What History Reveals about Forge River Pollution

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Preface

What History Reveals about Forge River Pollution is the first of a series of synthesis reports dealing with water and sediment quality of the Forge River. These syntheses reflect a cohesive program supported by the New York State Department of Environmental Conservation, Suffolk County Department of Health Services, and the Town of Brookhaven. The remaining reports summarize the data and information that have been collected as part of the project. In addition to elucidating the pollution problems of the Forge River, they will cover:

- water circulation
- nutrients
- sediments
- ecology

This report summarizes the development and utilization of the surface watershed including population growth, the duck farming industry, and dredging of the river. Historical water quality data as measured by nitrogen, phosphorus, and phytoplankton is also reviewed. The influence of Moriches Inlet on the hydrography of the bay is discussed in the context of water quality.

Introduction

The polluted condition of the Forge River reflects the anthropogenic development of the area. It is an ecosystem that has been under stress for the better part of a century. The Woods Hole Oceanographic Institution (WHOI), in the 1950s, referred to the tributaries of Moriches Bay (Forge and Terrell Rivers) as "objectionable" and "highly contaminated" (Redfield, 1952). The pollution problems of the bay were highlighted as a case study in a report of the Environmental Pollution Panel of the U.S. President's Science Advisory Committee in 1965. Additionally, physical changes such as the natural and artificial opening and closing of breaches and inlets in the barrier beach have been especially influential in altering that ecosystem as well.

The Forge River (Figure 1) has been known as Moriches Creek, as labeled on the Colton Map of 1836, and the Mastic River (Thompson, 1843). *The Atlas of Long Island, New York*, published by Beers, Comstock and Cline (1873) identifies the river as the Forge. It is a remnant streambed that cut through the southerly slopping glacial outwash plain deposited during the Wisconsin glaciation that ended some 20,000 years ago. The stream valley flooded as sea level rose and it now functions as a small estuary torpidly flowing into the northwest portion of Moriches Bay, a coastal lagoon protected from the Atlantic Ocean by a barrier island system.

The river watershed, with the exception of the northeast corner (Zone III), falls within Hydrogeologic Zone VI of Suffolk County. This zone is on the south shore of Long Island and discharges to stream flow and underflow to Moriches Bay and Great South Bay (Koppelman et al., 1992). Generally, the Soil and Conservation Service classifies the soils of the Mastic, Shirley, Moriches area as part of the Riverhead-Plymouth-Carver association (Table 1) (Warner et al., 1975). These soils are described as "deep, nearly level to gently sloping, well-drained and excessively drained, moderately coarse textured and coarse textured soils on the southern outwash plain." These largely unconsolidated soils allow for efficient transport of water through the relatively shallow vadose layer (soils above water table) into the aquifer and thence the river and bay. Valiela and Kinney (2008) note this same condition for Great South Bay.

At the scale of the watershed, the river (Figure 2) cuts through zones of Carver-Plymouth sands, Riverhead sandy loam, and Plymouth loamy sand (Warner et al., 1975). A key to the symbols on the map is indicated in Table 2. Note the land filled with dredge material near the entrance to Ely Creek. The surface soils throughout the drainage basin have been locally modified from those originally laid down as cut and fill techniques have been used for the extensive housing developments in the area. A description of the relevant soil types is shown in Table 1. Groundwater contamination from cesspools and septic tanks are generally associated with these soil types when the groundwater table is shallow (http://www.chipr.sunysb.edu/eserc/longis/geralsoilmap.html, downloaded 6 Nov. 2007) as is the case in this system. Munster et al. (2004) argued that the nitrate signal found in groundwater monitoring wells in Suffolk County is closely related to land use. Specifically, ground water near residentially developed areas using septic tanks and cesspools and having lawns can be distinguished from ground water associated with other land use categories such as open space or communities that have sewage treatment.

The surface watershed of the Forge River (Figure 3) including the river and all streams and tributaries is 43.06 km^2 (10,641 acres). The basin, not including the river, streams and tributaries, is 39.93 km^2 (9868.2 acres). Some 8.49 km^2 (2098 acres, 21.3 percent) of the northeast portion of the terrestrial part of the drainage basin (mostly north of Montauk Highway) are in the deep groundwater recharge zone (Zone III).

Redfield (1952) found that the volume of groundwater seepage to Moriches Bay was roughly 3.6 times that of stream flow. SoMAS found, based on a salt balance over a tidal cycle in the upper Forge River in 2007, that seepage was double that of stream flow. Over the period of December 1947 to April 1948, the measured flow of the east and west branches of the Forge River at Montauk highway (where the East and West Ponds converge) was $21.6x10^3$ m^3/day ($0.764x10^6$ ft^3/day) (Redfield, 1952). Stream flow measurements, using a flow meter, at the discharge of East and West Ponds in January 2007 by SoMAS amounted to $37.1x10^3$ m^3/day ($1.31x10^6$ ft^3/day).

Human Development

The flow in the Forge River was probably altered when West Pond was created. The colonial and post-colonial periods were when other streams and rivers were dammed in the area. For example, the Terrell River was dammed in 1737 (Field, 2005). West Pond is delineated on the 1836 Colton *Map of Long Island with Environs of New York and the Southern Part of Connecticut.* This map also indicates that manufacturing or milling was taking place on the Forge and may be the source of its modern name. By 1873, the *Atlas of Long Island New York* (Beers, Comstock & Cline, 1873) shows that there were two ponds, East and West Ponds or the twin ponds. The present Montauk Highway crosses the twin ponds at the dam. Dams, once constructed, were the logical locations to ford streams and rivers (Field, 2005) and Montauk Highway meanders to intersect these crossings throughout the area.

Forge River flow was further altered in the late 1800s at the time the Montauk branch of the Long Island Railroad was constructed. The 1896 Beers, Comstock & Cline map indicates that tracks over the Forge were completed. The railroad overpass does not appear to excessively restrict the river on the 1903 U. S. Geological Survey Quadrangle Map of Moriches (scale: 1:62,500). *The Long Island Advance* (2009) notes that in 1909 the wooden railroad bridge over the Forge was "completely destroyed by fire." The 1947 Quadrangle map (scale: 1:24,000) clearly delineates that the new overpass was constructed on fill extending from both banks across most of the width of the river, as is the case now (U.S. Geological Survey, 1947) (See Figure 1). This restriction has constrained the natural flow and for all practical purposes eliminated any navigability that might have been possible between the railroad bridge and Montauk Highway.

The population of the entirety of the Town of Brookhaven was 14,592 in the 1900 census (Long Island Regional Planning Board, 1982). In 1960, the combined populations of Mastic, Mastic Beach, and Shirley were 8952 (Table 3). These hamlets approximate the boundaries of the drainage area with the exception of the southeastern part of the basin. The southeasterly portion of the drainage basin does not appear to have been heavily populated at that time based on aerial photography. By 1980, these community boundaries had been adjusted (Long Island Regional Planning Board, 1982) so that Mastic, Mastic Beach, Shirley, and Moriches more closely corresponded to the surface watershed but again excluded a segment to the southeast. The 2005 population estimate for these hamlets was 59,000 (Long Island Power Authority, 2005). Relative to 1960, this is a population increase of 559 percent (Figure 4).

The greatest rate of population growth, on a decadal basis, was that between 1970-1980 when there was a 146 percent increase. During the same period, the Town of Brookhaven population increased by 49 percent. The Forge River Watershed Map (Figure 3) depicts that most of the west side of the drainage basin with the exception of the William Floyd Estate (part of the Fire Island National Seashore) is designated as high density (5-12 housing units /acre), medium density (2-4 housing units/acre) and low density (1 unit or less/acre) residential with some commercial use, particularly along Montauk Highway (Suffolk County Department of Planning, James Bagg, personal communication, Nov. 2, 2007). The William Floyd Estate at the mouth of the Forge River consists of 2.48 km^2 (613 acres) of marsh, woods, and fields as well as the estate buildings. The land use on the east side of the Forge River is much more mixed but still has considerable high and mixed residential.

Low, medium, and high-density residential zoning in the watershed (Figure 3) is currently estimated to be 4.28, 10.11, and 2.65 km^2 (1058, 2498, and 655 acres), respectively (Kathyrn Oheim, Suffolk County Department of planning, personal communication, Nov. 2, 2007). Thus, housing represents 42.7 percent of the total upland acreage of the watershed. About 6.43 km^2 (1590 acres) (16.1 percent) remain vacant and 4.35 km^2 (1075 acres) (10.9

percent) are devoted to recreation and open space. Wetlands, a portion of that open space, were mapped by the New York Department of Environmental Conservation in 1974. Using a planimeter, we measured the area of those wetlands along the Forge to be 0.13 km^2 (33.1 acres).

Mastic Neck, in early post-colonial times, was divided into farms that extended from Moriches Bay to the north for "some miles" (Thompson, 1843). Thompson stated that most farms of southern Long Island could be described as having salt meadows on the south of the property, cleared land in the middle, and wooded land on the north. In 1843, four such farms were identified as having been or still in the ownership of the families of General Woodhull, Richard Floyd, William Floyd, and William Henry Smith. Moriches, on the east side of the Forge River, was also noted for its good farming environment (Thompson, 1843). Moriches Bay was rich in resources such as "salt grass," fish used for fertilizer, and bass and other fishes (Thompson, 1843).

Apparently, the trend toward high-density residential development began in the early 1920s when the Smadbeck brothers using land purchased from August Floyd and William Dana created Mastic Park--a vacation/recreational area (Spooner, 2004). The brothers innovatively used the newspaper, *The Brooklyn Citizen*, to promote the development with advertisements that stated "The oft predicted Long Island Boom has started," "The beautiful Forge River winds its way through Mastic park," "full price only $ 55 per lot payable $ 10 down and $ 3 monthly" (Spooner, 2007). By 1926, the Smadbecks began development at Mastic Beach (Spooner, 2004) at "slightly higher" prices per lot.

