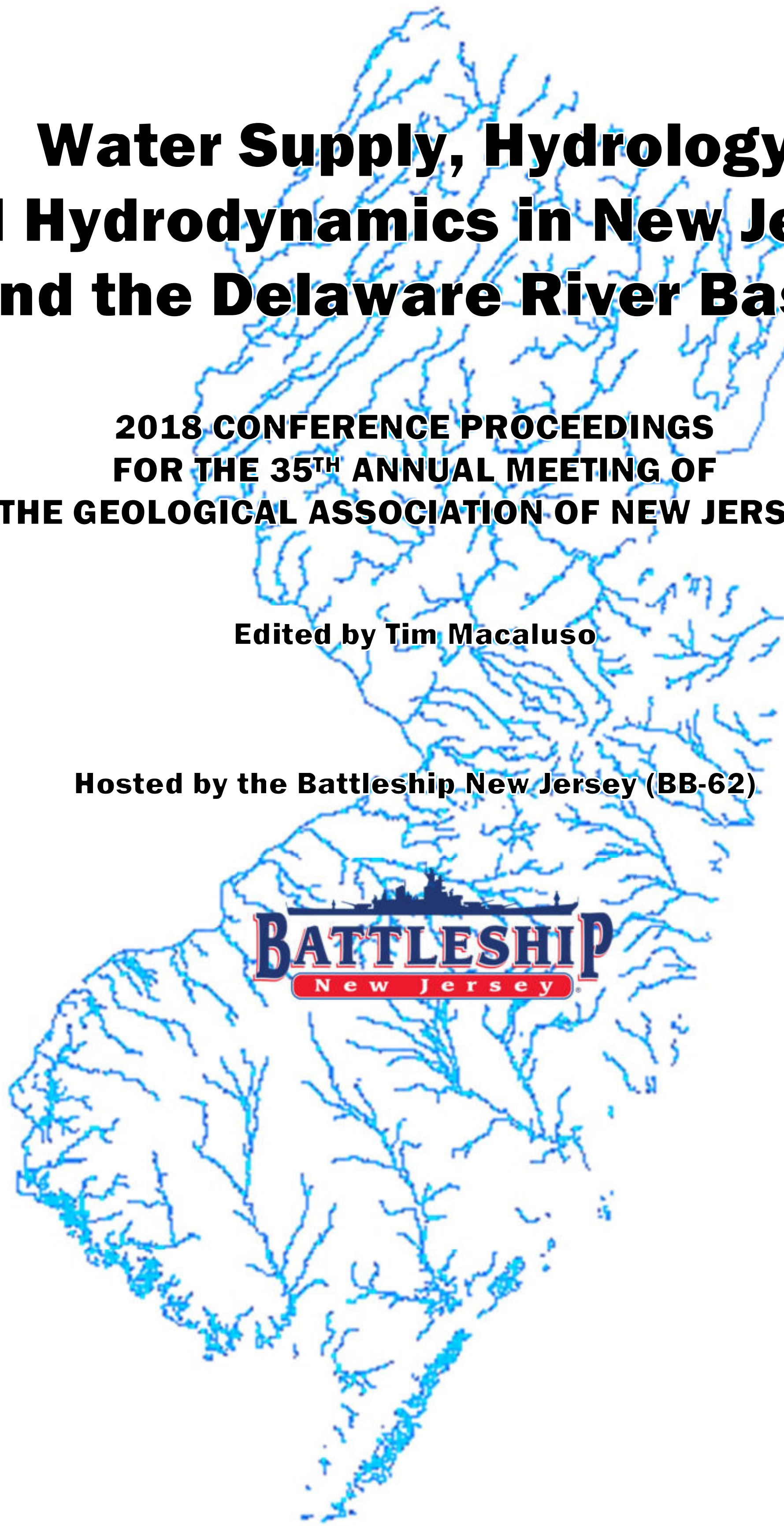
Water Supply, Hydrology and Hydrodynamics in New Jersey and the Delaware River Basin



2018 CONFERENCE PROCEEDINGS FOR THE 35TH ANNUAL MEETING OF THE GEOLOGICAL ASSOCIATION OF NEW JERSEY

Edited by Tim Macaluso

Hosted by the Battleship New Jersey (BB-62)

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CONFERENCE SCHEDULE

Friday, October 13, 2018 - Oral Presentations
Conference Room, The Battleship New Jersey

9:30	-	12:00	Tours of the Battleship New Jersey available
11:00	-	1:00	Registration
1:00	-	1:30	**An Environmental Biography of Coastal Plain Rivers** Claude Epstein, Professor Emeritus, Stockton University
1:30	-	2:00	**Deciphering Complex Deltaic Facies Using Integrated Sequence Stratigraphy, Magothy Formation (upper Turonian-Coniacian), New Jersey, USA** Peter Sugarman, New Jersey Geological & Water Survey
2:00	-	2:20	**Water Quality Improvements** John Yagecic, Delaware River Basin Commission
2:20	-	2:40	**Flow Management and Impact of Climate Change** Amy Shallcross, Delaware River Basin Commission
2:40	-	3:00	**Restoring Delaware Bay Oyster Reefs for Beach Resiliency** Tim Dillingham, Executive Director the American Littoral Society
3:00	-	3:30	Break/Business Meeting
3:30	-	3:50	**Water Supply in the Pine Barrens** Emma Witt, Stockton University
3:50	-	4:10	**Quaternary Geology Of The Lower Delaware Valley** Scott Stanford, NJ Geological & Water Survey
4:10	-	4:30	**Surface and Groundwater Management – A NJ Utility's Experience** Vincent Monaco, Engineering Manager at New Jersey American Water
4:30	-	4:40	Break
4:40	-	5:30	**Keynote: A Short History of Water Supply in New Jersey** Jeff Hoffman, New Jersey State Geologist
5:30	-	6:30	Cocktail Hour on the Deck of the Battleship New Jersey
6:30	-		Dinner at The Victor Pub

Saturday, October 14, 2018 - Field Trip
Freedom Elite Yacht, Penn's Landing, Philadelphia, PA

8:45	-	1:00	**Cruise of the Delaware River** Field Trip Leaders: Pierre Lacombe and Claude Epstein

TABLE OF CONTENTS

An Environmental Biography of Coastal Plain Rivers

Claude M. Epstein
Professor Emeritus, Stockton University, Stockton, NJ

Most of what follows is simple and perhaps self-evident. But what makes this work different is how all the geological and human land use elements come together to make a narrative-the biography of the coastal plain river landscapes. A good portion of this biography is its geologic history that created the overall landscape setting. These processes differentiated the landscape, rendering particular reaches useful for particular human activities. These activities make up the final portions of these landscapes history.

Chapter One: Antecedent Conditions: Development of the New Jersey Coastal Plain

Over 200 million years ago, Pangaea rifted into the western Laurasian plate and the eastern Gondwana plate. The rift grew northward, widened and deepened until it came in contact with the world ocean. It began to flood, and continued to widen and deepen, becoming the North Atlantic Ocean. Laurasia's eastern edge became the Atlantic's western shore. Early in rift history, rivers from the Laurasian interior emptied into the rift basin. When the climate was rainy, lakes and wetlands formed along with river floodplains. When climate was droughty it was replaced by salt flats and dunes. But once the Atlantic Ocean covered this area, the New Jersey Coastal Plain began to form. The terrestrial environments gave way to marine environments (Manspeizer, W., 1985).

When the Atlantic reached what would become New Jersey, probably in the early Cretaceous, the Atlantic Coastal Plain began to form deltas, estuaries, nearshore and shallow shelf environments. By late Cretaceous time into early Tertiary time the Atlantic grew wider and deeper, resulting in deep shelf environments in the developing New Jersey Coastal Plain. But sea levels began declining from middle Tertiary time and the New Jersey Coastal Plain became covered by shallow seas, then nearshore environments and, once again, an emergent coastal plain. This is portrayed in Table 1 (Newell, Wayne L. *& others*, 1998; Owens, J.P., & G.S. Gohn, 1985; Owens J. P. & N. F. Sohl, 1969; Owens, J.P., *& others*, 1998).

The resultant coastal plain strata decline in elevation toward the Atlantic Ocean. More recently, the development of the Delaware River Valley eroded the western portion of the coastal plain, exposing older updip strata (Figure 1) resulting in a western Inner Coastal Plain and an eastern Outer Coastal Plain.

Table 1. Coastal Plain Stratigraphy and Depositional Environments

Age (M.Y.)	River	Inner Delta	Outer Delta	Nearshore	Offshore	Geologic Units
<2				X		Cape May
7-2	X					Pensauken
13-7	X					Bridgeton
13-7	X					Beacon Hill
22-13				X		Cohansey
24-14		X		X	X	Kirkwood
33-25					X	Piney Point
65-35					X	Hornerstown-Shark River
72-66				X	X	Navesink-Tinton
78-70			X	X		Marshalltown-Mt Laurel
84-80		X	X	X		Merchantville-Englishtown
90-84		X	X			Magothy
95-94		X		X		Raritan
100-138	X	X				Potomac Group

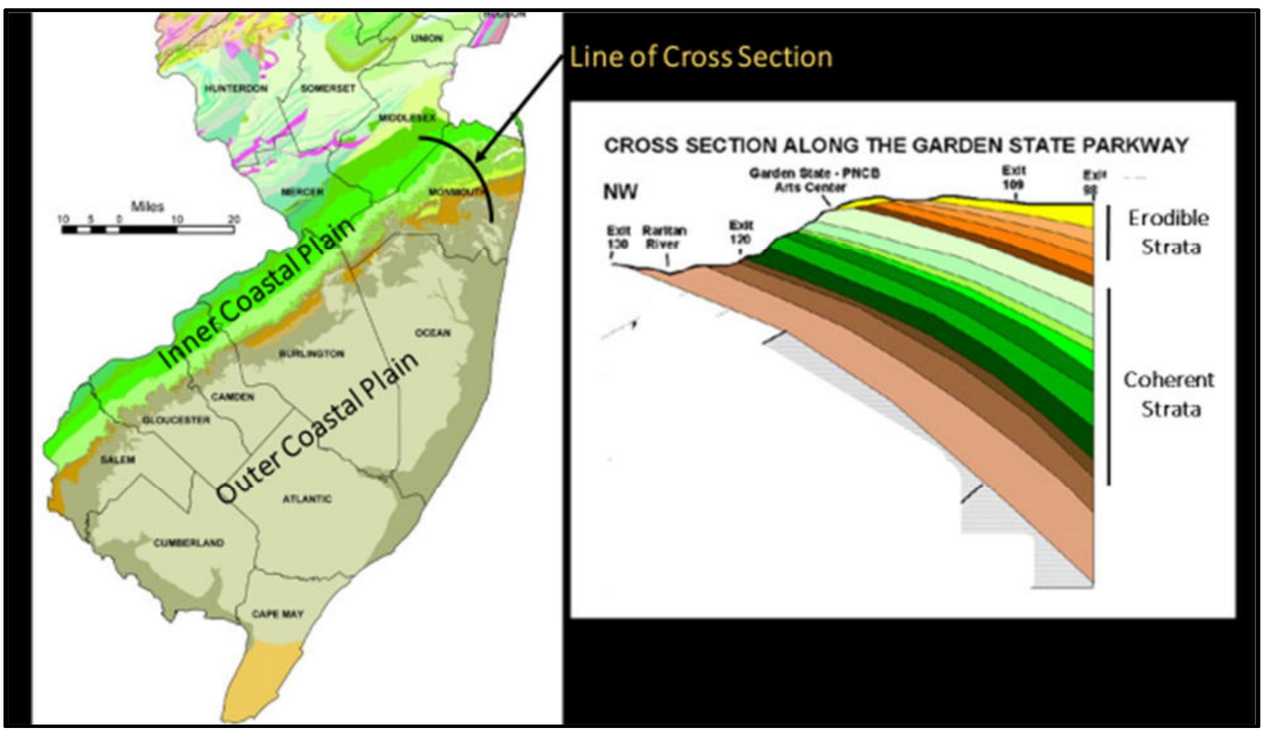


Figure 1. New Jersey Coastal Plain Stratigraphy
(Modified from NJDEP, Division of Water Supply & Geoscience (left); P.T. Lyttle & J.B. Epstein, 1987 (right))

Chapter Two: Geomorphic Valley Forming Processes in the New Jersey Coastal Plain

Streams from both parts of the Coastal Plain share one landscape process in common. They share the stream gradient trends common to most streams, that is, from source to mouth, gradients flatten, water volume increases, floodplain width increases, sinuosity increases, and sediment transport changes from primarily erosional to depositional. A consequence of this is that a stream can be divided into three reaches (i.e., upper, middle, and lower) where overall characteristics are similar for a particular reach.

Stream-related processes created most of South Jersey's topography (Salisbury, R.D., 1898, p.54). The processes that made these valleys, and their surrounding watersheds for that matter, resulted from the combination of stream erosion and groundwater seepage (Stanford, S.D., *& others*, 2002). South Jersey groundwater, flowing from higher to lower elevations, emerges at the surface as seeps or springs near the base of the valley's slopes. Where this occurs, the slope is weakened by a combination of factors. First, some of the finer particles are removed and transported to the surface by seepage, weakening sediment coherence. Second, streams formed below these seeps, undercut and steepen slopes. The steeper the slope, the more likely it is to slump. Third, the seepage zone, is lubricated and made heavier by the presence of groundwater. This too makes slopes more likely to slump. Over time, streams continue to erode deeper beneath their floodplains while also eroding backward into their uplands. As streams lengthen, they capture more seepage, thereby inducing more slump. Moreover, sea levels decline stimulates stream erosion deeper into floodplains and further into uplands. Large upland areas are thus dissected as streams extend over time (Stanford *& others*, 2002).

Watershed Growth and Stream Capture

Surface runoff and groundwater discharge provide the water for South Jersey streams. These, in turn, carve watersheds. Since the coast, much of the Delaware River below Trenton, and Raritan Bay are at or close to sea level, streams flow from the South Jersey interior uplands to the lower elevations of the Delaware, Raritan and Atlantic Ocean in a radial pattern. Neighboring streams create intervening divide. In addition, streams compete with one another for territory.

Table 2. South Jersey Watershed Areas (mi^2) (NJDEP, 1972)

Watershed	Area	Watershed	Area	Watershed	Area
Mullica River	569.6	Alloways Creek	62.1	Shark River	23.0
Maurice River	386.4	Big Timber Creek	59.3	Woodbury Creek	20.0
Rancocas Creek	341.4	Cedar Creek	55.8	Pompeston Creek	19.3
Great Egg Harbor R.	337.7	Matawan River	52.4	Kettle Creek	18.0
Toms River	191.2	Mantua Creek	51.2	Whale Pond Brook	17.3
Forked River	142.3	Assiscunk Creek	45.3	Wreck Pond	14.2
Crosswicks Creek	139.2	Raccoon Creek	44.4	Newton Creek	13.2
South River	132.8	Oldmans Creek	44.4	Miles Creek	12.6
Dennis Creek	130.8	Coopers Creek	40.5	Mill Creek	9.3
Salem Creek	113.6	Pennsauken Cr.	35.4	Whooping John Cr.	9.3
Dividing Creek	106.8	Repaupo Creek	34.8	Doughty Creek	9.0
Cohansey Creek	105.4	Patcong Creek	29.1	Mill Creek	8.6
Tuckahoe Creek	102.0	Jones Creek	28.8	Baldwin Run	6.8
Navesink River	95.0	Shrewsbury R.	27.4	Sloop Creek	6.1
Manasquan River	80.5	Crafts Creek	26.5	Maple Swamp	4.0
Metedeconk River	73.9	Absecon Creek	26.4		
Stow Creek	68.8	Blacks Creek	24.1		

This competition is marked by an increase in area in some watersheds at the expense of others. This occurs because one of the streams has either faster moving water, a steeper surface gradient, more easily eroded material, or has existed for a longer time. Table 2 lists the area for each South Jersey watershed. The watersheds of the Inner Coastal Plain, with the exception of Rancocas Creek, are small. The Outer Coastal Plain has most of the largest watersheds.

Modern Watershed Development

The development of today's watersheds came about during the last series of geologic events (Stanford, S.D., 2003, pp.21-49) (Figure 2). When sea level declined during the deposition of the Bridgeton and Pensauken Formations, between 2 and 9 million years ago, part of the Coastal Plain, approximately between Monmouth and Burlington County, became an upland area. The Atlantic Ocean lay to the east. But the ancestral Pensauken River, flowing out of New England along what is now Long Island Sound, then across the northern edge of the Coastal Plain (the Amboy-Trenton trough), then down the Delaware Valley, cut a broad floodplain west and south of this upland. Initially, the broad river channel that created the Bridgeton Formation flowed south of the aforementioned upland 7 to 9 million years ago. The antecedents of today's streams began to develop on the upland itself. Some flowed to the Atlantic Ocean while others flowed as tributaries to the Pensauken River. The deposition of the Pensauken Formation, 2 to 4 million years ago, extended the earlier upland to the west and south. Now the upland covered most of South Jersey. But then the Pensauken River was re-routed. The connection between the part that flowed through Long Island Sound and that which flowed through the Delaware Valley was severed. The Delaware River below Trenton took its present course. Now streams began to drain the more southerly parts of South Jersey. Several modern streams began draining this upland. These include the Millstone, Rancocas, Cohansey, Maurice, Great Egg Harbor, Mullica, Toms, Metedeconk, Manasquan, Shark and Navesink Rivers (Stanford, S.D., 2003, p.26). The lower reaches of many of these streams were then flooded when sea level rose approximately 125,000 years ago when the Cape May Formation was deposited. One consequence of this flooding was the widening of the lower reach floodplains. Sea level declined once more, stimulating stream expansion, valley widening and headward extension and valley slope retreat. Today's watersheds were the result (Figure 3).

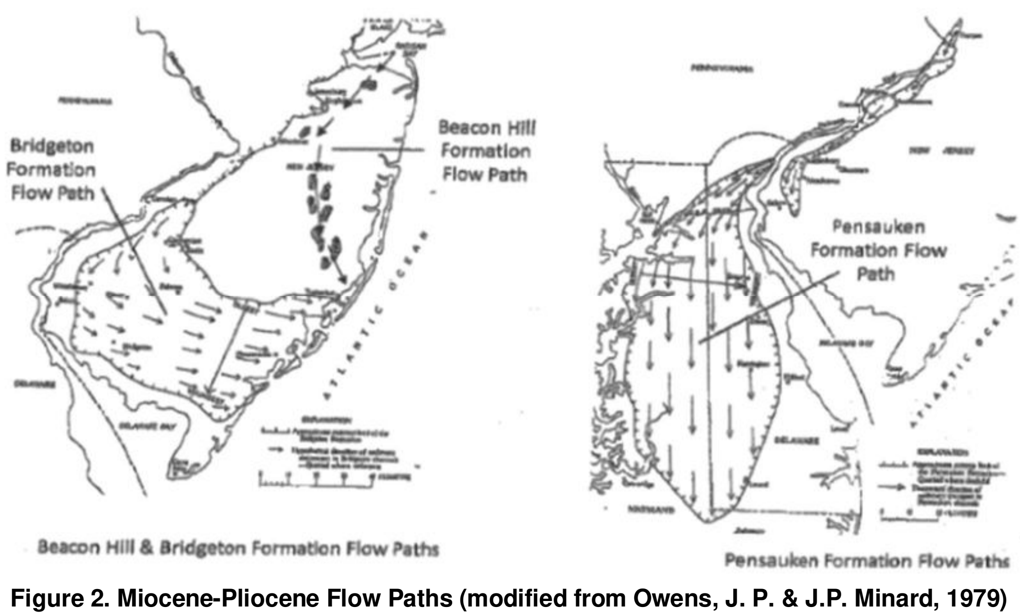


Figure 2. Miocene-Pliocene Flow Paths (modified from Owens, J. P. & J.P. Minard, 1979)

Figure 3. Streams of the New Jersey Coastal Plain

Chapter Three: Inner and Outer Coastal Plain River Valleys and Channels

Streams cutting through different textured sediment result in different valley morphologies. Inner Coastal Plain streams cut through more internally cohesive fine textured sediment. These streams are more prone to flash flooding which has a dramatic impact of these streams morphology. Over time, the stream channel cuts further below the surrounding valley bluffs that at first resist slumping. But when they do slump, the sediment falls away from the bluffs in massive quantities. As a consequence, the bluffs develop steep slopes flanking the channel and floodplain below. Groundwater discharge within these bluffs also induces slumping but only after the internal cohesiveness of the sediment is overcome by gravity. Outer Coastal Plain streams cut through less cohesive coarse textured sediment. The water table is close to the surface keeping these sediments lubricated, adding to the sediments weight, and lessening its cohesiveness. As the stream cuts through the sediment, slumping occurs almost as the bluff develops. The resultant bluffs are relatively flat, declining gradually toward the stream channel and floodplain. Flooding is more often the result of water table rising to and above the surface, a condition that lasts far longer than flash flooding. This also saturates the flood plains.

Coastal Plain streams are more confined within their valley than those of the Outer Coastal Plain. Their channels tend to be narrower and deeper than those of the Outer Coastal Plain. This difference is characterized by the channel's cross section (Table 3) and width to depth ratio (Table 4). Inner Coastal

Plain streams have smaller width to depth ratios than Outer Coastal Plain streams. But cross channel morphology also effects stream velocity gradients. These are depicted in Figure 4.

Table 3. General Geomorphic Properties of Inner and Outer Coastal Plain Streams

Property	Inner Coastal Plain	Outer Coastal Plain
Stream Flow	Less	More
Watershed Area	Smaller	Larger
Number of Tributaries	Fewer	More
Drainage	Fast	Sluggish
Valley Cross Section	Deep & Narrow	Shallow & Wide
Bank Steepness	Steep	Very Gradual
Stream Gradients	Steep	Flat
Channel Sinuosity	Sinuous	Straight
Water Turbidity	Muddy	Clear

a. Inner Coastal Plain Stream Valley: Tributary of Racoon Creek near Mullica Hill

b. Outer Coastal Plain Stream Valley: Tributary of Toms River near Colliers Mill WMA

Figure 4. Inner and Outer Coastal Plain Stream Valleys

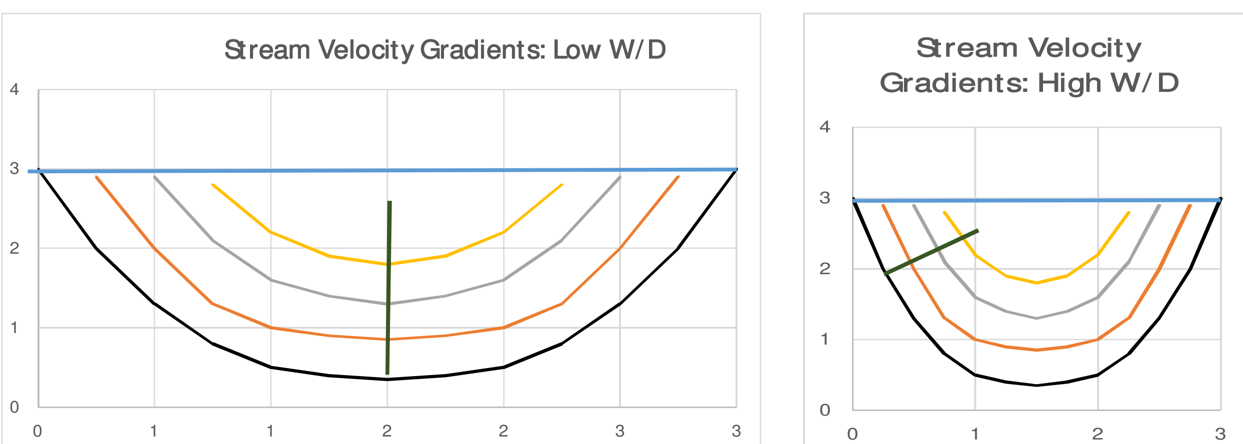


Figure 5. Outer (left) and Inner (right) Coastal Plain Channel Velocity Gradients
[Width (X-Axis) and Depth (Y-Axis) dimensionless; dark green line is maximum stream gradient]

Table 4. Stream Width/Depth Ratio & Bluff Height by Reach

Stream	Coastal Plain	W/D	Lower	Middle	Upper
Crosswicks	Inner	24.1	High		
Rancocas (N)	Outer	60.4	Low	Low	
Rancocas (S)	Inner	132.0	Moderate	Low	
Rancocas (SW)	Inner	123.6	Moderate	Low	Moderate
Pennsauken	Inner	35.0	Moderate	Low	
Cooper	Inner	27.4	Low	Moderate	
Big Timber	Inner	16.7	High/Mod.		Low
Mantua	Inner	19.0	Low	Moderate	
Raccoon	Inner	7.3	Low	Moderate	
Oldmans	Inner	16.5	Low	Moderate	Low
Salem	Inner	18.2	Near Flat	High/Mod.	
Cohansey	Inner	48.4	Near Flat	Moderate	Mod./Low
Navesink	Inner		High/Mod.	Mod./Low	
Shark	Inner	19.9	High/Mod.		
Manasquan	Inner	31.8	High	Moderate	
Metedeconk	Outer	36.8	Moderate	Low	
Maurice	Outer	84.0	Near Flat	Moderate	
Tuckahoe	Outer	113.0	Low		
GEHR	Outer	325.7	Moderate	Low	
Mullica	Outer	176.0	Low		
Batsto	Outer	213.0	Low		
Wading	Outer	160.5	Low	Mod./Low	Low
Oswego	Outer	138.1	Low	Moderate	Low
Mill	Outer	160.0	Low	Moderate	
Forked (N)	Outer	55.0	Low	High	High
Cedar	Outer	122.4	High	Low	
Toms	Outer	62.2	Moderate	Mod./Low	Low

Water velocity decreases from near the channel's surface to its bed. But the velocity decreases faster toward the channel's sides in Inner Coastal Plain streams and toward the channel bottom for Outer Coastal Plain streams. Consequently, the channel banks are more susceptible to erosion in Inner Coastal Plain streams while the channel bottom is more susceptible to erosion in Outer Coastal Plain streams (Figures 5a, 5b).

A further difference in the characteristics of Coastal Plain streams is the difference in turbidity. The finer textured sediment transported by Inner Coastal Plain streams renders the water more turbid, taking on a muddy appearance (see Manasquan River and Crosswicks Creek in Figure 7). The turbidity of Outer Coastal Plain streams is quite distinct. The water is generally clear but often tea-colored due to its suspended colloidal load.

Chapter Four:
Flooding in the New Jersey Coastal Plain

Texture also has a significant impact on the nature of flooding. Inner and Outer Coastal Plain streams react differently to storm events. Inner Coastal Plain streams are referred to as "flashy". They rise rapidly, often before the storm ends, and drain almost as quickly. But there is a lag, often of days, between the storm event and the onset of stage rise in Outer Coastal Plain streams. The stage rise is generally slight. Then it takes a long time for the stream to subside to its pre-storm level. Inner Coastal Plain streams are "flashy" because they are fed largely by storm water surface runoff caused by this regions naturally fine textured soils and the impervious surfaces of residential and commercial development. Moreover, municipal sewers carrying storm water runoff bring larger quantities of water very rapidly, discharging it into the nearest stream.

Case History

Hurricane Irene moved up the Atlantic seaboard and made landfall at Little Egg Inlet, N.J., on August 27th 2011 at 5:35 a.m. EDT (Table 5). Rainfall commenced and continued until Sunday, August 28th. Total rainfall from Hurricane Irene in South Jersey varied from 7 to 9 inches (NOAA National Hurricane Center, 2011).

Table 5. Total Rainfall from Hurricane Irene

Station	Total Rainfall (Inches)
Estell Manor	8.57
Windsor	8.40
Heislerville	8.50
Windsor	8.40
Somerdale	8.60
Woodstown	6.98

The Manasquan River gaging station at Squankum and the Great Egg Harbor River at Folsom represent examples of relatively un-urbanized watersheds. The Manasquan River is located on the Inner Coastal Plain while the Great Egg Harbor River is located on the Outer Coastal Plain. The Manasquan River gets most of its storm water discharge from surface runoff while the Great Egg Harbor River gets most of its storm flow from enhanced groundwater discharge. Figures 6a and 6b depict each stream's change in water level during and after Hurricane Irene. The Manasquan River rose approximately 10 feet about 24 hours before the Great Egg Harbor River reached its more subdued peak of approximately 4 feet. The Manasquan River shows an intense, rapid "flashy" response while that of the Great Egg Harbor River is "non-flashy".

Figure 6a. Manasquan River at Squankum

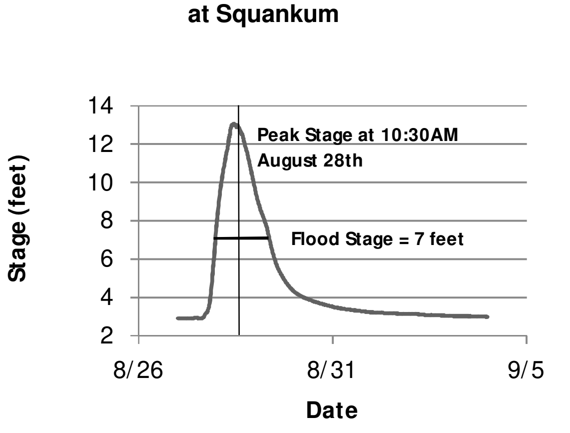
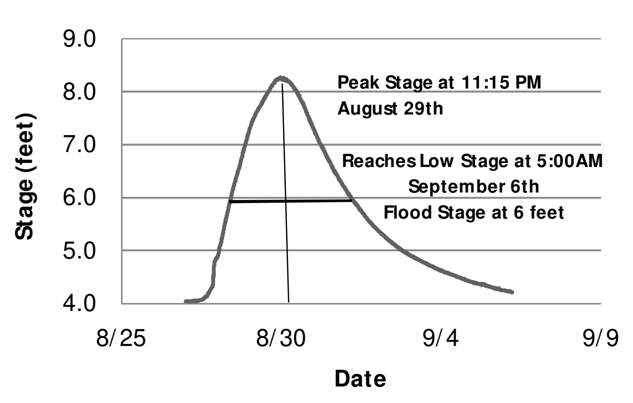


Figure 6b. Great Egg Harbor River at Folsom



Longer Term Flood Flow Distinctions

The hydrologic properties of Coastal Plain streams, monitored by the U.S. Geological Survey, were analyzed from their "continuous" flow record from 2008 through 2011 (U.S. Geological Survey C, Reviewed from 2008 to 2011). The rainfall from four U.S. Geological Survey rain gauges on the Coastal Plain was recorded for 353 storms that occurred during this interval. Twenty-four gaging stations were analyzed for corresponding storm flow peaks. These stations were partitioned into four groups. The first represents the most urban or "developed" streams. The second represents streams from the Inner Coastal Plain. The third represents streams from the Outer Coastal Plain. The last includes streams that flow through some of the Inner, but mainly flow through the Outer Coastal Plain. Four properties were analyzed, and then averaged for each station. These properties include (1.) Height of the stage rise (i.e., water level rise) from the onset of the rise to its peak stage, (2.) Time taken to reach peak stage, (3.) Duration of peak stage, and (4.) Lag time between the peak of rainfall and peak flow.

The values depicted in the Table 6 reveal fairly clear distinctions. Urban streams react fastest to a storm event. The time lag between rainfall peak and peak flow is the shortest and the duration of its stage rise and its peak flow is the briefest. The most urbanized watershed, the South Branch of Pennsauken Creek, has the highest stage rise. There is also a clear distinction between the Inner and Outer Coastal Plain streams. The Outer Coastal Plain steams show the least stage rise, the longest stage rise and peak flow durations and the longest lag times. Those of the Inner Coastal Plain show much higher stage rises, far shorter durations in stage rise and peak flow, and shorter lag times.

Each year streams' water levels, or stages, rise numerous times. Most of the time rain storms are the cause of this rise. A few streams have reservoirs used for water supply and cranberry agriculture. The size of a stream's channel (i.e., its depth and width) determines the volume of water it can hold prior to reaching flood stage. Once flood stage is exceeded, the stream begins to flood the surrounding area. The magnitude of floods exceeding flood stage is assessed through probability statistics. These magnitudes are referred to as the 2-year flood, the 5-year flood, 10- year flood, etc. These probability values are calculated from the largest flood each year for the last thirty years. Thus predicting the next years flood is based on the stream history of the last thirty years. As one year leads to the next, these statistics ought to be recalculated, dropping the oldest year and adding the newest one.

Table 6. Analysis of Peak Stream Stages

Type	Gaging Station Location	Stage Rise (ft)	Rise Duration (hrs)	Peak Duration (min)	Average Lag (hrs)
Urban	S Br. Pennsauken Cr.	1.79	11.95	43	5.92
	Cooper R.	0.42	10.07	108	6.44
	Mantua Cr.	0.28	12.03	176	8.82
Inner Coastal Plain	Crosswicks Cr	1.38	22.96	126	19.44
	Cohansey R.	0.47	15.23	151	10.88
	Raccoon Cr.	1.06	15.69	87	9.75
	Manasquan R.	0.76	11.53	81	13.31
	Salem R.	0.27	16.10	311	12.63

Type	Gaging Station Location	Stage Rise (ft)	Rise Duration (hrs)	Peak Duration (min)	Average Lag (hrs)
Outer	Greenwood Br.	0.23	36.48	716	35.97
Coastal	Westecunk Cr	0.22	19.82	392	21.94
Plain	Mullica R.	0.37	29.02	485	30.35
	Tuckahoe	0.22	20.68	558	20.88
	Great Egg Harbor R.	0.33	53.92	874	50.93
	East Branch Bass R.	0.28	20.78	543	18.81
	McDonalds Br	0.09	8.73	521	10.34
	Cedar Cr.	0.33	13.93	285	17.11
	Maurice R.	0.15	28.63	830	23.70
	N,Br. Rancocas Cr.	0.16	26.18	735	26.24
	Toms R.	0.61	31.91	326	37.67
	Oswego R.	0.20	22.95	584	25.63
	W.Br Wading R.	0.51	21.18	262	29.34
Mixed	SW.Br.Rancocas Cr.	1.09	18.60	101	14.12
	S.Br. Rancocas Cr.	0.93	26.61	191	22.07
	N.Br. Metedeconk R.	1 .15	19.56	95	17.71

Chapter 5. Anthropomorphic Changes in South Jersey Rivers

As mentioned before, stream gradients are a good place to start characterizing streams and their uses. The steepest gradients are near the stream's source while the flattest gradients are near the stream's mouth. As stream gradients flatten, stream discharge increases, while its channel gets wider, deeper, and more sinuous. In addition, floodplains get wider and more poorly drained, while its vegetation changes. Streams are divided into upper, middle, and lower reaches. These three reaches are depicted in Figure 7.

The lower reaches were the most accessible to early settlers. Seventeenth century Dutch tended to settle along the bay's shores, engaging in trade, while the Swedes and Finns settled near the lower reaches of the rivers, setting up farms. This tendency was described by William Penn in 1683 once the Quakers arrived in the Delaware Valley (P.S. Craig & K. Williams 2006, Vol. 1, p.76).

Future conflict, though not recognized as such then, involved the uses of rivers for commerce and for gathering natural resources. The earliest Europeans to assess these resources described how navigable the Delaware River and its tributaries were and how suitable they were for carrying on commerce (P. Lindström, 1654, p.156; A. van der Donck, 1655, p.10). At the same time they, along with the Englishman Robert Evelin in 1648 (G. D. Scull, 1881, p.97), listed the fish and water fowl resources of the Delaware Valley (P. Lindstrom, 1654, p.187; G.D. Scull, 1881, p.97; A. van der Donck, 1655, pp.42-60).

Figure 7. Upper, Middle, & Lower Reaches of Outer & Inner Coastal Plain Streams

LOWER REACHES

Reclamation of Wetlands

The lower reaches of streams were the easiest to get to and on which to settle. The earliest Delaware Valley towns now Wilmington, New Castle, Burlington and Salem were all established near or on the shores of the Delaware River or its larger tributaries. The marshlands on both sides of Delaware Bay must have felt familiar to the Dutch. They were like the marshlands of the Netherlands that they had been reclaiming and converting to farmlands for centuries. The English, somewhat later, undertook some serious marshland reclamation with the same goal in mind.

