Massachusetts Estuaries Project
Partnership for Nitrogen Management of the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuarine System

Project: **Data Collection and Analysis in Partial Fulfillment of Assessment and Modeling Required for Implementation of the MEP Linked Watershed -Embayment Nitrogen Management Approach in Support of Nitrogen Management and Estuarine Restoration**

Final Report/Technical Memorandum for Task 1B (of 8)

Cumulative Nitrogen Loading Determination

Completed for the Town of Plymouth

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I. Background Overview

The Massachusetts Estuaries Project (MEP) was developed as a cooperative effort among the towns and counties of southeastern Massachusetts, the Massachusetts Department of Environmental Protection (MassDEP), the regional planning agencies, and the School for Marine Science and Technology (SMAST) at the University of Massachusetts Dartmouth. Each partner in the project provides funding and assistance. SMAST's role is to produce high quality scientific characterizations of estuarine health and the linkage between watershed land-use, estuarine hydrodynamics and estuarine habitat and water quality. These assessments are used by MassDEP in the development of the system-specific Total Maximum Daily Load (TMDL) for nitrogen-impaired estuaries to meet the requirements of the federal Clean Water Act. Equally important, the MEP assessment and modeling approach creates estuarine-specific tools that can be used by Towns to develop and evaluate watershed and estuary management options.

The overarching task of the MEP is to assess the ecological health of estuaries from the south shore of Massachusetts, Cape Cod and the Islands, and along Buzzards Bay. The MEP process of assessing these estuaries involves evaluating site-specific water quality, refining watershed delineations, and development of linked watershed-estuary water quality models. These management models allow determination of estuarine response to changes in watershed land-use or estuarine hydrodynamics. This effort involves a multidisciplinary team of scientists and engineers coordinated through the SMAST Coastal Systems Program. A key aspect of the effort is the validation of the watershed delineations, land-use nitrogen model, and hydrodynamic and water quality models to allow their use in predicting future water quality and the impact of management strategies.

In order to begin the MEP effort for the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuarine System, SMAST proposed an overall strategy that could be funded in phases or all at once. Implementing the effort will be a collaboration between the Town of Plymouth (appropriate departments and a MEP committee to be established as liaison between Towns and MEP), other towns in the watershed, non-governmental organizations, and the SMAST MEP Technical Team.

The overarching goal of the Massachusetts Estuaries Project is the restoration and protection of the health of the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuarine System through watershed-embayment nitrogen management planning coordinated among the towns within the watershed. Key components of the Massachusetts Estuaries Project effort associated with this embayment system are:

- to conduct an estuary-wide water quality monitoring program over a minimum of 3 summers to establish the nutrient related water quality baseline necessary for habitat assessment and conduct of the MEP assessments and modeling efforts [note effort was undertaken coordinated by the Town of Kingston and the Coastal Systems Program-SMAST under a 604(b) grant];

- to compile, review and synthesize relevant studies related to the nutrient related health of the overall embayment system and the associated aquatic systems within its watershed;

- to conduct field data collection, produce an estuary-specific, data-validated linked Hydrodynamic and Nitrogen Water Quality Model of the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuarine System;

- to conduct field data collection of habitat and water quality to develop quantitative nitrogen thresholds for the Plymouth Harbor - Duxbury Bay - Kingston Bay Embayment System targeting the maintenance and/or restoration of habitat quality to designated water quality standards;

- to determine potential nitrogen management options for evaluation by the watershed Towns, including both soft solutions (ecological enhancements/restoration, green infrastructure, improved tidal efficiency, regulatory options, etc.) and hard solutions (wastewater treatment facilities, denitrifying septic systems, stormwater runoff treatment, etc.);

- to test "what if" restoration scenarios to address the efficacy of potential nitrogen management options recommended from regional and national experience, by the Town MEP Committee (to be established) and the Town's DPW and wastewater and stormwater engineering consultants (as appropriate);

- to provide further assistance to integrate the nitrogen management strategies and MEP findings with Town's Wastewater Facilities Planning (as needed); and

- to enhance and encourage public education as to the health of the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary, its future and best practices for its protection and restoration.

II. Current Project

While all the tasks associated with the above mentioned MEP goals must ultimately be completed in order to achieve the overarching goal of protecting/restoring the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Estuarine System, the current strategy is for the MEP tasks to be undertaken incrementally, as funding is made available. The current project discussed in this report is the development of the watershed nitrogen loading model for the MEP analysis. This effort builds on the watershed delineation and land use data collection effort that was completed in Task 1A (Eichner and Howes, 2011). The current effort uses the parcels, assessors' databases, town water use information, and other information collected in Task 1A to develop a watershed nitrogen loading model. The watershed nitrogen loading model is based on individual parcels and uses information about those parcels and regional information to develop nitrogen loads within each of the 85 subwatersheds to Plymouth Harbor. This model will be used in subsequent MEP tasks to link with the estuary water quality model and through calibration and validation steps develop a tool that can be used to predict the water quality impacts of watershed and/or estuary-specific management activities.

Each of the MEP tasks builds on past efforts. The current project builds on the tasks completed in Task 1A, including the watershed delineation, obtaining land use data/GIS parcel

data and municipal water use databases, wastewater treatment plant performance, landfill monitoring, and determination of cranberry bog and golf course areas. These activities, in turn, built on US Geological Survey (USGS) groundwater modeling of recharge areas within the watershed (Masterson, *et al*., 2009) and baseline monitoring completed by a joint effort between the Town of Kingston and the SMAST Coastal Systems Program (CSP) (Howes and Samimy, 2005). Just as each of these efforts involved refinements and re-reviews of previously developed assessments, it is anticipated that subsequent tasks to complete the MEP review of Plymouth Harbor will also include review and potential refinement of the results completed in this project. Completion of the entire MEP assessment of the Harbor will ensure that all data and interpretation are consistent across all the linked models.

I. Plymouth Harbor Watershed Nitrogen Loading Model

Management of nutrient related water quality and habitat health in coastal waters requires determination of the amount of nitrogen transported by freshwaters (surface water flow, groundwater flow) from the surrounding watershed to the receiving embayment of interest. In southeastern Massachusetts, the nutrient of management concern for estuarine systems is nitrogen and this is true for the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Estuarine System. Determination of watershed nitrogen inputs to these embayment systems requires the (a) identification and quantification of the nutrient sources and their loading rates to the land or aquifer, (b) confirmation that a groundwater transported load has reached the embayment at the time of analysis, and (c) quantification of nitrogen attenuation that can occur during travel through lakes, ponds, streams and marshes prior to reaching the estuary. This latter natural attenuation process results from biological processes that naturally occur within these ecosystems. Failure to account for attenuation of nitrogen during transport results in an over-estimate of nitrogen inputs to an estuary and an underestimate of the sensitivity of a system to new inputs (or removals). In addition to the nitrogen transport from land to sea, the amount of direct atmospheric deposition on each embayment surface must be determined as well as the amount of nitrogen recycling within the embayment, specifically nitrogen regeneration from sediments. Sediment nitrogen recycling results primarily from the settling and decay of phytoplankton and macroalgae (and eelgrass when present). During decay, organic nitrogen is transformed to inorganic forms, which may be released to the overlying waters or lost to denitrification within the sediments. Permanent burial of nitrogen in the sediments is generally small relative to the amount cycled. Sediment nitrogen regeneration can be a seasonally important source of nitrogen to embayment waters or in some cases a sink for nitrogen reaching the bottom. Failure to include the nitrogen balance of estuarine sediments and the watershed attenuation generally leads to errors in predicting water quality, particularly in determination of summertime nitrogen load to embayment waters.

In order to determine watershed nitrogen loading inputs to the PDK estuary system, the MEP Technical Team developed nitrogen-loading rates to each component of estuary and its watersheds. The PDK watershed was sub-divided to define contributing areas or subwatersheds to each of the major inland freshwater systems and to each major portion of the estuary. Further sub-divisions were made to identify watershed areas where a nitrogen discharge reaches estuary waters in less than 10 years or greater than 10 years. A total of 85 subwatersheds were delineated in the overall PDK watershed. Among the 85 subwatersheds, there are 56 to ponds, lakes or

reservoirs, 10 to public water supply or irrigation wells, 11 to streams or rivers, and the remainder directly discharge to various portions of the PDK estuary via groundwater (Figure 1). These subwatersheds are also aggregated in order to develop watersheds to the gauge location monitored during the 604b project at: Eel River, Jones River and Town Brook. The nitrogen loading effort also involved further refinement of watershed delineations to accurately reflect shoreline areas to freshwater ponds and each portion of the estuary.

The initial task in the MEP land use analysis is to gauge whether or not nitrogen discharges to the watershed have reached the estuary. This involves a temporal review of land use changes, the time of groundwater travel provided by the USGS watershed model, and review of data at natural collections points, such as streams and ponds. Evaluation and delineation of ten-year time of travel zones are a regular part of the watershed analysis. Ten-year time of travel subwatersheds in the PDK watershed have been delineated for ponds, streams and the estuary itself. Review of less than and greater than watersheds indicates that 95% of the unattenuated nitrogen load from the whole watershed is within less than 10 year travel time to the estuary (Table 1). This finding should not be surprising given how streams generally penetrate at least 50% of the distance from the coast to the edge watershed and how most of the watershed development is concentrated closer to the coast. The overall result is that the present watershed nitrogen load appears to accurately reflect the present nitrogen sources to the estuary (after accounting for natural attenuation, see below) and that the distinction between time of travel in the subwatersheds is not important for modeling existing conditions. Overall and based on the review of all this information, it was determined that the PDK estuary is currently in balance with its watershed load.

In order to determine nitrogen loads from the watersheds, detailed individual lot-by-lot data is used for some portion of the loads, while information developed from other detailed site-specific studies is applied to other portions. The Linked Watershed-Embayment Management Model (Howes, *et al*., 2001) uses a land-use Nitrogen Loading Sub-Model based upon subwatershed-specific land uses and pre-determined nitrogen loading rates based on regional analyses. For the PDK estuary system, the model used land-use data from the seven towns in the watershed that is transformed into nitrogen loads using both regional nitrogen loading factors and local watershed-specific data (such as parcel-by-parcel water use). Determination of the nitrogen loads required obtaining watershed specific information regarding wastewater, fertilizers, runoff from impervious surfaces and atmospheric deposition. The primary regional factors were derived for southeastern Massachusetts from direct measurements. The resulting nitrogen loads represent the "potential" or unattenuated nitrogen load to each receiving embayment, since attenuation during transport is included at a later stage.

Natural attenuation of nitrogen during transport from land-to-sea within the PDK watershed was determined based upon site-specific study of streamflow at three locations and assumed attenuation in the upgradient freshwater ponds. Streamflow was characterized at: Eel River, Jones River and Town Brook (Howes and Samimy, 2005). Subwatersheds to these stream discharge points allowed assignment of attenuation factors based on comparisons between field collected data from the streams and estimates from the nitrogen-loading sub-model. Nitrogen attenuation in individual ponds is conservatively assumed to equal 50% unless available

monitoring and pond physical data is reliable enough to calculate a pond-specific attenuation factor.

Natural attenuation during stream transport or in passage through fresh ponds of sufficient size to effect groundwater flow patterns (area and depth) is a standard part of the data collection effort of the MEP. If smaller aquatic features that have not been included in this MEP analysis were providing additional attenuation of nitrogen, nitrogen loading to the estuary would only be slightly (~10%) overestimated given the distribution of nitrogen sources within the watershed.

I. Land Use and Water Use Database Preparation

As described in detail in the Task 1A report, Estuaries Project staff obtained digital parcel and tax assessor's data from the seven towns to serve as a base for the watershed nitrogen loading model. Using GIS techniques, this data was linked to current zoning areas and parcel-by-parcel water use information for the towns with public water supply. Table 2 lists the data obtained from each of the seven towns in the watershed. The resulting unified watershed land use database also contains traditional information regarding land use classifications (MassDOR, 2012) plus additional information developed by the towns, such as building footprints.