Dredging the River

The Forge River is naturally shallow. The U.S. Coast and Geodetic Survey (1891) completed a hydrographic survey of Moriches Bay including the Forge River in 1891, prior to major duck farming in the area. This was followed by a more detailed survey in 1933 (Figure 5) (U.S. Coast and Geodetic Survey, 1933a). The depths from north of Lons Creek to Ely Creek were typically 1.2 m (4 ft) relative to mean low water (MLW). Depths of 0.6-0.9 m (2-3 ft) were found between Wills Creek and the current location of the Waterways Condominiums Marina. At the site of the present Brookhaven Town Dock, the depth was 0.91 m (3 ft) from the west bank well beyond mid-channel. North of Waterways Condominium Marina to the railroad bridge, typical depths were 0.3-0.6 m (1-2 ft).

A depth profile constructed from the 1891 and 1933 hydrographic surveys along the center of the river between Masury Point and the railroad bridge is shown in Figure 6. Both surveys were referenced to MLW. However, MLW varies with fluctuation in sea level. The 11.6 cm (0.38 ft) increase in MLW over the 42 years between surveys has been applied in Figure 6. For all practical purposes, there was no change in depth in four decades.

Because there was no opening to the ocean through a barrier beach in the early 20th century, there probably wasn't a large navigational need to consider dredging the Forge at the time. The first reported dredging of the river occurred in 1965 when some 203,300 m^3 (265,900 yd^3) of spoil, including spoil containing duck waste sludge, were removed for pollution control and to create the main navigational channel up the river. This channel was reported on Nautical

Chart 12352 (National Oceanic and Atmospheric Administration, 2006) to be 2.1 m (7 ft) deep and about 30.5 m (100 ft) wide. Subsequent to the original dredging, duck sludge was removed and small channels leading into most of the creeks along the river were created over the period of 1967-1973. In 1999, the southern portion of the Forge River out to the Intercoastal Waterway was dredged. Suffolk County Department of Public Works reports that 30,585 m^3 (40,000 yd^3) were removed at that time (Tom Rogers, personal communication, Oct. 31, 2007). Approved dredged depths are 1.8-2.4 m (6-8 ft). Thus, in excess of 0.84×10^6 m^3 (1.1×10^6 yd^3) were dredged from the Forge for polluted sediment removal and navigational purposes between 1965 and 1999 (Table 4).

The Intercoastal Waterway in Moriches Bay is part of a much larger Federal project extending from Patchogue to Shinnecock Canal. It was authorized in 1937 as part of the Rivers and Harbors Act and completed in 1940 (Suffolk County Planning Department, 1985). The channel is 30.5 m (100 ft) wide and 1.8 m (6 ft) deep. Continual maintenance dredging has been required at various locations within Moriches Bay. Suffolk County noted that such dredging occurred in 1943, 1949, 1956, 1957, 1959, 1962, 1963, 1965, 1968, 1970, and 1974 (Suffolk County Planning Department, 1982).

According to Jeffrey Kassner (Town of Brookhaven, personal communication, 2007) about 61,170 m^3 (80,000 yd^3) of material were removed from the Intercoastal Waterway between East and West Moriches over the period of October 2002-January of 2003. The authorized 1.8 m (6 ft) depth was maintained and the spoil disposed on East Inlet Island as nesting habitat for colonial water birds (Jeffrey Kassner, Town of Brookhaven, personal communication, 2007).

Moriches Inlet

Fire Island, a 48 km (25.9 nautical miles) barrier beach, and Westhampton Beach are integral parts of the Long Island south shore lagoonal regime. Oceanographically, these systems are distinct from classic estuaries in that they lack major riverine sources of fresh water and their openings to the sea are restricted.

Fire Island, now stretching from Fire Island Inlet to the westward and Moriches Inlet to the east, protects the western one-third of Moriches Bay and the eastern two-thirds of Great South Bay from exposure to the open Atlantic Ocean. Westhampton Beach is 24.6 km (13.3 nautical miles) long and extends from Moriches Inlet to Shinnecock Inlet. This barrier island forms the southern shore of eastern Moriches Bay. The extremes of the island are now artificially stabilized, but that has not always been the case. Moriches Inlet was opened to the sea between 1797 and 1829 at which time it closed (Redfield, 1951); subsequently it was breached in the March 1931 nor'easter. Shinnecock Inlet was opened during the great 1938 hurricane on September 21, the time of a spring tide (Leatherman, 1989). Figure 7 shows the history of breaches dating back to the 18th century (U.S. Army Corps of Engineers, 2004).

Suffolk County experimented with dredging channels in Moriches Inlet as early as 1933 (U.S. Coast and Geodetic Survey, 1933b) for the purpose of creating a stable inlet. Apparently, according to the same reference, the hypothesis was that a deep channel would be more permanent than a shallow channel. The approximately 365 m (1200 ft) channel located 1.59 km (0.86 km nautical miles) southeast of Tuthill Point was completed on October 1, 1933 and was

91 m (300 ft) wide and 1.83 m (6 ft) deep. The present inlet is about 1.1 km (0.6 nautical miles) to the west of the inlet then.

Moriches Inlet migrated westward more than a kilometer by 1947 at which time a jetty was constructed on the west side of the opening in order to stabilize it (Kassner and Black, 1982). This jetty, on the downstream side of the prevailing westward transport of sand in the littoral zone, contributed to the shoaling and closure in 1951 (Kassner and Black, 1982). Moriches Inlet remained closed from May 1951 to the spring of 1954. At that time of closure, Fire Island extended some 24 km (13 nautical miles) further east to Shinnecock Inlet. After reopening in 1954 partially due to dredging and partially due to a hurricane (Kassner and Black, 1982), Moriches Inlet was widened in 1958.

Pagenkopf and Bigham (1977) divided the history of Moriches Inlet into five time periods based on various combinations of opening and closing of Moriches and Shinnecock Inlets (Table 5). Kassner and Black (1982) subsequently added a sixth period following a breach to the east of Moriches Inlet in 1980. This latter period might be extended despite in December 1992 two breaches being formed just south of Remsenburg at Pikes Inlet and Little Pikes Inlet (Jeffrey Kassner, Town of Brookhaven, personal communication, 2007). These two breaches were closed by September 1993 (Conley, 1999) and both Shinnecock and Moriches Inlet remain opened. It should be pointed out that breaching is actually rather common. Breaches along Westhampton Beach occurred in 1950 (nor'easter), 1954 (probably Hurricane Carol) and 1962 (Ash Wednesday nor'easter) but they filled in rapidly.

The unstable geomorphology of Fire Island and Westhampton Beach has had a pronounced effect on the physical oceanographic conditions of Moriches Bay and consequently its biological community. Water quality in the bay and exchange of water with Great South Bay and Shinnecock Bay are also largely controlled by this same geomorphology.

The extent of Moriches Inlet instability is documented (U.S. Coast and Geodetic Survey, 1933b) in the Descriptive Report that accompanies the 1933 hydrographic survey. "Channels crossing the sand flats shifted with every change of tide and one day's work could not be made to check with the next."

Location and size of inlets are a dominant feature in determining the salinity regimes of Moriches Bay. In the 1950s, WHOI conducted a series of studies assessing the impacts of the Long Island duck farming industry on the water quality of Great South Bay and Moriches Bay. These studies spanned a period when Moriches Inlet was alternately opened, closed, and reopened. During this period, Shinnecock Inlet was continuously opened. Guillard et al. (1960) showed that the salinities in Moriches Bay were on the order of 10 practical salinity units (psu) lower when the inlet was closed relative to it being opened. However, they also pointed out that salinity of the bay is quite dependent on precipitation.

Over the period 1940 to 1951, the range of tide in Moriches Bay decreased from 0.21 m (0.7 ft) to 0.07 m (0.22 ft) (Redfield, 1952), the gradual effect of inlet shoaling. The tide range at East Moriches (U.S. Coast Guard Station) slowly increased some 0.06 m (0.2 ft) after the inlet was reopened and when the inlet was deepened and widened in 1958, the tidal range jumped to 0.18 m (0.6 ft) (Guillard et al., 1960).

Flow through Moriches Inlet has varied considerably with time because of its propensity to shoal. Redfield (1951) reported that in 1939 approximately 28.3×10^6 m^3 (1000×10^6 ft^3) of water per tide flowed through the inlet. (This is interpreted to mean that roughly 28.3×10^6 m^3 (1000×10^6 ft^3) flowed in on flood and 28.3×10^6 m^3 (1000×10^6 ft^3) flowed out on ebb.) By 1950, just prior to complete closure in 1951, that flow had been reduced to 1.1×10^6 m^3 (40×10^6 ft^3) to 1.7×10^6 m^3 (60×10^6 ft^3) per tide. According to Redfield (1952), the U. S. Army Corps of Engineers determined that in 1949 the net flow out of the bay over a 12.42 h tidal cycle at Moriches Inlet was 0.5×10^6 m^3 (17×10^6 ft^3); for the entire bay including Moriches Inlet, Quogue Canal, and Narrow Bay, the net flow out was 1.6×10^6 m^3 (56×10^6 ft^3) (Table 6).

Following the reopening of Moriches Inlet in 1954, Bumpus et al. (1954) estimated that the average volume flowing through Moriches Inlet on flood was about 4.0×10^6 m^3(140×10^6 ft^3). A similar volume was transported out on ebb. This was a 20 percent increase over the 1949 U.S. Army Corps of Engineers' estimates reported by Redfield in 1952.