Two major human activities altered the lower reaches natural condition. Floodplains were converted to agricultural land and pastures while channels were modified to facilitate commerce and travel. By the middle of the eighteenth century, wetlands in the interior, but especially along Delaware Bay, were extensively diked, ditched, and drained to render them "useful" to settlers. In 1759 Israel Acrelius, Provost of the Swedish Churches in America, wrote an extensive description of them in New Sweden. He reported that many of the swamps along the Delaware had been surrounded by 5 to 10 foot high banks in order to prevent flooding from the Delaware. These same wetlands were also extensively ditched to drain surplus water out into streams outside these banks by means of floodgates (Figure 8-4d). Once drained, they were plowed and seeded with clover or English hay (I. Acrelius, 1759, p.154). By the late nineteenth century, about half the acreage of Salem County marshland had been drained (C. C. Vermeule, 1894, p.261). In addition, bits of reclaimed land, both meadows and cultivated, had been mapped by C. C. Vermeule in the first New Jersey state survey, published between 1880 and 1883. Later, another reason these marshlands were ditched and drained was to control mosquito populations and limit infectious diseases.

Dikes, also referred to as levees, still exist along the Delaware River and Delaware Bay (U.S. Department of Agriculture, Natural Resources Conservation Service, July, 2010). Many of these were used to reclaim wetlands for agriculture. The levees of these reclaimed wetland farms occur along streams from Birch and Repaupo Creeks in Gloucester County through Alloways Creek in Salem County. In addition, many levees exist in the rivers and meadows that drain into Delaware Bay, including Stow Creek, the Cohansey and Maurice Rivers down to the small streams along Cape May County's Delaware Bay shoreline (Tables 7-9).

Table 7. Number and Total Length of Existing Levees

County	No.	Length (ft)
Cape May	6	89,627
Cumberland	28	143,612
Gloucester	3	31,100
Salem	30	23,805

Landings and Harbors

Landings mark the connection between the transport of people and goods from streams to overland regions. The creation of landings initiated a whole series of channel adjustments from their natural condition. Banks were cleared of vegetation, steepened and bulkheads built to secure these steepened banks. Many structures were built as these landings developed, including quays, wharfs, piers, and warehouses, not to mention nearby public houses and residences. A landing, with the passage of time, might build wharves, docks, or piers. Ferries were established with the increased need for transportation across large rivers. Later these places could become harbors or even ports. The lower reaches of these streams, being the most navigable to sailing craft, are where most landings were established (Figure 8).

Table 8 presents a list of landings from 23 different information sources. This list is probably not complete since many landings were probably not named or did not have their name recorded in some written source. Another group of sites may have been incorporated into larger municipalities, thereby losing their identity. But what this table suggests is that landings spread all over South Jersey. The date of the founding of these localities is difficult to determine, but most localities were founded, starting in the late 16^{th} century, expanded throughout the 18^{th} century and early 19^{th} century. The number of new landings decreased during the late 19^{th} and 20^{th} centuries while many of the earlier ones developed into harbors, ports, towns and cities.

Figure 8. Alterations of the Lower Reaches

Channel Excavation

Once Europeans established landings, they reconfigured their channels. They were deepened, widened, and straightened in order for lumber and other natural resources to be more easily rafted downstream to market as well as for the transportation of people, livestock, grain, and finished goods on sloops and schooners. Channels were straightened by excavations, through what are called cutoffs, across natural bends of the stream (called meanders). Now vessels could move in a more or less straight line to and from the landings without navigating around circuitous meanders. Canals were also excavated to allow navigation where no natural channel existed. Table 9 lists the canals, cutoffs, and places where canals were straightened for each watershed as depicted in the earliest aerial photographs taken by the U.S.D.A. Soil Conservation Service in the 1930's.

Most of the major canals were constructed in northern New Jersey. But many smaller canals were built in South Jersey. A canal from the Manasquan River to Barnegat Bay was authorized in 1833 (T.F. Gordon, 1834) while another was constructed at Penn's Neck shortly after 1868 (Salem County Historical Society, 1964, p.42), which considerably shortened the trip from Salem to Philadelphia (Cushing, T. & C.E. Sheppard, 1883, p.333). All currently existing canals, whether active or abandoned, are listed by the New Jersey Geological Survey canal and water raceway coverage for the Geographical Information System (GIS) compiled for the New Jersey Department of Environmental Protection. They were constructed to facilitate the passage of sailing craft and barges, avoiding a streams' natural sinuosity and to bring water from one stream to another to facilitate irrigation or augment a mill's power.

Table 8. Number of Landings and related Structures in South Jersey

Watershed	Landings	Wharf	Dock	Ferry	Port	Watershed	Landings	Wharf	Dock	Ferry	Port
Rancocas Creek	3	5		2	2						
Pennsauken Cr.	1					Gr. Egg Harbor R.	11				
Cooper River	7			1		Atlantic Ocean					1
Big Timber Creek	11			1		Great Bay	2				
Mantua Creek	5	1			1	Jenkins Sound	2				
Oldmans Creek	2					Absecon Bay	1				
Raccoon Creek	1					Absecon Creek	2	1			
Salem River	15	1				Nacote Creek					1
Alloways Creek	5					Mullica River	18				1
Delaware River	7	1	1	8	1	Wading River	7	2			
Stow Creek	4					Bass River	1				
Cohansey River	14	2				Tuckerton Creek	1				
Nantuxent Creek	2					Little Egg Harbor	3				
Cedar Cr.(Cum)	1					Mill Creek	1				
Maurice River	14	4	1	7	2	Forked River	3				
West Creek	1					Cedar Creek (Oc)	1				
Dennis Creek		1				Barnegat Bay	2				2
Goshen Creek	1					Toms River	4			1	
Delaware Bay	11	2		2		Metedeconk R.	2				
Jenkins Sound	2					Manasquan River	2				
Taylor Sound	1					Shrewsbury River					2
Tuckahoe River	1			1		Raritan Bay	2		6		1

MIDDLE REACHES

Rivers above their navigable reaches were recognized early in the seventeenth century as good places for the construction of water-powered mills (Lindström, P., 1654; van der Donck, A., 1655; Budd, T., 1698). The Swedes built the first mills in the Delaware Valley; a wind mill at Fort Christina, now Wilmington, in 1642 (Johnson, A., 1911, p.203) and a water-driven mill on Cobb's Creek, in what is now Philadelphia, in 1646 (Johnson, A., 1911. p.328). An application for a second water-powered mill was authorized by Dutch authorities at Turtle Creek near what is now Wilmington (Johnson, A., 1911, p.666). But the first water powered mills built in South Jersey came with the Quakers. In 1679, Mahlon Stacy built one on the Assunpink Creek, in what is now Trenton, while Thomas Olive built another on Mill Creek, a tributary of Rancocas Creek (DeCou, G., 1949, p.16). With continued settlement, operating mills on South Jersey streams was considered more reliable than many of those in eastern Pennsylvania because South Jersey streams could supply water power throughout the year while many of those in eastern Pennsylvania could not supply enough water power when water levels dropped or the creeks dried up all together during the late summer and fall.

Table 9. Number of Canals, Cutoffs, and Straightened Channels (Taken from U.S.D.A. Soil Conservation Service Aerial Photographs, 1930)

Watershed	canals	cutoffs	straightened channels	Watershed	canals	cutoffs	straightened channels
Alloways Creek	2	2		Newport Creek			
Assiscunk Creek	1			Newton Creek	1	3	
Big Timber Creek	2	2	2	Oldmans Creek		1	
Cohansey River		1		Oswego River	3	4	5
Cooper River	2	2		Pennsauken Cr.		5	
Crosswicks Creek		3		Pompeston Creek	1		
Dividing Creek				Raccoon Creek	1		
Forked River	2	1		Rancocas Creek		6	
Gr.Egg Harbor R.	1	4	2	Repaupo Creek		1	
Kettle Creek		2		Salem River	1		
Little Timber Cr.		2		Stow Creek		3	
Manasquan River	1			Toms River		3	
Mannington Creek				Tuckahoe River			
Mantua Creek	2	3		West Br. Wading	2	7	1
Metedeconk Cr.	2			Woodbury Creek		1	2
Mullica River	1	4					

The European settlers were the recipients of a long history building and using mills. Mills were used for a wide variety of tasks in Europe. Whatever needed to be ground, cut, compressed, stretched or needed a blast of air could easily be accomplished by a mill. Solids could be ground to fine powders, as in the case the case of grain, pepper, hemp, poppy seeds, malt and hops for beer, mustard seeds, cane sugar, mortar, lime and pigments. Fruits could be squeezed to yield olive oil, apple cider, and wine. Solids could also be compressed to make paper and sheet iron. Raw materials could be pounded, with the use of the cam, to pulverize ore, shape iron, make cloth from plant and animal matter, crush stone, and soften hides. They could cut lumber, pig iron and slabs of stone. They could raise furnace temperatures high enough to convert ore to metal, sand and lime to glass, or clay to bricks. They could bore into and polish metals and gems, and they could turn and trim wood and metal to make anything from cannons to table legs. They could also power cranks to stretch metal into wire (Reynolds, T.S., 1983, pp.136-149).

Mills became more productive through time. Power increased during the first five centuries of the Common Era. At first, they could produce between 1 and 5 horsepower (Reynolds, T.S., 1983, p.41). By the thirteenth and fourteenth centuries, they could produce as much as 60 horsepower (Reynolds, T.S., 1983, p.174). As far as eighteenth century South Jersey is concerned, mills could produce well over 100 horsepower (Swain, G.F., 1880, pp.122-124).

The construction of mills improved over time as well. The water wheel went through a series of improvements. The vertical water wheel, being more efficient, gradually replaced the horizontal wheel, except in smaller mountain streams, during the Middle Ages (Holt, R., 1988, p.119). Later, a perfected turbine, invented in 1832 came into use, replacing some of the vertical water wheels in the nineteenth century (Usher, A P., 1929, pp.382-391). In addition, dams, millponds, sluice gates and raceways were constructed to increase and control water flow by adjusting the water level of the dam throughout the year

Table 10. Water Mills of South Jersey

Watershed	Total	Unspecified	Grain Mills	Sawmills	Wood Works	Furnace/ Forge	Iron Works	Textiles	Paper	Manufactures	Food Industry	Infrastructure	Abandoned
Rancocas Creek	115	10	40	34		15	6		1	3	3	2	1
Mullica River	82	3	18	38		9		1	4	2	4	2	1
Big Timber Creek	69	2	20	24	4	1	3	1		1	1	11	1
Maurice River	68	5	22	30		4			1	3	3		
Great Egg Harbor R.	49	4	17	19	2	1		2	1		1	2	
Toms River	32	18	7	4							1	2	
Crosswicks Creek	32	3	19	10									
Cooper River	29	1	14	12	1							1	
Tuckahoe River	20	4	8	2		6							
Cohansey River	20	4	7	5			1	1		1			
Newton Creek	16		6	7			1			1			1
Metedeconk River	15	5	5	5									
Alloways Creek	12	8	3			1							
Cape May County	12		5	7									
Ocean County Coast	11		1	6					1	3			
Mantua Creek	11		9	2									
Blacks Creek	10	2	6	1		1							
Navesink River	10		7	3									
Dividing Creek	10		5	4							1		
Pennsauken Creek	9		7	1								1	
Stow Creek	9	1	5	3									
Absecon Creek	8		3	4					1				
Manasquan River	8		5	3									
West Creek	8		3	4					1				
Salem Creek	8		6	2									
Cedar Creek (Ocean)	6	3	1	2									
Oldmans Creek	6		4	2									
Kettle Creek	5	3		2									
Swedes Run	5	1	3	1									
Raccoon Creek	4	1	2	1									
Shark River	4		3	1									
Tuckerton Creek	3		1	1			1						
Westecunk Creek	3	3											
Delaware River	3	2		1									
Repaupo Creek	3		1	1						1			
Waycake Creek	3		2	1									
Wreck Pond	3		1	2									
Cedar Creek (Cumb)	3		2	1									
Dennis Creek	3	2		1									
Forked River	2	2											
Assiscunk Creek	2	1	1										
Shrewsbury River	2	2											
Whale Pond	2		1	1									
Cedar Run	2	2											
Doughty's Creek	1		1										
Oyster Creek	1	1											
Waretown Creek	1	1											
Assunpink Creek	1	1											
Crafts Creek	1		1										
East Creek	1	1											
Flat Creek	1		1										
Nantuxent Creek	1			1									
Pompeston Creek	1									1			
Total	746	96	273	249	7	38	12	5	10	16	14	22	4

thereby maintaining continual operation. Water-driven mills were the primary source for manufacture up to the nineteenth century. But they were replaced in the nineteenth century by steam boilers whose energy source was the combustion of wood, charcoal, coal, and later petroleum. Boilers as the agent of manufacture were later replaced by electrical motors and internal combustion engines. These innovations freed the mills from being built next to streams.

The Mills of South Jersey

It is difficult to determine the exact number, location, use, and construction of all the mills of South Jersey. Written records vary in accuracy and were created for different purposes. But coming up with a definitive list is not the purpose here. Twenty-two different sources were used to compile a list of almost 1300 mills built between the arrival of the Quakers after 1675 and the end of the nineteenth century. These written sources include local histories, county books of place names, state reports, maps, and books specifically about mills. The name, location, stream, watershed, county, earliest known date, and mill type were compiled but the sources vary in their completeness. In addition, some of these localities may have changed name over time but this redundancy has been kept to a minimum. Table 10 is based on an edited data base to determine the distribution and use of these mills throughout South Jersey from the 1670's to the end of the nineteenth century. Ambiguous or incomplete localities were eliminated. The types of mills have been aggregated for simplicity. Grain mills include grist, flouring, and corn mills. Wood works, being byproducts of sawmills, include lumber mills, charcoal & tar kilns as well as cedar stands.

Iron works, being byproducts of iron furnaces, include forges, foundries, slitting and bolting mills. Textiles include cotton, woolen, and fulling mills. Manufactures include glass factories, plaster mills, lime and brick kilns, salt pans, chemical and other factories. Food industries includes cranberry washing facilities, ice houses, canneries, creameries and fisheries. Infrastructure includes energy plants, water works, bridges, development projects and recreation facilities. Abandoned mills include those with ponds left undrained as well as those now dry.

Every South Jersey stream had at least one mill. Sawmills tend to occur in greatest abundance in the Outer Coastal Plain while grain mills tend to occur in abundance in areas of larger population. The data base was also partitioned temporally to get a sense of the number and kinds of mills through time (Figure 9). Far fewer mills have dates associated with them. Moreover these dates may represent different things. They could represent the date associated when a particular mill was built or the first date when it was mentioned or the time when the mill was owned by a particular person. In addition, many of these dates where the product of someone's memory and, as such, may not be precise. In any event, those mills with dates indicate, in a general way, the spread of mills across the South Jersey with the passage of time.

Some overall trends are recognizable. Mills were first established along the Delaware River and Bay as well as along Raritan Bay. The first mills were built in Mercer, Burlington, Camden, Salem and Cumberland Counties and in northern Monmouth County in the 1670's and 1680's. They were built somewhat later in Ocean, Atlantic and Cape May Counties from about 1700 to 1730. A decline in the number of mills can also be seen throughout the nineteenth century. The first mills were grain mills (i.e. grist mills) and saw mills, followed later by furnaces and textile mills (Figure 10).

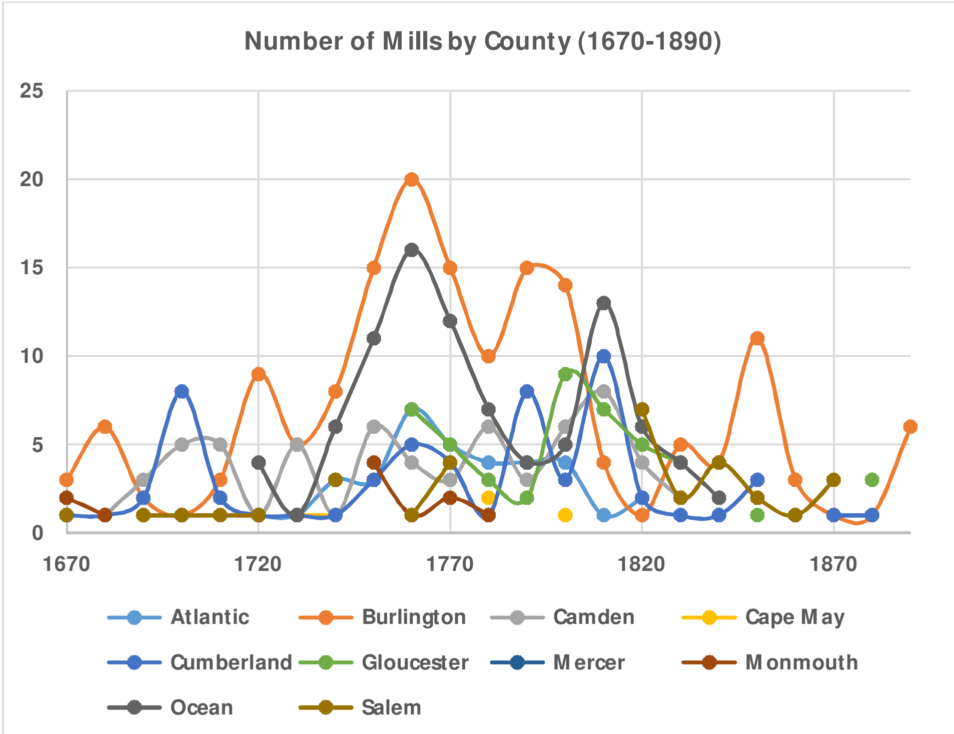


Figure 9. Number of Mills from 1670 to 1890 by County

The construction of mills altered the landscape of the middle reaches. (In a few cases, mills built in the lower reaches made similar changes.) First, part of the floodplain had to be cleared of vegetation and the surface graded to allow for the construction of the mill itself and allied structures, such as storage sheds. As the mill developed, more land was cleared and graded for the mill store, the mill managers house, workers quarters, barns for horses and wagons, landings, quays and docks, possibly a school and a hospital, and many sheds for storing raw materials and finished goods. Quite often farms and orchards were established onsite to help feed employees. Finally, roads had to be altered to accommodate wagon and horse traffic to and from the mill. More successful mills might also have a tavern and hotel for travelers and locals visitors. Charcoal was the major source of heat for putting furnaces "into blast", cooking, heating and for sale to other communities. The making of charcoal involved first clearing vast areas of forest for their wood that was then converted to charcoal in nearby kilns. Sawmills cleared Atlantic white cedar forests that lined streams and nearby floodplain swamps. This valuable commodity was sold in Philadelphia, New York, and even the West Indies.

In addition, wastes were generated and accumulated at mill sites. Aside from the tree debris and saw dust of sawmills, furnaces generated vast quantities of slag, a manmade glass formed in the furnaces by iron ore impurities fused with clam shell fluxes. Piles of slag accumulated onsite radically changing the surface topography and composition of the site's soils. At Martha Furnace, for instance, the soils were so altered that they are mapped as "urban" by the Soil Conservation Service (USDA Soil Conservation Service, 1971). This is ironic considering that Martha Furnace is one of the most remote and "protected" parts of the Pine Barrens.

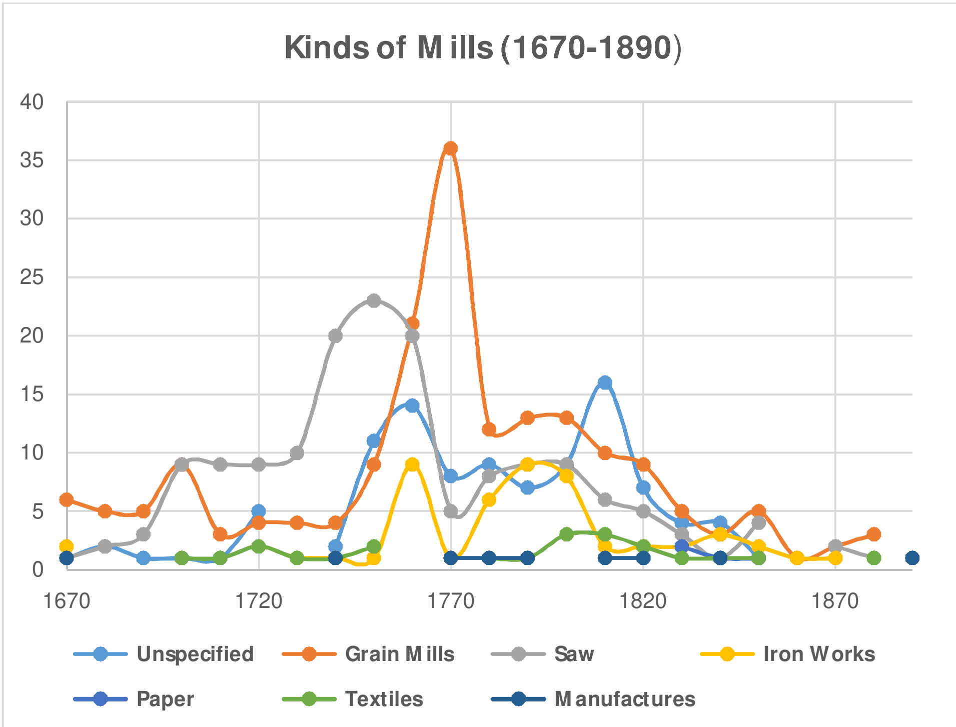


Figure 10. Temporal Distribution of Mills by Use

As far as the channel itself, the largest landscape alteration came with the construction of dams and mill ponds (Figure 11). A host of changes were brought about. The natural gradual decline in the stream's surface elevation, rather than declining gradually forms a *nickpoint* (i.e., a sudden drop in water surface elevation). Its gradient flattens where the stream enters the mill pond followed by a sudden drop in elevation from one side of the dam to the other. The stream becomes wider and deeper above the dam in the mill pond. The land surrounding the mill pond floods. Water velocity decreases and the mill pond's bottom becomes covered with muddy, organic-rich sediment. This requires periodic dredging along with the problem of where to dump the sediment. The stream's velocity below the dam suddenly increases beyond what it would have been under its prior natural gradient. This increased velocity causes the channel to become less sinuous while eroding the channel bottom and banks. The banks often require reinforcement with wooden bulkheads, concrete walls or large rock slabs. Moreover, the channel bottom changes to very coarse sands, gravels and sometimes even cobbles that are too heavy to move in spite the enhanced stream velocity. Finally, the water level in the mill pond is controlled at the raceway entrance. The base of the raceway entrance can be raised or lowered, thereby controlling the water level within the mill pond.

A raceway was required to divert water from the mill pond to the mill, where it turned the various machine wheels, gears and belts, and then returned to the stream further downstream. The raceway begins with a sluice gate in the dam, or a separate sluice gate from the reservoir itself. The sluice gate was constructed to control the flow volume and thereby allow for the efficient operation of the water wheels and mill machinery. The water velocity within the raceway was controlled by three related factors. These were the difference in water surface height between the mill pond and the stream below the dam, the natural steepness of the stream's water surface gradient, and the length of the raceway. Quite often, a raceway supplied water to more than one mill, for example a grist mill and a saw mill. Raceways required maintenance like dredging, reconstruction of its banks, and fixing its sluice gates. The lower parts of the middle reach were also altered to accommodate more convenient transportation of people and material. Channels were straightened and meanders cut through.

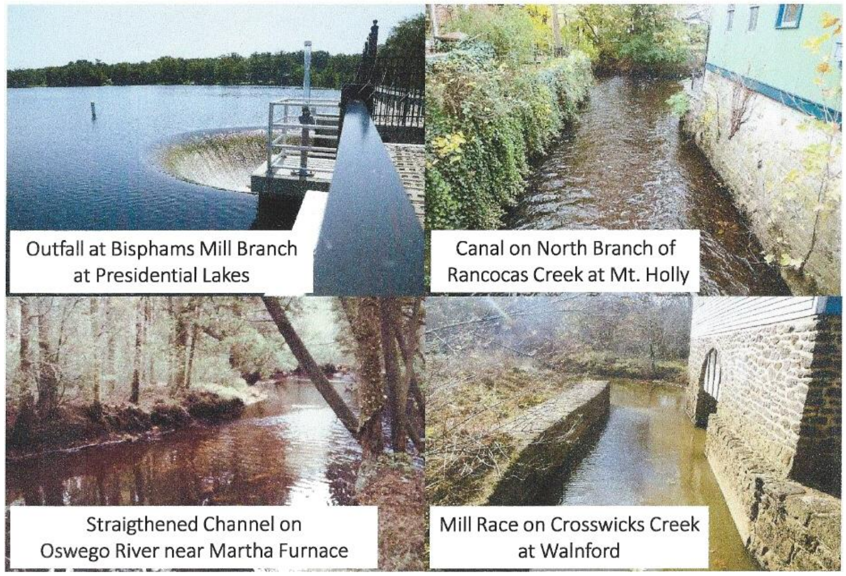


Figure 11. Alteration of Middle Reaches

Impact of the Bog Iron Industry and the Middle Reaches

Bog iron was excavated along the stream banks and adjacent swamps and then hauled by wagon or barge, sometimes called a scow, downstream to the furnace or forge. In addition, the bar iron or pig iron produced at the furnaces was transported below the millpond down river to market. Durham boats, like the ones that transported Washington's troops across the Delaware, also transported iron down river to Philadelphia. As in the case of mills, the channels were straightened and meanders cut through to allow for the easier passage of barges from the site of ore excavation to the furnaces or forges and from there to market. The above information comes from publications about the furnaces at Atsion (Braddock-Rogers, K., 1930, p.1496), Batsto (Boyer, C.S., 1931, pp.174-176), Budd's Iron Works on Manumuskin Creek (Boyer, C.S., 1931, pp.48-49), Martha (Boyer, C.S., 1931, pp.48-49) and Weymouth (Boyer, C.S., 1931, p.298). But the bulk of the ore was carted by wagon. Whether coming by wagon or barge, the ore involved the excavation of stream banks and adjacent swamps. This required the removal of surface vegetation and soil along the stream banks. Since furnaces required a water-powered bellows with their dams, millponds and raceways, these mills generally marked the base of the middle reach. Much of the excavated ore came from nearby parts of the middle reaches as well. In the case of the furnace at Atsion, bog iron ore even accumulated on the bottom of the millpond. The millpond was drained in winter and the ore scooped out (Braddock-Rogers, K., 1930, p.1496).

New stream channels were dug in the middle reaches for a number of reasons. First, almost every mill and furnace dug a raceway that drew water from the natural stream channel, used it to activate its machinery, and then returned it to the natural stream further downstream. Second, a kind of channel was dug between adjacent streams to increase a mill's power by adding the flow of another stream to its raceway. This has been recorded in three localities. First, in 1786, a canal was dug from Mechesetauxin Creek to the Mullica River at Atsion (Boyer, C.E., 1931. P.169) and another dug at Batsto from Nescochague Creek to the Mullica River sometime after 1827 (Pierce, A.D., 1957, p.201). A third canal was dug from the West Branch of the Wading River to the Oswego River after 1835 (Pierce, A.D., 1957, p.75). A third reason to dig a new channel was to gain easier access for barges to the bog iron sources. Such was the case at Weymouth Furnace in 1818 when a channel was dug from Weymouth Furnace to the Bog Ore Swamp (Boyer, C.S., 1931, p.251)

Iron furnaces and forges were built mostly along the middle reaches from 1674 in Tinton Falls until the middle of the nineteenth century (Table 11). Their construction followed along with the South Jersey's settlement. The Tinton Falls forge represents a very early outlier. Most of the furnaces and forges were built in the eighteenth and early nineteenth centuries. The first ironworks were set up near the original Quaker settlement at Burlington in the 1720's. After a three decade hiatus, ironworks began to be constructed southeastward on Rancocas Creek and on the Mullica River in the 1760's. A bit later, ironworks were built in Cumberland County in the 1770's. The Mullica and the Rancocas served as the focus of more ironworks construction in the 1780's. From the 1790's on, ironworks were constructed mainly along Atlantic coastal streams with some on the Wading River.

Thus the development of the bog iron industry, in addition to stream channel straightening, led to the excavation of new channels (Figures 12, 13), the excavation of bog iron ore along stream banks and floodplains, and erosion of stream banks by localized increases in stream velocity and foot, wagon and barge traffic along its banks and landings. Moreover, there also occurred the wholesale dumping of slag into channels and on to floodplains.

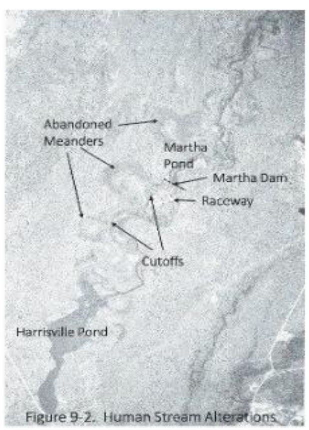


Figure 12. Cutoffs (Oswego R.)

Figure 13. Old Bog Iron Excavation Site

Impact of Forest Consumption on the Middle Reaches

European settlers undertook several kinds of activities that resulted in direct and indirect impacts on South Jersey streams. The first involved the consumption of Atlantic white cedar (*Chamaecyparis thyoides*) from floodplains and adjacent wetlands in the lower and middle stream reaches. The timber cut from the cedar bogs, according to Peter Kalm's in his *Travels*, was heavily sought for shingles, fence posts, barrel hoops, pipe staves, and even house construction. It was not only used locally but was shipped to Philadelphia, New York, and as far as the West Indies (Benson, A.B., 1937, pp.298-301). But its value far outweighed concerns about white cedar or wetland conservation. Kalm was highly critical of settlers' exploitation of South Jersey's white cedar.

"Thus the inhabitants here, are not only lessening the number of these trees, but are even extirpating them entirely. People are here (and in many other places) in regard to wood, bent only on their own present advantage, utterly regardless of posterity." -Peter Kalm, May 5th, 1749

While Atlantic white cedar has managed to persist on the Coastal Plain, its range decreased and its commercial potential limited. In 1911, the U.S. Department of Agriculture made the following prognosis (Hall, W.L. & H. Maxwell, 1911, p14).

"It may be expected, however, that supplies will be got for years from southern and eastern swamps, but the quantity and quality harvested in the early years need not be looked for again."

The second activity involved the harvesting of upland trees, primarily pitch pine (*Pinus rigida*) and various species of oak (*Quercus* spp.). Much of these woodlands were consumed for energy either directly as fuel wood or indirectly when converted to charcoal.

Significant activity involved the construction of saw mills. Initially, logs were rafted downstream to the nearest saw mill. But by the early eighteenth century, saw mills were being built where white cedars and other trees were "harvested" and then transported to market. The number of sawmills spread across South Jersey, starting with Quaker settlement after 1675. Table 12 and Figure 14 depict the distribution of saw mills by watershed and through time. The largest number of sawmills were on the Outer Coastal Plain's Pine Barrens.

Table 11. List of Coastal Plain Furnaces and Forges (Pierce, A.D., 1957)

Furnace/Forge	Watershed	Date	Furnace/Forge	Watershed	Date
Tinton Falls	Shrewsbury	1674	Union	Mullica	1800
Bordentown	Assiscunk	1725	Retreat	Rancocas	1800
Mount Holly	Rancocas	1730	Lisbon	Rancocas	1800
Atsion	Mullica	1765	Weymouth	Great Egg Harbor	1801
Batsto	Mullica	1766	Weymouth	Great Egg Harbor	1801
Etna	Rancocas	1766	Butchers	Metedeconk	1808
Taunton	Rancocas	1766	Dover	Cedar Creek (Oc)	1809
Cohansie	Cedar Creek (Cu)	1772	Ferrago	Cedar Creek (Oc)	1810
Pemberton	Rancocas	1781	Gloucester	Mullica	1813
Budd's Iron Works	Maurice	1785	Washington	Metedeconk	1814
Speedwell	Mullica	1785	Etna	Great Egg Harbor	1816
Federal Forge	Toms River	1789	Phoenix	Toms River	1816
Hanover	Rancocas	1791	Mary Ann	Rancocas	1827
Martha	Mullica	1793	Bergen	Metedeconk	1832
Wading River	Mullica	1795			
Federal Furnace	Toms River	1795			
Hampton	Mullica	1796			
Stafford	Westecunk	1797			

The establishment of saw mills altered the natural stream condition by adding dams, reservoirs, mill buildings and raceways. But onsite saw mills still required some transportation of logs to the saw mill and its lumber products to market. As before, channels needed to be deepened, widened and straightened to allow for easier transport. This applies to both lowland and upland timber. It also applies to the transportation of fuel wood and charcoal. The bulk of the saw mills were constructed throughout the eighteenth and early nineteenth centuries.

Table 12. Number of Saw Mills by Watershed

Absecon Creek	3	Dennis Creek	1	Nantuxent Cr.	1	Stow Creek	5
Alloways Creek	9	Dividing Creek	4	Navesink River	3	Toms River	9
Assiscunk Cr.	1	Doughty Creek	1	Newton River	7	Tuckahoe R.	2
Big Timber Cr.	21	G. Egg Harbor R.	18	Ocean Co.	6	Tuckerton Cr.	2
Blacks Creek	1	Kettle Creek	3	Oldmans Creek	5	Waycake Cr.	1
Cape May Co.	7	Manasquan R.	3	Pennsauken Cr.	2	West Creek	4
Cedar Creek	9	Mantua Creek	2	Raccoon Creek	7	Whale Pond	1
Cohansey R.	6	Maurice River	42	Rancocas Cr.	32	Wreck Pond	2
Cooper River	12	Metedeconk Cr.	5	Repaupo Creek	1		
Crosswicks Cr.	7	Mill Creek	1	Salem River	3		
Delaware River	1	Mullica River	48	Shark River	1		

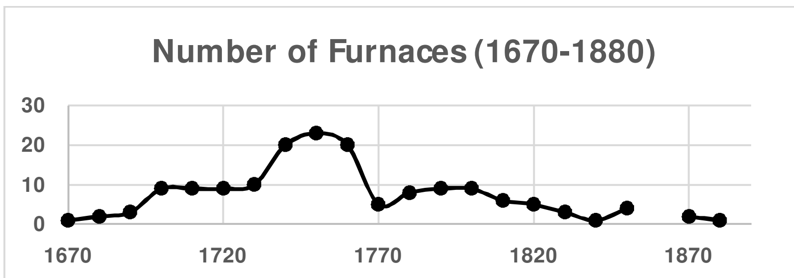


Figure 14. Number of Saw Mills through Time

UPPER REACHES

Hydrologic Setting

South Jersey streams become narrower and shallower in their upper reaches. They contain smaller volumes of water, have low sinuosity, and the steepest water level gradients under natural conditions. The lower and middle reaches receive much of their stream flow from upstream tributaries and groundwater discharge. Moreover, if the reach is urbanized, it receives runoff from natural and constructed impervious surfaces along with contributions from storm water sewers and ditches. But stream flow in the upper reaches is largely from groundwater discharge. The surface and the underlying water table, in general, decline in elevation from their watershed divide to their confluences (Figure 15). However the slope of the surface is steeper than the slope of water table. Consequently, the depth from the surface to the water table decreases until the water table intersects the surface. Springs or seeps form where this occurs. But the water table rises and falls with the seasons. Seeps and springs migrate to lower elevations by the end of summer and early autumn only to rise again by the late winter and spring. The lowest spring elevation is where the upper reaches begin since groundwater discharges here all year round.

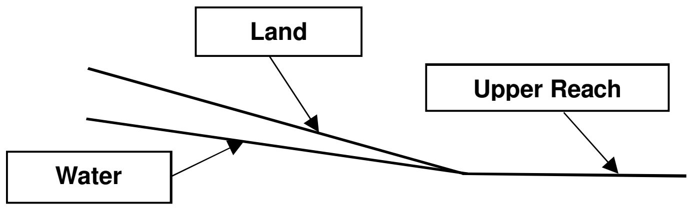


Figure 15. Upper Reach Cross Section

Upper reach landscapes differs from the Inner to the Outer Coastal Plain due to the nature of the underlying sediment. Inner Coastal Plain streams cut through finer textured sediments and have more turbid water. Their banks tend to be made of more coherent, erosion-resistant material and form relatively steep stream gradients and narrow stream valleys. Outer Coastal Plain streams, who cut through sandy sediments, have banks that are far less coherent and more vulnerable to erosion. They form wide, shallow stream valleys. One consequence of this difference is that springs and seeps in Inner Coastal Plain streams tend to be far more limited in extent than those of the Outer Coastal Plain. In other words, the zone where the water table and the surface converge is far broader on Outer Coastal Plain. This creates saturated conditions suitable for the growth of *Sphagnum*, or peat moss, and the formation of bogs. These bogs are covered with a dense growth or either Atlantic white cedar (*Chamaecyparis thyoides*) or deciduous hardwood trees, such as red maple (*Acer rubrum*), Black Gum (*Nyssa sylvatica*), and Sweet Bay (*Magnolia virginiana*). These bogs are far better developed in the floodplains of Outer Coastal Plain.