Figure 2 shows the land uses within the PDK estuary watershed. Land uses in the study area are grouped into ten land use categories: 1) residential, 2) commercial, 3) industrial, 4) agricultural, 5) multi-use, 6) recreational 7) undeveloped, 8) public service/government, including road rights-of-way, 9) freshwater, and 10) unclassified (properties without assigned town assessor's land use codes). These land use categories are generally aggregations derived from the major categories in the Massachusetts Assessors land uses classifications (MADOR, 2012). "Public service" in the MADOR system is tax-exempt properties, including lands owned by government (*e.g.*, wellfields, schools, open space, roads) and private groups like churches and colleges.

Residential land uses are generally the dominant land use type within the PDK watershed; they occupy the highest percentage area of land use types (35%) within the overall watershed and are the highest percentage in most of the subwatershed groupings shown in Figure 3. Examples of these land uses include single-family residences, condominiums, apartment buildings, and multi-family residences. Public service is generally the second highest percentage area, although it is the highest percentage area of land use types in the Eel River subwatershed. Overall public service lands are 20% to 40% of the land use areas in the subwatershed groupings in Figure 3. Examples of these land uses are lands owned by town and state government (including golf courses, open space, and wellhead protection lands), housing authorities, and churches. Undeveloped lands generally are the third highest area in the subwatershed groupings and are 9% of the land area within the overall PDK watershed.

In all the subwatershed groupings shown in Figure 3, residential parcels are the dominant parcel type (Figure 4). Residential parcels are 76% of the parcels in the Jones River subwatershed, 78% of parcels in the Town Brook subwatershed, 62% of all parcels in the Eel River system watershed and 72% of the parcels in the overall PDK watershed. Single-family

residences (MassDOR land use code 101) are the dominant type of residential parcel; these represent 85% to 96% of residential parcels counts in the gauged subwatersheds and 92% of the overall residential parcel area throughout the PDK system watershed.

II. Nitrogen Loading Input Factors

II.A. Wastewater Nitrogen Loads

The Massachusetts Estuaries Project septic system nitrogen loading rate is fundamentally based upon a *per capita* nitrogen load to the receiving aquatic system. Specifically, the MEP septic system wastewater nitrogen loading is based upon a number of studies and additional information that directly measured septic system and per capita loads on Cape Cod or in similar geologic settings (Nelson *et al*. 1998, Weiskel and Howes 1991, 1992, Koppelman 1978, Frimpter *et al*. 1990, Brawley *et al*. 2000, Howes and Ramsey 2000, Costa *et al.* 2002). Variation in *per capita* nitrogen load has been found to be relatively small, with average annual *per capita* nitrogen loads generally between 1.9 to 2.3 kg person-yr-1.

However, given the seasonal shifts in occupancy and rapid population growth throughout southeastern Massachusetts, decennial census data yields accurate estimates of total population only in selected watersheds. To correct for this uncertainty and more accurately assess current nitrogen loads, the MEP employs a water-use approach. The water-use approach is applied on a parcel-by-parcel basis within a watershed, where annual water meter data is linked to assessor's parcel information using GIS techniques. The parcel specific water use data is converted to septic system nitrogen discharges (to the receiving aquatic systems) by adjusting for consumptive use (e.g., irrigation) and applying a wastewater nitrogen concentration. The water use approach focuses on the nitrogen load that reaches the aquatic receptors downgradient in the aquifer.

All nitrogen losses within the septic system are incorporated into the MEP analysis. For example, information developed at the MassDEP Alternative Septic System Test Center at the Massachusetts Military Reservation on Title 5 septic systems have shown nitrogen removals between 21% and 25%. Multi-year monitoring from the Test Center has revealed that nitrogen removal within the septic tank was small (1% to 3%), with most (20 to 22%) of the removal occurring within five feet of the soil adsorption system (Costa *et al.*, 2002). Downgradient studies of septic system plumes in similar soils indicate that further nitrogen loss during aquifer transport is negligible (Robertson *et al*. 1991, DeSimone and Howes 1996).

In its application of the water-use approach to septic system nitrogen loads, MEP staff has ascertained for the Estuaries Project region that while the *per capita* septic load is well constrained by direct studies, the consumptive use and nitrogen concentration data are less certain. As a result, MEP staff has derived a combined term for an effective N Loading Coefficient (consumptive use times N concentration) of 23.63, to convert water (per volume) to nitrogen load (N mass). This coefficient uses a *per capita* nitrogen load of 2.1 kg N person-yr-1 and is based upon direct measurements and corrects for changes in concentration that result from per capita shifts in water-use (*e.g.*, due to installing low plumbing fixtures or high versus low irrigation usage).

The nitrogen loads developed using this approach have been validated in a number of long and short term field studies where integrated measurements of nitrogen discharge from watersheds could be directly measured. Weiskel and Howes (1991, 1992) conducted a detailed watershed/stream tube study that monitored septic systems, leaching fields and the transport of the nitrogen in groundwater to adjacent Buttermilk Bay. This monitoring resulted in estimated annual per capita nitrogen loads of 2.17 kg (as published) to 2.04 kg (if new attenuation information is included). Further, modeled and measured nitrogen loads were determined for a small sub-watershed to Mashapaquit Creek in West Falmouth Harbor (Smith and Howes, manuscript in review) where measured nitrogen discharge from the aquifer was within 5% of the modeled N load. Another evaluation was conducted by surveying nitrogen discharge to the Mashpee River in reaches with swept sand channels and in winter when nitrogen attenuation is minimal. The modeled and observed loads showed a difference of less than 8%, easily attributable to the low rate of attenuation expected at that time of year in this type of ecological situation (Samimy and Howes, unpublished data).

While census based population data has limitations in the highly seasonal MEP region, part of the regular MEP analysis is to compare expected water used based on average residential occupancy to measured average water uses. This is performed as a quality assurance check to increase certainty in the final results. This comparison has generally shown that the larger the watershed the better the match between average water use and occupancy. For example, in the cases of the combined Great Pond, Green Pond and Bournes Pond watershed in the Town of Falmouth and the Popponesset Bay/Eastern Waquoit Bay watershed, which covers large areas and have significant year-round populations, the septic nitrogen loading based upon the census data is within 5% of that from the water use approach. This comparison matches some of the variability seen in census data itself. Census blocks, which are generally smaller areas of any given town, have shown up to a 13% difference in average occupancy from town-wide occupancy rates. These analyses provide additional support for the use of the water use approach in the MEP study region.

Overall, the MEP water use approach for determining septic system nitrogen loads has been both calibrated and validated in a variety of watershed settings. The approach: (a) is consistent with a suite of studies on per capita nitrogen loads from septic systems in sandy soils and outwash aquifers; (b) has been validated in studies of the MEP Watershed "Module", where there has been excellent agreement between the nitrogen load predicted and that observed in direct field measurements corrected with other MEP Nitrogen Loading Coefficients (e.g., stormwater, lawn fertilization); (c) the MEP septic nitrogen loading coefficient agrees with specific studies of consumptive water use and nitrogen attenuation between the septic tank and the discharge site; and (d) the watershed module provides estimates of nitrogen attenuation by freshwater systems that are consistent with a variety of ecological studies. It should be noted that while points b-d support the use of the MEP Septic N Coefficient, they were not used in its development. The MEP Technical Team has developed the septic system nitrogen load over many years, and the general agreement among the number of supporting studies has greatly enhanced the certainty of this critical watershed nitrogen loading term.

At the outset of the MEP, project staff decided to utilize the water use approach for determining residential wastewater generation by septic systems because of the inherent difficulty in accurately gauging actual occupancy. Water use information exists for 73% of the 18,335 developed parcels in the PDK watershed. Parcels without water use accounts are assumed to utilize private wells for drinking water for the purposes of the nitrogen loading assessment. These are properties that are classified with land use codes that should be developed (*e.g.*, 101 or 325), have been confirmed as having buildings on them through a review of aerial photographs, and do not have either a listed account in the water use databases or the town does not have public water or an available water use database. Of the 4,909 developed parcels without water use accounts, 3,980 (81%) are classified as single-family residences (land use code 101).

Developed parcels that do not have measured water use are assigned water use based on the average water use for similarly classified properties. Single-family residences are assigned the watershed average water use of 213 gallons per day (gpd), while other residential properties, which are mostly various classifications of multi-family properties, are assigned a watershed average water use of 371 gpd. Existing flows at commercial and industrial properties have a wide range of water uses, which would be expected given the diversity of uses within these categories (*e.g.*, hotels and fast food restaurants are in the commercial category). Evaluation of the existing Plymouth water use within these categories found that the averages were above the 75th percentile; for this reason, median flows from existing properties with water use were used for existing commercial and industrial properties without water use records throughout the watershed. Commercial properties were assigned 279 gpd, while industrial properties were assigned 408 gpd.

Wastewater Treatment Facilities

When developing watershed nitrogen loading information, MEP project staff typically seeks additional information on enhanced wastewater treatment in the project study area. This information is reviewed and if judged reliable is included in the watershed nitrogen loading model.

During Phase 1A, MEP staff collected wastewater treatment plant performance data from the Massachusetts Department of Environmental Protection (personal communication, Brian Dudley, MassDEP, 4/10). There are 11 facilities with state Groundwater Discharge Permits (GWDPs) within the PDK watershed. A GWDP is required under MassDEP regulations for wastewater treatment systems with design flows greater than 10,000 gallons per day. The wastewater treatment facilities are located within the towns of Kingston, Plymouth, and Duxbury, and include municipal facilities for the Towns of Kingston and Plymouth. MEP staff received four years-worth of monitoring data (2006, 2007, 2008, and 2009) with average monthly effluent flows and total nitrogen concentrations. These flow and concentrations were used to develop annual loads. These annual loads were averaged and incorporated into the PDK watershed model on the sites of the wastewater discharge.

II.B. Fertilized Areas Nitrogen Loads

The second largest source of watershed nitrogen loading to estuaries is usually fertilized areas: lawns, golf courses, and cranberry bogs. Residential lawns are usually the predominant

source within this category. In order to add this source to the watershed nitrogen loading model for the PDK system, MEP staff reviewed available regional information about residential lawn fertilizing practices and incorporated site-specific information for the golf course, cranberry bogs and agricultural areas within the watershed.

Residential lawn fertilizer use has rarely been directly measured in watershed-based nitrogen loading investigations. Instead, lawn fertilizer nitrogen loads have been estimated based upon a number of assumptions: a) each household applies fertilizer, b) cumulative annual applications are 3 pounds per 1,000 square feet, c) each lawn is 5000 square feet, and d) only 25% of the nitrogen applied reaches the groundwater (leaching rate). Because many of these assumptions had not been rigorously reviewed leading up to the MEP, MEP Technical Staff undertook an assessment of lawn fertilizer application rates and lawn areas. Results of this assessment have been included in all MEP watershed nitrogen loading models.

The initial effort in this assessment was to determine nitrogen fertilization rates for residential lawns in the Towns of Falmouth, Mashpee and Barnstable. The assessment accounted for proximity to fresh ponds and embayments. Based upon ~300 interviews and over 2,000 site surveys, a number of findings emerged: 1) average residential lawn area is ~5000 square feet, 2) half of the residences did not apply lawn fertilizer, and 3) the weighted average application rate was 1.44 applications per year, rather than the 4 applications per year recommended on fertilizer bags. Using the assessment results with a nitrogen leaching rate of 20% results in a fertilizer contribution of nitrogen to groundwater of 1.08 lb N for each residential lawn. These factors are have been used in MEP watershed models, unless site-specific information is available. It should also be noted that a recent data review of fertilizer leaching in outwash plain settings confirmed that the 20% leaching rate is appropriate (HWG, 2009). It is likely that these load rates still represents a conservative estimate of nitrogen load from residential lawns. It should also be noted that professionally maintained lawns in the MEP three town survey were found to have the higher rate of fertilizer application and hence higher estimated annual contribution to groundwater of 3 lb/yr.

In addition to residential fertilizer nitrogen within the watershed, there are also eight golf courses. MEP and Town of Plymouth staff tried to contact superintendents at each golf course in order to obtain course- and turf-specific nitrogen fertilizer application information. Town of the golf course responded: Plymouth Country Club and Old Sandwich Golf Club. At the Plymouth Country Club, the following annual nitrogen application rates (in lbs/1,000 sq. ft.) were reported for the various turf areas: greens, 1.7; tees, 5.8; fairways, 1.2, and rough, 0.4 (personal communication, W. Weldon, 12/09). At the Old Sandwich Golf Club, application rates were: greens, 2.5; tees, 3.75; fairways, 2.25, and rough, 2.25 (personal communication, S. McCormick, 1/10). MEP staff reviewed the layout of the golf course from aerial photographs, classified the various turf types, determined which subwatershed turf was located in, applied a standard MEP 20% leaching rate, and developed course- and subwatershed-specific nitrogen loads.

