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# Hydrological Parameters for New Hampshire's Estuaries

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# New Hampshire Estuaries Project Hydrologic Parameters for New Hampshire's Estuaries

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# Introduction

The New Hampshire Estuaries Project (NHEP) is part of the U.S. Environmental Protection Agency's National Estuary Program which is a joint local/state/federal program established under Section 320 of the Clean Water Act with the goal of protecting and enhancing nationally significant estuaries. The NHEP's Comprehensive Conservation and Management Plan for New Hampshire's estuaries was completed in 2000 and implementation is ongoing. The Management Plan outlines key issues related to management of New Hampshire's estuaries and proposes strategies that are expected to collectively preserve and protect the state's estuarine resources.

The coastal watershed for the NHEP drains into two major estuary systems: the Great Bay Estuary and Hampton-Seabrook Estuary (Figure 1). There is also a small portion of the coastal watershed which drains directly to the Atlantic coast near Rye Harbor. The drainage area for the NHEP coastal watershed is 2,812.47 km² [1,085.90 mi²]. The watershed boundaries and hydrology for the Great Bay Estuary and Hampton-Seabrook Estuary are shown in Figures 2 and 3. Detailed maps (1:24,000 scale) of the watershed and tidal waters boundaries used for this study are documented in an Appendix.

The purpose of this report is to summarize the available hydrologic information for the Great Bay Estuary and Hampton-Seabrook Estuary. Estuary classification documents have been produced by Short (1992) and Jones (2000). UNH researchers have developed hydrologic models for the Great Bay Estuary (Brown and Arellano, 1980; Swift and Brown, 1983; Bilgili et al., 2005). Additional information has been created for licensing and regulatory reasons (e.g., PSNH, 1977). The information in these reports has been compiled and cross-checked against geographic databases and summarized in this report to provide accessible, consistent, and credible data. The values presented in this report will be used for all NHEP reporting and should be used for any national databases for estuarine classifications.

# **Great Bay Estuary**

## **Watershed Drainage Area**

The drainage area for the Great Bay Estuary is 2650.65 km<sup>2</sup> [1,023.42 mi<sup>2</sup>] (Figure 2). The portion of the Great Bay Estuary watershed that is in Maine covers 627 km<sup>2</sup> [242 mi<sup>2</sup>], which is 24 percent of the watershed.

#### **Tidal Shoreline**

Several different values of the length of tidal shoreline for the Great Bay Estuary have been reported. In synthesis documents for the estuary, Short (1992) and Jones (2000) reported the shoreline to be 160 km and 240 km, respectively.

For this report, the NHEP used the latest GIS shapefiles of surface waters to calculate the tidal shoreline to be 324 km [204 mi]. This value is the perimeter of all estuarine assessment units from the mouth of Portsmouth Harbor to the head of tide of all the rivers. The creeks on the Maine side of the Piscataqua were included in the calculation. The short distance across the mouth of the harbor was not subtracted off the perimeter. The assessment units extend to the mean high water mark, so the shoreline value corresponds to high tide conditions.

The tidal shoreline in Maine is approximately 83 km [52 mi]. This value was calculated from the perimeter of a merged polygon of all estuarine assessment units in Maine, minus the approximate distance down the centerline of the Piscataqua River and across the mouth of the Portsmouth Harbor. The value is approximate but it is reasonable to state that 25 percent of the shorelands of the estuary are in Maine.

The GIS shapefiles used for this assessment correspond to the 1:24,000 scale National Hydrography Dataset. The perimeter of the estuary will appear to increase if smaller scale hydrography datasets are used.

# Length

The linear distance from the head of tide to the mouth of the estuary is sometimes used for calculations. For Great Bay, we will assume that the "estuary" begins at the mouth of the Squamscott River at the trestle bridge and ends at Portsmouth Harbor. The distance between these two points following the flow of water is approximately 25 km [15.5 mi].

## **Surface Area**

The surface area of the estuary has been reported as 44 km², 47 km², 47 km², and 47.5 km² by Short (1992), Jones (2000), Bricker et al. (2007), and Engle et al. (2007), respectively. Analysis of the most recent GIS shapefiles by the NHEP showed that the surface area was slightly larger (54.66 km², 21.12 mi²). This value was calculated from the sum of the area for all estuarine assessment units from the mouth of Portsmouth Harbor to the head of tide of all the rivers (see Table 1). The creeks on the Maine side of the Piscataqua were included in the calculation. The assessment units extend to the mean high water mark, so the surface area value corresponds to high tide conditions. For the estuary upstream of Dover Point, the surface area was 29.7 km² (24.4 km² if the tidal rivers are removed).

#### Volume

Two sources are typically cited for the high and low tide volume of the Great Bay Estuary: Brown and Arellano (1979, 1980) and Swift and Brown (1983). Brown and Arellano (1979, 1980) estimated the volume of the Great Bay Estuary at low and high tides as  $167 \cdot 10^6$  m<sup>3</sup> and  $230 \cdot 10^6$  m<sup>3</sup>, respectively. The Swift and Brown (1983) estimates improved upon the earlier results. The values for the second study were  $156 \cdot 10^6$  m<sup>3</sup> and  $235 \cdot 10^6$  m<sup>3</sup> for low and high tides (values estimated from nomograph). The Swift and Brown (1983) values are assumed to be the most accurate because they are the most recent. From the same nomograph in Swift and Brown (1983), it is possible to estimate the estuarine volume of Great Bay and Little Bay upstream of Dover Point:  $67 \cdot 10^6$  m<sup>3</sup> and  $108 \cdot 10^6$  m<sup>3</sup> for low and high tides, respectively.