Alteration of the Upper Reaches

The upper reaches of Inner Coastal Plain streams are fairly accessible. They have, in general, the narrowest floodplains. They have the shallowest and narrowest channels that are easily forded or bridged. In addition, they are very close to their uplands. Many roads had been built across them by the late eighteenth and nineteenth centuries. These roads, and the streams they cross, are depicted in many of the nineteenth century atlases (Beers, F.W., 1872; A.C. Stansbie *& others*, 1846). Further large scale changes did not occur until the middle of the nineteenth century with the development of cranberry agriculture along with the expansion of railroads and better constructed roadways.

Wild cranberries had been harvested from boggy stream banks by the Lenape and early European settlers well before the nineteenth century. The first attempt to domesticate cranberries by growing them in manmade bogs occurred in 1835 near Pemberton. But cranberry growing as a vital New Jersey industry began in the 1850's. The first cultivated vines were planted in 1851 at Sim Place and Whitesbog, commencing this new form of agriculture. Like any new and initially successful industry, cranberry growing rapidly expanded in the 1860's (Eck, P., 1990 (pp.5-7). The acreage of bog consumed increased until 1920 before declining (Figure 16).

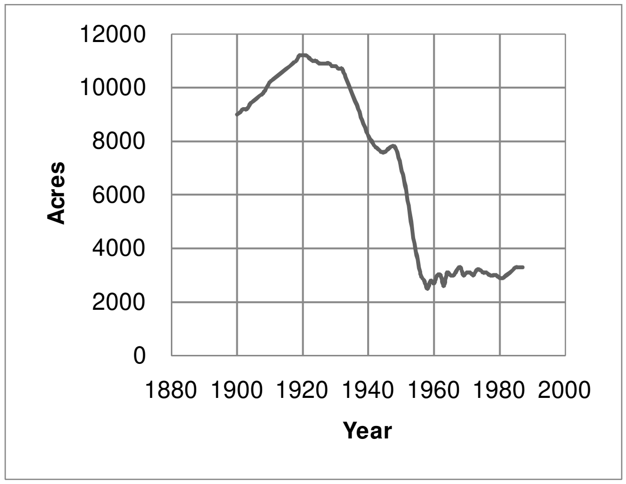


Figure 16. New Jersey Cranberry Acreage (P.Eck, 1990)

The construction of cranberry bogs substantially changed natural conditions. Initially, cranberry bogs were built on floodplains that had been covered by white cedar or hardwoods. All the natural vegetation was removed. A layer of sand was applied atop the now exposed muck soil in which vines were planted. Ditches were dug across and around the periphery of the bog to lower the water table (Figure 17). A reservoir was excavated just upstream of the bog (Figure 17). Water from the reservoir was used to facilitate harvesting of the berries in the fall and throughout the winter to prevent vines from freezing. But in the twentieth century cranberry bogs were now often built beyond floodplains, sometimes spreading to neighboring streams. In addition, stream water is taken from one stream, passed through the bog, and then discharged into another stream.

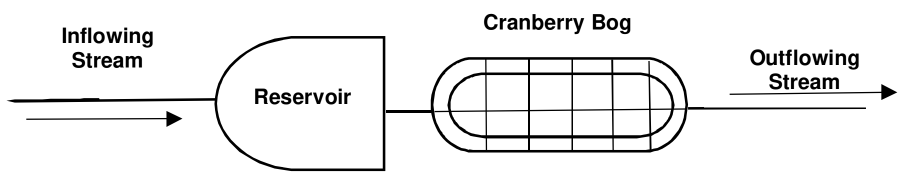


Figure 17. Cranberry Bog Schematic

Table 13. Area of Cranberry Cultivation by County & Township 1874

County	Township	Acres	County	Township	Acres
Atlantic	Hammonton	492	Monmouth	Wall	36
Burlington	Pemberton	978		Atlantic	40
	Southampton	210		Howell	166
	New Hanover	316	Ocean	Brick	590
	Woodland	158		Jackson	640
	Medford	397		Dover	359
	Little Egg Harbor	73		Manchester	178
Camden	Waterford	130		Plumstead	101
Middlesex	Monroe	124		Stafford	179
				Lacey	54
				Union	90

This constituted a major alteration of many upper reaches. Many counties and townships had cranberry bogs. Table 13 shows the area within each townships that grew cranberries just after the cranberry "boom" (French, N.R., 1874). Many Outer Coastal Plain streams felt the impact of cranberry agriculture. Early maps show the number of bogs in each watershed (Vermeule, C. C., 1870-1887). One cluster of watersheds, with adjoining divides, were heavily used for cranberry growing. These include the Metedeconk, Toms, Mullica, Rancocas and Crosswicks watersheds. Other sorts of agriculture used water from the upper reaches of South Jersey streams. Blueberry, orchard, and grain growers used this water to irrigate their crops. This occurred in the Outer Coastal Plain but especially in the Inner Coastal Plain (Figure 18).

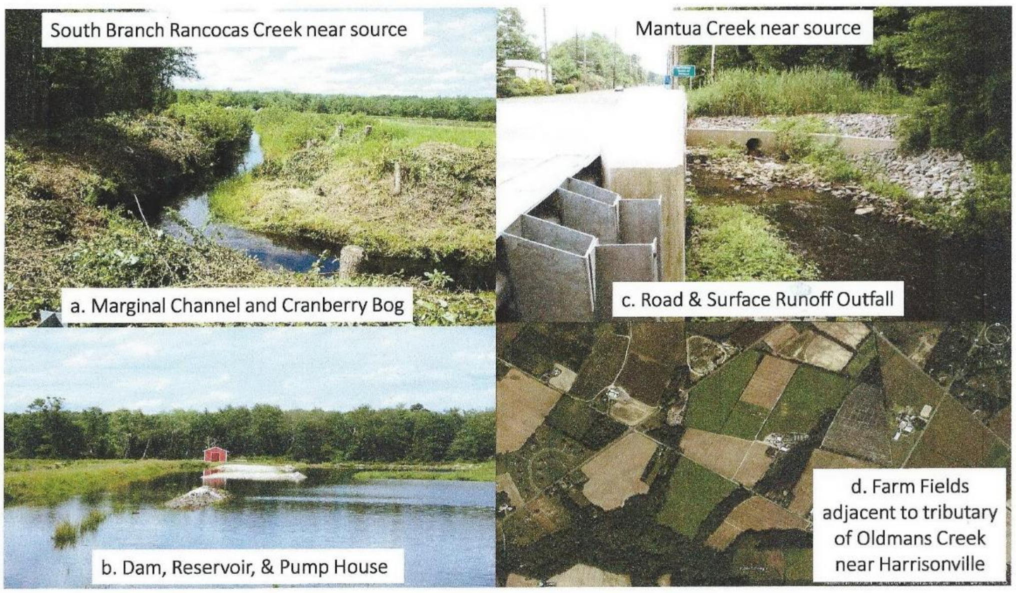


Figure 18. Alterations of Upper Reaches

Another use to which the upper reaches are put is for the disposal of storm water runoff. Various municipalities have constructed surface water runoff collection systems that dispose of storm water through a network of pipes to outfalls in the upper reaches of streams.

Later Human Impact

People made various structures that crossed all reaches of South Jersey streams. Many of these structures cross stream's upper reaches. Roadways are the most numerous but railroad tracks, dams, and power lines are also present in significant numbers. All restrict natural river flow. Some roadways can be as elaborate as highways while others can be as modest as unpaved roads. But in either case, a road bed is constructed across the floodplain while a bridge or conduit is built across the channel itself. Power lines pass over floodplains but vegetation has been cleared to allow maintenance vehicle access. More recently, some utilities, such as natural gas pipelines and electrical cables, pass across floodplains but these are mainly buried. Though not seen, they can still interrupt surface runoff, shallow groundwater flow and, perhaps, groundwater discharge. U. S. Geological Survey 7.5 minute topographic maps indicate the presence and their position and these are shown in Table 14. South Jersey streams have many such obstacles that, consequently, altered their natural flow characteristics.

Table 14. Number of Roadways and other Obstacles to Natural River Flow

	Highways	Roads	Unpaved Roads	Railroad Tracks	Dams	Power lines
Delaware River						
Crosswicks Cr.	1	25	10	4	8	
Blacks Creek	1	11	2	1	7	
Crystal Lake Cr.	2	4		1		
Crafts Creek	3	9	2	2	1	
Assiscunk Creek	2	11	0	1		
Rancocas Creek	1	82	39	8	43	
Pompeston Cr.		10		1	2	2
Pennsauken Cr.	5	22		3	4	
Cooper River	3	17		5	4	1
Newton Creek		14		3	1	
Big Timber Cr.	7	25	2	2	10	1
Woodbury Cr.	2	8		1	2	
Mantua Creek	3	9		3	3	1
Repaupo Creek	1	6		1	1	1
Raccoon Creek	1	15	2	1	3	2
Oldmans Creek	1	10		2		
Salem River		16	1	1	4	3
Alloways Creek		8			1	
Delaware Bay						
Cohansey River		12		1	3	1
Maurice River	3	62	7	6	19	6
West Creek		5	1		3	
Fishing Creek		4			1	
Green Creek		3	2			

	Highways	Roads	Unpaved Roads	Railroad Tracks	Dams	Power lines
Atlantic Ocean						
Tuckahoe River		8	8	1	4	
Gr.Egg Harbor R.	5	52	5	7	15	4
Wading River R.		10	19	1	13	
Mullica River	4	65	49	13	27	
Tuckerton Cr.	1	7	2		15	1
Westecunk Cr.	1	1	5		3	
Mill Creek	3	7	3			
Waretown Cr.	1	8	2			
Oyster Creek	1	5	2		10	
Forked River	3	8	9	4	4	
Cedar Creek	1	5	1		2	1
Toms River	2	33	12	4	17	2
Kettle Creek	1	8			3	
Metedeconk R.	3	34	5	2	9	1
Manasquan R.	2	15	1	1		
Wreck Pond Br.	2	10		1	4	
Shark River	1	11				
Deal Lake	1	5		1	1	
Poplar Brook		8				
Shrewsbury R.		5		2		
Swimming R.	1	12		1	1	
Whale Pond Br.		10		1	2	
Raritan Bay						
Matawan R.	1	8		1	1	

Floodplain Soils Impact on Channel Landscape

The soil that underlies most of South Jersey's wetlands is called muck by soil scientists. Muck is a sediment often overlooked by geologists. Inorganic particles such as gravel, sand, silt and clay are generally thought of as the kinds of sediments eroded, transported and deposited by flowing water. But muck consists of degraded organic particles made primarily by plants. With the exception of petroleum and coal geologists, organic particles are generally "beyond the pale" of geologists' notice.

Organic sediments accumulate almost out of default. At fast flows, coarse inorganic particles are transported and deposited. Organic particles are overwhelmingly finer textured and far lighter than inorganic particles. Consequently, organic particles are deposited in near stagnant conditions. As mentioned before, the soil that is made up of this accumulation of organic particles is called *muck*. While muck is generally thought of as accumulating at the bottoms of lakes, most of South Jersey's muck accumulates along the flat, broad floodplains of its rivers. This is especially true of the upper reaches and areas adjacent to the middle reaches of these rivers, especially in the Pine Barrens. Here, groundwater oozes on to these floodplains, slowly making its way toward stream channels. Stream flow is generally slow and even seasonally intermittent. In the lower reaches, channels occupy a small proportion of their floodplains, leaving much of these floodplains prone to swampy or marshy conditions. These saturated conditions give rise to abundant plant growth. *Sphagnum* moss and associated water-loving shrubs and trees dominate the upper and middle reaches while grasses, sedges, and rushes tend to dominate the lower reaches. In other words, the upper and middle reaches tend to become Atlantic white cedar bogs or hardwood swamps while the lower reaches tend to become freshwater meadows and salt marsh. When the ices ages abated and temperatures rose, as did sea level, conditions in previously formed stream valleys became moister, fostering the development of muck-forming vegetation. In the Pine Barrens this process was thought to have started approximately 10,000 years ago (M. Buell, 1970). Muck deposition began in all the counties of the coastal plain (Table 15.). In New Jersey, muck soil goes by the name *Manahawkin Muck*. Table 15 shows the various wetland, or hydric, soils found in South Jersey. Values for the Manahawkin Muck by county and estimates by watershed were derived from Department of Agriculture, Natural Resource Soil County Surveys (T.J.F. Hole, 1996; T.J.F. Hole & H.C. Smith, 1980; R.G. Hutchins, J.H. Johnson, W.C. Kirkham & V.K. Rowley, 1978; C.F. Jablonski, 1981; J.H. Johnson, 1978; S.C. Keen, 2003; M. Markey, 1966, 1971; L.M. Vasilas, 2004). Some watersheds contain more muck than others. In particular, Pine Barrens watersheds have much larger areas covered in muck soil.

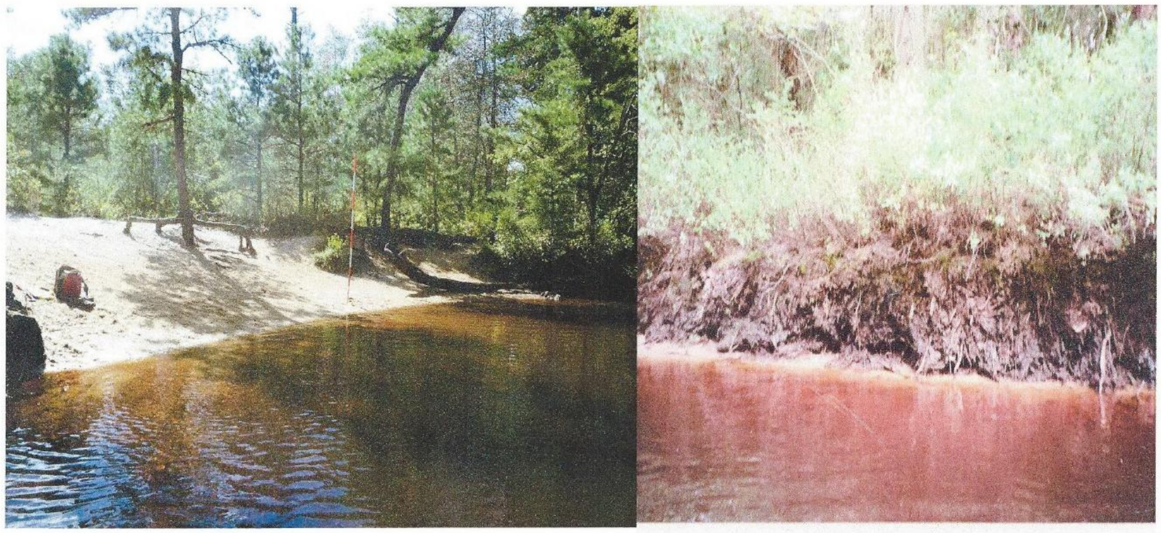
Table 15. County Distribution of Muck Soils

County	Acres	Hectares	Sq. Miles	Percent
Atlantic	25200	10198	39.38	6.9
Burlington	16000	6475	25.00	3.2
Camden	6700	2711	10.47	4.8
Cape May	6400	2590	10.00	3.7
Cumberland	16513	6683	25.80	5.1
Gloucester	11211	4537	17.52	5.2
Ocean	26800	10846	41.88	6.5
Monmouth	2840	1149	4.44	0.9
Salem	5322	2154	8.32	2.4
TOTAL	116986	47343	182.79	

The broad, flat floodplains of the streams that empty into the Atlantic Ocean and Delaware Bay as well as some that empty into the Delaware River, are the foci of large volumes of groundwater seepage. This is especially true in the Pine Barrens of the Outer Coastal Plain. The water table in the Outer Coastal Plain is near the surface and floods easily during moderate to heavy rains. These saturated conditions give rise to the development of massive layers of peat atop its floodplains and coastal meadows. As peat accumulates, its volatile constituents dissipate while its lower layers partially decompose to form muck.

Muck erodes differently from minerals soils is what happens to them when they dry out. Mineral soils (i.e., gravel, sand, silt, loam, and clay) absorb moisture and give it off periodically without changing their intrinsic character very much. However, when muck dries it rots and erodes through the action of moving water and wind. Its intrinsic nature is radically altered when its mineral soil counterparts remain fairly stable. Muck desiccation causes it to thin and disappear.

When muck is exposed along river banks, it behaves differently than exposed minerals soils. Muck tends to be more coherent than sands or loamy sands and forms steep banks while coarser textured mineral soils form gradual slopes (Figure 19). Muck exposed to stream flow softens and its finer particles are washed away while the network of roots and wood tends to remain.



a. Sand Banks b. Peat Banks

Figure 19. Stream Bank Morphology

Chapter 6.
River Water Changes

The river's channel, floodplain and valley have all been altered as people settled in South Jersey. Landings, ditched meadows, dammed channels, cleared wetland and adjacent upland forests and canals all altered the river landscape. Landscape alteration also involved additional water use for agriculture, manufacturing, and transportation. But the water flowing through the channels was also altered by human activity.

Changes in Water Quantity

The Lenape and the region's wildlife drank water from streams. The Lenape also used water for cooking. But their populations were small and actual water use limited. The Swedes, Finns and Dutch populations were also small and very few lived on the Jersey side of the Delaware. But the arrival of Quaker settlers after 1675 heralded an explosive population increase as well as increased water consumption for all sorts of mills and for agriculture (Table 16). The population rose from the lower hundreds to the thousands by the turn of the 18th century and tens of thousands at the turn of the 19th century. The first mills and wetlands reclaimed for agriculture occurred almost as soon as the first Quakers settled.

In addition to mills, meadows were drained and irrigated at the same time while cranberry bog development occurred in the second half of the nineteenth century.

Table 16. Number of Mills per Decade

Decade	Total	Atlantic	Burlington	Camden	Cape May	Cumberland	Gloucester	Monmouth	Ocean	Salem
1670	1									1
1680	5		4			1				
1690	11	2	1	4		2	1			1
1700	13		1	5		6				1
1710	10	1	1	5		2				1
1720	15	1	8	1		2			2	1
1730	13	3	3	5		1		1		
1740	21	1	6	1	2	1	2		5	3
1750	38	1	12	5		2		4	14	
1760	54	5	15	3		3	7	1	19	1
1770	46	3	13	3		3	5	2	13	4
1780	29	3	6	7	1	1	2	1	8	
1790	31	2	7	3		8	2		9	
1800	40	4	9	6	1	6	7		7	
1810	41		7	7		7	6		14	
1820	26	2	1	5		2	5		6	5
1830	13		1	2		1	4		4	1
1840	10	1	2			1			2	4

Stream Water Withdrawals

The State of New Jersey holds the water supply in trust for its citizens. Anyone taking ground or surface water must get a permit from the State. These permits involve reporting not only the volumes withdrawn but also its use if the withdrawal exceeds 100,000 gallons per day. The total number of withdrawal permits in each watershed is shown in Table 17. This information is posted on the NJDEP website (http://datamine2.state.nj.us/DEP_OPRA/OpraMain/get_long_report.

South Jersey stream withdrawals and their uses differ from stream to stream. Delaware River and nearby Salem Canal withdrawals are used for industry. Similar withdrawal magnitudes are used for public water supply in the eastern parts of the North Branch of Rancocas Creek and, across the divide, in the Metedeconk River basin. Withdrawals for irrigation (A/H/A), used on crops, ornamental plants, orchards and turf farms, though far more pervasive throughout South Jersey, occur generally at lower withdrawal rates. However, large withdrawals for this purpose occur in the Mullica River and Batsto River basins. There is also a fair volume used for this kind of irritation on the land adjacent to the Raritan Bay. In addition, golf course irrigation is common in northeastern Monmouth County. But withdrawals for irrigation and water supply are seasonal and reach their peaks during the growing season when stream stages are in decline naturally. Table 17. Number of Stream Permits, Withdrawals and Use by Watershed for 2005

HUC 11 Data File Name	Number of Permits					Withdrawal (MGY)				
	A/H/A Irrigation	General Irrigation	Golf Course Irrigation	Industry	Water Supply	A/A/A Irrigation	Golf Course Irrigation	Irrigation	Industry	Water Supply
Navesink River/Lower Shrewsbury River	1		4							
Whale Pond /Shark R./Wreck Pond Br.	0		2		1		8			
Matchaponix Brook	2		1			4	7			
Crosswicks Creek (above New Egypt)	16	1				66		4		
Raritan Bay/Sandy Hook Bay	26				2	3294				462
Rancocas Cr.(NBr.) (above New Lisbon)	0				1					7930
Pompeston Creek/Swedes Run	0		1				0			
Pennsauken Creek	1			1					91	
Cooper River	4			1					5139	
Woodbury/Big Timber/Newton Creeks	6					0				
Mantua Creek	14			1		61			2775	
Cedar Swamp/Repaupo Cr./Clonmell Cr.	14					89				
Raccoon Creek Birch Creek	0									
Oldmans Creek	30					288				
Salem R.(above dam)/Salem Canal	34			1		243			3756	
Allocays Creek/Hope Creek	1					5				
Stow Creek	2					7				
Cohansey River (above Sunset Lake)	5					5				
Maurice River (combined)	7					80				
Metedeconk River (combined)	0		1		3	0	8			2127
Toms River (combined)	3		1			171	72			
Manahawkin/U.Little Egg Harbor tribs	1					37				
Lower Little Egg Harbor Bay & tribs	0		1				0			
Batsto River	16					1047				
Mullica River (above Batsto)	13					136				
Wading River (combined)	8					6577				
Gr.Egg Harbor R (above Hospitality Br.)	2		1			6	1			
Patcong Creek/Great Egg Harbor Bay	1					23				
Tuckahoe River	2					19				

Stream Water Discharges

Rivers have been used for the disposal of wastes since ancient times. People have dumped all manner of things into rivers to get rid of them. Some polluting activities can be seen from the eighteenth century on. Tanneries and breweries in South Jersey, as elsewhere, dumped their wastes into the nearest streams. The same can be said for paper mills, textile factories, saw mills, tar kilns, chemical factories and furnaces, not to mention human and livestock wastes. The State of New Jersey now requires discharge permits (NJPDES) for the disposal of many sorts of waste water to the State's streams. Though there are other kinds of discharge in North Jersey, the kinds that have been permitted in South Jersey are listed in Table 18 These purposes can be clumped as follows: 1.) Domestic waste, 2.) Regional waste water authority outfalls, 3.) Industrial, commercial and thermal waste, 4.) Fuel and petroleum product clean ups, 5.) Non-contact cooling water, 6.) Oil-water separation, and 7.) Storm water and surface water runoff.

Table 18. Number and Purpose of NJPDES Permits

NJPDES Permit Type	No.
Domestic Waste Water	169
Regional Sewerage Outfalls	7
Industrial/Commercial/Thermal Waste Water	173
Thermal Waste Water	53
General Fuel Cleanup	30
Groundwater Petroleum Product Cleanup	92
Oil-Water Separation	2
Non-Contact Coolant Waster	19
Storm Water (2 Categories)	145
Surface Runoff	243
Other	4

(Source: www.nj.gov/dep/dwq/database.htm)

The number of discharge permits in South Jersey has increased from 4 in the 1970's to well over 200 in the 1990's. In addition, permits have been issued throughout South Jersey so that almost every stream has at least one (Tables 19a and 19b). The largest number occur on the Inner Coastal Plain along the Delaware River, north of Salem County, while the least occur on the Outer Coastal Plain.

The volume of water flowing through South Jersey streams has been augmented *via* New Jersey State discharge permits in some places while being diminished *via* New Jersey State water allocation permits in others. Moreover, South Jersey stream water quality has also been altered by the addition of permitted waste water. A discussion of this follows.

Changes in Water Quality

The perpetually increasing number of South Jersey settlers, along with novel technological uses of stream water, has effected water quality. Prior to this, forest and stream ecological processes, acting like a chemical filter, optimized the absorption of some chemicals that were prevented from reaching nearby streams. Quantifying this by watershed and over time is highly problematic.

There are a vast number of chemical constituents present in water aside from the overwhelming quantities of H_2O molecules. Water contains dissolved gases, non-aqueous liquids, dissolved ions and molecules, chemical complexes, colloids, organic and inorganic particles, as well as microscopic and macroscopic life. Monitoring water quality of streams began in a systematic way in the later part of the twentieth century. The number of streams monitored, the number of constituents analyzed, and the period of record has increased but all this accumulated data is inadequate to describe "normal" and "contaminated" conditions for all the reaches of all the streams in South Jersey, let alone to assess human-induced changes in water quality. In addition, changes in water quality can be long term or episodic depending on their source. Long term changes in stream water quality is also difficult to assess given the gaps in monitoring.

There are two ways to derive some generalizations about the nature of stream water quality due to "natural" and human activities. "Natural" water quality differs from the Inner Coastal Plain to the Outer

Coastal Plain. This was most likely true before European settlement. This has to do with the chemical nature of the soils and sediments through which rain water percolated on its way to the streams. Metaphorically, a watershed's soils are like tea in a tea bag while the precipitation is like the hot water into which the tea is dipped. Tea flavor varies from one kind of tea to another. So too, the teas' concentration depends on the residence time of the tea bag in the water. A stream's water quality depends on the kind of soils and sediments though which stream-bound water passes and the length of time the water takes moving through the soil or sediment to the nearest stream.

Table 19a. Number of Discharge Permits with Inner Coastal Plain Watersheds

	Domestic	Region Outfall Authority	Indiust./Comm./Thermal	DPCC-DCR Plan	Gen.Permit Fuel Clean Up	GW Product Clean Up	Thermal	Non-Contact Cooling Water	Storm water	Surface Runoff	Oil-Water Separation	Total (All Sources)	Human Generated
Delaware River	11		23		2	3	10		12	19		80	49
Rancocas Creek	20	2	9		3	8	3	2	8	23	1	79	48
Pennsauken Creek	14		10		2	5	5		8	19		63	36
Mantua Creek	2		16		1	5	2	2	12	16		56	28
Big Timber Creek	16				2	6			3	7		34	24
Cooper River	12		5		2				3	6		28	19
Crosswicks Creek	9		3			4	1		6	2		25	17
Blacks Creek	4		2			2	2		4	4		18	10
Salem River	3		4				2	1	1	5		16	10
Raccoon Creek	2		7						2	2		13	9
Alloway Creek	4		2				2		1	1		10	8
Oldmans Creek	3		2			1				6		12	6
Newton Creek	5								1	2		8	5
Assiscunk Creek	2					2				7		11	4
Compton Creek			2			1	1			1		5	4
Cohansey Creek	1		1					1	1	6		10	3
Crafts Creek	2		1						1			4	3
Woodbury Creek			1						33	1		35	1
Nj Codrainage	18	2	15		5	7	1	4	2	15		69	52
Navesink River	8		8			5	1	1	9	2	1	35	24
Metedeconk Cr.	4	1	2	1	2	8		2	3	10		33	20
Manasquan River	3		7		1	2	3	2	8	4		30	18
South River	1		5		1	5	3		2	5		22	15
Raritan Bay	3	1	6		1	3	1		3	3		21	15
Matawan Creek	4		3		1	3			1	1		13	11
Shark River	1				3	4						8	8
Shrewsbury River			1			2			2	2		7	3
Millstone River			1						1			2	1
Whale Brook	1								1			2	1
Deal Lake							1						1

Inner Coastal Plain soils tend to be finer textured, rich in clays and glauconite. They tend to hold more chemical constituents (i.e., soil nutrients) than the coarser textured quartz sands of the Outer Coastal Plain (J.C.F. Tedrow, 1986). The finer textured soil particles have more surface area which holds more chemical constituents until water flowing past these particles dissolves or transports them. In addition, rainwater, being exceeding low in chemical constituents, has the capacity to dissolve greater volumes of chemical constituents as it flows to the nearest stream. And since there tend to be more chemical constituents in Inner Coastal Plain soils, water passing through it picks up more soil chemical constituents than can be dissolved in the Outer Coastal Plain. In addition, soil moisture flows faster through the coarse textured soils of the Outer Coastal Plain than the finer textured soils of the Inner Coastal Plain. Consequently, the concentration of chemical constituents is greater in Inner Coastal Plain streams than in the Outer Coastal Plain streams. This is reflected in Table 20 from data derived from several U. S. Geological Survey Water-Resources Investigations Reports (M.K. Watt & M.L. Johnson, 1992; M.L. Johnson & M.K. Watt, 1996; M.L. Johnson & E.G. Charles, 1997; M.K. Watt *& others*, 2003; A.D. Gordon, 2004).

Table 19b. Number of Discharge Permits within Outer Coastal Plain Watersheds

OUTER COASTAL PLAIN	Domestic	Region Outfall Authority	Indiust./Comm./Thermal	DPCC-DCR Plan	Gen.Permit Fuel Clean Up	GW Product Clean Up	Thermal	Non-Contact Cooling Water	Storm water	Surface Runoff	Oil-Water Separation	Total (All Sources)	Human Generated
Maurice River	3		23			3	4	2	7	18		60	35
Gr. Egg Harbor R.	5		3		2	3	6		6	24		49	19
Mullica River	4		2				4	2	1	7		20	12
Toms River	1		4	1	1	5				8		20	12
Absecon Creek	2			2		2				4		10	6
Cedar Creek			1			1	1		1			4	3
Tuckerton Creek						2				2		4	2
Nantuxent Creek			2							1		3	2
Forked River			1						1	1		3	1
Dennis Creek	1									1		2	1
Mill Creek					1					1		2	1
Tuckahoe River			1									1	1
West Creek (Ocean)		1										1	1
Nacote Creek										3		3	0
Bass River									1	1		2	0
Cedar Swamp Creek										1		1	0
West Creek										1		1	0
Westecunk Creek										1		1	0

Human activity, such as agriculture and sewerage, is reflected in concentrations of NO_3, NO_2, NH_3, organic nitrogen, phosphate and fecal coliform. It may also be reflected in conductance, a proxy for total chemical constituents. It seems reasonable to assume that a difference in chemical concentrations between the Inner and Outer Coastal Plains existed prior to European settlement.

A change from Inner to Outer Coastal Plain stream water quality is observed in the Rancocas River watershed. This river consists of four recognized branches, all of whose upper reaches flow through the Outer Coastal Plain. Table 21 consists of the averages of data published in a Pinelands Commission Report (R.A. Zampella *& others*, 2003). Greenwood Branch is largely in forest and is the least developed. It has the lowest concentrations of nitrogen compounds, phosphates, and conductivity while also having the most acidic pH. The remaining three branches have been subject to far more residential and commercial development. The same parameters have higher concentrations and a less acidic pH in these three branches. While Zampella & others (2003) ascribe this differences in pH and conductivity to their position on the Inner or Outer Coastal Plain.

Table 20. Average Chemical Constituent Parameters of Coastal Plain Streams

Parameter	Inner	Outer	Parameter	Inner	Outer
Conductance	174	82	Calcium	13.3	7.34
pH	7.0	5.5	Magnesium	4.19	1.49
Diss.O_2	8.48	7.76	Sodium	8.37	1.37
BOD	3.8	9.5	Potassium	3.49	1.37
NO_2 +NO_3	1.15	0.58	Sulfate	25.67	9.69
NH_3 + Org N	1.00	0.95	Chloride	14.96	9.08
Phosphate	0.30	0.17	Fluoride	0.201	0.102
F. Coliform	2183		Silica	9.04	4.33

Another way to deal with the human-induced changes in stream water quality is to speculate on the impact of individual human activities that could influence water quality. Farming, manufacturing, waste disposal, etc. all have the potential to alter water quality.

Table 21. Averages of Several Chemical Parameters

Branch	NO_2 +NO_3	NH_3	Total P	pH	Conductivity
Greenwood	0.04	0.13	0.03	4.5	45
North	0.28	0.19	0.07	5.9	93
South	0.54	0.15	0.08	4.9	92
Southwest	0.25	0.22	0.07	6.1	126

Agriculture

The earliest water quality changing activity was farming. South Jersey forests were cleared to make way for agriculture. The earliest forest clearing involve the cutting of timber and burning the remaining vegetation to create a surface fertilizer of ash. The nutrients that had been stored in plant tissues, such as nitrogen and phosphate compounds, were released from this ash and washed into nearby streams. But this was an episodic input. Ash fertilizer gave way to the application of lake and swamp organic matter, livestock manure, glauconite (also known as greensand), and even ground up horseshoe crabs. This kind of fertilizer was applied annually and so its runoff was a more or less constant seasonal source of stream water quality change. Now more organic carbon, nitrogen, phosphorus and heavy metals from modern fertilizers make their way into stream water. Still later, synthetic organic fertilizers and pesticides replaced most of these earlier fertilizers. The number and rates of application of synthetic fertilizers and pesticides has expanded and have found their way into South Jersey streams. This has exposed South Jersey to progressively more public health and ecological hazards.

Domestic Wastewater

Initially the number of people and the manner by which they disposed of their wastes mitigated against changes in stream water quality. But as towns developed during the eighteenth and nineteenth centuries, some of which subsequently developed into small cities, the need for municipal waste disposal arose. The earliest such waste disposal systems were dumps for solids and gutters and underground sewers for liquids. The sewers eventually discharged into South Jersey streams. Now streams carried larger concentrations of particulates, bacteria and other microbes, nitrogen compounds, heavy metals, organic matter and compounds, and pharmaceuticals to name a few. Some of the results of this included the creation of more anaerobic conditions in streams and bays, higher concentration of environmental toxins, stimulation of infectious water-borne diseases, and changes in sediment texture. Now many of the original plants and animals disappeared and replaced by a smaller variety of more pollution tolerant species.

Mill and other Industrial Waste

Tanneries and breweries were often located by streams, one reason being the easier disposal of waste products. This was true for those in South Jersey. Tanneries are known to discharge polychlorinated phenol (PCB), chromium and other heavy metals, dyes, organic matter, salt, and hydrogen sulfide. Much of these are toxic to people and the environment. These discharges increase the biological and chemical oxygen demand (COD, BOD) thereby generating more anaerobic conditions (M. Mwinythija, 2010). Breweries are known to discharge chloride, nitrate, ammonia, other dissolved solids and heavy metals. This results in a more acidic pH, lower dissolved oxygen, higher biological oxygen demand (BOD), and greater stream turbidity (Ipeaiyeda, A.R., & P.C. Onianwa, 2009). South Jersey saw mills were located on streams, from which they derived their power. During the conversion of timber to lumber, unused piles of wood, especially twigs, leaves, and bark are disposed of nearby and pose a source of stream water contamination. These wastes generates leachates that are known to contain high concentrations of volatile organic acids, lignin-tannin and, under reducing conditions, iron and manganese. These all pose a threat to stream water quality (Sweet, H.R., & R.H. Fetrow, 1875). Paper factories, also located near South Jersey streams, also generate wastes that have the potential to change stream water quality. These include lignin, cellulose compounds, phenols, mercaptans, sulfides and chlorinated compounds. This, in turn, increased biological and chemical oxygen demand (BOD, COD) and thereby reduces dissolved oxygen (Garg, A., 2012). Additional contaminants include dyes from textile factories, organic wastes generated by charcoal and tar manufacture, industrial wastes from many other types of factories and the wastes generated by the chemical and pharmaceutical industries.

A more recently recognized phenomenon which has had impact of stream water quality is the acid deposition generated by far distant fossil fuel power plants. Nitrates, sulfates, acids and other ions and molecules are release from power plant chimneys and absorbed by atmospheric moisture. These are returned to the earth, and ultimately to its streams, during and even after rainstorms. This results in acidified streams, especially in the Outer Coastal Plain with their lower buffering capacity (NJDEP, Office of Science, 2013).

In sum, the South Jersey industrial diversification, increased and varied kinds of agriculture, and the progressive increase in human wastes undoubtedly changed its stream water quality in spite of the difficulty in quantifying these changes.

