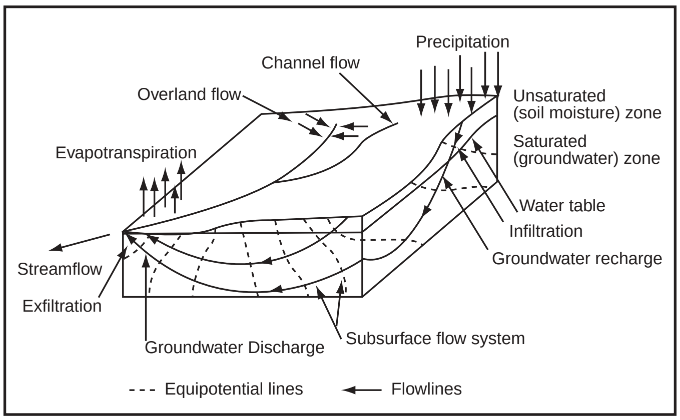
2.2 WATER RESOURCES

2.2.1 OCCURRENCES AND USES

Water is around us everywhere, in the air, on the ground, and beneath the ground. The movement of water from place to place and the processes that drive it are called the *"hydrologic cycle"* (*Figure 2.2-1*). Our own bodies are made up of more than 60 percent water, and we depend on it for life itself. It is obviously in our best interest to understand and wisely use this natural resource.

Figure 2.2-1

HYDROLOGIC CYCLE



Source: Freeze and Cherry, 1979

Naturally occurring water falls from the sky as rain or snow and at different times of the year is responsible for:

- Contributing to the flow of perennial streams;
- Growth of naturally occurring and ornamental vegetation, which affects our climate;
- Growth of agricultural crops; and
- Recharging ground-water aquifers, which provide drinking water for nearly all the Basin's inhabitants.

The Inland Bays are shallow, well-mixed estuaries having an average water depth of 3 to 8 feet and an average tidal range of 3 feet. The tidal flushing rates vary in different sections of the bays. The east end of the Indian River Bay and southern portion of Rehoboth Bay are well flushed by tidal action, but other parts of the bays are flushed at much slower rates. Although the Bays are slowly and unevenly flushed, they create a natural estuarine environment for finfish, shellfish, and waterfowl, which can bring about high biological productivity. This high productivity, however, depends upon the delicate balance between the living resources of the estuary and the quality of their environment. Any significant change to physical, chemical, and biological attributes of the Inland Bays can dramatically alter the natural balance of the bays and their living resources.

C O N T E N T S

WATER RESOURCES

2.2.1.1 Water Budget

The Inland Bays/Atlantic Ocean Basin receives an average precipitation of 45 inches per year. Of this, evaporation and transpiration by naturally occurring vegetation and agricultural crops consume about 26 inches (58 percent), surface runoff accounts for 4 inches (9 percent), and ground-water recharge takes 15 inches (33 percent). Precipitation also cleans the atmosphere of air-borne contaminants, which can then be transported into surface-water bodies and even into aquifers underground.

On average, rainfall recharges ground water in the Basin by 192.6 million gallons per day (MMGPD). Andres (1987) estimates that 21–43 MMGPD of fresh ground water enters the Inland Bays, which is less than one percent of the total volume of the bays. However, this ground water carries an average of 6.8 mg/L nitrate, which puts 1,197–2,451 pounds per day of nitrate into the bays. Rainwater has an average nitrate concentration of 3 mg/L.

2.2.2 ATMOSPHERE

Precipitation is distributed fairly evenly throughout the year, but there is usually a maximum in August (*Table 2.2-1*).

2.2.3 SURFACE WATER

2.2.3.1 Drainage Basins

There are eight watersheds in the Inland Bays/Atlantic Ocean Basin (*Map 1.2-1*). The magnitude of freshwater flows entering the Inland Bays Estuary through these tributaries is estimated based on the observed flows at several long-term and short-term stream-gauging stations in the Basin. These gauging stations are operated through cooperative agreements between the U.S. Geological Survey and the Department. One of the long-term stream-flow gauging stations is located on the Stockley Branch and has been in operation since 1947. The drainage area at this gauging station is 5.24 square miles with a long-term average flow of 6.93 cubic feet per second (cfs).