The NHEP confirmed these values and generated estimates for estuarine volumes of smaller segments of the estuary using a GIS calculation. Dr. Ata Bilgili provided the shapefile of points showing depth at mean tidal level for a Great Bay Estuary hydrodynamic model. ArcView software was used to select the points that fell in each assessment unit. Depth values less than or equal to zero were removed and then the average value of the depth values in each assessment unit was calculated. The volume of the assessment unit was calculated from the product of the average depth and the surface area. Low tide and high tide volumes were estimated by subtracting and adding, respectively, one meter from the average depth and then recalculating the volume. If the average depth at low tide was less than zero, the volume was considered to be

zero. The depth of the Spinney Creek assessment unit was assumed to be 2 meters based on data reported by the Spinney Creek Shellfish Company. When the volumes of all the assessment units were combined, the low tide and high tide volumes of the estuary were estimated to be  $124\cdot10^6$  m³ and  $232\cdot10^6$  m³, respectively. The high tide volume corresponds almost exactly with the estimate from Swift and Brown (1983). The low tide volume is approximately 20 percent lower than the Swift and Brown (1983) value. The depth and volume results for each assessment unit are shown in Table 2.

The average salinity for each assessment unit was calculated from data in the NH Department of Environmental Services (DES) Environmental Monitoring Database from 2000 through 2005. The average salinity was divided by a typical ocean salinity of 32 ppt to calculate the fraction of fresh water in each segment. The total volume of freshwater in the system at mean tidal level was estimated to be  $33\cdot10^6$  m<sup>3</sup>.

Summary: The best estimate of the volume of the Great Bay estuary is from Swift and Brown (1983). The high tide volume is  $235 \cdot 10^6$  m<sup>3</sup> and the low tide volume is  $156 \cdot 10^6$  m<sup>3</sup>. The resulting tidal prism volume is  $79 \cdot 10^6$  m<sup>3</sup>. The mid-tide volume is  $196 \cdot 10^6$  m<sup>3</sup>. The NHEP estimates of volumes for individual assessment units can be used for smaller scale studies of portions of the estuary.

# **Salinity**

The salinity of the Great Bay Estuary ranges from polyhaline at the mouth of the Piscataqua River to oligohaline at the head of tide of the tidal rivers. Many models need an average salinity value for an estuary. Therefore, the average salinity in the estuary was estimated from a weighted average of the salinities in each assessment unit (Table 2). The weighting factors were the mid-tide volume of the assessment unit divided by the mid-tide volume of all assessment units. Overall, the weighted average salinity of the Great Bay Estuary was 26.0 ppt. This value is confirmed by the estimated volume of freshwater in the estuary (33·10<sup>6</sup> m³), which is only 17 percent of the total volume. Seawater salinity (32 ppt) multiplied by 0.83 is 26.6 ppt.

# **Depth**

The water depth within the estuary fluctuates based on tide and topography. A deep channel extends from Portsmouth Harbor to Adams Point, with shallow subtidal or intertidal areas elsewhere. The average depth of the estuary at mid-tide was calculated using a weighted average of the mid-tide average depths in each assessment unit (Table 2). The weighting factors were the surface area of each assessment unit divided by the total surface area of the estuary. The resulting average depth for the estuary at mid-tide was 3.2 m.

## **Freshwater Input**

Eight rivers discharge to the Great Bay Estuary: the Winnicut, Exeter/Squamscott, Lamprey, Oyster, Bellamy, Cocheco, Salmon Falls, and Great Works rivers. The 10-year average flow from the rivers was calculated from USGS stream flow records from 1997 to 2006. A watershed area transposition technique was used to estimate flows from ungaged rivers. The contribution of runoff from land downstream of the tidal dams was estimated through watershed transposition from the Oyster River stream gage. The average freshwater inflow into the Great Bay Estuary for this period was  $4.26 \cdot 10^6$  m³/d [1,739 cfs]. The fraction of the flow contributed by each river is shown in Table 3. The median rate at which groundwater discharges to the estuary  $(0.06 \cdot 10^6)$ 

m<sup>3</sup>/d) is much lower than the rate for the rivers (Ballestero et al., 2004). Therefore, the groundwater contribution of freshwater to the estuary was not considered.

The watershed for the Great Bay Estuary covers  $2,650.65 \text{ km}^2$  [ $1,023.42 \text{ mi}^2$ ]. Rainfall in the watershed averages 1.07 m [42 in] of precipitation per year (1971-2000 climate normals for Durham, NH). This amount of precipitation is equivalent to  $7.76\cdot10^6 \text{ m}^3/\text{d}$  [3,167 cfs] of water imported into the watershed annually. The average runoff from the watershed through stream flow is  $4.26\cdot10^6 \text{ m}^3/\text{d}$  [1,739 cfs]. Therefore, approximately 55 percent of precipitation in the watershed reaches the estuary through stream flow.