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Deciphering Complex Deltaic Facies Using Integrated Sequence Stratigraphy, Magothy Formation (upper Turonian-Coniacian), New Jersey, USA

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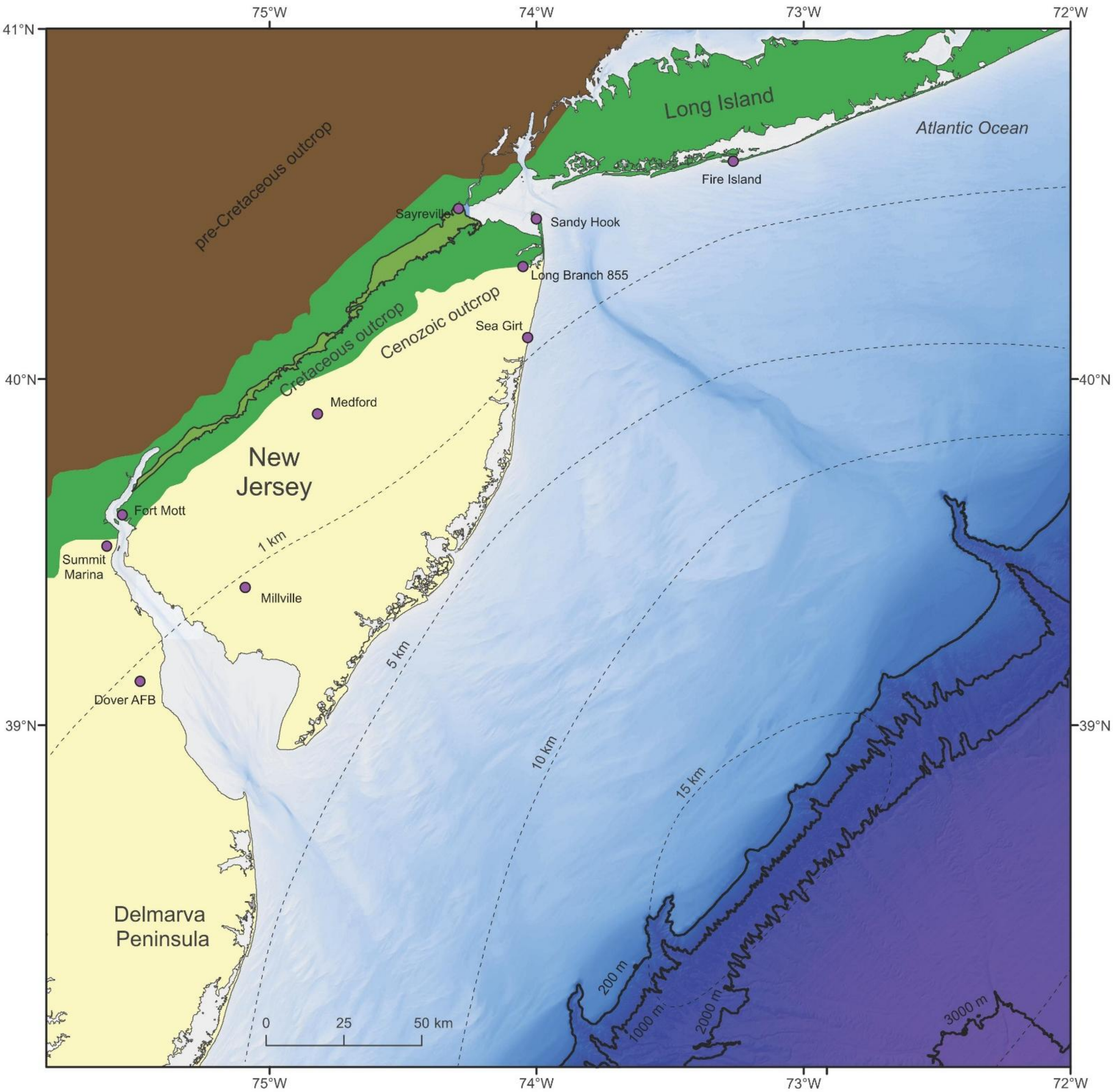
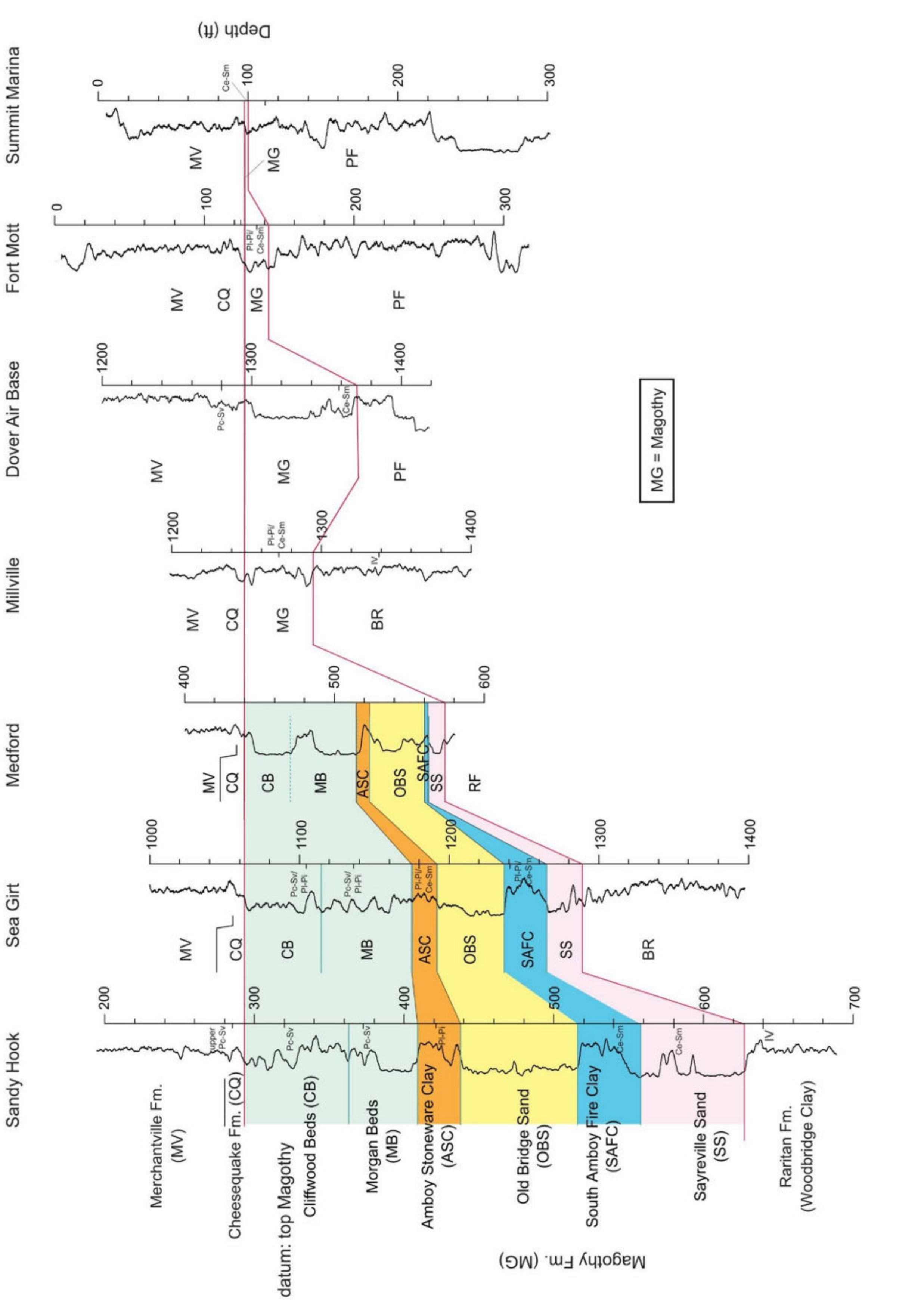
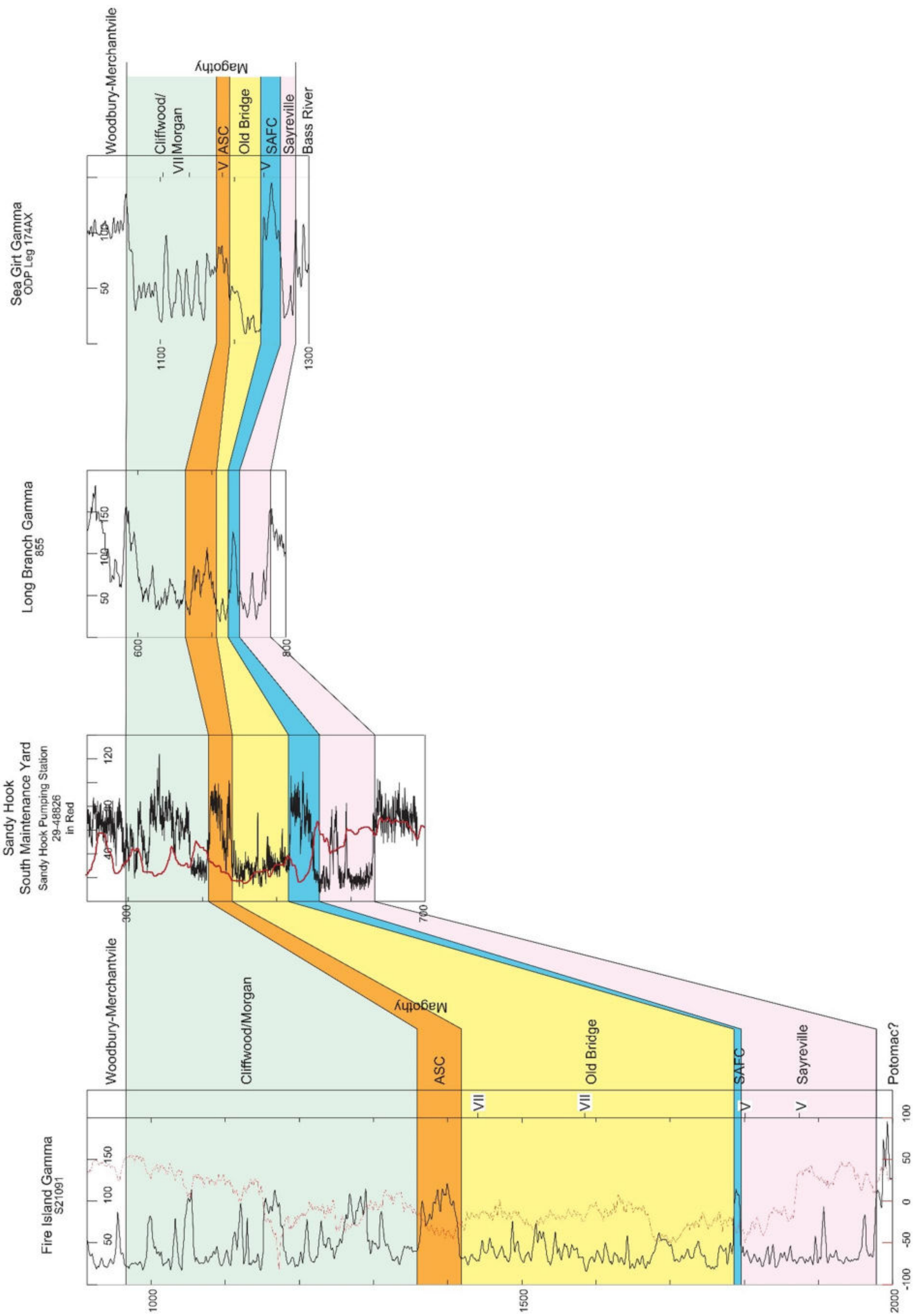
Abstract

Recent drilling at Sandy Hook and Sea Girt in Monmouth County, New Jersey has provided continuously cored, thick delta-plain and delta-front facies of the Magothy Formation (upper Turonian-Coniacian). The Magothy thickens northward across New Jersey (NJ) toward Long Island, New York (NY) with 2 to 3 large delta lobes and thins dramatically southward in NJ toward Delaware (DE) and Maryland (MD). The Magothy Formation is divided into 4 members (Sayreville Sand, South Amboy Fire Clay, Old Bridge Sand, and Amboy Stoneware Clay) and two informal beds (Morgan and Cliffwood). Here, we integrate physical evidence of erosion, rapid facies shifts, and pollen biostratigraphy to recognize and correlate these members and beds as 5 sequences. The sequences can be mapped along strike and downdip throughout the northern NJ Coastal Plain, but are thickest and best expressed at a new corehole at Sandy Hook, NJ where the Old Bridge and Sayreville Sand Members are thickest and show evidence of high rates of deposition. The basal member, the Sayreville Sand, overlies a major unconformity with the underlying Woodbridge Clay of the Raritan Formation, is a distinct upper Turonian sequence, was deposited in lower delta plain environments, and is an excellent local aquifer. The overlying South Amboy Fire Clay and Old Bridge Sand comprise an upper Turonian or possibly lower Coniacian sequence deposited in lower delta plain and tidally influenced delta front environments, respectively. The Old Bridge Sand is also an excellent aquifer. The Coniacian Amboy Stoneware Clay disconformably overlies the Old Bridge Sand, was deposited in delta front environments, and may be disconformable with the overlying Morgan beds that were deposited in subaqueous levees, interdistributary bays, and bay mouth bars. The Morgan beds are overlain by the Coniacian Cliffwood beds at an apparent unconformity. The Cliffwood beds show the strongest marine influence with tidally influenced interdistributary bays and swamps in lower delta plain environments, less organic-rich interlaminated sandy clays deposited in delta front environments, and slightly sandy clays in marine/prodelta environments. These non-and marginal marine strata are disconformably overlain by the marine Cheesequake Formation and sequence that apparently straddles the Coniacian/Santonian boundary based on our new calcareous nannoplankton biostratigraphy, firmly constraining the Magothy Formation to the Coniacian and older, in contrast to previous pollen correlations that extended it to the Santonian. The widespread distribution of Magothy sequences indicates stability of deltaic depositional systems despite known sea-level variations during the Turonian-Coniacian. Nevertheless, we note that the 5 sequence boundaries bounding the Magothy non-marine units correlate with 5 global unconformities of the global cycle chart, indicating a pervasive influence of sea-level change on lower delta plain to nearshore deposits.


75°W
74°W
73°W
72°W
41°N
40°N
39°N
pre-Cretaceous outcrop
Long Island
Atlantic Ocean
Fire Island
Sayreville
Sandy Hook
Long Branch 855
Cretaceous outcrop
Cenozoic outcrop
Sea Girt
Medford
New Jersey
Fort Mott
Summit Marina
1 km
Millville
Dover AFB
5 km
10 km
15 km
200 m
1000 m
2000 m
3000 m
Delmarva Peninsula
0
25
50 km



Cross-section from Sandy Hook, NJ to Summit Marina, DE showing Magothy Formation and members.



Cross-section from Fire Island, NY to Sea Girt, NJ showing Magothy Formation and members.

Delaware River Basin Commission Water Quality Management Case Studies

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Delaware River Basin Commission, West Trenton, NJ

Abstract

Throughout its history, the Delaware River Basin Commission has successfully addressed water quality challenges. This presentation will provide brief case studies of three successful water quality management efforts: (1) improvement of dissolved oxygen in the Delaware Estuary from the 1960's through the current, (2) addressing active pollution of legacy polychlorinated biphenyls, and (3) improving nutrient concentrations under an antidegradation program. This presentation will also consider the common features uniting all three efforts.

Delaware River Basin Commission

The Delaware River Basin Commission (DRBC) was formed in 1961 with the signing of the Delaware River Basin Compact by the governors of Pennsylvania, New Jersey, Delaware, and New York and President John F. Kennedy representing the Federal Government. Under the Compact, DRBC has broad authority and responsibility in the areas of:

- Water Supply;
- Drought Management;
- Flood Loss Reduction;
- Water Quality, including:
    - Establishment of Water Quality Standards;
    - Monitoring & Assessment;
    - Assimilative Capacity Determinations;
- Watershed Planning;
- Regulatory Review (Permitting);
- Outreach/Education; and
- Recreation

Dissolved Oxygen in the Delaware Estuary

One of the first water quality problems DRBC addressed was low dissolved oxygen in the Delaware Estuary in the urbanized reach near Philadelphia, Camden, and Wilmington. Figure 1 below shows a dissolved oxygen sag throughout most of the Delaware Estuary in 1963, with the lowest concentrations approaching 0 mg/L at River Mile 100 (in the vicinity of the Ben Franklin Bridge) beginning in May and persisting throughout most of the year.

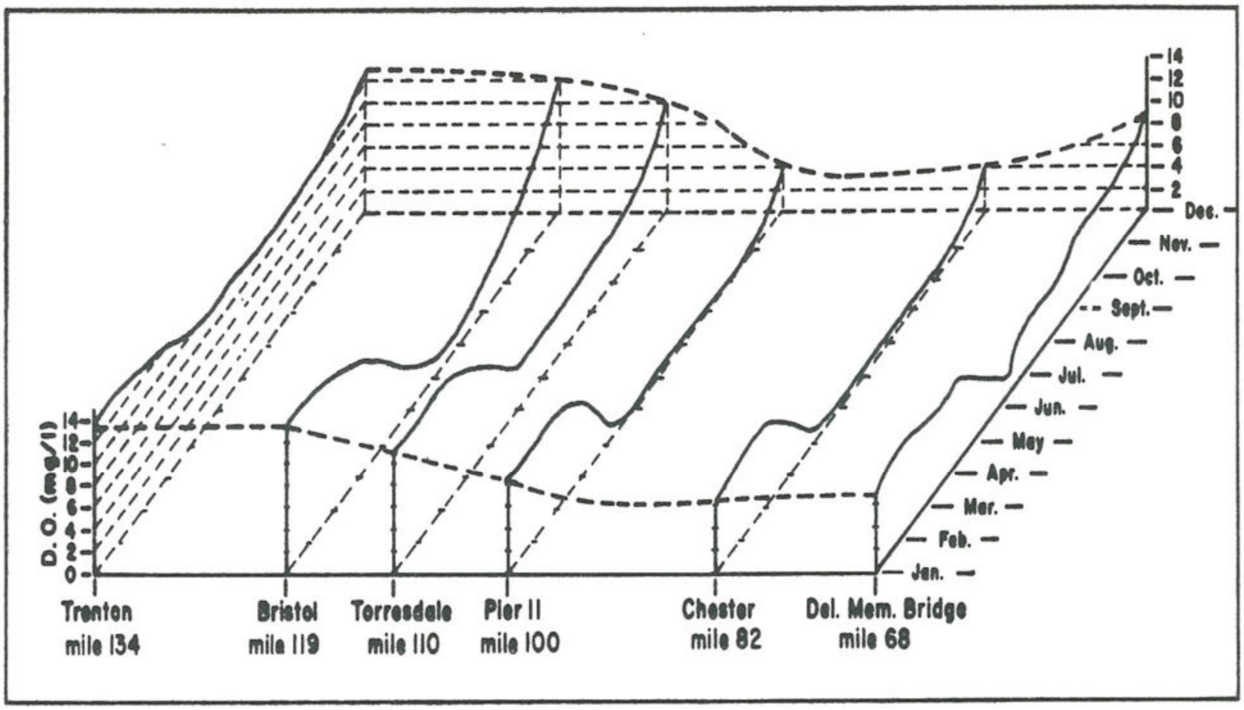

Figure 1. Spatial and Temporal variability in Delaware Estuary Dissolved Oxygen concentrations in 1963

Low dissolved oxygen presented a barrier to migratory fish, such as American Shad, whose life-cycle required returning to upper reaches of the non-tidal river to spawn. In 1967, DRBC established surface water quality standards for dissolved oxygen in the estuary, including a 24-hour dissolved oxygen concentration of not less than 3.5 mg/L in urbanized portion of the estuary. The new criteria was targeted at supporting migration of fish past the urbanized portion of the estuary, but not fish propagation. DRBC performed water quality modeling and in 1968 issued waste load allocations for estuary dischargers designed to achieve 3.5 mg/L of dissolved oxygen in the estuary even during summer months.

As a consequence of the new waste load allocations, waste water treatment facilities added secondary treatment (microbial biological digestion of waste) to their treatment trains during the 1970s and 1980s with funding provided under the Clean Water Act. Summer dissolved oxygen improved throughout the 1980s through the early 2000's such that criteria is nearly always met today. Figure 2 shows box and whisker plots of July dissolved oxygen concentrations measured at the USGS continuous water quality meter at the Ben Franklin Bridge (Station Number 01467200). The plot demonstrates the dramatic improvement in dissolved oxygen through 2016.

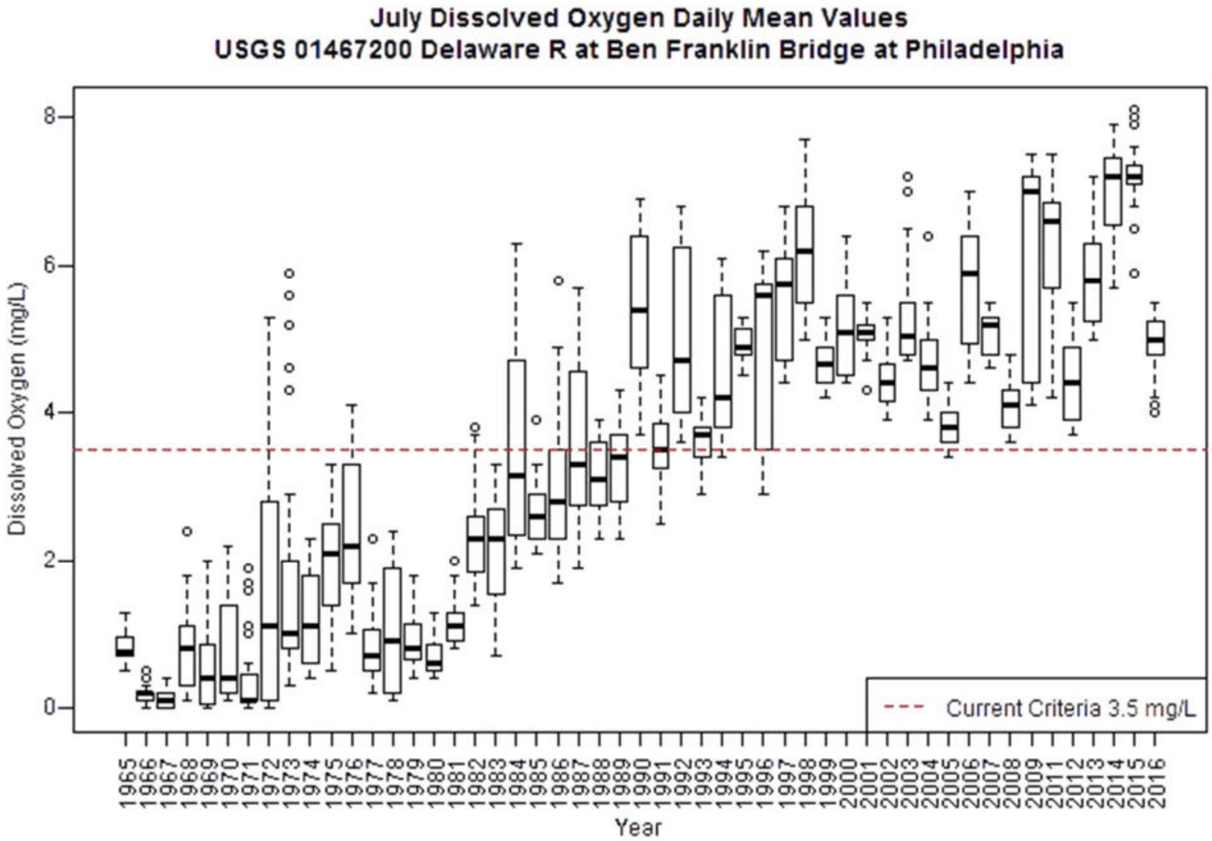

Figure 2. July dissolved oxygen concentration box and whisker plot by year measured at the USGS continuous water quality meter at the Ben Franklin Bridge (Station Number 01467200) compared to the current criteria of 3.5 mg/L.

DRBC's estuary water quality monitoring program also documents the improvement in summer dissolved oxygen. Figure 3 below shows 2017 July and August surface water dissolved oxygen measurements and a LOESS smooth of the data compared to criteria. Prior years' LOESS smooth lines are shown in gray. An animated version of the plot spanning the period from 1967 through 2017 is viewable at:

https://www.youtube.com/watch?v=eVV9_ncXa2A

It should be noted that in Figure 3 the water quality standard (24-hour average) is not directly comparable to the observations (near surface daytime spot measurement), but provides a useful visual reference.

As water quality improved, some level of fish propagation returned to the Delaware Estuary. DRBC's current project is to protect that propagation by establishing a new designated use and by developing revised dissolved oxygen criteria that will support this emerging new use.

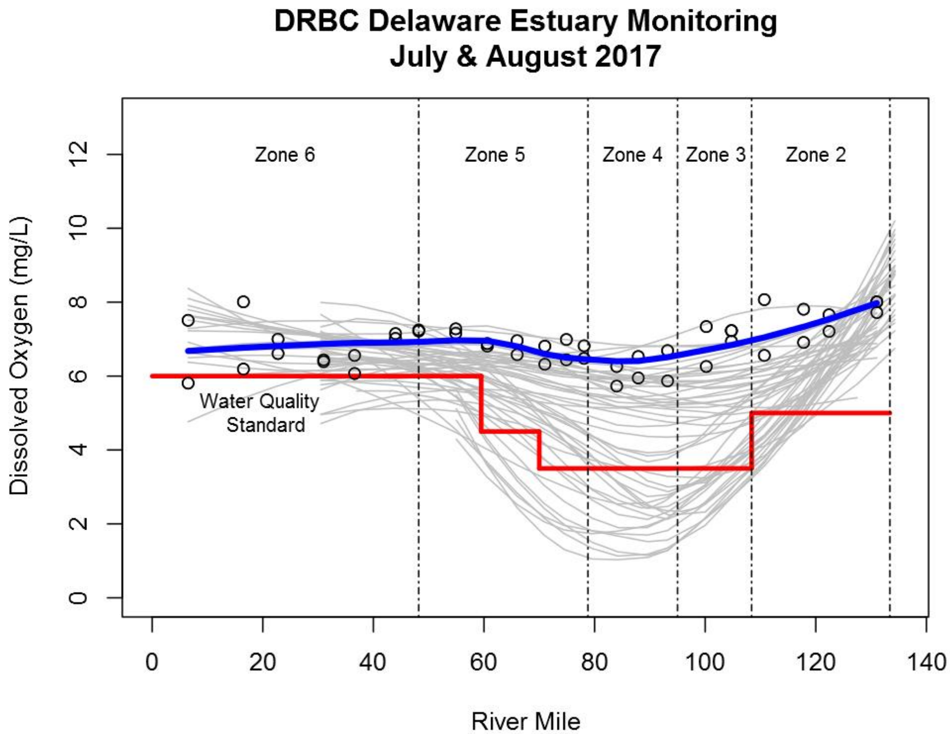

Figure 3. Comparison of July and August 2017 surface dissolved oxygen spot measurements to 24-hour standard and prior years LOESS smooth lines, demonstrating the spatial and temporal change in summer dissolved oxygen during the period from 1967 through 2017.

Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are a class of man-made chemical compounds that were commonly used in electrical and industrial equipment. PCBs are hydrophobic, bioaccumulative, and probable human carcinogens. Although the U.S. banned the manufacture of PCBs in the late 1970s, 1.5 billion pounds had already been produced and remained in use and persistent in the environment long after the ban. In fact, PCBs were the primary pollutant contributing to fish consumption advisories issued by Pennsylvania, New Jersey, and Delaware. Estuary water samples collected by DRBC showed that PCBs were present at two to three orders of magnitude higher than surface water quality standards.

In the early 2000's, DRBC developed a water quality model of PCBs in the Delaware Estuary and used that model to develop Total Maximum Daily Loads (TMDLs) for PCBs. EPA issued those TMDLs in 2003 (for Zones 2 through 5) and 2006 (for Zone 6, the Bay).

The TMDLs were implemented primarily through the requirement for point discharge facilities to develop and carry out Pollution Minimization Plans (PMPs) [DRBC, 2018]. Under the PMP program, dischargers to the estuary investigate their facilities, determine where PCBs were being introduced into their effluent, and take steps to eliminate those sources. For municipal waste water treatment facilities, this typically meant performing track down studies within their sewer-sheds. Addressing PCBs at their source, rather than at the end-of-pipe was expected to have several advantages. Since PCBs were no longer intentionally manufactured, identification and removal of known and potential sources would provide a perpetual load reduction. In addition, PCBs migrate from their original sources via multiple pathways including volatilization to the atmosphere and storm water runoff, so removing a source in sewer-shed would also eliminate exposure via those other pathways as well.

DRBC manages the PMP program for the Delaware Estuary in cooperation with state and federal environmental protection agencies, reviewing initial PMPs and subsequent annual reports, providing technical expertise, sharing successful strategies, and managing all the effluent monitoring data. DRBC compared 2016 PCB effluent concentrations to the 2005 baseline and found a 76% reduction among the top 10 point discharges as shown in Figure 4, confirming the effectiveness of the PMP approach. Notably, less strict fish consumption advisories have been issued by all estuarine states since 2015.

Achieving the TMDL is a decades-long commitment. PCBs discharged in the past adsorbed to sediment and carbon in the system and bleed back slowly into the water column. Substantial improvements in effluent PCB concentrations and the removal of PCB sources are the important first steps in reducing water column and fish PCBs.

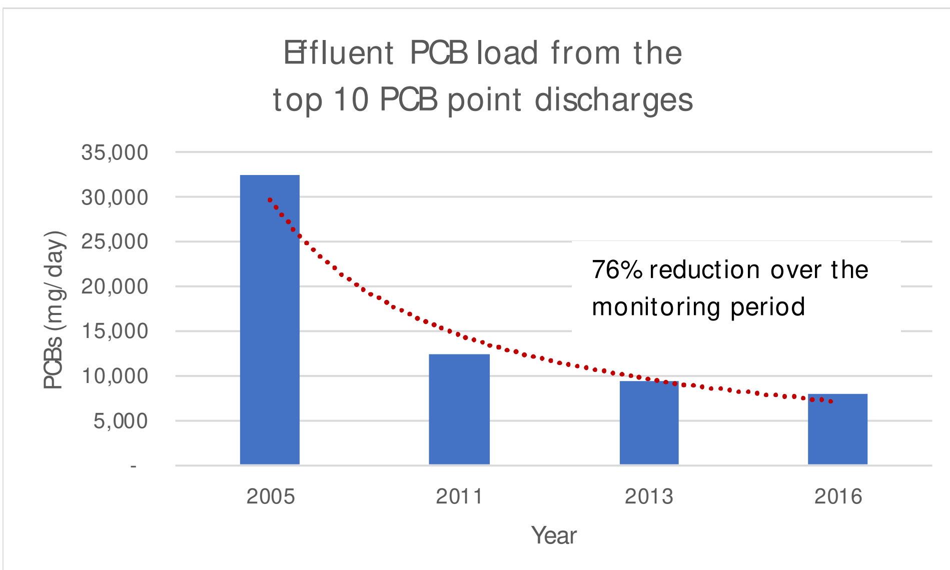

Figure 4. Combined effluent PCB data from top 10 point discharges showing a 76% reduction in PCBs between 2005 and 2016.

Special Protection Waters Program and Nutrient Reductions

The Special Protection Waters (SPW) program, initially adopted by the DRBC in 1992 and expanded in 1994 and 2008, is designed to prevent degradation in streams and rivers where existing water quality is better than the established water quality standards through stricter control of wastewater discharges and reporting requirements. Currently, the entire 197-mile non-tidal Delaware River from Hancock, N.Y. to Trenton, N.J. is designated as SPW. Three-quarters of this stretch of the river is also included in the National Wild and Scenic Rivers System.

The goal of SPW is that there be no measurable change in existing water quality except towards natural conditions [DRBC, 2008]. DRBC defined existing water quality through multi-year data collection and evaluation efforts at key locations in the main stem Delaware River and over 40 tributaries. New or expanding waste water treatment facilities planning substantial alterations or additions within SPW drainage must demonstrate to DRBC that their planned changes will not cause a measurable change to existing water quality. DRBC developed and utilized multiple water quality models in SPW drainage, to evaluate cumulative impacts from point and non-point sources. The models are used to set the effluent limits for multiple conventional water quality parameters for wastewater treatment plants to preserve existing water quality. Those new limits are incorporated into the applicant's permit.

In 2016, DRBC performed an assessment of the lower portion of SPW drainage, where the majority of new permits had been issued, comparing new water quality data to the older existing water quality definition data to determine whether or not the program had been successful in achieving the goal of preserving water quality [DRBC 2016]. That assessment showed that for most analytical parameters at most locations, existing water quality had been preserved, indicating that the program was successful. The data also indicated an apparent drop in nutrient concentrations at many locations over that time period. USGS developed and published a report assessing long trends a few months after the DRBC report [Hickman, 2017]. Although the USGS report used different data sets and a different assessment methodology, it corroborated DRBC's findings of improving nutrient concentrations in SPW drainage.

Common Features of Water Quality Success Case Studies

Although the water quality improvement case studies described here involve different water quality goals, different pollutant groups, and different portions of the Delaware River Basin, there are some features common to all three. Each effort required determination of mass loading rates, exposure pathways, chemical reactions, and water column response employing water quality modeling, application of engineering principles, and detailed technical analysis. All of the efforts involved intensive water quality monitoring to define conditions and inputs. Point discharge loads in all three cases remained an important loading category. In all efforts, substantial investments were required, by government and grant writing organizations to define problems and engineer solutions, and by dischargers and the regulated community to bring those solutions into reality. Finally, all three successful case studies required the cooperation and coordination of multiple agencies and organizations.

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Restoring Delaware Bay Oyster Reefs for Beach Resiliency

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Abstract

Shoreline erosion along New Jersey's Delaware Bay shoreline threatens both the integrity of coastal ecosystems as well as that of communities. Erosion is affecting the resilience, habitat quality and extent of tidal marshes and beaches. Over the last five years the American Littoral Society and partners have been building and testing the effectiveness of living shoreline techniques to mitigate and reduce erosion by restoring beaches and constructing intertidal oyster reefs to buffer the shoreline from wave action. With our previous experimental reefs, we have demonstrated that reefs have high oyster recruitment and survival and provide protection against beach erosion.

While it may be challenging to restore vast oyster reefs, the strategic use of living shorelines can, in the same manner, serve to dampen waves and slow shoreline erosion in strategically chosen areas. Oyster reef restoration is now a widely recognized living shoreline tool that can help achieve erosion-reduction.

Stemming erosion along the Delaware Bay shoreline is of vital importance for the resiliency of both ecological and human communities. There are many communities along the bayshore threatened by the combination of factors that now cause the bayshore to rapidly erode. This was shown in stark detail with the destruction caused by Hurricane Sandy, which destroyed major portions of towns from Reeds Beach to Fortescue. The heavy damage sustained by towns along the Delaware Bay has largely been unaddressed since the storm.

In 2013, in response to the damage to horseshoe crab spawning habitat caused by Hurricane Sandy, the American Littoral Society, Stockton Coastal Research Center and Conserve Wildlife Foundation of NJ were funded by National Fish and Wildlife foundation, the US Department of Interior and other sources to begin a long-term effort to restore habitat for breeding horseshoe crabs and create new resiliency for Delaware Beaches and communities. Our project also studied the horseshoe crab breeding behavior and microhabitats as well as intensively study the dynamics of beaches on Delaware Bay. Our work also focused on the erosion of Delaware Bay beaches, the causes and the remedies.

Characterization of Vernal Pools on Stockton University's Campus

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Introduction

Areas on the landscape that are seasonally saturated go by a multitude of names, including vernal ponds, vernal pools, ephemeral ponds, spungs, Carolina bays, Delmarva bays, whale wallows, seasonal forested pools, and likely many others. In each case, the term used to describe these features may tell the reader something about the formation, duration of saturation, location, or geomorphology of the feature. For example, a "spung" is a depression or basin found in southern New Jersey, on the outer coastal plain, with a peri-glacial origin (French and Demitroff, 2001). A Delmarva bay, or whale wallow, are elliptical depressional wetlands found on the Delmarva Peninsula, and are similar to Carolina bays (Fenstermacher et al., 2014). Bauder (2005) describes vernal pools in California as temporary wetlands fed by precipitation. A statewide survey of New Jersey vernal pools assigns a season to the classification of a vernal pool, noting that they should hold water in the spring, but may also have water well into the summer (Lathrop et al., 2005). Irrespective of the name or the specifics of the formation, morphology, or other local factors, these landscape features have a number of commonalities.