In 1958, the Northwest Passage just inside Moriches Inlet was widened to 61 m (200 ft) and deepened to 3.0 m (10 ft) (Kassner and Black, 1982). This opening did increase the tidal range in the bay but, based on limited data, apparently didn't have as positive an effect on reducing the pollution in the bay as was perhaps anticipated. Ryther et al. (1958) reported this following WHOI's many years of work in the bay over a variety of changes in oceanographic, meteorological, and pollution conditions in the 1950s. The conditions are summarized in Table 7. While data collection and analytical techniques were limited compared with today, the WHOI group was able to ascertain that pollution conditions throughout the bay were dependent upon complex interactions of a number of environmental conditions.

Apparently the 1954 dredging of the Northwest Passage led to erosion of the Westhampton Beach barrier island to the east of the east jetty that supposedly stabilized the inlet (Suffolk County Planning Department, 1982). Subsequently, the State of New York closed the channel in 1962 (Kassner and Black, 1982). The consequence was once again deteriorating water quality and thus Suffolk County redredged the Northwest Passage in 1966 to a depth of 3.7 m (12 ft) with a 91.4 m (300 ft) width (Suffolk County Planning Department, 1982).

The WHOI group concluded in 1957 that "If improved conditions in Great South Bay are to continue, it is mandatory, in the opinion of the group, that Moriches Inlet be widened, deepened and stabilized as quickly as possible." However, by 1958, that view had changed somewhat based on the variety of conditions experienced over the better part of a decade. They began to understand that Moriches Bay conditions depended on the complex interactions of flushing via Moriches Inlet, amount and timing of precipitation, and wind conditions. In fact, they said, "Despite the fact that Moriches Inlet was dredged in the spring of 1958, there is no indication that increased tidal flushing played an important role in cleansing the bays." "Thus, the dredging of Moriches Inlet in spring 1958 may have prevented further deterioration of conditions, but does not appear to have improved them significantly." Their bottom line was to stop the pollution at the sources unless the inlets in Moriches Bay and Great South Bay were significantly widened. In fact, Redfield (1951) summarized "---it would seem more effective and economical to attempt to reduce the pollution, rather than to compensate for it by excess enlarging the openings in the beaches."

The breaches at Pikes Inlet and Little Pikes Inlet in 1992 did have an effect on the tidal range several kilometers away. While Little Pikes Inlet was open, the mean range was 0.81 m (2.7 ft). Following closure, the mean range was reduced to 0.62 m (2.0 ft) at Speonk (Conley, 1999). Salinity near the breach increased about 1.4 psu but measurable changes weren't recorded at the extremities of Moriches Bay (Conley, 1999).

Duck Farming

Duck farming on Long Island, known as "duck ranching," commenced in the 1880s (Suffolk County Department of Planning, 1982). During the early 1960s, at the peak, some 7.5 million ducks were produced in Suffolk County each year. About 20 years earlier there were as many as 90 ranches (Ron Verbarg, Suffolk County Department of Planning, personal communication, 2007).

In 1931, duck ranching in the Forge River drainage basin (Figure 8) occurred along the creek north of West Pond, along both sides of East Pond, along Swift Creek, just south of Montauk Highway on the west side of the river, the north shore on Ely Creek, and along the south shore of Old Neck Creek. There had already been a ranch that had ceased operation on the east bank of the Forge River, north of Ely Creek (Suffolk County Department of Planning, 1982). Suffolk County records (Figure 8) indicate that, throughout the history of the duck industry on Long Island, there were ten areas in the Forge River drainage basin where ducks were reared (Ron Verbarg, Suffolk County Department of Planning, personal communication, 2007) although only eight ranches are actually named.

Regulation of the discharge of wastes from duck farms has been incrementally implemented beginning as far back as 1951. At that time, diking of the duck impoundments began in order to remove direct discharges to coastal waters although Redfield's (1952) sketch of a "typical" duck ranch does not include any diking.

Following the WHOI pollution studies of Moriches Bay in the 1950s, a letter was written in 1963 by the Southampton Town Baymen's Association to the governor of New York expressing concern about the duck ranching pollution. The Riverhead Town Board also passed a resolution expressing similar concerns addressed to the New York State Departments of Health, Environmental Conservation and the Suffolk County Health Department. The Suffolk County Department of Health initiated investigations of the status on duck waste treatment in the same year (Villa, 1964). Villa (1964) concluded that these actions led to improved enforcement but that more stringent regulations were needed.

There were 52 duck ranches using 59 growing areas at the time in Suffolk County. Apparently only 48 ranches were active, however (Villa, 1964). Eight ranches were located in the Forge River drainage basin producing from about 50,000 to 150,000 ducks per ranch annually. Three were located north of Montauk Highway. The effluent from these facilities was discharged into the stream at locations about 1.6 km, 0.8 km, and 0.4 km (1 mile, 0.5 miles, and 0.25 miles) north of the twin ponds. Three discharged directly to the Forge River and two discharged to Old Neck Creek (Villa, 1964). At the time, New York State Department of Health only required removal of "settleable solids" before effluent was discharged to receiving waters. Most ranches employed upland lagoons to remove solids (Villa, 1964).

These eight operations produced about 870,000 ducks in 1963. While none of the approved waste management facilities were totally compliant, there was no legal action recommended at the time of the inspections (Villa, 1964). Production was reported to be the same in 1966 (Federal Water Pollution Control Administration, 1966). According to the Suffolk County Planning Department (1982), most ranches continued to discharge to open waters until 1965. New York State imposed primary sewage treatment (settling, aeration, disinfection) to be in place by 1968 (Suffolk County Planning Department, 1982).

By 1982, there were only 22 duck ranches remaining in operation in Suffolk County but they were still producing about 4.5×10^6 ducks per year. Most of the duck industry was concentrated on Moriches Bay at the time but there were only two operating in the Forge River drainage basin. These were located north of the twin ponds (Suffolk County Planning Department, 1982) and are the sites of the current remaining duck ranches. The maximum number (maximum number at any given time) of ducks on these two properties in 1982 was 91,000 about evenly split between the two (Suffolk County Planning Department, 1982).

At the time of the Planning Department's 1982 study, the raising of ducks in the area could be undertaken about 35 weeks per year, although some operations apparently could function year round. It was estimated that five generations of ducks were produced annually, assuming it took seven weeks for a duck to reach marketable size. Using the County's assumptions, the annual production of ducks in the Forge River drainage basin was 455,000 (5 generations x maximum number of ducks reported per generation) (Suffolk County Planning Department, 1982).

The county estimated that it took 4.4 ducks to produce the nitrogen equivalent of one human (Suffolk County Planning Department, 1982). That being so, the 1963 and 1982 human population equivalents for the ducks produced were 198,000 and 103,000, respectively. Of course the duck wastes were concentrated in a much smaller area than the wastes of the human population and effluent was discharged to surface waters, not to ground water.

Recently, based on data and information from the Cornell University Duck Research Laboratory, the former ratio of duck to human nitrogen generation in waste has been altered to reflect the actual life cycle of the ducks on the site as they were raised for market. These studies indicated that a normal human consuming a normal diet generates 20 g (0.044 lb) of nitrogen per day or 7300 g/year (16.10 lb/year). A duck, over the seven weeks of growth, excretes 93.6 g (0.206 lb) of nitrogen. Added to this waste is an additional 10.6 g (0.023 lb) nitrogen per marketed duck for the brooder duck waste, assuming that the brooder generates 100 ducks per annum. The brooder lives year round. This results in 104 g (0.229 lb) nitrogen per marketed duck (Dean, 2005).

On a daily basis, the 104 g (0.229 lb) of nitrogen per marketed duck amounts to 2.1 g (0.0046 lb) (7 weeks or 49 days). Thus, it takes about 9.5 ducks to produce the same amount of nitrogen in excrement as one human at 20 g/day. The duck rearing practices make a great deal of difference with regard to the timing and actual amount of nitrogen released to the environment.

Using the above (104 g of nitrogen per marketed duck) and normalizing to a 365-day-year, the approximate human population equivalent for the 1963 and 1982 ducks marketed amounts to 12,400 and 6500, respectively. In human terms, the combined population of people and duck equivalents was about 23,500 in 1963 and 47,100 in 1982 (interpolated from population data in Table 3).

Today there are still two ranches left but the same proprietor operates them. One discharges to West Pond and soon will be required to have tertiary treatment of its duck waste; the other to a treatment lagoon that discharges to ground water (Anthony Leung, New York State Department of Environmental Conservation, personal communication, Nov. 20, 2007). State Pollution Discharge Elimination System (SPDES) permits are issued and at least in the case of the remaining ranch that discharges to West Pond, tertiary sewage treatment is required (i.e., nitrogen removal). Approximately 80,000 ducks are kept at any one time, yielding 400,000 ducks for market based on the previously mentioned production model. The largest ranch produces about 275,000 ducks.

This amounts to a total population of 5700 in terms of human equivalents for the two ranches producing 114 kg/day (251 lb/day) of nitrogen when averaged over a year. However, when the largest ranch implements tertiary treatment and assuming a 90 percent reduction in nitrogen released to water only, the daily load to the watershed will be 7.8 kg (17.2 lb) from the largest ranch and 35.6 kg (78.5 lb) from the other ranch. The annualized mass loads of nitrogen from ducks and people are shown in Table 8 and Figure 9.