Short (1992) reported that freshwater input to the estuary is 2 percent of the tidal prism exchange. The tidal prism volume for the estuary is  $79 \cdot 10^6$  m<sup>3</sup>. Over the course of a day, two tidal cycles will occur; therefore,  $178 \cdot 10^6$  m<sup>3</sup> of ocean water will enter and leave the estuary. The average freshwater input during the day is  $4.26 \cdot 10^6$  m<sup>3</sup>. The ratio of the freshwater input to tidal prism exchange is 2.4 percent, which confirms the estimate from Short (1992).

## **Flushing Times**

There are several different ways to specify the rate at which estuarine water is replaced with "new" ocean or fresh water. The most common metrics for estuarine flushing are the freshwater replacement time, the residence time, and the flushing time. All of the values listed below are for typical or average conditions. During extreme weather events, the flushing times will vary.

# Freshwater Replacement Time

The freshwater replacement time is defined as the time required for freshwater runoff from the watershed to replace all of the freshwater in the estuary. In the Great Bay Estuary, the volume of freshwater under normal conditions is  $33 \cdot 10^6$  m<sup>3</sup>. The average freshwater inflow rate from the watershed is  $4.26 \cdot 10^6$  m<sup>3</sup>. Therefore, the freshwater replacement time under average conditions is 7.8 days.

# Local Residence Time

Residence time is defined as the time required for a water parcel at a certain location to migrate out of the waterbody (Abdelrhman, 2005). The residence time varies with location in the estuary.

Bilgili et al. (2005) used a vertically averaged numerical circulation model to determine the local residence time for water parcels throughout the Great Bay Estuary. The model was used to calculate the mean "first ocean crossing time" for water parcels from different sections of the estuary. Water parcels from Great Bay, Little Bay and the Upper Piscataqua River exited the system and entered the ocean after 39.3, 30.3 and 25.3 tidal cycles [20.4, 15.7, and 13.1 days], respectively. For the Lower Piscataqua River and Portsmouth Harbor, the residence times of water parcels were 22.4 and 14.4 tidal cycles [11.7 and 7.5 days], respectively. The values reported from Bilgili et al. (2005) are averages of the results for four different simulations listed on Table 9 of that report.

# Flushing Time

Flushing time is different from residence time because it measures the rate at which the mass of a constituent is removed from the system, not the rate of movement of an individual water parcel (Abdelrhman, 2005). The flushing time varies with location in the estuary.

The first quantitative estimates of flushing time were determined by Brown and Arellano (1980). They found that the flushing times for water parcels entering at the head of the estuary during periods of low and high river flow were 54.5 and 45.9 tidal cycles [28.2 and 23.8 days], respectively. For a water parcel in the middle of Great Bay, the flushing time was between 50.5 and 37.9 tidal cycles [26.2 to 19.6 days]. At the mouth of the estuary in the lower Piscataqua River, the flushing time was determined to be 6 tidal cycles [3.11 days].

The results of Brown and Arellano (1980) were updated by Bilgili et al (2005). Bilgili et al. (2005) used a vertically averaged numerical circulation model to determine the flushing rates throughout the Great Bay Estuary. The flushing rates were reported as "e-folding times". The e-folding time of a process is similar to a half-life. The half-life is the time needed to reduce a value by a factor of 2. The e-folding time is the time needed to reduce the value by a factor of "e", 2.718, which is equivalent to a 63 percent reduction. The rates derived by Bilgili et al (2005) were based on the removal of conservative tracers from an area (e.g., Great Bay), not necessarily removal of the tracer from the whole estuary. The e-folding time for the whole Great Bay Estuary was found to be 55.0 tidal cycles [28.5 days]. For Great Bay the e-folding time was 17.8 tidal cycles [9.2 days]. In Portsmouth Harbor, the e-folding time was 6.9 tidal cycles [3.6 days]. Overall, the e-folding times from Bilgili et al. (2005) confirmed the results from Brown and Arellano (1980) for the estuary as a whole and for Portsmouth Harbor. However, the results did not agree for the middle of the estuary. This discrepancy likely was caused by different definitions of flushing time between the two studies. The values reported from Bilgili et al. (2005) are averages of the results from the first four simulations listed on Table 8 of that report.

The e-folding time for the whole estuary from Bilgili et al (2005) will be considered the best estimate of flushing time for the system.

## **Estuarine Classification**

The Great Bay Estuary has been included in several classifications of estuaries across the United States:

- NOAA Estuarine Drainage Area "N130X" roughly corresponds to the Great Bay Estuary watershed.
- Engle et al. (2007) placed the N130X EDA in "Group 8." The estuaries in this group had moderate area, volume and freshwater flow; high salinity; and were deep.
- The Great Bay Estuary is in EPA's Level III Ecoregion 59, "Northeastern Coastal Zone." The estuary is close to the boundary with Ecoregion 82 which covers most of the estuaries in Maine.
- Other estuaries with similar watershed drainage areas in the same classification and ecoregion are: Passamaquoddy Bay, Englishmans Bay, Blue Hill Bay, and Casco Bay.

