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 1A (of 8)

Land Use Data Collection and Watershed Delineation

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 (CSP). 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-CSP proposed an overall strategy that could be funded in phases. The effort is a collaborative effort 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 three (3) summers to establish the nutrient-related water quality baseline necessary for habitat assessment and to conduct 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[1]];

[1] 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.

- 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 with sewer collection systems, 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 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 relates to the watershed and land use component of the MEP analysis. The effort includes the delineation of the watershed to the receiving waters of the estuarine system and the collection of land use information that is required to develop the watershed nitrogen loading model that will be developed in subsequent phases. Later tasks will also integrate and link this information and any subsequent refinements with the estuary water quality model.

The current project discussed in this report utilizes selected portions of the successfully completed, embayment-wide water quality monitoring program that established baseline summer nutrient related water quality and which will provide additional core components of the Massachusetts Estuaries Project (MEP) analysis of PDK Embayment System. All MEP

assessments require a minimum three (3) years baseline water quality monitoring survey (with a focus on summers) to support the estuary-specific assessment and modeling effort. The water quality monitoring program for PDK Embayment System was developed as a joint effort between the Towns of Kingston, Plymouth, and Duxbury and the SMAST Coastal Systems Program and was funded by a Massachusetts 604(b) Grant.[2] Two years of baseline water quality monitoring (2003 and 2004) were funded under the 604(b) grant with the third year (2005) collected and funded by the CSP-SMAST. The current project was undertaken to delineate the watersheds and subwatersheds to the PDK system and collect the core of the land use information necessary to construct the watershed nitrogen loading model. Construction of the watershed nitrogen loading model during the next phase will involve use of the information collected during this project.

II.1. Watershed Delineation

Delineation of the land area that contributes freshwater and nutrients to downgradient estuarine waters typically includes a characterization of the hydrogeology, stream flows, and regional water table configuration. The land adjacent to the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Embayment System contains a complex mix of geologic types, which creates a complicated hydrologic environment for watershed delineation. The land adjacent to Plymouth Harbor is generally composed of highly transmissive, glacially-derived sands and gravels with tills (silty gravel) near the hills of the southern boundary. However, in the northern portion of the watershed, just to the south of the Jones River, a transition to less-transmissive, stratified drift soils occurs.[3] For the purposes of delineating a watershed, this geologic transition means that in the northern stratified drift area, watershed boundaries tend to be determined by land surface topography and precipitation on land surfaces tends to generate more surface runoff than infiltration/recharge to the groundwater. In contrast, the highly-transmissive sands of the southern watershed areas are part of the Plymouth Carver Aquifer system, which similar to Cape Cod, has watersheds primarily defined by the topography of the water table[4] and where precipitation tends to result in recharge to the groundwater aquifer rather than surface runoff.

Both areas are addressed in the groundwater model developed by the United States Geological Survey (USGS) predominantly for the Plymouth Carver Aquifer (PCA).[5] This 2009 PCA groundwater model is a second-generation groundwater model, building on the results from a first-generation version that the USGS completed in 1992.[6] These groundwater modeling efforts were primarily conducted as part of drinking water supply investigations, but were also used to generate sophisticated recharge area delineations for the MEP. The updated, second-generation version expands the spatial coverage of the model and includes delineation of recharge areas to major streams, public water supply-drinking water wells, freshwater ponds, and the coastline

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[2] *Ibid*.

[3] 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.

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

[5] Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009.

[6] Hansen, B.P., and Lapham, W.W. 1992. Geohydrology and simulated groundwater flow, Plymouth-Carver aquifer, southeastern Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 90-4204, 69p.

(Figure 1). These recharge areas form the basis for the watershed and subwatershed boundaries used by the MEP Technical Team for the PDK embayment system.

As with all groundwater modeling efforts, modeled groundwater recharge area delineations usually need to be adjusted to better reflect the actual geometry of freshwater ponds, streams, and the estuary coastline. Groundwater models based on the USGS MODFLOW groundwater modeling code, like the Masterson and others (2009) PCA version, are developed as grids, which create blocky or saw-toothed representations of shorelines, coastlines and river geometry. MEP Technical Team corrected the recharge areas using USGS topographic quadrangles and aerial photographs to better reflect actual shoreline geometry; this is a standard step in all MEP analyses as discussed with the USGS modelers.

During the development of MEP watersheds, Technical Team members also compare modeled USGS streamflows to measured streamflow volumes collected as part of the MEP process. As part of the MEP effort, stream gauges are placed in each of the major streams discharging to an estuary. The freshwater flow and nitrogen loads collected at the gauges are used as a check on the watershed delineations and the measured flows and loads are incorporated into the estuary water quality model. As documented in Howes and Samimy (2005), surface fresh water inflows to the PDK embayment system were measured and water quality samples were collected just prior to discharge to estuarine waters at three locations shown in Figure 2. These locations are:

- Jones River at Rt. 3A, Monitoring Station PDH-16
- Town Brook at Rt. 3A, Monitoring Station PDH-17
- Eel River down-gradient at Plymouth Harbor, Monitoring Station PDH-18

Stage recorders were placed at each of these gauge locations and stage-discharge relationships (rating curves) determined. Water level data was recorded every ten (10) minutes and daily flow readings were developed and summed to create annual flows. As with all MEP analyses, tidal influence on stream stage (an issue at the Jones River and Eel River Monitoring Stations) was removed from the daily stages in order to determine accurate freshwater flows.

Another part of the regular MEP approach is to compare MEP-collected data to data available from other sources, including historic streamflow data collected by the USGS. USGS has established numerous long-term stream gauge locations, usually on larger streams in New England, and has often collected spot measurements at other smaller streams in the same general area. USGS data also occasionally have water quality data associated with their streamflow readings.

USGS readings often have a longer historic record than the MEP records, but the MEP measurements are collected at the time of estuary water quality data collection and are collected more frequently than USGS readings during that time. Therefore, the MEP streamflow readings are more appropriate for comparing to all the other estuary data[7] collected at the same time, as well for use in the development of an estuary water quality model. However, this distinction means that the MEP flows may be slightly different than the USGS long-term averages, so

[7] *e.g.,* surface water data, eelgrass assessments, sediment cores, benthic community, etc.

comparative analysis of USGS and MEP streamflow records is conducted to assess reasonable long-term average flow conditions. In addition, the MEP also usually collects data at streams where USGS has either not collected data or only collected periodic spot measurements. For example, in the PDK system the continuous MEP flow measurements collected between 2003 and 2005 at Town Brook are the most detailed flow dataset available; USGS collected a total of 20 instantaneous flow readings between 1968 and 2010. Overall, the density of data collection for a given estuary/watershed system under the MEP is generally more refined and detailed than any prior assessments and this is certainly the case for the PDK system.

The groundwater model provides another context for review of streamflows since the area of the recharge areas produced by the model are based on capture of 27 inches of annual recharge. In other words, the area times the recharge rate equals an average annual rate of flow (volume per time) and should reasonably balance with average measured streamflow. Because of this relationship between area and recharge, recharge capture areas for a public water supply wellfield should also balance with the annual volume of water pumped from that wellfield. Of course, flow at streams and pumping from wellfields will vary from year to year depending on how much precipitation falls. MEP staff evaluated collected readings and compared them to available historic data and USGS model calibration data, as well as developing an understanding of hydrologic conditions during the time readings were collected.

Table 1 shows the streamflows measured by both MEP and the USGS at the respective gauging locations, as well as the flows calculated from the subwatershed delineations derived from the USGS model. Figure 3 shows the spatial coverage of the MEP subwatersheds, with the outer boundary being the overall watershed to the PDK Embayment System. Table 2 shows the areas and calculated discharge for each of the 85 subwatersheds to the PDK system, including areas contributing to public water supplies, selected ponds, and stream gauge locations. It should be noted that these watersheds should be considered draft as they may be adjusted during the next phases of the MEP assessment and full comprehensive QA/QC of the linked model for the PDK estuary. 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 basins of the PDK estuary via groundwater.

In order to develop the streamflow estimates from the recharge areas, subwatershed flows to each of the gauge locations are summed. Groundwater flow from ponds to downgradient subwatersheds is determined by estimating the downgradient shoreline of each pond and dividing the watershed flow from the pond among each of the downgradient subwatersheds based on the percentage of downgradient shoreline bordering the downgradient subwatershed. For example, Great South Pond discharges pond water back to the aquifer and into four different downgradient subwatersheds: Russell Mill Pond, Cooks Pond, South Triangle Pond, and Little South Pond (see Figure 3). The total downgradient shoreline from Great South Pond is 7,218 ft. and its discharge is apportioned to the downgradient pond subwatersheds by the length of shoreline: 4,262 ft. (59%) to Russell Mill Pond, 1,335 ft. (18%) to South Triangle Pond, 1,293 ft. (18%) to Cooks Pond, and 328 ft. (5%) to Little South Pond.