The U.S. Department of the Interior in 1968 determined that there were 3.98×10^6 m^3 (5.21×10^6 yd^3) of duck sludge in the tidal portion of the Forge River that included both Ely and Old Neck Creeks. For the entire bay the estimate was 5.58×10^6 m^3 (7.3×10^6 yd^3) (Suffolk County Planning Department, 1982). These estimates were based in part on the organic content of sediment samples. Some duck waste sludge was dredged (Table 4), along with the navigation dredge spoils over the period 1965-1973.

The number of ranches on the Forge was small compared to the total located on the bay. Yet about 71 percent of the polluted sediments thought to be in the bay's tributaries were in the Forge. Reasons for this may be the size of the ranches (Forge River ranches appear to have produced nearly double the number of ducks compared to other ranches on the bay in 1963), the age of the ranches, and the fact that the Forge may be much more sluggish than the other bodies of water receiving duck wastes.

The sediments in the Forge River were most likely muddy and organic rich well before colonial times. The U.S. Coast and Geodetic Survey (1891) hydrographic sheet indicates that the surficial sediments of the center of the river were "soft." The 1933 hydrographic survey (U.S. Coast and Geodetic Survey, 1933a) was a little more specific, calling the sediments "muddy" throughout (Figure 5).

The Woods Hole Oceanographic Institution suspected that suspended solids polluted with duck wastes had accumulated to "deposits more than ten feet deep" (Redfield, 1952). Nichols (1964) described the tributary sediments leading to the bay as "soupy, black, clayey" with an odor of hydrogen sulfide (H_2S). They lacked internal structure and also benthic invertebrates and foraminifera. Diatoms apparently were present (Nichols, 1964). The organic content of duck-sludge-polluted sediments was enriched relative to typical muddy sediments. The Suffolk County Planning Department (1982) stated that 18 percent organic content can be expected in the duck-sludge-polluted sediments compared to typical muds which have about 10 percent organic content. Nichols (1964) identified the sediments of the Forge as having a maximum organic content of 21 percent dry weight just off Poospatuck Creek.

None of the five duck ranches that were located along the tidal Forge (Figure 8) are still in operation. The one located along Swift Creek on the west side of the river is partly used as a shopping center and as open space. The four on the east side of the Forge are now used primarily for housing.

Water Quality

Review of the histories of development in the Forge River drainage basin and of the natural processes affecting the river elucidates some of the reasons why the river is especially sensitive to man's activities, and its water and sediment qualities are considered unacceptable. The river is naturally sluggish, with relatively low current speeds. The nutrients and organic matter discharged into it are not readily flushed as evidenced by the extensive accumulation of fine-grained organic sediments along the river bottom. These sediments are highly enriched with organic matter, a large reservoir of nutrients and oxygen demand that contributes (along with existing pollutant inputs) to summer-long depletion of water column oxygen. The small stream flow to the river also inhibits estuarine pollutant transport out of the river. Fresh water is trapped on the rising tide and is only released as the tide falls, according to Redfield (1952), and substantiated in 2006 salinity measurements by SoMAS.

The low stream flow to the Forge is a consequence of the permeable soils throughout the watershed. Most freshwater flow to the river is via groundwater seepage. A large portion of the flows from tributaries and East and West Ponds is most likely the result of groundwater discharge as well. As the water table of the drainage basin is shallow < 3.0 m (≤ 10 ft), waste products that leach or are flushed into the soils tend to seep into the river and eventually the bay.

The duck ranches that fringed parts of the Forge River in the mid-20th century were determined to be a significant factor contributing to its deplorable condition. Phosphorus was found to be a good indicator of pollution in Moriches Bay (Bumpus et al., 1954). This interpretation was based on comparison of phosphorous to nitrogen ratios in duck farm-affected Moriches Bay and contributory tidal rivers. Duck excrement is highly enriched in phosphorus in comparison to the nitrogen. Thus, following utilization of nitrogen by phytoplankton and algal growth, phosphorous remained in the water; consequently nitrogen was the limiting nutrient. At the time, Redfield (1952) indicated that the N: P ratios were 3.3:1, 3.6:1, 6:1, and 15:1 for duck waste, Terrell River, Moriches Bay, and ocean waters, respectively . Therefore, the nitrogen in the form of duck waste added to the tributaries, like the Forge River, stimulated phytoplankton growth to such an extent that hypoxic and anoxic conditions in riverine waters resulted. Redfield (1952), based on work in the Terrell River, found that the nitrogen in uric acid from the duck waste was transformed to soluble forms of nitrogen easily useable for phytoplankton production during transport to the central bay. A similar situation existed in the Forge. It is of interest to note that uric acid levels are greatly reduced in the Forge River, and levels in Moriches Bay have decreased over the past few decades and are now undetectable. It is not obvious, however, that such trends are indicative of changes in pollution inputs from duck ranches on the Forge and elsewhere in the system.

Since the WHOI studies of the 1950s, the Suffolk County Department of Health Services measured phosphorus and ammonia concentration data over the period 1977 to 2006 in Moriches Bay which have been plotted in Figure 10 for station 080110 (0.32 km, or 0.2 miles, west-southwest of Masury Point). The timing and frequency of data collection varied considerably within and among years. Nevertheless, phosphorus concentrations generally appear to have declined (including many more non-detects in recent years) while ammonia concentrations remained steady. Nitrite plus nitrate concentrations appear to have slightly increased with time (Figure 11). The ratio of nitrogen to phosphorus (Figure 11) increased with time over the three decades. The latter may be indicative of the reduced influence of duck ranching as facilities closed and treatment of the wastes from those remaining became more stringent.

Nichols (1964) summarized the sequence of WHOI studies showing that oxygen saturation in summer in the bay improved with Moriches Inlet opened. In the tributaries (i.e., Forge River) however, oxygen saturation indicated nearly anoxic conditions at night when the inlet was closed.

The species of phytoplankton varied from year to year, as did the general water quality condition. It was suggested that there was a relationship between the status of pollution and species composition that was controlled by complex interactions such as the inlet being opened or closed, precipitation, solar radiation, and wind. For example, pollution was rated as being low in 1958 when the bay salinity was low, but yet Moriches Inlet was opened more than at any other time during the WHOI studies. Intuition suggested that salinity should have been high with the inlet opened; if salinity were high, flushing would have been good and pollution low. Since salinity was low, it might have been anticipated that flushing was poor, and indicators of pollution high. However, flushing was apparently improved due to high precipitation, lowering salinity but still resulting in low indication of pollution. It should be noted that many of the measures of pollution considered can vary over short time periods and be affected by many processes that could be difficult to understand from the limited timescale studies conducted by the WHOI scientists.

Nannochloris, a green alga referred to as a "small form," was found to be dominant in the bay in 1952 when the inlet was closed. In subsequent years, following the reopening of the inlet, the phytoplankton population was more diverse and included diatoms and flagellates (Bumpus et al., 1954; Ryther et al., 1958). *Nannochloris* was in excess of 2.9×10^6 cells/mL in 1952 at Moriches Dock (near the present Brookhaven Town Marina). By 1957, these counts were down to 0.14×10^6 cells/mL. Over the same time, diatoms and flagellates increased from zero to 0.24×10^6 cells/mL (Ryther et al., 1957). *Nannochloris* was determined in laboratory experiments to do well in medium salinities (17 psu) and in N: P ratios of 5:1 (Ryther, 1954). It was suggested that the small forms may have been characteristics of oceanographic conditions during inlet closure.

However, in tributaries like the Forge River, where excessive phytoplankton growth affects oxygen demand of waters, sediments and to a much greater extent, foodwebs, the phytoplankton species composition may not have been as important as the total biomass and rates of phytoplankton growth. Bumpus et al. (1954) asserted that the volume of the typical flagellate is 100 times that of a small form. Over the summer period 1956-1959, six sets of measurements of chlorophyll concentrations at two stations in the Forge River varied between 57 μg/L and 292 μg/L with a mean of 126.8 μg/L ± 30.4 μg/L (Guillard et al., 1960). This mean was about seven times greater than the mean of all other observations (17.8 μg/L ± 83.0 μg/L) in Moriches Bay and its tributaries (10 stations).

Secchi disk readings (affected by higher phytoplankton biomass) at the same locations from 1957-1959 also indicated the poor condition of the water in the river. They varied between 0.4-0.9 m (1.3-3.0 ft) with the exception of June 1958 when the disk could be seen at the bottom -- about 1.2 m (4 ft).

Discussion

In 1963, some 870,000 ducks were raised for market on the river and this generated enough nitrogen to be equivalent to a human population of 12,400 along the river banks. The 1963 human population was about 11,000. The WHOI team of researchers repeatedly recommended elimination of the duck wastes from Moriches Bay including the tributaries like the Forge River. Market forces, along with the implementation of pollution controls by government, caused the population of ducks to drop to the current annual production of 400,000.

But, while the impacts of ducks on the environment of the area have significantly declined, the impact of humans has greatly increased. The population in the surface watershed in 2005 was 59,000. This is a 559 percent increase in population since 1960, when duck ranching was at its peak. A conservative estimate for the per capita generation of sewage is 378 L/day (100 gallons/day) (the Suffolk County daily per capita water usage is 587 L (155 gallons) [Suffolk County Water Authority, 2007]). Thus, a minimum of $22x10^6$ L ($5.9x10^6$ gallons) of sewage is discharged to the ground each day. For the 17 km^2 (4211 acres) of residentially developed area of the watershed, this equates to $1.31x10^6$ L/km^2/day (1400 gallons/acre/day). For a comparison, the Southwest Sewer District serves 280,000 people treating some $104x10^6$ L/day ($27.6x10^6$ gallons/day) (Interstate Environmental Commission, 2007).