# **Tidal Range**

The mean tidal range in the Great Bay Estuary varies from 2.6 m [8.6 ft] in Portsmouth Harbor to 2.0 m [6.4 ft] at Dover Point. The time of high and low tide lags behind the tide gage for Portland, Maine by different amounts depending on location within the Great Bay Estuary. In general, the tide stage is 1.5 hours later at Dover Point and 2.5 hours later at the mouth of the Squamscott River. Tidal ranges and tide lags from NOAA for various stations in the estuary are available at: http://tidesandcurrents.noaa.gov/tides07/tab2ec1a.html#7.

# **Hampton-Seabrook Estuary**

# Watershed Drainage Area

The watershed draining to the Hampton-Seabrook Estuary covers 118.6 km<sup>2</sup> [45.79 mi<sup>2</sup>] (Figure 3). The watershed extends for 21.49 km<sup>2</sup> [8.30 mi<sup>2</sup>] into Massachusetts around the upstream reaches of the Blackwater River. Almost all of the watershed area in Massachusetts is in the town of Salisbury (21.47 km<sup>2</sup>), with a small sliver in Amesbury.

## **Tidal Shoreline**

In Jones (2000), the tidal shoreline in the Hampton-Seabrook Estuary was reported to be 116 km [72 mi]. However, the perimeter of the estuarine waters in the Hampton-Seabrook Estuary, including the portion of the Blackwater River in Massachusetts, sums to 211 km [131 miles] of tidal shoreline. The shapefiles used for this assessment correspond to the 1:24,000 scale National Hydrography Dataset. The perimeter of the estuary will appear to increase if smaller scale hydrography datasets are used.

#### **Surface Area**

The surface area at high tide of all the estuarine waters in the harbor is 4.96 km² [1.92 mi²] with 0.32 km² [0.12 mi²] in Massachusetts (Table 4). This surface area estimate is for the harbor area and channels. It does not include the area of salt marsh which is covered by water during a spring tide.

#### Volume

The low and high tide volumes of the estuary were reported in PSNH (1977), a hydrographic survey of the harbor for the Seabrook Station commissioning. At low tide, the harbor contains  $1.9 \cdot 10^6$  m<sup>3</sup> of water. At high tide, the volume in the harbor increases to  $15.9 \cdot 10^6$  m<sup>3</sup>. The mid tide volume and tidal prism can be inferred from these values to be  $8.9 \cdot 10^6$  m<sup>3</sup> and  $14.0 \cdot 10^6$  m<sup>3</sup>, respectively.

# **Salinity**

All the salinity measurements in Hampton-Seabrook Estuary were queried from the DES Environmental Monitoring Database. Average values were calculated for different sections of the harbor (Table 5). The overall average salinity (29.5 ppt) was calculated from the weighted average based on the surface area of the different sections. In the main harbor area, the average salinity was 30.5 ppt.

#### **Depth**

The estuary consists of large intertidal flats and dendritic channels draining the salt marsh. The sandy sediments in the estuary and intertidal flats frequently shift due to currents. It is not possible to estimate an average depth for the estuary with the available data.

## **Freshwater Input**

The freshwater input to the estuary was reported in Jones (2000) to be  $0.01 \cdot 10^6$  m<sup>3</sup>/d [4.08 cfs]. An analysis of the watershed area and estimated runoff coefficients indicates that a higher value would be more accurate. The watershed area is 118.6 km<sup>2</sup> [45.79 mi<sup>2</sup>]. For the watershed draining to the Great Bay Estuary, the ten-year average runoff coefficient was 1,600 m<sup>3</sup>/d/km<sup>2</sup>

[1.70 cfs/mi<sup>2</sup>] (Table 3). The product of the drainage area and the runoff coefficient can be used to estimate the freshwater input to the estuary from stream flow to be  $0.19 \cdot 10^6$  m<sup>3</sup>/d [77.84 cfs]. Compared to the tidal prism flushing, the amount of freshwater is negligible (0.7% of tidal prism).

# **Flushing Times**

## Local Residence Time

This parameter could not be estimated from existing reports.

# Freshwater Replacement Time

The average freshwater volume in the harbor is  $0.7 \cdot 10^6$  m<sup>3</sup> based on the average salinity (29.5 ppt), ocean salinity (32 ppt) and mid-tide volume (8.9·10<sup>6</sup> m<sup>3</sup>). With an average freshwater delivery rate of  $0.19 \cdot 10^6$  m<sup>3</sup>/d, the freshwater replacement time will be 3.7 days.

# Flushing Time

Quantitative estimates of flushing time have not been calculated for the Hampton-Seabrook Estuary. However, recognizing that 88% of the water in the estuary is exchanged on each tide and 6% of the ebb tide plume returns to the estuary on the next tidal cycle (PSNH, 1977), the flushing time will be less than one day.

#### **Estuarine Classification**

The Hampton-Seabrook Estuary has been included in several classifications of estuaries across the United States.

- NOAA Estuarine Drainage Area "N140X" roughly corresponds to the Hampton-Seabrook Estuary watershed.
- Engle et al. (2007) placed the N140X EDA in "Group 8." The estuaries in this group had moderate area, volume and freshwater flow; high salinity; and were deep.
- The Hampton-Seabrook Estuary is in EPA's Level III Ecoregion 59, "Northeastern Coastal Zone." The estuary is close to the boundary with Ecoregion 82 which covers most of the estuaries in Maine.
- Other estuaries of similar size in the same classification and ecoregion are: Wells Estuary and Waquoit Bay.