The MEP watershed modeled flows, MEP measured flows and the USGS measured flows generally agree (Table 1). The average MEP measured flow at the Eel River in 2003 to 2005 is within 2% of the average USGS measured flow. In addition, the MEP estimated flow based on the watershed recharge area is essentially the same as the average MEP measured flow. It is notable that the most recent USGS monitoring of the Eel River (2006-2009) has a 16% higher average flow at the Eel River gauge than the 1969-1971 average used in the calibration of the USGS regional groundwater model. It is also notable that MEP readings were collected in 2003-2005, a time period when the USGS was not monitoring the river. The coefficient of variation for daily flow in the older USGS time period is 20%, which is indicative of some moderate variability in flow; MEP stage readings indicate regular peaks in measured flow that would be consistent with this variation.[8]

Table 1. Comparison of MEP and USGS Measured Streamflows and MEP Watershed Flows at Gauge Locations in the Plymouth Harbor Watershed

Gauge Location	MEP Gauge	MEP Measured Flow - Mean[a]	MEP Watershed Flow[b]	USGS Measured Flow[c] - Mean	USGS Measured Flow – Standard Deviation	USGS data points	USGS Measuring Period
		m3/d	m3/d	m3/d	m3/d	n	Years
Jones River	PDH-16	103,642	114,497	86,161[d]	77,673	16,088	1966-2010
Town Brook	PDH-17	52,939	47,136	Regular measurements not collected			
Eel River	PDH-18	68,893	69,036	67,741	13,542	651	1969-1971
Eel River				78,914	19,155	1,173	2006-2009

Notes:
[a]measured flows from MEP monitoring 2003-2005 (Howes, B. and R. Samimy. 2005.)
[b]estimated flow based on recharge of 27 inches/yr and MEP-refined versions of USGS modeled contributing areas (Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009.)
[c]USGS data from http://waterdata.usgs.gov/nwis/
[d]USGS Jones River gauge location is approximately 0.6 miles upstream of the MEP gauge and is expected to have a lower flow

Flow at the Jones River MEP station indicates significantly more variability between the MEP and USGS average measured flows, but this appears to be reasonable given the variability of flow in the river and the difference in gauge locations. The USGS gauge is ~0.6 miles upstream of the MEP gauge. The result is that the USGS gauge captures flow from less of the watershed than the MEP gauge, which accounts for a significant portion of the difference in observed flow. The USGS historic daily flow readings have been collected daily since 1966 and they have an extremely high variability (coefficient of variation = 90%).[9] This variability is also seen in the MEP stage readings where peak flows occur rapidly during storms, but only slowly decrease back to baseflow conditions, often taking weeks to attain pre-storm flows.[10] The gauge records are not

[8] Howes, B. and R. Samimy. 2005.

[9] Automated-retrieval info: http://waterdata.usgs.gov/nwis/?automated_retrieval_info for USGS 01105870 JONES RIVER AT KINGSTON, MA

[10] Howes, B. and R. Samimy. 2005.

Table 2. MEP Draft Subwatersheds for Plymouth Harbor (Area and Recharge)			
Shed #	Subwatershed Name	Area_m2	Recharge m3/d
1	Plymouth Harbor LT10	32,685,111	61,412
2	Careswell Pond	793,459	1,491
3	Duxbury Marsh	14,296,498	26,862
4	North Hill Pond	1,539,210	2,892
5	Bluefish River LT10	3,615,225	6,793
6	Duxbury PWS3	707,053	1,328
7	Duxbury PWS1	168,196	316
8	Bluefish River GT10 N	944,184	1,774
9	Island Creek Pond	1,636,656	3,075
10	Duxbury PWS2	327,127	615
11	Bluefish River GT10 S	627,474	1,179
12	Bog Pond N	666,056	1,251
13	Bog Pond S	1,569,064	2,948
14	Upper Chandler Pond	722,537	1,358
15	Hill Pond	538,212	1,011
16	Lower Chandler Pond	2,861,173	5,376
17	Halls Brook Reservoir	410,621	772
18	Bracketts Pond	1,833,676	3,445
19	Pembroke St South Pond	2,376,731	4,466
20	Silver Lake	12,401,876	23,302
21	Blackwater Pond	930,069	1,748
22	Harrobs Corner Bog Pond	1,203,142	2,261
23	Jones River USGS Gauge	31,692,345	59,547
24	Muddy Pond	1,213,613	2,280
25	Indian Pond	566,546	1,064
26	Smelt Pond	1,708,166	3,209
27	Little Smelt Pond	265,376	499
28	Kingston PWS1	1,201,106	2,257
29	Foundry Pond Stream	3,766,110	7,076
30	Spooner Pond Stream LT10	2,551,138	4,793
31	Plymouth PWS2	159,309	299
32	Bay State Comp. Bog Reservoir	1,589,658	2,987
33	Dennets Pond	336,489	632
34	Jones River Gauge LT10	2,756,266	5,179
35	Jones River Gauge GT10	1,202,285	2,259
36	Triangle Pond	1,242,667	2,335
37	Little Muddy Pond	206,884	389
38	Crossman Pond	388,667	730
39	Plymouth PWS1	1,540,113	2,894
40	Kings Pond	390,775	734
41	Spooner Pond Stream GT10	1,340,999	2,520
42	Billington Sea LT10	8,285,637	15,568
43	Little Pond	699,955	1,315
44	Town Brook Gauge	5,665,219	10,644
45	Lout Pond	477,151	897

Table 2. MEP Draft Subwatersheds for Plymouth Harbor (Area and Recharge) (continued)			
Shed #	Subwatershed Name	Area_m2	Recharge m3/d
46	4 Ponds	1,887,187	3,546
47	Ellis Pond	363,808	684
48	Little Micajah Pond	207,433	390
49	Micajah Pond	457,620	860
50	Plymouth PWSS3	740,311	1,391
51	Briggs Reservoir	957,101	1,798
52	Billington Sea GT10	2,356,045	4,427
53	Eel River Gauge	26,089	49
54	Eel River 3A	3,850,453	7,235
55	Howland Pond	625,034	1,174
56	Eel River Mid	890,910	1,674
57	Forge Pond	442,306	831
58	Eel River W	6,255,864	11,754
59	Hayden Mill Pond	279,438	525
60	Cold Bottom Pond LT10	431,566	811
61	Russell Mill Pond	6,814,848	12,804
62	Cold Bottom Pond GT10	433,577	815
63	Eel River S	4,265,013	8,014
64	WELL GC1	180,709	340
65	Valley Road Pond	254,139	478
66	WELL GC2	121,476	228
67	Pine Road Pond	159,804	300
68	WELL	461,671	867
69	Cooks Pond	682,789	1,283
70	South Triangle Pond	244,185	459
71	Island Pond	243,655	458
72	Little South Pond LT10	1,183,501	2,224
73	Great South Pond LT10	2,048,404	3,849
74	Great South Pond Inlet	83,887	158
75	Boot/Ingalls Ponds LT10	1,670,030	3,138
76	Gunners Exchange/Hoyt Ponds LT10	553,833	1,041
77	Gunners Exchange/Hoyt Ponds GT10	389,247	731
78	Little South Pond GT10	855,157	1,607
79	Great South Pond GT10N	447,657	841
80	Powderhorn Pond LT10	284,549	535
81	Powderhorn Pond GT10	243,106	457
82	Great South Pond GT10S	118,779	223
83	Little Widgeon Pond	222,030	417
84	Widgeon Pond	302,420	568
85	Boot/Ingalls Ponds GT10	1,676,475	3,150
	TOTAL[a]	195,811,934	367,912

Note:
[a] Total recharge flow to Plymouth Harbor may be less than the sum of these subwatersheds due to splitting of selected boundary subwatersheds and subsequent flow out of the system.

significantly different ($\rho<0.05$), with the MEP mean well within one standard deviation of the USGS mean. Overall, given the flow variability at each of the gauge locations and the differences in gauge placement, the MEP watershed estimated flows for the Jones River and the Eel River are reasonable and provide a reasonable match for the MEP and USGS streamflow readings.

II.2. Watershed Nitrogen Loading Information Collection and Development

Once the MEP watershed is delineated, technical staff must assemble and integrate the variety of land use and nitrogen source databases and appropriate field studies needed to develop a watershed nitrogen loading model. MEP watershed nitrogen loading model construction begins by accounting for each individual parcel of land within the watershed. Having the model based on individual parcels allows nitrogen loading information to be added into the watershed at the correct locations and provides a common-sense framework for the comparison to other collected data. It also provides a reasonable basis for future evaluation of management scenarios ('what if" scenarios) such as sewer collection areas ("sewersheds"), development of green infrastructure and enhancements of natural nitrogen reduction/attenuation, and spatially consistent evaluation of other watershed restoration projects, such as pond restorations, or other changes in the watershed.

Aside from parcel data, additional databases typically included in the MEP watershed nitrogen loading model include: town assessor's land use classifications, town zoning, and public water supplier water use. In addition, MEP staff incorporate additional source data pertinent to determining accurate watershed nitrogen loads, including monitoring data from municipal and private landfills and other solid waste disposal sites, wastewater treatment facilities with state Ground Water Discharge Permits or Ocean Outfalls, alternative nitrogen-reducing septic systems, available fertilizer application information from golf courses and athletic fields, and agricultural fertilizer applications and farm animal counts. Because data for each of these non-point sources is sometimes not comprehensive across a given watershed, conservative assumptions may have to be developed for some locations; assumptions are usually based on previous MEP assessments and often involve insights and estimates developed by town staff. The following sections discuss the assembled information associated with the MEP development of the watershed nitrogen loading model for the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Embayment System.

II.2.a. Land Use and Parcel Information

The PDK watershed is comprised of land areas within seven towns (Figure 4):

- Duxbury (20% of the watershed)
- Halifax (1% of the watershed)
- Kingston (24% of the watershed)
- Marshfield (2% of the watershed)
- Pembroke (7% of the watershed)
- Plymouth (39% of the watershed)
- Plympton (7% of the watershed)

However, the portion of each town within the watershed varies widely, 94% of the Town of Kingston is within the watershed, but accounts for only 24% of the PDK watershed area. Other

watershed percentages for the towns in the PDK watershed are: Duxbury, 67% of the town is in the PDK watershed; Plympton, 36%; Plymouth, 29%; Pembroke, 22%; Marshfield, 5%; and Halifax, 5% (Figure 5).