The Waterways Condominiums located on the site of a former duck ranch on the east side of the river, south of Montauk Highway but north of Ely Creek is zoned high density residential. It is primarily a retirement community with 514 units. This development has its own tertiary sewage treatment plant so that nitrogen reduction should be about 90 percent. Thus nitrogen input is low compared to the rest of the relatively densely populated watershed. The capacity of the plant is $0.303x10^6$ L/day (80,000 gal/day) but treats only $0.132x10^6$ - $0.151x10^6$ L/day (35,000-40,000 gal/day) (Walter Hilbert, Suffolk county Health Services, personal communication, Dec. 12, 2007). Based on the County's estimate of 568 L/day (150 gal/day) of sewage generated per household, the population of the retirement community is around 500.

Nitrogen discharged daily in 1963 in the drainage basin by humans at 20 g per day (0.044 lb) amounted to 220 kg (485 lb); by ducks roughly 250 kg (550 lb) for a total of 470 kg (1035 lb). Today, roughly 1170 kg (2580 lb) are contributed daily by people and 114 kg (250 lb) by ducks. Thus, the total load of nitrogen going into the surface watershed today is on the order of 2.7 times greater than 45 years ago.

The WHOI group concluded that the pollution problems of Moriches Bay were due to excessive discharges of duck waste into a poorly flushed lagoonal system driven by complex interrelationships among natural environmental processes. They pointed out that anthropogenic controls were limited but did include manipulating the flow through Moriches Inlet and eliminating the pollution source.

Dredging the inlet was thought to be a necessity to increase flushing in the bay but dredging would not solely solve the problem. Substantial reduction of the sources of pollution into the bay was the favored remedy. Further, they emphasized those conditions in the highly impacted tributaries like the Forge could only be improved by source reduction (Redfield, 1952).

Experience has shown that maintenance of Moriches Inlet had unpredictable consequences. Channels in such a dynamic sedimentary environment seemed to open and close in ways that are difficult to predict. The uncertainties of the consequences of dredging resulted in the state closing a channel at the inlet in 1962 only to have the county reopen it in 1966. Thus, given the unpredictability of past experiences, keeping Moriches Inlet open is imperative, but dredging to the extent of significantly reducing pollution in the Forge over an extended period of time will be an extremely challenging task.

Positive steps have been taken to reduce duck ranching in general and to require pollution control measures for those ranches remaining. The nitrogen load from duck ranching has been reduced some 54 percent since 1963. Unfortunately, the human input of nitrogen from sewage alone to the Forge River ecosystem has increased 432 percent. The lessons from the past are applicable today -- hydrological and meteorological conditions play a major factor controlling conditions in the bay. However, those same studies show that pollution sources were so extreme in the Forge and even Moriches Bay that natural or engineered modifications that increased flushing of the system did not by themselves solve the serious pollution problems that existed and still exist today. Engineered solutions to flushing need to be considered as part of the solution, although it should be recognized that such solutions are inherently challenging to design and maintain. Reducing pollutant loading into the Forge River has to be a major aim of the overall strategy to relieve pollution problems in the river.

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We appreciate the assistance provided by Suffolk County, particularly that of Mac Waters, DeWitt Davies, Jim Bagg, Ron Verbarg, Walter Hilbert, Tom Rogers, and Kathyrn Oheim. They made historic data and files readily available. They generated maps and spent hours discussing the history of the Forge River with us. Tony Leung of the New York State Department of Environmental Conservation kept us apprised of recent developments occurring concerning duck ranching along the Forge. Cynthia Dietz and Maria Riegert created ready access to historical map resources at the Frank Melville Memorial Library at Stony Brook University. Jeffrey Kassner, who has conducted research in Moriches and Great South Bays, was extremely helpful in identifying information sources and in sharing data and insights concerning functioning of the bay systems. Captain Gerd Glang and Dan Neumann of the National Oceanic and Atmospheric Administration made the historic hydrographic surveys readily available. Finally, Christine O'Connell and Bonnie Stephens were invaluable in their help in creating graphics, editing and otherwise assisting to generate the report.

Figures

Tables

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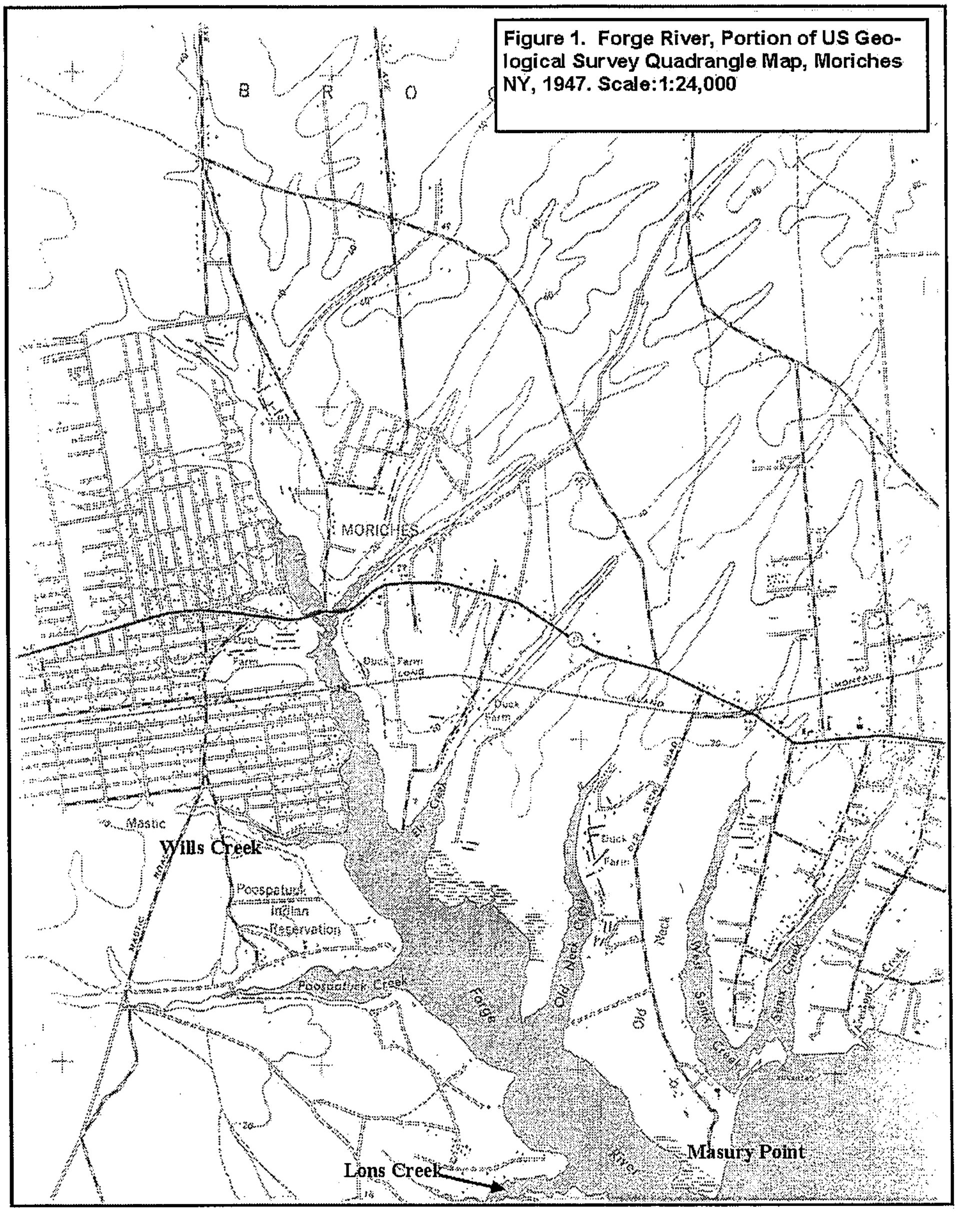


Figure 1. Forge River, Portion of US Geological Survey Quadrangle Map, Moriches NY, 1947. Scale:1:24,000

Figure 1. Section of 1947 USGS Quadrangle map showing the Forge River. Note the duck farms.

Figure 2. Soils map of Forge River area. Scale: 1:20,000. Warner *et al.*, 1975. See Table 2 for key to symbols.