#### **Tidal Range**

The mean tidal range in the Hampton-Seabrook Estuary is 2.5 m [8.3 ft]. The time of high and low tide in the main portion of the Hampton-Seabrook Harbor lags behind the tide gage for Portland, Maine by 14 minutes and 32 minutes, respectively. Tide tables from NOAA are available at: http://tidesandcurrents.noaa.gov/tides07/tab2ec1a.html#7.

# **Summary**

Final values for watershed and estuarine hydrologic parameters for both the Great Bay Estuary and the Hampton-Seabrook Estuary are summarized in Table 6.

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Table 1: Surface area of Great Bay Estuary assessment units at mean high water

Aggregate Waterbody	Assessment Unit	Waterbody Name	Area (ha)
SALMON FALLS RIVER	MEEST600030406-01	SALMON FALLS RIVER	74.503
	NHEST600030406-01	SALMON FALLS RIVER	73.338
UPPER PISCATAQUA RIVER-	MEEST600031001-01-01	UPPER PISCATAQUA RIVER	23.342
NORTH	NHEST600031001-01-01	UPPER PISCATAQUA RIVER-NORTH	27.455
UPPER PISCATAQUA RIVER-	MEEST600031001-01-02	UPPER PISCATAQUA RIVER	78.041
DOVER WWTF	NHEST600031001-01-02	DOVER WWTF SZ	84.239
UPPER PISCATAQUA RIVER-	MEEST600031001-01-03	UPPER PISCATAQUA RIVER-SOUTH-ME	57.907
SOUTH	NHEST600031001-01-03	UPPER PISCATAQUA RIVER-SOUTH	57.911
LOWER PISCATAQUA RIVER	MEEST600031001-02	LOWER PISCATAQUA RIVER	348.644
•	NHEST600031001-02	LOWER PISCATAQUA RIVER	288.239
UPPER PORTSMOUTH	MEEST600031001-11	UPPER PORTSMOUTH HARBOR-ME	393.286
HARBOR	NHEST600031001-11	UPPER PORTSMOUTH HARBOR-NH	186.679
COCHECO RIVER	NHEST600030608-01	COCHECO RIVER	71.825
LAMPREY RIVER	NHEST600030709-01	LAMPREY RIVER	44.053
SQUAMSCOTT RIVER	NHEST600030806-01	SQUAMSCOTT RIVER	124.041
OYSTER RIVER	NHEST600030902-01-01	OYSTER RIVER (JOHNSON CR)	0.550
	NHEST600030902-01-02	OYSTER RIVER (BUNKER CR)	3.997
	NHEST600030902-01-03	OYSTER RIVER	115.546
BELLAMY RIVER NORTH	NHEST600030903-01-01	BELLAMY RIVER NORTH	65.052
BELLAMY RIVER SOUTH	NHEST600030903-01-02	BELLAMY RIVER SOUTH	111.625
WINNICUT RIVER	NHEST600030904-01	WINNICUT RIVER	49.978
GREAT BAY PROHIB SZ1	NHEST600030904-02	GREAT BAY PROHIB SZ1	210.126
GREAT BAY PROHIB SZ2	NHEST600030904-03	GREAT BAY PROHIB SZ2	268.964
GREAT BAY	NHEST600030904-04-01	GREAT BAY CONDITIONALLY APPROVED	1153.268
CONDITIONALLY APPROVED	NHEST600030904-04-02	CROMMENT CREEK	16.423
	NHEST600030904-04-03	PICKERING BROOK	53.741
	NHEST600030904-04-04	FABYAN POINT	3.695
UPPER LITTLE BAY	NHEST600030904-06-11	ADAMS POINT TRIB	2.592
	NHEST600030904-06-09	U LITTLE BAY (NORTH)	336.214
	NHEST600030904-06-10	ADAMS POINT MOORING FIELD SZ	92.192
	NHEST600030904-06-12	U LITTLE BAY (SOUTH)	33.896
LOWER LITTLE BAY	NHEST600030904-06-13	LOWER LITTLE BAY	141.883
	NHEST600030904-06-14	LOWER LITTLE BAY MARINA SZ	118.774
	NHEST600030904-06-15	LOWER LITTLE BAY GEN. SULLIVAN BRIDGE	23.245
BACK CHANNEL	NHEST600031001-05	BACK CHANNEL	170.631
LITTLE HARBOR	NHEST600031001-08	WENTWORTH-BY-THE-SEA	5.961
	NHEST600031002-02	LITTLE HARBOR	80.121
WITCH CREEK	NHEST600031002-01	WITCH CREEK	37.772
SAGAMORE CREEK	NHEST600031001-03	UPPER SAGAMORE CREEK	38.794
	NHEST600031001-04	LOWER SAGAMORE CREEK	30.853
SOUTH MILL POND	NHEST600031001-09	SOUTH MILL POND	7.475
NORTH MILL POND	NHEST600031001-10	NORTH MILL POND	31.849
STURGEON CREEK	MEEST600031001-01-50	STURGEON CREEK	14.556
SPINNEY CREEK	MEEST600031001-02-50	SPINNEY CREEK	51.724
SPRUCE CREEK	MEEST600031001-11-50	SPRUCE CREEK	227.903
CHAUNCEY CREEK	MEEST600031001-11-51	CHAUNCEY CREEK	33.198
TOTAL			5466.101