For the six other golf courses without reported nitrogen application rates, turf types were classified and assigned to various subwatersheds based on aerial photographs. Nitrogen application rates and loads for each of these golf courses were determined from average

application rates developed from 23 other courses (collected during the MEP). The average turf application rates are (in lbs/1,000 sq. ft.): greens, 3.5; tees, 3.5; fairways, 3.2, and rough, 2.4.

Nitrogen loads were also added for site-specific agricultural land uses. Cranberry bog fertilizer application rate and percent nitrogen attenuation in the bogs is based on an enhanced review of nitrogen export from cranberry bogs in southeastern Massachusetts (Howes and DeMoranville, 2009; Howes and Teal, 1995). Based on these studies, only the bog loses measurable nitrogen, the forested upland releases only very low amounts. For the PDK watershed nitrogen loading analysis, MEP staff obtained a MassDEP GIS coverage that is maintained for Water Management Act purposes (personal communication, Jim McLaughlin, MassDEP SERO, 1/13). Based on this GIS coverage, there are 995 acres of cranberry bogs within the PDK watershed. Cranberry bogs are located within 32 of the 85 sub-watersheds in the PDK MEP watershed.

Recent quantitative work on local bogs has indicated that non-flow through bogs lose less nitrogen to downgradient systems than those with regular or continuous flow through the bogs. After reviewing previously existing and new studies of nitrogen export from regional cranberry bogs (*e.g.*, Howes and Teal, 1995; DeMoranville, *et al*., 2009), MEP staff refined the nitrogen loading factors assigned to cranberry bogs based on whether water continuously flowed through the bog or was pumped or diverted onto the bog (non-flow through bogs) from an outside source of water. Based on this refinement, non-flow through bogs are assigned a downstream nitrogen loss of 6.95 kg/ha/yr, while flow-through bogs are assigned a nitrogen load of 23.1 kg/ha/yr. In order to distinguish between flow through and non-flow through bog, MEP staff reviewed available aerial photographs and classified each bog for the purposes of the watershed nitrogen loading model. Review of historic aerial photographs also shows that growers are regularly changing their bogs and are often configuring them to achieve non-flow through configurations. Details on assignments for purposes of the nitrogen loading are contained in the MEP Data Disk that accompanies this report.

MEP also reviewed aerial photographs to determine the area of agricultural fields. This review identified 241 acres of agricultural fields. This review identified most of these fields as either pasture or hay. Both of these types of fields were assigned a nitrogen application rate of 5 kg/ha/yr, which is the MEP standard for these types of agricultural fields. Details are contained in the MEP Data Disk that accompanies this report.

II.C. Landfill Nitrogen Loads

MEP staff contacted MassDEP to obtain any nitrogen monitoring data for solid waste sites within the PDK system watershed. MassDEP has seven sites listed in their solid waste database that are located within the PDK watershed. Among these, three have available monitoring data: Duxbury Landfill, Kingston Landfill, and the Plymouth South Street Landfill (Mark Dakers, SERO, personal communication, 9/10). Development of nitrogen loads for each of these sites is based on the available monitoring data that is discussed in this section.

II.C.1. Duxbury Landfill

The Duxbury Landfill is located within the Bluefish River subwatershed (subwatershed #8). According to the MassDEP database, the landfill is capped, but not lined, and occupies 9.7 acres. MassDEP provided six sampling runs of biannual compliance monitoring data between November 2004 and April 2008, as well as groundwater elevation data, a map of well locations, and an interpretative groundwater contour map (Weston and Sampson, 2010a). MEP staff reviewed contaminant concentrations in wells along the prospective downgradient flow path.

The available Duxbury landfill groundwater monitoring data includes nitrate-nitrogen concentrations, but does not include total nitrogen or ammonium-nitrogen data. MEP staff estimated the rest of the dissolved nitrogen concentration during each sampling run based on alkalinity concentrations and the relationship between alkalinity concentrations and ammonium-nitrogen concentrations from groundwater monitoring of the Town of Brewster landfill (Cambareri and Eichner, 1993). After calculation, the estimated ammonium-nitrogen concentrations are added to the measured nitrate-nitrogen concentrations to provide an estimate of dissolved inorganic nitrogen (DIN), which is also used as an estimate of total nitrogen.

Based on the estimates, DIN concentrations in the downgradient wells ranged between 0.42 mg/L and 11.46 mg/L. MEP staff selected the wells with the two highest concentrations and, using the PDK recharge rate and the landfill area, determined the annual nitrogen load from the Duxbury Landfill is 247 kg/yr. This load is added to the subwatershed #8 load.

It is acknowledged that this approach for estimating a nitrogen load includes a number of assumptions, but it is appropriate based on the available data. A detailed assessment of all the available data is beyond the scope of the project, but staff balanced reasonable estimates of the various factors based on the general MEP guidance from MassDEP to include conservatism in nitrogen loading estimates when uncertainty exists in the data. A more refined evaluation and assessment of the established monitoring well network, including, at a minimum, analysis of total nitrogen concentrations and well construction details, would help to refine this assessment and future management options.

II.C.2. Kingston Landfill

The Kingston Landfill is located within the Foundry Pond Stream subwatershed (subwatershed #29). According to the MassDEP database, the landfill is capped, but not lined, and occupies 35 acres. MassDEP provided six sampling runs of biannual compliance monitoring data between October 2007 and April 2010, as well as groundwater elevation data, a map of well locations, and an interpretative groundwater contour map (Weston and Sampson, 2010b).

Direction of groundwater flow at this site appears to be complicated. A small stream flows along the south-southeastern edge of the site and water level readings in the stream suggest that groundwater flow should be toward the stream. However, water table elevations on the landfill site show flow away from the stream. With this in mind, MEP staff reviewed all contaminant concentrations in the available monitoring data.

The available Kingston landfill groundwater monitoring data includes nitrate-nitrogen concentrations, but does not include total nitrogen or ammonium-nitrogen data. MEP staff estimated the rest of the dissolved nitrogen concentration during each sampling run based on alkalinity concentrations and the relationship between alkalinity concentrations and ammonium-nitrogen concentrations from groundwater monitoring of the Town of Brewster landfill (Cambareri and Eichner, 1993). After calculation, the estimated ammonium-nitrogen concentrations are added to the measured nitrate-nitrogen concentrations to provide an estimate of dissolved inorganic nitrogen (DIN), which is also used as an estimate of total nitrogen.

Based on the derived estimates, DIN concentrations in the four most contaminated wells ranged between 0.94 mg/L and 1.76 mg/L. In addition, MEP staff reviewed historic aerials and estimated the solid waste area of 13.9 acres. MEP staff selected these four wells and, using the PDK recharge rate and the estimated solid area, determined the annual nitrogen load from the Kingston Landfill is 46 kg/yr. This load is added to the subwatershed #29 load.

It is acknowledged that this approach for estimating a nitrogen load includes a number of assumptions, but it is appropriate based on the available data. A detailed assessment of all the available data is beyond the scope of the project, but staff balanced reasonable estimates of the various factors based on the general MEP guidance from MassDEP to include conservatism in nitrogen loading estimates when uncertainty exists in the data. A more refined evaluation and assessment of the established monitoring well network, including, at a minimum, analysis of total nitrogen concentrations and well construction details, would help to refine this assessment and future management options.

II.C.3. Plymouth Landfill

The Plymouth Landfill is located within the Eel River West subwatershed (subwatershed #58). According to the MassDEP database, the landfill is capped, but not lined, and occupies 97.5 acres. Review of current and historic aerial photographs shows that the landfill is located under the Shops at 5 Plaza and that the solid waste area was estimated to cover 49 acres. MassDEP provided two sampling runs of biannual compliance monitoring data from 2009, but did not provide a map of well locations, an interpretative groundwater contour map, or well construction details.

Based on the limited information, MEP staff decided to review the available monitoring data and selected the monitoring well (MW-3) with the highest contaminant concentrations. The available Plymouth landfill groundwater monitoring data includes nitrate-nitrogen concentrations, but does not include total nitrogen or ammonium-nitrogen data. MEP staff estimated the rest of the dissolved nitrogen concentration during each sampling run based on alkalinity concentrations and the relationship between alkalinity concentrations and ammonium-nitrogen concentrations from groundwater monitoring of the Town of Brewster landfill (Cambareri and Eichner, 1993). After calculation, the estimated ammonium-nitrogen concentrations are added to the measured nitrate-nitrogen concentrations to provide an estimate of dissolved inorganic nitrogen (DIN), which is also used as an estimate of total nitrogen.

Based on the estimates, DIN concentrations at MW-3 were 12.32 mg/L on 4/26/09 and 19.71 mg/L on 10/22/09. Using the PDK recharge rate and the estimated solid area, MEP staff determined the annual nitrogen load from the Plymouth Landfill is 2,177 kg/yr. This load is added to the subwatershed #58 load.

It is acknowledged that this approach for estimating a nitrogen load includes a number of assumptions, but it is appropriate based on the available data. A detailed assessment of all the available data is beyond the scope of the project, but staff balanced reasonable estimates of the various factors based on the general MEP guidance from MassDEP to include conservatism in nitrogen loading estimates when uncertainty exists in the data. A more refined evaluation and assessment of the established monitoring well network, including, at a minimum, analysis of total nitrogen concentrations and well construction details, would help to refine this assessment and future management options.

II.D. Jones River: Freshwater Wetlands Nitrogen Loads and Reconciling Flow

During the course of the MEP, staff have found a number of occasions where relatively high flow rivers in non-outwash hydrogeology that stream nitrogen loads have not matched MEP watershed nitrogen loading estimates (*e.g.*, Howes, *et al*., 2012). Since the MEP assessment approach is data-driven, MEP staff began the process of exploring the cause of these higher nitrogen loads by re-reviewed all of the data leading to the preliminary watershed loads, including the watershed delineations, the nitrogen loading inputs, and re-reviewing the streamflow and concentration data. These steps led to additional clarification of the flows in the Jones River and suggested that there was another nitrogen source in the Jones River watershed that was not included in the preliminary model. Evaluations in the Town Brook and Eel River watersheds did not find a similar situation.

The Jones River watershed includes Silver Lake (subwatershed #20). Silver Lake has water withdrawals and additions as part of the Town of Brockton's water supply system (Gomez and Sullivan, 2013). Water levels in Silver Lake fluctuate significantly because of natural fluctuations and the withdrawals and additions and the Lake may go through significant period where it does not discharge surface waters to the Jones River. MEP staff reviewed water levels in the Lake during the period that 604b stream gauging occurred (September 2003 to August 2004) and found that the Lake discharged to the Jones River approximately five months during that period (December 2003 to April 2004). Adjusting the watershed discharge from Silver Lake to account for this limitation resulted in excellent balance (<1% difference) between the estimated Jones River flow based on recharge within the USGS recharge area and measured 2003-04 flow.

While the water flow balanced between measured and estimated for the nitrogen loading model, the initial nitrogen load in the model was lower than the measured load. In the prior evaluations where nitrogen loading estimates were initially less than measured stream nitrogen loads, MEP staff identified extensive wetland and swamp lands surrounding streams and rivers feeding into the estuary as the most likely unaddressed nitrogen source within the watershed (*e.g*, Howes, *et al*, 2012). Studies have indicated that the ability of river wetlands to attenuate nitrogen is directly related to their hydraulic residence times (*e.g.*, Jansson, *et al*., 1994; Perez, *et*

al., 2011; Toet, *et al*., 2005) with longer residence times resulting in greater nitrogen reduction. Direct data in the overall MEP study area generally confirms this relationship with lower flow/longer residence times streams on the eastern portion of the overall MEP study area having greater nitrogen attenuation, as well as ponds and lakes, which have even longer residence times, having nitrogen attenuation rates of 50% or higher (*e.g*., Howes, *et al*., 2006).