In order to complete the development of a parcel-based PDK watershed nitrogen loading model, spatial parcel boundaries need to be incorporated into a Geographic Information System (GIS). The GIS environment provides a common frame of spatial reference and ensures that additional spatial information, such as shorelines or roads, is in correct locations. Once parcels are in a GIS environment, information about each parcel such as assessor's records, which includes land use classifications and house size, can be linked to the individual parcels.

MEP Technical Team contacted each of the seven towns in the PDK watershed to gather, organize, and evaluate available data. As the PDK project progressed, the MEP Technical Team found that suitable GIS parcel information is currently available for only six of the seven towns in the PDK watershed: Marshfield, Duxbury, Plympton, Kingston, Halifax, and Plymouth, but not Pembroke.

The Towns of Marshfield[11], Duxbury[12], and Halifax[13] provided 2010 town parcel and assessors data (Table 3). The Towns of Plympton[14], Plymouth[15], and Kingston[16] provided 2009 town parcel and assessors data. The linked parcels and assessor's data for the portions of each of these towns in the PDK watershed are included in the MEP PDK database completed for this project.

The Town of Pembroke does not have geo-referenced, GIS parcels available. To advance the land use effort, MEP Project Staff purchased the 2010 Town of Pembroke assessor's database. Through discussions with town staff, project found that the town maintains digital pictures (jpegs) of assessor's maps. Pictures of the assessor's maps for areas within the PDK watershed were purchased and MEP staff created GIS parcels by bringing the parcel lines from the digital pictures into a geo-referenced, GIS environment. These parcels were then linked to the assessor's data by assigning parcel numbers. The method used to create these parcels means they can be properly used for the MEP watershed nitrogen loading assessment, but should not be used for property assessments or any other associated tasks.

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[11] personal communication, Ron Menard, Information Technology Department, Town of Marshfield

[12] personal communication, Mary Beth MacQuarrie, Information Systems Administrator, Town of Duxbury

[13] personal communication, Suzan Duggan, Principal Assessor, Town of Halifax

[14] personal communication, Steve Dunn, Town Assessor, Town of Plympton

[15] personal communication, George Dunbar, GIS Coordinator/Application Manager, Town of Plymouth

[16] personal communication, Maureen Thomas/Tom Bott, Town of Kingston. Kingston parcels and assessor's data were obtained separately and linked by Patrick Farah of the Town of Plymouth staff.

Table 3. Status of Land Use information in Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Watershed. Categories show the year represented in data obtained from the towns. Collected information will be incorporated into a watershed nitrogen loading model for the PDK Embayment System in the next phase of this project (Task 1b).

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	2010[b]	Town contacted[e]	No sewers
Kingston	2009	2009	2009	2008 to 2010	2009
Marshfield	2010	2010	2010	Town contacted[e]	2010
Pembroke	2010[a]	2010	2010[d]	Town contacted[e]	No sewers
Plymouth	2009	2009	2009	2008 to 2010	2009
Plympton	2009	2009	2009[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]Halifax is in the midst of updating parcels and zoning GIS; while parcels were available, only currently available GIS zoning is a MassGIS version; town staff confirmed that current minimum parcel size for all zoning districts is 40,000 sq. ft.

[c]Plympton does not have GIS zoning; only current available GIS zoning is MassGIS version; town staff confirm that all zoning districts have a current minimum lot size of 60,000 sq. ft. with exception of retreat lots, which are listed in the assessor's data and are required to have 120,000 sq. ft.

[d]Pembroke does not have GIS zoning; only current available GIS zoning is MassGIS version; an updated map of 2010 zoning is included in the most current town zoning bylaws and shows that the entire area of the town within the PDK watershed is in the Residential A zone, which has a 40,000 sq. ft. minimum lot size.

[e]Towns have been contacted for water use data, but it has not been received. If parcel-by-parcel water use is not received for watershed nitrogen loading model development during the next phase, town-specific water use estimates will be developed based on occupancy and water use information in the other towns in the PDK watershed. Towns currently without parcel-based water use represent 10% of the PDK watershed area.

II.2.b. Zoning information and Buildout

MEP watershed analysis includes an assessment of the impact of nitrogen loading from full development (or buildout) of all parcels within the watershed. In order to develop this nitrogen loading scenario, MEP staff prepare a simplified buildout assessment (or scenario) of potential development within the study area watershed based on current town zoning regulations.

The buildout procedure typically completed by MEP staff evaluates town zoning bylaws to determine minimum lot sizes in each of the zoning districts, including overlay districts (*e.g.*, water resource protection districts) and land use classifications of properties assigned by town assessors. Larger lots classified as developable are subdivided by the minimum lot sizes specified in zoning to determine the total number of new lots. In addition, large existing developed properties are also reviewed for any additional development potential; for example, residential lots that are twice the minimum lot size, but have only one current residence, are assumed to have one additional residence at buildout.

Most of the focus of the buildout assessment, however, is on properties classified as developable by the town assessor. For example, properties that are assigned state class land use codes 130 and 131 are classified by the town assessor as developable residential properties.[17] Town assessors assign similar commercial and industrial properties that are developable. Properties classified by a town assessor as "undevelopable" (*e.g.*, codes 132 and 392) are not assigned any development in MEP buildout assessments. Although commercial and industrial properties with development potential are identified, the buildout nitrogen loads for these properties in the watershed nitrogen loading model will be based on nitrogen loading associated with similar properties in the watershed, rather than subdividing these into numbers of units. Buildout nitrogen loads for all properties will be determined during the next phase of the PDK MEP watershed assessment.

MEP staff identified the town zoning districts and minimum lot size for parcels within the PDK watershed. Zoning is based on information from each of the towns; the year of the zoning for each town is listed in Table 3. Staff then reviewed the most recent, available town zoning bylaws to identify the minimum lot sizes within each district; adjustments were made for minimum lot sizes in overlay zones, such as water resource protection areas. Given the high proportion of wetland areas in the PDK watershed, staff also excluded wetland areas, as identified from a MassDEP GIS coverage.[18] Once the wetland areas were excluded, the remaining lot area of each parcel was subdivided by the minimum lot size specified in the zoning bylaws. Parcels classified as undevelopable, Agricultural/Horticultural (700 land use codes), Recreational Land (800 land use codes), and Exempt (900 land use codes) were not subdivided or assigned any additional development. Parcels classified as Forest Land (600 land use codes), which tend to be properties with "current use" tax designations were treated as developable. Properties identified as having conservation restrictions in the town assessors' databases were not assigned any additional development. Table 4 summarizes the results from the buildout assessment, as well town-specific factors used in completing the buildout.

The MEP buildout approach does not include other, more detailed provisions of zoning, such as setbacks, frontage or lot configurations calculations. As noted, this buildout approach is relatively simple, but appropriate as a first step to assess the potential future impacts of watershed development on the PDK estuary. More refined buildout projections have been completed by towns and their water quality impacts have been assessed in MEP scenarios once the completed MEP linked watershed-estuary model is calibrated and validated.

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[17] Massachusetts Department of Revenue. June, 2009. Property Type Classification Codes, Non-arms Length Codes and Sales Report Spreadsheet Specifications. Prepared by the Bureau of Local Assessment.

[18] DEP Wetlands (1:12,000) - January 2009. Available at: http://www.mass.gov/mgis/wetdep.htm

Table 4. Buildout within the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Watershed. Buildout estimates based on current zoning bylaw minimum lot sizes and town assessor's land use classifications within the PDK watershed. Buildout includes developable lots and developed lots with areas more than twice as large as minimum lot sizes. Lot areas were also adjusted by removing DEP wetland areas. Zoning categories listed for each town are only those within the PDK watershed. Buildout estimates are based exclusively on minimum lot sizes and do not include frontage, lot configuration, or other zoning bylaw requirements. Buildout results will be incorporated into a watershed nitrogen loading model for the PDK Embayment System during the next phase of this project (Task 1b).

Town	Minimum Lot Sizes in Zoning/Overlays Districts in PDK watershed (sq. ft.)[a]	New Residential Units[b]	New Commercial Parcel Area[c] (sq. ft.)	New Industrial Parcel Area[c] (sq. ft.)
Duxbury	15,000; 40,000; 60,000	945	1,128,324	167,703
Halifax	40,000[d]	1	1,205,690	44,521
Kingston	10,000; 20,000; 30,000; 40,000; 80,000	1,139	2,346,870	8,789,838
Marshfield	10,000; 20,000; 43,560	391	0	0
Pembroke	40,000[e]	217	0	0
Plymouth	20,000; 25,000; 30,000; 35,000; 40,000; 55,000; 120,000	137	10,773,260	3,851,737
Plympton	60,000; 120,000	408	0	7,852,520

Notes:

[a] Details of town zoning districts are included in Appendix A.

[b] New residential unit estimates are based on individual parcel areas divided by minimum lot areas specified in town zoning bylaws. Individual parcel areas have been reduced by subtracting wetland areas. Residential parcels include both undeveloped lots classified as developable by the respective town assessors, as well as additional development on developed lots with area greater than minimum lot areas specified in zoning. Wastewater nitrogen loading estimates for these properties, which will be developed under the next phase of this project (Task 1b), will be based on number of units.

[c] New commercial and industrial areas are based on minimum lot areas specified in town zoning bylaws. New parcel areas are based on both undeveloped lots classified as developable by the respective town assessors, as well as additional development on developed lots with area greater than minimum lot areas specified in zoning. Wastewater nitrogen loading estimates for these properties, which will be developed under the next phase of this project (Task 1b), will be based on the square footage of each parcel.

