NATURAL and CULTURAL FEATURES of MONMOUTH COUNTY

Background Reading for Environmental Health Investigations

MCHD Rev. 07/29/13

INTRODUCTION

Monmouth County in central New Jersey is entirely located within the Inner and Outer Coastal Plain, part of the Atlantic Plain geology that extends 2200 miles from Cape Cod to the Yucatan Peninsula (USGS, 2003). There are 53 municipalities within a land area of 471.74 square miles of highly erodible soils that were originally deposited as runoff from the slopes of the Appalachians (MCPB, 2005).

Some County History

Following Henry Hudson's exploration of the Sandy Hook shoreline in 1609, Monmouth County was predominantly under Dutch influence from about 1614 to 1664 (Colts Neck Historical Society, 1965). The New Jersey coastline had previously been sited and claimed for England (Giovanni Caboto, 1497), France (Giovanni de Verrazano, 1524), and Spain (Estevan Gomez, 1525); and had been Scheyichbi, Long Land Water, to the Lenape Indian Nation (Colts Neck Historical Society, 1965). Four major trails used by Native Americans terminated at the Navesink River: the Achkinkeshacky (Hackensack) Trail from the Hudson River; the Minisink Trail from the Great Lakes region; the Raritan-Lopotcong Trail from the west, and the Crosweeksung Trail from the southwest. This last trail entered NJ at Trenton, passed through Freehold to the Yellow Brook at Colts Neck, where it split into a northern path to Tinton Falls and Red Bank, and a southern path to the Shark River and Manasquan (NFECA, 2009).

The first settlers in Middletown, the oldest settlement in NJ, are reported to have arrived as early as 1613, seven years before the Pilgrims landed in Massachusetts; Middletown was originally called Shaquaset by the Lenape (Boyd, 2004; Mandeville, 1927). In 1664, the Dutch gave the rights to land between the Hudson and Delaware Rivers to the English; a year before, a group of Englishmen who were aware that this would happen sailed from Long Island and began to negotiate with the Native Americans to purchase the land along the Navesink and Shrewsbury Rivers (NFECA, 2009).

In 1665, the Monmouth Patent allowed settlers to have town meetings, courts and a General Assembly under English rule (MCDPI, 2005). Monmouth County was formed in 1683 by the Proprietary Assembly, and is one of the original four counties of "East Jersey" (the others were Bergen, Essex, and Middlesex; the East Jersey Board of Proprietors had been established in 1682 in the provincial capital of Perth Amboy) (MCDPI, 2005; LWV, 1974). The County may have been named after Monmouthshire in South Wales, England; it extended from the Navesink River to Little Egg Harbor (MCDPI, 2005; LWV, 1974). In 1693, Middletown, Freehold, and Shrewsbury - which included most of present-day Ocean County - were the first townships to be formed (Ocean County was not established until 1850) (LWV, 1974; MCDPI, 2005). In 1713, John Reid sold land in Freehold on the Burlington Path stagecoach route to the Board of Chosen Freeholders for a Court House, on the southwest corner of South and Main Sts., across from what is now the Hall of Records (Blair, 1993; MCDPI, 2005). By 1758, the Lenape (Delaware) Indians that were still living in the County were being relocated to the first Indian reservation in the US, at Indian Mills in Burlington County (Colts Neck Historical Society, 1965).

In 1775, a raiding party from Portland Point (Atlantic Highlands and Middletown) boarded the English ship the "London" in Sandy Hook Bay and threw its cargo of tea overboard to protest the closing of the port of Boston by the British following the Boston Tea Party two years earlier (Boyd, 2004). In 1777, the British massacred American troops in the County's first engagement of the Revolutionary War at the Battle of Navesink Hills, near Hartshorne Woods and Highway 36 in Highlands (Boyd, 2004). In 1778 the Battle of Monmouth was fought in Manalapan in one of the largest battles of the American Revolution, and is memorialized at Monmouth Battlefield Park off Rt. 33, and at "Molly Pitcher's Well" (actually a spring) along Rt. 522 west of Freehold (MCDPI, 2005). The 12-mile long English army retreated to New York over an Indian trail in Freehold and Colts Neck that is now Dutch Lane Road. Following the ridgeline of the Mount Pleasant Hills, they marched on Kings Highway East in Middletown to cross a pontoon bridge built of anchored, planked boats over a now-closed inlet by Plum Island for embarkation from Sandy Hook (Boyd, 2004; Colts Neck Historical Society, 1965).

The first iron works in New Jersey was constructed around 1674 in Tinton Falls, Monmouth County; the industry peaked after the war of 1812 until about 1844, when transporting coal as well as richer ores of iron from Pennsylvania and other states west of NJ became more cost effective (Forman, 1998). During the Industrial Revolution of the 19^{th} century, the first railroads helped to develop seaside resorts such as Highlands (Waterwitch), Long Branch, and Asbury Park, doubling the population of Monmouth, Ocean, Atlantic, and Cape May counties from 55,700 in 1850 to 111,000 by 1885 (Roberts and Youmans, 1993). In 1870, the first section of the Atlantic City boardwalk was opened. Steamboats brought tourists from New York to the railroad pier at Atlantic Highlands, where they could connect with the New Jersey Southern Railroad and cross a "scissors" bridge between Highlands and Sandy Hook to towns along the way to Long Branch (the City of Keansburg ferry operated until 1968) (APP, 2006a; Gallo, 2000). A 2000 foot long pier was constructed at Cedar St. in Keyport, and steamboats traveled up Matawan Creek to wharves and warehouses that had existed along Lake Lefferts as far as Rt. 516 in Matawan before it silted in (Gallo, 2000; Kisk, 2006). Although most of the County that was not along the coast still remained farmland, its transition to suburbia accelerated when the majority of the 164-mile Garden State Parkway was completed by 1954, having begun construction in Union County a year after the end of World War II (NYCroads.com, 2005).

OCEAN

NJ bordered Morocco 245 million years ago, at the beginning of the Triassic Period, when the Appalachian and Anti-Atlas mountains that are now in Africa were a single range that may have been higher than the Himalayas (Gallagher, 2003; Wikipedia, 2009). This lasted about 75 million years, until the supercontinent Pangaea began to rip apart (Gallagher, 2003). As lava formed into the basalts of the Watchung Mountains in Somerset and Passaic, and igneous intrusions cooled into the columns of the Palisades, the water surrounding Pangaea rushed in to fill the rift between the new continents, creating the Atlantic Ocean (Gallagher, 2003).

Tourism

Sixty one percent of NJ's 8.4 million residents live within 25 miles of the shoreline (Marlowe & Company, 2006). In 2006, tourism in NJ generated $7.5 billion in federal, state and local revenues, a 4.4% increase over 2005; $23 billion out of the $35 billion tourism industry statewide was generated from Monmouth, Ocean, Atlantic, and Cape May in 2006 (Corzine, 2007; SNJ, 2008). Monmouth and Ocean counties generated about $5.3 billion in tourism revenue in 2006, up 3.4 percent from 2005 (Diamond, 2007b). In 2005, 4 out of the 5 counties in NJ that had benefited the most from tourism were the Atlantic shore counties that run from Monmouth to Cape May (Conroy, 2005). Tourism revenue grew statewide that year by 12.5% to $36.3 billion; in Monmouth County, it rose that year by 15.6%, up $1.9 billion from 2004 (Conroy, 2006). Tourism was 5.9% of NJ's Gross State Product in 2005; it resulted in 472,300 jobs and 72,240,000 visitors to NJ (Conroy, 2006). Locally in 2004, tourism resulted in 38431 jobs, $1 billion in payroll, $.6 billion in spending at restaurants, $.5 billion in real estate sales, and $.2 billion in recreation spending; as well as $224.5 million in state taxes and $82 million in local taxes (MCDEDT, 2005; MCPBb, 2005). Sandy Hook alone receives about 46,000 visitors every summer weekend, and over 2 million annually (Terwilliger, 2004). NJ retains 72% of each tourism dollar spent in the state (Corzine, 2007).

Nationally, a typical swimming day is worth $30.84 in tourist revenue per individual; a home within 300 feet of a water body increases in value by 28 % (Stoner et al., 2006). In contrast, the EPA reports that during the extended beach closings due to sewage overflows and garbage washups in 1987 and 1988, New York and New Jersey lost an estimated 2-4 billion dollars in tourist revenue (Grebe, 2006). In 1976, a devastating anoxic (no oxygen) event in the continental shelf off NJ resulted in over $550 million in estimated losses to shellfishing, finfishing, and related industries; New Jersey is the fourth-largest seafood producer in size and catch on the East Coast (APP, 2006b; Glenn et al., 2006). An Orange County, California study estimated the costs of swimming related diseases per ailment: gastrointestinal illnesses ($36.58), acute respiratory disease ($75.76), ear ailments ($37.86), and eye ailments ($27.31); the annual cost of swimming related disease for the two beaches studied was found to be $3.3 million, not including out-of-pocket costs for prescriptions (Stoner et al., 2006).

Fresh and Waste Water Discharges

Monmouth County has 27 of the 127 miles of Atlantic coastline in NJ; and 26 miles of shoreline along Raritan Bay (NJ has 1750 miles of interior tidal shoreline) (NJDOH, 1990). Eleven of the 18 lakes, estuarine inlets and one stream that discharge into the ocean along the 127 miles of the state's Atlantic coastline are in Monmouth County (NJDOH, 1990). Nine of 10 coastal lakes in the County discharge directly into the ocean from Long Branch to Sea Girt (Sunset Lake in Asbury discharges into Deal Lake). The only ocean beaches without stormwater outfalls are in Manasquan, and from Monmouth Beach to Sandy Hook. Poplar Brook in Deal is the last freshwater stream on the East Coast with a direct, unchanneled discharge onto an ocean beach (Asbury Park Press, 2000). Stormwater discharges affect both water and sediment quality at nearby beaches. It is known that a change in shoreline orientation, such as the mouth of an estuary, can intercept the littoral transport of sediment; sediment transported within the estuary can be deposited at the mouth where the current slows as it discharges into the ocean (Stumpf et al., 1988). The building up of a delta or shoal off the mouth of a surface water discharge may be more efficient during the summer because of the decreased frequency of storms, and troughs in sand waves or ripples that form on the seafloor can fill with mud, until a storm eventually resuspends the accumulated sediment (Stumpf et al., 1988). The Shark River Inlet in particular is noted for its dynamic offshore shoaling (RSCNJCRC, 2006b; USDI, 2004).

In 1970, when the Clean Water Act was passed, there were 39 sewer treatment plants discharging into the ocean off NJ, none of which provided secondary treatment; by 1988, there were 13 plants, all of which provide at a minimum secondary treatment and chlorination (NJDOH, 1990). The last primary treatment plant in the County to discharge sewage a few hundred feet past the swimming zone was taken out of service in Asbury Park in 1988. Currently there are 7 sewage outfalls in the County from Sandy Hook to South Belmar, mostly constructed during the 1960's and 1970's, that discharge secondary or tertiary treated sewage into the ocean at flows rated from 4.4 to 33 million gallons per day (MGD) from 1500 to 5800 feet offshore.

The County's Bayshore and ocean beaches are closest to the 700 Combined Sewer Overflows discharging into the NY/NJ Harbor or to its tributaries, 250 in NJ and 450 in NY (and some in Connecticut), that legally discharge sewage into the Hudson-Raritan Bay complex (Gaugler, 2006; HEP, 2005). As little as 0.04" per hour of rain in NYC can overload the capacity of a sewer plant and cause a bypass of sewage into the Bay (EPALISO, 2009). Since 1936, the Interstate Environmental Commission has been mandated to protect the Tri-States' region's waters (http://www.iec-nynjct.org/).

Many CSOs in NJ are now screened with "Net Capture" or other devices to retain floatables, which include fecal material congealed in cooking grease and soap known as 'greaseballs' or 'sewage cakes' when they are found in the wrack line. The total number of CSO's in all of NJ had been 275, but as of 2009 there were 222. This includes CSO's in southern NJ on the Delaware River, in Camden County and in Trenton in Mercer County. However as of 2009 in northern NJ in the Hudson-Raritan Bay watershed, there were 187 CSO's, 156 (83%) with solids/floatable controls like Netcapture; the remainder are in design/construction phase. The original number of CSO's in NJ has been reduced by about 20%, from 275 to 222; 52 were eliminated when municipalities like New Brunswick and Rahway eliminated their CSOs by converting to modern dual systems (separate storm water and sanitary sewer) (Olko, 2009). The most southern CSOs on NJ's Atlantic coast are the 9 in Perth Amboy on the Raritan River estuary in Middlesex County.

In contrast, NYC has screened few of their 450 CSOs, relying instead on open water skimmer vessels to catch floatables after they have been discharged into the bay (Gaugler, 2006; Meakim, 2005). NYC's yearly average of 43" of rain causes about 27 billion gallons of untreated stormwater and sewage to be discharged from these CSOs in a year (Riverkeeper, 2009). This means that almost 63 million gallons of untreated CSO waste is discharged into the Bay from NYC for every tenth of an inch of rainfall.

Geology and Structures

Beach sands generally become whiter and coarser from north to south; this is because silt and clay formations outcrop along Raritan Bay and the northern coast, while the heavier Kirkwood-Cohansey sands dominate beaches from Asbury Park south. Geology is one reason why the ocean in northern Monmouth is usually not as blue as it is by Manasquan. The dappling that occurs on the surface of flowing water happens because bright convex parts rise and focus sunlight, while dark concave parts dip and diffuse the light (Ross, 2000).

The beaches along the bluffs in Deal and Long Branch are uniquely darkened by the black sands of the glauconitic Hornerstown and Vincentown outcrops; the black sands from these formations appear again at the other end of the County in the streambed of Crosswicks Creek in Upper Freehold, which is only about 40 feet above sea level (MCPB & MCEC, 1999). Darlington Avenue in Deal has the best preserved bluff shoreline along the Monmouth coastline (Farrell et al., 2008).

The Shrewsbury Rocks off Monmouth Beach, and the Elberon Grounds (aka the Deal/Elberon Rocks) from Lake Takanassee to Allenhurst, are some of the few natural structures that provide habitat for fish and other marine life (NJ Scuba Diver, 2005; USGS, 2003). The Shrewsbury Rocks are a series of ironstone and marl outcrops submerged in fourteen to fifty feet of water that may be the remnants of a barrier beach; a pale green glauconitic concretion locally called "moonstones" washes up as rounded pebbles along the shoreline by the Rocks (Dahlgren, 1977; Grant, 2005; NJ Scuba Diver, 2005; Steimle et al., 2000; USGS, 2003). The Shrewsbury Rocks are located across the Shrewsbury River from the Rumson-Fair Haven peninsula, where as recently as 1685 there had been an open inlet to the ocean (Dahlgren, 1977; USGS, 2003). The Rocks are located off a bulge of shoreline in Monmouth Beach that is the state's easternmost point jutting into the ocean (MBEC, 1976).

Known nationally as "New Jerseyization", the majority of the jetties and groins that partition the shoreline in Monmouth are constructed of igneous basalt because of its resistance to weathering. Groins, locally called jetties, are built perpendicular to the shoreline, and is from *groyne*, derived from *groign*, Old French for snout or promontory; jetties are 'T' or 'L' shaped structures that are designed to shelter the shoreline and harbors from waves, and is derived from *jeter*, to throw, e.g., the current is "thrown" out into the open water (Wikipedia, 2008). Almost all the jetties (groins) in Monmouth County have tips that extend underwater for 20 to 30 yards (Freda, 2007). The 4 mile seawall between Sandy Hook and Sea Bright, originally built by the US Army to protect Fort Hancock in 1898, has metamorphic gneiss and schist boulders as well as basalts (Condie, 2005; Terwilliger, 2004; Titus and Strange, 2008). The Manasquan Inlet was constructed with timber jetties as early as 1882, and is the oldest of the improved inlets along the NJ coastline (ACE, 2006; Coch, 1999; USDI, 2004). Following the damaging "Long Island Express" Hurricane of 1938, the Shark River, Manasquan and Barnegat Inlets were armored with stone jetties by 1940 (Coch, 1999; USDI, 2004). While littoral drift is building up barrier spits like Sandy Hook and Barnegat, as well as beaches located by inlets (although to a much lesser extent), most of the shoreline is receding (USDI, 2004).

The NJ Office of Emergency Management reports that the NJ coast is shaped by episodic storm events that recur at intervals of 25 years or more; the Heinz Center has found that much of the NJ coastline erodes an average of 3 feet a year (URS, 2008). The first beach nourishment projects, at Sandy Hook and Long Branch, date from the 1940's, although control of beach erosion was first attempted at Ocean City NJ in 1907 (ACE, 1974; USDI, 2004). In 1963, the Army Corps of Engineers Operations Division at Sea Girt experimented with the hydraulic pumping of sand to beaches from offshore dredging (ACE, 1974). Following Hurricane Gloria and moderate nor'easter in 1984, the NJDEP focused on obtaining federal assistance for beach restoration; in 1988 the Cape May City Shore Protection project was initiated, followed in 1992 by the Ocean City Shore Protection project (Farrell, 2007). This led to the $250 million Shore Protection Project from 1994 to 2000, which rebuilt 21miles of shoreline from Sea Bright to Manasquan, and is the largest beachfill project in the world (Farrell, 2007; USDI, 2004). Construction includes a 100 foot wide beach berm that is 10 feet above mean low water that is drawn from sand 1.5 miles offshore; beaches were planned to be replaced every 6 years until 2044 (Bates, 2006; Farrell, 2007). In 2006, the project won a national award from the American Shore and Beach Preservation Association (Bates, 2006). Sandy Hook Cove, Monmouth Beach and southern Long Branch are the only beaches needing renourishment as of 2007 (Farrell, 2007). NJ spends the highest amount of dollars per mile of coastline on beach replenishment than any other state, including California and Florida (Farrell, 2007).

Currents

Sediment transport is almost entirely driven by wave action. The littoral, wind-driven current flows to the north in Monmouth County, depositing sand on the south side of jetties (the "updrift side") during the summer (ACE, 1974; Herrington, 2005; USDI, 2004). In addition, net sand movement along the coast reverses direction around a dynamic nodal point between the Manasquan Inlet and Ortley Beach, due to the location of Long Island, NY. Because Long Island shelters the Monmouth County coast from large winter waves generated by Nor'easters, a greater proportion of wave energy from the southeast dominates the Monmouth county shoreline, leaving more sand on the south side of jetties (ACE, 1974; Herrington, 2005; RSCNJCRC, 2006; USDI, 2004). The opposite happens south of the Barnegat Inlet; because Nor'easter waves reach this part of the coast unimpeded, net littoral drift deposits more sand on the north side of jetties. (ACE, 1974; Herrington, 2005; USDI, 2004). It is estimated that 382,000 cubic meters of longshore sand pass from Manasquan through Sandy Hook every year, while 38,000 cubic meters pass from Manasquan to the Barnegat Inlet (Terwilliger, 2004; USDI, 2004).

In addition to littoral drift, there is a second ocean current that is driven by the Hudson-Raritan plume, which carries floatables from the metropolitan area after rainfall. The Hudson-Raritan plume generally flows south and landfalls between Monmouth Beach and Long Branch. Local circulation patterns can run counter to this southerly current and cause it to slow down and reverse direction, altering the biological and chemical conditions of the water, and trapping floatables, which will then drift with onshore winds onto beaches. For example, the area around the discharges of the Manasquan River and Barnegat Inlet have small nodes of current bifurcation, where fresh water discharges can actually flow north against the prevailing southerly current of the ocean (Ashely et. al., 1986). These are also areas where floatables from the Hudson–Raritan plume have historically washed up following heavy rains and strong onshore winds. The NJDEP has reported that their "Clean Shores" program has removed 110 million pounds of floatable debris from the NJ coastline from 1989 through 2005, and now average removing about 5 million pounds from 100 miles of beach annually (Harrington, 2006). When seaweed or trash float on the water in a relatively straight line, it indicates that a tideline has formed (Ross, 2000). Tidelines occur when different types of waters meet, and commonly form outside estuaries and inlets. Differences in salinity will cause freshwater to ride over the denser sea water, and debris will be skimmed into these lines; differences in the tidal currents will also cause a tideline to set up (Ross, 2000).

The dispersal of the Hudson River plume by wind was modeled for dry weather conditions (May 2004) and wet weather conditions (April of 2005) as part of the Rutgers LaTTE program (Choi and Wilkin, 2007). Their results reinforce that wind from the south (northward wind) pushes the plume, and local stormwater, with its bacteria and floatables, offshore, away from the swimming area. Wind from the north (southward wind) contains the plume and local stormwater within the swimming area. Generally, during dry weather (low flow conditions):

"**Northward wind** causes the initial plume … to drift to the east and spread out in a thin (6 m) low-salinity layer. Saline subsurface water upwells along the New Jersey coast and flows northward. A new plume of water discharged from Raritan Bay flows along the Long Island coast. **Southward wind** pushes the plume against the New Jersey coast and the plume thickens. A strengthened coastal jet drains freshwater to the south along the coast. **Eastward wind** enhances freshwater export from the estuary into the New York Bight and accumulates low-salinity water in an anticyclonic bulge in the apex of New York Bight. Surface currents flow southeastward over the northeastern part of the bulge, and then join a southward flow that is detached from the coast. **Westward wind** retards freshwater export through the estuary mouth and squeezes the plume toward the New Jersey coast, with the structure of the coastal current and freshwater transport along the coast being similar to the unforced plume. " (Choi and Wilkin, 2007).

During wet weather (high flow conditions):

Northward wind displaces the bulge eastward and redirects Raritan Bay outflow toward the Long Island coast … the north side of the displaced bulge efficiently sweeps freshwater eastward … Even more effective at draining the bulge is **southward wind**, which promptly shuts down the northward recirculation and accelerates the southward New Jersey coastal current. **Eastward wind** moderately increases the initial export of freshwater from Raritan Bay but also increases the flux of freshwater away to the east. The overall effect is to accumulate slightly more freshwater in the bulge than in any other wind condition …The strong recirculation persists and little of the river discharge has been dispersed by day 20. These winds drive northward flow at depth that brings water up the axis of the Hudson shelf valley. Under **westward wind** the shape of the bulge becomes elongated and distorted … On the easternmost flank of the bulge Ekman flow tends to predominate and carry water northward, whereas closer to the center the buoyancy gradient is stronger and southward geostrophic flow prevails. There is a subsurface maximum in the southward flow, and the magnitude of the southward transport is second only to the southward wind case." (Choi and Wilkin, 2007).