Some degree of hydrologic isolation, also described as confinement, is a characteristic of depressional wetlands. These wetlands lack both inflowing and outflowing streams (Lathrop et al., 2005), and their annual water budget is dominated by precipitation (input) and evapotranspiration (output), with the importance of groundwater contributions varying (Brooks, 2004). Additionally, these sites are of great importance for amphibian breeding (Zedler, 2003). Finally, the apparent lack of connection to the larger hydrologic system and exclusion from the U.S. Army Corps jurisdictional wetland definition have limited the protections afforded these areas. Massachusetts was the first state to offer protections to vernal pools, and New Jersey has developed guidelines to protect these areas based on hydrology, hydroperiod, and use by obligate or facultative pool breeders (Lathrop et al., 2005).

The objective of this research is to measure vernal pond hydrology and morphology for pools on the Stockton University campus to further characterize these important coastal plain habitats. Deepening our understanding of these landscape features will help in future assessments of the impact of land use changes and disturbances.

Site Description and Methodology

Four vernal pools located on the Stockton University campus were selected for hydrologic monitoring as part of a forest management project. The pools and campus are located in Atlantic County, New Jersey, in the Pinelands National Reserve and Atlantic Coastal Plain. Vegetation is a mixed mesic and xeric oak-pine forest with pitch pine (*Pinus rigida*), shortleaf pine (*Pinus echinata*), blackjack oak (*Quercus marilandica*), and post oak (*Quercus stellata*) as dominant canopy species (Whittaker, 1998).

The shrub layer in the more xeric uplands is dominated by heath shrubs, including huckleberry, bayberry, and inkberry. In the moister soils of the vernal pools, this layer is greatly diminished or absent.

Soils of the study area are formed from coastal sediments deposited during the Tertiary, namely the Kirkwood and Cohansey formations (Tedrow, 1998). Given their parent material, soils in this area are coarse textured, sandy soils with high infiltration capacity and hydraulic conductivities. These soils are Ultisols, with Spodosols, Histisols, Inceptisols, and Entisols mapped nearby (Soil Survey Staff[2], n.d.) (Figure 1). The study ponds are located near the mapped boundaries of the Downer and Aura series, which are both Ultisols. The Aura series description clearly identifies a fragipan layer, which is missing from the Downer description (Soil Survey Staff).

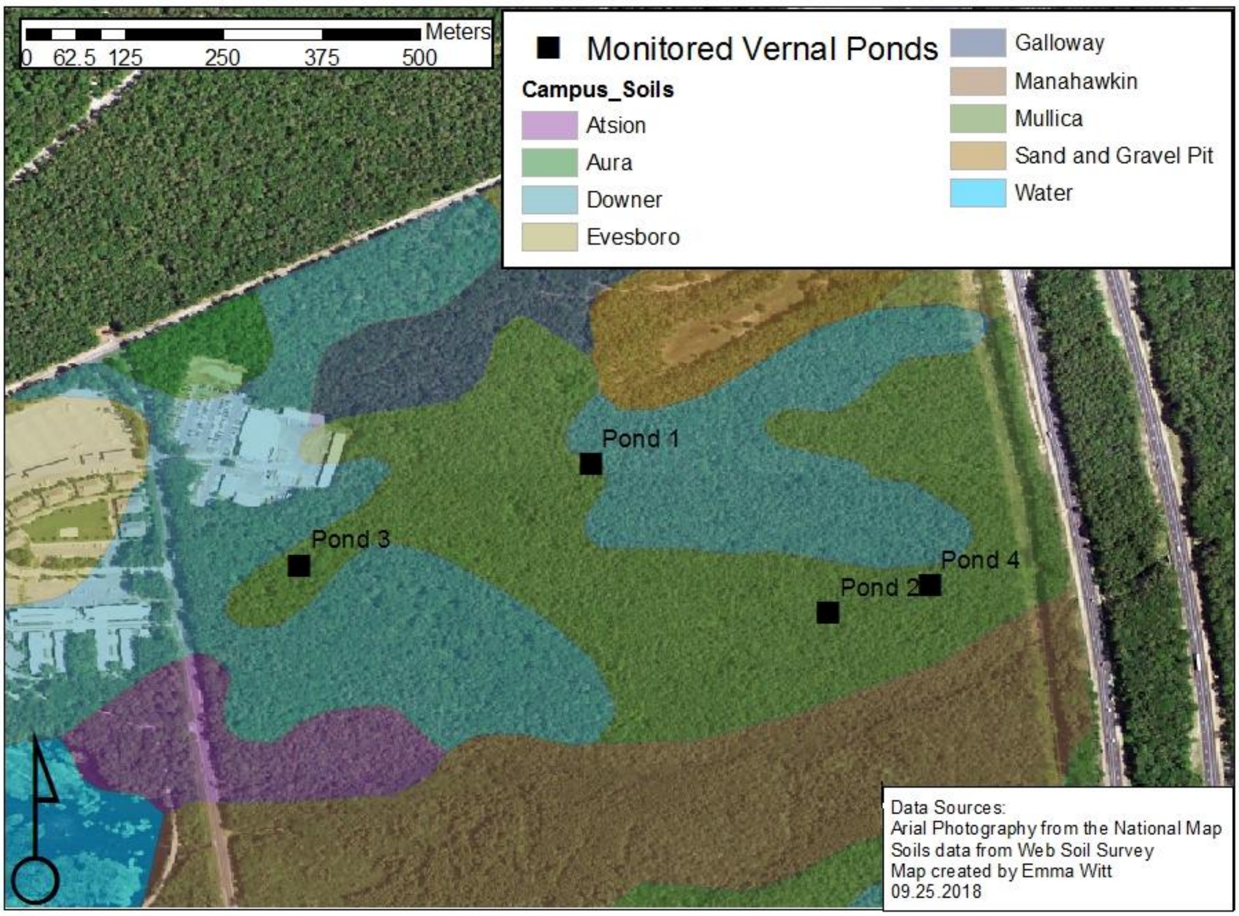

Figure 1: Site map with soil series. Soils data were downloaded from the Web Soil Survey.

Climate of the study site is characterized by warm summers (average temperature = 23 C) and cool winters (average temperature = 2 C), with an average annual temperature of 12.4 degrees C and annual precipitation of 1060 mm (Arguez et al., 2010). Precipitation is nearly uniformly distributed throughout the year, with each month receiving 73-107 mm of precipitation (NCEI, 2018).

Four vernal ponds were identified and monitoring wells were installed between 2015 and 2017. Wells were equipped with datalogging pressure transducers (Solinst Levelogger™ Jr. Edge, Solinst Canada Ltd., Georgetown Ontario) that record water level and water temperature on 15 minute intervals. Soils were sampled by hand using augers in 2018, making note of the presence or absence of the clay layer in each location. Hydrologic analyses included separation of the hydrograph into three components: rise time, fall time, and total event duration. Additionally, duration of ponding was determined for each vernal pond.

Results and Discussion

Soils and Geomorphology

Of the four ponds, two (Pond 1 and Pond 4) had the presence of a clay layer in the upper part of the soil profile. Ponds 2 and 3 did not have a clay layer in the upper 1.2 m at the locations sampled. With the exception of the clay layers the soils in all pools had loamy sand textures, with small gravels present in the profile. In terms of hydrology, one question that has been posed in relation to these pools relates to the source of the water. Are these seasonally wet because the groundwater table is near the surface during the “wet” (low evapotranspiration) season and they are at low spots in the landscape? Or are they features where precipitation is perching due to the presence of a low hydraulic conductivity layer? Based on the discontinuous nature of the clay layer, it seems both situations may be influencing the ponds in this area.

The geomorphology of the area may provide additional clues to the hydrology of these ponds. Ecological monitoring at pond 3 has been ongoing for ten years or longer, which has led to a deeper understanding of this pond relative to the others. It has been hypothesized that this pond formed in an area of peri-glacial dunes, which resulted in the low landscape position it currently occupies (Cromartie, personal communication). Examination of the LiDAR map of the area indicates support for this idea, and may contribute to the understanding of pond 2 (Figure 2).

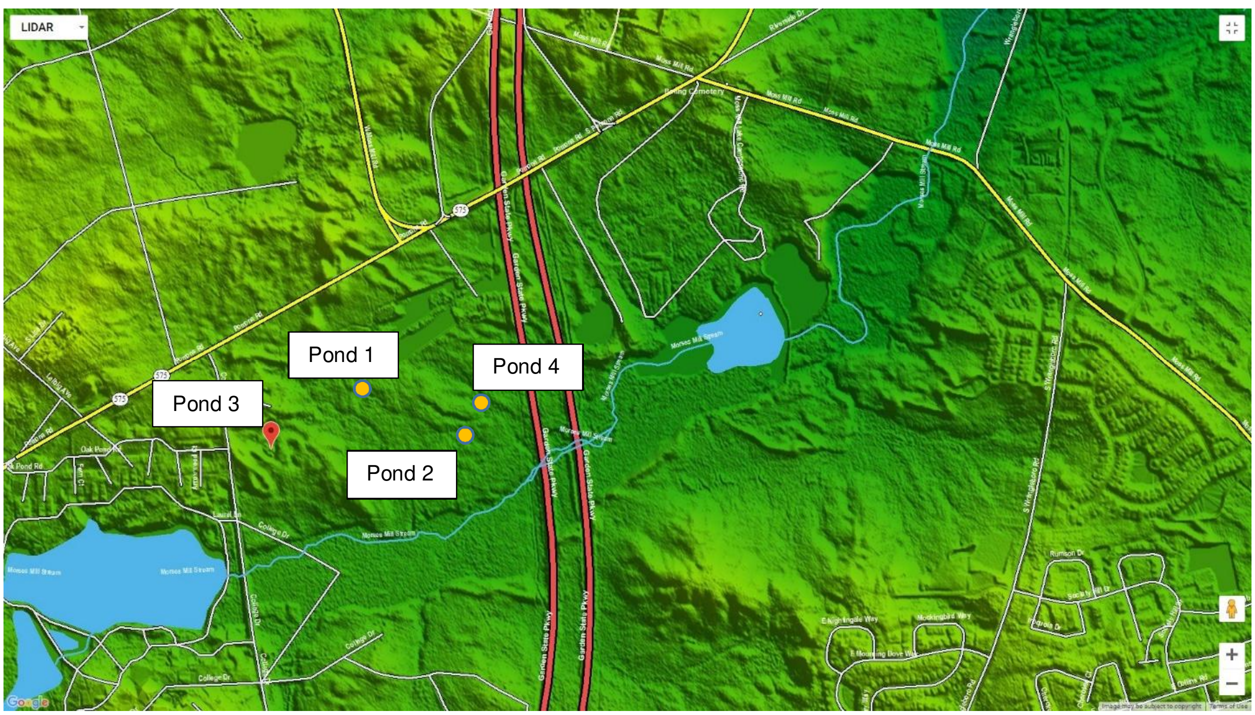

Figure 2: LiDAR map of the study area. The red marker indicates the location of Pond 3. The location of Ponds 1, 2, and 4 are estimated. Map from https://maps.njpinebarrens.com.

An additional dune structure may be present between Pond 2 and Pond 4. This dune does not appear to be as extensive as the dunes around Pond 3. Further, additional characterization of these landforms needs to be completed to evaluate their origin and determine what influence they are having on the vernal ponds. Future work may include determining the elevation of the bottom of each pond, and conducting ground based LiDAR surveys of the area.

In addition to the dunes visible on the LiDAR map of the area, an old stream channel appears to be present in the area, running south from Pond 1 to Morse's Mill stream. More evidence for this can be seen in the 1930 aerial photo (Figure 3). The pond complexes that currently include Pond 1 can be easily seen in the photo, and appear to be connected by a stream that may at one time have drained the area into Morse's Mill stream. The hydrology of Pond 1 may be more influenced by shallow subsurface (interflow or throughflow) processes than the other three study ponds. Further work on the characterization of this pond may include ground based LiDAR and hydrologic tracers.

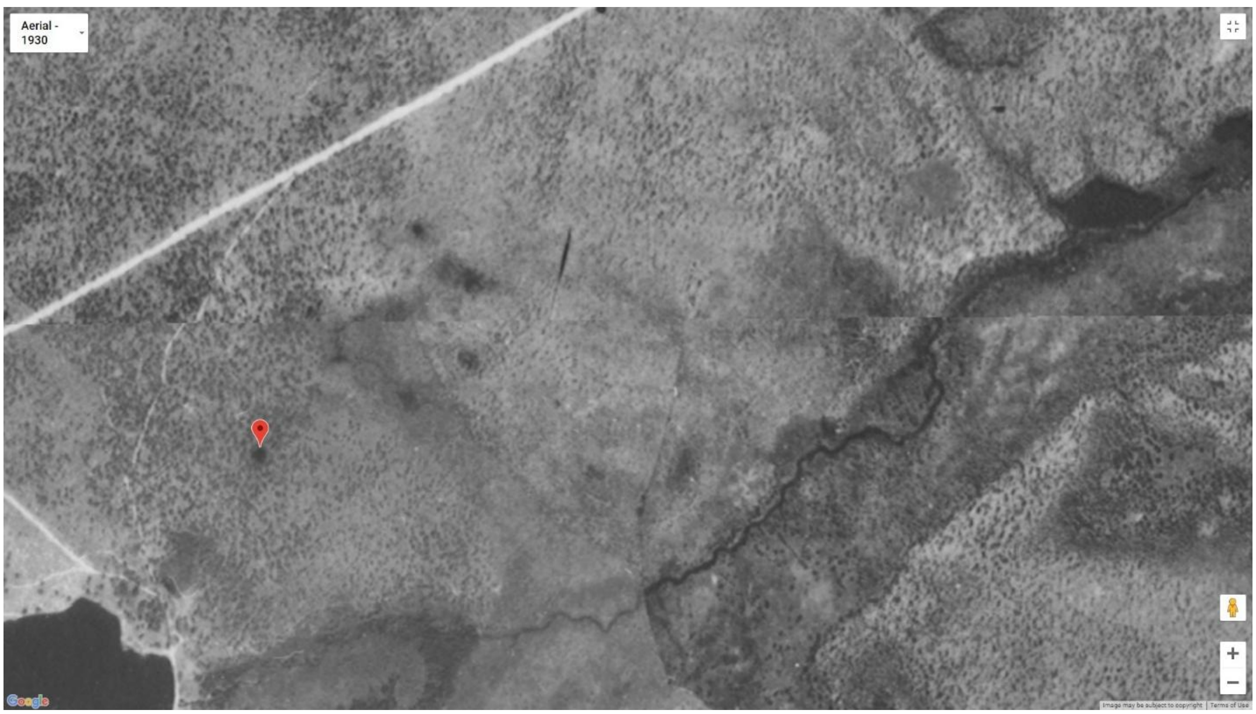

Figure 3: 1930 aerial photo of the study area. The red marker indicates the location of Pond 3. Pond 1 is located to the northeast of pond 3.

Hydroperiod

Data from the wells in Ponds 2 and 4 indicate that the water table in these pools fluctuates rapidly in response to precipitation events, and responded similarly to precipitation events in March of 2017 that led to the most extensive ponding for both pools (Figure 4, Figure 5, Figure 6). The presence or absence of a clay layer does not seem to impact the hydrologic response of these ponds. Future work will evaluate the hydrologic response of these pools to precipitation and incorporate the hydroperiods of Pools 1 and 3.

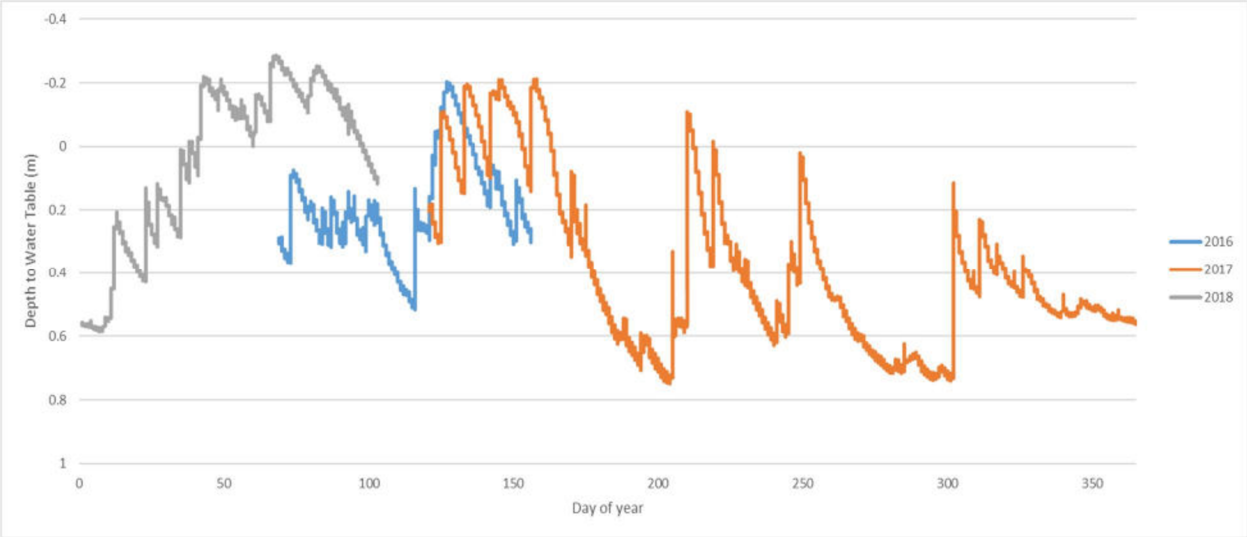

Figure 4: Water table depth data for Pond 2.

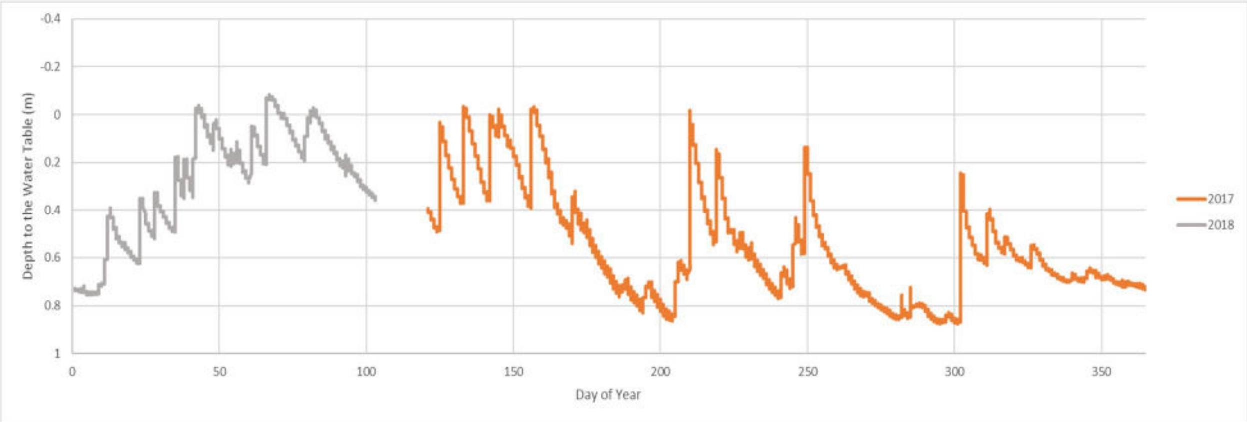

Figure 5: Water table depth for Pond 4

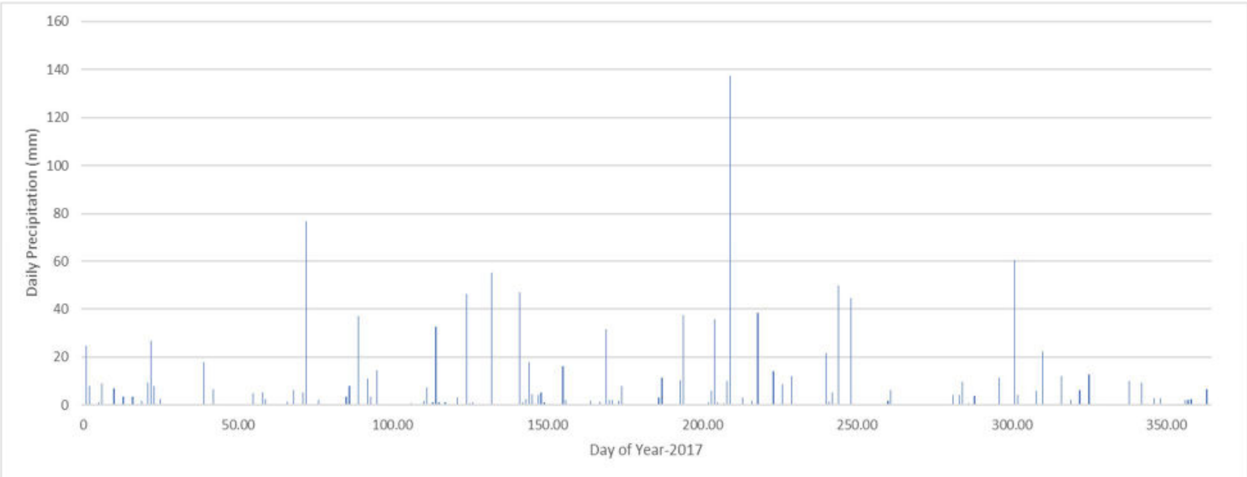

Figure 6: Daily precipitation measured in 2017. Data were measured at the Atlantic City International Airport. Data from the National Centers for Environmental Information. https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00093730/detail

Conclusions

The similar hydrologic response initially seen between wells with differing sub-surface soils is encouraging, given that these data are being collected in anticipation of forest management activities in the area. Vernal pools whose hydrology is mainly governed by precipitation and evapotranspiration would be more likely to respond to vegetation changes than those with a significant groundwater interaction, although a response in those cases would be expected as well. An additional takeaway from the use of aerial photos to examine the morphology is that the lack of forest cover seen in the 1930 aerial (Figure 3) shows the extent to which these ponds were visible, with surface water, under different vegetation management strategies. Future work on this project will focus on building a more complete hydrologic dataset as well as further examination of the morphology of the area.

Acknowledgements

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Quaternary Geology of the Lower Delaware Valley

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Abstract

Quaternary deposits in the lower Delaware River valley include estuarine, nonglacial fluvial, and glaciofluvial sediments of middle to late Pleistocene and Holocene age. They occupy an inner valley within a broader Pliocene valley. The inner valley was cut in the early Pleistocene. Middle and upper Pleistocene estuarine sediments are grouped into the Cape May Formation. This formation consists of three units: the Cape May 1, which forms a terrace at 60 to 70 feet in elevation and was likely laid down around 400 ka, the Cape May 2, which forms a terrace at 30 feet and was laid down around 125 ka, and the Cape May 3, which forms a terrace at 15 feet and was likely laid down between 110 and 80 ka. Nonglacial fluvial deposits include upper and lower terrace sediments. Deposition of the upper terrace occurred principally during the Illinoian glacial period (300-150 ka), or earlier, and, in places, continued in the Sangamon interglacial (125-80 ka) and possibly into the Wisconsinan glacial period (80-11 ka). Lower terraces formed in the middle and late Wisconsinan (40-11 ka). Glaciofluvial gravels include small erosional remnants of Illinoian outwash and a prominent late Wisconsinan (28-18 ka) outwash plain in the Trenton area. Postglacial sediments include alluvial terrace and floodplain deposits inset into the late Wisconsinan outwash, and estuarine sediments that aggraded during Holocene rise of sea level. Continuing sea level rise over upcoming centuries will return to levels marked by the Cape May terraces.

Introduction

The Delaware and Susquehanna are the only rivers on the east coast to flow from glaciated terrain across unglaciated areas to the ocean. The Delaware enters the Coastal Plain at Trenton and then flows as a tidal river along the inner edge of the Coastal Plain for 65 miles to the head of Delaware Bay near Salem. It has a longer route through low-relief Coastal Plain terrain than the Susquehanna, which empties into Chesapeake Bay directly from its gorge in the Piedmont. The Quaternary deposits in the lower Delaware valley between Trenton and the head of Delaware Bay thus provide a unique record along the east coast of river response to changing climate, glaciation, and the rise and fall of sea level during the glacial-interglacial fluctuations of the Quaternary over the past 2.5 Ma.

During the Quaternary the Laurentide ice sheet grew to near its maximum extent about ten times. At least three of these advances entered the Delaware basin. With the repeated growth and melting of ice sheets, global sea level fell and rose over a range of more than 400 feet. During at least two of the interglacial highstands, sea level in the Delaware valley was higher than at the present interglacial.

This paper will use the Quaternary sediments and landforms in the lower valley between Trenton and Salem to understand the response of the river to this dynamic history of climate, glaciation, and sea level. The observations presented here are based on 1:24,000 geologic mapping in the New Jersey part of the lower valley, including subsurface data from logs of several thousand water wells and test borings (Stanford, 2003, 2004a, b, c, 2006a, b, 2008a, b, 2009, 2012, 2014). This work was funded by matching grants from the Statemap component of the National Geologic Mapping Program between 1998-2012. These maps are available for free viewing and download on the N. J. Geological and Water Survey website (www.njgeology.org). The Quaternary geology of the Pennsylvania part of the lower valley is from mapping in Bascom and others (1909a, b), Peltier (1959), and Owens and Minard (1975). Quaternary geology in the Delaware part of the lower valley is from Ramsey (2005).

The juxtaposition of estuarine, glaciofluvial, and nonglacial fluvial sediments in the lower valley, particularly in the Trenton area where the topographic grade of the various deposits converge, is a challenge for Quaternary geologists. This complexity, and our evolving understanding of the relationships between glaciation, sea level, sedimentation, and land motions, has resulted in a confusing trail of stratigraphic nomenclature (see discussion in Stanford, 2014). Because of this confusion I have chosen to use descriptive terms such as "upper terrace deposits" and "late Wisconsinan outwash" rather than formal or semi-formal names such as "Trenton Gravel" and "Van Sciver Lake beds" for the deposits, except for the Cape May Formation, which is a well-established unit mappable around the entire New Jersey coast.

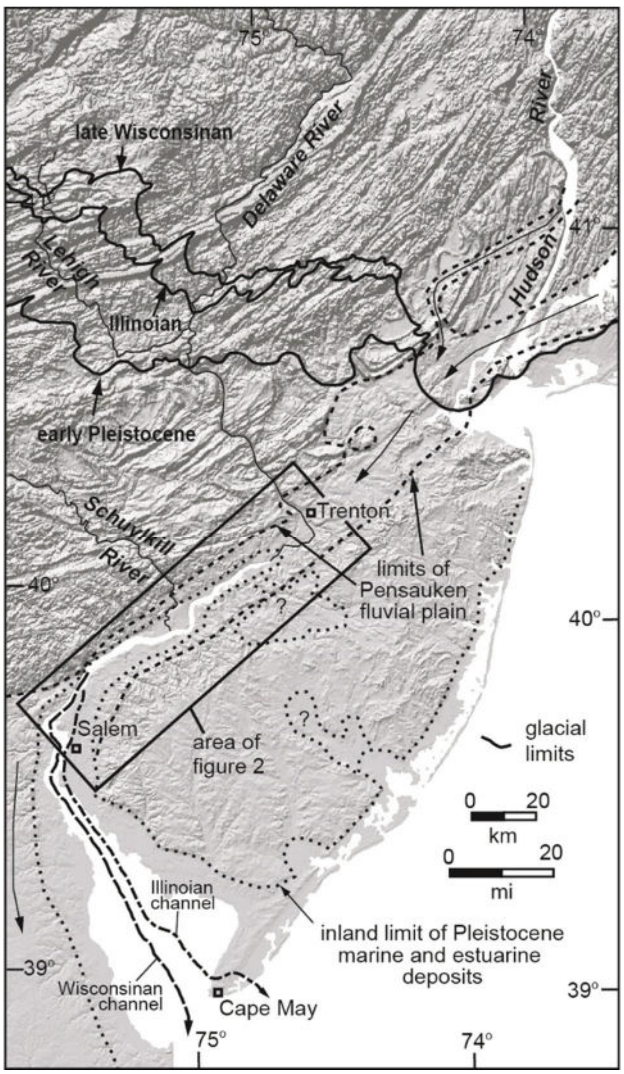

Figure 7. Glacial limits, Pensauken plain, limit of Pleistocene marine deposits, and lowstand channels.

Pliocene and early Pleistocene (5 Ma-800 ka)

The general form of the lower valley took shape in the late Miocene and early Pliocene, when the Pensauken River incised a valley to a depth near modern sea level along the inner edge of the Coastal Plain between the New York City area and the Delmarva Peninsula (fig. 1). This river included the ancestral Hudson, Delaware, and possibly rivers from southern New England, and so was a major trunk drainage for the northeast. The Delaware joined the trunk river at Trenton. The right-angle bend to the southwest at Bordentown is an inheritance of this junction. During the mid-Pliocene highstand of sea level sand and gravel fluvial deposits aggraded in the valley to a thickness of as much as 140 feet, forming a braidplain as much as 15 miles wide (fig. 1). This deposit is the Pensauken Formation (Salisbury and Knapp, 1917). Remnants of the Pensauken cap uplands within the present valley with top elevations of about 130 feet in the Trenton area, declining to about 80 feet in the Salem area. This gradient, and paleocurrent measurements from cross beds (Owens and Minard, 1979; Martino, 1981: Stanford, 2010) document southwesterly flow. Upstream from Trenton, rock-cut benches with gravel lags about 120 feet above the river that grade downvalley to the plain mark the position of the river during Pensauken time.

The Pensauken River was diverted southeasterly to the Atlantic in the New York City area during an early Pleistocene glaciation. The extent of this glaciation (fig. 1) is known from patches of deeply weathered and eroded till (Port Murray till of Stone and others, 2002) in northern New Jersey. This advance may correlate to the earliest Laurentide glaciation, which is dated in the Missouri River valley to between 2 and 2.5 Ma (Roy and others, 2004; Balco and others, 2005; Balco and Rovey, 2010). Following the diversion, the Pensauken plain south of New York City was abandoned and a new drainage network was established on the plain by former tributaries. The Delaware adopted its course on the former plain between Trenton and Salem and, in the early Pleistocene, incised an inner valley about 100 feet below the former plain. The younger Quaternary deposits were laid down within this inner valley.

Middle Pleistocene (800-130 ka)

The oldest Quaternary deposit in the inner valley is unit 1 of the Cape May Formation (Salisbury and Knapp, 1917; Newell and others, 1995; renumbered to Cape May 3 by Newell and others, 2000). This deposit consists of estuarine sand, silty sand, and gravel that forms eroded benches and terraces within modern valleys with top elevations between 60 and 75 feet. The base of the deposit is near the bottom of tributary valleys, indicating that the valleys had been eroded to near their present depth before deposition of the Cape May 1. It has been eroded from beneath the main Delaware valley by later lowstand incisions (fig. 2a). A clay-silt bed in the Cape May 1 in Pennsauken known as the Fish House clay (Woolman, 1897) contains freshwater mussel, mammal, fish, and plant fossils (Woolman, 1897; Bogdan and others, 1989) indicating a temperate interglacial climate.

Amino-acid racemization ratios (AAR) on shells in the Cape May 1 sampled in a corehole on the Cape May peninsula (Sugarman and others, 2007) and in sand pits on the north shore of Delaware Bay (Lacovara, 1997; O'Neal and others, 2000) indicate that the deposit was laid down either during the MIS (marine isotope stage) 9 (peak at 330 ka) or MIS 11 (peak at 400 ka) highstands. Coral terraces in Bermuda and the Bahamas at similar elevation to the Cape May 1 are dated to MIS 11 (Olson and Hearty, 2009) and no other middle Pleistocene highstands reached this height (Rohling and others, 2014). Thus, most of the Cape May 1 deposition was likely during MIS 11. The MIS 11 interglacial was of particularly long duration, allowing more time for glacioisostatic subsidence in the forebulge area, including southern New Jersey, around the Laurentide ice sheet, thereby raising relative sea level in that zone (Raymo and Mitrovica, 2012).

During the lowstand after MIS 11, and during subsequent lowstands following the MIS 9 and 7 interglacials, the Delaware incised the Cape May 1 valley fill to depths between 50 to 100 feet along the main channel. This incision was completed by the time of Illinoian glaciation (MIS 6, peak at 150 ka) because erosional remnants of Illinoian outwash occur on the bedrock surface at the base of the valley in the Trenton area. The Illinoian glacier advanced to a terminal position near Phillipsburg (fig. 1). Glaciofluvial gravel formed an outwash plain in the valley that extended downstream to the Trenton area. Today the deposit is preserved only in small isolated erosional remnants against the valley wall about 30 feet above the late Wisconsinan outwash plain in the narrow valley north of Trenton. It may be more extensive in the subsurface beneath the late Wisconsinan outwash in the Trenton plain, where it has been observed in several deep excavations and in two small outcrops that protrude above the plain. The Illinoian gravel is identified by the weathering of feldspars in gneiss and arkosic sandstone clasts. These clasts are generally unweathered in late Wisconsinan deposits. Illinoian outwash cannot be positively

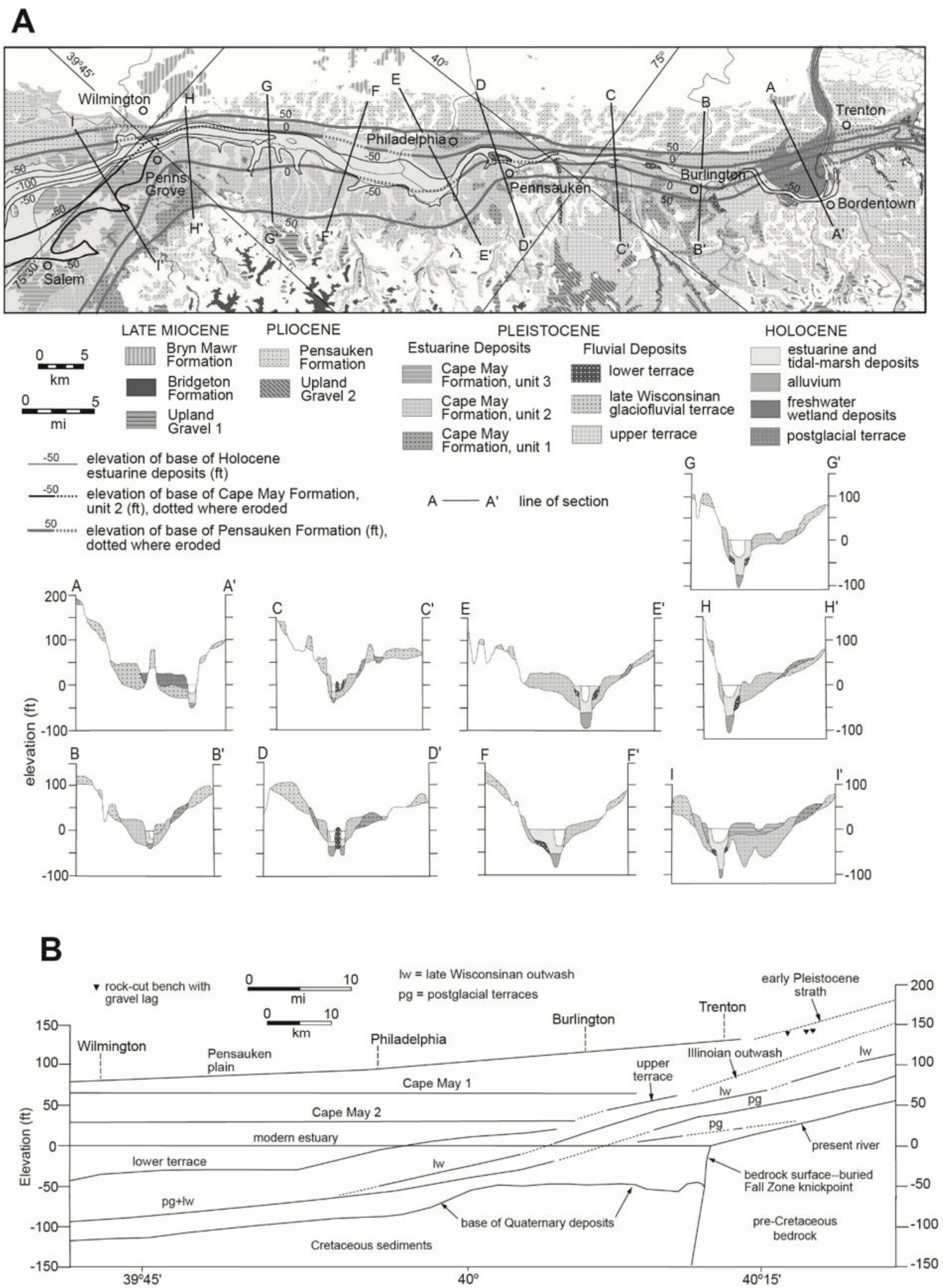

Figure 8. Map and sections (A) and topographic profile (B) of surficial deposits in the lower Delaware valley.

identified south of the Trenton area, either because it was removed by Wisconsinan erosion or buried by Cape May 2 interglacial deposits.

