III. DELINEATION OF WATERSHEDS

III.1 BACKGROUND

The Massachusetts Estuaries Project team includes technical staff from the United States Geological Survey (USGS). The USGS groundwater modelers were central to the development of the groundwater modeling approach used by the Estuaries Project. The USGS has a long history of developing regional models for the six-groundwater flow cells on Cape Cod. Through the years, advances in computing, lithologic information from well installations, water level monitoring, stream flow measurements, and reconstruction of glacial history have allowed the USGS to update and refine the groundwater models. The MODFLOW and MODPATH models utilized by to the USGS to organize and analyze the available data utilize up-to-date mathematical codes and create better tools to answer the wide variety of questions related to watershed delineation, surface water/groundwater interaction, groundwater travel time, and drinking water well impacts that have arisen during the MEP analysis of southeastern Massachusetts estuaries, including the Rushy Marsh embayment system. The Rushy Marsh Pond System and its watershed is fully located within the Town of Barnstable, Massachusetts and is situated between Popponesset Bay to the west and Three Bays to the east.

In the present investigation, the USGS was responsible for the application of its groundwater modeling approach to define the watershed or contributing area to the Rushy Marsh Pond system under evaluation by the Project Team. Unlike larger estuaries, Rushy Marsh did not require additional modeling to sub-divide the overall watershed into functional sub-units based upon: (a) defining inputs from contributing areas to each major portion within the embayment system, (b) defining contributing areas to major freshwater aquatic systems which generally attenuate nitrogen passing through them on the way to the estuary (lakes, streams, wetlands), and (c) defining 10 year time-of-travel distributions within each sub-watershed as a procedural check to gauge the potential mass of nitrogen from "new" development, which has not yet reached the receiving estuarine waters. The Rushy Marsh Pond embayment functions as a single horizontally mixed basin. There are no public water supply wells or "significant" streams or fresh ponds (e.g. >10 acres or which capture large amounts of groundwater) within its watershed. Furthermore, given the relatively small watershed, all of the recharged groundwater reaches the estuary in less than 10 years. Therefore a single watershed was used for the Linked Watershed-Embayment Management Model. Rushy Marsh Pond is similar to the larger Oyster Pond Estuary in Falmouth.

The relatively transmissive sand and gravel deposits that comprise most of Cape Cod create a hydrologic environment where watershed boundaries are usually better defined by elevation of the groundwater and its direction of flow, rather than by the land surface topography (Cambareri and Eichner 1998, Millham and Howes 1994a,b). Freshwater discharge to estuaries is usually composed of surface water inflow from streams, which receive much of their water from groundwater base flow, and direct groundwater discharge. For a given estuary, differentiating between these two water inputs and tracking the sources of nitrogen that they carry requires determination of the portion of the watershed that contributes directly to the stream and the portion of the groundwater system that discharges directly into the estuary as groundwater seepage. In the case of Rushy Marsh Pond, direct groundwater discharge was the sole pathway, although a stream may have existed prior to road construction. A field survey did not find any surface water inflow to the Pond of sufficient flow (generally ~0.0005 m^3 s^{-1} is required) to support a MEP stream gauge.

III.2 MODEL DESCRIPTION

Contributing areas to the Rushy Marsh system and local freshwater bodies were delineated using a regional model of the Sagamore Lens (Walter and Whealan, 2005). The USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh et al., 2000) was used to simulate groundwater flow in the aquifer. The USGS particle-tracking program MODPATH4 (Pollock, 2000), which uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer, was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. This approach was used to determine the contributing areas to the Rushy Marsh Pond basin.

The Sagamore Flow Model grid consists of 246 rows, 365 columns and 20 layers. The horizontal model discretization, or grid spacing, is 400 by 400 feet. The top 17 layers of the model extend to a depth of 100 feet below NGVD 29 and have a uniform thickness of 10 ft. Layers 1-7 are stacked above NGVD 29 and layers 8 to 20 extend below. Layer 18 has a thickness of 40 feet and layer 19 extends to 240 feet below sea level. The bottom layer, layer 20, extends to the bedrock surface and has a variable thickness depending upon site characteristics. The rewetting capabilities of MODFLOW-2000, which allows drying and rewetting of model cells, was used to simulate the top of the water table, which varies in elevation depending on the location in the Lens. Since the Rushy Marsh Pond watershed is relatively distant from the top portion of the Sagamore Lens (i.e. it is near the coast), most of the uppermost layers of the groundwater model are inactive in its delineation.