This has practical implications for beach water quality. For example, during the study period, in July 2004, a slick of trash that was recirculating in the bulge off the Monmouth coast was blown in when the wind changed and created a seven mile long trash slick off the northern NJ shore, before blowing away again (Capuzzo, 2004; Schofield and Glenn, 2013). On 8/23/10, following moderate rainfall and northeasterly winds, Monmouth County had 21 enterococcus exceedences (4 in estuary, 1 outfall, 16 along the ocean) and Ocean County had 16 (9 estuary, 9 ocean). All 75 ocean resamples (3 per original failure) in both counties (as well as the 3 bay resamples at Ideal Beach in Monmouth) - using 2 different laboratories - dropped below the standard by Tuesday morning's resampling on 8/24/10, when the wind shifted. Exceedences were in areas in Monmouth and Ocean without storm drain outfalls, and sewer plants did not malfunction, but under conditions described in the above study for southward (NE) winds trapping the HR plume against the NJ shoreline (MCHD, 2012).

Jetty Rips

The strong, infrequent rip currents that are associated with beach closures and drownings occur near sandbars, jetties and piers, when longshore currents are strongest, waves are high, and the wind is blowing onshore during falling tides, when more water is draining seaward (Ross, 2004). Smaller rips regularly form over the high spots/small sandbars that build up on the shallower, southeast side of jetties (groins) in Monmouth County, where southerly winds drive the predominant south-to-north littoral drift against the rocks (Freda, 2007). As these small sandbars build up, the sand on the other, northeast side of the jetty erodes, until a deep hole forms at the end; rip currents will form here as well (Freda et al., 2004; Freda, 2007; Ross, 2000). Rip currents form because water "is continuously supplied to the longshore current by the incoming waves, but eventually this water must move seaward, which happens when the volume of water in the longshore current overcomes water in the incoming waves. Now the water in the longshore current moves seaward in a strong narrow current called a rip current. The longshore current essentially is 'feeding' the rip current" (Ross, 2000). Rip currents form or break up depending on bottom topography, beach slope, wave direction, wave height, and the period of the incoming waves (Ross, 2000).

Cross-shore circulation like rip currents is important in exchanging nutrients, food, and planktonic larvae; "cross-shore circulation probably has a disproportionate influence on nearshore ecosystems"(Pineda, 1994). When the normal seaward movement from small rips along jetties stagnates due to hydrodynamic and weather conditions, there can be less mixing than normal of the dry-weather stormwater flows from outfalls discharging into the surf zone. Because stormwater is not treated, the primary cause of the decline in enteroccocus concentrations from stormwater discharges within the surf zone is due to dilution; followed by inactivation by sunlight (ultraviolet rays), and grazing by phages (viruses) and other bacterial predators (Boehm et al., 2005). Dilution is caused primarily by cross shore currents flowing perpendicular to the shoreline, like rips, and also by the longshore littoral drift that flows parallel to the shoreline (Grant et al., 2005). The plume from the Talbert Marsh by Huntington Beach in California was sampled during 2 days of dry weather along a stretch of shoreline without any jetties. The plume maintained its integrity in the longshore littoral drift, and caused enterocococus, E. coli, and/or total coliform exceedences of the swimming standard, for up to one and a quarter miles. Bacterial levels decreased, however, when the plume drifted into "a retardation in along-shore current" caused by "spatial non-uniformities", such as sandbars and a pier, that turned the plume seaward to dilute (Grant et al., 2005). The authors concluded that "negative divergences of drift will probably increase the cross-shore mixing of contaminants into adjacent offshore waters via rip currents" (Grant et al., 2005). However the longshore current in the surf zone at these beaches was 50 to 300 times larger than the cross shore drift, and "as a result, pollutants entrained in the surf zone hug the shore" (Grant, 2005).

Dry-weather flows from stormwater outfalls in the surf zone in Monmouth are predominantly caused by groundwater seeping into stormwater lines in areas with high water tables. Dry weather flows that are not significantly contaminated with sewage in the Coastal Plain will appear clear orange from the iron bacteria that builds up on the pipe in between storms; turbid grey or black stormwater indicates a significant-volume sewage break. Small-volume sewage discharges will not overcome the red color of the iron bacteria because it is diluted by the much higher volume of groundwater. For example, when a sewer line from a single house with a family of 4 is illicitly connected to a storm drain, an average of 8-16 gallons an hour (200-400 gallons/day) of waste is discharged; the Wreck Pond outfall, the largest natural freshwater discharge along the ocean, discharges 2.2 million gallons an hour during low tide, when it's not raining (Hires et al., 2005).

ESTUARY

About 18,000 years ago, the lower Hudson River estuary near the present day Battery in NY was a 100-650' deep fjord gouged by the northward retreat of the Laurentide Ice Sheet. Around 2000 BC, the bedrock was flooded by the rising ocean and filled by river sediments for the next 3000 years, turning the fjord into an estuary (Blumberg et al., 2004; Geyer et al., 2001). During the late Wisconsinan glacial period, the Raritan River had flowed northeastward along the northern shore of Staten Island directly into the Hudson River, along the route of the present day Arthur Kill and the Kill van Kull (Gaswirth et al., 1999; USGS, 2007). When the Laurentide Ice Sheet eventually retreated, massive amounts of runoff from the melting glacier re-routed the river to the southeast into present day Raritan Bay (Gaswirth et al., 1999).

"The post-glacial geologic history of the Hudson River Estuary as a fjord filled by proglacial lake sediments distinguishes it from classic drowned river valleys, such as the Chesapeake Bay.

During the retreat of the Laurentide ice sheet, meltwater was impounded between terminal moraines and much of the Hudson Valley was covered by glacial lakes (Uchupi et al., 2001; Donnelly et al., 2005). Lacustrine sediments accumulated on top of glacial till and bedrock, filling much of the valley of the Hudson River. Following the breach of the terminal moraines, meltwater from the lakes drained to the sea, eroding a new fluvial channel into the lacustrine sediments.

The remaining space has been almost completely filled by the relatively thin package of fluvial and estuarine sediments that has been accumulating since the time brackish water invaded the Hudson River (Worzel and Drake, 1959; Newman et al., 1969; Weiss, 1974). Stratigraphic profiles, developed from seismic observations and bridge borings, indicate that >80% of the sedimentary infill is lacustrine sediments, while <20% is estuarine sediments (Worzel and Drake, 1959; Newman et al., 1969)." (Slagle et al., 2006).

Freshwater Discharges and Bay Hydrodynamics

The New York-New Jersey Harbor Estuary consists of Upper and Lower New York Harbor (from the Battery to the Verrazano-Narrows Bridge), Newark Bay, and Raritan Bay (USACE, 2004). Raritan Bay and Sandy Hook Bay measures about 109 square miles, with a surface area of about 69,188 acres, the inshore portion measuring about 33,500 acres (USFWS, 2007). The Estuary receives most of its freshwater flow from the Hudson and Raritan Rivers, and the Arthur Kill; and drains a watershed of about 16,300 square miles (NY/NJCOST, 2004; NY/NJHEP, 2007); USGS, 2007). More than 85% of the freshwater discharged into the Bay passes underneath the Verrazano-Narrows Bridge, while the Raritan and Passaic Rivers contribute about 14% (NY/NJCOST, 2004). Although the Raritan River discharges only 7% of the total freshwater, it dominates water quality along the Bay's southern coast in Monmouth County, especially when heavy rain occurs during an ebbing tide (Jeffries, 1962; NY/NJCOST, 2004; USGS, 2007). In Monmouth County, the Navesink-Shrewsbury Rivers, four lakes from Aberdeen to Union Beach, and numerous streams throughout the Bayshore flow into the Bay.

The residence for Bay water is about 60 tidal cycles or 16 to 21 days; the Hudson River Estuary flushes in less than 40 days during the high inflow periods in the spring, while during the summer low flow periods it takes about 200 days to flush (Blumberg et al., 2004; Geyer et al., 2001; Jeffries, 1962; Stehlik et al., 2004; Zimmer, 2004). Winds conditions may also temporarily affect residence time and flushing time. During upwelling (southwest) winds that predominate during the summer, the Hudson River flows to the east, and flushing times may be shorter then during downwelling (northeast) winds, when the Hudson flows west into Raritan Bay and slows the flushing time. The potential affect on nitrogen and algae blooms is being actively researched by Rutgers (Chant and Kohut, 2009). See the 'Currents' section under 'Ocean' in this report for a discussion of the effects of winds on the direction of the HR plume.

Water depths in Raritan Bay average less than 20 feet deep outside the dredged channels; the easternmost part of the bay is somewhat deeper (Ray, 2004; USFWS, 2007). Dredged channels in Raritan Bay and Sandy Hook Bay range from 80 to 1400 feet wide, and from 10 to 35 feet deep (Ray, 2004; USFWS, 2007). The mean tidal range is about 5.5 feet, but storm surges can reach 12 feet or higher (USGS, 2007). Raritan Bay tidal currents are counterclockwise, with major inward flows along the north shore (NY) from the Ambrose Channel, and outward flows moving along the southern shore (Monmouth County) exiting through the Sandy Hook Channel (Ray, 2004; USFWS, 2007). The average flood tide into the bay flows about 2 knots at the Ambrose Channel entrance while the ebb tide is generally stronger than the flood tide by 10% or more (the 76-foot high Ambrose Lighthouse marks the entrance to Ambrose Channel, which is the principal deepwater channel into Raritan Bay) (MBEC, 1976; Sorensen, 2005). Salinities range from a low of about 12 ppt near the mouth of the Raritan River to 32 ppt at Sandy Hook (USGS, 2007). Since the difference in density between salt and fresh water is about 3.5% or less, denser salt water enters the estuary in the lower part of the water column, while the lighter fresh water floats on top (Blumberg et al., 2004). Water temperatures in Raritan Bay range from about 33 F in January to 78 F in late August (USGS, 2007).

The Hudson-Raritan plume discharges an average of 23,000 million gallons a day of freshwater into the ocean through a five and a half mile opening between Sandy Hook, NJ and Rockaway Point, NY, where the bottom is armored with pea gravel due to the fast-moving tidal flow (Jeffries, 1962; NJ Scuba Diver, 2005; NY/NJCOST, 2004). In contrast, water entering the Bay at the mouth of the Raritan River has a net movement east of about 500 yards a day (Zimmer, 2004). A slow moving, cyclonic (counterclockwise) circulation pattern (a gyre) has been noted in Raritan Bay along the muddy flats between Point Comfort in Keansburg and the Naval Weapons Station Earle Pier in Leonardo (Jeffries 1962; Zimmer, 2004). The current is driven by "exiting fresh water from the Raritan River, which hugs the southern bayshore until it is deflected toward deeper water by Point Comfort in Keansburg " (MTEC, 1995).

"The sand buildup along the jetties shows diverging littoral currents at the Spy House", now known as the Seabrook-Wilson House, which is located on headlands between Pews and Comptons Creek. "East of the Spy House, jetties have a sand buildup on the west side, such as the beach near the Leonardo Marina. West of the Seabrook Wilson House, the Pews Creek jetty has sand accumulated on its east side showing a westward moving littoral current. This westward moving current continues along Ideal Beach towards Keansburg. The Spy House is an area where littoral currents change direction. Such an area is a nodal point" (MTEC, 1995).

In 1988, an extensive multi-species fishkill occurred when a large algal bloom arriving from western Raritan Bay depleted the dissolved oxygen in the flats at Leonardo Beach just east of this 2.9 mile-long pier (2.2 miles of the pier actually extend into the Bay). Up to 1 million sea robins, summer flounder, winter flounder, bluefish, American eels, etc. died after "localized hypoxia created by wind and tidal concentration of phytoplankton from a bloom of Heterosigma carterae, Katodinium rotundatum and Eutreptia lanowii" (Reid et al., 2002).

Wastewater

About one tenth of the 23,000 MGD of freshwater flow into the estuary is from wastewater plants, storm drains, and Combined Sewer Overflows (NY/NJCOST, 2004). Twelve major wastewater treatment plants in NJ discharge about 600 MGD of treated wastewater into the estuary (NY/NJCOST, 2004). The water quality of the southern coast of the Bay along Monmouth County is dominated by both the Raritan River and the Middlesex County Utility Authority's outfall in the Bay off Cheesequake Creek in Sayreville, about 3 miles west of

Conaskonk Point in Union Beach (Cheesequake Creek also drains the former Global Landfill in Old Bridge, and the swimming lake and wetlands of Cheesequake State Park) (Jeffries, 1962; Ray, 2004; USFWS, 2007; Zimmer, 2004). MCUA's permitted flow for their H-shaped diffuser outfall is 160 million gallons per day (MGD), with flows in excess of 200 MGD reported; in addition, a second outfall located on the northern bank of the Raritan River adjacent to the treatment facility is used to capture additional flows from rain and can exceed 150 MGD (Zimmer, 2004). The MCUA's influence on water quality along the southern shoreline was demonstrated on March 4, 2003 after 570 million gallons of raw sewage discharged into the bay from a pump station in Sayreville; subsequent DEP sampling maps showed a bacterial plume hugging the southerly shoreline, most densely in the western part of Monmouth at Aberdeen and Keyport, then breaking up east of the Earle Navy pier (http://www.nj.gov/dep/update/fecalcharts.html) (DEP, 2005). A 1989 study of the effluent plume from the plant, which was upgraded to secondary treatment in 1996, shows that during ebb tide the plume generally follows the primary flow pattern of the Raritan River, moving to the southeast until Union Beach, then flowing northeast towards the southern edge of Staten Island, into the dredged shipping lanes of the Raritan Channel (NY/NJCOST, 2004; Zimmer, 2004). At low tide, two smaller channels closer to the Monmouth shoreline than the Raritan Channel can be observed under the 2400 foot long Keansburg fishing Pier: a smaller channel that appears to have been formed by the flow from adjacent Waackaack Creek, and a wider channel closer to the end of the pier, that may serve as a secondary flow channel for the Raritan River.

The Kills

The Arthur Kill, near the mouth of the Raritan River, is not considered a significant source of water draining into Raritan Bay, although it exerts a "milking action which accelerates the seaward movement of freshened water along the south shore of Raritan Bay" (Jeffries, 1962). The Arthur Kill receives drainage from Newark Bay and the Hackensack and Passaic Rivers, as well as draining the world's largest landfill – the now-closed Fresh Kills Landfill on Staten Island (NY/NJCOST, 2004; USGS, 2007). It connects Newark Bay with Raritan Bay, and is about 13 miles long and about 35 feet deep, ranging between 800 and 2800 feet wide, with a 500 foot wide navigation channel; the Kill Van Kull connects Newark Bay with Upper New York Harbor, and is about 5 miles long and 800 feet wide, ranging in depth from 11 to 50 feet (USACE, 2004). Tidal movement in the Kill Van Kull mixes water between Newark Bay and the Upper Bay, particularly during spring tides; while tidal excursions in the Arthur Kill are significantly shorter and usually don't generate a complete transfer of water between Newark and Raritan Bays (NY/NJCOST, 2004). In fact, the residence time for water in the Arthur Kill is about 2 weeks, but because its tides at the Raritan Bay and the Kill Van Kull are so balanced, the direction of its net flow remains definitively undefined (Waldman, 1999).

Sea level drops more rapidly in the shallower Raritan Bay than in the deeper Upper New York Bay, and wind can enhance or negate the effect of tides in the Kills and Raritan Bay (Chant et al., 2006). Strong westerly winds over the NY Bight region pushes water towards the east into the ocean, and lowers the water level in Raritan Bay; if this occurs for several days, it can result in higher net flows out of Newark Bay through the Kill van Kull and into the ocean (Chant et al., 2006; NY/NJCOST, 2004; Pence et. al., 2005). Several days of easterly winds raises the water level in Raritan Bay, and causes water to flow from the Kill van Kull into Newark Bay, which then empties into the Arthur Kill (Chant et al., 2006; NY/NJCOST, 2004; Pence et. al., 2005). Although the Arthur Kill is likely not the channel for filling and emptying Newark Bay, northerly winds can create a "set-down" of the Arthur Kill at Perth Amboy and drive water out of Newark Bay (Chant et al., 2006). Northwesterly winds can drop sea level and drive a strong southerly flow out of the Arthur Kill into Raritan Bay against the tide (as flow is entering the eastern Kill van Kull (Chant et al., 2006). During east-west winds, the currents turn first at the Kill van Kull, then an hour later at Newark Bay, then 2 hours after that at the Arthur Kill (Chant et al., 2006).

Seventeen hundred tankers carry 18 billion gallons of petroleum into NY Harbor every year (Waldman, 1999). Some of the world's largest petroleum importing, refining, and storage facilities are located on the Arthur Kill: the ConocoPhillips' Bayway Refinery in Linden, the Hess facility in Woodbridge, and the Chevron refinery in Perth Amboy (NY/NJCOST, 2004; USGS, 2007). The Bayway Refinery, located in the Tremley Point area of Linden, was originally the Standard Oil Refinery, built on a former racetrack by John D. Rockefeller in 1909; it was later owned by Exxon and Tosco, and presently has the capacity of processing about 250,000 barrels of crude oil a day (Colorantshistory.org, 2007). In 1990, over a million gallons of oil spilled into the Kills during the first 6 months of the year (USACE, 2004; Waldman, 1999). This included 567,000 gallons of No.2 fuel oil from a ruptured pipeline at the Bayway Exxon on January 2, 1990 ; about one quarter of this spill was recovered by 680 people, 60,000 feet of boom, 40 vacuum trucks, 10 skimmers, and 70 vessels (Waldman, 1999). Two months later an explosion on Cibro Savannah barge owned by Citgo Petroleum Corporation released 127,000 gallons of No.2 heating oil (Waldman, 1999). Then the tanker BT Nautilus ran aground near the Bayonne Bridge on the Kill Van Kull on June 7, and spilled 260,000 gallons of heavy No.6 fuel oil (Waldman, 1999). In 1991, 11 out of 15 million dollars in Exxon's penalties paid for financed restoration, land acquisition, and environmental studies of the Arthur Kill (Waldman, 1999).

Combined Sewer Overflows and sewage treatment plants discharge into the Arthur Kill (example: the Joint Meeting of Essex and Union Counties, the Linden-Roselle Sewerage Authority, and the Rahway Valley Sewerage Authority); and at least 16 tributaries discharge into the Arthur Kill (USACE, 2004). The Kills have a number of derelict vessels; the Arthur Kill alone has 275 wrecks within five "vessel graveyards" along the Staten Island shoreline (USACE, 2004). In one study of contaminated sediments in Raritan Bay, the highest levels of hydrocarbons, copper, lead, nickel, chromium and zinc were found in the silty sediments at the western extent of Raritan Bay by the mouth of the Arthur Kill (Steimle et al., 1989). The other area with elevated levels of these pollutants was to the east in Sandy Hook Bay, between the Navy pier and the Sandy Hook shoreline north of Horseshoe Cove (Steimle et al., 1989). This zone of contaminated, silt-clay sediments (Site 16 in the report) is located between two channel systems: along the western edge of the 20 foot contours of the Navesink Shrewsbury channel, and south of where the Chapel Hill Channel joins the channel dredged for the Navy pier. The Chapel Hill Channel begins where it splits from the Ambrose Channel, south of where the Hudson River passes under the Verrazano-Narrows Bridge (Steimle et al., 1989). These two divergent areas in Raritan Bay were near where the lowest number of benthic macrofauna (sediment dwelling organisms more than 1 millimeter in size) were found; the mollusc Mulina lateris dominated the biomass in both zones (Steimle et al., 1989).

Stormwater in the Shrewsbury River

At the southeasterly end of the estuary in the Shrewsbury River watershed is a major point source of animal fecal bacteria, the Monmouth Park Racetrack in Oceanport. In 1996, this was the only racetrack in NJ (and one of the first in the US) to be required to control the discharge of its manure-laden stormwater runoff (by the NJDEP: 100k dry weather, 250k wet weather). Since 2004, a federal Concentrated Animal Feeding Operation (CAFO) – 1 of 6 racetrack CAFOs in the US according to the EPA – has mandated that all stable runoff must be discharged into the Two Rivers Water Reclamation Authority, rather than into Branchport Creek, except during a 25-year storm (effective 2007). A 25-year storm is 6.25", which would generate approximately 10M gallons of runoff from MP; Hurricane Floyd, the greatest natural disaster in NJ to date, "only" dropped 6.4 inches of rain in Hazlet, 5.82" in Marlboro, 5.2" in Sandy Hook, and 4.57" in Keansburg (URS, 2008). In nearby Parkers Creek, nutrients in runoff from commercial centers and well manicured lawns discharge into the sluggish, shallow waters along Gooseneck Point, contributing to some of the highest chlorophyll a levels (a measure of algal mass) that the DEP has measured in NJ's coastal waters (DEP, 2004).

Bay Sediments

Riverine sediments become trapped within the estuary due to the landward tidal flow of the bottom current, which also carries ocean sediments into the Bay (Geyer et al., 2001). During the highest runoff events in March and April, suspended sediment loading from the Hudson River can increase to over 100,000 metric tons per day into the estuary, one hundred times the long term mean of 1100 metric tons per day (Woodruff et al., 2001). The upper Hudson River is the dominant source of sediment into Upper New York Bay, about 1 million metric tons per year; during the spring most of this sediment from the Hudson River is temporarily stored in the lower Hudson River and Upper New York Bay, near the Kill van Kull (Chant et al., 2006). On average, sediment is exported from the Bay into the ocean only when enough rain-driven flow occurs during a spring tide (the new and full moon) to push this "saline wedge" to the mouth of the estuary; peak concentrations of suspended sediment during the neap tide (the first and third quarters of the moon) are ten times lower (Geyer et al., 2001). Mud from the Raritan River is filling portions of the Bay at a rate of about 0.75 inches per year (USGS, 2007). Most of the silts discharged into Raritan Bay appear to originate from the Raritan River (Steimle, et al., 1989). The sediments of the Bay closest to Monmouth County, south of the east-west Raritan Channel, have the finest grain size, and are predominantly fine sand, silt and clay; north of the Raritan Channel and west of the north-south Chapel Hill Channel, sediments are mainly medium sand, with a mixture of sand, silt and clay near the channels; north of Sandy Hook Bay, including Ambrose Channel to the shores of Brooklyn, are gravel, sand, silt, and broken shell, with beds of blue mussel (Ray, 2004; Stehlik, 2004). One exception is the coarse and medium sands in the intertidal areas east of Conaskonk Point in Union Beach (Ray, 2004; Stehlik, 2004; Steimle et al., 1989).

Sandy Hook

Sandy Hook across from Highlands has one of the last remaining marine forests (holly and eastern red cedar) in the US; it was called Racko Rumwaham by the Lenape and Sant Punt by the Dutch (Boyd, 2004; USGS, 2003). It is the end of a long peninsula that begins at the headland bluffs in Long Branch, and is an average of about 3000 feet wide at the northern end (RSCNJCRC, 2006; USFWS, 2007).