[d] All zoning districts in the Town of Halifax utilize 40,000 square feet as a minimum lot area..

[e] All of the portion of Pembroke that is within the PDK watershed is within the Residence District A zone, which has a 40,000 sq. ft. minimum lot size.

II.2.c. Wastewater Nitrogen Loads

Wastewater is generally the predominant source (>70%) of nitrogen within estuarine watersheds in southeastern Massachusetts. In order to develop wastewater nitrogen loads, MEP watershed nitrogen loading assessments typically include parcel-by-parcel water use data, identification of properties connected to municipal sewers, and performance data from wastewater treatment facilities. Most watersheds do not have all of this information available and estimates from measurements of these sources within the region must be used. This section discusses the

specific sources of data that have been collected and will be used during the next phase to determine wastewater nitrogen loading in the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) watershed.

In MEP assessments, wastewater generation is typically derived from parcel-specific water use. This approach has the advantage of automatically adjusting for seasonal population changes and provides reasonable estimates of current populations. MEP staff strive to obtain a number of years of water use data to smooth out year to year precipitation influences (*e.g.*, higher water use due to irrigation in dry years). The resulting average water use is then linked to the parcel data, after validation using data from wastewater flows and/or population data within the watershed. The water use is adjusted in the MEP watershed nitrogen loading model to account for consumptive use and allow water use to be a reasonable proxy for wastewater generation.

In the PDK watershed, MEP staff contacted town staff in each town to assess whether public water was available in the town and, if so, whether the data could be obtained for the PDK assessment. MEP staff have obtained three years of public water use data from the towns of Duxbury, Kingston and Plymouth (see Table 3). The Town of Plympton does not have public water supplies and relies on private, on-site wells and septic systems. The available water use data has been linked to the parcel/assessors database for these towns and will be used for parcel-by-parcel wastewater estimates during the development of the PDK watershed nitrogen loading model during the next phase.

MEP staff have also contacted water suppliers in the towns of Marshfield, Pembroke and Halifax, but water use for these portions of the PDK watershed is not presently available.. If this information becomes available prior to the development of the watershed nitrogen loading model, it will be linked to the respective parcels. If it is not available, project staff will review occupancy information to develop water use estimates for parcels in these towns. These three towns collectively occupy 10% of the PDK watershed, so wastewater loading developed during the next phase will predominately be based on individual parcel information.

MEP also contacted town staff to obtain parcel-by-parcel listings or GIS coverages of properties connected to municipal sewers. Sewer service areas collect wastewater, bring it to a wastewater treatment facility (WWTF) where the nitrogen concentration is reduced, and treated effluent from the facility is discharged with a lower nitrogen load at a different location than where it was collected. Understanding this treatment and redistribution of wastewater nitrogen is important for proper watershed nitrogen loading modeling.

The towns of Plymouth, Marshfield, Duxbury, and Kingston have municipal sewer service areas within the PDK watershed. Town staff were contacted and GIS coverages or parcel lists of sewered properties were obtained and the information was linked to the GIS parcel coverages. During the next phase, MEP staff will incorporate this information into the watershed nitrogen loading model and reconcile water use at the sewered properties and the flow at the WWTFs.

In order to determine loading from WWTFs in the PDK watershed, MEP staff also obtained discharge flow and concentration data from each municipal and private WWTF. WWTFs with design flows greater than 10,000 gallons per day are required to have a state Ground Water

Discharge Permit (GWDP). GWDPs require regular reporting of treatment performance and discharge volumes to the Massachusetts Department of Environmental Protection (MassDEP). Based on MassDEP records, there are 11 WWTFs with GWDPs within the PDK watershed (Table 5). Additional details about these WWTFs, including their performance, discharge locations, and likely effluent groundwater plumes, will be incorporated into the development of the PDK watershed nitrogen loading model during the next phase.

Table 5. Wastewater Treatment Facilities with MassDEP Ground Water Discharge Permits and associated flow and nitrogen concentration data that currently operate within the Plymouth Harbor MEP Watershed

DEP Facility #	Town	Description	Monitoring Data			Mean Flow (gpd)	Permit Flow (gpd)
			Beginning Yr	End Yr	Frequency		
500	Duxbury	Duxbury School Complex	2006	2009	Monthly	9,530	30,500
433	Duxbury	Villages at Duxbury	2006	2009	Monthly	34,502	54,000
191	Kingston	Town & Country Mobile Home	2006	2009	Monthly	17,671	31,400
394	Kingston	Silver Lake Regional HS	2006	2009	Monthly	5,985	30,000
417	Kingston	Independence Mall	2006	2009	Monthly	19,873	90,000
462	Kingston	Evanswood	2006	2009	Monthly	18,122	65,000
494	Kingston	Summer Hill Plaza	2006	2008	Monthly	7,331	10,000
659	Kingston	Kingston WWTF	2006	2009	Monthly	240,855	907,000
226	Plymouth	Summer Hill Condo	2006	2009	Monthly	23,037	48,970
665	Plymouth	Sunrise Assisted Living	2006	2009	Monthly	5,115	13,500
677	Plymouth	Town of Plymouth WWTF	2006	2009	Monthly	1,670,260	3,450,000

Note: all flow information supplied by MassDEP (personal communication, Brian Dudley, SERO, April 2010)

II.2.e. Fertilizers: Lawns, Golf Courses, Agriculture, and Athletic Fields

Fertilizers are typically the second largest source of nitrogen from estuary watersheds in southeastern Massachusetts. The MEP watershed analysis typically uses nitrogen loading factors derived from studies in the region to estimate residential lawn fertilizer nitrogen loads and supplements this information with site-specific fertilizer application information for sites where this information is generally readily available, including application data from golf courses, athletic fields, and agricultural uses.

During this phase, MEP staff identified eight golf courses within the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) watershed (Table 6). Project staff contacted staff at each of the eight golf courses, but were provided course-specific fertilizer use information from only two of the courses: Plymouth Country Club[19] and Old Sandwich Golf Club.[20] At the Plymouth Country

[19] W. Weldon, personal communication, December 1, 2009

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, while the following rates were reported for Old Sandwich Golf Club: greens, 2.5; tees, 3.75; fairways, 2.25, and rough, 2.25.

Golf courses typically have different fertilizer application rates for different turf areas, usually higher annual application rates for tees and greens (~3-4 pounds per 1,000 square feet) and lower rates for fairways and roughs (~2-3.5 pounds per 1,000 square feet). MEP staff continues to seek comparable information from the remaining courses for inclusion in the PDK watershed nitrogen loading model, but has application rates from the more than 17 golf courses in southeastern Massachusetts and will use the average nitrogen application rates if course-specific information cannot be obtained. Additional work to be completed during the next phase of the project will be digitizing various course turf areas based on aerial photographs, development of nitrogen loads and apportionment of loads to appropriate subwatersheds.

Table 6. Golf Courses in the Plymouth Harbor - Duxbury Bay - Kingston Bay MEP Watershed. All courses have been contacted by MEP staff and Town of Plymouth staff and asked to provide site-specific nitrogen fertilizer application data. To date, average application information has been obtained from Plymouth Country Club and Old Sandwich Golf Club. If site-specific data cannot be obtained prior to the development of the PDK watershed nitrogen loading model during the next phase of this project, MEP staff will rely on average application data developed from other courses in southeastern Massachusetts.

Golf Course	# of holes	Town
Squirrel Run Golf & Country Club	18	Plymouth
The Crosswinds Golf Club	27	Plymouth
Waverly Oaks Golf Club	36	Plymouth
Old Sandwich Golf Club	18	Plymouth
Plymouth Country Club	18	Plymouth
Indian Pond Country Club	18	Kingston
Duxbury Yacht Club	18	Duxbury
North Hill Country Club	18	Duxbury

MEP staff also worked with MassDEP and local US Department of Agriculture staff to identify reliable information about the area of cranberry bogs within the PDK watershed. Following numerous discussions, staff obtained a GIS coverage from MassDEP that is maintained for Water Management Act permitting; this coverage identifies the active area of each cranberry bog. MEP staff have also worked closely with UMASS Cranberry Station staff to determine reasonable estimates of nitrogen export from different types of cranberry bogs operating within the region of the Plymouth-Carver aquifer from multi-year studies of functioning bog systems.[21] During the next phase, MEP staff will work with USDA and UMass Cranberry Station staff to identify bog-specific nitrogen loads and their apportionment to specific-subwatersheds based on site-specific bog characteristics. Next phases of the project will also involve further interviews with town

[20] S. McCormick, personal communication, January 6, 2010

[21] Personal communication, Carolyn DeMoranville, Station Director, UMass Cranberry Station

staff to identify other agricultural fertilizer uses, fertilized athletic fields and local contacts for applicator information.

II.2.f. Other watershed nitrogen sources: Landfills and Farm Animals

Often within a given estuary watershed, there are other site-specific sources of nitrogen, such as landfills, farms, and composting sites, that are important for understanding water quality measured in the estuary and streams and for development of appropriate management strategies. Identifying all these sites typically involves interviews with local experts (*e.g*. town planners, health agents, conservation agents, regional planning agency staff) and subsequent collection of pertinent information for the development of site-specific nitrogen loads. Once the loads are developed, they are incorporated into the MEP watershed nitrogen loading model at the site of the loading. In the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) watershed, project staff continue to focus on identifying remaining sources, although nitrogen loading information has been captured and evaluated on the primary sources.