Table 2.2-1

MONTHLY MEAN AIR TEMPERATURES AND PRECIPITATION AT LEWES, DE (1960–1990)

MONTH	MEAN TEMPERATURE (°F)	MEAN PRECIPITATION (IN.)
January	34.6	3.47
February	36.1	3.33
March	43.3	4.21
April	53.1	3.41
May	62.1	3.54
June	70.7	3.70
July	75.2	4.16
August	74.3	5.36
September	68.4	3.26
October	57.5	3.33
November	48.0	3.49
December	38.5	3.82
Annual Average	**55.5**	**44.67**

Source: NOAA

Table 2.2-2

STREAMS DRAINING THE INLAND BAYS/ATLANTIC OCEAN BASIN

RECEIVING WATER BODY	TRIBUTARY NAME	DRAINAGE AREA, ACRES
Rehoboth Bay	Lewes-Rehoboth Canal	9,353
	Love Creek	14,041
	Herring Creek	15,808
	Guinea Creek	8,765
	Lingo Creek	4,450
Indian River Bay	Swan Creek	13,658
	Millsboro Pond	35,433
	Iron Branch	14,819
	Pepper Creek	10,265
	Vines Creek	9,951
	Blackwater Creek	8,770
	White Creek	8,365
Little Assawoman Bay	Miller Creek/ Dirickson Creek	23,775

Streams in all but two of these watersheds eventually flow into one of the three Inland Bays (*Table 2.2-2*). Portions of two watersheds straddle the Delaware-Maryland line and drain southward into Maryland.

There are two long-term stream-flow gauges in the Basin. One is on the Stockley Branch, which eventually flows into Millsboro Pond,and the other is at Millsboro Pond Outlet (*Table 2.2-3* and *Figure 2.2-2*).

Table 2.2-3 shows that long-term average stream flows in cubic feet per second (cfs) are 1.3 times the stream's drainage area in square miles. This relationship can be used to estimate the flow volume of ungauged streams.

Tidal characteristics of the Inland Bays Estuary are monitored by several tide gauges in the bays. These tide gauges are located at the Coast Guard Station near the Indian River Inlet, at Rosedale Beach, and at Bethany Beach.

Tidal records at the Coast Guard Station near Indian River Inlet indicate that the mean tidal range at this site is 2.7 ft, with a mean low tide of 1.4 ft and a mean high tide of 3.2 ft. *Figure 2.2-3* shows tidal elevations during January 1–7, 1999.

2.2.4 GROUND WATER

Ground water is the sole source of drinking water for residents living within the Inland Bays/Atlantic Ocean Basin. It is replenished by rainfall that recharges the Basin's unconfined Columbia Aquifer at an average rate of 193 million gallons per day. The majority of the Basin has fair to good recharge potential as depicted in *Map 2.1-4*. In some areas, a portion of the ground water in the unconfined aquifer infiltrates downward through leaky confining layers and helps recharge deeper aquifers. Columbia ground-water volumes are not only sufficient to meet the demand of public, irrigation, domestic, and industrial wells withdrawing water from the aquifer, but are also generally adequate to maintain the hydraulic heads necessary to prevent saltwater intrusion into aquifers along the coast.

2.2.4.1 Aquifers

From oldest to youngest, these are the principal aquifers in the Inland Bays/Atlantic Ocean Basin: the Manokin Aquifer, Pocomoke Aquifer, Columbia/Pocomoke Aquifer, and Columbia Aquifer. The Manokin and Pocomoke aquifers are generally considered confined. Locally, these aquifers may be unconfined where their confining layers are thin, discontinuous, or have been removed by erosion.

The Columbia/Pocomoke and Columbia aquifers are generally considered to be unconfined. They may, however, be locally confined where overlying sediments of the Omar Formation are sufficiently thick and impermeable to form a confining layer.

Hydrologic characteristics of the aquifers in the Basin are only sparsely available, except for the Columbia Aquifer. In addition, hydrologic characteristics of the deeper aquifers are highly variable (Andres, 1986).

Figure 2.2-2

STREAM FLOW (CFS) ON STOCKLEY BRANCH AND MILLSBORO POND OUTLET

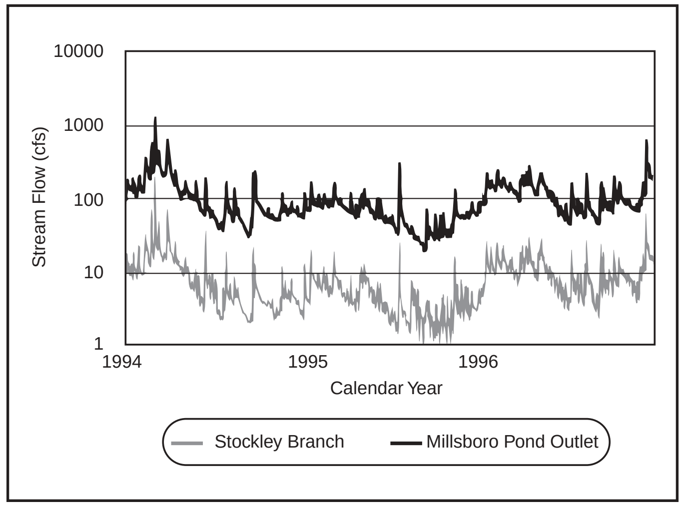


Figure 2.2-3

TIDAL ELEVATION NEAR INDIAN RIVER INLET (JANUARY 1–7, 1999)