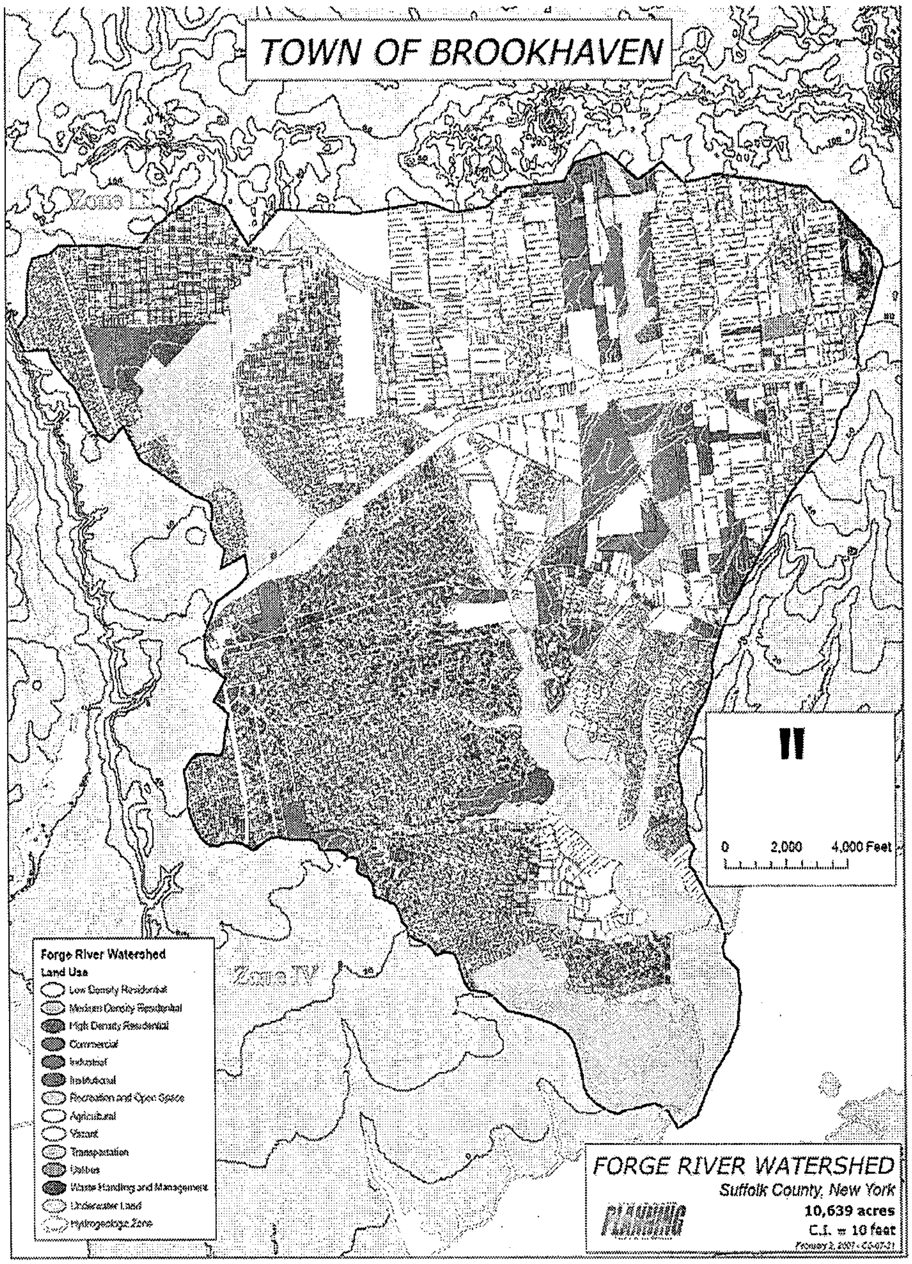


Figure 3. Forge River watershed and land use map.

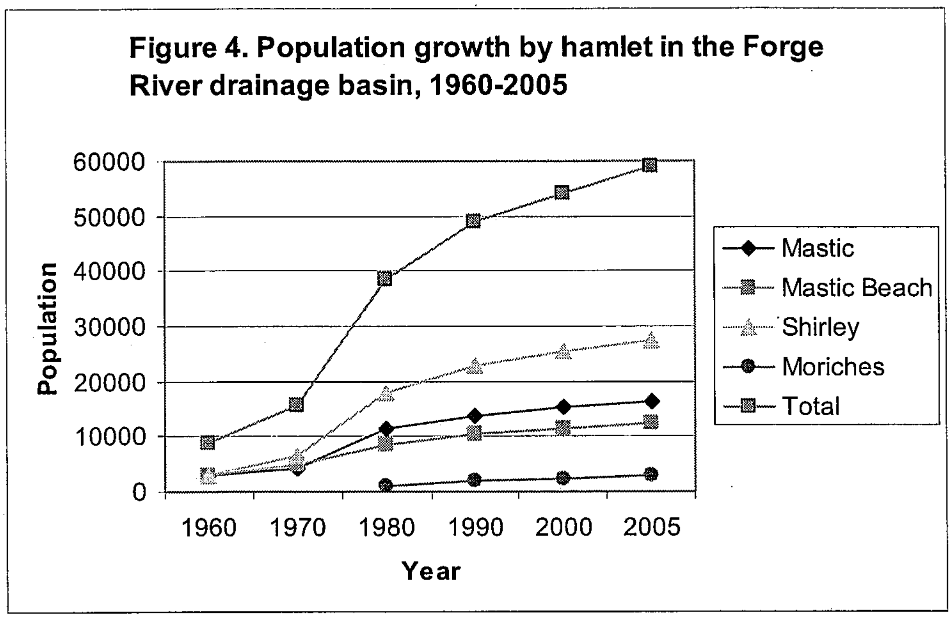


Figure 4. Population growth by hamlet in the Forge River drainage basin, 1960-2005.

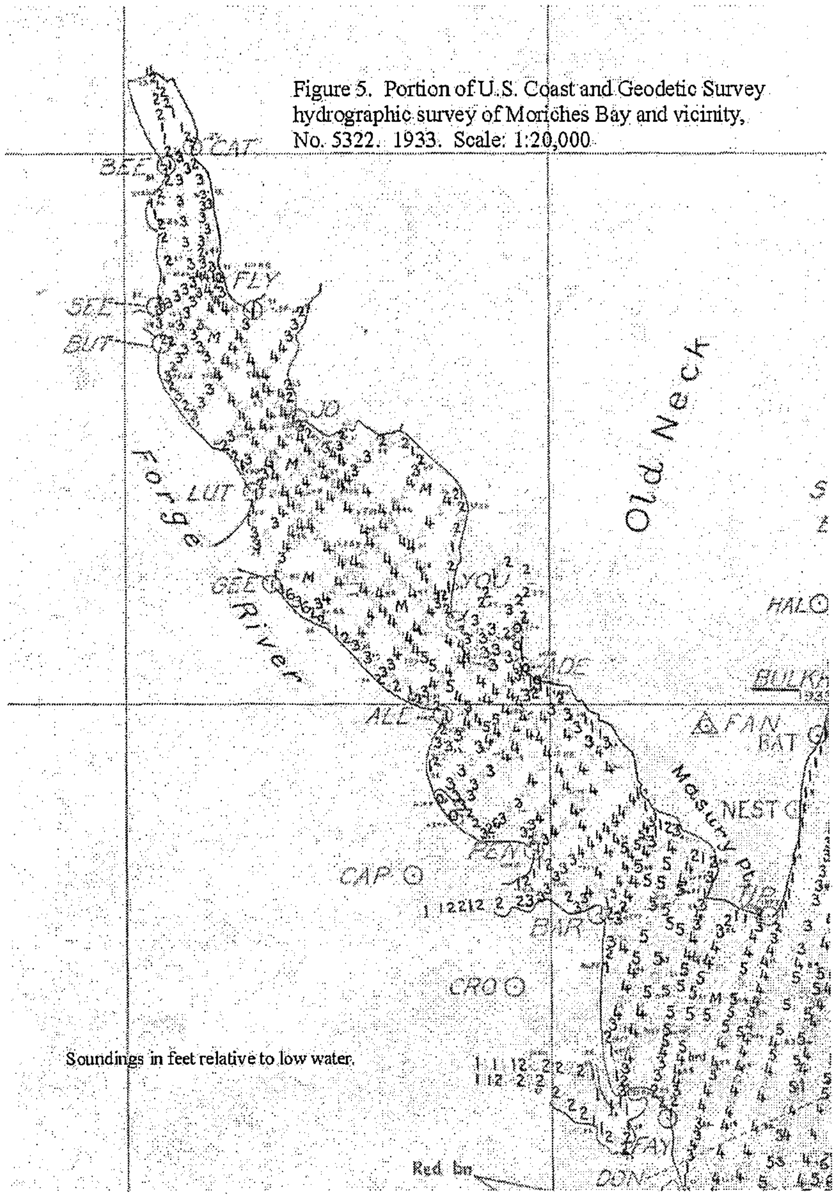


Figure 5. Portion of the U.S. Coast and Geodetic Survey hydrographic survey of Moriches Bay and vicinity, No. 5322. 1933. Scale 1:20,000.

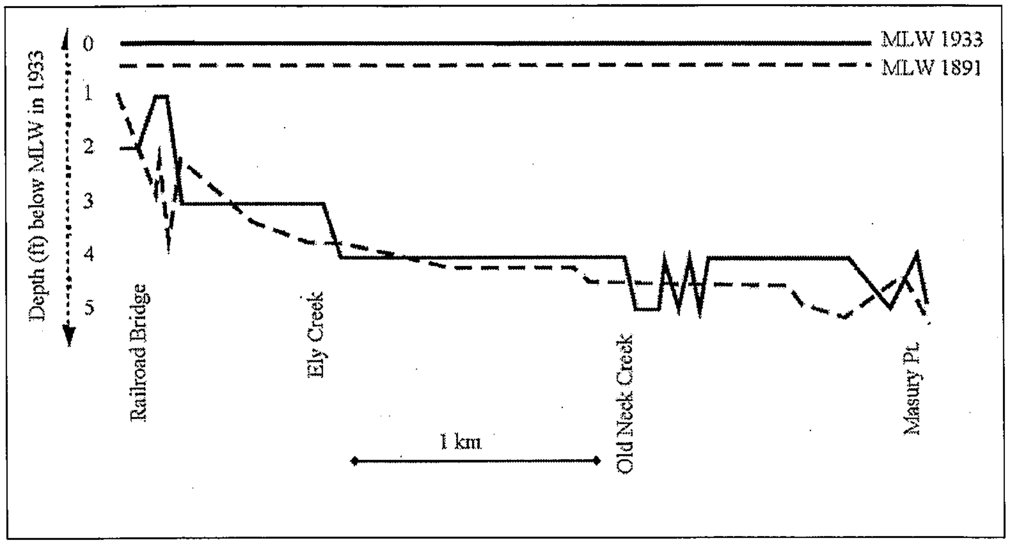


Figure 6. 1891 and 1933 depth profiles relative to mean low water in 1933 along centerline of Forge River from Masury Point to the railroad bridge.