The US Army acquired Sandy Hook from the Hartshorne family in 1817, and has occupied the peninsula under various names from 1807 through 1974, protecting the metropolitan area as a fort, a proving ground, a firing range, an ammunition storage area, an anti-aircraft defense site, and a Nike Missile site (Roberts and Youmans, 1993; SSH, 2008). A year after the start of the

War of 1812, the Army built a temporary fortification called Fort Gates; in 1857, construction began on Fort Hudson (sometimes called Fort Lincoln), which was eventually renamed Fort Hancock in 1895 (Roberts and Youmans, 1993; SSH, 2008). In 1874, the Sandy Hook Proving Ground became the first ammunition proving ground established in the US; in 1918, the year WWI ended, it was moved to Aberdeen Proving Ground in Maryland; the Army has been conducting a preliminary investigation of the status of unexploded ordinance at selected areas within Sandy Hook since 1991 (Roberts and Youmans, 1993; SSH, 2008; USPMCD, 1996). The Fort subsequently became an anti-aircraft site through World War II; the SCR-270 radar system was developed at Sandy Hook and tested locally before it was sent to Hawaii in 1941 (unfamiliarity with it resulted in the failure to detect the attack on Pearl Harbor; the radar facility was moved to Camp Evans in Wall in 1942) (Moore, 2009). The base was deactivated in 1950, then reactivated because of the Korean War (1950-1953) (Biddinger and Rasa, 2009; USPMCD, 1996). The Fort's Nike Battery NY-56, a four-magazine, double-missile battery site, was activated in 1955 and continued operation until the Fort's closure in 1974 (Biddinger and Rasa, 2009). In 1958, 10 soldiers and civilians were killed when a Nike Ajax missile exploded in a Battery in the vicinity of Belford and Leonardo. This is memorialized at Guardian Park, which is familiar to anyone who has driven to the old military housing at the tip of Sandy Hook, where an Ajax and a Hercules missiles and a granite monument to those killed in the accident sit on a triangle of land at a juncture in the roads (Biddinger and Rasa, 2009).

Sandy Hook is now part of the Gateway National Recreation Area, except for the northern tip, which is owned by the US Coast Guard. It has the oldest operating lighthouse in the US; when it was built in 1764, the 85-foot tall lighthouse was 500 feet from the tip of the hook, but today because of sediment buildup it is 1.5 miles away (Roberts and Youmans, 1993). While it has changed from island to peninsula over the years, Sandy Hook is currently a 7-mile, 1825-acre barrier spit, expanding northward from the littoral drift of sand primarily from beaches in Sea Bright and Long Branch, and shaped by the Shrewsbury and Navesink Rivers as they flow into Raritan Bay (Terwilliger, 2004). In the 1880's, these rivers discharged directly into the ocean at an near the present day Highlands Bridge by the entrance to the park, which was then an amusement park named Sandlass Beach, by the beginning of the present seawall along Ocean Avenue. Plum Island near Parking Lot A is the remnants of this inlet (Roberts and Youmans, 1993; USGS, 2003). Now, the primary flow pattern along the bayside of Sandy Hook is northwest from the mouth of the Shrewsbury near Highlands, flowing parallel to the southern edge of Sandy Hook, following the spit's contours until it turns into the dredged shipping channels (Zimmer, 2004).

Wrack Line

The coal chunks occasionally found on bay beaches are probably from cellar ash that had been dumped in the bay, or spillage from ships, since coal remained an important source of heat in public buildings and power facilities until the late 1960's. Some chunks may also be lignite deposits from the Raritan-Magothy Formation where it outcrops along the shore (USGS, 2003). Lignite is a precursor of coal that is formed from compacted peat (Dahlgren, 1977). At low tide, large and small 'worm reefs' resembling hard, sandy sponges that are actually colonies of the sand tube worm, Sabellaria vulgaris, can be seen in the muddy flats along Raritan Bay, especially from Keansburg to Port Monmouth. Generally, deposit feeders such as worms are found in mud, while sandy areas are utilized by filter feeders such as clams. Sediment type, which is related to water depth, appears to be a dominant influence of benthic biomass; major macrofaunal zones are divided into sand, silty-sand, and silt-clay fauna (Reid and Steimle, 1988; Steimle, 2005;

Terwilliger, 2004). In a study of the biomass of Arthropoda (invertebrates such as crustaceans) in the Middle Atlantic Bight, one of two areas with the highest levels was in Sandy Hook Bay, due mainly to amphipods and decapods, such as prawns and crabs (the other area was south of Cape Cod, due to high levels of barnacles) (Reid and Steimle, 1988). One study of the infauna inhabiting the tidal flats between Keansburg and Middletown found a low of 2,681 animals/m2 at Point Comfort, and a high of 38,271 animals/m2 at Port Monmouth (Ray, 2004). Zooplankton in the NY Bight are dominated by about 14 species of copepods, which is a tiny crustacean that feeds on phytoplankton and is a major source of food for fish and seabirds (Connor et al., 1979).

New Jersey's coastline supports the world's largest population of horseshoe crabs, Climulus polyphemus, known as a 'living fossil' because it has evolved so little since it first appeared almost half a billion years ago (Wikipedia, 2005). Their eggs provide food for the 1.5 million migratory shorebirds that visit NJ's beaches and wetlands every year (Cooper et. al., 2005). Monmouth County is a stopover on the Atlantic flyway, which measures 9000 miles from Patagonia, at the tip of South America, to the Arctic; Cape May is also linked with the Asian and western North American flyways (the tundra swan migrates to Chesapeake and Delaware Bays after nesting in Alaska) (Barnes, 2005). The most common gulls seen during the summer are Laughing Gull, the Herring Gull, and the Great Black-backed Gull; the black-backed is common year round, and is the world's largest species of gull (Seidel, 2006). Spring and fall shorebird migration counts have reached as high as 20,000 birds per week; the peak months for birds living along Raritan Bay are in June and August, with the primary locations being Great Kills on Staten Island, the flats inside Sandy Hook, and the Union Beach shoreline between Chingarora Creek and Conaskonk Point (USFWS, 2007). Located in the Kills, Shooter's Island, Prall's Island, and the Isle of Meadows comprise the "Harbor Herons Complex", accounting for 25% of the wading birds that breed in coastal NJ, NY and Connecticut, as well as providing ground-nesting habitat for gulls and terns (seagulls do not nest at Sandy Hook because they would be vulnerable to predators) (Barnes, 2005; USACE, 2004). Raritan Bay is the southernmost location where American Lobsters can live near shore (they live south of the Bay on the continental shelf), and the northernmost area where blue crabs occur in large numbers year round (USGS, 2007). There are only about 12 square miles of coastal wetlands left in the Bayshore, from South Amboy to Highlands - mostly in Cheesequake State Park in Old Bridge, Conaskonck Point in Union Beach, and the Bayshore Waterfront Park in Port Monmouth and Belford. (Reynolds, 2006). During the 1800s and early 1900s, tidal flats exposed along the Bay during the lowest spring tides were up to a mile wide (USGS, 2007).

Bunkers (Atlantic Menhaden)

The first recorded bunker kill in the area was observed by a Dutch settler, Jasper Danckaerts, in a creek in Staten Island in 1679 (Waldman, 1999). The largest fishkill on record in the coastal waters of Monmouth County took place in 2000, when 3.9 million juvenile menhaden (peanut bunkers) suffocated in Little Silver Creek in the Shrewsbury estuary (Reid et al., 2002). While they are very sensitive indicators for pollution and algae blooms, large numbers of "bunkers" also suffocate almost every summer when they are cornered by bluefish and other predators. When they are frightened they defecate and pack themselves into tight schools; this uses up all the remaining oxygen in the warm water where they are trapped by the circling bluefish (known as a bluefish blitz) (Waldman, 1999). Bunker kills indicate a localized dissolved oxygen (DO) drop to at least 2.0 mg/l (a good level of DO is 5.0 mg/l) (Zimmer, 1996).

“Moss bunkers” is derived from marsbanker or horse mackerel, from the early Dutch settlers; menhaden are actually members of the herring family (Franklin, 2007; Waldman, 1999). Bunkers are also called shad, fatback, and pogie or pogy (not porgy), from "pauhagen," the word for fertilizer used by the Abenaki tribe of Maine (Franklin, 2007). In fact, the Native Americans of Massachusetts may have taught the Pilgrims to use bunkers as fertilizer when planting corn (Franklin, 2007). Bunkers that are caught commercially, known as reduction fishing, are “reduced” to fish meal, proteins, and oils (including omega vitamins); are used as animal feed and in cosmetics, and since colonial days, as fertilizer (Franklin, 2001).

From mid June through the early fall of 2007, a record 11 bunker kills occurred in the Bayshore and the Shrewsbury River, 3 estimated in the hundreds of thousand to million range. Newspaper pictures showed dead peanut bunker (juveniles) littering the phragmites along Matawan Creek in Keyport like cherry blossoms, in spite of average water quality and dissolved oxygen. The only unusual condition that year was that the water temperature had spiked to 75^{o}F by Memorial Day (as recorded at the USGS station at Keansburg), which had contributed to a significant diatom bloom in Sandy Hook Bay, the first to occur during the Memorial Day weekend in 10 years. In 2008, bunker and other baitfish were predominately spotted by fisherman in the ocean south of Long Branch rather than in the Bay. There were only a few minor bunker kills in local estuaries that year, mostly linked to the bacteria Vibrio ordalii and Photobacterium damselae, which cause respiratory disease in fish, not humans (USFWS Fish Health Center, Lamar, Pennsylvania, 2008).

A 2001 law prohibiting reduction fishing by commercial trawlers within 1.2 nautical miles of the NJ shoreline went into effect in 2002. Bunkers reproduce at age 3, so there have been more than 2 full generations of bunkers since then. Since 2005, the numbers of bunkers have been increasing along NJ, and have reached the highest level recorded by NOAA from 1985 through 2008 (Eilperin, 2009; Hohn, 2009). In 2010, the New Jersey Bureau of Marine Fisheries estimated the East Coast bunker fishery at about 35 billion (Degener, 2010). The local abundance of bunkers may be attracting more dolphins to the NJ coast, such as the pod of 16 that moved into the Navesink and Shrewsbury estuaries from June 2008 until January 2009 (Eilperin, 2009). Rep. Jim Saxton, R-NJ., and Rep. Wayne Gilchrest, R-Md, introduced a bill in 2008 (H.R. 3840) that would impose a moratorium and would prohibit commercial menhaden fishing in the U.S. Exclusive Economic Zone, which extends from three miles to 200 miles into the Atlantic Ocean (Gieser, 2008). Besides their vital role at the base of the food chain, adult bunkers are filter feeders that consume phytoplankton, and so like oysters, may be an important natural BMP (Best Management Practice) for controlling algae blooms in coastal waters (Franklin, 2001).

PARKS AND FARMS

There are many County parks, conservation areas, and golf courses (12,802 acres as of the end of 2004); there are 42,809 acres of protected open space, which is 14.2% of the county land area, an area larger than Howell Township, the County’s largest municipality (MCPB, 2005b). Tatum Park in Middletown has a grove of tulip trees growing along its steep hill trails; the almost branchless, straight trunks are some of the tallest trees on the Coastal Plain (USGS, 2003). The Swimming River Reservoir near the bridge over Longbridge Rd in Colts Neck, Marlu Lake in Thompson Park in Holmdel, and Burkes Creek in the Manasquan watershed in Freehold, have the only reported populations of painter’s mussels, Unio pictorum, a greenish, non-native species that is several inches in length (a five inch specimen was observed in the reservoir). Crosswick

Creek Park in Upper Freehold has a striking, black sand creek flowing in the glauconitic Hornerstown and Vincentown formations along the ironstone ridge that Cream Ridge is named for (USGS, 2003). Almost 11% of the County - 42,111 acres - is public open space, 19,200 of which are County owned (MCPB, 2005a). According to Golf Digest, Hominy Hill Golf Course in Colts Neck is among the top 50 public courses nationwide, as is Howell Park (MCPB, 2005).

The "Monmouth Brooks" fossil sites includes Big Brook Park on the Marlboro and Colts Neck border, where Big Brook flows through an ancient mud reef in the glauconitic Navesink formation that contains numerous sharks teeth and fossils of invertebrates such as mollusks and Belemnites. As early as 1863, the Smithsonian Institute in NY sent staff there to gather fossils (Colts Neck Historical Society, 1965). Many of the same types of Cretaceous fossils also exist in the Navesink formation in Poricy Brook in Poricy Park in Middletown (Gallahger, 2003). A heel bone of a ground sloth (Megatherium america,_tm Blmnenbach) was found in 1883 at Long Branch (Richards, 1951).

The Lenape Indians started using a garden style of farming in Monmouth County around 1000 A.D. (Aberdeen Twp., 2005; Colts Neck Historical Society, 1965). In 2007, about 20% of the County's 300,000 acres were used for farming - 60,000 acres; during WWII, at the beginning of the move to the suburbs, 110,000 acres were farmed (Sapia, 2007c). According to the US Census of Agriculture (2002), while the average farm size in the County today is 53 acres, over half are smaller than 5 acres; in 2002, the County had 892 farms totaling 47,198 acres, while in 1978, there were 732 farms (FSCD, 1985; MCPB, 2005b). About 550 acres of farmland have been converted to urban land since 1969 (ESDRU, 2006). The Meade Farm, a 70 acre sod farm in Howell, was the first farm entered into the Farmland Preservation Program in 1978; as of 5/23/07, Monmouth became the seventh county in NJ to reach 10,000 acres of preserved farmland, with the preservation of the 131-acre Ernst Farm in Upper Freehold (Jordon, 2007). The last dairy farm closed in 2000; farms that once produced traditional crops such as vegetables are being replaced with higher revenue generating operations such as nurseries, organic farms and exotic produce. The County is 48th among counties in the U.S. for nursery, greenhouse, floriculture and sod. Upper Freehold has the most preserved farmland in the state (6,700 acres). Monmouth has the largest number of horses in the state, with 19,000 acres devoted to equine activities; it is 49th in the U.S. for horse and pony inventory (MCPBa, 2005). NJ's has a 1.1 billion dollar a year horse industry; 29% of NJ's 42,500 horses are part of the racing industry (Sapia, 2007c).

TERRAIN

Lowlands and plains characterize most of the County, with a small isolated fragment of the Pine Barrens along the border of Manalapan, Marlboro and Middlesex County (MCPB, 1975). Scattered throughout the Coastal Plain are numerous shallow basins that originated during the Wisconsinan glacial age in the Late-Pleistocene. These 'spungs' were formed when strong winds blowing down the Hudson River Valley across the Laurentide ice sheet blasted the barren terrain of central and south Jersey, eroding 'blowouts' in the ground. (French and Demitroff, 2001). When the glaciers melted and sea level rose, these periglacial depressions filled with groundwater and formed bogs and ponds, some of which still remain today as (seasonally ephemeral) vernal pools. Over the last 125 years, many of these pools have degraded or dried up as the water table fell due to over-withdrawal and urbanization. (Demitroff, 2006; Kraft, 2001; Lathrop et. al., 2005).

The most prominent landform in the County is an erosion-resistant ridge of glauconite and sand formations capped by Tertiary ironstone conglomerate and yellow gravel (MCPB, 1975; USGS, 2003). The Mount Pleasant Hills extend from Keyport southwest through Imlaystown to the Delaware Bay in Salem County, and is the drainage divide between the Inner and Outer Coastal Plain (Kraft, 2001; MCPB, 1975). These cuesta shaped hills, which are named after what is now known as the Freneau section of Aberdeen, also extend eastward from Keyport to the Navesink Highlands – the hills of Atlantic Highlands, Highlands and Middletown that face Sandy Hook Bay (a cuesta is a long ridge with a gentle slope on one side and a deep scarp face on the other) (Aberdeen, 2005; Kraft, 2001). Mount Mitchill in the Navesink Highlands rises abruptly from sea level to a maximum elevation of 266 feet, and is the highest point on a shoreline of the eastern seaboard south of Maine (MCPB, 1975; USGS, 2003). During the most subarctic period of the Wisconsinan, peaking about 21,000 years ago, the Navesink Highlands was a high escarpment along the valley of the combined Hudson/Raritan Rivers before glacial melt drowned the two rivers into an estuary about 6000 years ago; during the Wisconsinan, Mt. Mitchill may have been as much as 600 feet above sea level (Smith, 2000; USGS, 2003). About 15 million years earlier, after deposition of the Cohansey Sands and during the last great rise in sea level from mid-Miocene to early Pliocene time, the ancestral Hudson River cut southwest across the Coastal Plain during an uplift of the rocks in northern NJ. The Hudson turned south near Clarksburg and arced east to discharge into the ocean near Tuckerton; it left behind the yellow gravel of the Beacon Hill Formation, named for a 373 foot hill in Leonardo near the Atlantic Highlands border (Dahlgren, 1977; Owens and Minard, 1979; USGS, 2003).

From the Navesink Highlands westward, the Mount Pleasant Hills range in elevation from 200 feet at Chapel Hill, Middletown, to 391 feet at Crawford Hill in Holmdel, which is the highest point in the County (MCPB, 1975). Near Perrineville a series of hills rise to nearly 360 feet in elevation; west of Imlaystown the relief again flattens out, as it also does west of Morganville, and the hills only rise to 100 feet or so in elevation (MCPB, 1975). Wind scour markings on sandblasted ironstone blocks capping the high points around Perrineville that were formed during the Late Pleistocene (as well as the widespread presence of wind-abraded stone and cobbles throughout South Jersey) indicate a harsh climate like that of North Greenland during the Ice Age's coldest periods (French and Demitroff, 2001; French et al 2003, 2005; Moore 2003). A smaller group of hills called the Hominy Hills (formerly called Manhomony Hills) stretch from Colts Neck nearly to Eatontown; elevations range from nearly 200 feet to 307 feet at Naval Weapons Station Earle (MCPB, 1975; Colts Neck Historical Society, 1965). The Lakewood Plain lies to the south of these hills and the Freehold-Colts Neck lowland to the north. If sea level rose by 100 feet the tops of these 2 hills systems would be the only significant landforms left, along with the Monmouth County Reclamation Center, which has reached an altitude of about 256 feet since it opened in 1976 (MCPB, 1975; Royte, 2005).

SURFACE WATER

The Mount Pleasant Hills, the drainage divide between the Inner and Outer Coastal Plain, divide drainage in the County into three major directions. West of the Hills streams flow into the Delaware River and Raritan River basins; north of the Hills streams empty into the Raritan and Sandy Hook Bays; and east of the hills streams flow to the Atlantic Ocean, and in the case of the north branch of the Metedeconk River, into Barnegat Bay. Major streams flowing to the Delaware River are Crosswicks Creek, Doctors Creek and Assunpink Creek; streams flowing into the Raritan River Basin are Deep Run, Manalapan and Matchaponix Brooks and the Millstone River; the Navesink and Shrewsbury Rivers, Comptons, Chingarora and Matawan

Creeks all flow into Raritan or Sandy Hook Bays; the Shark and Manasquan Rivers flow into the Atlantic Ocean. All streams except Crosswicks Creek have their headwaters in Monmouth County and flow outward; this also includes Toms River and the north branch of the Metedeconk River (MCPB, 1975). Groundwater in the Coastal Plain generally flows from northwest to southeast. Streams that flow in this direction, i.e. towards the Atlantic Ocean, are known as "consequent" streams, because they flow in the same direction as the dip of the underlying strata; "obsequent" streams, like those that flow to the north towards Raritan Bay, flow opposite to the dip of the underlying geology (Mulhall, 2003).

Some headwater tributaries in the Toms, Metedeconck and Manasquan Rivers and the Reevy Branch in the Shark River watershed are tea-colored like the creeks found throughout the Pine Barrens. Because their sandy soils support smaller microbial populations than soils with silt and clay, leaf litter and other organic material is inefficiently decomposed, producing the humic and fulvic acids that color the baseflow of the stream.

Surface waters used for drinking water include the New Jersey American Water Company's Swimming River Reservoir (1901, expanded 1961) in Colts Neck, and the Glendola Reservoir (1965) in Neptune Township, that is sourced by the Shark River Brook and in the past, Jumping Brook (MCPBb, 2005). The reservoir at Swimming River, which controls about half the Navesink watershed, and extends to about 560 acres; when full, it impounds about 8000 acre-feet of water (FSCD, 1985). Other surface supplies are the New Jersey Water Supply Authority's Manasquan River Reservoir (1990) in Howell; United Water Company's Matchaponix Brook intake (1993) near Englishtown; and the Brick Township MUA Reservoir (2005) on the border of Wall Township that is sourced by the Metedeconck River. Projections indicate that the county's watershed areas will have substantial water surpluses in 2010 (MCPBb, 2005).

There are about 59 square miles of surface water in the County. Stream patterns are for the most part symmetrical and dendritic, resembling tree root systems, with feeder streams nearly equally distributed on both sides of the main stream (MCPB, 1975). Monmouth County's 6 Watershed Management Areas are uniquely susceptible to erosion. This is because they flow through soils that are the geologic ecotone of the fine glauconitic silt and clay of the Inner Coastal Plain, that lie between the Piedmont cobble to the northwest and the coarse Kirkwood-Cohansey sands of the Outer Coastal Plain.

MCHD's Rapid Bioassessment work has uniquely identified a multitude of stream sites in glauconitic soils that are dominated by pollutant-tolerant benthic organisms that are associated with erosion and siltation. During streambank erosion, clay and silt sized particles remain colloidally suspended in the water column, prolonging turbidity. These fines blanket the streambed and smother the least hardy macroinvertebrates that live in the sediment. Additionally, streams in glauconitic soils downcut as they erode and eventually lose their ability to overflow into adjacent wetlands. In contrast, streams flowing in the coarse sands of the Kirkwood-Cohansey outcrop can maintain wetland availability during 2-year, bankfull storms (3.4 inches in 24 hours). They are more stable than downcut streams since they can store stormwater in the wetlands and release it over longer periods of time. That is why the majority of Non-Impaired streams with pollutant intolerant macroinvertebrates are found in the sandy mid to southern part of the County. Sandy streams like the Metedeconck even retain their excellent, Non-Impaired quality near developed areas like Route 9 in Howell, but the few Non-Impaired streams in the glauconitic outcrops are always found in undeveloped areas.

The eroded clay and silt fines that blanket streambeds and lakes also adsorb pollutants and nutrients more efficiently than sand, and provide habitat for the regrowth of bacteria and other microbes during the warmest months of the summer. This bacterial-laden muck will resuspend in the water column during rainfall, and has been linked to ocean beach closures near lake outfalls. As freshwater colloids enter estuaries, the increase in salinity causes these pollutant-laden fines to acquire an ionic charge and clump together into aggregates, which sink and accumulate in the estuarine sediment. It has been estimated that up to 80% of freshwater pollutants accumulate in estuaries; furthermore, "probably less than 5% of the sediment reaching the coastal zone in the Atlantic seaboard of the U.S. is transferred to the continental shelf or to the deep sea" (DePetris, 1996).