Landfills are often a source of nitrogen within estuary watersheds. To date, project staff have identified six solid waste facilities within the PDK watershed. Staff has obtained available water quality monitoring data for three of these sites, but the other three do not have monitoring data available through MassDEP (Table 7). Additional site-specific information, including manure handling for farm animals, will be evaluated during the next phase of this project.

Table 7. Solid Waste Sites in the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Watershed. Sites are based on MassDEP regulated sites database. Water quality monitoring data is available through MassDEP for three of the six sites.

DEP ID	Permit Category	SITE_NAME	ADDRESS	TOWN	Current Groundwater Monitoring Data?
SL0082.001	Landfill	DUXBURY LANDFILL	MAYFLOWER ST	DUXBURY	Yes
EP0082.005	none	UNCONFIRMED SITE	TREMONT ST	DUXBURY	No
SL0145.001	Landfill	KINGSTON LANDFILL	CRANBERRY RD	KINGSTON	Yes
DL0231.003	Landfill	JOHN HILL DEMOLITION DUMP	SCHOOL ST/RTE 27	PEMBROKE	No
SL0239.009	Landfill	PLYMOUTH SOUTH STREET LANDFILL	SOUTH ST	PLYMOUTH	Yes
SL0240.001	Landfill	CAL'S ENTERPRISES - LANDFILL	RING RD	PLYMPTON	No

Note: all monitoring information supplied by MassDEP (personal communication, Mark Dakers, SERO, September 2010); identification of solid waste sites based on MassGIS coverage of DEP landfills/SW facilities, coverage dated 12/07

II.2.g. Watershed nitrogen sinks: Pond and stream monitoring data

A fundamental feature of MEP watershed assessments is the incorporation of nitrogen removal by natural systems during transport from source to estuarine waters. Nitrogen removal typically occurs as part of the natural cycling of nitrogen in surface water bodies such as streams, ponds and wetlands. Nitrogen is incorporated into the nitrogen cycle of these systems and as a result a portion is either denitrified and released to the atmosphere or permanently buried in the sediments. MEP staff gather available data that can support site-specific attenuation estimates for incorporation into watershed nitrogen loading model. This data is in addition to that collected by the MEP specifically for this purpose on "major" streams that have potentially significant attenuation rates. Ultimately, these efforts allow management strategies to target nitrogen sources that actually reach the estuary rather than treating all watershed sources equally.

Part of the objective in the 2005 MEP monitoring on the streams within the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) watershed was to adequately document the nitrogen removal in these monitored streams which capture nitrogen from a large portion of the overall watershed.[22] Nitrogen attenuation in the majority of freshwater streams evaluated during the course of the MEP analysis of over 50 estuaries typically range between 20% and 40%. Determination of the nitrogen attenuation in Eel River, Jones River, and Town Brook will occur during the development of watershed nitrogen loads during the next phase of the project.

The next phase of the project will also involve mining local knowledge regarding any available water quality monitoring for any of the 45 freshwater ponds with subwatersheds within the PDK watershed. MEP analyses typically assign a 50% nitrogen attenuation rate within pond watersheds unless more refined monitoring is available. Refined monitoring typically includes comprehensive water quality monitoring including dissolved oxygen and temperature profiles and total nitrogen, total phosphorus, chlorophyll concentrations throughout a whole year[23] or a number of summers. Alternative pond nitrogen attenuation rates also require pond bathymetry, and stream inflow and outflow, as applicable. Attenuation rates of 80% or higher have been found for freshwater ponds in selected MEP analyses.[24]

Key ponds among the 45 freshwater ponds in the PDK watershed are:

Silver Lake in Halifax, Pembroke, Kingston, and Plympton,
Lower Chandler Pond in Duxbury and Pembroke,
Island Creek Pond in Duxbury,
Foundry Pond in Kingston,
Smelt Pond in Kingston,
Triangle Pond in Plymouth,
Billington Sea in Plymouth,
Great South Pond in Plymouth,
Little South Pond in Plymouth,

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[22] Howes, B. and R. Samimy. 2005.

[23] Eichner, E. 2008. Lake Wequaquet Water Quality Assessment. Completed for the Town of Barnstable and the Cape Cod Commission. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth. 81 p.

[24] 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.

Boot Pond in Plymouth,
Hoyt Pond in Plymouth,
Russell Mill Pond in Plymouth,
Little Pond in Plymouth, and
Lout Pond in Plymouth.

The Town of Plymouth has supplied available information for 13 ponds within the PDK watershed, and project staff also reviewed available data from MassDEP. MEP project staff will review available information for all ponds in the watershed and determine appropriate nitrogen attenuation rates during the development of the PDK watershed nitrogen loading model during the next phase.

III. Summary: Completion of Data Gathering

Massachusetts Estuaries Project assessments are based on collection and development of extensive site-specific watershed information. The project discussed in this report focuses on the collection, organization, and development of key data necessary for the development of a MEP watershed nitrogen loading module for the Plymouth Harbor - Duxbury Bay - Kingston Bay (PDK) Embayment System. Determination of nitrogen loadings from sub-watersheds to estuarine waters is the second phase in a multi-phase project to support use of a linked watershed – estuary nitrogen management modeling approach for the PDK estuarine system. This latter effort relies on integration of data from the present project and a previous 2005 MEP project that collected streamflow and stream and estuary water quality data throughout the PDK system[25] Into a PDK watershed nitrogen loading model that can later be linked to the MEP estuarine module to allow predictions of estuarine response resulting from changes in watershed nitrogen loading.

In the current project (Task 1a) MEP staff completed 1) the delineation of a draft MEP watershed to the PDK estuary and 2) collection of available land use, water use and site specific nitrogen loading information to support development of the MEP watershed nitrogen loading module for the PDK system. The watershed delineation is fundamentally based on the recharge areas developed by the US Geological Survey (USGS) through their modeling of the Plymouth-Carver-Kingston-Duxbury aquifer system.[26] These 85 recharge areas include 10 year time of travel areas, 56 subwatersheds to 45 ponds, 11 recharge areas to streams and rivers, and 11 to public water supply wellfields and irrigation wells. Staff refined these recharge areas or subwatersheds by refining modeled outputs to better reflect actual pond, stream, and coastal shorelines.

Estimated subwatershed flows from the resulting recharge areas were then compared to streamflows measured at Eel River, Town Brook, and Jones River during the 2005 MEP study and available USGS long-term measurements. These comparisons showed that the modeled subwatershed recharge flows are reasonably consistent with the available measured flows and are appropriate to begin the development of the MEP's PDK watershed nitrogen loading module. The MEP watershed delineations are considered draft because comparison of nitrogen loading results to measured nitrogen concentrations may result in refinements. This comparison is a

[25] Howes, B. and R. Samimy. 2005.
[26] Masterson, J.P., Carlson, C.S., and Walter, D.A. 2009.

standard MEP QA/QC step and can only be conducted during subsequent phases of the MEP assessment of the PDK system.

MEP watershed nitrogen loading models are based on nitrogen loads from individual parcels within the watershed. Individual parcel information is summarized for each of the subwatersheds in order to accurately assign the magnitude and location of nitrogen loads entering a given portion of the estuary. Portions of seven towns are located within the PDK watershed: Plymouth, Marshfield, Duxbury, Pembroke, Halifax, Plympton, and Kingston. Available parcel information was collected from six of the towns, but had to be developed by MEP staff for the portion of the Town of Pembroke that is located in the PDK watershed. All parcel information has been incorporated into a Geographic Information System (GIS) environment to ensure that all data is spatially consistent and geo-referenced.

The GIS parcel databases have had other available information linked to them in order to construct a unified database of parcels within the PDK watershed. These combined databases will serve as the backbone for the creation of the MEP's PDK watershed nitrogen loading model during the next phase of the project. Town assessor's databases were collected and linked to the parcel databases so town-specified land uses can be determined. Available town zoning districts, minimum lot sizes based on zoning, and a MassDEP wetland coverage were also collected and linked to the parcel databases in order to complete buildout assessments. A state wetland coverage was linked to the parcels to determine upland area to modify buildout calculations. Current town zoning bylaws were reviewed for minimum lot sizes and this was incorporated into the combined databases to determine potential buildout for each parcel. Parcel –by-parcel water use and sewer connections were also incorporated into the combined database.

MEP staff also began the process of gathering other information that will be necessary for developing nitrogen loading for selected individual parcels in the PDK watershed. Additional data collected during the current project that will be necessary for the development of a MEP nitrogen loading model of the PDK watershed included: 1) cranberry bog areas, 2) landfill and solid waste site identification and monitoring data, 3) wastewater treatment plant and discharge locations, performance and monitoring data, 4) golf course locations and fertilizer application information, and 5) available freshwater pond water quality monitoring data for the 45 ponds in the PDK watershed.

The collected information represents the completion of Task 1A in the overall MEP assessment of the Plymouth Harbor – Duxbury Bay – Kingston Bay (PDK) estuary system. Land use database information will be provided to the Town of Plymouth and other towns who request it. This information will be integrated to produce a watershed nitrogen loading model for the PDK system during the next phase/task. This model will be used to develop existing and future buildout watershed nitrogen loads. Subsequent tasks will also include linking of the watershed model with a hydrodynamic/water quality model and development of estuarine nitrogen management thresholds (management targets). The linked model with existing nitrogen loads will then be validated with existing water quality data. The resulting validated model can then be used with an assessment of the water quality in the PDK estuary to evaluate potential impacts of future development within the watershed and available options protect and restore water quality in the PDK estuary.