This impact of surrounding wetlands seems to be associated with the underlying geology and how wetlands occur within different geologic settings. In most of the streams and rivers on Cape Cod, the Islands and eastern Buzzards Bay, the sandy aquifer-dominated, outwash-plain systems typically have only limited fringing freshwater wetlands leading to MEP stream gauge locations, have comparatively low streamflows, and streamflow patterns that tend to be less influenced by rainfall events and more influenced by regional groundwater fluctuations. These streams in the eastern portion of the overall MEP study area generally produce N attenuation rates of 25 to 30%. In systems that are underlain by bedrock and till, like the Jones River, the groundwater flow paths to the river are shorter and the flows tend to be flashier and more influenced by rainfall events. These rivers also tend to have higher flows.

In addition, reviews of river wetlands have indicated that have threshold effects like those seen in estuaries and ponds. This means that they can become loaded with nitrogen and act as transformers of nitrogen (changing nitrate+nitrite to organic forms), but not attenuators of nitrogen (*e.g*., USDA, 2011). This change appears to be related to the amount of nitrogen received, as well as inter-related factors such as hydraulic residence time, temperature, plant surface coverage, and plant density (*e.g*., Hägg *et al*., 2011; Kröger, *et al*., 2009; Alexander, *et al*., 2008).

Based on insights gathered from previous MEP assessments, staff incorporated nitrogen loading from the wetland areas in the Jones River watershed by assigning the water surface nitrogen loading factor (1.09 mg/l TN) to the wetland areas identified in a MassGIS/MassDEP 1:12000 wetland coverage (available at MassGIS: http://www.mass.gov/mgis/wetdep.htm). The wetland areas in this coverage were corrected to remove surface waters for freshwater ponds and cranberry bogs since loads for each of these are calculated and added separately. For the purposes of the MEP assessment, the treatment of these wetlands as water surfaces is appropriately conservative without further data to refine the spatial differences in residence times, plant communities/densities and the role of seasonal impacts along the various streams and rivers in the Jones River watershed system.

II.E. Other Nitrogen Loading Input Factors

The nitrogen loading factors for atmospheric deposition, impervious surfaces and natural areas in the PDK assessment are from the MEP Embayment Modeling Evaluation and Sensitivity Report (Howes and Ramsey 2001). The factors are similar to those utilized by the CCC's Nitrogen Loading Technical Bulletin (Eichner and Cambareri, 1992) and MassDEP's Nitrogen Loading Computer Model Guidance (1999). The recharge rate for natural areas and lawn areas is the same as utilized in the USGS groundwater modeling effort (Masterson, *et al*., 2009). Factors used in the MEP nitrogen loading analysis for the PDK watershed are summarized in Table 3.

Road areas are based on GIS information developed by the Massachusetts Executive Office of Transportation, which provides road, sidewalk, and road shoulder widths for various road segments April 2012 GIS coverage available through MassGIS). MEP staff utilized the GIS to sum these segments and their various widths by subwatershed. Project staff also checked this information against parcel-based rights-of-way.

III. Watershed Nitrogen Loading Model Development

Once all the land and water use information is linked to the parcel coverages, parcels are assigned to various watersheds based initially on whether at least 50% or more of the land area of each parcel is located within a respective subwatershed. Following the assigning of boundary parcels, all large parcels are examined individually and are split (as appropriate) in order to obtain less than a 2% difference between the total land area of each subwatershed and the sum of the area of the parcels within each subwatershed. This effort results in "parcelized" watersheds that can be more easily used during the development of management strategies.

The review of individual parcels straddling watershed boundaries includes corresponding reviews and individualized assignment of nitrogen loads associated with lawn areas, septic systems, and impervious surfaces. Building footprints, for example, is based on available information for towns that have this within their assessor's database. Project staff used the average single-family residence building footprint based on available properties in the MEP study area (1,720 sq ft) for any single-family residential units without footprint information. Commercial and industrial footprints for properties without building footprint information are also based on average building coverage of individual lots with similar land uses within the town. Individualized information for parcels with atypical nitrogen loading (condominiums, golf courses, etc.) is also assigned at this stage. It should be noted that small shifts in nitrogen loading due to the above assignment procedure generally have a negligible effect on the total nitrogen loading to the PDK estuary. The assignment effort is undertaken to better define sub-estuary loads and enhance the use of the Linked Watershed-Embayment Model for the analysis of management alternatives.

Following the assignment of all parcels, subwatershed modules were generated for each of the 85 subwatersheds in the PDK study area. These subwatershed modules summarize, among other things: water use, parcel area, frequency, private wells, and road area. All relevant nitrogen loading data is assigned to each subwatershed. Individual sub-watershed information is then integrated to create the PDK Watershed Nitrogen Loading module with summaries for each of the individual 85 subwatersheds. The subwatersheds are generally paired with functional embayment/estuary units for the Linked Watershed-Embayment Model's water quality component.

For management purposes, the aggregated estuary watershed nitrogen loads are partitioned by the major types of nitrogen sources in order to focus development of nitrogen management alternatives. Within the PDK study area, the major types of nitrogen loads are: wastewater (*e.g.*, septic systems), wastewater treatment facilities, fertilizers (including contributions from agriculture and golf courses), impervious surfaces, direct atmospheric deposition to water surfaces, and recharge within natural areas (Table 4). The output of the

watershed nitrogen-loading model is the annual mass (kilograms) of nitrogen added to the contributing area of component sub-embayments, by each source category (Figure 5). In general, the annual watershed nitrogen input to the watershed of an estuary is then adjusted for natural nitrogen attenuation during transport to the estuarine system before use in the embayment water quality sub-model.

III.A. Natural Nitrogen Attenuation: Freshwater Pond Nitrogen Loads

One of these natural nitrogen attenuation adjustments occurs in the freshwater ponds. Freshwater ponds in aquifer systems like those in the Plymouth-Carver-Kingston-Duxbury Aquifer are generally kettle-hole depressions that intercept the water table of surrounding groundwater. Groundwater typically flows into the pond along the upgradient shoreline, then lake water flows back into the groundwater system along the downgradient shoreline. Occasionally these ponds will also have a stream outlet or herring run that also acts as a discharge point; many of the ponds in the PDK watershed are connected to each other through streams and rivers, as well as connections that have been developed for cranberry bog operations.

Since watershed nitrogen loads flow into the ponds along with the groundwater, the pond biomass (plants and animals) have the opportunity to incorporate some of the nitrogen, as well as transporting some of it to the pond sediments. As the nitrogen is captured and used in the pond ecosystem, it is also changed amongst its various oxidized and reduced forms. These interactions also allow for some chemical denitrification and release of some of the nitrogen to the atmosphere, as well as permanent burial in the pond sediments of some portion of the load that the pond receives. Through the cumulative effect of these interactions with the pond ecosystem, some of the nitrogen from the pond watershed is removed and is not transferred downgradient or downstream. If this reduced (or attenuated) load does not encounter any streams or other ponds, it will eventually discharge to the downgradient embayment. If it enters another pond or stream prior to discharge, this load can be further attenuated. In the nitrogen loading summary in Table 4, the unattenuated loads are those without any natural nitrogen attenuation, while the attenuated loads include the attenuation within ponds, streams, and, in some cases, the cumulative effect of attenuation within a number of ponds and streams as the water moves toward discharge in the estuary.

Pond nitrogen attenuation in freshwater ponds has generally been found to be at least 50% in MEP analyses, so this value, which has been shown to be conservative, is generally used as a standard MEP default attenuation rate when sufficient pond-specific data is not available. In order to estimate nitrogen attenuation in the ponds, available physical and water quality data for each pond is reviewed. Available bathymetric information is reviewed relative to measured pond temperature profiles to determine whether an epilimnion (*i.e.*, well mixed, uniform temperature, upper portion of the water column) exists in each pond. This step is completed to assess whether available data is influenced significantly by sediment regeneration of nitrogen. Bathymetric information is necessary to develop a residence or turnover time and complete an estimate of nitrogen attenuation.

In the PDK watershed, MEP staff worked with Town of Plymouth staff and reviewed available MassDEP and other data sources to review available pond monitoring and physical

characterization data. Much of the Town of Plymouth's pond data is available on a web site: http://www.plymouth-ma.gov/Public_Documents/PlymouthMA_Marine/pondinfo/pondpage. Among the 45 freshwater ponds with delineated subwatersheds, data is generally limited to selected bathymetric maps and limited, snapshot water quality monitoring. This data is insufficient for pond-specific nitrogen attenuation rates. For this reason, the standard MEP 50% attenuation was assigned to all freshwater ponds with delineated subwatersheds.

Since groundwater outflow from a pond can enter more than one downgradient sub-watershed, the length of shoreline on the downgradient side of the pond was used to apportion the pond-attenuated nitrogen load to respective downgradient watersheds. The apportionment was based on the percentage of discharging shoreline bordering each downgradient sub-watershed. So for example, Billington Sea has a downgradient shoreline of 6,264 feet; 45% of that shoreline discharges into the Lout Pond subwatershed (watershed #45 in Figure 1) and 55% discharges to the Town Brook Gauge subwatershed (watershed #44). The attenuated nitrogen load discharging from Billington Sea is divided among these sub-watersheds based on these percentages of the downgradient shoreline.

III.B. Natural Nitrogen Attenuation: Freshwater Stream Nitrogen Loads

Just as freshwater ponds provide opportunities for natural nitrogen attenuation within the estuary watershed, so do freshwater streams. Streams are lined with aquatic plant communities and wetlands that can slow travel time of water to the estuary and provide opportunities for nitrogen loss through capture or natural cycling. Because their retention time tends to be shorter than freshwater ponds, natural attenuation in streams is generally lower, but part of the MEP process is designed to collect system-specific data at major streams. Since these sites are selected just upstream of the discharge into the estuary, these monitoring locations provide a check on the overall watershed load, as well as the freshwater input.

As mentioned previously, Jones River, Eel River, and Town Brook were monitored extensively during the 604b project (Howes and Samimy, 2005). Nitrogen and flow data were collected throughout at least one hydrologic year (September 2003 through August 2004). These measurements were used to develop annual nitrogen loads and these were compared to the projected watershed nitrogen loads based on the watershed nitrogen loading model.

As discussed in the freshwater wetlands nitrogen loading section, the original watershed nitrogen loading for the Jones River was less than the measured load. After rechecking all other factors, project staff added load based on the area of freshwater wetlands. The resulting nitrogen load was within 0.3% of the measured load without any additional attenuation. This result is consistent with saturation of these wetlands and no additional attenuation within the wetlands. As a result, the standard attenuation for the ponds is the only natural attenuation within the Jones River watershed.

In the Town Brook and Eel River, the watershed nitrogen loads were in excess of the measured nitrogen loads so attenuation rates of 16% and 30%, respectively, were assigned to these rivers. These rates are consistent with the structure of the watersheds; Town Brook has limited wetlands and ponds, while Eel River has extensive interior wetlands and numerous

ponds. It would be expected that residence time of water within the Eel River watershed would be longer than in Town Brook. Details on attenuation rates and the flow paths for water are contained in the MEP Data Disk that accompanies this report.

IV. Future Nitrogen Loads: Buildout

Part of the regular MEP watershed nitrogen loading modeling is to prepare a buildout assessment of potential development and accompanying nitrogen loads within the study area watersheds. The MEP buildout is relatively straightforward and is generally completed in three steps: 1) each residential parcel classified by the town assessor as developable is identified and divided by minimum lot sizes specified in town zoning and the resulting number of new residential units is rounded down, 2) parcels classified as developable commercial and industrial parcels by the town assessor are identified, and 3) residential, commercial and industrial parcels with existing development and areas greater than twice zoning's minimum lot size are identified, divided by the minimum lot size and the resulting number of new units is rounded down.

It should be noted that the initial MEP buildout approach is relatively simple and does not include any modifications/refinements for lot line setbacks, wetlands, road construction, frontage requirements, parcel shape requirements, or other more detailed zoning provisions. The MEP buildout approach also does not include potential impacts associated with the higher densities usually associated with 40B affordable housing projects. The approach includes provisions to maintain current commercial and industrial uses. Chapter 61A lands (land use code 601), which tend to be forest lands in "agricultural use" are assumed to remain in this use at buildout. Data on permanently protection open space is also incorporated if available.

As an example of how the MEP approach might apply, assume an 81,000 square foot lot is classified by the town assessor as a developable residential lot (land use code 130). This lot is divided by the 40,000 square foot minimum lot size specified in town zoning and the result is rounded down to two. As a result, two additional residential lots would be added to the subwatershed in the MEP buildout scenario. This addition could then be modified during discussion of town staff.