A general rule regarding streambank erosion is that the southern (north-facing) and eastern (west-facing) streambanks erode faster than the opposite banks because of the higher rates of freezing and thawing during the winter. Occasionally erosion is significantly increased during the winter when a frozen slurry of streambank is sloughed off after the temperature rises and it rains (Smith, 2000). Erosion from road runoff first escalated in the County with the development that followed the opening of the Garden State Parkway in 1954. For example, Lake Matawan was originally created in 1923 by damming Gravelly Creek. The lake extended to Church Street in Matawan, where an extensive wooden railroad tressel was built over the lake at nearby Water St. But because of the siltation that began in the 1960's, the Lake ends near Little St. in Matawan, and the still-existing tressel at Water St. now crosses over wooded wetlands instead of a lake (Kisk, 2006; Starace, 2006).

GLAUCONITE

Glauconite (marl, greensand, rotten stone, poison marl, hardpan) is a green to black silicate of iron, potassium, and phosphorous that formed from the droppings of sediment-dwelling invertebrates in the shallow regions beyond the breakers of Cretaceous and Tertiary seas (Tedrow, 1986); specifically, in a low oxygen, reduced iron environments in a specific facies array associated with silica-consuming diatom blooms in upwelling zones close to the coast (Earthscape, 2007). A modern, anthropomorphic example of glauconite formation: glauconite abundance (associated with upwellings and hypoxia) increased dramatically in the 1940's and 1950's in marine sediments in the Gulf of Mexico (NOAA, 2007). Sediment cores of hypoxic zones in the Gulf of Mexico indicate that algal production, deposition, and oxygen stress were much lower in the earlier 20th century, with an increase in biogenic silica (a measure of diatom abundance) and organic carbon beginning in the 1950's (NOAA, 2007).

Glauconite is found in various amounts in almost every geological deposit in Monmouth County except the Keyport and Elkton sands in the northern tip of the County, and the Kirkwood Cohansey sands in the southern part of the County (Smith, 2000). Although the Kirkwood Formation contains clay, most of the clay and silt in the County are associated with glauconite. The late Cretaceous Merchantville Formation, which overlies the oldest aquifer system in the County, the Raritan-Magothy, is the oldest glauconitic formation. (Zapecza, 1984).

The first dinosaur discovered in North America, the duck-billed state dinosaur, Hadrosaurs foulkii, was discovered in 1858 as a result of marl-mining at a farm near Haddonfield, NJ (Forman, 1998; Geoworld, 2005). Glauconite became widely used as a soil conditioner after Peter Schenck started using it on his farm in 1768 near aptly named Marlboro (Forman, 1998;

Geoworld, 2005). Its chemical properties as well as its size make glauconite's role in water quality controversial. While the DEP NJGS has determined that the phosphorous in its matrix is chemically bonded to iron, and so will not become available as a nutrient in surface water at natural pH's, DEP's Watershed Unit has found, based on a limited data set in the glauconitic Manasquan River, that phosphorous levels rose as iron levels rose in the water column (Dooley, 2000; Jacobsen, 2002). The Middletown Environmental Council has also found an association between elevated phosphorous levels in McClees Creek, wherever its springs originate in the glauconitic Navesink formation (MTEC, 1999).

Glauconitic soils are an aggregate of fine particles that are easily smeared and compacted, and can become up to 100 times less permeable after compaction. This susceptibility to compaction, as well of the dispersal of the soil aggregate by sodium-containing soap, is why glauconite-bearing soils are poorly suited for septic systems, especially in the Pemberton, Colemantown, Marlton, and Kresson soils in Monmouth (Smith, 2000).

The greensand (glauconite) filter is one of the oldest types of water treatment used to remove metals from drinking water - including radium. Strontium glauconite is used medically to speed up the elimination of internal strontium contamination from the human body (IAEA, 1998). In Belorussia, in the vicinity of the Chernobyl disaster, one radioecology study has concluded that glauconite is a successful natural sorbent for removing radioisotopes from contaminated matrices (Sucharev et al., 2006). Local runoff after Chernobyl was heavily contaminated with cesium and strontium, which adsorb more efficiently to clays than sand, as do most metals (IAEA, 2006). Clays have been added to isotope-contaminated wetlands by the Savannah River site in South Carolina to increase the removal of cesium from water through sediment adsorption (Kaplan et al., 1999). In addition to its affinity for radioisotopes because of its aggregate of fine particles, glauconite contains varying amounts of potassium, which is also used in medical treatment and environmental remediation for radioactive contamination. Some optimum form of glauconitic clay matrix in the Inner Coastal Plain may be a useful Best Management Practice (BMP) for a runoff related release of a radionuclide.

GROUNDWATER

There are about 400,000 private wells used for drinking water in New Jersey (NJDEP, 2006). Depending on the location within Monmouth County, wells can be drilled in any of three to five distinct aquifers. Well depths range from the shallow unconfined water table to about 1200 feet (a well in Point Pleasant Borough drawing from the confined Raritan-Magothy aquifer is 1242 feet deep) (NJGS, 1983). These 'layer cake' aquifers were mainly established in marine sands separated by clay aquitards during the Tertiary (65 to 1.8 million years ago) and Cretaceous (135 to 65 million years ago) Periods (USGS, 2003). Ancient east-flowing streams carrying the erosion from the mountains to the northwest filled the coastal plain shelf, which then subsided under this weight, was flooded over by the ocean and then filled in again, creating the wedges of the different geologic layers (USGS, 2003). In NJ, these sediments begin at the "Fall Line" near Rt 1 and thicken to more than 6500 feet in southern Cape May County (Mulhall, 2003). In Monmouth County, these sediments increase from about 300 feet near Raritan Bay to almost 2000 feet at the mouth of the Manasquan River (Dahlgren, 1977). The age of the Coastal Plain formations runs northwest to southeast, with the oldest deposits outcropping in the northwest (Mulhall, 2003). From youngest to oldest, the major and minor aquifers used for wells in Monmouth County are the Cohansey (Tch), Kirkwood (Tkw), Vincentown (Tvt), Red Bank-

Tinton (Krb), Mt. Laurel-Wenonah (Ktw), Englishtown (Ket), and Raritan-Magothy (Kmr) (CNEC, 1983).

Heavy concentrations of glauconite in fine silt and clay sediments indicate “transgressive” deposits that were layed down during the major incursions of the ocean; formations include the Merchantville, Marshalltown, Navesink, Hornerstown Sand, and the Manasquan Formations (Zapecza, 1984). The “regressive” units that overlie these major glauconitic formations are made of more coarse sediments that were deposited in inner-shelf, near-shore, and beach areas as the ocean receeded; these include the Englishtown, Wenonah, Mount Laurel Sand, Red Bank Sand, Vincentown, Kirkwood and Cohansey Sand Formations (Zapecza, 1984). Generally the regressive deposits formed aquifers while transgressive deposits formed confining beds (Zapecza, 1984).

The Coastal Plain was deposited on a bedrock of Wissahickon gneiss and schist, metamorphic rocks formed from shale and sandstone, that are the base of a Precambrian mountain range that existed 600 million years ago, at the beginning of the Paleozoic Era (20 miles across Raritan Bay from Belford, Manhattan’s skyscrapers in midtown and downtown are built on Fordham schist and gneiss that outcrop closer to the surface, part of the range that underlies Philadelphia, Baltimore, and Washington, D.C.) (USGS, 2003; Waldman, 1999). NJ exists where part of a volcanic island arc collided with the continent 550 to 430 million years ago, in one of several Paleozoic plate tectonic events, known as the Taconic Orogeny (USGS, 2003). This ultimately produced the Appalachian Mountain chain, known in NJ as the Highlands (part of the Reading Prong), and Valley and Ridge Provinces, which was formed about 300 million years ago (USGS, 2003).

Most of these aquifers were formed in deltic marine environments; the ancient shoreline during the Cretaceous was as far west as Scranton and Wilkes Barre, Pennsylvania, and during the Tertiary it reached between Middlesex and Morris County (Merguerian, 2005). About 35,000 years ago, sea level was about where it is today; but later during the Late Wisconsin Glaciation, when the terminal moraine of the glacier extended as far south as Perth Amboy, the shoreline extended 60-80 miles southeast onto the continental shelf to the edge of the present Hudson Canyon (USGS, 2003). By about 9000 B.C., at the beginning of the modern Holocene period when Paleo-Indians first settled in the Manasquan watershed near Squankum Yellowbrook Road in Howell, the Wisconsin glacier had withdrew from this area and the shoreline was about 50 miles from where it is today (MWMG, 1999; Kraft, 2001). Monmouth County property records from the 1600’s indicate that the shoreline has retreated up to 2000 feet since about 1650 (RSCNJCRC, 2006). The shore now slopes steadily out to the edge of the Hudson Canyon, about 600 feet (100 fathoms) underwater, then drops off drastically to the abyssal plains, about 6000 feet deep; the thickness of the coastal plain sediments on the continental shelf increases to more than 10,000 feet (USGS, 2003).

The Kirkwood Cohansey formation is the largest single outcrop of any formation in Monmouth County, and is the predominant water table aquifer used for private wells; it runs as deep at 150’ in Wall near the border with Brick Township (Dahlgren, 1977; Hulhall, 2003). The DEP ranks this aquifer as B to A, meaning that wells can sustain yields from 251 to more than 500 gallons per minute (Dahlgren, 1977; Hulhall, 2003). (The DEP ranks aquifers according to their capacity to support high well yields associated with commercial/industrial water users; “A” aquifers can yield in excess of 500 gallons per minute, and “E” aquifers can yield at 25 gpm or below (Mulhall, 2003). The average well yield for large capacity wells in Monmouth County is

410 gallons per minute (Mulhall, 2003).) The soil matrix of the Kirkwood in Monmouth most resembles the Kirkwood formation in Salem County, rather than the other counties in the Coastal Plain, because it was deposited at the perimeter of an ancient bay, where silts and clays settled in with the sand because of the low-energy environment (Smith, 2000).

Recent studies of the Kirkwood-Cohansey in the Rancocas Creek and Wading River watersheds in the Pinelands looked at how old the groundwater is, i.e., how long water entering the KC as recharging rain remains in the aquifer before it leaves as surface water discharge (Zampella et al., 2008). Groundwater stayed in the aquifer longer in thicker parts of the aquifer near major basin divides, where vertical flow predominates, unlike the thinner parts of the aquifer where horizontal flow predominates and the residence time is shorter (Zampella et al., 2008). Recharge occurring near major watershed divides flowed to the most distant parts of the aquifer system (Zampella et al., 2008). The "residence time" of the groundwater ranged from zero to about 200 years, averaging less than 20 years (Zampella et al., 2008). In the same report, Szabo indicated that most water that recharges near wetlands is discharged to the wetlands within 5 to 10 years (Zampella et al., 2008).

The interlaminated sands and clays of the middle-Miocene Kirkwood aquifer contains sulfur deposits like pyrite that acidify the groundwater and gives it a rotten-egg odor; its black clay base contains bits of lignite, a precursor of coal (Dahlgren, 1977). Wells in shallow, water-table aquifers with a pH of 5 or less, like the KC, have a 1 in 2 chance of exceeding the Maximum Contamination Limit for radium in drinking water, because the natural radium deposits in the Coastal Plain dissolve into the groundwater under the acidic conditions that are predominantly caused by the geologic sulfur deposits (Szabo, 2003). In addition, as determined by studies of groundwater residence time in the KC in the Pinelands, most of the well water drawn today from the KC originally fell as rain that had been acidified by the emissions associated with the Industrial Revolution that began in the late 18th and early 19th centuries.

Of the 400,000 private wells in New Jersey, about 26,065 or 6.5% were sampled between 2002 and 2004, following the passage of the Private Well Testing Act (PWTA) in 2002 (NJDEP, 2006). Of these tested wells, 91% did not exceed Maximum Contaminant Levels (MCL) for all the required primary (health based) standards for drinking water (with the exception of lead, which may be an artifact of not running the water long enough in houses that have been empty). A total of 62.1% of the tested wells exceeded one or more of the recommended upper limits and/or optimum range for secondary (aesthetic) parameters, e.g., iron. Monmouth had the highest amounts of iron in well water of all the counties; an ion exchange conditioner that removes iron from the drinking water for a family of three or four with moderately hard water can contribute up to 1452 lbs per year of dissolved sodium chloride (halite salt) to surface and groundwater (Panno et al., 2002). Of the 343 wells statewide that exceeded the MCL for Volatile Organic Compounds (VOC) – which indicate pollution from solvents, paints, gasoline, oil etc. – the most common VOCs were: trichloroethylene (136), tetrachloroethylene (108) and benzene (33) (NJDEP, 2006). The first two are often associated with dry cleaners, the last with gasoline from leaking Underground Storage Tanks (USTs).

An interesting hypothesis was presented by the NJDEP in 2012 regarding counter intuitive PWTA data that showed that there was less frequent detection of coliform bacteria in shallow but acidic wells than there was in deeper wells with higher pH in the coastal plain aquifer. They speculated about the lower survival rates in the acidic shallow aquifer:

“wells with lower pH water might be due to strong adsorption of downward-migrating microbes to the unconsolidated matrix at pH levels below 6, possibly shorter survival times due to lack of nutrients or inhibitory agents, and, at very low pH levels, pH itself. … Giannella et al. (1972) and Zhu et al. (2006) showed, respectively, that the survival time of Salmonella and E. coli is shorter at pH levels <4.0 than at higher pH levels. … Attachment to positively charged surfaces may be bacteriocidal (Asadishad et al. 2011). Gerba and Bitton (1984) observed shorter microbial survival times in acidic soils, which they attributed to lower nutrient availability and increased action of inhibiting agents. Finally, for reasons related to their isoelectric point, coliform bacteria adhere less well to unconsolidated sediment matrices at pH levels higher than 6.0, as shown for native GW bacteria by Harvey et al. (2010) and for other bacteria (reviewed in Pedley et al. 2006).” (Atherholt et al., 2012).

IRON AND SULFUR

Since the first iron works in New Jersey was constructed around 1674 in Tinton Falls, Monmouth County was mined for limonite (iron oxide: locally known as bog iron, ironstone, peanut stone, or hardpan), an orange colored precipitate produced in acidic streams and marshes that contains up to 40% iron; a few geologic formations, such as the Manasquan, also have deposits of siderite (iron carbonate) (Keelen, 2003; Forman, 1998). This industry peaked after the war of 1812 until about 1844, when transporting coal as well as richer ores of iron from Pennsylvania and other states west of NJ became more cost effective (Forman, 1998).

As acidic groundwater seeps into a stream and becomes oxygenated surface water, dissolved ferrous iron (Fe(ii)) will precipitate out of solution to ferric iron oxide (Fe(iii)), raising the pH somewhat as it changes to iron hydroxide (variants of Fe(OH)) (Dahlgren, 1977). The Leptothrix, Clonothrix and Gallionella bacteria derive their metabolic energy by oxidizing iron; the acidophilic autotroph, Ferrobacillus ferroxidans, is able to oxidize iron in low pH environments (Biovir, 2005). There is such a predominance of slimy iron bacteria floc in County streams that many look like they have been impacted by ‘Acid Mine Drainage’. Iron bacteria also produce a biofilm with an iridescent rainbow sheen that mimics an oil spill. Living at the air water interface, these bacteria deposit a mixed film of iron oxides at the water surface, and the light being reflected from this film interferes with the light being reflected from the water, producing the misleading iridescent sheen (Patterson, 2006). When an iron oxide film is stirred, however, it will break into randomly shaped platelets, while a petroleum spill that is broken up will swirl back into itself and maintain an intact surface film (Antel, 2006).

The headwaters of Poplar Brook in Ocean Township have a unique yellow-ochre color for which its dominant iron bacteria, Lepothrix ochracea, is named. The streambed below the dam at Rising Sun Tavern Lake in Millstone looks like it is covered in tomato sauce, probably because the dam footings opened up springs from the underlying Navesink Formation. Heavy iron leaching impairs the ability of benthic organisms to survive in the flocculated sediment. The headwaters of Shark River Brook in Wall channel through the glauconitic ironstone remnants of the Hominy Hills; its streambed is heavily flocculated from the iron that is leaching from the peanut stone that lines the streambank. In contrast, the springs of the adjacent tributary of the Shark River, the Reevy Branch, originate below the ironstone ridges. Without the iron leaching, this boggy, tea-colored stream, flowing through light grey sand and gravel, has a completely different ecology. The Reevy Branch is one of the few high quality (Non-Impaired) streams in this area of the County, and supports a significant colony of the acid tolerant stonefly, Leuctridae.

Iron is also a catalyst for algal growth. In 2009, iron sulfate powder was spread over more than a hundred square miles of Antarctic waters in a controversial attempt to cause a massive algae bloom that could cheaply control global warming by stripping carbon dioxide from the atmosphere. Algae absorb large amounts of carbon dioxide from the air, and when the bloom died off, the algae and its scavenged carbon dioxide would sink to the bottom of the ocean and be absorbed into the sediments (Earthweek.com, 2009). The controversy is that the ecological effects on food webs etc. are unknown when a relatively barren area of the ocean is artificially induced to be productive.

Acid soils are predominantly found in the Woodbury, Englishtown, Wenonah, Marshalltown and Navesink formations; in some parts of the County acidic soils make it difficult to grow grass (MCPB, 1975). The Cretaceous Englishtown formation has acidic sulfur deposits of pyrite (fool's gold) and marcasite (crystallized pyrite) that have lowered the pH of Lake Matawan to 3.0; acid-tolerant diatoms and microspora are some of the only species that are able to tolerate this light concentration of sulfuric acid. Because its acidic water has more iron and aluminum in solution than in the particulate form, this lake has the unusual lime green color characteristic of gravel pits and quarries that is caused by the way these dissolved metals scatter light.

Sulfur is found in aquatic systems and groundwater in its oxygenated form, sulfate, or its anaerobic form, sulfide; since hydrogen sulfide is black and smells like rotten eggs, it is often mistaken for sewage. In fresh water sediments, the production of hydrogen sulfide can be determined by the amount of sulfate present when free-iron concentrations have already been precipitated out of solution as iron sulfide (Lomans et al., 1997). While salt water can hold less dissolved oxygen than freshwater (due to what is called the "salting effect"), freshwater usually has higher levels of Biological Oxygen Demand than saltwater because of its higher levels of organic material (NY/NJCOST, 2004). Dimethyl sulfide (DMS) and methanethiol are the most abundant volatile organic sulfur compounds in marine systems; and dimethylsulfoniopropionate, a compound that controls osmotic pressure in marine phytoplankton, is a precursor for DMS formation (Lomans et al., 1997).

These oxygen stressors make tidal interfaces in estuaries vulnerable to the effects of sulfur. For example, iron sulfate contributes to some tidal streams in the Bayshore and the Navesink and Shrewsbury Rivers turning black and smelling like sewage when sulfate is reduced to hydrogen sulfide. This happens when the dissolved oxygen in the water is overwhelmed as sulfur bacteria consume decaying sea lettuce (Ulva species) on the incoming tide during warm dry summers (Frankenstein, 2000; Olapade et al, 2006; Stahl et al., 1984). As sea lettuce grows, it layers into closely packed mats where water flow slows or stops; the layers closest to the bottom begin to die, mix with the sediment, turn black and produce hydrogen sulfide gas (MacKenzie, 2005). This also happens along the shoreline of Lake Michigan on decaying Cladaphora mats (Frankenstein, 2000; Olapade et al, 2006; Stahl et al., 1984). In Many Mind Creek in Atlantic Highlands, this problem is exacerbated when tidal debris blocks the mouth of the stream, causing the flow to back up, pond, and turn anoxic; the original Lenape name for this creek was Cuppanickinn, which means "obstructed stream" (Boyd, 2004). Decaying sea lettuce can build up in sheltered coves to such an extent that the hydrogen sulfide gas can blacken nearby houses painted with lead paint when it forms lead sulfide (MacKenzie, 2005). Two consecutive removals of these mats from the shoreline along the Navesink River reduced the thickness of the mat and maintained the area nearly free of it (MacKenzie, 2005). The Shark River also is known for its shoreline mats of sea lettuce, and Musquash Brook in the Shark River Watershed supports visible growths of white filamentous sulfur bacteria (Beggonia species).

Poor tidal flushing in warm weather can also lead to anoxic conditions in estuaries with shallow channels and wide mudflats. An odor complaint on Oceanport Creek was investigated in August of 2009 immediately following a fishkill in Branchport Creek. The western portion of the creek had turned septic: black with a foul odor. Anoxic dissolved oxygen and elevated temperature levels were noted. Anoxic conditions were still present the following day, but were showing significant improvement, following changes in wind and rain conditions. The earliest known report of anoxic conditions in this area of the Shrewsbury watershed dates back to 1892, when it was recorded by the Shrewsbury Township Board of Health on page 310 of the 1892 Report of the Board of Health of the State of New Jersey. This report states: "There is a complaint of tide-water backing up on a tributary of the South Shrewsbury, known as Little Silver Creek, causing decay of vegetable matter and jeopardizing the health of neighbors surrounding it. This Board wishes information as to how it should be opened, and what steps are necessary to be taken in the matter, as all persons owning property adjacent to the creek claim that they have no legal right to proceed in the matter, as it is the bed of the river." (BOHSNJ, 2010). Little Silver Creek is also where the largest fishkill on record in the coastal waters of Monmouth County took place on July 9, 2000, when 3.9 million juvenile menhaden (peanut bunkers) suffocated due to low dissolved oxygen (0.98 ml/l) (Reid et al., 2002). As recently as July 24, 2013, residents left numerous postings on the Oceanport webpage about having to close their windows because the odor was so bad in Blackberry Bay. The hydrogen sulfide odor and black water had followed a heat wave and moderate algae bloom in this poorly flushed area (Bates, 2013).

Streambeds near malfunctioning septic systems and active, unlined landfills will also turn black from the sulfide produced during the anaerobic decomposition of organic material and nutrients; further downstream, these streambeds may support growths of "sewage fungus", a grey floc produced by the filamentous bacteria Sphaerotilus natans (Curtis and Curds, 1971).

The interlaminated sands and clays of the middle-Miocene Kirkwood aquifer, which is the largest single outcrop of any formation in the County, contains sulfur deposits that give wells a rotten-egg odor; its black clay base contains bits of lignite, a precursor of coal (Dahlgren, 1977). Generally, wells in shallow, water-table aquifers in NJ are acidic, predominantly due to geologic sulfur deposits (Szabo, 2003).

AIR QUALITY AND PRECIPITATION

There are now 39 (formerly 87) ambient monitoring stations in the state that actively monitor for carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, lead, or particulate matter. The NJDEP posts air quality updates once every hour to its web site (www.njaqinow.net) and the EPA AirNow webpage (www.airnow.gov). The one NJDEP air monitoring station in Monmouth County is located at Monmouth University in West Long Branch and measures ozone levels (the sulfur dioxide station was removed from the corner of Court and West Main St. in Freehold Borough. Stations in nearby counties that measure for fine particulate matter are in Toms River, Trenton, and Rahway (http://www.njaqinow.net/Default.ltr.aspx)).