IV. References

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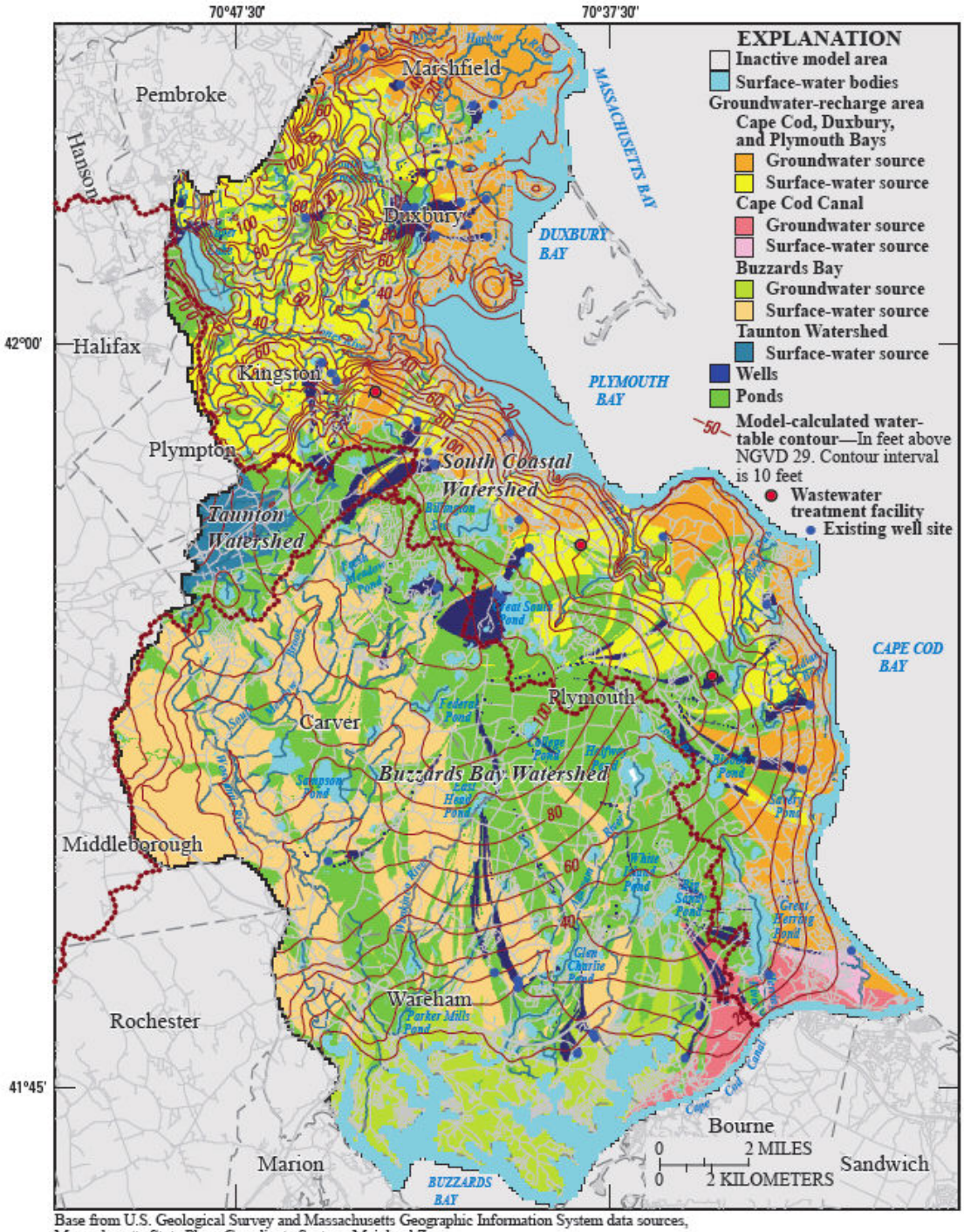

Base from U.S. Geological Survey and Massachusetts Geographic Information System data sources, Massachusetts State Plane Coordinate System, Mainland Zone

Figure 1. US Geological Survey Plymouth-Carver-Kingston-Duxbury Groundwater Recharge Areas. USGS aquifer system model-calculated groundwater-recharge areas for public water supply wells, freshwater ponds and lakes, streams, and coastal areas based on 2005 average well pumping and recharge conditions [figure from p. 16 of Masterson, *et al*. (2009)].

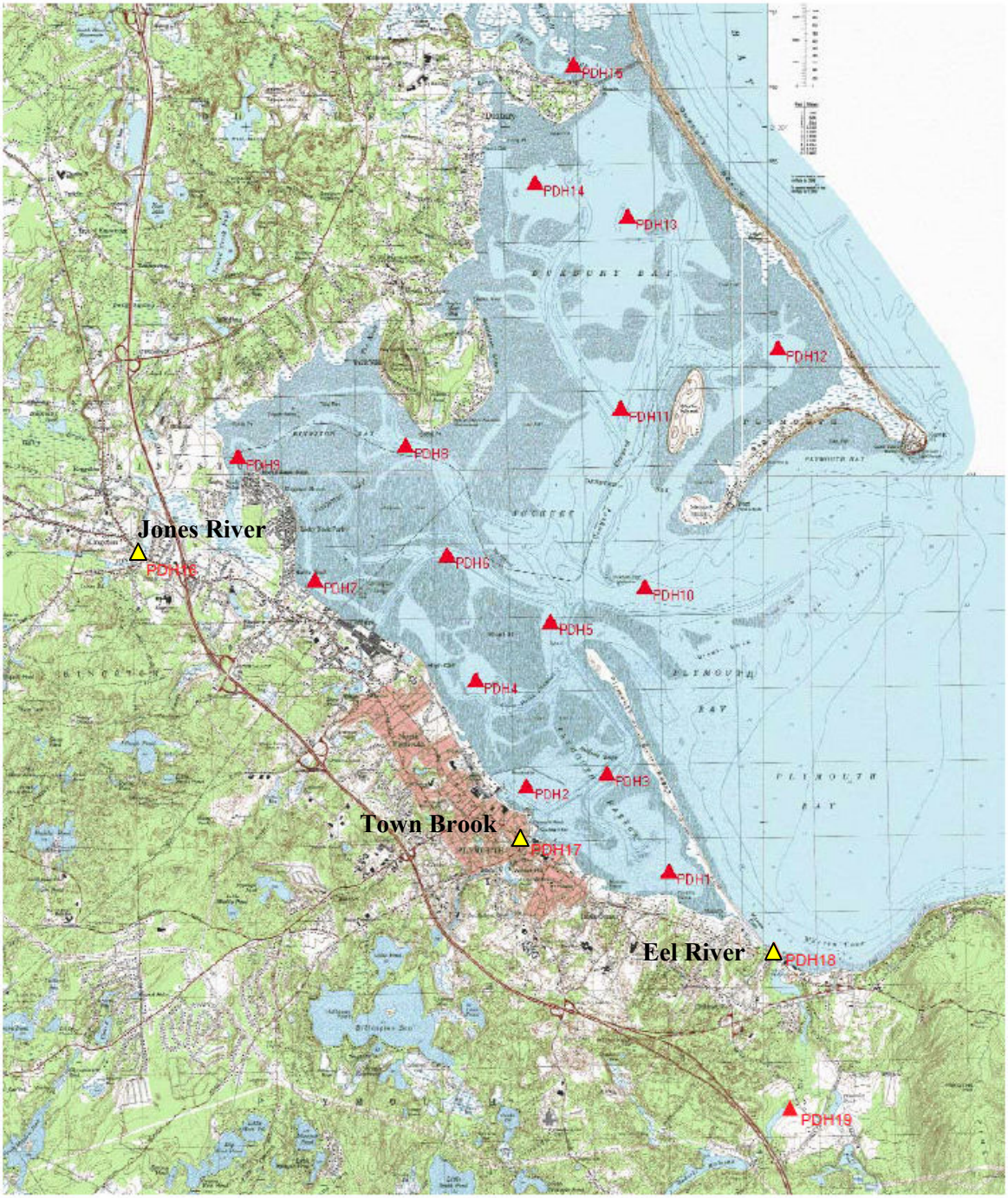

Figure 2. Plymouth Harbor - Duxbury Bay - Kingston Bay Embayment System Estuary and Stream sampling stations (modified from Howes and Samimy, 2005). Massachusetts Estuaries Project stream stations are labeled and indicated by yellow triangles. Water samples at stream stations and Harbor stations (indicated by red triangles) were regularly collected and analyzed for nitrogen constituents. Water flows were measured at stream stations.