Late Pleistocene (130-11 ka)

During the MIS 5 interglacial highstand, also known as the Sangamonian Stage in North America, sea level in the New Jersey area reached an elevation of 30-35 feet. Estuarine sand and gravel of the Cape May Formation, unit 2 (equivalent to the Lynch Heights Formation in Delaware) form a nearly continuous terrace in the lower valley at that elevation south of the Burlington area. Between Burlington and Penns Grove these deposits form a shallow fill (generally less than 30-40 feet thick) in the valley cut into the Cape May 1 during earlier lowstands. From Penns Grove to Salem a buried channel of the main Delaware, known as the Pennsville paleovalley, lies a mile or so east of the present Delaware channel. It is filled with as much as 100 feet of Cape May 2 deposits, including organic silt as much as 40 feet thick. This valley connects to a seismically-imaged buried channel beneath Delaware Bay (Knebel and Circe, 1988) and the Rio Grande paleovalley beneath the Cape May peninsula (Gill, 1962; Newell and others, 1995; Sugarman and others, 2016). Together they mark the route of the lower Delaware during the Illinoian and, possibly, earlier lowstands (fig. 1). Filling of the valley during the Sangamon highstand, and southward growth of the Cape May spit (now the Cape May peninsula) at that time, blocked the channel and caused the Delaware to incise a new channel to the west during the subsequent Wisconsinan lowstand.Radiocarbon dates on organic material from the Cape May 2 in the lower valley and around the north shore of Delaware Bay (Richards, 1960; Gill, 1962; Kraft, 1976; Owens and Minard, 1979; Jengo, 2006; Stanford and others, 2016) are all dead (>40 ka). AAR dates on shells sampled from the Cape May 2 on the Cape May peninsula and the north shore of Delaware Bay (Lacovara, 1997) indicate an MIS 5 age. AAR dates from the Lynch Heights Formation in Delaware are older (MIS 9) but the Lynch Heights includes an older, higher terrace at an elevation of 45 feet that is not present in the Cape May 2 (Ramsey, 2010). Pollen (Newell and others, 1995), plant fossils, including an *in situ* bald cypress stump in Philadelphia (Richards, 1930), and marine fauna (Richards, 1933; MacClintock and Richards, 1936) from the Cape May 2 indicate a climate warmer than present. This suggests that the Cape May 2 was laid down during the peak interglacial conditions at substage 5e (around 125 ka).

In tributary valleys in the Coastal Plain, and in the main valley upstream of Burlington, fluvial sand and gravel forms terraces 15 to 40 feet above the present floodplain and estuary. These upper terraces grade to, or are onlapped by, the Cape May 2 terrace, indicating that the upper terrace is of the same age as, or slightly older than, the Cape May 2. In the Trenton area, where the late Wisconsinan glaciofluvial deposit aggraded in the main valley to an elevation (50-55 feet) close to that of the upper terraces in tributary valleys, radiocarbon dates on wood and peat in the terrace sediments (Sirkin and others, 1970; Stanford and others, 2016) show that some deposition on the downstream end of the upper terraces occurred in the late Wisconsinan. Upstream from the main valley in the Pennsauken, Rancocas, and Assiscunk creek basins (queried area on fig. 1) the upper terrace broadens into an extensive plain that crosses drainage divides in several places. This plain, which has a surface between 40 and 60 feet in elevation, may have initiated as an estuarine bay during the Cape May 1 highstand, because Cape May 1 deposits extend into the plain from the main valley at top elevations of 60-70 feet. The upper terrace of this plain is shallowly inset into the Cape May 1, so it may be only slightly younger than the Cape May 1 here. Thus, deposition on the upper terrace in valleys that were upstream of main-valley incision may span a long period between the Cape May 1 highstand (400 ka) and the end of glaciofluvial aggradation during the late Wisconsinan (18 ka), when the main Delaware channel downcut and tributary streams could finally incise below the terrace. Terrace deposition may have occurred during both cold periods, when more sediment was eroded from uplands due to the formation of permafrost and reduced tree cover, and during interglacial highstands, when the lower reaches of valleys alluviated as sea level rose.

In the main valley below the Penns Grove area a lower estuarine terrace with a top surface at 10 to 15 feet in elevation is inset into the Cape May 2. Sediments forming this terrace are unit 3 of the Cape May Formation (renumbered to Cape May 1 by Newell and others, 2000) equivalent to the Scotts Corners Formation in Delaware. The Cape May 3 rings Delaware Bay, where it is inset into the Cape May 2 along a scarp known as the Cedarville scarp, and extends up the Atlantic coast to the Mullica estuary. As with the Cape May 2, radiocarbon dates on organic material at two places in the Cape May 3 are >40 ka (Sirkin and others, 1970; Newell and others, 1995). There are no AAR dates from the Cape May 3 in New Jersey or from the Scotts Corners in Delaware (Ramsey, 2010). Two luminescence dates of >37 and >100 ka were obtained from depths of 3 and 6 feet, respectively, in the Cape May 3 terrace on the north shore of Delaware Bay (O'Neal and Dunn, 2003). Pollen from four sites in the Cape May 3 along the bayshore (Sirkin and others, 1970; Newell and others, 1995) show a mix of warm-temperate and cold-temperate taxa. These characteristics all suggest that the Cape May 3 was laid down in late MIS 5 as sea level fell from the MIS 5e peak, possibly when sea-level fall was interrupted by periods of slight rise during substages 5a (85 ka) and 5c (110 ka).

After deposition of the Cape May 3 sea level fell as ice sheets grew in the Wisconsinan (80-11 ka). The Delaware again incised. Downstream from Penns Grove it adopted a course to the west of its Illinoian lowstand channel, which had been filled with Cape May 2 and 3 sediments. In the middle Wisconsinan (MIS 3, 60-35 ka), sea level rose to an elevation of about -50 to -60 feet off southern New Jersey, as recorded by offshore beach and back-bay sediments (Sheridan and others, 2000; Wright and others, 2009; Uptegrove and others, 2012). This period of higher sea level, and the onset of periglacial conditions towards the end of the middle Wisconsinan, led to deposition of fluvial sediments in the incised channel. These sediments form the lower terrace deposits, which are dated by radiocarbon at several places in the lower valley to between 44 and 33 ka (Kraft, 1976; Jengo, 2006; Stanford and others, 2016, all finite dates based on radiocarbon ages are stated in calibrated years). This terrace crops out as low islands in the river or as narrow terraces along the riverbank between Burlington and Philadelphia, and is present in the subsurface beneath a cover of Holocene estuarine silt south of Philadelphia as a bench bordering the thalweg of the channel (sections E through I, fig 2a). The topographic profile of the terrace flattens downvalley at an elevation of -40 to -50 feet (fig. 2b), perhaps marking a transition from fluvial to estuarine conditions in response to the MIS 3 highstand.

Renewed fall of sea level during maximum expansion of ice sheets in the late Wisconsinan (MIS 2) led to incision of the lower terrace, to a depth of 130-140 feet below sea level in the Salem area and to about 50 feet below sea level just south of Trenton. At Trenton, where the incising channel encountered gneiss and schist bedrock rather than easily eroded Coastal Plain sediments, a nickpoint formed and incision halted (fig. 2b).

The late Wisconsinan glacier was in the Delaware basin between 28 and 18 ka, reaching its terminus at 25 ka. During this period, meltwater descended the river and deposited outwash gravels, which built a plain in the valley between Trenton and Burlington. Downstream from Burlington the plain narrows, passes below sea level, and is covered by Holocene estuarine sediment (fig. 2b). It becomes indistinguishable from postglacial alluvial gravel in the valley thalweg below the Philadelphia area. At Trenton a part of the plain extends northeast, crosses a low divide, and descends the Millstone River valley to the Raritan River. This routing occurred because of glacioisostatic depression to the north and forebulge growth to the south, which tilted the valley enough to divert the Delaware northeastward to exit to the ocean via the Raritan and Hudson Shelf Valley (Stanford and others, 2016). This diversion continued until the forebulge had subsided enough to restore southwesterly flow, probably by 14 or 15 ka. A similar diversion may have occurred during the Illinoian glaciation, because the Illinoian glacier had a mass distribution like that of the late Wisconsinan glacier (fig. 1).

After ice retreated from the Delaware basin and forebulge subsidence reopened downvalley drainage, the Delaware, free from glacial sediment load, incised into the outwash plain to a depth of 60 to 70 feet. Radiocarbon dates on organic materials at the base of postglacial alluvium in the main and tributary valleys indicate that this incision was complete by 12 to 14 ka (Sirkin and others, 1970; Stanford, 1993; Schuldenrein, 2003, Southgate, 2010).

Holocene (11 ka to present)

After incision into the late Wisconsinan outwash was complete, postglacial sediments have been deposited in terraces with top surfaces up to 25 feet above the river, and in the active floodplain. Radiocarbon dates on organics from the postglacial sediments, sampled mostly at archeologic sites, indicate that they have been accumulating since about 13 ka. The postglacial sediments are vertically accreted sand and silt deposited mostly from overbank flood deposition, in contrast to the gravelly braided channel outwash sediments. Postglacial terraces flank the river and form low islands in the river downstream to the Bordentown area, where they are onlapped by the Holocene estuarine fill (fig. 2b). In the narrow valley at and upstream from Trenton the postglacial terrace occupies most of the modern valley bottom. At and upstream from Trenton most of the postglacial terrace is within the 100-year floodplain and so still receives some overbank sedimentation. The modern floodplain upstream from the head of the estuary at Trenton is not much wider than the active channel and is submerged by annual or semi-annual floods.

Radiocarbon dates on salt-marsh peat and organics within estuarine silts in the bay and lower valley (Sirkin and others, 1970; Kraft, 1976; Ramsey and Baxter, 1996; Nikitina and others, 2000; Jengo, 2006; Engelhart and others, 2011) show that the rising sea had entered the bay by 11 ka at a depth of about 80 feet below present sea level. By 6 ka it had risen to a depth of 30 feet and had fully submerged the late Wisconsinan channel in the bay and lower valley. The remaining 30 feet of rise since 6 ka has expanded onto flatter areas (mainly the lower terraces within the main valley, perhaps an MIS 3 estuarine terrace in the bay) above the channel, forming Delaware Bay and its fringing salt marshes. The volume of Holocene sediment in the bay and estuary is about 9 km^3 (2.2 mi^3) (Fletcher and others, 1992; Stanford and others, 2016). Since little sediment exits the bay to the shelf (Fletcher and others, 1992), this volume yields a Holocene denudation rate of about 23 m/my (75 ft/my) for the Delaware basin. This rate is consistent with a rate of 20 m/my calculated from the modern river load (Judson and Ritter, 1964).

The Holocene estuarine deposit is chiefly organic clayey silt and fine sand with some shelly sand and gravel in tidal channels and peat in the marshes that fringe the channel. It is as much as 100 feet thick in the thalweg of the late Wisconsinan channel in the Salem-Penns Grove area and thins to about 30 feet just below the nickpoint at Trenton. The sand fraction consists chiefly of easily weathered minerals and rock fragments (Jordan and Groot, 1962; Owens and others, 1974) that indicate the sediment is largely from erosion of lightly weathered surficial deposits of Wisconsinan age and fresh bedrock in valleys rather than saprolite or older surficial materials on uplands.

Correlation to the Global Sea Level Record

Figure 3 is a reconstruction of global sea level over the past 800 ka based on the marine oxygen-isotope record, which is a proxy for global ice volume, scaled to sea level using dated coral reef and other

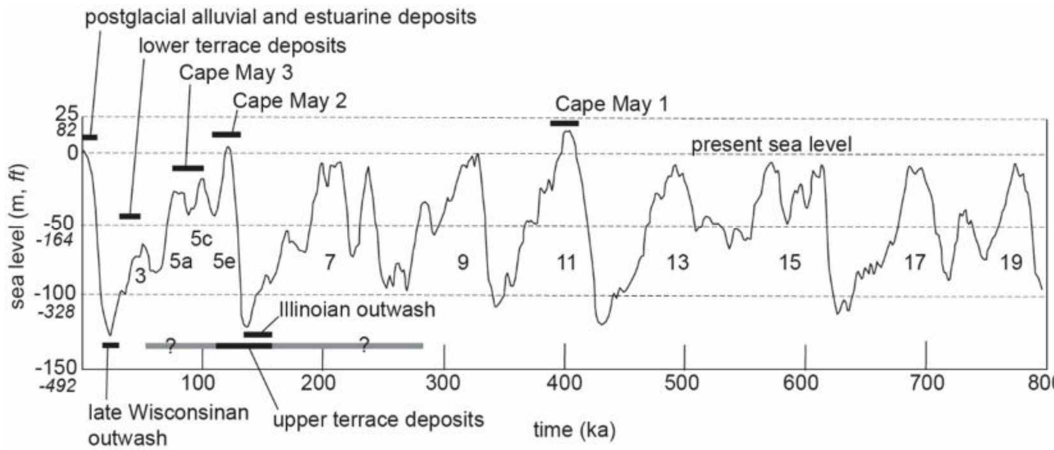

Figure 9. Lower Delaware valley deposits correlated to global sea level. Sea level curve from Spratt and Lisiecki (2016). Numbers are marine isotope stages.

indicators (Spratt and Lisiecki, 2016). Local relative sea level will vary from global sea level as a result of vertical land movement due to mantle dynamics, denudational unloading, sediment loading, and glacioisostasy. These effects have been documented or hypothesized along the east coast (Pazzaglia and Gardner, 2000; Rowley, 2013; Roy and Peltier, 2015). Nevertheless, the highstands shown on figure 3 correlate well with those recorded by the Cape May 1 and 2 at MIS 11 and MIS 5e. This may be because the glacioisostatic state of the crust at the present full interglacial, which is about 25 ky after a full glacial, is like that at previous full interglacials like MIS 5e and 11, which also followed about 25 ky after a full glacial. Thus sea levels then should be parallel to present sea level and their height should be similar to global sea level (Potter and Lambeck, 2003). As more time passes after a glacial maximum, such as at MIS 5c, 5a, and 3, there is more glacioisostatic adjustment. Areas on the forebulge, like southern New Jersey, will sink further and areas north of the forebulge, like northern New Jersey, will rise. Thus, sea level at these times will be higher to the south (because the land has sunk more) and lower to the north (because the land has risen) compared to its full-interglacial state (adjusted for any global change). This seems to be the case with the Cape May 3 (MIS 5a or 5c) and MIS 3 offshore sediments. Deposits of both these ages are at higher elevation to the south of New Jersey on the Delmarva Peninsula, Virginia, and North Carolina (Mallinson and others, 2008; Scott and others, 2010; Parham and others, 2013; DeJong and others, 2015), and decline in elevation to the north.

Tide gauges show that sea level in the Delaware estuary and bay has risen at a rate of 2.94 mm/yr (0.96 ft/100 yr) at Philadelphia (period of record 1900-2017), at 3.56 mm/yr (1.17 ft/100 yr) at Reedy Point, Delaware (1956-2017) (near Salem, NJ), at 4.57 mm/yr (1.5 ft/100 yr) at Cape May (1965-2017) and at 3.44 mm/yr (1.13 ft/100 yr) at Lewes, Delaware (1919-2017) (opposite Cape May) (data at https://tidesandcurrents.noaa.gov/sltrends/sltrends.html). The higher rates at Reedy Point, Cape May, and Lewes are due in part to compaction of underlying Coastal Plain sediments because of groundwater withdrawal (Miller and others, 2013). Global sea level is expected to rise between 0.3 m (1 ft) and 1 m (3.3 ft) by 2100 due to glacier melt and thermal expansion (Church and others, 2013). This range may be too low because polar ice sheets are melting faster than expected. In the Delaware valley, subsidence due to glacioisostatic adjustment, groundwater withdrawal, and sediment compaction, and local increase in sea level due to ocean circulation changes in the North Atlantic, will add an additional 20 to 30 cm (0.5 to 1 ft) to the global rise by 2100 (Miller and others, 2013). It is certain that sea level will continue to rise for long after 2100 (Church and others, 2013). Both the MIS 11 and 5e highstands occurred when the atmospheric CO_2 content was <300 ppm; today it is >400 ppm. CO_2 content is closely correlated to global sea level (Hansen and others, 2013). These relationships suggest that over the upcoming centuries sea level will again rise to the levels of MIS 5 and 11.

Summary

Quaternary deposits in the lower Delaware valley show that:

- Estuarine sediments were laid down during three interglacial highstands: at 400? ka (+65 feet, Cape May 1), at 125 ka (+30 feet, Cape May 2), and at 80-110 ka (+15 feet, Cape May 3).
- Nonglacial fluvial sediments were laid down during, and possibly before, the Illinoian glacial period and, in places, continuing through the Sangamon interglacial and into the Wisconsinan glacial period (upper terraces) and in the middle to late Wisconsinan (lower terrace). Deposition of the terrace sediments occurred due to increased sediment influx to valleys under periglacial climate and due to alluvial backfilling during sea level highstands.
- Glaciofluvial gravels were laid down during the Illinoian (peak at 150 ka) and late Wisconsinan (peak at 25 ka) glaciations. Glacioisostatic tilting diverted the Delaware to the Hudson Shelf Valley via the Millstone and Raritan valleys for a time at glacial maxima.
- Postglacial sediments include alluvial terraces and floodplain deposits, laid down mostly since 13 ka, and estuarine sediments laid down since the rising sea entered the baymouth at 11 ka.
- Incision occurred as sea level fell after highstands and when sediment loads were reduced following glacial periods.

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Surface and Groundwater Management – A NJ Utility's Experience

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Abstract

Vincent Monaco is Engineering Manager – Regional Asset Planning for New Jersey American Water Company, the largest investor-owned water utility in the State of New Jersey. His focus is on Statewide regional planning strategies, and GIS/Asset Management. Previously, Vince worked at NJDEP in various capacities within the Division of Water Supply & Geoscience. He is a New Jersey licensed Profession Engineer, a lifetime member of AWWA-NJ, and a 2006 Fuller Awardee.

New Jersey American Water owns and operates seven (7) surface water treatment plants and nearly 250 wells, providing high quality and reliable water and/or wastewater service to approximately 2.7 million people. The focus of the presentation is on New Jersey American Water's assets operating in the Delaware River basin from Warren to Salem County. He will describe the interrelations with other public water utilities in the region and challenges New Jersey American Water faces from aging assets, changing water quality, and emergent contaminants. New Jersey American Water invests over $300 million annually on capital projects and asset renewals. The company has approximately $ 4.9 billion in operating assets (Utility Plant[1]) within State of New Jersey.

[1] Source: New Jersey American Water - 2016 Annual Report to the New Jersey Board Of Public Utilities

Salty Water Trend and Sources of Salt in the Delaware River

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Abstract

There were apparent upward trends of sodium and chloride concentrations between 1944 and 2018 in the Delaware River. The increase of chloride concentration shows more significance than that of the increase of sodium concentration and the higher adsorption affinity of sodium to soil particles caused a more sustained sodium concentration than that of chloride. There were 13 recorded periods when sodium concentrations were above the 20 mg/l in drinking water recommended by US EPA and American Heart Association between 2009 and 2018 for the Delaware River at USGS Trenton gage station. If the current trend continues, the projection here is that by approximately year 2050 (or sooner), annual average sodium concentration in the Delaware River at Trenton station will reach this benchmark of 20 mg/l level. Philadelphia Water Department Plants downstream of Trenton station might reach this level sooner than water plants above Trenton station. Among the five sources of sodium chloride (winter deicing road salt, weathering of rocks, agricultural fertilizer, sewage treatment plants and precipitation) deicing road salt contributes to about 2/3 of the total salt loading and the continuing increase in the Delaware River. Annual retention of sodium from the deicing salt is about 30 to 40% (or more depending on the annual precipitation) in the Delaware River based on past studies. Though using calcium chloride as an alternative winter deicing salt might be more beneficial ecologically, short-term impact on the accelerated release of sodium stored in the soil and long-term impact of calcium chloride still need to be studied.

Introduction - Sodium Chloride Trend

Between 1945 and 2018, sodium concentration in the Delaware River (DR) at Trenton increased about 4 times and chloride concentration increased about 6.3 times. There were 13 recorded periods in the Delaware River at Trenton showing sodium concentrations being above the 20 mg/l limit in drinking water recommended by the US Environmental Protection Agency and America Heart Association between 2009 and 2018. Regular road salt applications are the likely underlying reason for the observed increases in sodium concentrations in the Delaware River Watershed (DRW). Both sodium and chloride

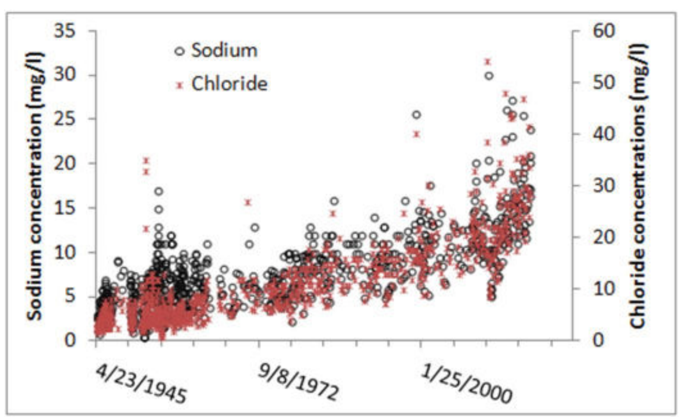

Figure 1. Sodium and chloride concentrations in the Delaware River at Trenton station between 1944 and 2018.

concentrations also increase downstream because of the accumulated salt loading from upstream. Most of the population in the DRW obtain their drinking water from the Delaware River. Sodium is not removed during the water treatment process, and it has been known that high sodium intake is an issue for people with high blood pressure (particularly seniors) and multiple sclerosis (Farez et al., 2015; Sun and Sun, 2018). Therefore, understanding the trend and sources of the sodium chloride in the Delaware River Basin can have a significant public health implication and is the first step for possible future measures in salt reduction in the DRW.

Sources of sodium in the Delaware River Basin

Before large applications of road deicing salt (around 1960s), weathering of albite and other minerals were the source of sodium in the Delaware River. Average Na/Cl molar ratios were well above 1 (Figure 2). However, continued disturbance of the natural balance of sodium and chloride by the anthropogenic salt inputs has lowered the Na/Cl molar ratios steadily during the last 50 years. A lower Na/Cl molar ratio in the DR water is a reflection of the increasing sodium retention in the basin because of the higher adsorption affinity of sodium to soil particles than that of chloride (Weil and Brady, 2017; Drever, 1997). Retention of sodium will likely contribute to the sustained increases of sodium chloride concentration in the DR water in the near future even if the anthropogenic salt input is suspended. There are five major sources of sodium chloride that contribute to the total sodium chloride concentration and related aqueous geochemical change in the DRW.

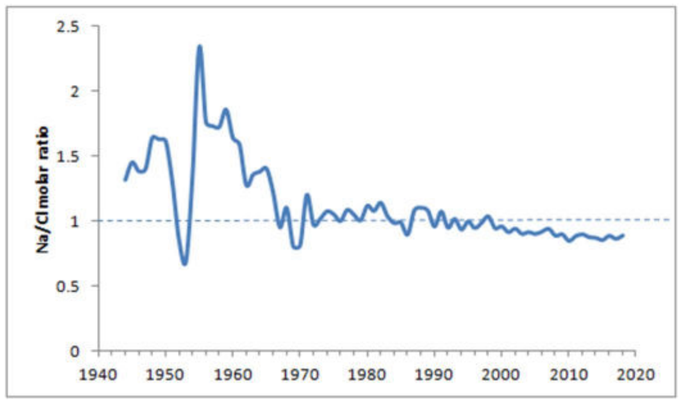

Figure 2. Decline of Na/Cl molar ratios because of the increased application of deicing salt. (Modified from Sun et al., 2012).

1) Deicing Salt Application

The largest salt source in the DRW is the winter deicing salt. The contribution of its proportion has increased with time. Currently, deicing salt is estimated to contribute to about 2/3 of the total sodium input in the Delaware River (Sun et al., 2012, and Sun et al., 2014). The sodium and chloride retention rates are 30-40% which are comparable to retention rates reported in other previous studies (Kelly et al. , 2008; Howard and Haynes,1993). There are many similar situations in other areas of the Northern United States, Canada and Europe where road salt application is the main source of sodium chloride in their water bodies (Corsi et al., 2010; Dailey et al., 2014; Jackson and Jobbagy, 2005). Therefore, understanding of the road salt input and sodium chloride retention can have implication for studies in regions around the world (Lofgren et al., 2001).

2) Weathering Supply from Nature

Our estimation is that sodium supply from natural weathering is less than 15% of the total sodium in the Delaware River (Sun et al., 2014). Because surficial geology of the DRW is mainly sedimentary rock, little natural salts remain. The main sources of natural sodium are albite, a type of feldspar, various clay particles and organic matters that have adsorbed sodium (Weil and Brady, 2017).

Table 1. Normalized 10-year average annual concentrations and regression trends of major ions and pH in precipitation at Milford, PA and Washington Crossing, NJ and Delaware River water at Trenton, NJ USGS station*. Units: Kg/hectare/year except for pH (Modified from Sun et al., 2014).

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	pH
Milford, PA (precipitation)						
1981-1990	0.88	0.27	1.12	0.26	2.33	4.29
1991-2000	0.84	0.22	1.27	0.20	2.43	4.35
2001-2010	0.94	0.23	1.24	0.31	2.42	4.54
Washington Crossing, NJ (precipitation)						
1981-1990	1.25	0.47	2.09	0.29	4.12	4.33
1991-2000	0.83	0.37	2.26	0.24	4.28	4.38
2001-2010	1.01	0.34	2.13	0.24	4.12	4.50
Delaware River at Trenton (n=695, basin area, 17560 square kilometers, downstream)						
1944-1950	90.16	30.39	31.46	8.60	31.68	7.03
1951-1960	91.61	31.10	32.68	9.54	36.16	7.10
1961-1970	63.82	22.08	25.73	6.26	35.79	7.12
1971-1980	107.85	36.55	46.27	11.78	67.06	7.92
1981-1990	94.26	32.89	50.83	7.91	75.11	8.00
1991-2000	89.38	29.87	56.82	7.96	88.10	7.88
2001-2011	115.07	38.11	84.84	9.91	143.10	7.86
Regression Trends of Ion Concentrations in the Delaware River at Trenton between 1944 and 2012. For SO_4^{2-}, between 1980-2012						
Regression t-test	4.09	3.73	25.61	-2.92	34.30	18.34
Number of datum	694	694	693	466	694	693

**Precipitation data are from National Atmospheric Depositional Program and stream data are from the US Geological Survey (USGS). Regression t-test is for the regression slope of concentration vs. sample date. Any t value >1.97 or <-1.97 indicates a significant trend with 95% confidence. A positive t value indicates an increasing trend while a negative t value indicates a decreasing trend. The higher the t value is, the stronger the trend*

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3) Agricultural supply

Contribution of salt from agricultural sources to the total salt in the DRW might be significant before the application of deicing road salt becomes dominant. However, between 1950 and 2004, the farmland in the DRW was reduced by about 47.6%, while the national farmland was reduced only by 22.1% during the same period (Sun et al., 2006). Reduction of the farmland in DRW was almost twice as fast as the national average. Therefore, it is unlikely that agricultural supply is a significant contributor to the sodium and chloride concentration increases in the DRW.

4) Precipitation

Precipitation accounts for less than 4% of the sodium and chloride concentrations in the Delaware River (see the underneath Table 1). Its contribution have not changed significantly based upon the available data between 1983 and 2013. There are no significant trends for sodium and chloride concentrations in the precipitation at the two stations (shown in Table 1) in the DRW.

5) Discharge from Water Treatment Plants

Sodium level in recycled water can be twice the sodium level in potable water (PWD, 2007). The salt here mainly comes from the salt in food, water softener, disinfectants (sodium hypochlorite), etc. Increased salt proportion in this category over the years is mainly because of the population increase. In 1950, the human population of the DRW was about 5.1 million. By 2010, the population increased to about 8.7 million people. This source can account for 3-4 % of the total sodium in the DRB.

Projection of the Salt Trend in the Delaware River

Projection based upon the regression trend of Figure 1 is that by about year 2050 or sooner, average annual sodium concentration in the Delaware River at Trenton will reach the 20 mg/l EPA and AHA recommended limit. By the end of the century (or sooner), the average annual sodium concentration will be about 29 mg/l, well above the 20mg/l benchmark. Sodium concentration at the intake points of the Philadelphia Water Department will reach this 20 mg/l benchmark sooner than at the Trenton gauge station. Between now and 2050, there will be more periods in January and February where sodium concentrations will exceed the EPA and AHA recommended limit of 20 mg/l.

Impact on Water Quality by Increased Salt Application

1) Water is getting saltier and harder.

Table 1 shows the normalized 10-year average annual concentrations and regression trends of major ions, pH in precipitation at Milford station, PA and Washington Crossing station, NJ, and in the Delaware River at Trenton, NJ station (Sun et al., 2014). Statistically significant upward trends can be identified for calcium and magnesium concentrations between 1944 and 2013 in the Delaware River. Trends for concentrations of other elements can be identified as well. However, not all the trends are due to the cation exchange of sodium with other cations or the anion exchange/complexation of chloride with other ions.

2) Concentrations of heavy metals in water may be affected.

Complexation of chloride with lead and mercury can lead to in-situ mobilization of these metals in soil solution. Dispersion from hydrated sodium can also lead to the increased concentration of arsenic in soil solution. There are positive concentration correlations between Na, Hg, Cl and Pb from the Centennial Lake Watershed in the DRW (Sun et al., 2015; Sun et al., 2016).

Alternative to Sodium Chloride for Deicing: Calcium Chloride?

Since calcium is a macronutrient element in soil and water, it can be taken up by organisms in soil easily and moderate amount of calcium can be beneficial. Calcium salt might also help neutralize acidity in soil and water from acid rain. Therefore, calcium chloride ($CaCl_2$) can be used as an alternative salt in place of sodium chloride for deicing. However, a few drawbacks of calcium chloride application need to be recognized as well. Because calcium has a higher cation exchange capacity than sodium, there will be an initial accelerated release of sodium stored in soil from previous application of sodium chloride salt in the past few decades. We will not expect a decrease in the concentration of sodium in the Delaware

River for many years to come, even if all the deicing salt were switched to calcium chloride now. Strong cation exchange capacity of the calcium might accelerate the release of other unwanted metals from soils locally. Also increased calcium and magnesium concentrations increase the hardness of water. Studies on the long-term ecological impact of calcium chloride salt are needed as well.

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A Short History of Water Supply in New Jersey

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Abstract

The supplies are ample for all our population for a long period in the future, *provided surplus waters are conserved and contamination prevented*, but their complete utilization will entail the expenditure of vast sums of money. With increasing population, the dangers of contamination and the difficulty of securing pure supplies will rapidly increase. Nature has provided an abundant supply; it remains for the people of the State to administer it wisely. (Board of the Riparian Commissioners, 1907, emphasis in the original)

The history of water supply in New Jersey shows an ongoing evolution, of finding and developing an adequate water supply and then trying to maintain that supply in light of increased demand and upstream impacts on water quality and quantity. The goals expressed in 1907 by the Board of the Riparian Commissioners are key to maintaining a safe and adequate water supply into the future – wise administration of the resource. This will take cooperation among the stakeholders – watershed residents, potable water purveyors, consumers, and wastewater dischargers.

The history of New Jersey's water supply is a broad topic which this paper examines through two stories that illustrate key points, the growth of the Newark Water Department and the establishment of Water Supply Critical Areas in southern New Jersey. While this gives short shift to numerous other interesting stories these two illuminate many of the significant factors which have affected the changing water supply characteristics of New Jersey. This paper also includes a short description of the regulatory environment in which water resources are currently managed in New Jersey.

Newark Water Department

A good example of how water supplies evolved in northeastern is that of the Newark Water Department. Newark was one of the largest cities in NJ in the 1800s, bustling with significant industrial and commercial activity. It grew from a population of 8,008 in 1810 to a peak of 442,337 in 1930. In 2014 the population was estimated at 280,579 (fig. 1).

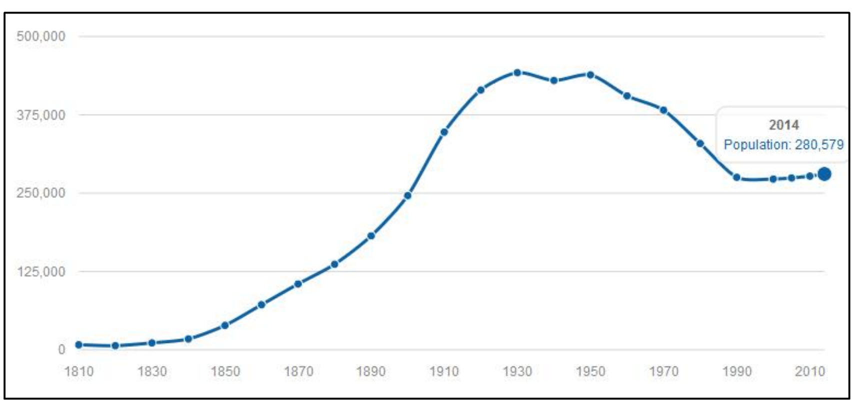

Figure 1. Newark Population, 1810-2014
From http://population.us/nj/newark/#1

Newark was founded in 1666. As with all of New Jersey, the earliest European settlers were supplied either by shallow, dug wells or by hauling water from a nearby spring or stream. In Newark two small streams met at 'the Watering Place' and most residents, along with their livestock, got water either from here or from shallow wells. In 1800, however, water demand from the growing population for a more convenient water supply led to the chartering of the Newark Aqueduct Company. This private firm laid wood pipes under the streets to deliver water from the Watering Place to its customers. They starting using iron pipes around 1828. In the early 1840s the company expanded its distribution network, built small reservoirs throughout Newark for storage and to maintain pressure, and tapped additional springs as water sources. In 1845 the city of Newark contracted with the Newark Aqueduct Company for water for firefighting.

This new system quickly became insufficient. In 1860, the Newark Aqueduct Board, a municipal organization, was chartered to locate additional water supply for the city. This Board was authorized to purchase the Newark Aqueduct Company and given the authority to pump water from the Passaic River. It started building a reservoir on high ground in Belleville, several miles to the north of Newark in 1860. Work was delayed by the Civil War but was finished in 1870. Passaic River water was pumped into this reservoir and then sent to Newark via transmission mains.

Water quality was as great a concern as quantity. It has long been known that improper usage near wells could impact water quality. In 1610 General Gage of Virginia addressed water quality issues at Jamestown:

> There shall be no man or woman dare to wash any unclean linen, wash clothes, nor rinse or make clean any kettle, pot, or pan or suchlike vessel within twenty feet of the old well or new pump. Nor shall anyone aforesaid, within less than a quarter mile of the fort, dare to do the necessities of nature, since by these unmanly, slothful, and loathsome immodesties, the whole fort may be choked and poisoned.

Newark residents were hopeful that the change in the source of their water supply, away from local sources, would increase the quality as well as quantity. However, it was immediately apparent that the Passaic River water was not as good of quality as had been hoped. The villages and towns upstream of Newark on the Passaic River, especially Patterson, were also growing by leaps and bounds. They, like Newark, discharged sewage directly to the river. This had been known but it had been assumed that the Passaic River had enough flow to dilute this effluent. This proved not to be true. The pollution from upstream discharges was amplified by the discovery that incoming tides pushed Newark's sewage upstream, to the Belleville Reservoir intake. Immediately Newark's residents started demanding the clean, plentiful water supply they had been promised by the Newark Aqueduct Board.