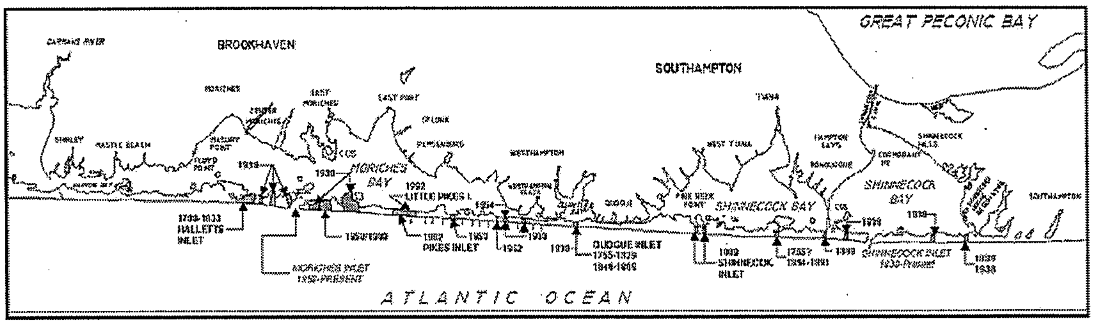


Figure 7. Historical breach and inlet location map. U.S. Army Corps of Engineers, 2004.

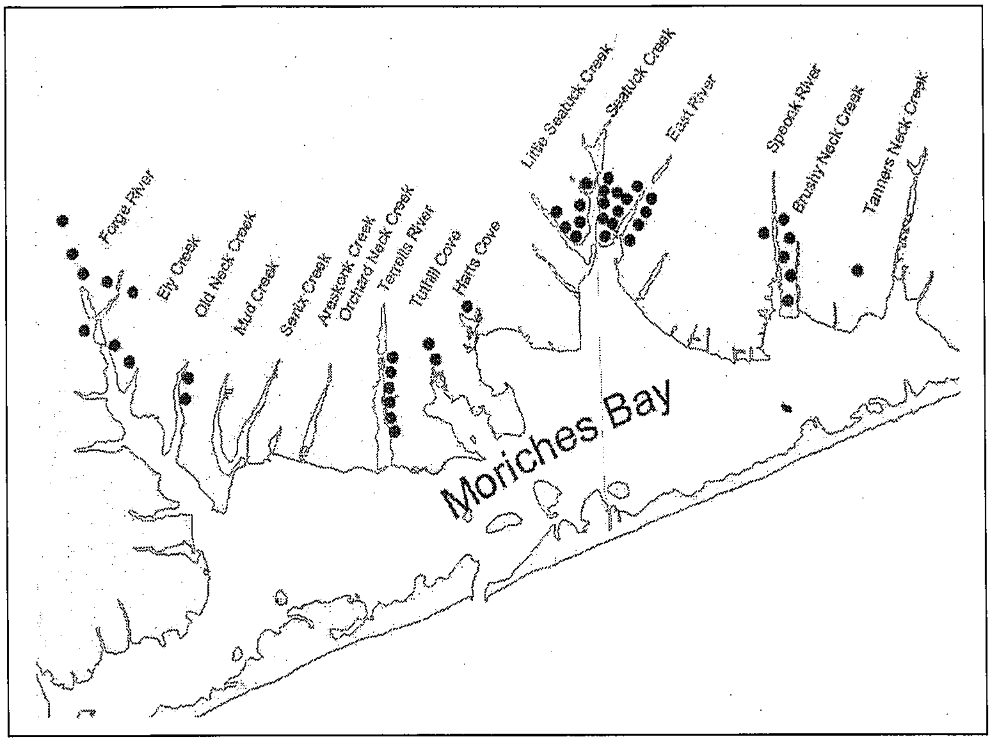


Figure 8. Location of existing and historic duck ranches on Moriches Bay. Ron Verbarg, Suffolk County Department of Planning, personal communication.

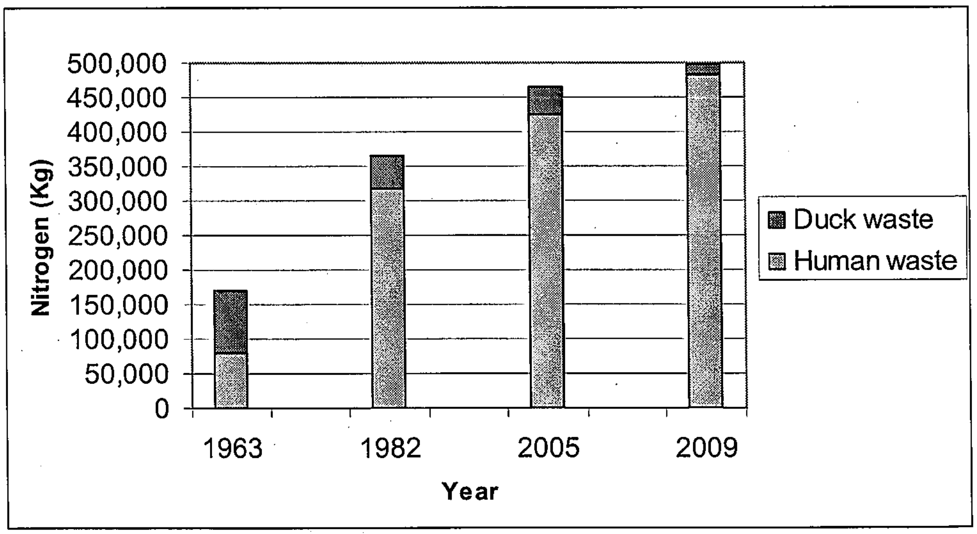


Figure 9. Annual mass discharge of nitrogen from human waste and duck waste to the Forge River drainage basin.

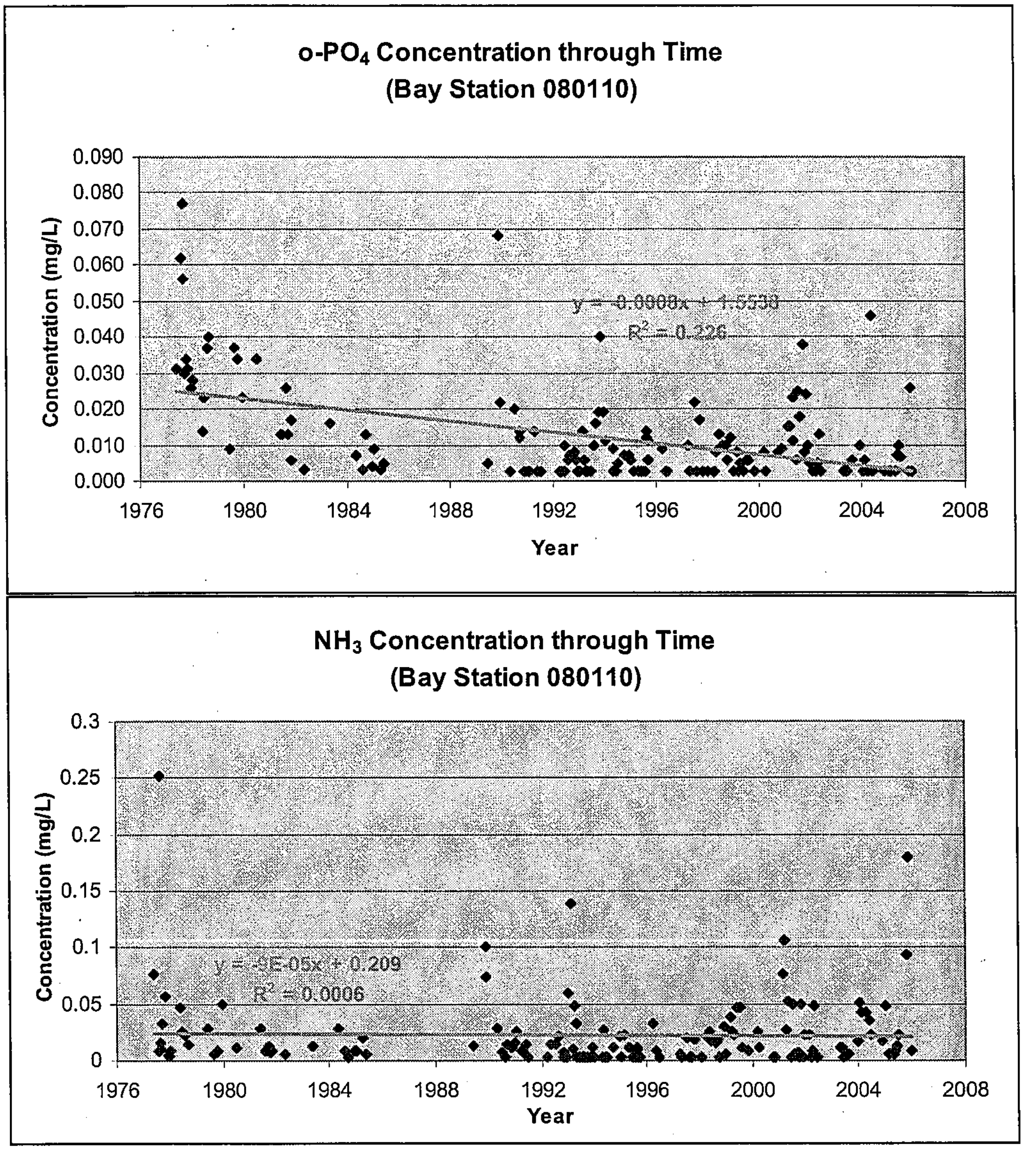
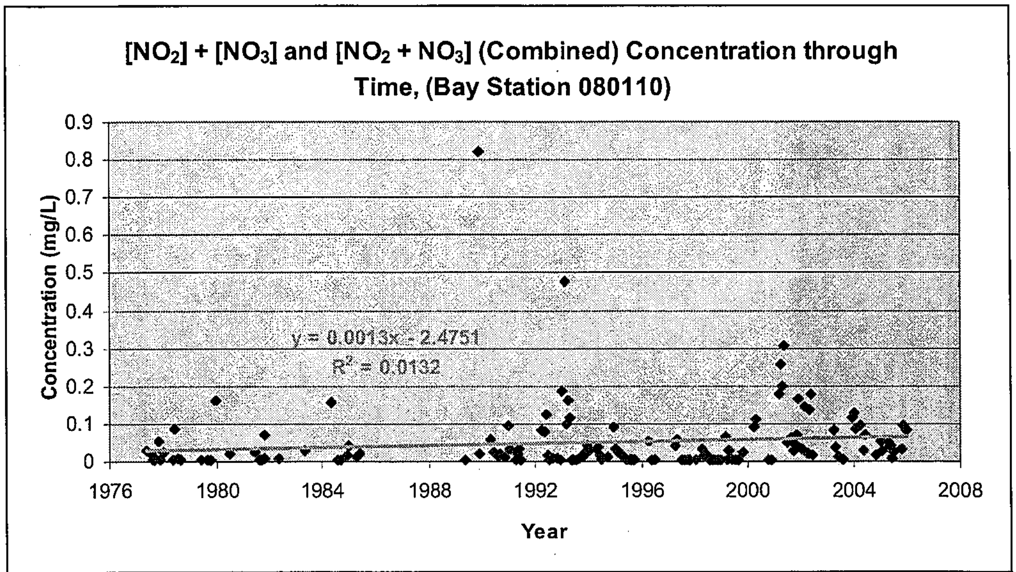