The EPA has classified Monmouth County as a non-attainment area for ozone, which is significant in the summer because it forms in the presence of heat and sunlight, and is associated with vehicular emissions. About 1 out of 5 car trips is work related, and about 75 % of commuters use ‘single occupancy vehicles’. The USDOT estimates that 2.3 billion gallons of fuel are wasted nationally every year while motorists wait in traffic for 3.7 billion hours (Chebium, 2006). Monmouth County ranked third highest in NJ for the number of hours per year drivers spend in traffic delays, according to a 2001 study by the Foundation of the NJ Alliance for Action and the National Center for Transportation and Industrial Productivity at the NJ Institute of Technology (Higgs, 2006). From 1994 to 2004, the yearly average is: 326 ‘healthy’ days and 29 ‘moderately healthy days, with about 3% of the year classified as ‘unhealthy and ‘unhealthy air for sensitive groups.’

During the winter, winds predominate from the northwest in the Middle Atlantic Bight, due to the dominance of the cyclonic (counterclockwise winds) Icelandic Low; while during the summer south and southwest winds predominate due to the anticyclonic (clockwise winds) Bermuda High (Cook, 1988; MCPB, 1975; MCPB, 2005). The average wind speed of 11 mph is highest in the spring (ESDRU, 2006). The mean annual temperature for Monmouth County is 53 degrees F; the average January temperature is 31.3 degrees and the average July temperature is 74.5 degrees. The hottest day of record for Freehold is 106 degrees F in July 1936, and the coldest was -20 degrees F in February 1934 (MCPB, 1975; MCPB, 2005). Temperatures of 32 degrees F or less have been recorded as late as May 17th and as early as September 24th in the fall. In the Freehold area the growing season averages 178 days in length from April 23rd to October 18^{th} (MCPB, 1975; MCPB, 2005). The average killing frosts occur between October 25 and April 20 (FSCD, 1985). At dawn, the average humidity is about 75%, while by mid-afternoon it drops to an average of about 50%; the sun shines 60% of the possible time in the summer and 50% in the winter (ESDRU, 2006). At 4 p.m. on 8/1/06, 1.1 million JCPL customers used 6,548 megawatts during a multi-day heat wave where it reached 101 degrees at a weather station near the Manasquan River; this broke the company’s record that had been set the previous year (Vellucci et al., 2006).

Precipitation in Monmouth County ranges from 45 to 47 inches a year; the average January precipitation is 3.17 inches and the average July precipitation is 4.69 inches (MCPB, 1975; MCPB, 2005). About 23 inches (50%) falls between April and September; in 2 out of 10 years there is less than 19 inches of rain during this period (ESDRU, 2006). The heaviest rainfall amounts Countywide normally occur during the summer months when tropical storms and hurricanes pass north along the New Jersey Coast; thunderstorms occur about 35 times a year, and the heaviest one-day rainfall recorded from 1951-1973 was 7.18 inches at Freehold on 8/28/1971 (ESDRU, 2006). A drought that lasted from September 1961 through August 1966 was one of the most significant multi-year departures from normal precipitation in recent years (MCPB, 1975; MCPB, 2005). Coastal areas of NJ have precipitation patterns that are typical of the Mid Atlantic coastal region: an average of 60 storms per year, lasting about ten hours, with an intensity of 0.08 to 0.09 inches per hour, and a volume per event of 0.65 inches (Zimmer, 2004). For Monmouth County the 24-hour rainfall is as follows: 1 year storm - 2.9 inches; 2 year storm - 3.4 inches; 10 year storm - 5.3 inches; 25 year storm - 6.0 inches; 100 year storm - 7.5 inches. Snowfall on a countywide basis averages around 25 to 26 inches a season and the greatest depth at any one time was 26 inches; an average of 9 days per year have at least one inch of snow (ESDRU, 2006). The maximum year snowfall for Freehold was 66.9 inches during 1957-1958. The majority of snow falls between the months of December and March inclusive, although snow has fallen on all months from October through May inclusive (MCPB, 1975; MCPB, 2005).

ALL-HAZARDS

Hurricanes, Nor'easters, and El Nino

The hurricane season lasts between June 1 and November 30, although hurricanes are most likely to occur in NJ from August through October; Nor'easters usually occur here from November to mid April. Nor'easters are the most common type of major storm, followed by coast-parallel hurricanes, and the rarest, coast-normal hurricanes (ones that cross inland from the coast) (Coch, 1999). While several nor'easters hit the coast every year, hurricanes move close enough to coastal areas to cause significant damage every 4-5 years (Coch, 1999). According to NOAA records since 1850, 11 hurricanes and 23 tropical storms have passed within 75 miles of NJ, including six Category 2 hurricanes and five Cat 1, with 9 of the tropical storms moving directly through Monmouth (there have been 2 estimated Category 3 hurricanes, discussed below) (URS, 2008). NOAA records predict a 22% chance of a hurricane or tropical storm coming within 75 miles of Monmouth, and a recent study from Colorado State University that there was a 13.2% chance of a named storm making landfall in the vicinity of the County (URS, 2008). Recent Federal Disaster Declarations occurred in coastal NJ after storms in 1991, 1992 and 1998 (Farrell, 2007).

Hurricanes in the northern hemisphere rotate west to east (counterclockwise/cyclonic) but move through the ocean from east to west. Most Atlantic hurricanes form when the ocean is at least 80 degrees F off the west coast of Africa, where the desert air of the Sahara rises to meet the cool air drifting west over the mountains; periods of heavy rainfall in West Africa appear to be related to an increased frequency in Atlantic hurricanes (deVilliers, 2006; Howstuffworks, 2006; Coch, 1999). These converging equatorial winds collide near the surface and push warm, moist air upward where it is held together at higher altitudes by strong but uniform-speed winds. The rising warm air can then continuously cool and release water and heat (the "latent heat of condensation") - and build into a hurricane (Howstuffworks, 2006). The eye of a hurricane is always a low pressure area, and the right eye wall in the northern hemisphere has the fastest, most violent winds because the wind speed and the hurricane speed of motion are in sync (Howstuffworks, 2006). In fact, while the occurrence of a hurricane greater than a Category 3 in the northeast is remote, the right eye wall under certain conditions can have the destructive potential of a Cat 4 or 5 storm (Coch, 1995). The position of the right eye wall as it moves over populated land areas is what makes a "coast normal" hurricane the most destructive (Coch, 1999)

Hurricanes are accelerated by westerly weather systems as they move north of Cape Hatteras; hurricanes in the northeast move 2-3 times faster than in the southeastern US - westerlies can move a storm from South Carolina to Newfoundland in 24 hours (Coch, 1995; deVilliers, 2006). All of the major northern hurricanes have made landfall by the end of September or later (Coch, 1995). The right angle shape that is formed where the coasts of NY and NJ meet increases surge levels in the NY Bight as hurricanes approach Long Island's southern shore (Coch, 1995). A gentle slope and large shelf width such as is found on the continental shelf south of Long Island also increases surge levels (Coch, 1995). As many as ten times a year, a low pressure trough is caught between a well developed Bermuda High that is located more northerly than usual, and a high pressure system moving across the continent from the west (Coch, 1999). This set up is ideal for a hurricane propelled by slow easterly Trade Winds to move around the western edge of the Bermuda High, enter the trough, and accelerate towards the northeastern US (Coch, 1999). These were the conditions that made the 1938 "Long Island Express" the fastest moving storm on record (Coch, 1999).

Evidence of the earliest hurricanes on record in NJ have been uncovered from analyzing deep sediments at Brigantine; one heavy layer of beach sand was deposited by a hurricane between 1278 and 1438, and another during the 6th or 7th century, when sea level was lower and the beach was hundreds to thousands of feet east of the current coastline (Moore, 2006c). A hurricane on Aug. 19, 1788 (estimated Cat 3) had a high tide that was nearly 10 feet above sea level (Moore, 2006c). On September 3, 1821, the most severe hurricane on record in NJ (estimated Cat 3) occurred when a storm surge flooded the entire coast; it was the only recorded time New York ever took a direct hit, raising a 10 to 12 foot surge of water into the Battery in one hour (the highest surge recorded until Hurricane Donna in 1960) (Carlowicz, 2002; Coch, 1995; MBEC, 1976). When it hit the area by Long Beach Island, it leveled ancient Atlantic white cedar trees, some of which were later excavated from wetlands during the construction of the Garden State Parkway in the 1950s (Moore, 2006c). Some of the most destructive hurricanes in NJ were in 1938 (the "Long Island Express", a Cat 3), 1944 (the "Great Atlantic Hurricane", Cat 3), 1954 (Carol), 1960 (Donna), 1976 (Belle, Cat 1), 1985 (Gloria, Cat 2), and 1991 (Bob) (USDI, 2004). On September 2, 1999, a surface vortex of wind left the Sahara Desert for the Atlantic Ocean and developed into Hurricane Floyd (Cat 3), which caused extensive flooding in the Raritan River and 4 other major watersheds in NJ; in 12 to 18 hours Bound Brook and Manville received up to 15 inches of rainfall (deVilliers, 2006; Hurricane.com, 2005). Hurricane Floyd was the greatest natural disaster in NJ to date, due to the rain more than to wind gusts, which rarely exceeded 50 mph; precipitation totals include 6.4" in Hazlet, 5.82" in Marlboro, 5.2" in Sandy Hook, and 4.57" in Keansburg (URS, 2008). In one day, a moderate hurricane can release the equivalent energy of four hundred 20-megaton nuclear bombs (a one megaton bomb produces 71 times the energy of the bombs dropped on Hiroshima and Nagasaki) (deVilliers, 2006).

The most destructive hurricane seasons in recorded history have occurred recently; seven of the ten historically worst storms worldwide have happened between August 2004 and December 2005 (Asbury Park Press, 2005(a)). The Atlantic basin may be in a 20-25 year cycle of increased hurricane activity that began in 1995 (RSCNJCRC, 2006b). In contrast, geological research indicates that there has been little variation in hurricane frequency along the east coast in the last 700 years, starting with the 'Little Ice Age' that lasted from the 14th century to the mid 19th centuries, to the present warming trend that coincides with the beginning of the Industrial Age in the mid to late 18th century (Carlowicz, 2002). Older evidence from the Gulf of Mexico backs this up; it indicates mild hurricane activity along the Gulf Coast from 5000 to 3400 years ago, a 'hyperactive' period from 3400 to 1000 years ago, but a relatively quiet period for the last 1000 years (Carlowicz, 2002). The earliest wind records for the New York Harbor area only date back to weather readings taken in Central Park in 1869, and accurate hurricane wind data from this site was not available until 1893; wind data at Sandy Hook dates from 1914.

Winter nor'easters start at the western edge of the northerly Gulf Stream where the warm water mixes with the southerly Labrador current from Canada. Turbulence develops if a low pressure system of counter-clockwise winds and warm air near the Gulf Stream is pulled up the coast by strong northeasterly winds at the leading edge of the storm and collides with a front of high pressure (clockwise winds) blowing down from the Arctic (deVilliers, 2006; URS, 2008). Nor'easters in NJ have increased in frequency and intensity since 1980; the 'Halloween' Nor'easter of 1991 caused more than $1.5 billion in damage along the mid-Atlantic coast (Cooper et. al., 2005). Unlike hurricanes, nor'easters have cold cores and no distinct eye; have a destructive wind radius of hundreds of miles instead of less than one hundred; last for several tidal cycles sometimes over a few days, instead of one or two cycles; but "only" have storm surges of up to 6 feet instead of 22-30 feet, and have winds up to 74 mph vs. more than 155 mph for hurricanes (Coch, 1999). Some of the most destructive Nor'easters were in 1931, 1950, 1962, 1984, 1991, and 1992 (USDI, 2004). The Ash Wednesday Storm in March of 1962 was the worst nor'easter event on record according to the NJOEM; during 3 days, gale force winds caused 5 successive tides to stack while 20 to 30 foot high waves tore through dunes and coastal properties (URS, 2008). During the winter nor'easters of 1997-98, 80% of replenished sand was washed away from Sandy Hook; during the Nor'easter on December 11-12, 1992 Sandy Hook was breached and severely eroded (Coch, 1995; USDI, 2004). The nor'easter in December of 1992 caused tides in some back bays to rise an estimated 10 feet above mean low water, which is 4-5 feet higher than normal (URS, 2008). Nor'easters that are sustained for over 24 hours cause a "stacking of the tides" in the Shrewsbury River. After the high tide surges past the narrows separating Rumson and Sea Bright, severe easterly winds slow the ebb discharge; the next high tide accumulates on the previous one and causes minor street flooding, and the third high tide can flood up elevations in Monmouth Beach up to 4 feet above the ground.

An El Nino warming event in the tropical Pacific causes conditions including warmer than average winters in the northeast and wetter than average conditions over parts of the Gulf Coast (the companion cooling event, La Nina, causes colder than usual winters in the northeast) (Bates, 2006b; deVilliers, 2006). For example, the record warming in November and December of 2006 was due to an El Nino event (as well as the polar jet stream staying to the north, a lack of high pressures systems from the north so that air moving west across the nation did not pick up cold northern air, below-normal snow cover in North America, and global warming) (Bates, 2007). During a weak to moderate El Nino, more frequent nor'easters can occur in NJ because cold air is more likely to intrude south and mix with the subtropical jet stream off the East Coast and Gulf of Mexico. Jet streams control the movement of high and low pressure systems; high pressure to the north and low pressure to the south can result in prolonged east to west winds; waves from the east hit the coast perpendicular to it and can cause the most erosion (Bates, 2006b; Bates, 2006c). Some of the more frequent storms that occur in the Southeast during an El Nino come up the coast instead of going out to sea, although an El Nino winter is typically calmer in NJ; in contrast, the years 1982-83 and 1997-98 had both strong El Nino events and more nor'easters (Bates, 2006b). A buoy 26 miles southeast of Cape May that was installed in 1986 alerts forecasters to potentially damaging storms; when waves are 15-20 feet high at this buoy, waves breaking on NJ beaches are usually about 50-60% as high (Bates, 2006c). (This is Station 44009, National Data Buoy Center - http://www.ndbc.noaa.gov/station_page.php?station=44009). While the replenished beaches in Monmouth County continue to maintain their resilience, Long Beach Island is "probably the most vulnerable" to storm-driven waves along the NJ coastline (Bates, 2006b). A February 2003 storm produced a 25.3' high wave at the buoy, the highest recorded; in September 2006, Tropical Storm Ernesto produced a 22.3' wave at the buoy, which is the highest recorded for the month of September (Bates, 2006c). On 11/15/09, a 28.5-foot wave was recorded at the Texas Tower buoy (Station 44066 - Texas Tower #4 - http://www.ndbc.noaa.gov/station_page.php?station=44066) well off the NJ coast (Bates, 2009).

Wide beaches and high dunes reduce storm surge; one method of dune restoration that proved successful in reducing surge damage from Hurricane Hugo was from vegetated berms bulldozed from sand dumped from inland areas (suggesting that dewatered dredge spoils may likewise be an appropriate berm base in NJ) (Coch, 1999). In emergency planning, the "clearance time" for an area is defined as how long it takes to evacuate residents before gale force winds (39 mph) arrive, toppling trees as low roadway chokepoints begin to flood (Coch, 1995, 1999). The Rutgers Weather Network maintains a webpage for emergency planners about severe weather at http://www.erh.noaa.gov/er/phi/emerman.htm . A general rule is that as whitecaps appear, the wind speed is at least about 15 knots (Ross, 2000).

Sea Level Rise and Tides

During the last 800,000 years, global sea level has risen and fallen about 460 feet in naturally occurring 100,000-year cycles, when variances in the Earth's orbit have changed the distribution of solar radiation that it receives (EPA, 2009; NOAAPB, 2009). We are still coming out of the last Ice Age, part of the Pleistocene Epoch that lasted 1.8 million to 12,000 years ago (USGS, 2003). The last major advance of the North American Laurentide ice sheet from Canada during the Pleistocene is called the Wisconsin Glacial Episode, occurring 100,000 to 10,000 years ago, and was composed of 3 distinct ice ages separated by interglacial periods (Wikipedia, 2009). The most recent ice age occurred during the late Wisconsin, beginning about 30,000 years ago, advancing to its maximum extent about 21,000 years ago, and ending about 10,000 years ago, which marks the beginning of present geologic time, known as the Halocene Era (Wikipedia, 2009). At the peak of the Ice Age, sea level dropped about 400 feet lower than present, opening the Beringian land bridge between Alaska and Siberia and enabling the settlement of North America from Asia (EPA, 2009; Wikipedia, 2009).

With the exception of a brief glacial period 12,900–11,500 years ago in the northern hemisphere known as the Younger Dryas, the current interglacial period is still warming, and the ocean is still rising since the last Ice Age peaked about 21,000 years ago (USGS, 2003). Initially, sea level rose as much as 50 mm per year from glacial "meltwater pulses", then slowed to about 0.2 mm per year during the past 2000 to 3000 years (EPA, 2009). But in the late 19th century during the Industrial Revolution, sea level accelerated globally to 1.7 mm per year, and between 1993 and 2003, it increased to 3.12 mm per year in the mid-Atlantic region between northern New Jersey and southern Virginia - almost twice the present rate of global sea-level rise (EPA, 2009). While comparing data from decades and epochs can be like comparing apples and oranges, some scientists are so convinced of the influence of humans on the Earth that they have renamed the latest 200 years of the Halocene as the Anthropocene Era (EPA, 2009).

How high might sea level rise before the earth begins to cool again? The previous interglacial period (the Eemian), occurring about 125,000 years ago, lasted about 10,000 to 12,000 years and warmed to temperatures that are already predicted for the 22nd century, with global sea levels that were 13 to 20 feet higher than present (incidentally, the present Halocene is about 11,700 years old) (EPA, 2009; NOAAPB, 2009). This is significantly higher than the most severe hurricane on record in NJ, an estimated Category 3 storm that occurred on September 3, 1821, the only recorded time that New York ever took a direct hit from a hurricane. It raised a 10 to 12 foot storm surge (Carlowicz, 2002; Coch, 1995; MBEC, 1976). A Category 3 hurricane, the largest hurricane that is currently able to strike NJ, causes storm surges between 9-12 feet; a Category 4 hurricane, potentially possible in NJ within 100 years due to climate change, causes a 13-18 foot rise (URS, 2008). A Category 5 hurricane causes surges greater than 19 feet (URS, 2008).

The "Jersey Shore" is anything but static; it has been as far east as the Hudson Canyon during the Pleistocene, and as far west as Scranton during the Cretaceous (145.5 to 65.5 million years ago) (USGS, 2003). During the Tertiary Period (65 million to 1.8 million years ago) the shoreline had reached between Middlesex and Morris County; about 35,000 years ago during the middle Wisconsin, sea level was about where it is today (Merguerian, 2005; USGS, 2003). But then during the Late Wisconsin Glaciation, when the terminal moraine of the glacier extended as far south as Perth Amboy, the shoreline extended 60-80 miles southeast onto the continental shelf to the edge of the present Hudson Canyon, which is now about 600 feet (100 fathoms) underwater (USGS, 2003). By about 9000 B.C., at the beginning of the modern Holocene period when Paleo-Indians first settled in the Manasquan watershed near Squankum Yellowbrook Road in Howell, the Wisconsin glacier had withdrawn from the area and the shoreline was about 50 miles east of where it is today (MWMG, 1999; Kraft, 2001). Monmouth County property records from the 1600's indicate that the shoreline has retreated up to 2000 feet west since about 1650 (RSCNJCRC, 2006).

Cores of the seafloor a few hundred feet off the coastal lakes in Monmouth County has revealed under thin layers of sand the remnants of saltwater marshes - peat deposits of ancient white cedar trees that had existed before the flooding ocean had moved inland, following the low areas along stream channels (RSCNJCRC, 2006). The NJ coastline was shaped by the an extremely rapid rise in sea level (2 mm. per year) when glaciers began to melt; the last of 3 glaciations in the past 2-3 million years, the Wisconsin, began melting about 21,000 years ago. The resulting sedimentation from the glacial melt built out a broad sloping plain and a continental shelf for about 185 miles from the present shoreline (NOAAPB, 2009). About 2500 years ago, sediment along the shore began accumulating and barrier islands, dunes, bays and other aspects of the present-day shoreline began to develop (Roberts and Youmans, 1993). Barriers are the dominant shoreline type along the Atlantic coast, but only comprise 15% of shorelines globally (EPA, 2009). The shaping of the Atlantic coast is due to its sloping landscape, the slow rates of sea level rise for the past 5000 years, the sufficient sand supply, and relatively minor tectonic activity (the cliffs that characterize the Pacific coast are due to the more recent collision of tectonic plates) (EPA, 2009). About 500 years ago the accumulation of sediment along the Atlantic coast reversed, and sand began to be eroded offshore (Roberts and Youmans, 1993).

If massive amounts of glacial meltwater reduce the salinity of the ocean in the North Atlantic, it could prevent the northward flowing Gulf Stream from sinking near Greenland and flowing south along the ocean floor towards Antarctica, shutting down the global network of currents that sustains climate (WU, 2009). Studies of ocean sediments in the North Atlantic and of ice cores in Greenland reveal that the Great Ocean Conveyor Belt (also know as thermohaline circulation and the Meridional Overturning Circulation) has shut down many times in the past, often coinciding with abrupt climate change (WU, 2009). According to a 2005 report by Princeton University, sea level rising slowed 6000 years ago; a global-mean sea level rise of .1 to .2 mm/year has been happening in the last 3000 years, and this rate may have doubled since the mid nineteenth century. Their model predicts that sea levels will rise 2-4 feet by the end of the 21st Century, moving the shoreline back 240-480 feet, which will inundate 1-3% of NJ's land areas, and periodically flood 6.5-9%. It may increase flooding 3-20 times in the coastal areas located in the current 100-year flood level of 9.5 ft (2.9 m), and predicts that 100-year floods will occur every 5 years (Cooper et. al., 2005). For every degree that the ocean warms, sea level rises about a foot; a three foot rise would jeopardize all bayside property with flooding (Farrell, 2007). NJ is especially vulnerable to rising sea level due to geologic subsidence (the coastline is sinking under the weight of accumulating and compacting sediment, due in part to freshwater withdrawal from coastal aquifers), the topography of its coastline, current coastal erosion, and a high density of coastal development (EPA, 2009; SNJ, 2008). If the Greenland ice sheet continues to melt at the rates currently being measured, global sea level rise will increase significantly, and the severity and frequency of coastal flooding in New Jersey will be even greater (SNJ, 2008). Fourteen of the twenty largest urban centers in the US are located within 100 km (62 miles) of the coast with elevations less than 10 m (32.8 ft) above sea level (the 10 m elevation is the common benchmark to study flooding) (EPA, 2009).