Other provisions of the MEP buildout assessment include undevelopable lots, commercial and industrial properties, and lots less than the minimum areas specified by zoning. Properties classified by the town assessor's as "undevelopable" (*e.g.*, MassDOR codes 132, 392, and 442) are not assigned any development at buildout. Commercial and industrial properties classified as developable are not subdivided; the area of each parcel and the factors in Table 3 are used to determine a building size and wastewater flow for these properties. Pre-existing lots classified by the town assessor as developable are also treated as developable even if they are less than the minimum lot size specified in zoning; so, for example, a 10,000 square foot lot classified by the town assessor as a developable residential property (130 land use code) will be assigned an additional residential dwelling in the MEP buildout scenario even though the minimum lot size required by the zoning in the area is 40,000 square feet. Most town zoning bylaws have a lower minimum lot size for pre-existing lots (usually 5,000 square feet) that will minimize instances of regulatory takings. Existing developed residential properties that are larger than zoning's

minimum lot sizes are also assigned additional development potential only if enough area is available to accommodate at least one additional lot as specified by the zoning minimum.

All the parcels with additional buildout potential within the PDK watershed are shown in Figure 6. Overall, this buildout includes a projected 4,700 additional residences at buildout, 10,805,535 square feet of additional commercial properties and 27,131,170 square feet of additional industrial properties. Each additional residential, commercial, or industrial property added at buildout is assigned nitrogen loads for wastewater and impervious surfaces. Residential additions also include lawn fertilizer nitrogen additions. All wastewater loads are assumed to come from standard on-site septic systems unless the parcel is designated as already having a sewer connection (for additional development on existing lots) or identified within the sewer service area. Cumulative unattenuated buildout loads are indicated in a separate column in Table 4. Buildout additions within the PDK watersheds will increase the unattenuated loading rate by 17%.

V. Summary

The Town of Plymouth asked the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP-SMAST) to complete the construction of a watershed nitrogen loading model for the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Estuarine System. Development of this model utilized individual parcel land use, water use, and other factors and information collected during a previous effort completed by CSP-SMAST (Eichner and Howes, 2011). The current effort reviewed, assessed, and organized all of this information to develop site- and subwatershed-specific nitrogen loads that were aggregated to create a PDK watershed nitrogen loading model. The resulting modeled loads were checked and harmonized with previously collected data in the Jones River, Town Brook and Eel River (Howes and Samimy, 2005). The stream water quality and flow, watershed delineation, and watershed nitrogen loading model development are usual steps toward completion of a Massachusetts Estuary Project (MEP) assessment of an estuary, which culminates with development of a nitrogen threshold for ensuring a healthy ecosystem and acceptable water quality and a calibrated and validated linked estuary-watershed model that can be used to evaluate the benefits of watershed or estuary management options. The next steps in the MEP assessment process include the development of the estuary hydrodynamic/tidal model, evaluation of benthic health and nutrient contributions, and harmonizing of water quality results, both in the estuary and from the watershed, within a water quality model. The MEP team, led by CSP-SMAST, looks forward to continuing to work with the Town of Plymouth and the other towns in the PDK Estuarine System to complete these next steps and ensure that the ecosystem and water quality in the Plymouth Harbor - Duxbury Bay - Kingston Bay meets all community goals.

VI. References

Alexander, R.B., J.K. Bohlke, E.W. Boyer, M.B. David, J.W. Harvey, P.J. Mulholland, S.P. Seitzinger, C.R. Tobias, C. Tonitto, W.M. Wollheim. 2009. Dynamic modeling of nitrogen losses in river networks unravels the coupled effects of hydrological and biogeochemical processes. *Biogeochemistry* (2009) 93:91–116. DOI 10.1007/s10533-008-9274-8.

Brawley, J.W., G. Collins, J.N. Kremer, C.H. Sham, and I. Valiela. 2000. A time-dependent model of nitrogen loading to estuaries form coastal watersheds. *Journal of Environmental Quality* 29:1448-1461.

Cambareri, T.C. and E.M. Eichner. 1993. Hydrogeologic and Hydrochemical Assessment of the Brewster Landfill (Brewster, Massachusetts). Cape Cod Commission and Barnstable County Department of Health, Human Services, and the Environment, Barnstable, MA.

Cambareri, T.C. and E.M. Eichner, 1998. Watershed Delineation and Ground Water Discharge to a Coastal Embayment. *Ground Water*. 36(4): 626-634.

Costa, J., G. Heufelder, S. Foss, N.P. Millham, and B.L. Howes. 2002. Nitrogen removal efficiencies of three alternative septic technologies and a conventional septic system. *Environment Cape Cod* 5(1):15-24.

DeMoranville, C., B. Howes, D. Schlezinger, and D. White. 2009. Cranberry phosphorus management: How changes in practice can reduce output in drainage water. *Acta Horticulturae* 810:633-640.

DeSimone, L.A. and B.L. Howes. 1996. Denitrification and nitrogen transport in a coastal aquifer receiving wastewater discharge. *Environmental Science and Technology* 30:1152-1162.

Eichner, E.M. and B.L. Howes. 2011. Final Report/Technical Memorandum for Task 1A (of 8). Plymouth Harbor - Duxbury Bay - Kingston Bay Estuarine System: Land Use Data Collection and Watershed Delineation. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts – Dartmouth.

Eichner, E.M. and T.C. Cambareri, 1992. Technical Bulletin 91-001: Nitrogen Loading. Cape Cod Commission, Water Resources Office, Barnstable, MA. Available at: http://www.capecodcommission.org/regulatory/NitrogenLoadTechbulletin.pdf

Frimpter, M.H., J.J. Donohue, M.V. Rapacz. 1990. A mass-balance nitrate model for predicting the effects of land use on groundwater quality. U.S. Geological Survey Open File Report 88:493.

Gomez and Sullivan Engineers, P.C. March 2013. Forge Pond Dam Fish Passage Improvement Feasibility Study and Preliminary Design, Jones River, Kingston, MA. Draft Final Feasibility Report. Massachusetts Division of Marine Fisheries.

Hägg, H.E., C. Humborg, D.P. Swaney and C.M. Mörth. 2011. Riverine nitrogen export in Swedish catchments dominated by atmospheric inputs. *Biogeochemistry*. DOI: 10.1007/s10533-011-9634-7

Horsley Witten Group. 2009. Evaluation of Turfgrass Nitrogen Fertilizer Leaching Rates in Soils on Cape Cod, Massachusetts. Prepared for Brian Dudley, Department of Environmental Protection. Sandwich, MA.

Howes, B., E. Eichner, R. Acker, R. Samimy, J. Ramsey, and D. Schlezinger. 2012. Massachusetts Estuaries Project Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading Thresholds for the Westport River Embayment System, Town of Westport, MA. Massachusetts Department of Environmental Protection. Boston, MA.

Howes, B.L. and J.M. Teal. 1995. Nitrogen balance in a Massachusetts cranberry bog and its relation to coastal eutrophication. *Environmental Science and Technology* 29:960-974.

Howes, B.L., J.S. Ramsey and S.W. Kelley, 2001. Nitrogen modeling to support watershed management: comparison of approaches and sensitivity analysis. Final Report to MA Department of Environmental Protection and USEPA, 94 pp. Published by MADEP.

Howes B.L., N.P. Millham, S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2012. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Slocum's and Little River Estuaries, Dartmouth, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Howes, B. and R. Samimy. 2005. Summary of Water Quality Monitoring Program for the Plymouth, Kingston, and Duxbury Harbor Embayment System. Completed for Town of Kingston, Town of Duxbury, Town of Plymouth, and MADEP 604b Program. Coastal Systems Laboratory, School for Marine Science and Technology, University of Massachusetts Dartmouth.

Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner. 2006. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Jansson M., R. Andersson, H. Berggren, and L. Leonardson. 1994a. Wetlands and lakes as nitrogen traps. *Ambio*. 23: 320-325.

Jansson M., L. Leonardson and J. Fejes. 1994b. Denitrification and nitrogen retention in a farmland stream in Southern Sweden. *Ambio*. 23: 326-331.

Koppelman, L.E. (Ed.). 1978. The Long Island comprehensive waste treatment management plan. Vol II. Summary documentation report, Long Island Regional Planning Board, Hauppage, N.Y.

Kroger, R., M.T. Moore, M.A. Locke, R.F. Cullum, R.W. Steinriede Jr., S. Testa III, C.T. Bryant, C.M. Cooper. 2009. Evaluating the influence of wetland vegetation on chemical residence time in Mississippi Delta drainage ditches. *Agricultural Water Management* 96 (2009) 1175–1179.

Massachusetts Department of Revenue. March, 2012. Property Type Classification Codes, Non-arm's Length Codes and Sales Report Spreadsheet Specifications. Prepared by the Bureau of Local Assessment. Boston, MA.

Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009. Hydrogeology and simulation of groundwater flow in the Plymouth-Carver-Kingston-Duxbury aquifer system, southeastern Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5063, 110 p.

Nelson, M.E., S.W. Horsley, T.C. Cambareri, M.D. Giggey and J.R. Pinnette. 1998. Predicting nitrogen concentrations in groundwater- An analytical model. Focus Conference on Eastern Groundwater Issues, National Water Well Association, Stamford, CT.

Perez, B., J. Day, D. Justic, R. Lane, and R. Twilley. 2011. Nutrient stoichiometry, freshwater residence time, and nutrient retention in a river-dominated estuary in the Mississippi Delta. *Hydrobiologia*. 658(1): 41-54.

Robertson, W.D., J.D. Cherry, and E.A. Sudicky. 1991. Ground-Water Contamination from Two Small Septic Systems on Sand Aquifers. *Ground Water.* 29(1): 82-92.

Toet, S., Van Logtestijn, R.S.P., Kampf, R., Schreijer, M., and J.T.A. Verhoeven. 2005. The effect of hydraulic retention time on the removal of pollutants from sewage treatment plan effluent in a surface-flow wetland system. Wetlands 25(2), pp. 375–391.

Town of Plymouth. 2008. Operational Monitoring Program, Data Report for 2006 and 2007. Department of Public Works, Environmental Management Division. Plymouth, MA. Available at: www.plymouth-ma.gov/Public_Documents/PlymouthMA_ EnvironManage /2006-07Report.pdf.

US Department of Agriculture. 2011. Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States. L.H. Pardo, M.J. Robin-Abbott, and C.T. Driscoll, editors. Available at: http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs80.pdf

Weiskel, P.K. and B.L. Howes, 1991. Quantifying Dissolved Nitrogen Flux Through a Coastal Watershed. *Water Resources Research*, Volume 27, Number 11, Pages 2929-2939.

Weiskel, P.K. and B.L. Howes. 1992. Differential transport of nitrogen and phosphorus from septic systems through a coastal watershed. *Environmental Science and Technology* 26: 352-360.

Weston and Sampson Engineers, Inc. June 2010a. Semiannual Environmental Monitoring Report, Duxbury Sanitary Landfill. Peabody, MA.

Weston and Sampson Engineers, Inc. May 2010b. Semiannual Environmental Monitoring Report, Kingston Sanitary Landfill. Peabody, MA.