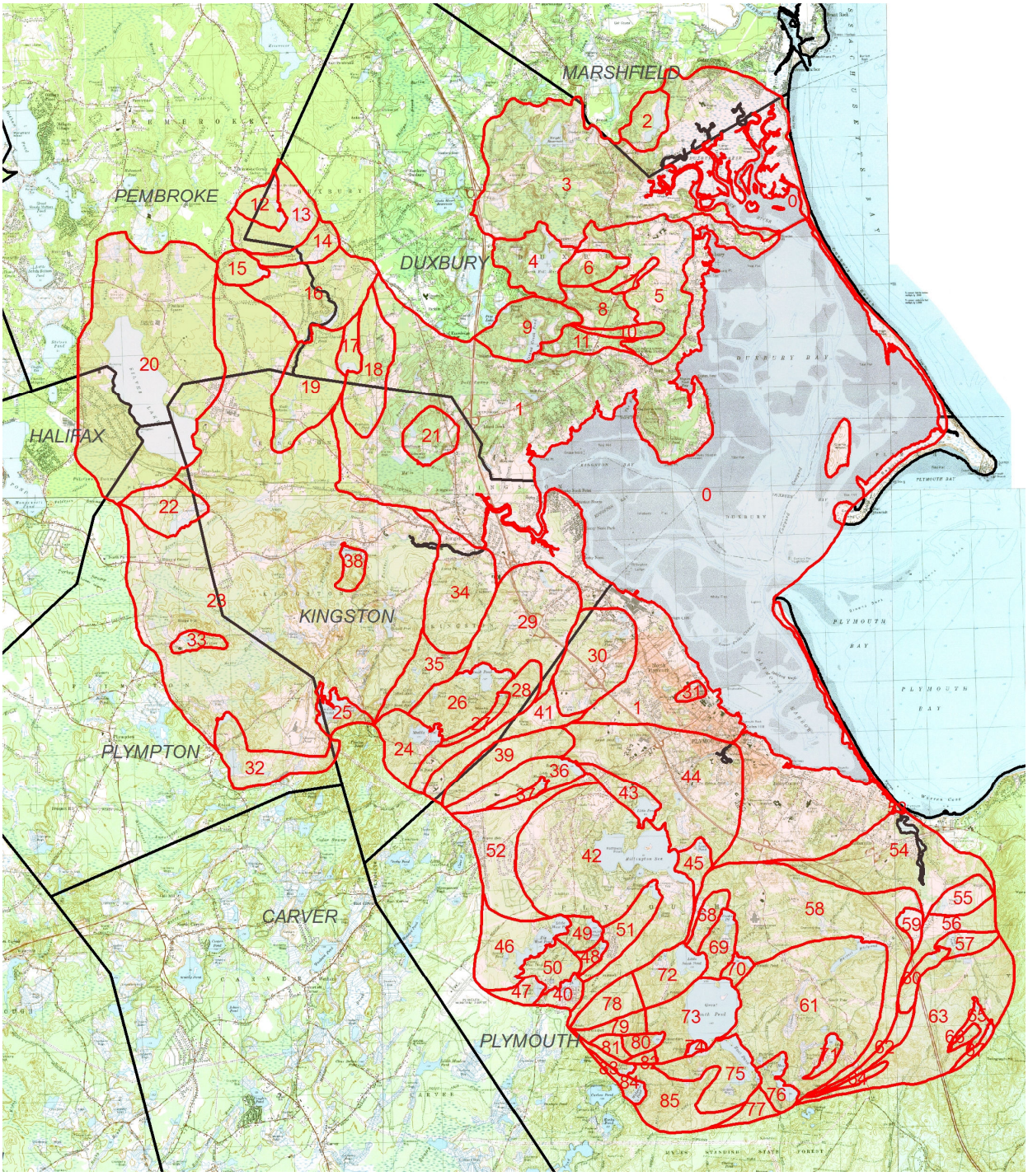

Figure 3. Massachusetts Estuaries Project *Draft* Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary Watersheds and Subwatersheds. MEP staff used the USGS recharge area outputs (Masterson, *et al*., 2009), refined for pond, stream, and coastal shorelines, to complete these delineations. The subwatersheds boundaries are draft because assessment and integration of nitrogen loading and water quality during subsequent phases (Task 1B) of the MEP analysis may result in reassessment of individual subwatershed boundaries.

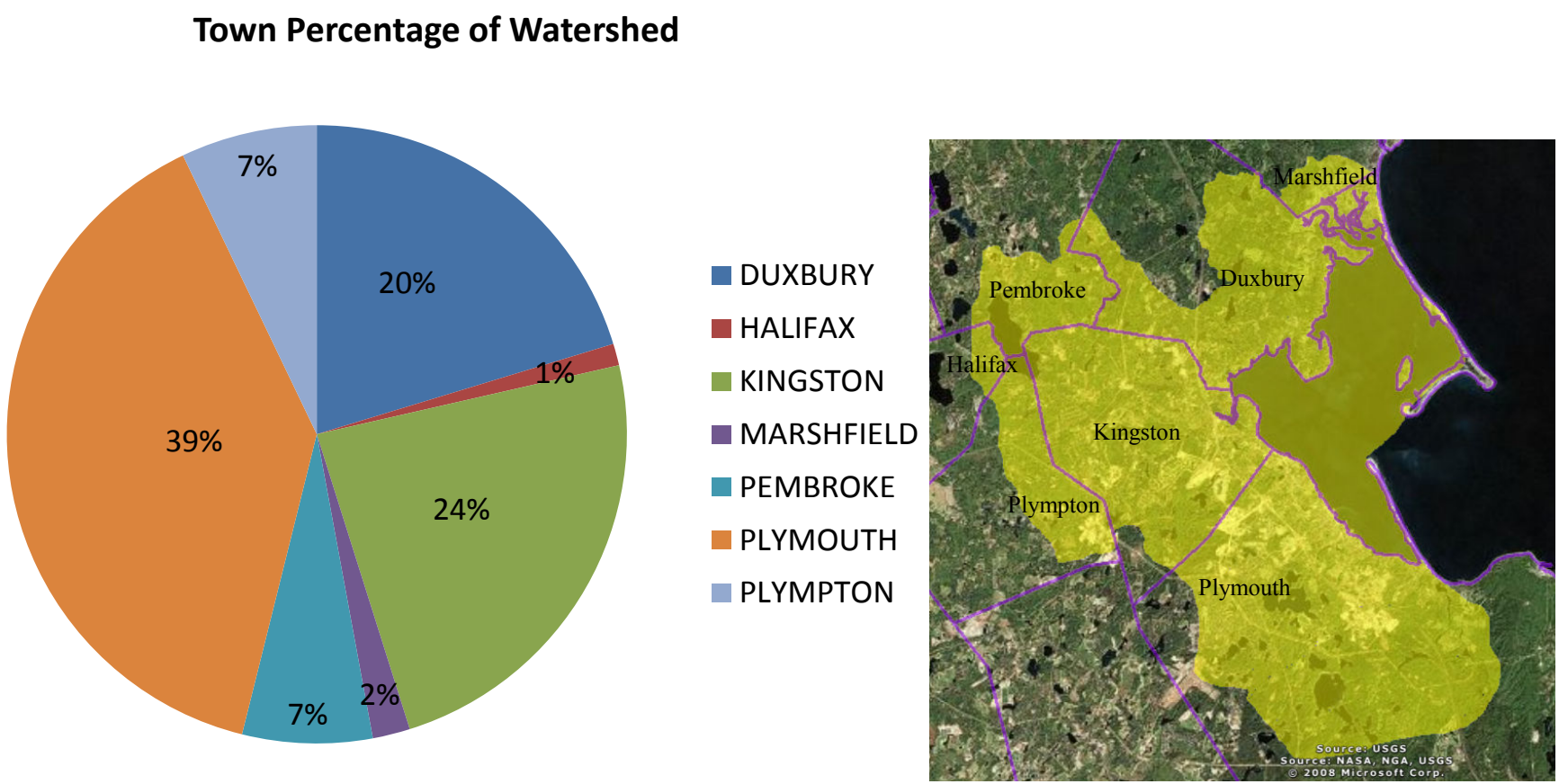

Figure 4. Town Percentage in the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary MEP Watershed. The draft MEP Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary Watershed is approximately 48,000 acres and is made up of portions of seven towns. The map shows the portions of each town and the pie graph shows the percentage area of the whole watershed for each of the towns. For example, the Town of Plymouth is 39% of the watershed area, while the Town of Kingston is 24% of the watershed area.