Table 2: Depth, volume and salinity for different segments of the Great Bay Estuary

Aggreggate	Area (ha)	Depth (m)	Total Volume (m3)	Total Volume (m3)	Total Volume (m3)	Salinity	Salinity Average	Freshwater Volume (m3)
Waterbody	MHW	MWL	MWL	MHW	MLW	(N)	(ppt)	MWL
SALMON FALLS								
RIVER	147.841	1.27	1.884E+06	3.363E+06	4.059E+05	62	10.65	1.257E+06
UPPER PISCATAQUA								
RIVER-NORTH	50.797	2.16	1.098E+06	1.606E+06	5.905E+05	116	13.19	6.457E+05
UPPER PISCATAQUA								
RIVER-DOVER	162.28	2.62	4.24CE+0C	5.0000100	2 (245+06	224	10.02	1.7255+06
WWTF UPPER PISCATAQUA	162.28	2.62	4.246E+06	5.869E+06	2.624E+06	324	18.93	1.735E+06
RIVER-SOUTH	115.818	1.96	2.269E+06	3.428E+06	1.111E+06	80	22.24	6.922E+05
LOWER	113.010	1.90	2.209E+00	3.426E+00	1.111E+00	80	22.24	0.922E+03
PISCATAQUA RIVER	636.883	7.92	5.045E+07	5.682E+07	4.408E+07	394	28.55	5.442E+06
UPPER	050.005	7.52	3.0 ISE '07	3.0022.07	1.1002.07	371	20.00	3.1122.00
PORTSMOUTH								
HARBOR	579.965	7.71	4.474E+07	5.054E+07	3.894E+07	231	29.70	3.213E+06
COCHECO RIVER	71.825	1.03	7.403E+05	1.459E+06	2.205E+04	296	6.93	5.800E+05
LAMPREY RIVER	44.053	1.42	6.244E+05	1.065E+06	1.839E+05	709	10.26	4.243E+05
SQUAMSCOTT								
RIVER	124.041	1.50	1.861E+06	3.102E+06	6.208E+05	339	8.10	1.390E+06
OYSTER RIVER	120.093	1.55	1.865E+06	3.066E+06	6.642E+05	285	20.71	6.581E+05
BELLAMY RIVER								
NORTH	65.052	1.01	6.552E+05	1.306E+06	4.649E+03	45	18.52	2.760E+05
BELLAMY RIVER								
SOUTH	111.625	1.63	1.817E+06	2.933E+06	7.005E+05	382	23.54	4.802E+05
WINNICUT RIVER	49.978	0.29	1.443E+05	6.441E+05	0.000E+00	119	14.63	7.833E+04
GREAT BAY PROHIB			• • • • • • • • • • • • • • • • • • • •	4 6 4 0 = 0 6			4 6 0 4	4.00
SZ1	210.126	1.21	2.539E+06	4.640E+06	4.375E+05	76	16.81	1.205E+06
GREAT BAY PROHIB	260.064	0.62	1.6625+06	4.2525+06	0.0005+00	0.5	10.06	( 775F + 05
SZ2 GREAT BAY	268.964	0.62	1.663E+06	4.353E+06	0.000E+00	95	18.96	6.775E+05
CONDITIONALLY								
APPROVED	1227.127	1.28	1.565E+07	2.792E+07	3.379E+06	503	21.92	4.929E+06
U LITTLE BAY	464.894	4.39	2.041E+07	2.506E+07	1.576E+07	726	23.83	5.208E+06
LOWER LITTLE BAY	283.902	5.41	1.537E+07	1.821E+07	1.253E+07	577	25.14	3.297E+06
BACK CHANNEL	170.631	1.21	2.071E+06	3.777E+06	3.646E+05	384	29.79	1.429E+05
LITTLE HARBOR	86.082	1.83	1.579E+06	2.440E+06	7.182E+05	472	29.87	1.429E+05
WITCH CREEK	37.772	0.58	2.193E+05	5.971E+05	0.000E+00	172	19.24	8.750E+04
SAGAMORE CREEK	69.647	0.72	5.037E+05	1.200E+06	0.000E+00	147	28.93	4.836E+04
SOUTH MILL POND	7.475	0.47	3.488E+04	1.096E+05	0.000E+00	218	26.93	5.523E+03
NORTH MILL POND	31.849	1.06	3.368E+05	6.553E+05	1.828E+04	162	21.70	1.084E+05
STURGEON CREEK	14.556	0.23	3.383E+04	1.794E+05	0.000E+00	5	15.50	1.744E+04
SPINNEY CREEK	51.724	2.00	1.034E+06	1.552E+06	5.172E+05	2	27.00	1.616E+05
SPRUCE CREEK	227.903	1.33	3.024E+06	5.303E+06	7.450E+05	16	27.37	4.375E+05
CHAUNCEY CREEK	33.198	1.11	3.678E+05	6.998E+05	3.582E+04	9	29.55	2.816E+04
TOTAL			1.772E+08	2.319E+08	1.245E+08		26.0	3.333E+07
Values from Swift and			405 57 03	445	4=			
* For the methods use			195.5E+06	235E+06	156E+06			

<sup>\*</sup> For the methods used to calculate these values, see the "Volume" section on pp. 2-3 of this report.