Figure 10. Ortho-phosphate and ammonia concentrations from 1977-2005. Data from Suffolk County Department of Health Services.



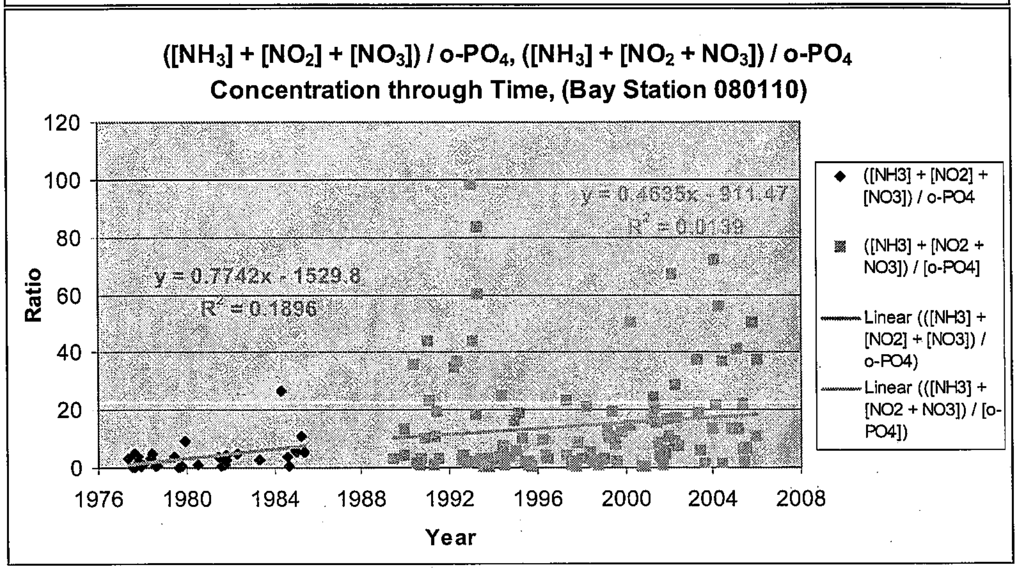


Figure 11. Temporal variation of the sum of nitrite and nitrate concentrations (mg/L) from 1976 to 2005; and ratio of nitrogen species to ortho-phosphate concentrations. Data from Suffolk County Department of Health Services.

Table 1. Major soils of the Forge River drainage basin. Warner et al., 1975.

Type	Description
Carver Series	Deep, excessively drained, coarse-textured soils, low moisture capacity, very low natural fertility, permeability rapid
Plymouth Series	Deep, excessively drained, coarser-textured soils that form in a mantle of loamy sand or sand in thick layers of stratified coarse sand and gravel, very low moisture capacity, low natural fertility, permeability rapid except those in silty substratum where permeability is moderate
Riverhead Series	Deep, well-drained moderately coarse-textured soils that formed in a mantle of sandy loam or fine sandy loam over thick layer of coarse sand and gravel, moderate to high moisture capacity, moderately rapid permeability in surface layer and subsoil, very rapid in substratum, low natural fertility

Table 2. Soil types and their symbols for the Forge River area (Warner et al., 1975).

Soil Type	Symbol	Depth (ft) to seasonal high water table
Carver and Plymouth sands, 0-3 percent slopes	CpA	> 4
Cut and fill land, gently sloping	CuB	
Carver and Plymouth sands, 3-15 percent slopes	CpC	> 4
Carver and Plymouth sands, 15-35 percent slopes	CpE	> 4
Deerfield sand	De	1.5-2
Fill land, dredged material	Fd	
Gravel pits	Gp	
Muck	Mu	
Plymouth loamy sand, 0-3 percent slopes	PIA	> 4
Plymouth loamy sand, 3-8 percent slopes	PIB	> 4
Riverhead sandy loam, 0-3 percent slopes	RdA	> 4
Riverhead sandy loam, 3-8 percent slopes	RdB	> 4
Sudbury sandy loam	Su	1.5-2
Tidal marsh	Tm	
Walpole sandy loam	Wd	0.5-1.5
Wareham loamy sand	We	0.5-1.5

Table 3. Population growth by hamlet in the Forge River drainage basin, 1960-2005.

	1960	1970	1980	1990	2000	2005
Mastic	2931	4118	11296	13642	15165	16412
Mastic Beach	3035	4872	8318	10293	11543	12358
Shirley	2986	6678	18072	22936	25395	27374
Moriches			869	2067	2172	2856
Total	8952	15668	38555	48938	54275	59000

Table 4. Forge River dredging log.

Project Name	Dates Dredged	Volume (m^3)	Volume (yd^3)	Spoil Disposal	Facilities Served
Forge River[1]	1965	203,300	265,900	Upland on Barrier Island and upland on main land	Town marina and boat club
Old Neck Creek[1]	1965 1973	84,260 133,100	110,200 174,100	Ocean surf Ocean surf	Marina and ramp
Lons Creek[1]	1967	114,700	150,000	Ocean surf	None
Poospatuck Creek[1]	1967	114,700	150,000	Ocean surf	None
Wills Creek[1]	1967	114,700	150,000	Ocean surf	None
Crystal Beach[1]	1972	58,100	76,000	Beach nourishment	Homeowners association dockage
South End of Forge River from Intercoastal Waterway[2]	1999	30,600	40,000	Disposal dike, Smith Pt. Park, Barrier beach	

[1] Suffolk County Planning Department, 1985. Analysis of dredging and spoil disposal activity conducted by Suffolk County. 85 pp.

[2] Tom Rogers, Suffolk County Department of Public Works.

Table 5. Modern history of Moriches Inlet

Period	Moriches Inlet	Shinnecock Inlet	Nearby Breaches
Pre-1931[1]	closed	closed	
1931-1938[1]	opened	closed	
1938-1951[1]	opened	opened	
1951-1953[1]	closed	opened	
1953-1980[2]	opened	opened	
1980-present[3]	opened	opened	1980 - breach just east of Moriches Inlet
			1992 – 305 m breach at Pikes Inlet, closed by filling in January 1993
			1992 – 914 m breach at Little Pike Inlet. Closed by filling between Aug. and Nov. 1993

[1] Pagenkopf and Bigham, 1977

[2] Kassner and Black, 1982

[3] Kassner, 2007, personal communication

Table 6. Flux of water in and out of Moriches Bay in 1949 per tidal cycle (Redfield, 1952).

Flow	**Flood** 10^6 m^3 10^6 ft^3	**Ebb** 10^6 m^3 10^6 ft^3
Narrow Bay	0.31 11	1.6 55
Quogue Canal	0.82 29	0.68 24
Moriches Inlet	3.0 106	3.5 123
Total	**4.1** **146**	**5.7** **202**

Table 7. Conditions in Moriches Bay in the 1950s.

Year	Moriches Inlet	Salinity	Pollution	Precipitation
1952	Closed	Low	High	Above average for first half of year
1956	Opened	High	Low	Above average for first half of year
1957	Opened	High	High	Below average all year
1958	Opened and widened	Low	Low	Above average all year

From Ryther et al., 1958

Table 8. Human population, ducks produced, and annual mass discharge of nitrogen from human waste and duck waste.

Year	Human population	Ducks produced	Nitrogen from human waste kg lbs	Nitrogen from duck waste kg lbs	Total Nitrogen from human and duck waste kg lbs
1963	11,000	870,000	80,300 177,060	90,480 199,510	170,780 376,570
1982	43,630	455,000	318,500 702,290	47,320 104,340	365,820 806,630
2005	59,000	400,000	427,400[1] 942,420[1]	41,600 91,730	469,000 1,034,150
2009 projected	66,500	400,000	482,160[1] 1,063,160[1]	15,860[2] 34,970[2]	498,000 1,098,090

[1] assumes tertiary sewage treatment for 500 people in watershed.

[2] assumes tertiary waste treatment for 275,000 ducks.