The glacial sediments that comprise the aquifer of the Sagamore Lens consist of gravel, sand, silt, and clay that were deposited in a variety of depositional environments. The sediments generally show a fining downward with sand and gravel deposits deposited in glaciofluvial (river) and near-shore glaciolacustrine (lake) environments underlain by fine sand, silt and clay deposited in deeper, lower-energy glaciolacustrine environments. Most groundwater flow in the aquifer occurs in shallower portions of the aquifer dominated by coarser-grained sand and gravel deposits. The Rushy Marsh watershed is situated in the midst of the very-coarse grained Mashpee Pitted Plain deposits (Masterson et al., 1996). Lithologic data used to determine hydraulic conductivities used in the groundwater model were obtained from a variety of sources including well logs from USGS, local Town records and data from previous investigations. Final aquifer parameters were determined through calibration to observed water levels and stream flows. Hydrologic data used for model calibration included historic water-level data obtained from USGS records and local Towns and water level and streamflow data collected in May 2002.

The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Large withdrawals of groundwater from pumping wells may have a significant influence on water tables and watershed boundaries and therefore the flow and distribution of nitrogen within the aquifer. After accounting for the 15% consumptive loss and measured discharge at municipal treatment facilities, water withdrawn from the modeled aquifer by public drinking water supply wells is evenly returned within designated residential areas utilizing on-site septic systems. Since the watershed to Rushy Marsh is lacking municipal sewers, this area is part of the Barnstable residential area in the groundwater model.

III.3 RUSHY MARSH POND CONTRIBUTORY AREA

Newly revised watershed and sub-watershed boundaries for the Rushy Marsh Estuary were determined by the United States Geological Survey (USGS). Model outputs of MEP watershed boundaries were "smoothed" to (a) correct for the grid spacing, (b) to enhance the accuracy of the characterization of the pond and coastal shorelines, and (c) to more closely match the sub-embayment segmentation of the tidal hydrodynamic model. The smoothing refinement was a collaborative effort between the USGS and the rest of the MEP Technical Team. This task was simplified for Rushy Marsh Pond as the contributing area is best represented as a single watershed and no great fresh ponds (>10 acres) are present. However, the USGS modeled output did require accounting for the grid spacing and incorporation of correct shoreline configuration (Figure III-1).

The daily discharge volume for the watershed was calculated by the groundwater model and the volume was used to assist in the salinity calibration of the tidal hydrodynamic models The MEP delineation determined that groundwater travel times were less than 10 yrs throughout the watershed.

The Rushy Marsh watershed from the USGS modeling effort is estimated to have an average annual freshwater discharge of 249,247 m^3 yr^{-1} to Rushy Marsh Pond. This estimate agrees well with estimates of freshwater input (watershed plus rainfall) calculated from a simple mixing model and measured dilution rates of Rushy Marsh Pond salinities (September 2002 through July 2003), when inputs of tidal water to the Pond were negligible. The freshwater estimate from the salinity dilution model was ~20% less than from the groundwater inflow and net rainwater inputs. However, this most likely results from salt diffusion from the pond sediments or slight amounts of tidal water entering over the sampling interval. The freshwater input estimates based upon salinity dilution were similar for both short (~1 month) and long (9 month) intervals. These data support the areal extent of the watershed delineation from the USGS groundwater model. The watershed delineation completed for the MEP project is the first for the Rushy Marsh Estuary.

The groundwater modeling approach to watershed delineation allows the Rushy Marsh delineation to be brought into congruence with adjacent watersheds and their supporting data. The evaluation of the Rushy Marsh watershed on the local and sub-regional scales (including the incorporation of new and old data) is important as it decreases the level of uncertainty in the final calibrated and validated linked watershed-embayment model used for the evaluation of nitrogen management alternatives. Errors in watershed delineations do not necessarily result in proportional errors in nitrogen loading as errors in loading depend upon the land-uses that are included/excluded within the contributing areas. Small errors in watershed area can result in large errors in loading if a large source is counted in or out. Conversely, large errors in watershed area that involve only natural woodlands have little effect on nitrogen inputs to the downgradient estuary.