Table 3: Stream flow in watersheds draining to the Great Bay Estuary for 1997-2006

Watershed	Average Daily Flow (cfs)	Percent of Total Flow to the Estuary	Drainage Area (mi <sup>2</sup> .)	Runoff Coefficient (cfs/mi <sup>2</sup> .)
Winnicut	24.1	1.4%	14.24	1.69
Bellamy	46.6	2.7%	27.30	1.71
Lamprey	354.4	20.4%	211.56	1.68
Oyster	33.5	1.9%	19.83	1.69
Salmon Falls	393.6	22.6%	235.00	1.68
Cocheco	301.9	17.4%	175.23	1.72
Exeter	187.0	10.8%	106.92	1.75
Great Works	149.4	8.6%	86.70	1.72
Coastal Drainage*	248.1	14.3%	146.65	1.69
Total	1738.7	100.0%	1023.42	1.70

<sup>\*</sup> Coastal drainage area is the total area of the Great Bay Estuary watershed minus the drainage areas for the defined subwatersheds.

Table 4: Surface area of the Hampton-Seabrook Estuary assessment units at mean high water

Aggregate Waterbody	Assessment Unit	Waterbody Name	Area (ha)
HAMPTON FALLS RIVER	NHEST600031003-01	HAMPTON FALLS RIVER	2.868
TAYLOR RIVER	NHEST600031003-02	TAYLOR RIVER	8.555
	NHEST600031003-03	TAYLOR RIVER	12.096
	NHEST600031003-04	TAYLOR RIVER (MARINA)	1.020
	NHEST600031004-02-01	TAYLOR RIVER-DS OF MARINA	2.798
	NHEST600031004-02-02	TAYLOR RIVER	4.772
HAMPTON FALLS RIVER	NHEST600031003-05	HAMPTON FALLS RIVER RESTRICTED TRIB	1.607
	NHEST600031004-01-01	HAMPTON FALLS RIVER (UPPER)	18.360
	NHEST600031004-01-02	HAMPTON FALLS RIVER (LOWER)	15.499
BLIND CREEK	NHEST600031004-02-03	BLIND CREEK	8.419
NUDDS CANAL	NHEST600031004-02-04	NUDDS CANAL	5.461
TIDE MILL CREEK	NHEST600031004-03-01	TIDE MILL CREEK 1	15.773
	NHEST600031004-03-02	TIDE MILL CREEK 2	15.737
HAMPTON RIVER	NHEST600031004-04-01	HAMPTON RIVER 1	40.064
BROWNS RIVER	NHEST600031004-05	BROWNS RIVER	24.494
HUNTS ISLAND CREEK	NHEST600031004-06	HUNTS ISLAND CREEK	6.472
MILL CREEK	NHEST600031004-07	MILL CREEK	12.687
BLACKWATER RIVER	NHEST600031004-08-03	BLACKWATER RIVER	56.873
	NA	BLACKWATER RIVER IN MA	31.470
HAMPTON/SEABROOK HBR	NHEST600031004-09-03	HAMPTON/SEABROOK HARBOR	159.333
	NHEST600031004-09-04	HAMPTON/SEABROOK HARBOR	51.751
TOTAL			496.109

Table 5: Salinity for different segments of the Hampton-Seabrook Estuary

Aggregate Waterbody	Area (ha) MHW	Salinity (N)	Salinity Average (ppt)
HAMPTON FALLS RIVER	2.868	0	NA
TAYLOR RIVER	29.241	204	25.56
HAMPTON FALLS RIVER	35.466	325	26.48
BLIND CREEK	8.419	0	NA
NUDDS CANAL	5.461	0	NA
TIDE MILL CREEK	31.510	6	30.38
HAMPTON RIVER	40.064	129	29.74
BROWNS RIVER	24.494	4	30.28
HUNTS ISLAND CREEK	6.472	0	NA
MILL CREEK	12.687	7	22.46
BLACKWATER RIVER	88.343	106	29.96
HAMPTON/SEABROOK HARBOR	211.084	1501	30.46
Average Salinity*			29.47