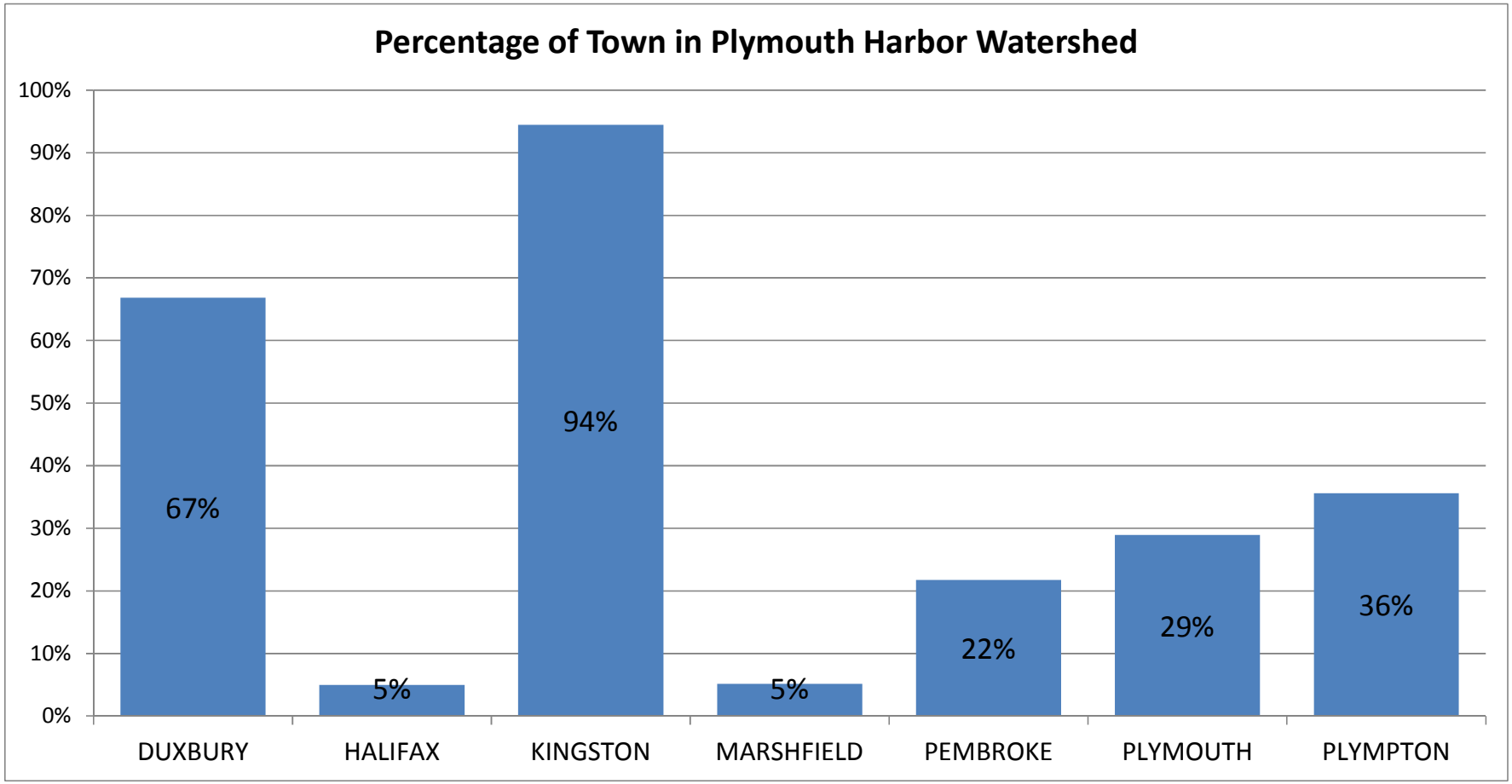

Figure 5. Percentage of each town within the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary MEP Watershed. Each town occupies a portion of the watershed, but the watershed occupies a percentage of the town. For the Town of Kingston, for example, 94%, or almost the whole town is included in the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary Watershed. In comparison, only 5% each of the Town of Halifax and the Town of Marshfield is included in the watershed.

APPENDIX A.

Minimum Lot Sizes in Current Zoning Bylaws for Towns in
Plymouth Harbor - Duxbury Bay - Kingston Bay Estuary MEP Watershed

Town of Duxbury
From: ARTICLE 400: USE, INTENSITY, DIMENSIONAL AND COVERAGE REGULATIONS FOR ALL DISTRICTS (July 26, 2011 printing)
Available at:
http://www.town.duxbury.ma.us/Public_Documents/DuxburyMA_Planning/Zoning%20Bylaws/Index

Minimum lot size for parcels in PDK MEP Watershed

Zone	Zone Name	Minimum lot size (sq. ft.)
NB-1	Neighborhood Business-1 District	15,000
NB-2	Neighborhood Business-2 District	15,000
RC	Residential Compatibility District	40,000
AP	Aquifer Protection Overlay District	60,000

Town of Halifax
From: Chapter 167 of Town of Halifax bylaws
Available at: http://www.town.halifax.ma.us/bylaws8.doc and
http://www.town.halifax.ma.us/bylaws9.doc

All zoning districts in Halifax have a minimum lot size of 40,000 sq. ft.

Town of Pembroke
From: Town of Pembroke Zoning bylaws
Available at: http://www.pembroke-ma.gov/pdfs%20and%20forms/PembrokeZoning%20ByLaws%209%20TOWN.pdf

Portion of town within PDK MEP Watersheds is all within Residential A zoning district, which has a minimum lot size of 40,000 sq. ft. (Section IV.1.D.).

Town of Plympton
From: Town of Plympton Zoning bylaws (Section 5.1 Table of Intensity of Use) – edited 11/15/10
Available at: http://town.plympton.ma.us/pdf/land/plympton_bylaws_2010_11_15.pdf

All zoning districts in Plympton have a minimum lot size of 60,000 sq. ft. with the additional modification that all lots classified as Retreat Lots have a minimum lot area of 120,000 sq. ft.

Town of Plymouth
Modified from: Zoning Bylaw Table 5 (revised through April 2010)

Available at: http://www.plymouth-ma.gov/Public_Documents/PlymouthMA_TownClerk/Bylaws/Ch%20205%20Table%205.pdf

Zoning bylaw at: http://www.plymouth-ma.gov/Public_Documents/PlymouthMA_TownClerk/Bylaws/Zoning%20Bylaw%204310.pdf

Minimum lot size for parcels in PDK MEP Watershed

Zone	Zone/District/Overlay Name	Primary Minimum lot size (sq. ft.)
RR	Rural Residential	120,000
R-40	Residential Single Family	40,000/55,000 (multi-family)
R-25	Residential	25,000/35,000 (multi-family)
R-20SL	Small Lot Residential	20,000/30,000 (multi-family)
R-20MD	Medium Density Residential	20,000/30,000 (multi-family)
R-20MF	Multi-family Residential	20,000/30,000 (multi-family)
WF	Waterfront	20,000
NC	Neighborhood Commercial	20,000
TC	Transitional Commercial	20,000
GC	General Commercial	20,000
AC	Arterial Commercial	40,000
LI	Light Industrial	40,000
LI/WF	Light Industrial/Waterfront	20,000
MC	Mixed Commercial	40,000
HC	Highway Commercial	40,000
AP	Airport	40,000 (industrial)/20,000 (commercial)
DH	Downtown/Harbor	No minimum specified
OSMD	Open Space Mixed Use Development Overlay	120,000

Town of Kingston
From Section 5.2 of Town of Kingston Zoning bylaws (revised through April 2010)
Available at: http://www.kingstonmass.org/filestorage/52/Complete_Zoning_By-Laws.pdf

INTENSITY SCHEDULE
(Amended 5/3/99 ATM Article 48; 5/9/00 ATM Article 24)

	Minimum Lot Size		Max. Height Dimensions	Max. Lot Coverage by Bldg.	Min. Open Space	Minimum yard Size					
District	Lot Area in Square Feet	Continuous Frontage in Feet	Ft	In % (2)	In %	Side Yard in Feet	Rear Yard in Feet	Front Yard in Feet			
Conservancy	80,000	100	15	10	75	50	20	50	-	-	-
Industrial District	40,000 (6)	250	40	25	25	40	40	50	-	-	-
Commercial/ Industrial	40,000 (6)	250	40	50	25	40	40	50	-	-	-
Commercial	40,000	200	35	50	30	40	40	50	-	-	-
Town Center	10,000	80	40	50	30	15	20	15	-	-	-
Residential M Mobile Home Park	8000(5)	70	15	25	25	15	15	20	-	-	-
							Street Type	Arterial	Collector	Sub-Collector	Local or Minor
Residential 80	80,000	200	35	25	50	30	40	50	50	40	25
Residential 40	40,000	200	35	25	50	30	40	50	50	40	25
Residential 20	20,000 (3) 30,000 (4)	100	35	25	40	15	20	50	50	40	25
3A Design District	30,000	150	35	40	40	20	30	-	-	-	-
3A Design District	-	-	-	-	-	Maximum Front Building Setback		35	30	30	25

(1) Fences and flagpoles are allowed in the required front, side and rear yards
(2) Included accessory buildings
(3) Single family dwellings
(4) Two family dwellings
(5) Per mobile home unit. The minimum area of a mobile home park shall be fifty (50) acres. See Section 5.5.1.3.
(6) Per principal building or use. Where and if the lot abuts residential zone areas, the minimum side lot must be 50 feet .

Town of Marshfield

From Table of Dimensional and Density 6.10 of Town of Marshfield Zoning bylaws (revised through April 2010)
Available at: http://www.townofmarshfield.org/Collateral/Documents/English-US/building/Article_VI_Sec_6-10_Table_of_Dimensional_and_Density_Regs.pdf

Section 6.10

TABLE OF DIMENSIONAL AND DENSITY REGULATIONS

Zone	Use	Minimum lot area** (sq. ft.)	Width and frontage (ft.)	Minimum lot depth (ft.)	Minimum Yards Front (ft.)	Side (ft.)	Rear (ft.)	Maximum Height (ft.)	Maximum stories	Maximum Building area (percent)	Minimum open space area (percent)
R-1	Any permitted use	43,560	125	150	40	20	40	35	*2.5	15	50
R-2	Any permitted use	20,000	100	120	40	15	40	35	*2.5	25	40
R-3	Any permitted use	10,000	80	100	15	15	30	35	*2.5	40	30
R-B	a. Residential use	20,000	125	150	40	15	40	35	2.5	25	40
	b. Other use	20,000	125	150	40	15	40	##25	##1	40	30
OP	Any permitted use	20,000	125	100	40	20	40	25	2	40	30
B-1	Any permitted use	10,000	100	100	5	none	10	35	3	none	none
B-2	Any permitted use	20,000	150	150	40	#15	40	35	2.5	40	20
***B-3	Any permitted use	5,000	80	80	20	5	15	35	2.5	40	20
***B-4	Any permitted use	10,000	100	100	10	5	15	35	2.5	60	20
I-1	Any permitted use	40,000	150	150	40	20	40	65	2	none	30
A	Any permitted use	20,000	125	100	40	20	40	35	3	40	30

* In the R-1, R-2, R-3 Districts, the height may be increased to three stories if the minimum front yard is increased by 14 feet and the minimum side yard is increased by five feet.

** For lots partially within the Inland Wetlands or the Coastal Wetlands District, the application of the minimum lot areas set forth in this Article shall be governed by the regulations of Article XIII.

*** Except as noted in Section 6.08.

The minimum side yard setback may be reduced or eliminated as noted in Section 11.11 of the Bylaws.

Buildings may be increased by 1.5 stories (maximum 35 feet) for a residential unit above the first floor.