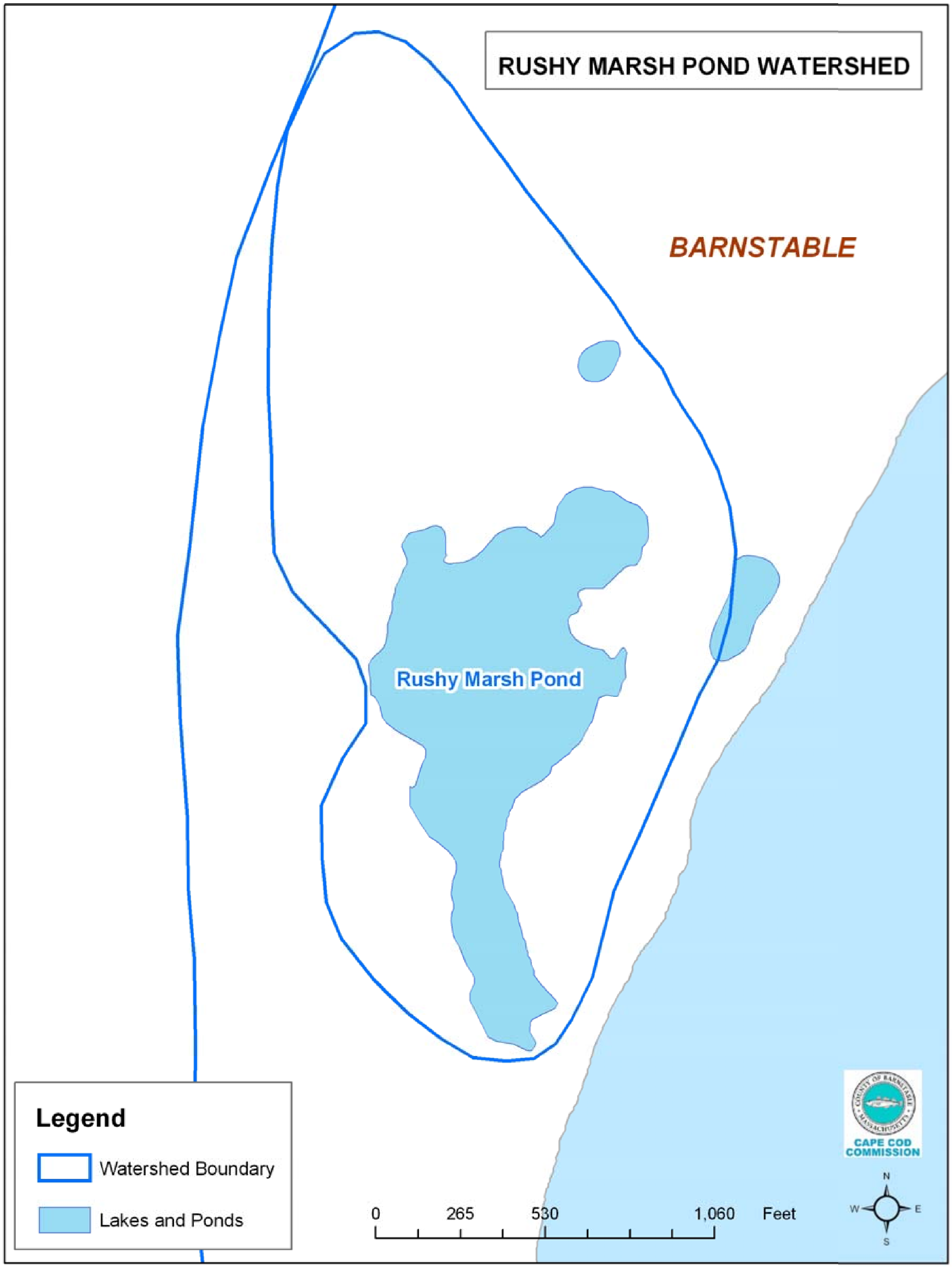

Figure III-1. Watershed delineation for the Rushy Marsh Estuary. All recharge reaches the estuary within ten years. A single watershed to the embayment was selected based upon the functional estuarine unit in the water quality model (see Chapter VI). The Popponesset Bay watershed is to the west.