<sup>\*</sup>Surface area weighted average

Table 6: Summary of hydrologic data for New Hampshire's estuaries

Parameter	Great Bay Estuary	Hampton-Seabrook Estuary	
Watershed Drainage Area	2650.65 km <sup>2</sup> [1,023.42 mi <sup>2</sup> ]	118.6 km <sup>2</sup> [45.79 mi <sup>2</sup> ]	
Tidal Shoreline (high tide)	324 km [204 mi]	211 km [131 mi]	
Length	25 km [15.5 mi]	NA	
Surface Area (high tide)	54.66 km <sup>2</sup> [21.12 mi <sup>2</sup> ]	4.96 km <sup>2</sup> [1.92 mi <sup>2</sup> ]	
Volume (low tide)	156·10 <sup>6</sup> m <sup>3</sup>	1.9·10 <sup>6</sup> m <sup>3</sup>	
Volume (mid tide)	196·10 <sup>6</sup> m <sup>3</sup>	8.9·10 <sup>6</sup> m <sup>3</sup>	
Volume (high tide)	235·10 <sup>6</sup> m <sup>3</sup>	15.9·10 <sup>6</sup> m <sup>3</sup>	
Volume (tidal prism)	79·10 <sup>6</sup> m <sup>3</sup>	14.0·10 <sup>6</sup> m <sup>3</sup>	
Freshwater volume (mid tide)	33·10 <sup>6</sup> m <sup>3</sup>	$0.7 \cdot 10^6 \mathrm{m}^3$	
Salinity (average)	26.0 ppt	29.5 ppt	
Average Depth (mid tide)	3.2 m [10.5 ft]	NA	
Freshwater Input	4.26·10 <sup>6</sup> m3/d [1739 cfs]	0.19·10 <sup>6</sup> m3/d [78 cfs]	
Freshwater Replacement Time	7.8 days	3.7 days	
Local Residence Time	Great Bay: 20. 4 day Little Bay: 15.7 day Upper Piscataqua: 13.1 day Lower Piscataqua: 11.7 day Portsmouth Harbor: 7.5 day	NA	
Flushing Time (whole system)	28.5 days	<1 day	
NOAA Estuarine Drainage Area	N130X	N140X	
EPA Classification	Group 8	Group 8	
EPA Level III Ecoregion	Ecoregion 59	Ecoregion 59	
Average Tidal Range	2.0-2.6 m [6.4-8.6 ft] 2.5 m [8.3 ft]		

Figure 1: Watershed Areas for the Great Bay Estuary, Hampton-Seabrook Estuary, and New Hampshire's Atlantic Coast

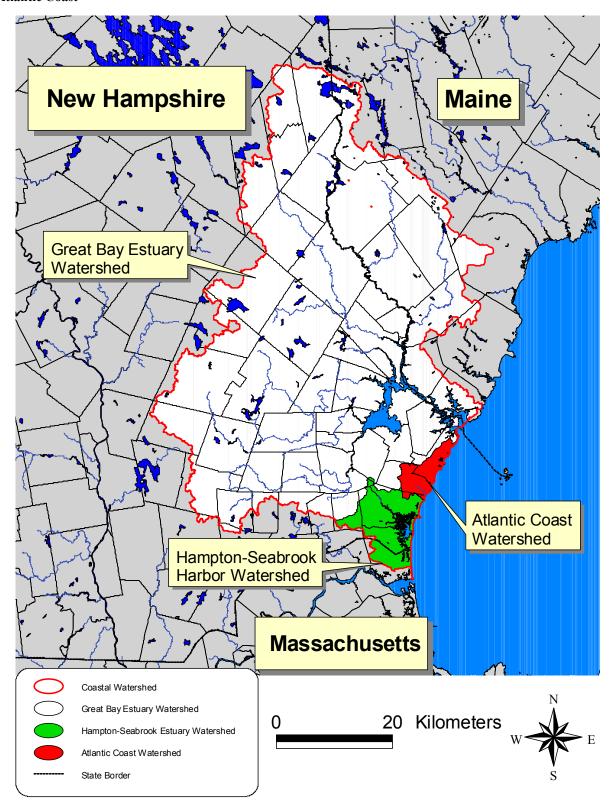


Figure 2: The Great Bay Estuary Watershed

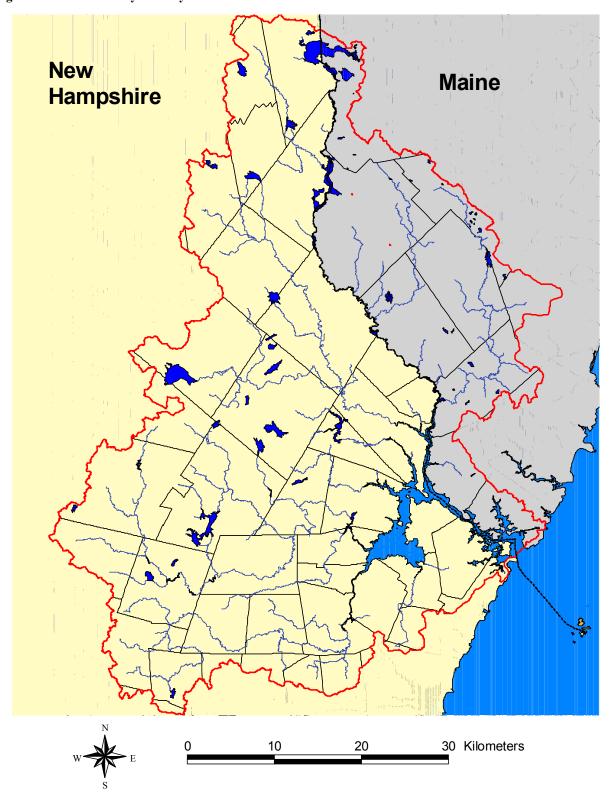


Figure 3: The Hampton-Seabrook Estuary Watershed