In the late 1800s the NJ State Geologist issued annual reports of the activities of the NJ Geological Survey. This included analysis of geological and water supply issues. The 1876 annual report includes the results from a committee, consisting of mayors of major cities, convened to look at the problems of maintaining a clean water supply:

> The present supply for Newark and Jersey City is drawn from the Passaic river near Belleville. This stream receives the sewage from Paterson, a city of near forty thousand inhabitants. The recent clearing of the channel above Newark, by the United States Government, has given more freedom to the tidal movement of the water, so that salt water from the bay and sewage from Newark may flow further up the stream than they formerly

> did. On account of these circumstances, there has been much doubt expressed as to whether this water was suitable and safe to be used for household purposes, and hence the inquiry.

Pollution of rivers was a statewide problem. By 1889, the NJ State Geologist's reports become more strident about the need for a clean water supply and indeed posed the question of what is a more important use of a river, for water supply or waste disposal:

> The importance of the subject to the people of the State is apparent from the fact that two-thirds of its population are not dependent on systems of public water-supply. The pollution of our streams goes hand in hand with this, and, as we have seen, now directly affects one-third of our population. On the Delaware, Bordentown, Burlington and Camden suffer from this cause; the sewage of Trenton being responsible in the former two cases. On the Passaic, Newark, Jersey City and Bayonne have been driven out by the sewage of Paterson and Passaic. The adjustment of troubles from this cause gives rise to some very nice questions. Is a stream more necessary to the town below for water-supply than it is to the town above for drainage? It would seem that the Delaware below Trenton, and the Passaic below Paterson, are the natural sewers of their respective districts, and must be abandoned to that use.

Drinking water treatment in the late 1800s was rudimentary by today's standards. It generally consisting of a settling tank and, maybe, a sand filter. Much research was underway on appropriate treatment technologies, especially after Louis Pasteur published his germ theory of disease which showed how microbes in water could transmit illness. But the best possible alternative was a pure water source from a lightly settled watershed. In 1881, the NJ State Geologist stated:

> The question of a supply of pure, wholesome water is assuming greater importance with every passing year. The gathering of population in towns and cities is increasing the need for more copious supplies, at the same time that the accumulation of filth and impurities on the surface is contaminating the supplies from the wells, which in former times were the chief reliance. … The only resource then is in the streams, springs and lakes, in some mountainous and thinly-settled district of the country, where rocky, wooded and uncultivated soil occupies most of the surface, and where such a state of things is likely to continue.

The Newark Water Board was made very aware of the danger of the polluted Passaic River once water from the Belleview Reservoir was shown to be unhealthy. They began exploring the near-pristine watersheds to the west, in Morris and Passaic Counties. The Board settled on the watershed of the Pequannock watershed as an appropriate water source. This look to the west was not unusual for the cities of northeast New Jersey. It was about this same time that Jersey City was planning the Boonton Reservoir in the Rockaway River watershed, the Hackensack Water Company was expanding its sources northwards to the lightly settled Hackensack River watershed. And In the early 1900's a consortium of cities (including Newark and Patterson) formed the North Jersey District Water Supply Commission to tap the Wanaque watershed.

Figure 2 shows current water supply reservoirs in New Jersey. It is interesting to note that over the past 150 years a larger number have been proposed. Figure 3 is a 1930 map showing existing and potential reservoir sites across northern New Jersey. These sites were selected based on topography and available water. They were studied to determine potential safe yield, what transmission mains would be required to deliver water to what demand centers, and how much land would have to be purchased. Several of these have been developed as proposed or altered (#31 is now the Round Valley Reservoir, a smaller version of #38 is the Spruce Run reservoir). Most of these proposals have not been built. In the last few decades the ecological impacts of flooding a valley have become more apparent and a significant concern. Any new reservoir proposals will likely have to address numerous issues that the builders of a century ago did not.

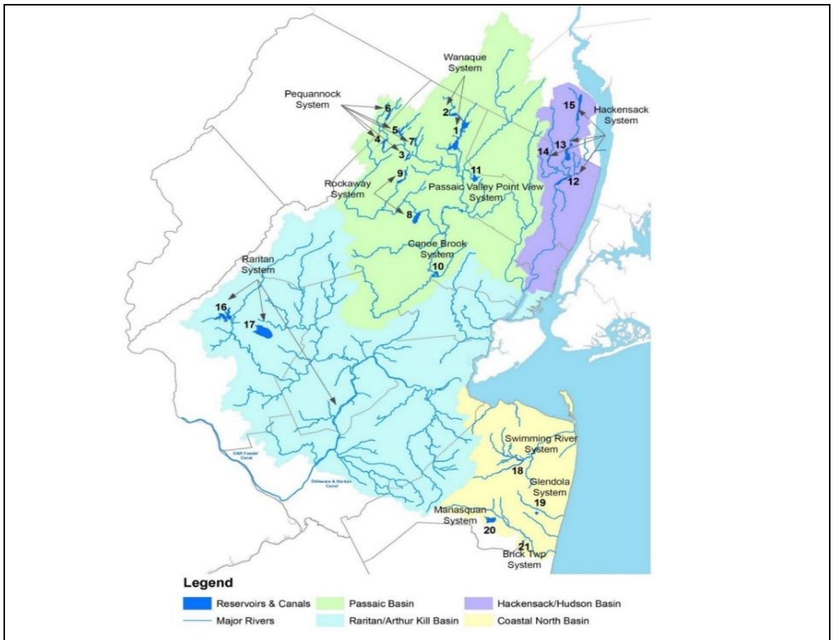

Figure 2. Current water supply reservoirs in New Jersey (NJDEP, 2017).

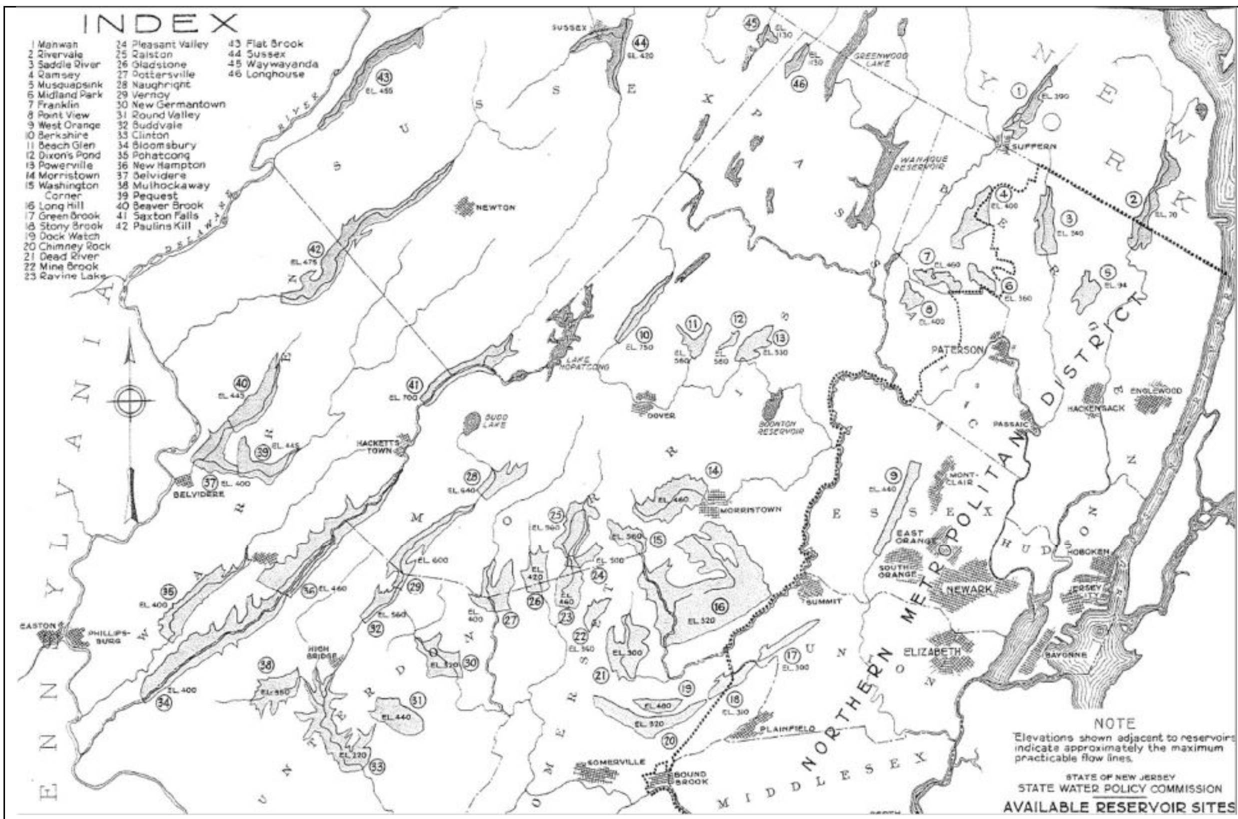

Figure 3. Existing and potential reservoir sites, 1930. (State Water Policy Commission, 1929.)

In contrast, groundwater was sometimes seen as a purer water source. Carroll Phillips Bassett, founded the Commonwealth Water Company to serve water to Millburn and surrounding areas. The company's water came generally from the sand-and-gravel buried-valley aquifers in western Essex County. In 1915 Bassett was trying to convince neighboring towns to purchase water from his company instead of tying into regional systems supplied by surface water reservoirs. He claimed:

> Any stream water stored in open reservoirs...can never be a satisfactory substitute as potable water from an underground supply collected on an unpopulated watershed which is cool, clear and sparkling, distilled in nature's own laboratory, stored in the deep recesses of the earth away from all forms of life, so that it is practically sterile, and delivered to the consumer without having at any time come in contact with anything but the clean metal of the pumps and mains.

Newark's Pequannock system first consisted of the Oak Ridge, Clinton and Macopin reservoirs with the 36" Pequannock aqueduct bring fresh water to the Belleville Reservoir for distribution to Newark. Operation began in 1892 with a supply of 27.5 million gallons per day. This quickly proved to be inadequate. In the very cold winter of 1899 many Newark residents kept their water running to prevent freezing pipes which resulted in a severe overdraft of the Belleville reservoir. In order to maintain pressure the intake on the Passaic River was reactivated. Unfortunately this led to contaminated river water entering the distribution system. The New York Times of February 28, 1899 reports:

> NEWARK, N.J., Feb. 27. - In a death certificate issued by a doctor this morning he gave as the cause of death, "dysentery - Passaic water."

Newark experienced approximately 100 deaths from typhoid fever and dysentery that winter. In response to this crisis, Newark built the Cedar Grove reservoir (completed 1904) to hold more Pequannock water for peak needs and eliminate the need to pull from the Passaic River. The intake on the Passaic River was eventually abandoned.

Newark was able, eventually, to purchase most of the watershed above its reservoirs. (This is a story of insider knowledge, land speculators, overlapping water rights, and money.) Today this watershed area is a significant ecological resource in northeastern NJ. However, there are occasional calls to allow economic development of this area for the advantage of the municipalities which are contained within the watershed. Newark established the Watershed Conservation & Development Corporation in the 1970s as a nonprofit, semi-independent organization charged with protecting the watershed. However it was dissolved in 2013 after charges of mismanagement and kickback resulting in several employees being convicted of corruption. The watershed is now directly overseen by Newark.

Newark's water demand has decreased due to its drop in population and a decline in industry since the 1960s. Its watershed would be able to supply additional water, especially if it were done in a conjunctive manner with other water purveyors. Managing this watershed, to the benefit of the residents of Newark and citizens of New Jersey is a challenge for the future.

Groundwater in Southern New Jersey - Critical Areas 1 and 2

In southern New Jersey there are fewer areas topographically suitable for a major reservoir. The result is that up until recently most potable water has come from wells. Exploring for an adequate water supply led drillers and geologists to look deeper and deeper underground.

One of the best known examples of this is the exploration performed in order to find an adequate water supply for Atlantic City. Beginning in the mid-1800's Atlantic City was developed as a major tourist and recreation center. With the advent of regional railroads allowing for convenient access from Philadelphia and New York, Atlantic City became a booming summer resort town. The need for an assured water supply led to exploration of surface water on the mainland as well as adequate wells. The drilling program led to the discovery of an artesian aquifer located approximately 800' below land surface at Atlantic City. This prolific sand member, a part of the lower Kirkwood aquifer (fig. 4) is now officially named the Atlantic City 800-foot sand regardless of the depth at which it is encountered. It is overlain by several other aquifers and confining units (fig. 4).

When first drilled, water from this aquifer flowed at the surface. Increased withdrawals, both in Atlantic City and in many other shore communities, has resulted in groundwater levels that are now as much as 100 feet below land surface (Thompson, 1928; McAuley and others, 2001). This has resulted in a concern that lateral saltwater intrusion may impact water quality and has been investigated by both the U.S. Geological Survey and the N.J. Geological and Water Survey. The current understanding of the groundwater resource is that with proper management the Atlantic City 800-foot sand can be an assured water source for centuries. Overpumpage, however, could accelerate saltwater intrusion and decrease the useful life of the resource.

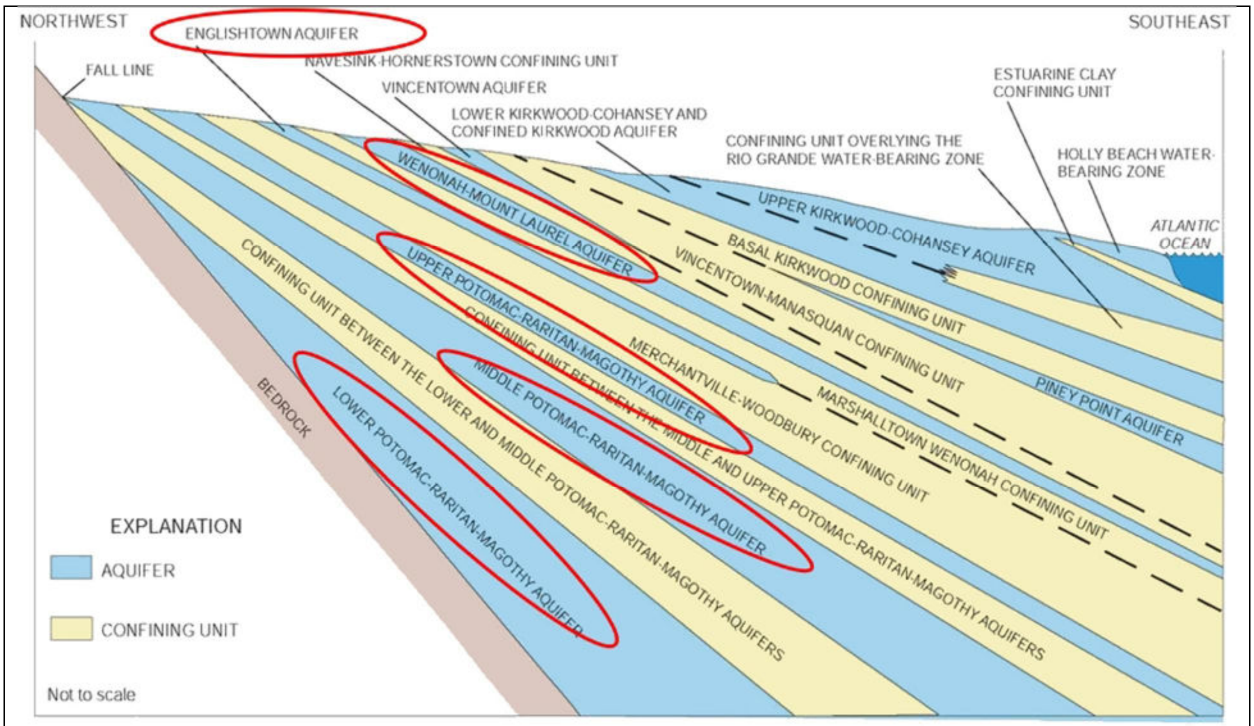

Figure 4. Generalized cross section through the New Jersey Coastal Plain. Aquifers regulated under the water supply critical area 1 or 2 are circled.

Groundwater declines, and the potential for saltwater intrusion, are of concern in many areas in southern New Jersey. NJDEP is charged with protecting the water resources of the State for current and future users. This includes the wise stewardship of groundwater so as not to permanently degrade the resource. NJDEP regulations (N.J.A.C. 7:19-8) allow the creation of "areas of critical water supply concerns." if these criteria apply:

(1) Shortage of surface water due to previous diversions in an area >10 mi^2.

(2) Shortage of groundwater due to diversions exceeding dependable yield in an area >10 mi^2 as shown by:

   a. A lowering of groundwater levels that threatens the supply to existing wells, or

   b. Lowering of groundwater levels in a confined aquifer so that the -30' elevation contour is within five miles of salt water or intersects the 250 ppm chloride isochlor, or

   c. Lowering of groundwater levels in an unconfined or semi-confined aquifer so that the 0' elevation contour is within five miles of salt water or intersects the 250 ppm chloride isochlor.

(3) Significant groundwater contamination may reasonably be expected to affect a significant portion of the aquifer.

These regulations were implemented because of the concern about excessive drawdown in the aquifers of southern New Jersey. Two such areas are now in effect in New Jersey (fig. 5). Critical Area No. 1 (CA1) is in New Jersey's northeast coastal plain and applies to the Wenonah-Mt. Laurel, Englishtown, Old Bridge (upper PRM equivalent) and Farrington (middle PRM equivalent) aquifers. Critical Area No. 2 (CA2) is in southwestern New Jersey and applies to the Potomac-Raritan-Magothy (PRM) aquifer. NJDEP ordered pumpage reductions from these aquifers beginning in 1990 as water from alternate sources became available.

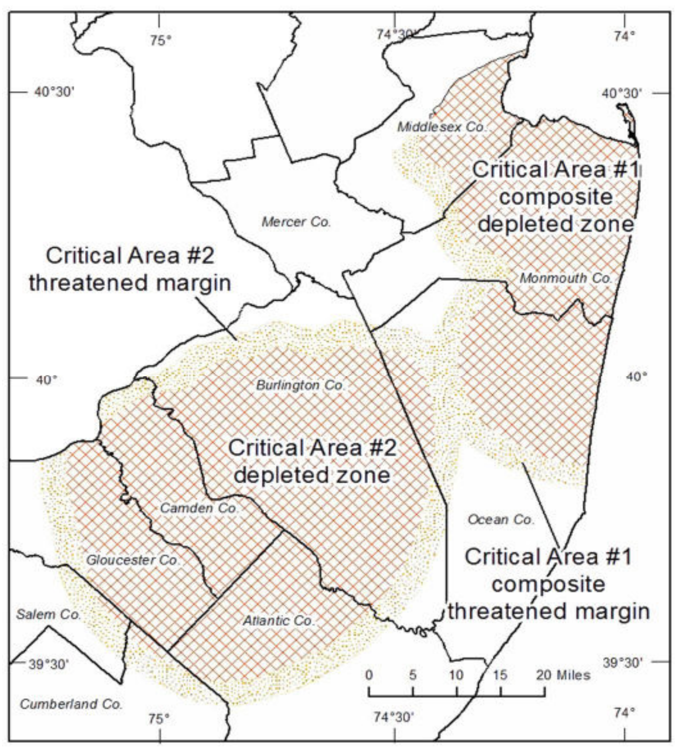

Figure 5. Water Supply Critical Area 1 and 2.

This program has resulted in significant groundwater recoveries. Pumping reductions of about 25% from CA1 have created water-levels recoveries of as much as 150 feet (fig. 6). In CA2 water level rises have been less dramatic but are still significant, up to 50 feet (fig. 7). These rises have helped preserve the resource by lessening the threat of saltwater intrusion.

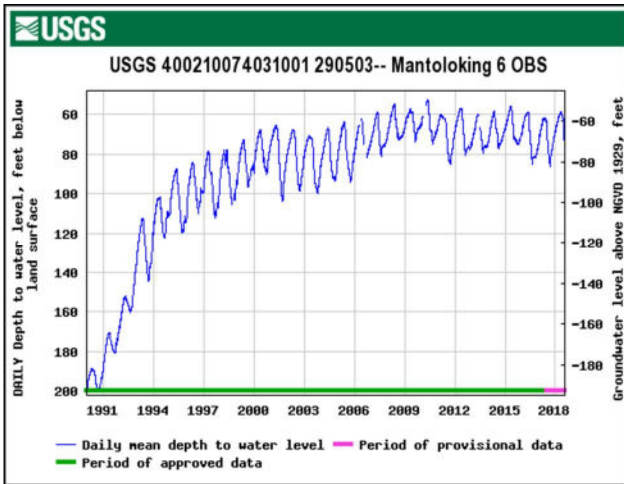

Figure 6. Observed depth to water, Englishtown aquifer, Monmouth Co, CA1. (Data from USGS NWIS database)

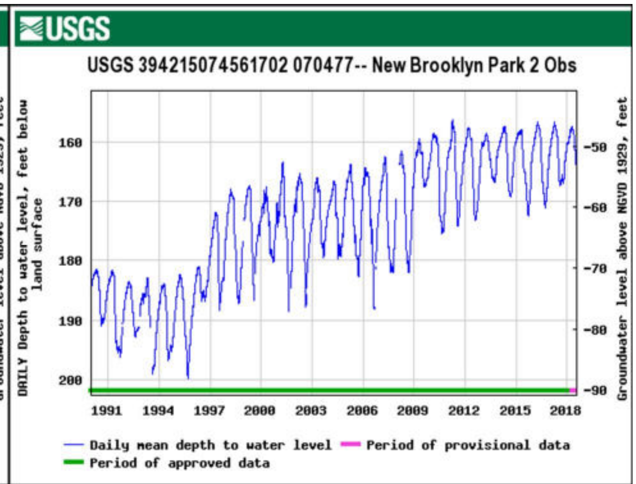

Figure 7. Observed depth to water, upper PRM aquifer, Camden County, CA2. (Data from USGS NWIS database)

The problem of declining groundwater levels has forced a reevaluation of regional water supplies. The critical area reductions in groundwater withdrawals were implemented as alternate water supplies came online. In CA1, surface water from the Manasquan Reservoir was a major replacement source for reductions in the affected aquifers. In CA2, the Delran surface water intake on the Delaware River has become a major regional water supply and its importance may increase.

Laws governing water supply

New Jersey water law is riparian in nature. That is, land owners have the right to use water flowing by or over their property for beneficial purposes provided they do not adversely impact other users. There are several court cases from the late 1700's and early 1800's where new water users were sued by older, downstream water users. Many of these are filed by water mills arguing that an upstream water use has decreased the amount of available water, especially in dry times, and that this has resulted in the inability of the mill to function efficiently.

About 1850, the first public potable water supply was commissioned by the NJ Legislature (Shanklin, 1974). For a number of years water companies were granted charters by the NJ Legislature that specified the water supply and the area to be served. These charters were often granted to men of influence, those either in the Legislature or with friends in it (Sackett, 1914). An example is of Garrett Hobart who became Vice President of the Unites States in 1897. Prior to that he was the speaker of the NJ General Assembly and also president of the Senate. He was a member of board of directors of the Acquackanonk Water Company and then the East Jersey Water Company. He was also on the boards of, and invested in, numerous railroads, electrical utilities, and banks. In 1905 the East Jersey Water Company, through its contract to serve Bayonne, was suspected of planning to export Passaic River water to Staten Island. The contracts and initial steps had been taken in secret so that when this information came public there was very little time for public opposition to organize. A hearing in the NJ legislature led to a proposed act to prohibit exports. But this act didn't make it out of committee, rumored to be held up by a legislative leader who was associated with Wharton (who wanted to export groundwater from the

Cohansey aquifer in the Pinelands to Philadelphia). Eventually New Jersey managed to get this matter heard by the U.S. Supreme Court who ruled that water could not be exported from a state without that state's approval. The plan to export water to Staten Island failed. Staten Island was tied into New York City's water distribution network and it now receives high quality water that arises from NYC's watersheds.

The effort of reviewing individual requests for water charters was too much for the NJ Legislature. In 1876 they passed the General Incorporation Act for Water Companies which led to rubberstamping requests for new water company charters. This resulted in overlapping service areas, multiple demands on the same water source, and numerous lawsuits by competing water companies. In particular, in northeastern New Jersey this led to conflict with the water rights of Patterson's Society for Establishing Useful Manufactures (SUM). SUM had been established in 1791 as the brainchild of Alexander Hamilton to harness the hydropower potential of the Great Falls of the Passaic River. SUM had been very successful in promoting and powering industrial activity in Patterson through the 1800's. SUM was very proactive about protecting its water rights and for over a century fought any upstream development that it felt would lead to a diminution of its ability to generate hydropower.

In 1907 the New Jersey legislature established the State Water Supply Commission. This was a board that reviewed all requests for new, major withdrawals so as to ensure a logical development of water supplies. This board required all new requests to come with a finding of fact and allowed for objectors to make a case that the proposed withdrawal would harm existing water rights. This established the principle that the waters of New Jersey are owned by the citizens of the State and that anyone wishing to use these waters must do so to the benefit of the citizens. All significant water uses are overseen by state government to ensure that newer users do not harm previous users.

One way this protection is implemented is by establishing as a permit condition the requirement that the withdrawal cease when stream flow falls below a set amount. In New Jersey this is referred to as a passing flow, as this much flow must be allowed to pass the monitored point. (The term 'passing flow' is unique to New Jersey. Elsewhere this is referred to as flow by, pass-by flows, minimum by-pass, residual streamflow, or compensation flows. (Hoffman and Domber, 2013). Passing flows can be applied in New Jersey to both surface water and unconfined-aquifer withdrawals.

The State Water Supply Commission was merged in the NJ Department of Conservation and Development in 1915. This department produced, in 1922, the first statewide water supply plan for New Jersey (Hazen, Whipple and Fuller, 1922). Since that time the authority of state government, as implemented by the successive Department of Conservation and Economic Development and then the Department of Environmental Protection (NJDEP), has been reaffirmed and expanded. Currently the Division of Water Supply and Geoscience in the NJDEP has the authority granted by the water Supply Management Act ((N.J.S.A. 58:1A-1 et seq.) to regulate withdrawals and conduct water supply planning. These are implemented under the Water Supply Management Act Rules (N.J.A.C. 7:19) through its water allocation program. These are available at https://www.state.nj.us/dep/watersupply/g_reg.html.

The recently issued New Jersey Water Supply Plan 2017-2022 continues NJDEP's record of state-wide water supply planning. This plan is available at https://www.state.nj.us/dep/watersupply/wsp.html and builds on earlier plans in 1982 and 1996.

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GANJ 2018 Field Trip
On the Freshwater Tidal Delaware River:
Upstream and Downstream of Philadelphia

Boarding time 8:45AM Spirit of Philadelphia Yacht Elite

Today the Delaware River transports sediments from upland regions to Delaware Bay and the Atlantic Ocean. The historical Delaware River and its ancestral rivers using the same channel transported sediments from upland regions and deposited time-stratigraphic units such as the Spring Lake Formation, Cape May Formation, Pennsauken Formation, and Bridgeton Formation.

During the Cretaceous–Miocene, unrelated rivers crossed from north to south the yet to be created Delaware River Corridor. These rivers carried and deposited sediments into the proto-Atlantic Ocean thus creating scores of strata of the New Jersey Coastal Plain.

During the Triassic-Jurassic, an earlier suite of unrelated rivers crossed from south to north. These Triassic rivers transported sediments from uplands that flanked the south side of the Newark Rift Zone. Initially, the rivers were high-energy streams that crossed the yet to be crated Delaware River Corridor. The Jurassic Rivers deposited the pebbly sediments creating conglomerates and sandstones of the Stockton Formation and younger Triassic and Jurassic Strata.

During the middle and late Paleozoic, mountains occupied the space of the present Delaware River corridor. Streams from these mountains transported sediments to be deposited north of the Delaware. These north flowing river deposits formed strata of the Pocono Mountains and NJ Valley and Ridge Province.

During the late Proterozoic and early Paleozoic, rivers flowed from the craton outward and formed the shoreline deposits that later lithified and metamorphosed to the Chickies Formation and the mud and sand deposits that were the foundation of the of the Wissahickon Formation.

This terse description of the rivers that flowed through the Delaware River corridor and that earlier crossed the yet to be created corridor in every conceivable direction is this field trips introduction to Delaware river and the impact of rivers on NJ geology.

Once upon a time, 100 years ago, the Delaware River corridor was easy to tour geologically. Scores of clay mines, sand and gravel quarries, and rock quarries were available to visit. Today, those mines and quarries are housing tracts, commercial property, or heavily overgrown. A traditional walking and digging field trip is possible but not as educational or as fun as sitting on a yacht for a four hour tour to see the land from the center of the river.

Distances measurements along the Delaware River were created by the US Coast Guard. The mouth of Delaware Bay near Cape May County starting at River Mile 0. All other river features are labeled from that point. See figure 1-4.

Speakers will also cover the ancestral river patterns, bridges, islands, dredging, biology, shore line features, and water use of and along the Delaware.

Flow Regimes of the Delaware River Region:

Since the 1600's

Flow changes due to:	River contamination Dredging and fill Dam construction and up river water release

During the Pleistocene

Flow changes due to:	Multiple glacial periods Multiple interglacial period Glacial depression

During the Pliocene

Flow changes due to:	Hudson-Delaware interaction

During Miocene to Paleocene

River flow:	Deposition of Outer NJ Coastal Plain

During Cretaceous

River flow:	Deposition of Inner NJ Coastal Plain

During Jurassic and Triassic

River flow:	Deposition of Newark Basin

During early Paleozoic

River flow:	Trenton Prong

Dredging operations over past 130 years

1885	Federal government authorizes permanent improvement of the Delaware River and Bay (through construction of anchorages, dikes, revetments, and harbors)
1894	Smiths and Windmill Island dredged near Philadelphia, fill placed on League Island to improve new Navy Yard.
1896	Thirty-foot channel authorized from Bombay Hook to Philadelphia
1910	Main shipping channel project adopted
1930	Main channel dredged to 35 feet and then to 40 feet
1940	First major deepening project removes 42 million cubic yards of dredge material from the channel, deepening it by 40 feet
1941	Channel maintenance dredging removes 29 million cubic yards of dredge material
1962	Forty foot channel completed between the Navy Base and Alleghany Avenue
2015	Dredging of Delaware to 45 ft blasting bedrock where needed to 47 ft

Reported contamination issues over past 280 years

1739	Benjamin Franklin petitions the Pennsylvania Assembly to stop waste dumping and remove tanneries due to foul smells, low property values, and disease
1769	Pollution first noted in Estuary
1789	Benjamin Franklin leaves money in his will to build a freshwater pipeline to Phila because of concern for the link between polluted water and disease
1793	Yellow Fever epidemic, leading cause of 5,000 deaths between Aug and Nov in Philadelphia
1797	Philadelphia Watering Commission established to provide safe drinking water
1799	Work starts on Schuylkill Water Works, first water plant of its kind in the U.S.
1799	First pollution study conducted in the Estuary
1800	Intense turbidity develops in estuary
1820	Coal silt pollution problems in Estuary due to coal mining operations
1832	Philadelphia law prohibits discharge of any "putrid or noxious matter" to the River
1850	First Philadelphia water intake on the Delaware
1880	Many of Philadelphia's streams are converted into sewers as part of the city plan
1886	Pennsylvania State Board of Health is established to improve sanitary conditions
1899	Rivers and Harbors Act, considered to be the first federal environmental law
1905	Pennsylvania creates Department of Health to control sewage discharges by permit
1913	PA passes Act 375, prohibits discharge of anthracite coal, culm, or refuse into streams
1920	Shad fishery is almost eliminated due to pollution, habitat loss, and overfishing
1937	Anti-stream pollution law authorizes $5 million to remove coal silt from Schuylkill
1937	Pennsylvania first exerts controls on industrial water pollution
1940	DO levels reach catastrophic lows, anoxic conditions, 20 miles around Philadelphia
1941	Only 8% of industrial waste is treated before discharge
1942	Estuary suffers from gross pollution
1955	Philadelphia Southwest sewage treatment plant opens, with only primary treatment
1965	PA passes Anthracite Coal Mine Act: prevents pollution from anthracite mining
1965	DRBC declares a state of water supply emergency in the Delaware River Basin
1967	DRBC adopts higher water quality standards; require 88% reduction in BOD
1968	DRBC issues waste-load allocations to more than 90 discharges
1971	Establishment of U.S. EPA
1981	Philly sewage treatment plants upgraded to secondary treatment with disinfection
1983	60% reduction in BOD waste discharge loading compared to 1958
1983	Large scale chlorination of municipal and industrial waste begins
1985	Grand Eagle Oil Spill, Marcus Hook, PA - 435,000 gallons of Ninian crude oil
1989	Oil Spill, Marcus Hook, PA - 306,000 gallons of #6 oil, heavy industrial grade
1994	T/V Kentucky Oil Spill, Paulsboro, NJ - 13,000 gallons of Arabian light crude oil

Figure 1 Burlington to Trenton

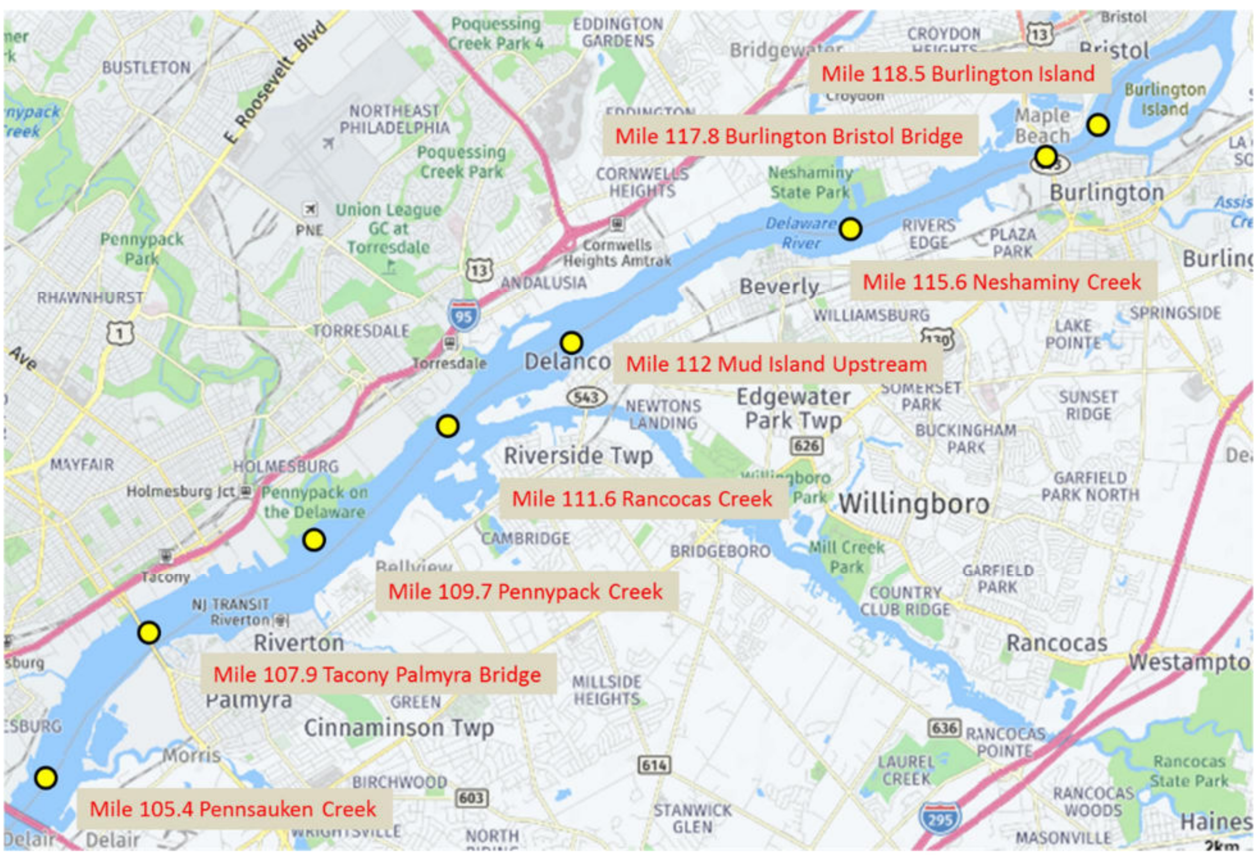

Figure 2 Betsy Ross Bridge to Burlington

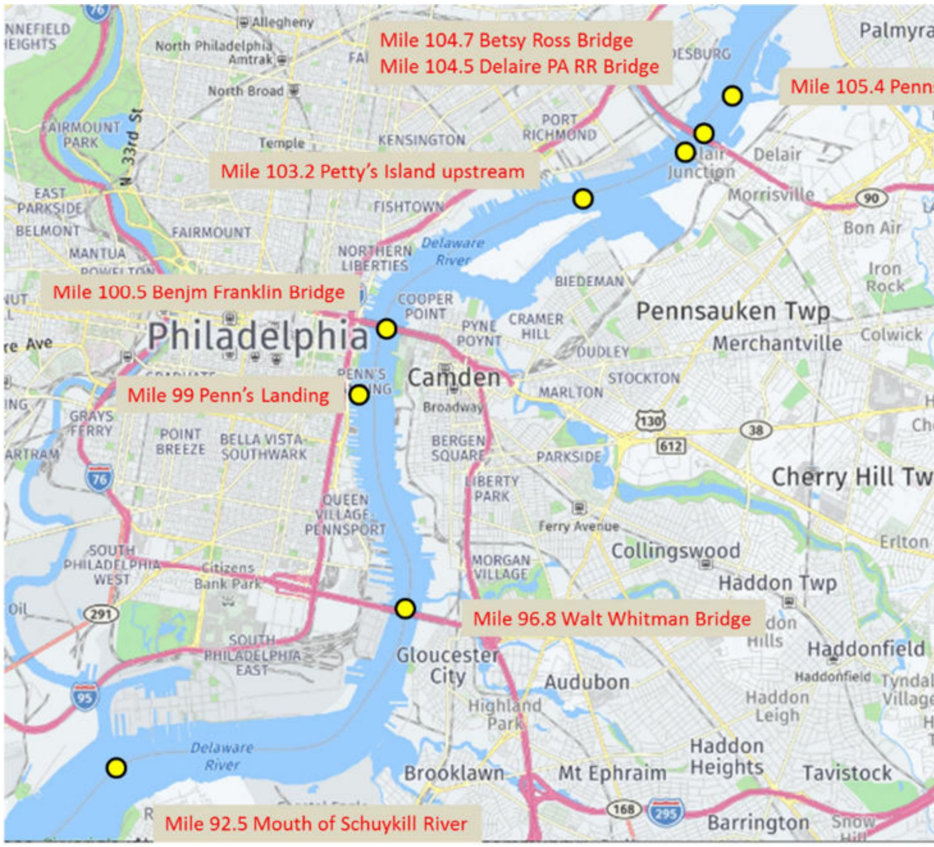

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Figure 3 Philadelphia to Betsy Ross Bridge