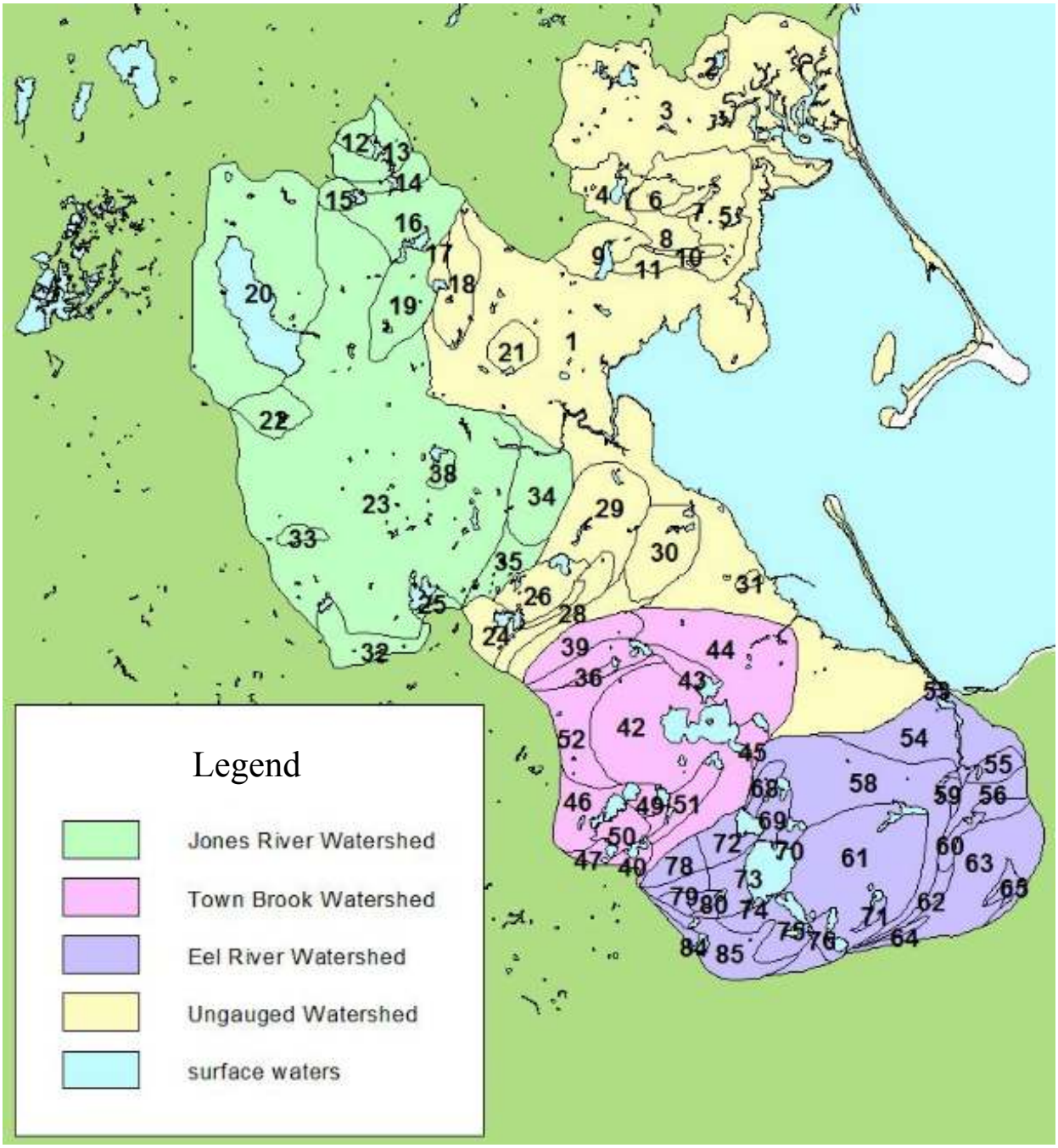


Figure 1. Massachusetts Estuaries Project *Draft* Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary Watersheds and Subwatersheds. Watershed delineations were completed during Task 1A based on recharge area outputs from the regional USGS groundwater model (Masterson, *et al*., 2009) refined for pond, stream, and coastal shorelines. Subwatersheds to the gauged streams are indicated. The subwatersheds boundaries are draft because assessment and integration of nitrogen loading and water quality as the MEP proceeds may result in reassessment of individual subwatershed boundaries.

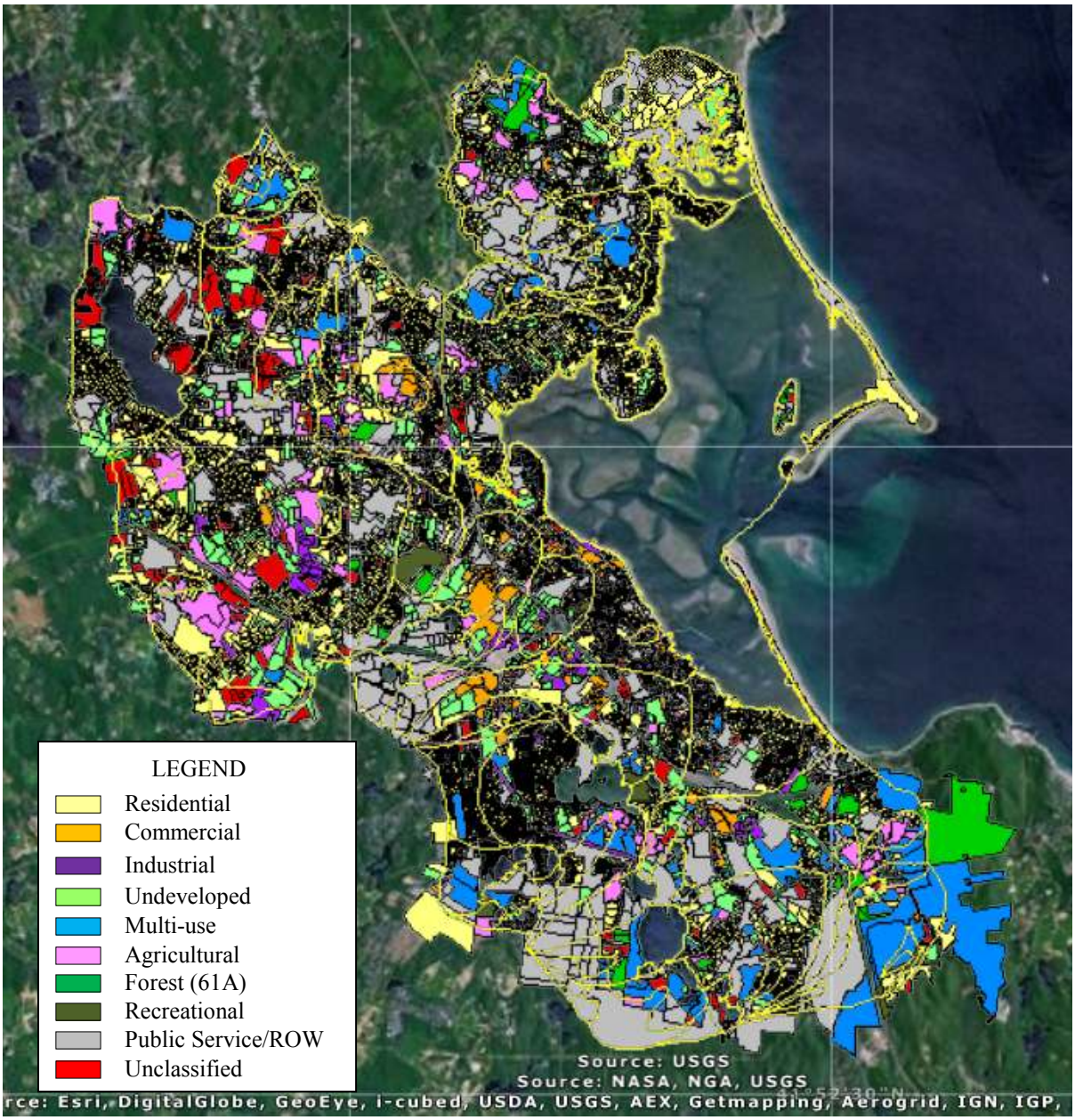


Figure 2. Land Use within the Plymouth Harbor - Duxbury Bay - Kingston Bay Watershed. Land uses are based on town assessors' land use classifications from the seven towns within the watershed. Residential parcels are the dominant land use type both in terms of area and number of parcels. Classifications are aggregated based on the MassDOR general categories (MassDOR, 2012). Undeveloped parcels include parcels classified by the town assessors' as undevelopable (*i.e.*, land use categories 132, 392, and 442). Unclassified properties did not have land use category assignments in the assessors' databases used in the assessment. The assessors' databases were current as of the years listed in Table 2.

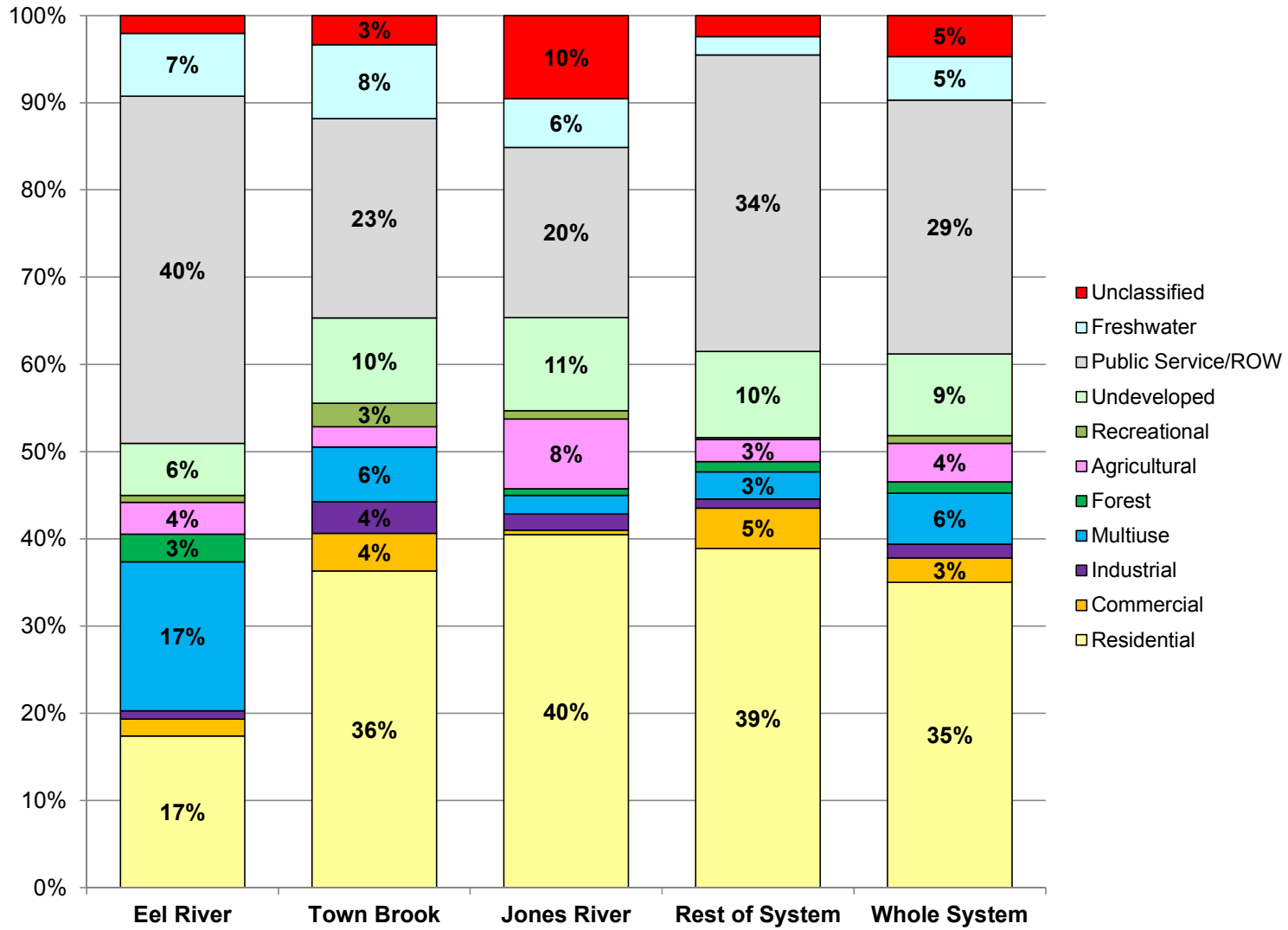


Figure 3. Distribution of land-uses by area within the Plymouth Harbor - Duxbury Bay - Kingston Bay system watershed and four component subwatersheds. Land use categories are generally based on town assessors' land use classification and groupings recommended by MADOR (2012). Unclassified parcels do not have an assigned land use code in the town assessors' databases. Only percentages greater than or equal to 3% are shown.