Between 1780 and 1980, thirty nine percent of NJ's original 6000 km2 of coastal and interior wetlands, which buffer storm surges along the coast, were lost to human activities; about one fifth of this happened between 1950 and 1970. The annual rate of loss slowed to 7 km2 between 1986 and 1995 (Cooper et. al., 2005). The additional stormwater volume from impervious surfaces like asphalt – which produce as much as 16 times more water than undeveloped woods - increases the probability that two-year, channel forming (bankfull) storms will swell streams from once every 2 years, to 5 times every 2 years (Snodgrass, 1998). Bankfull storms are used as design storms for constructing stormwater infrastructure and Best Management Practices such as detention basins; it is predicted that by the end of this century, as Atlantic City floods, storms that are now happening once every hundred years will be occurring once every 1-2 years (UCSUSA, 2008). The present 100-year storm produces a rise of 2.89 meters above National Geodetic Vertical Datum (NGVD) for the Atlantic coast of New Jersey (Lathrop et al., 2007). This means that if this prediction is accurate, design storms of the near-future, bankfull storms, will produce what would now be a 9.5 foot rise over normal coastal levels.

Ten percent of lands within Monmouth County are now located within the 100-year floodplain; 41 municipalities in Monmouth (77%) have already been identified by the OEM being at risk to storm surge (URS, 2008). Sea Bright has been experiencing coastal erosion for over 100 years; the Shrewsbury River now overtops the western bulkhead every moon tide and during moderate storms (URS, 2008). Areas vulnerable to flooding include present and past inlets along the ocean and Bayshore. There are only 2 inlets in the area north of the Barnegat Inlet (the Manasquan and the Shark Rivers), but in the past there were as many as 21; now there are only 11 along the entire coast of NJ, and 6 of these, including both in Monmouth, are armored with rock jetties (ACE, 1974; RSCNJCRC, 2006). Closed or former inlets in Monmouth County that may be prone to flooding during the "current interglacial period" are: Deal Lake Inlet (Asbury Park), Elberon Pond Inlet (Long Branch), Fresh Pond Inlet (Spring Lake), Goose Pond Inlet (Bradley Beach), Navesink (near Highlands bridge in Sea Bright), the Shrewsbury Inlet (off Monmouth Beach), Sea Girt Inlet (now Wreck Pond, also called Rack or Wrack Pond, for seaweed, not shipwrecks), Silver Lake Inlet (Belmar), Sunset Lake Inlet (Asbury Park), Three Corner Pond Inlet (between Shark River and Manasquan River inlets), Wesley Inlet (Asbury Park), and Whale Pond Inlet (Long Branch) (Bilby, 2008; Roberts and Youmans, 1993; Dahlgren, 1977). In 1775, the Manasquan Inlet opened to the Atlantic near Stockton Lake, about 1.5 miles north of where it is today (MWMG, 1999). Street flooding in the Bayshore communities of Keansburg, Union Beach, Middletown and Hazlet is managed by the NJDEP-operated Bayshore Floodgate on the Keansburg-Hazlet border (Zimmer, 2004). A 50 ton dam that can be closed by the Floodgate during high tide (using 4 diesel pumps, each capable of 200 gpm) is located at the junction of Thorns and Waackaack Creek, and 3 to 4 miles of earthen berms are located throughout the upstream wetlands (Zimmer, 2004).

Tidal cycles occur every 24 hours and 50 minutes; the NY Bight has semidiurnal tides, meaning 2 highs and 2 lows of about the same height (Ross, 2000). Every 14.8 days, at full and new moons, the moon and sun are in phase and produce the highest tide, known as the spring tide. Likewise, about every 15 days when they are the most out of phase at the first and third quarter moons, the lowest or neap tide occurs, when the difference between daily low and high tides can be very small (Blumberg, 2004). For semidiurnal tides like those in the NY Bight, the highest tides actually occur 1 or 2 days after the full moon, and the lowest neap tides occur 1 or 2 days after the quarter moons; this is known as "the age of the tide" (Ross, 2000). The mean range of the tide at Sandy Hook is 4.7 feet, and one complete tidal cycle passes every 12.4 hours (MBEC, 1976). The morning high tide at Sandy Hook after the first complete night of a full moon is always within a few minutes of 8:00 AM (Sorensen, 2005).

Onshore winds can increase the level of the tide, and a 1 foot rise in tide levels can occur when there is a change of 1" in the barometric pressure in a stationary low pressure system (Ross, 2000). Higher than average spring tides, called Perigean Spring Tides, happen when a full or new moon occurs during the moon's perigee - the point in its 28-day elliptical orbit when it is closest to the Earth (the furthest point is called the apogee). Proxigean Spring Tides occur when the moon is at its closest perigee, which occurs at most once every 1.5 years (Enchanted Learning.com, 2008). In NJ, these tides will only be about an inch higher than normal spring tides, unless they occur during a storm surge, heavy rains, or some other synergistic weather event; then they can increase the risk of flooding and resuspending trash that has accumulated along shorelines. A Proxigean Spring Tide occurred on 12/12/2008 that was the closest the moon had come to the earth since 1993, and which would not occur again until 2016. The moon was just 118 miles farther away than the nearest perigee measured during a 375-year period from 1750 through 2125 (221,441 miles on Jan. 4, 1912) (Roylance, 2008). Since this occurred a few hours after 3-4" of rain fell during northeast winds, the morning high tide was about 2' higher than either of the flanking high tides, reaching all the way to the dunes, brimming wetlands and flooding low lying coastal streets in the Bayshore and along the coast. Luckily, the northeast winds did not last for more than 24 hours; when that does happen, the onshore winds cause a "stacking of the tides" in the Shrewsbury River by slowing the ebb discharge, so that the next high tide accumulates on the previous one (MBEC, 1976). The next Perigean Spring Tide will occur on 7/21/09. NASA's Phases of the Moon, which lists various aspects of the moon including perigees is at http://eclipse.gsfc.nasa.gov/TYPE/moonphase.html , and a "Lunar Perigee and Apogee Calculator" is located at http://www.fourmilab.ch/earthview/pacalc.html . Stevens Institute of Technology tracks tidal surges at Sandy Hook at http://hudson.dl.stevens-tech.edu/SSWS/index.php?did=N021 .

Earthquakes

The first recorded earthquake in New Jersey was a 5.2 magnitude quake in 1737, and there have been a number of imperceptible ones since; as recently as, 12/8/05, there was a 2.1 in Morris County (Asbury Park Press(b), 2005). In 1979 a noticeable quake (3.5) occurred near Monmouth County in Cheesquake; there had also been a 3.8 in 1927 in Asbury Park. They are predominantly caused by the Ramapo Fault, named after the mountains along the northwestern margin of the Newark Basin in NY and NJ, and Cameron's Line, which runs southward from New England through central NJ under the Coastal Plain. The Newark Basin sits between these 2 fault lines. The Ramapo Fault was very active 200 million years ago and at 1 billion years is one of the oldest faults in the US. One of the reasons that the East Coast of the US is less active than the West Coast is because it is geologically older; the crust on the East Coast is also cooler and more rigid than on the West Coast, so seismic waves disperse further (Graver and Rubin, 1995; Jacob, 1995; Pasfield, 2005).

Cameron's Line is an 80 to 180 foot wide band of crushed rock that lies about 600' below NY Harbor (Waldman, 1999). It may be the remnants of a subduction zone that ceased during one of the Appalachian uplifts during the Paleozoic Era, when the Taconic island arc collided and attached to the continent (Graver and Rubin, 1995; Jacob, 1995; Pasfield, 2005). Four hundred and thirty million years ago, as the oceanic plate slid under the continental plate, a piece of the ocean crust broke off and buckled against the continent, forming the green serpentine rock of Todt Hill in central Staten Island (USGS, 2003). Serpentine deposits are markers for subduction zones, indicating that Cameron's Line lies to the west of Todt Hill (USGS, 2003). At 410 feet, it is the highest natural point on the eastern seaboard south of Maine; Todt means 'dead' in Dutch, as the hill's naturally-occurring, chrysotile asbestos soils were treeless, due to the abundance of magnesium (USGS, 2003). The New Jersey Geological Survey has a map of "Earthquakes Epicentered in New Jersey" at http://njgeology.org/geodata/dgs04-1.htm . (Actually, the highest hill on the eastern seaboard south of Maine is now the Fresh Kills Landfill on Staten Island, which had been designed to reach a maximum height of 450 feet when it was closed in March of 2001, reopened on 9/13/01 after the attacks on the World Trade Center, and finally closed in 2003 (Americas Roof, 2006; IEI, 2007)).

Nuclear Power

New Jersey has four nuclear reactors; 6 more are in Pennsylvania (the closest of these to NJ is in Limerick, Pennsylvania, 20 miles northwest of Camden) and New York (2 in Westchester County) that are within 50 miles of the NJ border. The nearest to Monmouth County, Oyster Creek in Forked River, Ocean County, is about 20 miles from Monmouth's southern border, placing Monmouth outside the limits of the State's 10-mile "Emergency Planning Zone" around this reactor.

It was almost closer. In October 1953, JCP&L proposed building a coal-fired plant on Gull Island in the Manasquan River, but due to local opposition, this plan was dropped. The plant was eventually built in 1969 at Oyster Creek, but as a nuclear-powered facility; it can power as many as 600,000 homes and is the nation's longest running commercial nuclear power plant (Clunn, 2006; Moore, 2006). A second, 900 watt nuclear plant was then planned for Union Beach on Raritan Bay; but in 1972, Brick Township negotiated with JCP&L to build this second nuclear plant near Reedy Creek. "Save Barnegat Bay" in Ocean County was originally founded to protect Reedy Creek on the south side of Mantoloking Point (it is now part of the Edwin B. Forsythe National Wildlife Refuge), and this plan was dropped. Instead, this second nuclear plant was built in Middletown, near Harrisburg, Pennsylvania, at Three Mile Island, operating until the core meltdown on March 28, 1979 (Moore, 2006b; USNRC, 2006).

Meteorites

On January 4th, 2007 the Asbury Park Press first reported that a lumpy, smooth object, weighing 13 ounces and measuring 2.5 inches by 1.5 inches, had crashed through the roof and had become embedded in the bathroom wallof a residence in Freehold Township off Rt. 537 near Freehold Borough on 1/2/07 at 4:30 PM (Clunn, 2007; Sapia, 2007). This object was thought to be an iron-nickel meteorite from the asteroid belt near Jupiter, dating from 4.6 billion years ago when the solar system formed; and by convention it was named "Freehold Township" (Clunn, 2007). However, it was reported on 5/12/07 that recent testing under an advanced electron microscope at the American Museum of Natural History in New York had detected the metal chromium, indicating that the object was man-made (Sapia, 2007b). The only recorded meteorite to have fallen in NJ was in 1829 in Deal, Monmouth County (Clunn, 2007).

War and Terrorism

On 9/11/01, about 800 people fleeing Manhattan by ferry were decontaminated at Atlantic Highlands by the MCHD Hazmat Team, and as many as twice that number at Highlands by the Fort Monmouth Hazmat Team (Miller, 2005). (Representing about 40% of Monmouth's available hazmat teams, it will be disbanded when Fort Monmouth is closed in 2011). During the next 2 months, the MCHD Hazmat Team responded to over 300 calls about "white powder" and other suspicious letters and packages, following the anthrax attacks in October. These events and the bombing of the World Trade Center on 2/25/93 are the most recent acts of war experienced by residents of the County.

It is well known that Monmouth was the scene of large and small battles during the early history of the nation. One of the largest battles of the American Revolution, the Battle of Monmouth, was fought in Manalapan in 1778; the 12-mile long English army then retreated across the County along the ridgeline of the Mount Pleasant Hills, and embarked to New York from Sandy Hook (Boyd, 2004; Colts Neck Historical Society, 1965; MCDPI, 2005). During the War of 1812, the coastal area was targeted by the British, who attacked shipping off Sandy Hook and sent raiding parties into Barnegat Inlet from a blockading fleet (NJDMVA, 2008). In 1813, the US Army built a temporary fortification at Sandy Hook called Fort Gates (renamed Fort Hancock in 1895), and in 1814 the NJ militia was organized to combat British attacks until the Treaty of Ghent ended the war later that year on December 24th (OCCHC, 2008; SSH, 2008)

What is much less known is that during WWII, the coastal waters from New England to Florida, including Monmouth County, were patrolled by German U-Boats during Operation Drumbeat, Germany's invasion of shipping lanes along the US East Coast that was planned by Hitler just 5 days after Pearl Harbor (Bilby, 2008; FTH, 2008; Larson, 2008). The first attack took place on January 12, 1942, when the British passenger steamship "Cyclops" was sunk 300 miles off Cape Cod; 2 days later, the "Norness" was sunk 60 miles off Montauk Point, Long Island, during the first attack in the NY Bight (FTH, 2008; Larson, 2008). A couple of weeks later on January 26, the "RP Resor", owned by Standard Oil (Exxon) and carrying 78,729 barrels of crude oil, was torpedoed about 20 miles east of the Manasquan Inlet, where it burned and drifted for 2 days until it sank in 130' of water, 31 miles east of Barnegat Light (EDC, 2008). The 2-day fire was so spectacular that crowds gathered at Asbury Park to watch (EDC, 2008; Berg, 2008).

During the first 6 months of 1942, as 397 merchant ships and tankers were being torpedoed along the East Coast by the U-Boat "wolf packs", residents near Wreck Pond left turpentine on their back porch so they could clean their feet of the tarry crude oil that was washing ashore; and in early spring of 1942, students were sent home from school in Leonardo when a sub was spotted off Sandy Hook (Bilby, 2008; Cassone, 2008; DD, 2008; FTH, 2008). Shore-bound tourists were only able to enjoy their 4th of July weekend in 1942 after 300 workers, including 65 from the Works Progress Administration (WPA), had removed all the oil, tarballs, and wreckage that had washed up in late June along 7 miles of beaches from Belmar to Manasquan (Bilby, 2008; New York Times, 1942).

Three days after Pearl Harbor, mariners were notified that a "mined area covering the approaches to New York Harbor has been established. Incoming vessels will secure directions for safe navigation from patrol vessels stationed off Ambrose Channel Entrance" (FTH, 2008). A submarine net and booms were eventually laid by the US Navy Net Depot of Bayonne across the Verrazano Narrows, from Norton's Point in Coney Island to Hoffman Island (FTH, 2008). On January 15, 1942, the U-123, which had sunk the Norness off Montauk Point the day before, cruised west along Long Island, navigating with a NYC tourist map off the Parachute Jump and Wonder Wheel on Coney Island, so close that they almost beached in the shallows along the southward curve of the Rockaways near Fort Tilden (FTH, 2008; VWHCAP, 2008). NYC Mayor Fiorello La Guardia later questioned whether “the Republic could even guarantee the defense of Coney Island" (FTH, 2008). It is now known that slogans such as “Loose Lips Sink Ships” were more effective at calming the public than at frustrating the Germans submarines, who located their targets by intercepting ship radio transmissions (FTH, 2008).

The U-Boats attacked at night when the target boats were silhouetted against the shoreline, and teenagers in NJ took their dates to the beach to watch “submarine races” (VWHCAP, 2008). East Coast cities, initially reluctant to order blackouts, were finally ordered to “dim-out” waterfront and sky signs on April 18, 1942, and blackouts were imposed by May (FTH, 2008; Larson, 2008). The US Coast Guard Reserve (now USCG Auxiliary) formed in 1939, the same year that the war had begun in Europe. They checked “commercial fishing boats and their crews upon departure and arrival at docks in Wildwood, Two Mile, and Cape May to guard against their carrying supplies to enemy vessels off-shore or bringing enemy agents ashore. . . .” (Larson, 2008). The 2 largest USCG Coastal Picket Force bases in the NY Bight were at Manasquan, NJ and Greenport, Long Island; formed in 1942, motor and sailboat volunteers were ordered to “observe and report the actions and activities of all hostile submarine, surface and air forces.” (Larson, 2008). On December 1, 1942, a Greek freighter was torpedoed 10 miles off Ambrose Light in the Mud Hole (FTH, 2001).

By March 1943, the “underwater snipers” were no longer as effective in the 500-mile “gap” in the mid-Atlantic, due to hastily-added technology like radar, hydrophones, and magnetic detection loops (FTH, 2008; Larson, 2008; NYT, 1943). A related plan by the Nazis to launch air attacks on the US East Coast from bases in the Azores was never initiated (Bilby, 2008; FTH, 2001; Larson, 2008). On January 3, 1944, the last sinking off NY Harbor occurred when the destroyer the USS Turner exploded from “undetermined origin” where it was anchored in the Ambrose Channel, within 3 miles of Ambrose Light (FTH, 2001; Larson, 2008).

The first time Germany attacked NJ had been during WWI. A ship was sunk 10 miles off Fire Island by a U-Boat; and just as it would be repeated 2 decades later, steel netting was lowered into the area of the present-day Verrazano-Narrows Bridge between Brooklyn and Staten Island (FTH, 2001). After German subs planted mines around Sandy Hook, 16 tug boats out of Staten Island were employed as mine sweepers (FTH, 2001). An explosion opposite the Statue of Liberty at a munitions pier on Black Tom Island in Jersey City in July of 1916, as well as a fire at the Roebling Steel foundry in Trenton in 1915, were conducted by German saboteurs retaliating for US support of the British naval blockade of Germany, prior to the US entering the war on April 6, 1917 (Germany didn’t finish paying WWI reparations for these and other acts of war until 1979) (Karnoutsos, 2008).

DEMOGRAPHICS AND TRANSPORTATION

Monmouth has a land area of 471.74 square miles (1222.48 km2) and is comprised of 53 municipalities: two cities, Long Branch and Asbury Park, fifteen townships, thirty-five boroughs and one village. The most populated municipality is Middletown Township, the least populated is the Village of Loch Arbor, and the most densely populated township is Hazlet Township; Howell Township has the largest land mass of 64 square miles (MCPB, 2005).

In the early twentieth century much of the housing was used as summer homes; today, two thirds of the year-round population live within a five-mile corridor along the Bayshore coastline and the Atlantic Ocean coastline (MCPB, 2005). The most current population estimate is 645,349; it is the 4th most populated county in N.J., and has the 6th largest land mass. Monmouth has 7.3 % of the total state population on 6.2 percent of the total state land area. (MCPB, 2005; MCPBb, 2005). Its summer population has been estimated by the New Jersey Department of Health and Senior Services to be as high as 1.2 million. The median age as of 2002 was estimated at 39.2 years; there are 84,248 children aged 9 or less and 137,557 adults aged 55 or more. There are 497,917 Caucasians, 46,893 African Americans, 41,693 Hispanics (15,209 Mexican and 14,847 Puerto Rican), and 27,841 Asians (15,687 Chinese and 5,209 Indians), and 5,867 other races. There are 224,925 family households and 58,147 nonfamily households; there are 5,942 families below poverty (MCPB, 2005). Between 1990 and 2000, white residents increased by 7.4% and blacks by 5%, while Hispanics increased by 70.4% and Asians by 61.6% (MCBPb, 2005). The 2000 Census indicated that the population is concentrated in households with parents in the 35-55 year old age bracket (MCPBb, 2005). Age restricted developments rose 83% from 2003 to 2004 in the County - 3162 single and multi-family units; more than 50% were built in Ocean and Manalapan townships (MCPB, 2005c).

The greatest rate of population growth in Monmouth County was when it more than doubled between 1950 and 1970, following the post war boom and the opening of the Garden State Parkway in 1954, from 225,337 in 1950 to 461,489 in 1970 (MCPBb, 2005). It increased by 9% from 1970 to 1980, 10% from 1980 to 1990, and 11% from 1995 to 2005 (MCPBb, 2005). During the boom years of 1950-1970, almost 50% of the population growth occurred within 3 miles of the Parkway; since 1990, much of the growth takes place in western Monmouth, in Howell (16%), Marlboro (14%), Freehold Township (11%), and Manalapan (11%) (MCPBb, 2005). The MCPB's analysis of vacant land, development trends and current zoning predicts a 0.5% increase in population growth per year for the County, from the current estimate of 645,349, reaching 697,071 in 2025 (MCPBb, 2005).

In 2004, more than 60% of the new single family units were found in western Monmouth, while 65% of the multi-family units were found in the coastal region (MCPB, 2005c). According to the 2000 Census, homes valued under $100,000 accounted for only 6.7% of the County's housing stock, while homes valued over $300,000 accounted for 24.9% (MCPBb, 2005). In 2004, there were 343 new single family development homes built that were worth more than $1 million, about a 76% increase over 2003 (MCPBb, 2005). The County was third in NJ for issuance of 2,628 residential building permits in 2004, but second in terms of total value of residential development, at $410,856,945; Manalapan, Howell, Middletown, Upper Freehold and Marlboro issued the most single family permits in 2004 (MCPBb, 2005). Proposed residential activity is near a 15 year high (MCPBb, 2005). The municipalities with the greatest amount of the 207 non residential site plans that were submitted to the MCPB in 2004 were Upper Freehold (32%), Freehold Township (16%), Wall (11%), Tinton Falls (10%), Howell (5%) and Middletown (4%) (MCPBb, 2005). Industry in the County is small, only 24 million square feet compared to 36 million in Somerset and 98 million on Rt. 287 near the NJ Turnpike (MCPBb, 2005). There are 3 enclosed malls, as well as Monmouth Park Raceway, the PNC Arts Center, and Wall Stadium.

The top 5 employers in Monmouth County as of 2005 are: Meridian Health Systems (7500), Fort Monmouth (5500), AT&T (4050),Monmouth County (3607), Foodarama (2458) (MCPBa, 2005). Ft. Monmouth accounts for 5500 workers, 5000 of which are private contractors; Naval Weapons Station Earle provides 1500 jobs (MCPBb, 2005). In 2005, Fort Monmouth, the 2nd major employer in the County, announced it will be closing its base, and in 2006, Lucent Industries, the 11th top employer, announced it was selling its facility in Holmdel.

As of 1990, there were a total of 274,238 commuters; almost 65 % of commuters worked within the County, 25% commuted to other New Jersey counties, and almost 10% commuted to New York State. In 2002, the number of vehicles reported as owned were: none: 12,538; three or more: 51,619; one: 63,816; two: 96,952 (MCPB, 2005; MCDEDT, 2005). Between 1990 and 2000, the number of County residents working in Staten Island rose by 35.7%, in Brooklyn by 36.4%, and Manhattan by 17.7% (MCPBb, 2005). Of the 286,271 (2000) workers 16 years or older who commute, about 85% drive, and of those 243,943 drivers, only about 10% carpool (MCPBb, 2005). Of the 22,061 who take public transportation, about 55% are bus riders, 31% take the train, and 4% take ferries; 7,654, or 2.7% of the total workers, work at home, a bit more than those who walk to work (6,672) (MCPBb, 2005). A report in 2006 by the Tri-State Transportation Campaign found that between 1997 and 2004 found that about 1 in 10 NJ commuters take mass transit, and that mass transit use is growing as twice as fast as driving; although 95% of all types of trips were made by private car (Higgs, 2006).