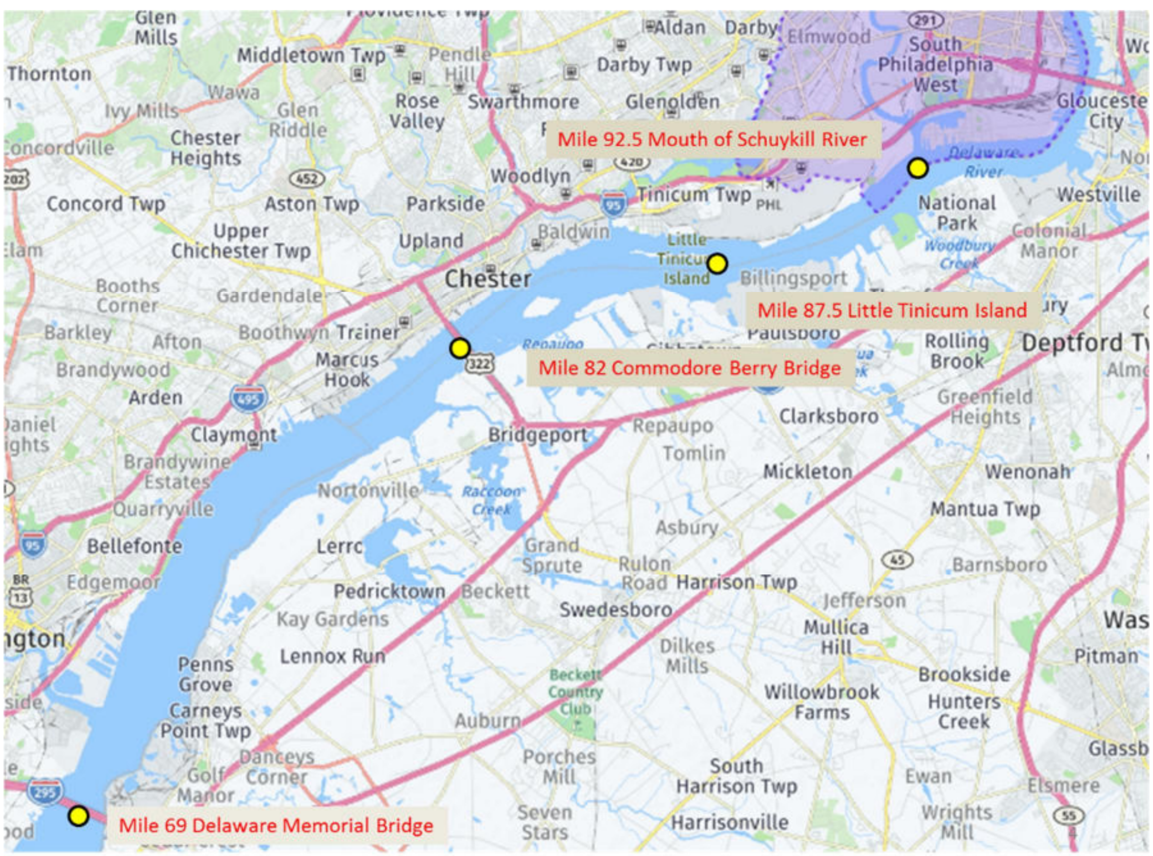


Figure 4 Delaware Memorial Bridge to Philadelphia

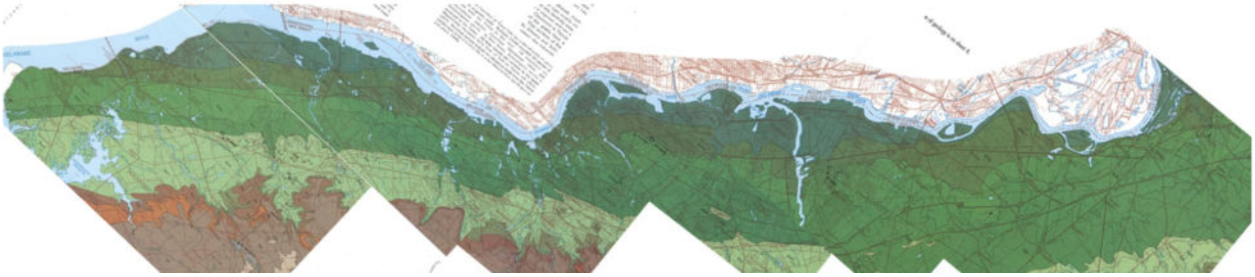


Figure 5 Bedrock Geology of NJ Coastal Plain

The Bedrock Geology of the NJ Coastal Plain (fig 5) is simple and is not exposed in most places.

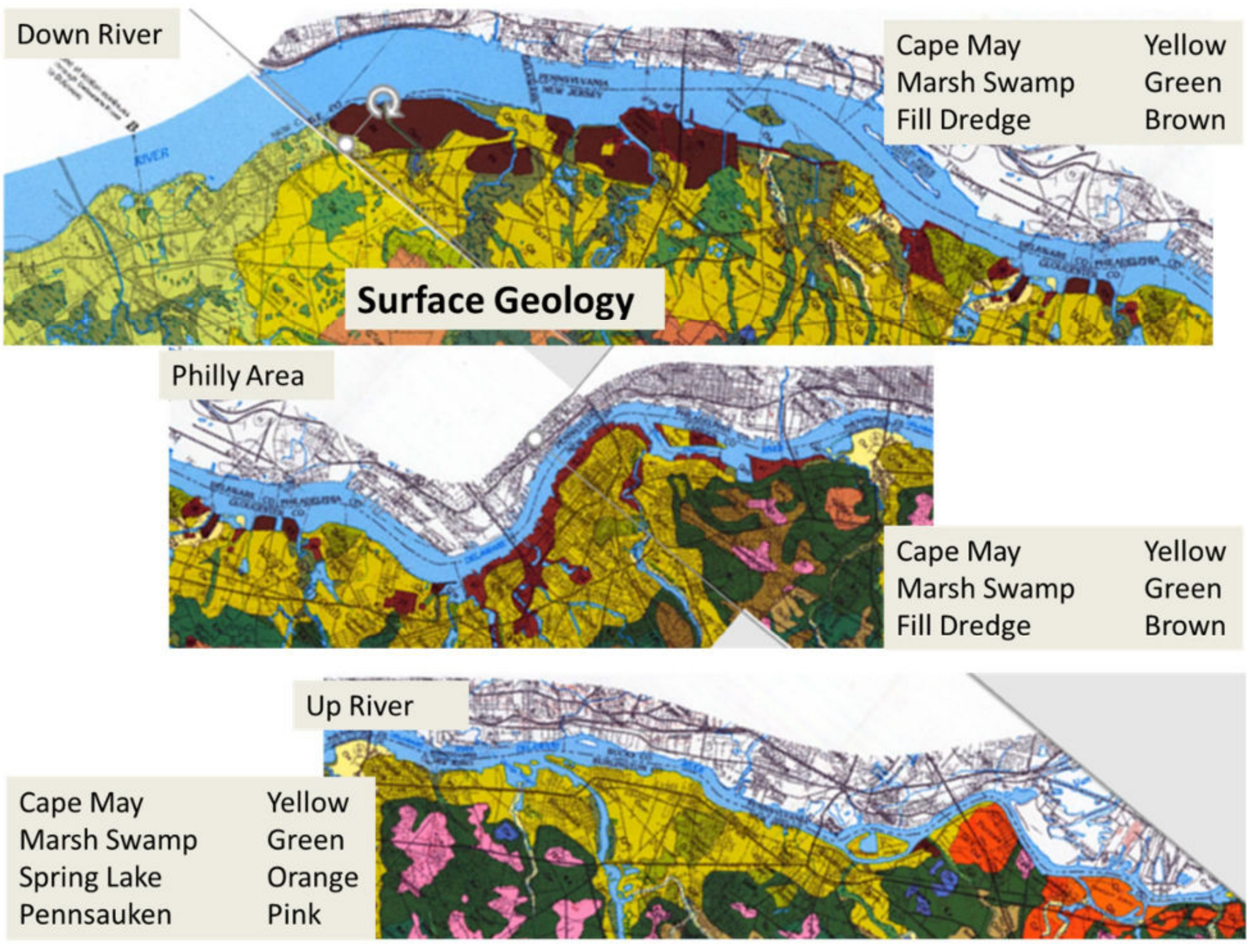


Figure 6 Highly dissected Surface geology of NJ coastal Plain

The Surface Geology of the NJ Coastal Plain (Fig 6 is highly dissected

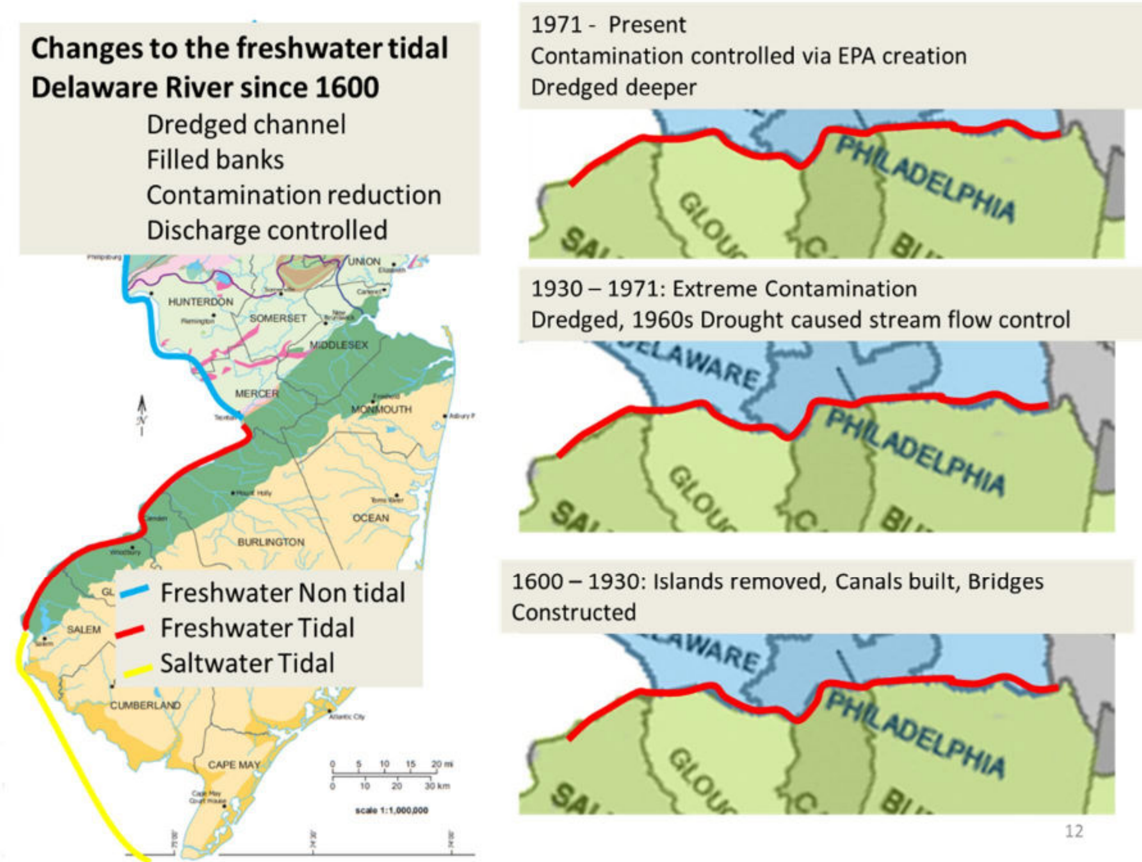


Figure 7 Flow of Delaware During modern times

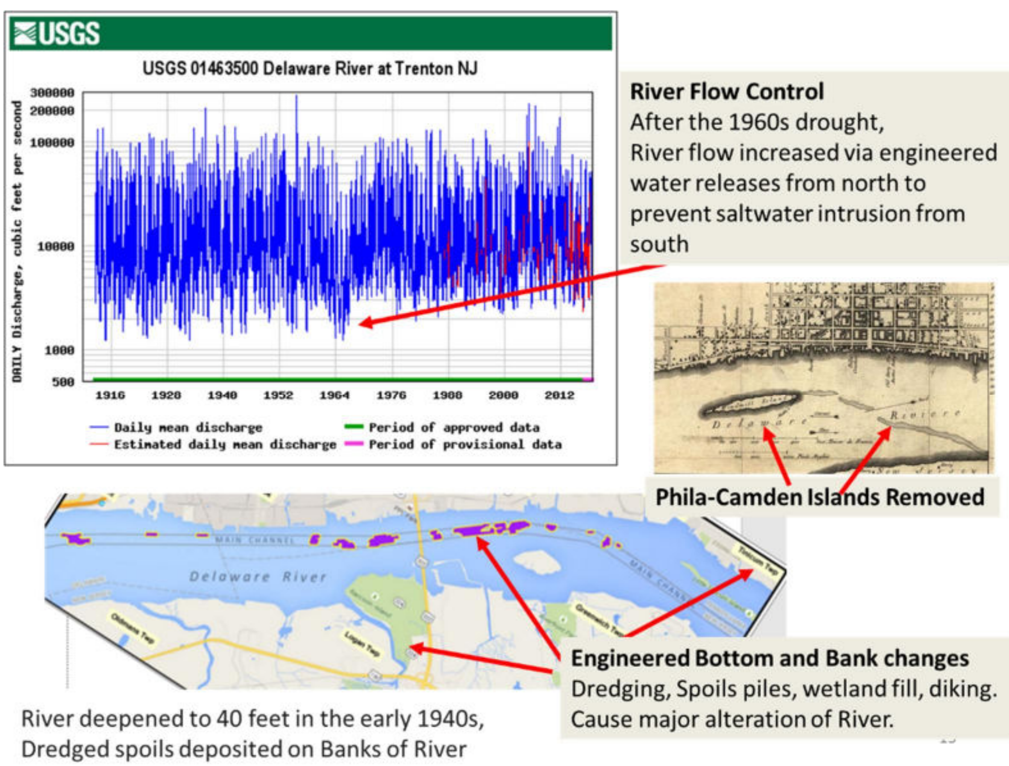
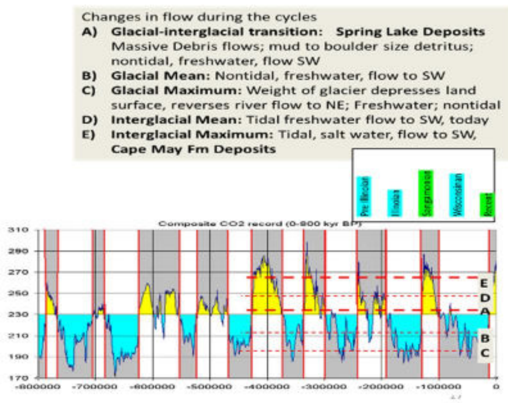


Figure 8 Changes of Delaware flow due to discharge regulations and dredging



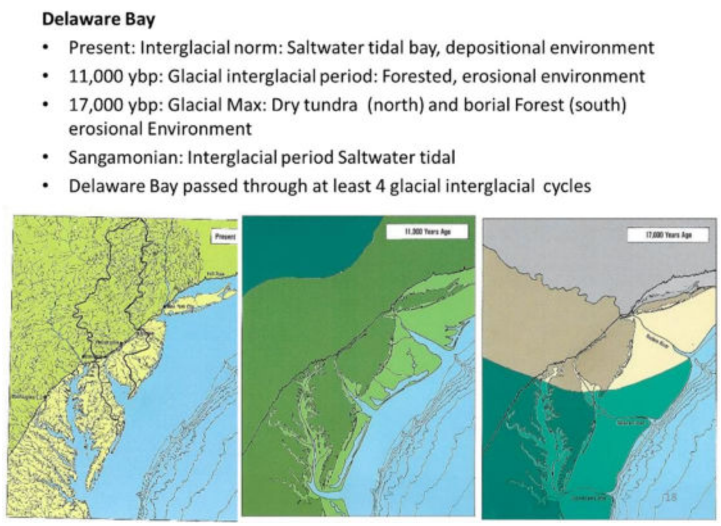


Figure 9a Changes in Delaware Flow during glacial epochs and source of Spring Lake and Cape May Formations
Fig 9b Changes in water level of Delaware Bay during Glacial Epochs

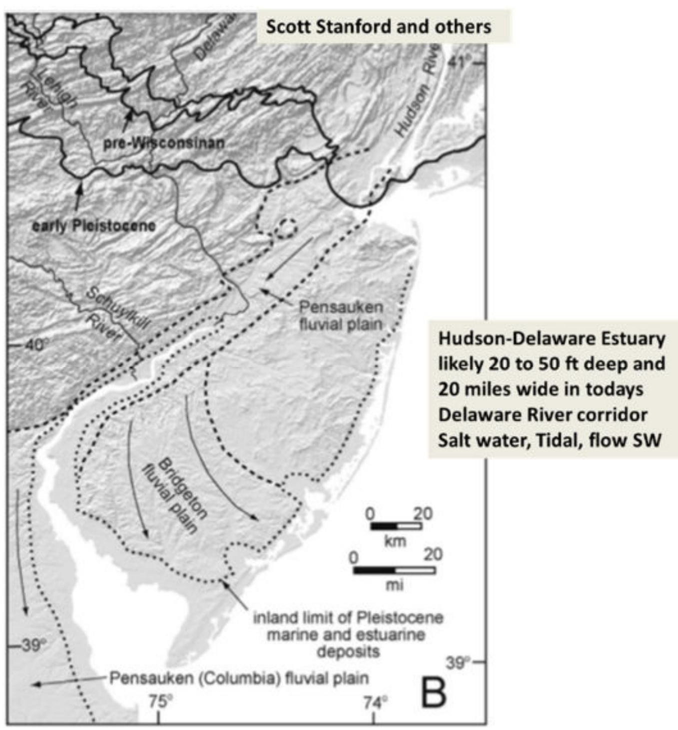


Figure 10 Ancestral Delaware River showing Pennsauken and Bridgeton Formations.

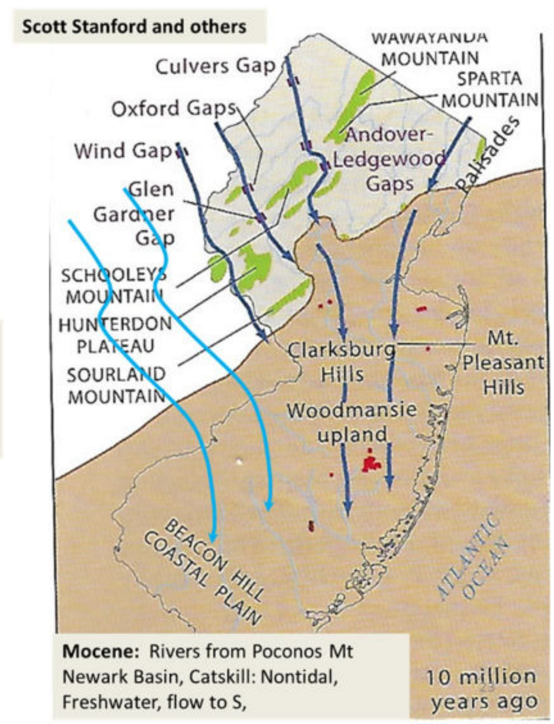


Figure 11 Cretaceous to Miocene Rivers that cross the Delaware Corridor to create inner and outer NJ Coastal Plain.

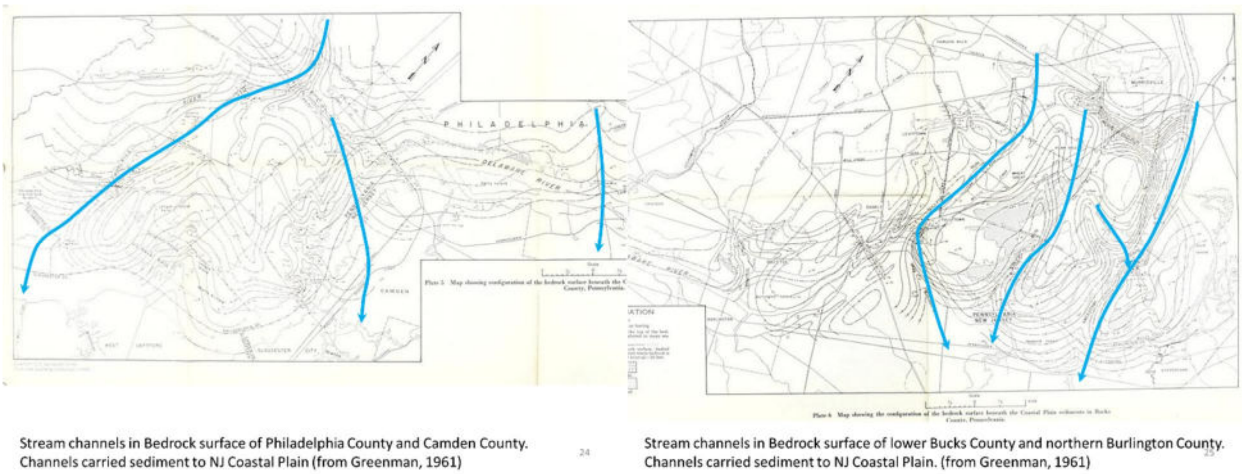


Figure 12a and 12b River channels incised in Wissahickon Formation.

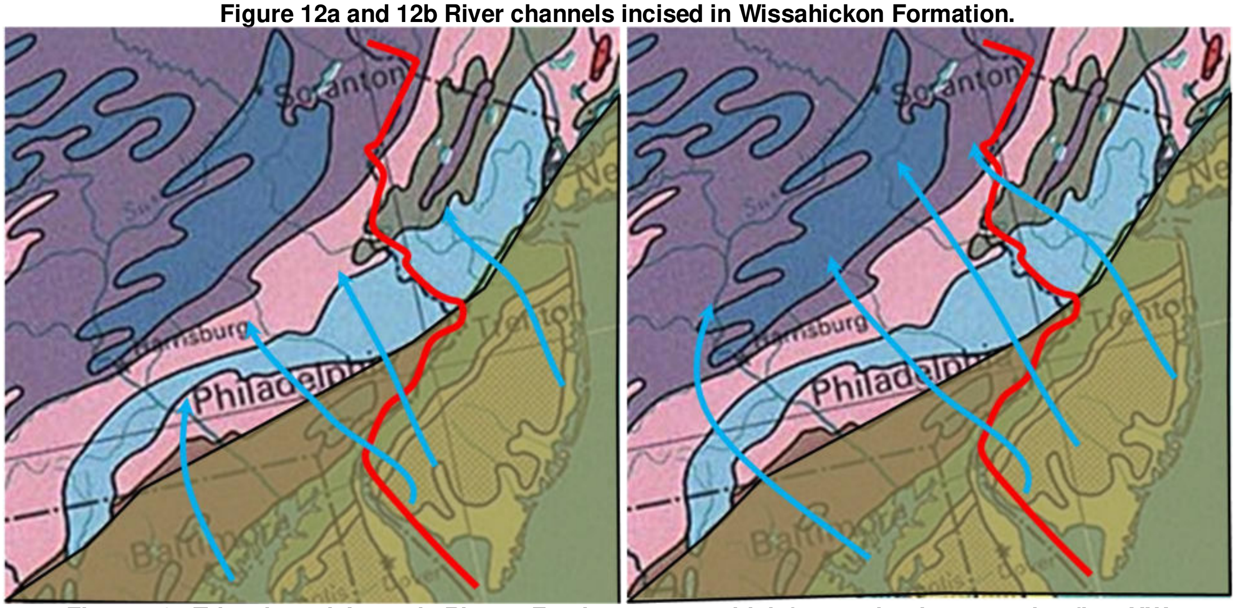


Figure 13a Triassic and Jurassic Rivers: Freshwater, non-tidal, from uplands mountains flow NW
Figure 13b Upper Paleozoic Rivers: Freshwater, non-tidal, from Taconic Mountains flow NW

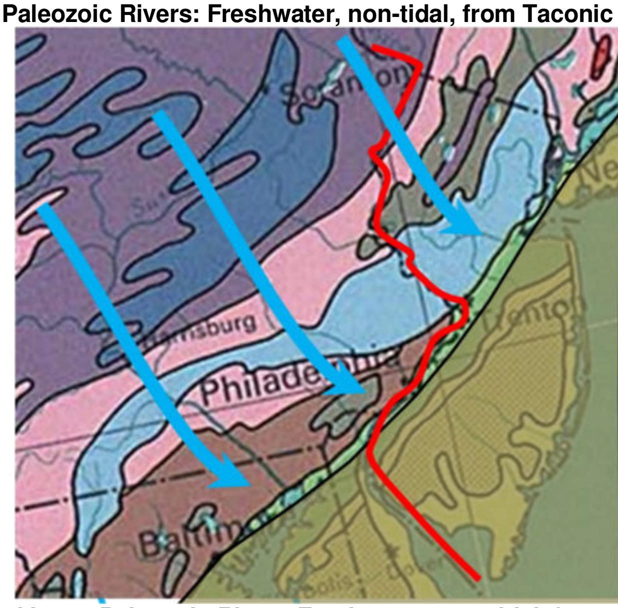


Figure 14 Proterozoic and lower Paleozoic River. Freshwater, non-tidal, from Craton flow SE to form NJ Highlands Trenton Prong, NJ Basement, and Manhattan Prong.

Bridges over the Delaware

Delaware Memorial Bridge

Commodore Berry Bridge

Walt Whitman Bridge

Benjamin Franklin Bridge

Pennsylvania Railroad Delair Bridge

Betsy Ross Bridge

Tacony Palmyra Bridge

Burlington Bristol Bridge

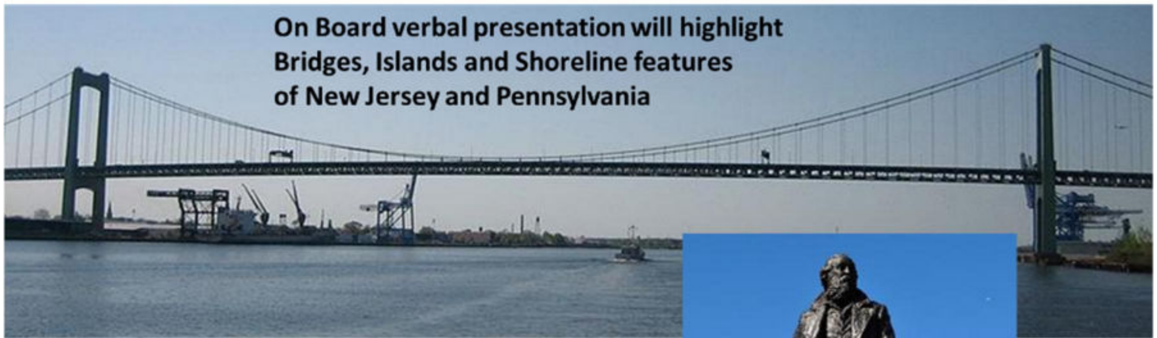
PA Turnpike Bridge

Delaware Memorial Bridge

- Architect also designed Walt Whitman and Verrazano Bridge
- Steel Suspension Bridge
- Total length ~10,800 feet
- Width ~59 feet
- Longest span 2,150 feet
- Clearance above 17.9 feet
- Clearance below 174 feet
- History
- Opened August 16, 1951; (eastbound) September 12, 1968(westbound)

Commodore Barry Bridge

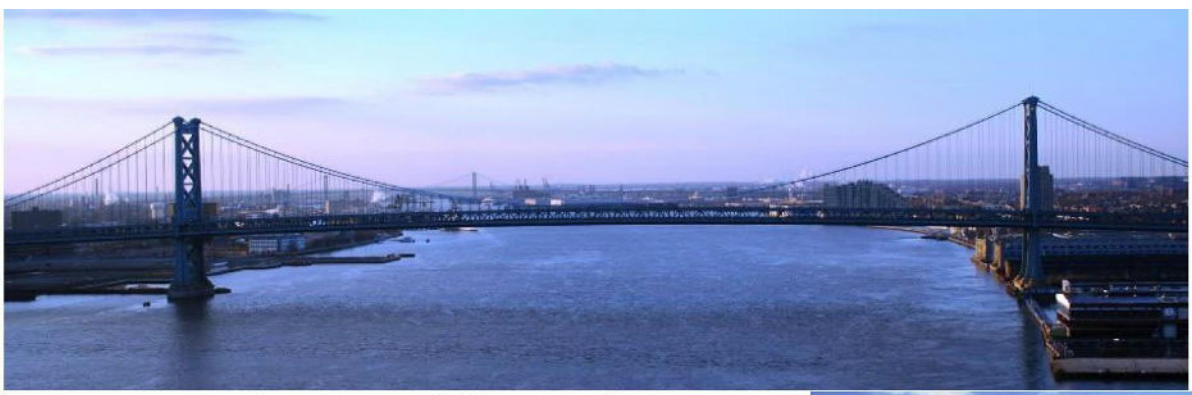
- Steel cantilever bridge
- Chester, PA to Logan, N. J
- American Revolutionary War & Philadelphia resident John Berry.
- Opened February, 1974
- Total length 13,912 feet
- Width 77 feet
- Longest span 1,644 feet
- Clearance below 192 feet



Walt Whitman Bridge

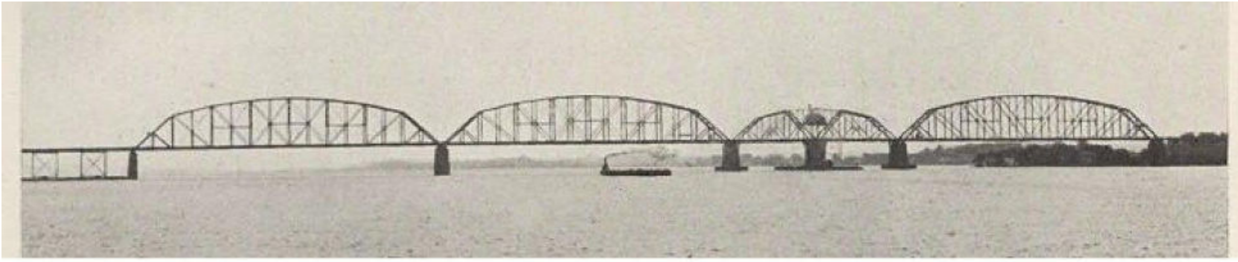
- Steel suspension bridge
- Total length 11,981 feet
- Width 92 feet
- Longest span 2,000 feet
- Clearance below 153 feet
- History
- Opened May, 1957;
- Test borings for the bridge began in September 1952. However, due to delays caused by material shortages during the Korean War, construction of the bridge did not begin until August 1953. Concrete anchorages were dug 60 feet deep on both sides of the Delaware River. Each anchorage measured 200 feet long, 120 feet wide and 130 feet above the ground. The tower piers, which each measured 174 feet by 64 feet, were dug 100 feet below the river on the Philadelphia side, and 80 feet into the river on the New Jersey side.

30



Benjamin Franklin Bridge

Steel suspension bridge
Total length 9,573 ft
Width 128 ft
Height 385 ft
Longest span 1,750 ft
Clearance above 16.8 ft
Clearance below 135.1 ft
Opened July 1, 1926
2 main cables (each 30 inches in diameter)
25,100 miles of wire used in constructing the enormous cables.
Manhattan (4 main cables 20 ½ inches in diameter) or 4 cable
Brooklyn (4 main cables 15 ¾ inches in diameter)



Pennsylvania Railroad Delair Bridge

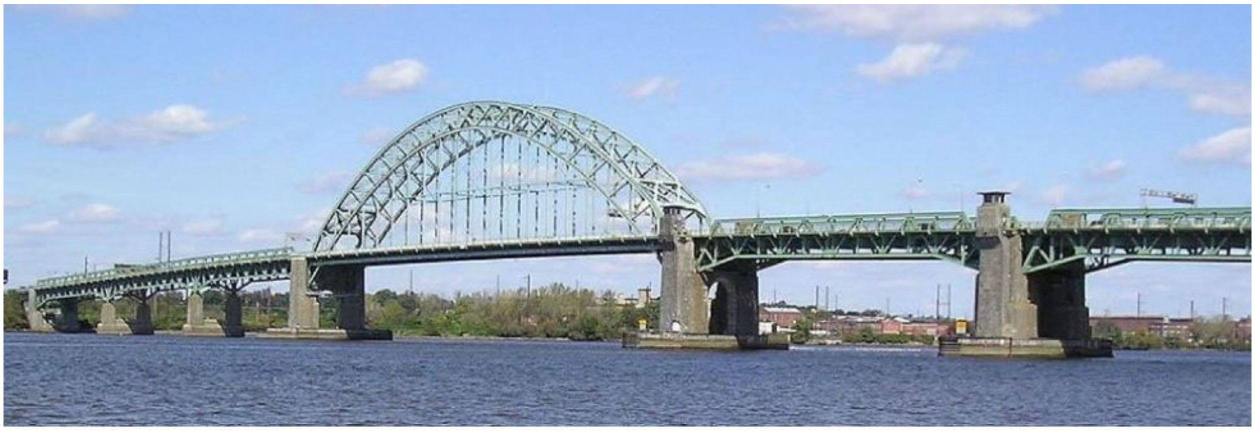
Riveted Warren truss vertical-lift span; Steel Lift Bridge

Total length 4,396 feet

Longest span 542 feet

Opened 1896

- World's heaviest center-bearing swing span, and
- Longest double-track vertical-lift span, added in 1959.
- Both movable spans are still present, which is an unusual
- First River crossing at Philadelphia,
- Lower Delaware's extreme width, tidal current, and soft bottom made foundation work difficult, therefore extremely long spans needed
- Each trestle is 4 stepped granite footings on wooden pile foundation are in a sand and gravel layer and capped with a tiaite grille
- Timber caissons; most rectangular,
- Hexagonal caisson accommodating the cylindrical swing span pivot pier, No. 4.
- Pier masonry with concrete core
- Granite blocks 18” to 24" thick, or 30" in the coping, with some blocks weighing more than 20 tons.



Tacony Palmyra Bridge

Steel tied arch bridge with bascule opening

Total length	3,659 ft
Width	38 ft
Longest span	558 ft
Clearance above	14.5 ft
Clearance below	61 ft (arch), 54 ft (bascule)
Opened	August 14, 1929;