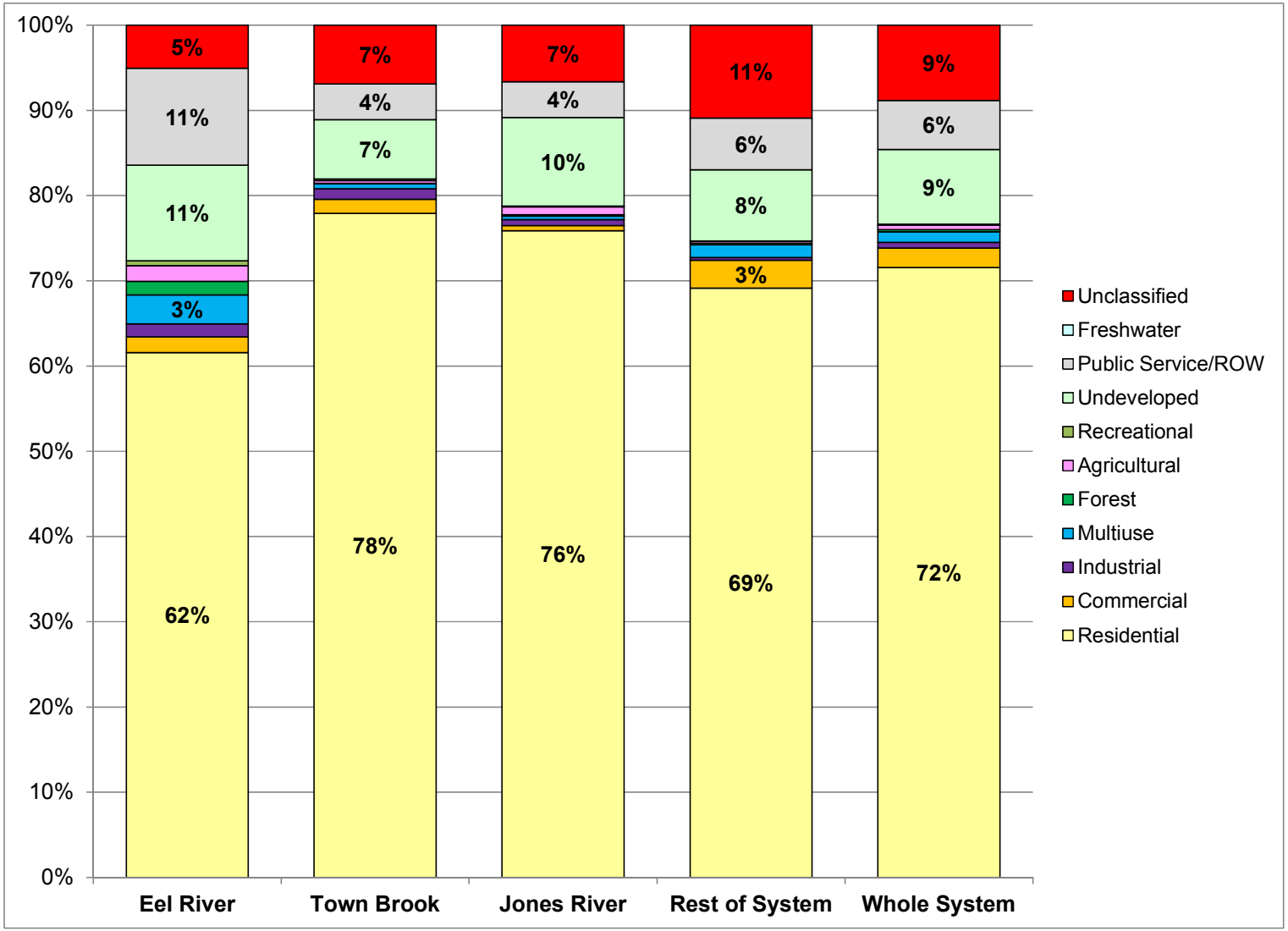
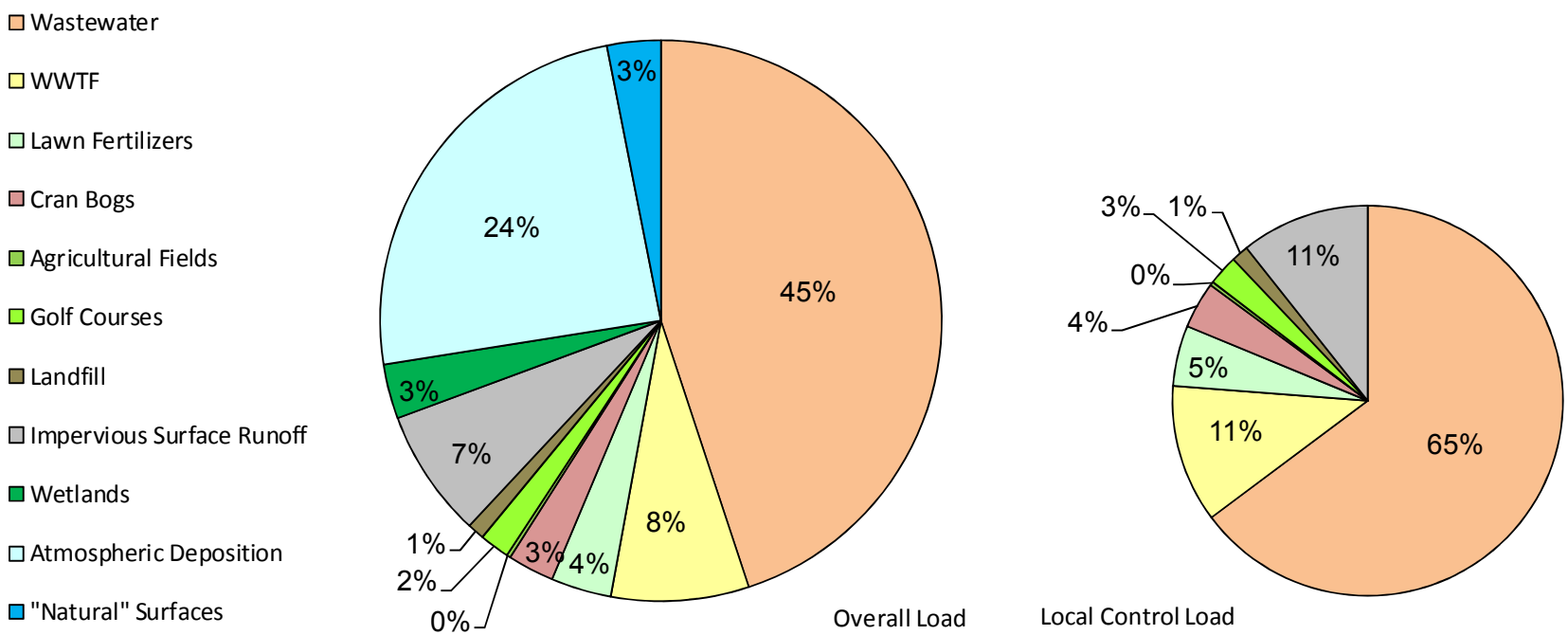


Figure 4. Distribution of land-uses by parcel count within the Plymouth Harbor - Duxbury Bay - Kingston Bay system watershed and four component subwatersheds. Land use categories are generally based on town assessors' land use classification and groupings recommended by MADOR (2012). Unclassified parcels do not have an assigned land use code in the town assessors' databases. Only percentages greater than or equal to 3% are shown.



A. Whole Plymouth Harbor System

Figure 5: 5A. Land use-specific unattenuated nitrogen loads (by percent) to the A) whole Plymouth Harbor - Duxbury Bay - Kingston Bay system watershed. "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. Atmospheric Deposition category includes inputs to both freshwater ponds and the estuary surface.

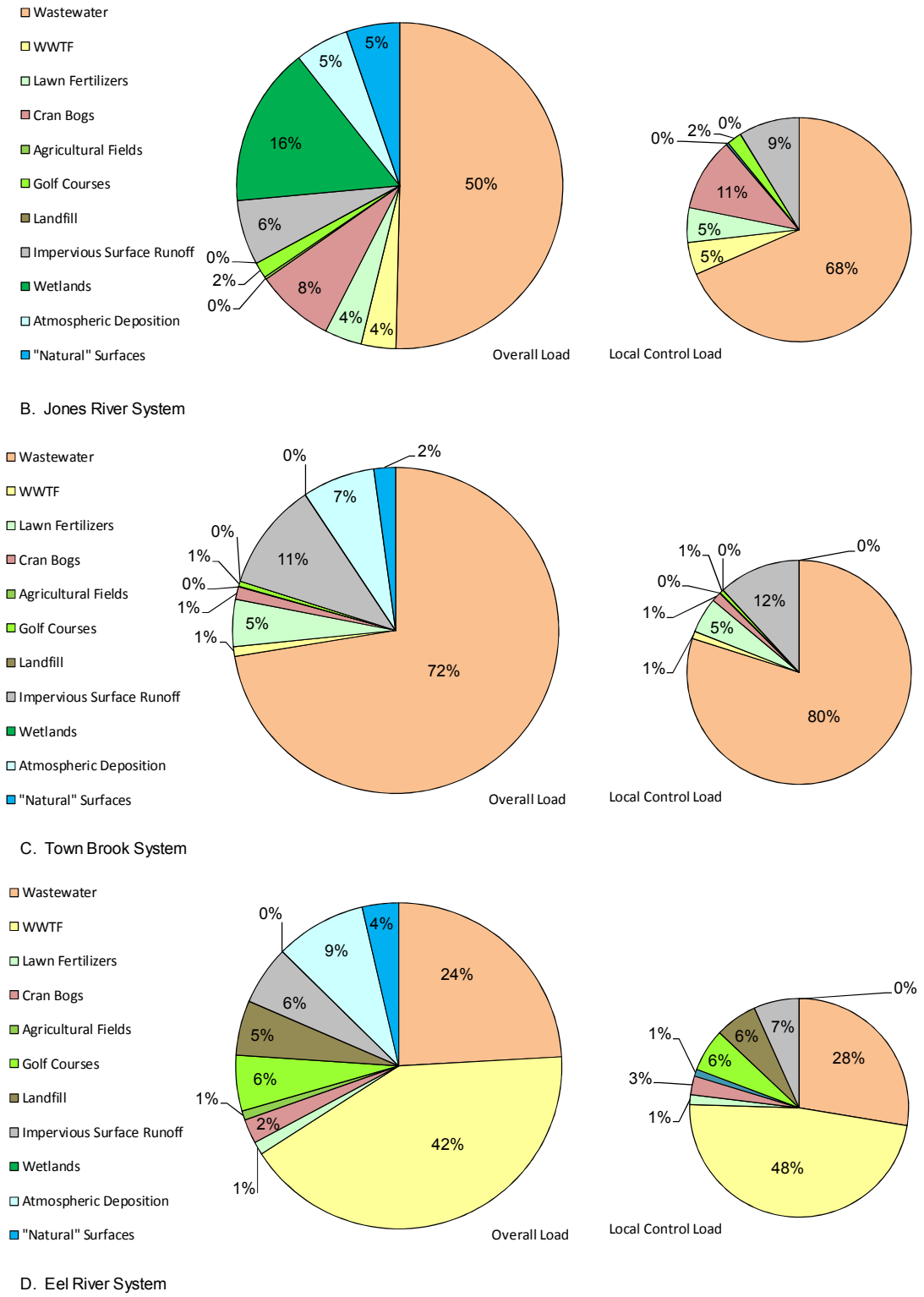


Figure 5 (continued): 5B, 5C, and 5D. Land use-specific unattenuated nitrogen loads (by percent) to the B) Jones River, C) Town Brook, and D) Eel River. "Overall Load" is the total nitrogen input within the watershed, while the "Local Control Load" represents only those nitrogen sources that could potentially be under local regulatory control. Atmospheric Deposition category includes inputs to both freshwater ponds and the estuary surface.

Figure 6. Developable Parcels in the Plymouth Harbor - Duxbury Bay - Kingston Bay Watershed. Parcels colored green are parcels with additional development potential based on current zoning. Developable parcels are based on town assessor classifications and minimum lot sizes specified in town zoning; these parcels are assigned estimated nitrogen loads in MEP buildout calculations. Details on additional development assigned to individual parcels are available in the MEP Data Disk that accompanies this report.

Table 1. Percentage of unattenuated nitrogen loads in less than ten year time-of-travel subwatersheds to Plymouth Harbor.