Of the estimated 291,938 (2000) County residents that work, about 60% work in the County; so about 116,775 leave the County during the workweek. About 10% work in Manhattan and other cities in NY, 10% work in Middlesex County, and about 9% work in other NJ counties to the north, for a total of about 84,662 riders who commute to workplaces to the north of the County. About 3% work to the south in Ocean County (MCPBb, 2005). Of the 241,708 (2000) people who work in Monmouth County, about 72% are residents; so about 67,678 more non residents work in the County during the workweek. About 15% are from Ocean County, 5% from Middlesex, 1% from Mercer, and the remainder from other NJ and NY counties (MCPBb, 2005). Based on the estimates that about 116,775 work out of the County and 67,678 non residents work in the County during the workweek, there are about 49,097 less people, about 7.5% of the 645,349 total County population, residing in the County during the average, non-summer workweek.

New York City is 20 miles to the north across Raritan Bay from Belford, and Philadelphia is 75 miles to the southwest of the County. There are 2,756 miles of highway in the County, including the Garden State Parkway (27 miles), Interstate 195, and several state highways (MCPB, 2005b). Rail freight shipments in Monmouth County are handled by CSX Transportation and Norfolk Southern, using Conrail as their agent, which they jointly own. Passenger rail service is provided by the New Jersey Transit's North Jersey Coast Line from 13 locations in Monmouth County; the Amtrak rail service is located near the western border in Middlesex County. New Jersey Transit, Suburban and Academy buses provide service along the main corridors (MCDEDT, 2005).

Ferry service from the Bayshore to NY has recently resumed, since the City of Keansburg made its last run in 1968 (Williams, 2006). Ferries to New York operate out of Highlands (24 miles to NYC), Atlantic Highlands (22 miles), and Belford (20 miles). NY Waterway carries about 1200 riders a day each way from Belford to NYC on 4 catamarans, 2 that carry 350 people each and 2 that carry 149 each (Diamond, 2007). SeaStreak carries about 750 riders a day from Atlantic Highlands and 1200 per day from Highlands, on 4 catamarans that carry 400 passengers each (Diamond, 2007; MCPBb, 2005). On 9/11, about 800 people fleeing Manhattan by ferry were decontaminated at Atlantic Highlands by the MCHD Hazmat Team, and as many as twice that number at Highlands by the Fort Monmouth Hazmat Team (Miller, 2005). Monmouth Executive

Airport, at Rt. 34 and I-195 in Wall, serves corporate and personal aircraft; it is built on a hill of Cohansey sand and gravel that divides the Manasquan River and Wreck Pond watersheds.

REFERENCES

Data is taken from the files of the Monmouth County Health Department; much was also based on the seminal 1975 "Natural Features Study for Monmouth County" by Robert Hughey and other members of the Monmouth County Planning Board, parts of which are posted on the MC Mosquito Commission website, and can be accessed from www.visitmonmouth.com. The majority of geologic references are from USGS sites including; "The Atlantic Coastal Plain" at http://3dparks.wr.usgs.gov/nyc/coastalplain/coastalplain.htm and others at the "Geology of the New York City Region" http://3dparks.wr.usgs.gov/nyc/ .

Aberdeen Township. Accessed 12/5/05. "Aberdeen Township Then and Now. http://www.twp.aberdeen.nj.us/about_aberdeen.html

Americas Roof. Accessed 7/10/06. NYC-Staten Island. http://americasroof.com/nyc-statenisland.shtml

Army Corps of Engineers. 1974. The District: A History of the Philadelphia District, U.S. Army Corps of Engineers 1866-1971. Chapter 19. Preserving a coastline. http://www.usace.army.mil/publications/misc/un16/c-19.pdf

Antel, R. Accessed 10/26/06. Peat ponds. Seattle, Washington. Quoted at www.newscientist.com/lastword/article.jsp?id=lw804

Asbury Park Press. 4/6/00. Report to Outline Work on Deal Lake Pipe. Kirk Moore.

Asbury Park Press(a). 12/4/05. Coastal Construction Booming Despite Hurricane Anxiety. Page A27. Associated Press Article.

Asbury Park Press(b). 12/11/05. Scientists Say Jolt was Small Quake.

Asbury Park Press. 7/2/06a. Keansburg: A time line. Page A14.

Asbury Park Press. 7/7/06b. Belford bass and more. Editorial page.

Ashley, F., Halsey, S., Buteux, C. 1986. New Jersey's Longshore Current Pattern. Journal of Coastal Research. Vol 2 No. 4. pps. 453-463.

Atherholt, T; Raymond T. Bousenberry, Gail P. Carter, Leo R. Korn, Judith B. Louis, Michael E. Serfes, and Debra A. Waller. 2012. Coliform Bacteria in New Jersey Domestic Wells: Influence of Geology, Laboratory, and Method. Ground Water. 2012 Oct 1. doi: 10.1111/j.1745-6584.2012.00997.x. http://www.ncbi.nlm.nih.gov/pubmed/23025712

Barnes, S. 2005. Personal Communication. Audubon Society. Sandy Hook.

Bates, Todd. 4/25/06. Restored stretch of Shore beach praised from sea to shining sea. Asbury Park Press. Page B4.

Bates, Todd. 12/17/06b. Storm Warning. Asbury Park Press. Page C1.

Bates, Todd. 12/17/06c. Recent storms cause unusually high waves. Asbury Park Press. Page C6.

Bates, Todd. 1/7/07. Where the heck is winter? Asbury Park Press. Page AA1.

Bates, Todd. 11/16/09. Recycling rates rise in New Jersey but still don't meet goal. Twitter Weekly Updates for Monday. Asbury Park Press.

Bates, Todd. 7/26/13. Shrewsbury River's rotten-egg odor blamed on algae. Asbury Park Press. http://www.app.com/article/20130727/NJNEWS/307270013/Shrewsbury-River-s-rotten-egg-odor-blamed-algae

Berg, D.Accessed 12/27/08. The RP Resor Shipwreck New York and New Jersey's (Wreck Valley). Aqua Explorers Inc. http://www.aquaexplorers.com/shipwreckrpresor.htm

Biddinger, E. Rasa, M. Accessed 1/4/09. Nike Missile Radar Site. Gateway NRA/Sandy Hook. http://www.nikemissile.org/sandyhook.shtml

Bilby, J. 2008. Sea Girt NJ. A Brief History. The History Press. Charleston, SC.

Biovir Laboratories. Accessed 12/16/05. Iron Bacteria. http://www.biovir.com/Images/pdf029.pdf

Blair, J. 1993. Freehold Township – The First 300 Years. Freehold Township Historical Society.

Board of Health of the State of New Jersey. Accessed 2/18/10. Annual Report. University Libraries Special Collections New Jersey Health Statistics from 1877 to 2000: An Historical Electronic Compendium of Published Reports. Compiled and Annotated by Mark C. Fulcomer, Ph.D. and Marcia M. Sass, Sc.D. University of Medicine and Dentistry of New Jersey. http://libraries.umdnj.edu/History_of_Medicine/NJHS/statistics.html .

Boehm, A.B, D. P. Keymer, G. G. Shellenbarger. 2005. An analytical model of enterococci inactivation, grazing, and transport in the surf zone of a marine beach. Water Research, 39, 3565-3578. http://www.stanford.edu/~aboehm/grazing1.pdf

Blumberg, A. and Hellweger, F. 2004. Hydrodynamics of the Hudson River Estuary. Stevens Institute of Technology, Hudson NJ. http://www1.coe.neu.edu/~ferdi/files/hres2004.pdf

Boyd, Paul. 2004. Atlantic Highlands – From Lenape Camps to Bayside Town. Arcadia Publishing. Charleston, S.C.

Capuzzo, Jill. July 18, 2004. A 'Fairly Typical' Year for Beach Closings. NYT. http://www.nytimes.com/2004/07/18/nyregion/a-fairly-typical-year-for-beach-closings.html?pagewanted=all&src=pm

Carlowicz, M. 2002. Digging into Hurricanes. Woods Hole Currents. Published on the Asbury Park Press Website, accessed 7/24/06. http://www.whoi.edu/home/about/currents_v9no3_hurricanes.html

Cassone, Mary. 12/25/08. Personal Communication. Atlantic Highlands.

Chant, R. and Kohut, J. 5/18/09. Grant proposal: Meterological modulation of the exchange between the Raritan Bay and the coastal ocean. NJ Sea Grant College Program.

Chebium, R. 6/26/06. Interstate system altered NJ, nation. Asbury Park Press. Pps 1-2.

Choi, Byoung-Ju, John L. Wilkin, 2007: The Effect of Wind on the Dispersal of the Hudson River Plume. J. Phys. Oceanogr., **37**, 1878–1897. http://dx.doi.org/10.1175/JPO3081.1 http://journals.ametsoc.org/doi/pdf/10.1175/JPO3081.1

Clunn, N. 7/1/06. Anti-nuclear producer returns to shore to fight Oyster Creek. Asbury Park Press.

Clunn, N. 1/6/07. Scientists: what struck house was a meteorite. Asbury Park Press, Page 1.

Coch, N. 1995. Hurricane hazards along the Northeastern Atlantic Coast of the United States. In, Journal of Coastal Research Special Issue No. 12, Coastal Hazards, Chapter 9, p. 115-147. Accessed 8/1/06 on the Asbury Park Press website: http://www.app.com/apps/pbcs.dll/section?Category=SHORE02

Coch, N. 1999. Hurricane Hazards in New Jersey. In, New Jersey Beaches and Coastal Processes from a Geologic and Environmental Perspective, J. Puffer(Ed.), Geological Association of NJ Annual Proceedings, V. 16, pps. 65-98. Accessed 8/1/06 on the Asbury Park Press website: http://www.app.com/apps/pbcs.dll/section?Category=SHORE02

Colorantshistory.org. Accessed 2/14/07. Arthur Kill – Tremley Point History. http://www.colorantshistory.org:80/TremleyHistory.html

Colts Neck Environmental Commission. 1983. Natural Resources Inventory. Chapter 10. Hydrology And Lithology. http://www.colts-neck.nj.us/env/nrichap10.html#chap10

Colts Neck Historical Society. 1965. History of Colts Neck. http://www.westfieldnj.com/whs/history/Counties/MonmouthCounty/coltsneck.htm

Condie, C. 2005. Email. Monmouth County Health Dept.

Conner, W., Aurand, D., Leslie, M., Slaughter, J., Amr, A., and Ravenscroft, F. 1979. Disposal of Dredged Material within the New York District. Volume 1. Present Practices and Candidate Alternatives. The Mitre Corporation, Virginia, for the US Army Corps of Engineers. Contract No.: DACW51-C-77-0061.

Conroy, W. 4/7/06. Tourism Was Hot in NJ. Asbury Park Press. Page 1.

Cook, S. 1988. Physical Oceanography of the Middle Atlantic Bight. In Pacheco, A. 1988. Characterization of the Middle Atlantic Water Management Unit of the Northeast Regional Action Plan. NOAA Technical Memorandum NMFS_F/NEC-56. US Department of Commerce. National Oceanic and Atmospheric Administration. Sandy HooK Lab, National Marine Fisheries Service, Highlands NJ.

Corzine, Jon. 5/21/07. Correspondence. State of the Shore Press Event. NJ Marine Sciences Consortium, Sandy Hook.

Curtis, E; Curds, C. 1971. Sewage fungus in rivers in the United Kingdom: the slime community and its constituent organisms. Water. Resources. Vol. 5, No. 12, pp. 1147-1159.

Dahlgren, P. 1977. Geology of Monmouth County in Brief. New Jersey Geological Survey.

Degener, R. 8/14/10. Delaware Bay fish kill not expected to have impact on bunker populations, official says. Press of Atlantic City. http://www.pressofatlanticcity.com/news/breaking/article_78337f06-a728-11df-a278-001cc4c002e0.html

Delmar Dustpan. 3/8/2008. U-Boats off Delaware Bay – 1942. Blog. http://delmardustpan.blogspot.com/2008/03/u-boats-in-delaware-bay-1942.html

Demitroff, Mark. 2006. Communications (1/21/06 - 2/14/06).

Department of Environmental Protection. November 24, 2004. Email. Bureau of Marine Water Monitoring.

Department of Environmental Protection. Accessed 11/17/05. “Sayreville Sewage Spill Update.” http://www.nj.gov/dep/update/update030603.html

DePetris, P. 1996. Riverine Transfer of Particulate Matter to Ocean Systems. Scientific Committee On Problems of the Environment (SCOPE). http://www.icsu-scope.org/downloadpubs/scope57/chapter-4.pdf

deVilliers, M. 2006. Windswept. Walker and Company.

Diamond, M. 11/4/07. Sea of Troubles. Asbury Park Press. B1.

Diamond, M. 3/30/07b. Tourism revenue up at the Shore. Asbury Park Press.

Dooley, J. 2000. Personal communication. NJ Geologic Survey. NJDEP.

Earthscape. Accessed 6/14/07. Marine Lithologic Indicators of Paleoclimate: Chapter 3. http://www.earthscape.org/r3/parrish/parrish03.html

Earthweek.com. Accessed 2/1/09. Brewing and ocean cure for global warming. http://www.earthweek.com/2009/ew090130/ew090130a.html

Eilperin J. 1/26/09. Officials and Scientists Debate the Criteria for Rescuing Animals. The Washington Post. A04. WashingtonPost.com

Enchanted Learning. Accessed 12/12/08. Proxigean Spring Tide. http://www.enchantedlearning.com/subjects/astronomy/glossary/indexp.shtml

Environmental Science Department, Rutgers University. 10/18/2006. Draft final report for the Shrewsbury River watershed basin characterization project. Coordinated by the Freehold Soil Conservation District, Freehold, NJ.

EPA Long Island Sound Study. Accessed 6/16/09. Chapter VI. Floatable Debris. EPA Long Island Sound Office Stamford, CT. http://www.longislandsoundstudy.net/ccmp/floatable_debris.pdf

Explorers Dive Club. Accessed 12/27/08.Wreck Diving Articles. RP Resor. http://www.explorersdiveclub.org/wrecks.htm

Farrell, S. 5/21/07. Beach erosion issues in NJ. State of the Shore Press Event. NJ Marine Sciences Consortium, Sandy Hook. Richard Stockton Coastal Research Center.

Farrell, S. et al. 2008. Monmouth County. Raritan Bay and Sandy Hook to Manasquan Inlet. NJBPN Profile #'s 187-256. Prepared for New Jersey Department of Environmental ProtectionDivision of Construction and Engineering. NJ Beach Profile Network. P 52.

Forman, Richard (Ed.). 1998. Pine Barrens: Ecosystem and Landscape .

Fort Tilden History. 2/14/99. Nazi U-Boats Attack New York Shipping! http://www.geocities.com/fort_tilden/uboats.html

Fort Tilden History. October 16, 2001. The US Life Saving Service Station at Rockaway Point, NY. http://www.geocities.com/fort_tilden/uslss.html

Frankenstein, G. 2000. Blooms of Ulvoids in Puget Sound. Puget Sound Water Quality Action Team. http://www.psat.wa.gov/Publications/blooms_report.pdf

Freda, J., Quigley, G., Caris, S. 2004. Saltwater Fishing: A Tactical Approach. Burford Books.

Freda, J. 6/8/07. Shore catch on the fly. Bass, blues will hit flies on the beach now. Asbury Park Press.

Franklin, H. Bruce. 2007. The Most Important Fish in the Sea. Menhaden and America. Island Press, Washington, DC.

Franklin, H. Bruce. 2001.The Most Important Fish in the Sea. Discover Vol. 22 No. 9 (September 2001). http://andromeda.rutgers.edu/~hbf/menhaden.htm

Freehold Soil Conservation District. 1985. Navesink Watershed Plan. USDA, SCS.

French, H.; Demitroff, M. 2001. Cold-climate origin of the enclosed depressions and wetlands ('spungs') of the Pine Barrens, southern New Jersey, USA. Permafrost and Periglacial Processes. Vol. 12. Issue 4. Pps. 337-350. http://www3.interscience.wiley.com/cgi-bin/abstract/89011416/ABSTRACT

French, H.; Demitroff, M. and Forman, S. 2003. Evidence for Late-Pleistocene Permafrost in the NJ Pine Barrens (Latitude 39N), Eastern USA. Permafrost and Periglacial Processes. Vol. 14. Pps. 259-274.

French, H.; Demitroff, M. and Forman, S. 2005. Evidence for Late-Pleistocene Thermokarst in the NJ Pine Barrens (Latitude 39N), Eastern USA. Permafrost and Periglacial Processes. Vol. 16. Pps. 173-186.

Keelen, Kate and Jerry. 2003. "The Navesink Watershed – A Short History" http://www.shore.co.monmouth.nj.us/area12/SubNavesink/navesink%20history%20keelens.pdf

Gallagher, W. 2003. When Dinosaurs Roamed New Jersey. Rutgers University Press. New Brunswick, NJ.

Gallo, T. 2000. Henry Hudson Trail – Central RR of NJ's Seashore Branch. Arcadia Publishing. Charleston, S.C

Gaswirth, S., Ashely, G., Sheridanf, R. 1999. Seismic stratigraphic evidence for the last glacial sea-level rise, Raritan Bay, NJ. Dept. of Geological Sciences, Rutgers University, Piscataway, NJ. http://www.geo.sunysb.edu/lig/Conferences/Abstracts99/Gaswirth/Gaswirth_MS.htm

Gaugler, L. Undated, received 2/16/2006. Draft 2005 Floatables Action Plan Assessment Report. Division of Enforcement and Compliance Assistance, EPA Region II.

Gieser, J. May 16, 2008. Bunker bills will protect this valuable resource. Asbury Park Press.

Geoworld. Accessed 11/17/05. "Prehistoric New Jersey." http://www.geoworld.org/na/usa/nj/prehistory

Glenn, S.; Crowley, M.; Haidvogel, D. and Song, D. Accessed 5/29/06. Underwater observatory captures coastal upwelling off New Jersey. American Geophysical Union (AGU) http://www.agu.org/sci_soc/eisglenn.html

Grant, D. 12/15/05. Email. Brookdale Community College.

Grant, S. B., J. H. Kim, B. H. Jones, S. A. Jenkins, J. Wasyl, and C. Cudaback (2005), Surf zone entrainment, along-shore transport, and human health implications of pollution from tidal outlets, J. Geophys. Res., 110, C10025, doi:10.1029/2004JC002401. http://www.cws.msu.edu/documents/Grant_2004JC002401-1.pdf

Graver F. and Rubin, C. 1995. "NY Earthquake". http://pbisotopes.ess.sunysb.edu/classes/oldclasses/GEO201/NYearthquake.htm ;

Grebe, Helen. 4/20/06. Recreational Beach Monitoring Breakout Session at NJ Monitoring and Assessment Technical Workshop. Rutgers EcoComplex, Colombus, NJ.

Geyer, W., Woodruff, J. and Traykovski, P. 2001. Sediment Transport and Trapping in the Hudson River Estuary. Estuaries. Vol 24, No.5, p. 670-679. http://estuariesandcoasts.org/journal/ESTU2001/ESTU2001_24_5_670_679.pdf

Jacobsen, Brian. 2002. Personal Communication. DEP, Division of Watershed Planning.

Jeffries, H. 1962. Environmental Characteristics of Raritan Bay, A Polluted Estuary." Narragansett Marine Laboratory. No. 35. Rhode Island.

Harbor Estuary Program. Accessed 12/12/05. "Fact Sheet. Combined Sewer Overflows in the NY/NJ Harbor Estuary." http://www.hudsonriver.org/hep/pdf/hep_cso.pdf

Harrington, T. 2006. 110 million pounds of debris removed from NJ shoreline. Watershed Focus, Spring, 2006. NJDEP. http://www.state.nj.us/dep/watershedmgt/DOCS/focus/SPRING06.pdf

Herrington, T. 6/20/05. Email. Stevens Tech.

Higgs, L. 7/30/2006. Traffic conditions rated poor in shore area by 48 percent. Page 1. Asbury Park Press.

Higgs, L. 12/21/06. Report: 1 in 10 take mass transit. Asbury Park Press. Page B1.

Hires, R., Herrington, T., Miskewitz, R. 2005.Impacts of the proposed extension of the Wreck Pond outfall on nearshore water quality and littoral drift of sand. Coastal Protection Technical Assistance Service, Davidson Laboratory Technical Report SIT-04-09-2848, November 2005.

Hohn, A. 1/13/09. Worldwide Distribution of Bottlenose Dolphins. Slide 16. NOAA Southeast Fisheries Science Center.Bottlenose Dolphin Seminar. Pollak Theatre. Monmouth University.

http://www.nefsc.noaa.gov/njdolphins/Coastal%20Migratory%20Bottlenose%20Dolphins.pdf

Howstuffworks.com. Accessed 8/1/06. How Hurricanes Work. http://www.howstuffworks.com/hurricane.htm

Hurricance.com. Accessed 11/28/05. "Remembering Floyd 5 Years Later". http://www.hurricaneville.com/floyd.html

International Atomic Energy Agency. 1998. Planning the Medical Response to Radiological Accidents. Safety Report Series No.4. Table III Examples of Substances which Speed Up the Elimination of Radionuclides from the Human Body. Vienna. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1055_web.pdf

International Atomic Energy Agency. 2006. Environmental Consequences of the Chernobyl Accident and Their Remediation: 20 years of Experience. Report of the Chernobyl Forum Expert Group 'Environment'. Chapter 3. Radioactive Contamination and the Environment. Vienna. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1239_web.pdf

Interstate Environmental Commission. 2007. 2006 Annual Report of the Interstate Sanitation Commission. http://www.iec-nynjct.org/reports/2007/annual.report.2006.pdf

Jordon, R. 5/23/07. Preserving the land. Asbury Park Press. Page B1.

Karnoutsos, C. Accessed 1/1/09. Black Tom Explosion. Black Tom Island - Upper New York Bay and Jersey City Waterfront. New Jersey City University. http://www.njcu.edu/programs/jchistory/Pages/B_Pages/Black_Tom_Explosion.htm

Kaplan, D., T. G. Hinton, A. C. Knox, S. M. Serkiz. 6/3/99. In Situ Remediation of 137CS Contaminated Wetlands Using Naturally Occurring Minerals. WSRC-TR-99-00229. Westinghouse Savannah River Company, Savannah River Site, Aiken, South Carolina 29808. http://www.osti.gov/bridge/servlets/purl/9834-SXPrdv/webviewable/9834.PDF

Kisk, J. 4/21/06. Phone call. Matawan Historical Society.

Klaus Jacob. 1995. "Earthquakes in the Eastern US. http://www.earth2class.org/docs/scientistsppt/TchrSem.ppt

Kraft, H. 2001. The Lenape-Delaware Heritage: 10,000- B.C. – A.D. 2000.

