focussing on wastewater treatment and zoning options, non-wastewater nitrogen management approaches should be carefully evaluated for the loading from the upper watersheds of each pond. While modeling of all alternatives are part of future project tasks, reduction of river nitrogen inputs through engineered wetlands and increased flushing of Bournes Pond should be evaluated as part of a balanced nitrogen management program.
- Pondwatch data has indicated that both nitrogen and chlorophyll a periodically increase to excessive levels in Perch Pond. This increase likely is related to poor exchange of Perch Pond waters with Vineyard Sound waters (poor tidal flushing); therefore, channel dredging should be evaluated as a method for improving tidal flushing in Perch Pond. Dredged sediment could be utilized to (a) fill the deep portion of Perch Pond to reduce the volume and improve tidal flushing, and (b) cover the red tide cysts that exist within the bottom sediments.