Shed #	Subwatershed Name	Less than 10 year Time-of-travel to Harbor	Greater than 10 year Time-of-travel to Harbor	Total	% LT10
		kg/yr	kg/yr	kg/yr	
1	Plymouth Harbor LT10	40,583		40,583	100%
2	Careswell Pond	594		594	100%
3	Duxbury Marsh	11,421		11,421	100%
4	North Hill Pond	910		910	100%
5	Bluefish River LT10	5,143		5,143	100%
6	Duxbury PWS3	345		345	100%
7	Duxbury PWS1	189		189	100%
8	Bluefish River GT10 N		753	753	0%
9	Island Creek Pond	786		786	100%
10	Duxbury PWS2	432		432	100%
11	Bluefish River GT10 S		922		0%
12	Bog Pond N	231		231	100%
13	Bog Pond S	866		866	100%
14	Upper Chandler Pond	522		522	100%
15	Hill Pond	514		514	100%
16	Lower Chandler Pond	3,004		3,004	100%
17	Halls Brook Reservoir	293		293	100%
18	Bracketts Pond	1,409		1,409	100%
19	Pembroke St South Pond	1,417		1,417	100%
20	Silver Lake	10,045		10,045	100%
21	Blackwater Pond	851		851	100%
22	Harrobs Corner Bog Pond	634		634	100%
23	Jones River USGS Gauge	23,345		23,345	100%
24	Muddy Pond	304		304	100%
25	Indian Pond	352		352	100%
26	Smelt Pond	498		498	100%
27	Little Smelt Pond	37		37	100%
28	Kingston PWS1	255		255	100%
29	Foundry Pond Stream	3,187		3,187	100%
30	Spooner Pond Stream LT10	2,078		2,078	100%
31	Plymouth PWS2	279		279	100%
32	Bay State Comp. Bog Res.	579		579	100%
33	Dennets Pond	189		189	100%
34	Jones River Gauge LT10	3,234		3,234	100%
35	Jones River Gauge GT10		1,179	1,179	100%
36	Triangle Pond	2,422		2,422	100%
37	Little Muddy Pond	212		212	100%
38	Crossman Pond	595		595	100%
39	Plymouth PWS1	1,660		1,660	100%
40	Kings Pond	1,101		1,101	100%
41	Spooner Pond Stream GT10		891	891	100%
42	Billington Sea LT10	12,659		12,659	100%

Table 1. Percentage of unattenuated nitrogen loads in less than ten year time-of-travel subwatersheds to Plymouth Harbor. (continued)

Shed #	Subwatershed Name	Less than 10 year Time-of-travel to Harbor	Greater than 10 year Time-of-travel to Harbor	Total	% LT10
		kg/yr	kg/yr	kg/yr	
43	Little Pond	1,314		1,314	100%
44	Town Brook Gauge	9,010		9,010	100%
45	Lout Pond	349		349	100%
46	4 Ponds	2,516		2,516	100%
47	Ellis Pond	335		335	100%
48	Little Micajah Pond	377		377	100%
49	Micajah Pond	1,085		1,085	100%
50	Plymouth PWSS3	547		547	100%
51	Briggs Reservoir	1,003		1,003	100%
52	Billington Sea GT10	6,017		6,017	100%
53	Eel River Gauge	8		8	100%
54	Eel River 3A	3,275		3,275	100%
55	Howland Pond	391		391	100%
56	Eel River Mid	293		293	100%
57	Forge Pond	184		184	100%
58	Eel River W	22,903		22,903	100%
59	Hayden Mill Pond	161		161	100%
60	Cold Bottom Pond LT10	102		102	100%
61	Russell Mill Pond	4,737		4,737	100%
62	Cold Bottom Pond GT10		324	324	0%
63	Eel River S	2,453		2,453	100%
64	WELL GC1	362		362	100%
65	Valley Road Pond	185		185	100%
66	WELL GC2	94		94	100%
67	Pine Road Pond	47		47	100%
68	WELL	216		216	100%
69	Cooks Pond	249		249	100%
70	South Triangle Pond	152		152	100%
71	Island Pond	399		399	100%
72	Little South Pond LT10	686		686	100%
73	Great South Pond LT10	1,513		1,513	100%
74	Great South Pond Inlet	67		67	100%
75	Boot/Ingalls Ponds LT10	649		649	100%
76	Gunners Exchange/Hoyt Ponds LT10	308		308	100%
77	Gunners Exchange/Hoyt Ponds GT10		19	19	0%
78	Little South Pond GT10		44	44	0%
79	Great South Pond GT10N		24	24	0%
80	Powderhorn Pond LT10	76		76	100%
81	Powderhorn Pond GT10		12	12	0%
82	Great South Pond GT10S		8	8	0%

Table 1. Percentage of unattenuated nitrogen loads in less than ten year time-of-travel subwatersheds to Plymouth Harbor. (continued)

Shed #	Subwatershed Name	Less than 10 year Time-of-travel to Harbor	Greater than 10 year Time-of-travel to Harbor	Total	% LT10
		kg/yr	kg/yr	kg/yr	
83	Little Widgeon Pond		52	52	0%
84	Widgeon Pond		136	136	0%
85	Boot/Ingalls Ponds GT10		179	179	0%
	TOTAL	189,218	10,562	199,780	95%

Table 2. Land Use information in Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Watershed. Categories show the year represented in digital data obtained from the towns. Collected information has been incorporated into a PDK watershed nitrogen loading model during this phase of this project utilizing GIS techniques.

Town	Parcels	Assessor's Land Use Classifications	Zoning	Parcel-by-parcel Water Use	Sewered Parcels
Duxbury	2010	2010	2010	2008 to 2010	2010
Halifax	2010	2010	unavailable[b]	unavailable[e]	No sewers
Kingston	2009	2009	2009	2008 to 2010	2009
Marshfield	2010	2010	2010	unavailable[e]	2010
Pembroke	2010[a]	2010	unavailable[d]	unavailable[e]	No sewers
Plymouth	2009	2009	2009	2008 to 2010	2009
Plympton	2009	2009	unavailable[c]	No public water	No sewers

Notes:

[a]Official Pembroke parcels were unavailable from town. Parcels in PDK watershed were digitized and created by MEP staff using town parcel maps.

[b]Town staff confirmed that current minimum parcel size for all zoning districts within the watershed is 40,000 sq. ft. No town GIS zoning coverage available.

[c] Town staff confirmed that current minimum parcel size for all zoning districts within the watershed is 60,000 sq. ft, except for retreat lots (120,000 sq ft minimum), which are listed in the assessor's data. No town GIS zoning coverage available.

[d] Town staff confirmed that current minimum parcel size for all zoning districts within the watershed is 40,000 sq. ft. No town GIS zoning coverage available..

[e]Towns were contacted for water use data, but it was not available. Water use for developed parcels was based on water used for similarly classified properties within the PDK watershed. Towns without parcel-based water use represent 10% of the PDK watershed area.

Table 3. Primary Nitrogen Loading Factors used in the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Estuarine System MEP analysis. General factors are from MEP modeling evaluation (Howes & Ramsey 2001). Site-specific factors are derived from Duxbury, Halifax, Kingston, Marshfield, Pembroke, Plymouth, and Plympton town data.

Nitrogen Concentrations:	mg/l
Road Run-off	1.5
Roof Run-off	0.75
Direct Precipitation on Embayments, Ponds, and wetlands in the Jones River watershed	1.09
Natural Area Recharge	0.072
Wastewater Coefficient	23.63

Recharge Rates:[2]	in/yr
Impervious Surfaces	44
Natural and Lawn Areas	27

Water Use/Wastewater (all in gpd): [3]	
Parcels wo/water use and buildout	
All others based on parcel-specific water use from town databases. Wastewater loads are corrected to remove any additions from parcels connected to municipal sewers.	
Single-family residential parcels	213
Multi-family residential parcels	371
Commercial parcels	548
Industrial parcels	911
Nitrogen loads for the 11 wastewater treatment facilities within the watershed are based on MassDEP compliance monitoring data from 2006-2010.	

Fertilizers:	
Average Residential Lawn Size (sq ft)[1]	5,000
Residential Watershed Nitrogen Rate (lbs/lawn) [1]	1.08
Cranberry Bogs export – flow through (kg/ha/yr)	23.1
Cranberry Bogs export – non-flow through(kg/ha/yr)	6.95
Nitrogen fertilizer for golf courses determined based on site-specific turf areas and application information if available.	
Nitrogen fertilizer for farm fields based on standard MEP application rate of 5 kg/ha/yr for pasture/hay. All fields assumed to be for pasture/hay based on review of aerial photography.	

Building Area [4]	
Single-family residential parcels	1,720
Other residential parcels	2,288
Buildout commercial (% of lot)	17%
Buildout industrial (% of lot)	20%

Notes:

1) Data from MEP lawn study in Falmouth, Mashpee & Barnstable 2001.
2) Recharge based on USGS rate for Plymouth-Carver-Kingston-Duxbury Aquifer Model (Masterson, *et al.*, 2009) and precipitation is 1981-2010 average at Plymouth Airport (NOAA)
3) Based on Town of Plymouth 2008-2010 water use billing records
4) Based on averages within Town of Plymouth. Areas assigned to existing developed parcels without individual parcel footprint information in the town assessor's records. Percentages used for buildout estimates.
5) Based on averages with the Town of Plymouth

Table 4. Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Watershed Nitrogen Loads. Existing and buildout unattenuated and attenuated nitrogen loads are shown along with breakdowns in to component sources. Attenuated nitrogen loads are based on measured nitrogen loads and assigned attenuation factors for gauged streams (rows colored pink). Attenuated nitrogen loads also incorporate MEP standard 50% attenuation for all ponds with delineated watersheds. An expanded accounting of all attenuation rates and nitrogen loads within each of the 85 subwatersheds is included in the MEP Data Disk that accompanies this report. All nitrogen loads are kg N yr-1.

		Plymouth Harbor N Loads by Input (kg/y):												% of Pond Outflow	*Present N Loads*			*Buildout N Loads*		
Watershed Name	shed ID#	Wastewater	WWTF	Lawn Fertilizers	Cran Bogs	Agricultural Fields	Golf Courses	Landfill	Impervious Surface Runoff	Wetlands	Atmospheric Deposition	"Natural" Surfaces	Buildout		UnAtten N Load	Atten %	Atten N Load	UnAtten N Load	Atten %	Atten N Load
Plymouth Harbor Whole System		**113,543**	**20,048**	**8,783**	**6,773**	**555**	**4,379**	**2,471**	**18,711**	**7,946**	**61,694**	**7,798**	**42,118**		**252,700**		**200,958**	**294,818**		**233,659**
Plymouth Harbor LT10	1	29,663	1,013	2,989	521	15	-	-	5,061	-	48	1,273	8,835		40,583		40,583	49,418		49,418
Plymouth PWS2	31	160	-	34	-	-	-	-	81	-	-	3	89		279		279	368		368
Blackwater Pond	21	657	-	11	55	-	-	-	52	109	36	36	87		956		956	1,042		1,042
Bracketts Pond TOTAL	BP	1,167	-	92	14	26	-	-	167	6	97	90	643	100%	1,660		767	2,303		1,017
Duxbury Marsh TOTAL		8,440	80	707	653	-	252	-	1,088	-	158	637	3,417		12,015		12,015	15,431		15,431
Foundry Pond Stream TOTAL		1,806	134	192	57	-	-	46	1,148	-	569	328	2,016		4,281		3,786	6,297		5,753
Spooner Pond Stream TOTAL		1,817	-	234	-	-	-	-	673	-	92	153	1,657		2,969		2,969	4,626		4,626
Blue Fish River TOTAL		5,839	-	292	149	-	925	247	537	-	599	336	1,108		8,926		8,811	10,034		9,901
Jones River Gauge TOTAL		24,929	1,701	1,820	3,857	120	783	-	3,186	7,831	2,634	2,626	10,603		49,486		38,731	60,089	-	46,780
Town Brook Gauge TOTAL		29,414	388	1,898	503	30	206	-	4,371	-	2,923	873	9,209		40,606	16%	24,839	49,815	16%	30,777
Eel River TOTAL		9,649	16,732	514	963	364	2,212	2,177	2,347	-	3,615	1,443	4,455		40,018	30%	16,299	44,472	30%	17,622
Plymouth Harbor Estuary Surface											48,882				48,882		48,882	48,882		48,882
Duxbury Marsh Estuary Surface											2,040				2,040		2,040	2,040		2,040