Larson, C.K. Accessed 12/31/08. Bravo Zero: The Coast Guard Auxiliary in World War II. National Historian United States Coast Guard Auxiliary. http://www.cgauxinternational.org/AuxHx.pdf

Lathrop, R. and Love, A. Vulnerability of New Jersey's Coastal Habitats to Sea Level Rise. Grant F. Walton Center for Remote Sensing & Spatial Analysis, Rutgers University. In partnership with the American Littoral Society Highlands, New Jersey. http://crssa.rutgers.edu/projects/coastal/sealevel/report/Vulnerability_of_New_Jersey_coastal_habitats_v4.pdf

Lathrop, R.; Montesan, P.; Tesauro, J.; Zarate, B. 2005. Statewide mapping and assessment of vernal pools: A New Jersey case study. Journal of Environmental Mangement 76. Pps. 230-238 http://www.ci.uri.edu/Projects/RI-Monitoring/Docs/NJ%20Vernal%20Pool%20Mapping.pdf

League of Women Voters. 1974. Our County – Monmouth.

Loman, B., Smolders, A., Intven, L., Pol, A., Op den Camp, H., and Van der Drift, C. 1997. Formation of dimethyl sulfide and methanethiol in anoxic freshwater sediments. Applied and Environmental Microbiology. Dec. 1997, p. 4741-4747. http://aem.asm.org/cgi/reprint/63/12/4741.pdf

MacKenzie, Clyde. 2005. Removal of Sea Lettuce, Ulva spp., in Estuaries to Improve the environments for invertebrates, fish, wading birds, and eelgrass, Zostera marina. Marine Fisheries Review. 67, 4. http://spo.nmfs.noaa.gov/mfr674/mfr6741.pdf

Manasquan Watershed Management Group. Monmouth Coastal Watershed Partnership. 1999. Mansquan River Watershed Initial Characterization and Assessment Report. http://www.visitmonmouth.com/area12/DOCUMWMG/Characterization/CharLk03Contents_Tables_Figures.pdf

Mandeville, Ernest. 1927. The History of Middletown. Middletown Township Courier.

Marlowe & Company. Accessed 8/10/06. The value of America's beaches to the economy. Washington DC. http://www.marloweco.com/value_of_beaches.php

Meakim, J. 6/13/05. Email. Fresh Creek Technologies. http://www.freshcreek.com/

Merguerian (Dr.). Accessed 11/17/05. "Metasedimentary and Metavolcanic Rocks of the Appalachian Cycle." Hostra University. http://www.people.hofstra.edu/faculty/charles_merguerian/Abstracts%20and%20Papers/1CManual0209.htm

Middletown Township Environmental Commission. 1995. Coastal Habitats of the Middletown Bayshore. A Natural Resource Inventory of the Bayshore Region.

Middletown Township Environmental Commission. 1999. "Nonpoint Source Contaminant Study in the McClees Creek Watershed, Middletown Township, Monmouth County, New Jersey."

Miller, E. (12/16/05). Email. Fort Monmouth Hazmat Team.

Monmouth Beach Environmental Commission (MBEC). 1976. Environmental Inventory Report, Borough of Monmouth Beach.

Monmouth County Department of Economic Development and Tourism. Accessed 11/17/05. http://www.shore.co.monmouth.nj.us/econdev/trans.asp

Monmouth County Department of Public Information. Accessed 11/17/05. History. http://www.visitmonmouth.com/publicinformation/index.html

Monmouth County Health Department. 4-10-12. Three Transient, Miles-Long Clusters Of Elevated Enterococcus Along Monmouth And Ocean Counties, And The Potential Role Of The Hudson-Raritan Plume. http://co.monmouth.nj.us/documents/121/8-23-10exceedences_mabsc.pdf

Monmouth County Planning Board. 1975. Natural Features Study for Monmouth County. Freehold, NJ.

Monmouth County Planning Board and Monmouth County Environmental Council. 1999 "North Coast Environmental Planning Region, Monmouth County NJ: Ecological Resource Inventory." (Chapter 2). http://www.shore.co.monmouth.nj.us/03230planboard/EnvirNorthCst/NCChap2.pdf

Monmouth County Planning Board. 2005a. Monmouth County Planning Indicators. Freehold, NJ. http://www.monmouthplanning.com/

Monmouth County Planning Board. 2005b. Monmouth County Profile 2005. Freehold, NJ. http://www.visitmonmouth.com/03230planboard/MCData/Profile%202005.pdf

Monmouth County Planning Board. 2005c. New Residential Development. Freehold, NJ.

Moore, K. 2006. Geological discoveries are reshaping Pineland's past. Asbury Park Press. Pps AA1-2.

Moore, K. 2/20/06b. The nuclear future that didn't come to pass. Asbury Park Press. Pps A1-2.

Moore, K. 7/23/06c. Buried cedar trees, sediments yield evidence of long-ago storms. Asbury Park Press. http://www.app.com/apps/pbcs.dll/article?AID=/20060723/NEWS/607230407

Moore, K. 12/7/09. Radar miss at Sandy Hook could have altered history in Pearl Harbor. Asbury Park Press.

Mulhall, M. 2003. Evaluation of groundwater resources of Millstone Township, Monmouth County, NJ. M2 Associates Inc., Hampton, NJ.

Naval Facilities Engineering Command Atlantic. April 2009. Final Environmental Impact Statement for Laurelwood Housing Area Access. Naval Weapons Station Earle. Colts Neck, NJ. Volume 1. Contract No. N62472-01-D-1390. Norfolk, Va. Pps 3-65 to 3-66.
http://www.laurelwoodeis.com/Resources/Documents/Final_EIS_April_2009_Volume_I.pdf

New Jersey Department of Environmental Protection. 2006. NJ Private Well Testing Act Program – September 2002 to October 2004. NJDEP Division of Water Supply/Bureau of Safe Drinking Water and Division of Science, Research and Technology.

New Jersey Department of Health. 1990. Ocean Health Study. A study of the relationship between illness and ocean beach water quality in New Jersey. Final Report. September 1990. Division of Occupational and Environmental Health. Environmental Health Service. Trenton, NJ.

NJ Department of Military & Veterans Affairs. Accessed 1/1/09. Historical Narratives: The War of 1812 National Guard Militia Museum of New Jersey. Trenton, NJ. http://www.state.nj.us/military//museum/warof1812.html

New Jersey Geological Survey. 1983. Deep Wells of the New Jersey Coastal Plain.

New Jersey Scuba Diver. Accessed 12/12/05. Natural Rock Formations.
http://www.njscuba.net/biology/misc_bottom.html

NYCroads.com. Accessed 12/1/05. "Garden State Parkway: Historic Overview".
http://www.nycroads.com/roads/garden-state/

NOAA. Accessed 6/19/07. The causes of hypoxia in the Northern Gulf of Mexico. National Ocean Service.
http://oceanservice.noaa.gov/products/hypox_finalcauses.pdf

NOAA Paleoclimatology Branch. Accessed 1/26/09. The Penultimate Interglacial Period. Penultimate Interglacial Period ca. 125,000 Years Ago. http://www.ncdc.noaa.gov/paleo/globalwarming/interglacial.html

NY/NJ Clean Ocean and Shore Trust, Columbia University Department of Earth and Environmental Engineering, and the NYC DEP. 2004. The 2003 New York Harbor Water Quality Report.
http://www.scc.rutgers.edu/coastweb/NYCDEPHarbor_survey/docs/hqr.pdf

NY/NJ Harbor Estuary Program. Accessed 2/20/07. About the harbor estuary program.
http://www.seagrant.sunysb.edu/HEP/about.htm

NY Times. 7/2/1942. Oil Cleared off Beaches, Jersey Ready for Holiday.

NY Times. 4/25/1943. New Weapons Aid Fight on U-Boats.

Ocean County Cultural & Heritage Commission. Accessed 1/1/09. History of Ocean County.
http://www.ocean.nj.us/museums/history.htm

Olko, J. 3/26/09. Email.NJDEP.

Olipade, O., Depas, M. et al. 2006. "Microbial Communities and Fecal Indicator Bacteria Associated with Cladaphora Mats on Beach Sites Along Lake Michigan Shores." Applied and Environmental Microbiology. Vol. 72, No. 3. Pps. 1932-1938.

Owens, J.; Minard, J. 1979. Upper Cenozoic Sediments of the Lower Delaware Valley and the Northern Delmarva Peninsula, New Jersey, Pennsylvania, Delaware, and Maryland. Geological Survey Professional Paper 1067-D.

Panno, S.V., K.C. Hackley, H.H. Hwang, S. Greenberg, I.G. Krapac, S. Landsberger and D.J. O'Kelly. 2002. Source Identification of Sodium and Chloride Contamination in Natural Waters: Preliminary Results. Wilkes University Center for Environmental Quality. Environmental Engineering and Earth Sciences. http://www.water-research.net http://www.water-research.net/Waterlibrary/privatewell/nacl.pdf

Pasfield, Kristen. Accessed 11/28/05. "Seismological analysis and the Effects of Earthquakes in NY and Long Island." Stony Brook. http://pbisotopes.ess.sunysb.edu/lig/Conferences/abstracts_00/Pasfield/Pasfield_abs.htm

Patterson, D. Accessed 10/26/06. Peat ponds. Dept of Biological Sciences, University of Sidney. Quoted at www.newscientist.com/lastword/article.jsp?id=lw804

Pence, A., Bruno, M. and Blumberg, A. 2005. Hydrodynamics governing contaminant transport in the Newark Bay complex. In Proceedings of the Third International Conference on Remediation of Contaminated Sediments. http://www.stevens.edu/engineering/ceoe/fileadmin/ceoe/pdf/alan_publications/AFB099.pdf

Pineda, Jesus. 1994. Internal tidal bores in the nearshore: Warm-water fronts, seaward gravity currents and the onshore transport of neustonic larvae. Journal of Marine Research, 52, 427-458,1994 http://science.whoi.edu/labs/pinedalab/PDFdocs/Pineda_1994.pdf

Ray, G. 2004. Monitoring the intertidal benthos on the shoreline of Raritan and Sandy Hook Bays, New Jersey: interim report. US Army Engineer District, NY. US Army Engineer Research Development Center, Vicksburg, MS. http://www.csc.noaa.gov/benthic/data/northeast/raritan/Raritan_Benthos_Report.pdf

Reid, R. and Steimle, F. 1988. Benthic Macrofauna of the Middle Atlantic Continental Shelf. In Pacheco, A. 1988. Characterization of the Middle Atlantic Water Management Unit of the Northeast Regional Action Plan. NOAA Technical Memorandum NMFS_F/NEC-56. US Department of Commerce. National Oceanic and Atmospheric Administration. Sandy HooK Lab, National Marine Fisheries Service, Highlands NJ.

Reid, R., Olsen, P., and Mahoney, J. 2002. A compilation of reported fish kills in the Hudson-Raritan Estuary during 1982 through 2001. Northeast Fisheries Science Center Reference Document 02-09. www.nefsc.noaa.gov/nefsc/publications/crd/crd0209/crd0209.pdf

Reynolds, J. 6/2/9/06. Wetlands are the best flood protection in the Bayshore. Atlantic Highlands Herald. http://www.ahherald.com/oaktrail/2006/oot060629_bayshore_wetlands.htm

Richards, H. 1951. Some Recent Discoveries Of Pleistocene Mammals From New Jersey. In Short GeologicPapers by Cuthbert, FL et al. Bulletin 60 Geologic Series. State Of New Jersey Department Of Conservation And Economic Development. PDF pg. 92. http://www.state.nj.us/dep/njgs/enviroed/oldpubs/bulletin60.pdf

Richard Stockton College of NJ Coastal Research Center. Accessed 8/11/06. New Jersey Geologic History. The NJ Beach Protection Network. http://gannet.stockton.edu/njbpn2004/2004/nj_geologic_history.htm

Richard Stockton College of NJ Coastal Research Center. Accessed 8/11/06(b). New Jersey Shoreline Protection and Vulnerability. The NJ Beach Protection Network. http://gannet.stockton.edu/njbpn2004/2004/nj_shoreline_protection.htm

Riverkeeper, Inc. Accessed 3/27/09. NYC: Combined Sewer Overflows. CSO – Information. 828 South Broadway Tarrytown, NY 10591. Phone: 800-21-RIVER. info@riverkeeper.org . http://www.riverkeeper.org/campaign.php/pollution/the_facts/1307-cso---information

Roberts, R. and Youmans, R. 1993. Down the Jersey Shore. Rutgers University Press, New Brunswick, NJ.
M. Cooper, M. Beavers, M. Oppenhiemer. 2005. "Future Sea Level Rise and the New Jersey Coast". http://region.princeton.edu/resource_91.html

Ross, D. 2000. The Fisherman's Ocean. Stackpole Books.

Roylance, F. Posted 12/12/08. Tonight's Long Night Moon is closest in 15 years. Marylandweather.com http://weblogs.marylandweather.com/2008/12/tonights_long_night_moon_is_cl.html

Royte, E. 2005. Garbage Land. Little Brown and Co. NY.

Sapia, J. 1/4/07. Roof pierced by mysterious rocklike item. Asbury Park Press, Page 1.

Sapia, J. 5/12/07b. Tests show object isn't meteorite. Asbury Park Press, Page 1.

Sapia, J. 8/1/07b. Tour de Farms. Asbury Park Press, Page 1.

Save Sandy Hook. Accessed 1/1/09. Sandy Hook History. http://www.savesandyhook.org/history.php?PHPSESSID=e11d86a7869f9fa86a56d6bfe2c74de0

Schofield, Oscar and Scott Glenn. Accessed 7/16/13. Ocean Science in the New Millennium: The history and the potential for regional partnerships. Rutgers Marine and Coastal Sciences. http://www.state.nj.us/dep/wms/DEP_september04.pdf

Seidel, B. 8/26/06. Birds of the Shore. Jersey Life, Asbury Park Press. (quoting Scott Barnes of the NJ Audubon Society).

Slagle, A.L, W.B.F. Ryan, S.M. Carbotte, R. Bell, F.O. Nitsche, T. Kenna. 2006. Late-stage estuary infilling controlled by limited accommodation space in the Hudson River. Marine Geology. http://www.ldeo.columbia.edu/~carbotte/2006Slagle-MG.pdf

Smith, C. (Natural Resources Conservation Service).10/17/00. "Soils in Monmouth County." Area 12 TMDL Subcommittee Meeting. http://www.visitmonmouth.com/area12/DOCUMENTS/soilsmith3.pdf

Snodgrass, W.J, Kilgour, L., Eyles, J., Parish, J. and Barton, D. 1998. "Applying ecological criteria for stream biota and an impact flow model for evaluating sustainable urban water resources in Southern Ontario." quoted in Pitt, R. Stormwater Quality Management, Part One: Drainage Design Philosophy, Effects and Sources of Stormwater. CRC/Lewis. New York.

Sorensen, D. 12/5/05. Email. Monmouth County Health Department.

Sucharev, Y.I, Kuvykina, E.A. Accessed 11/13/06. Zeolits and Possibility of their Use for Peelings Surrounding Water Ambience from Contamination. Southern Ural State University, Chelyabinsk, Russia. sucharev@water.tu–chel.ac.ru . http://csc.ac.ru/news/2001_4/2001_4_10_5e.pdf .

Stahl, L. and Krumbein, W. 1984. Metabolism of cyanobacteria in anaerobic marine sediments. Deuxieme Colloque International de Bacteriologie Marine. Actes de Colloques, 3, 1986, pp. 301-309. http://www.ifremer.fr/docelec/doc/1984/acte-974.pdf

Starace, M. 4/25/06. Email. Matawan Historical Society.

State of New Jersey. 12/15/08. Draft Global Warming Response Act Recommendation Report. http://www.state.nj.us/globalwarming/home/documents/pdf/final_report20081215.pdf

Stehlik, L, Rikanowski, R, and McMillan, D. 2004. The Hudson-Raritan Estuary as a crossroads for distribution of blu (Callinectes sapidus), lady (Ovalipes ocellatus), and Atlantic rock (Cancer irroratus) crabs. Fisheries Bulletin. 102:693-710. http://fishbull.noaa.gov/1024/stehl.pdf

Steimle, F. and Caracciolo-Ward, J. 1989. A reassessment of the status of the benthic macrofauna of the Raritan Estuary. Estuaries. Vol112, No. 3, p. 145-156. http://estuariesandcoasts.org/cdrom/ESTU1989_12_3_145_156.pdf

Steimle, F and Zetlin, C. 2000. Reef habitats in the middle Atlantic bight: abundance, distribution, associated biological communities, and fishery resource use. Marine Fisheries Review. http://spo.nwr.noaa.gov/mfr622/mfr6222.pdf

Steimle, F. 2005. National Marine Fisheries Service. Email.

Stoner, N. and Dorfman, M. 8/2006. Testing the waters 2006. Natural Resources Defense Council. http://www.nrdc.org/water/oceans/ttw/titinx.asp

Stumpf, R. and Biggs, R. Surficial Morphology and Sediments of the Continental Shelf of the Middle Atlantic Bight. In Pacheco, A. 1988. Characterization of the Middle Atlantic Water Management Unit of the Northeast Regional Action Plan. NOAA Technical Memorandum NMFS_F/NEC-56. US Department of Commerce. National Oceanic and Atmospheric Administration. Sandy HooK Lab, National Marine Fisheries Service, Highlands NJ.

Szabo, Zoltan. 9/16/03. Notes from seminar on at DEP, Trenton: "Radiological Waste from Treated Water" .

Tedrow, J. 1986. Soils of New Jersey. Krieger Publishing Company. Florida.

Terwilliger, K. 2004. Sandy Hook, Gateway National Recreation Area, NJ. Sand Slurry Pipeline Cyclical Beach Replenishment. Essential Fish Habitat Assessment. Terwilliger Consulting for NPS. http://www.nps.gov/applications/parks/gate/ppdocuments/ssp%20efha.pdf

Titus, J and Strange, E. . 2/12/2008. Appendix C. The New Jersey Shore. In Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic RegionUSEPA. http://www.climatescience.gov/Library/sap/sap4-1/public-review-draft/sap4-1-prd-appC.pdf

Union of Concerned Scientists USA. Accessed 12/24/08. Confronting Climate Change in the U.S Northeast: New Jersey. http://www.climatechoices.org/assets/documents/climatechoices/new-jersey_necia.pdf

U.S. Army Corps of Engineers New York District.06/2004. Arthur Kill/Kill Van Kull Study Area Report. The Hudson Raritan Environmental Restoration Feasibility Study. http://www.nan.usace.army.mil/harbor/links/ArthurKill_SAR_RevSep04.pdf

U.S. Army Program Manager For Chemical Demilitarization.1996. Survey and Analysis Report Second Edition. Project Manager For Non-Stockpile Chemical Materiel. http://chppm.amedd.army.mil/chemicalagent/PDFFiles/NonStockpileLocationsSurvey1996.pdf

United States Department of the Interior. 2004. Environmental Survey of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. Chapter 3. Regional Geomorphic Change. Minerals Management Service. http://www.oceanscience.net/mms_nj_ny/project%20report.htm

U.S. Environmental Protection Agency. January 15, 2009. Coastal Sensitivity to Sea Level Rise: A Focus on the Mid-Atlantic Region. U.S. Climate Change Science Program. Synthesis and Assessment Product 4.1. http://www.climatescience.gov/Library/sap/sap4-1/default.php

U.S. Fish and Wildlife Services. Accessed 1/29/07. Significant habitats and habitat complexes of the NY Bight watershed. Raritan Bay-Sandy Hook Complex. Complex #17. Southern New England - New York Bight Coastal Ecosystems Program in Charlestown, Rhode Island. http://training.fws.gov/library/pubs5/web_link/text/rb_form.htm

United States Geological Survey. 2003. Geology of the New York City Region. http://3dparks.wr.usgs.gov/nyc/

United States Geological Survey. Accessed 1/29/07. Geologic History of Raritan Bay. http://3dparks.wr.usgs.gov/nyc/morraines/raritanbay.htm

U.S. Nuclear Regulatory Commission. Accessed 6/30/06. Fact Sheet on the Accident at Three Mile Island. http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

URS. 7/2008. Multi-Jurisdictional Natural Hazard Mitigation Plan Monmouth County, New Jersey – DRAFT. Wayne, New Jersey. MC OEM. http://www.visitmonmouth.com/page.aspx?Id=3020

Vellucci, J. and Zedalis, J. 8/3/06. Hot and inhuman. Page 1. Asbury Park Press.

Virginia Wing Headquarters Civil Air Patrol. Accessed 12/31/08. History Of Civil Air Patrol. http://www.vawg.cap.gov/history.html

Waldman, J. 1999. Heartbeats in the Muck. The Lyons Press.

Weather Underground. Accessed 1/26/09. The Science of Abrupt Climate Change: Should we be worried? http://www.wunderground.com/education/abruptclimate.asp

Widmer, Kemble. 1964. Geology and Geography of New Jersey .

Wikipedia. Accessed 2/17/09. Anti-Atlas. http://en.wikipedia.org/wiki/Anti-Atlas

Wikipedia. Horseshoe Crab. Accessed 12/1/05. http://en.wikipedia.org/wiki/Horseshoe_crab .

Wikipedia. Human. Accessed 12/1/05. http://en.wikipedia.org/wiki/Homo_sapiens

Wikipedia. Jetty. Accessed 12/24/08. http://en.wikipedia.org/wiki/Jetty

Wildcat Ridge Enhancement Site. Accessed 11/17/.05. “The Geology of New Jersey” (‘retyped Source data from: New Jersey Geological Survey for appearance’). http://fvanderb.home.att.net/geology/geology.html ; USGS . “51. Atlantic Highlands”.

Williams, C. 7/2/06. Keansburg: a time line. Asbury Park Press. Page A14.

Woodruff, J., Geyer, W., Sommerfield, C. and Driscoll, N. 2001. Seasonal variation of sediment deposition in the Hudson River estuary. Marine Geology. Vol. 179 P. 105-119.

Zampella, Robert A., Nicholas A. Procopio III, Mariana U. Du Brul, and John F. Bunnell. 2008. An Ecological-Integrity Assessment Of The New Jersey Pinelands. NJ Pinelands Commission. New Lisbon, NJ. http://www.nj.gov/pinelands/images/pdf%20files/EIA_Final_Report.pdf

Zapecza, O. 1984. Hydrogeologic Framework of the New Jersey Coastal Plain. Open-File Report 84-730. United States Geological Survey.

Zimmer, B. 2004. Raritan and Sandy Hook Bays Sanitary Survey Report 1997-2000. Bureau of Marine Water Monitoring. NJDEP. http://www.state.nj.us/dep/wmm/bmw/ReportMonmouth.htm

Zimmer, K. 1996. How Low Dissolved Oxygen Conditions Affect Marine Life In Long Island Sound. New York Sea Grant Extension Program for the Long Island Sound Study. http://www.longislandsoundstudy.net/pubs/facts/lodo.pdf

12/30/05