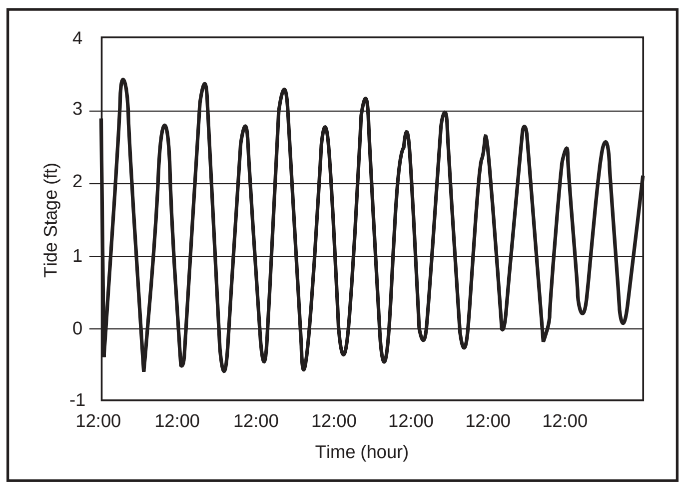


Table 2.2-3

STREAM-GAUGE CHARACTERISTICS

STATION NUMBER	STATION NAME	DRAINAGE AREA, MI^2	NORTH LATITUDE	WEST LONGITUDE	PERIOD OF RECORD	LONG-TERM AVERAGE FLOW, CFS
01484500	Stockley Branch at Stockley	5.24	38°38'19"	75°20'31"	4/1/43–9/30/97	6.93
01484525	Millsboro Pond - Outlet at Millsboro	66	38°35'40"	75°17'29"	5/1/86–9/30/88 and 3/16/91–9/30/97	88.1

Manokin Aquifer

The Manokin Aquifer is a gray, fine-to-very-coarse sand that occasionally contains lignite and peat (Phelan, 1987). This confined aquifer forms the base of the freshwater aquifer system in most areas of the Basin (Talley and Andres, 1987). The top of the Manokin Aquifer occurs at a depth of approximately 170 feet below sea level and is 50 – 90 feet thick in the Lewes area (Andres, 1986; Phelan, 1987). Down-dip near Fenwick Island, the top of the aquifer, is approximately 280 feet below sea level (Talley, 1987; Phelan, 1987), and it is approximately 120–150 feet thick. The Manokin is rated good to excellent as an aquifer. Pump test data (Talley and Andres, 1987) indicate that:

- Transmissivity (T) values range from 2,500 ft^2/day near Dewey Beach to 17,420 ft^2/day near Lewes. The average transmissivity of the Manokin is 7,030 ft^2/day. (The T value obtained from Lewes is high. This value likely indicates that the Manokin and overlying formations at Lewes are interconnected to form an unconfined aquifer system.)
- Specific capacity (S.C.) values range from 1.5 gpm/ft near Fenwick Island to 26.3 gpm/ft near Millsboro. The average S.C. value for the Manokin is 11.8 gpm/ft.
- Yields from the Manokin Aquifer range from 40 gpm near Five Points (2½ miles southwest of Lewes) to 1,000 gpm near Millsboro. The average yield for the aquifer is 253 gpm. Higher yields may be obtained where the Manokin is interconnected with shallower, overlying aquifers (Talley, 1987).
- Storativity (S) value of 0.0005 is thought to be representative of the Manokin (Sundstrom and Pickett, 1985).

Pocomoke and Columbia/Pocomoke Aquifers

The Pocomoke and Columbia/Pocomoke are aquifers within the Bethany–Beaverdam formations (refer to *Table 2.1-1*). These formations comprise a heterogeneous sequence of geologic units, whose members cannot always be differentiated or correlated from place to place. Locally, some sands have been named (e.g., Ocean City Aquifer), but these names are not universally accepted.

This heterogeneity combined with some structural deformation [there are some faults in the Bethany Formation (refer to *Map 2.1-2*) near the coast] requires very careful work when attempting to perform groundwater-quality assessments and computer simulations.

The Pocomoke Aquifer is characterized as a silty, fine to coarse, light gray sand containing occasional fine gravel (Hodges, 1984; Denver, 1983). It is generally considered to contain both a “lower sand” and an “upper sand.”

South of Indian River Bay and west of Little Assawoman Bay in the southwestern portion of the Basin, the uppermost confining beds of the Bethany Formation are missing, and the Pocomoke Aquifer is hydraulically connected to, and is part of, the shallow, unconfined Columbia water-table aquifer. This area is referred to as the Pocomoke subcrop. Farther west, the Pocomoke is a separate, confined aquifer.

The “lower sand” of the Pocomoke Aquifer ranges in thickness from 6 feet near Millsboro and Five Points to approximately 75 feet at Indian River Inlet and 110 feet in the Bethany Beach area (Hodges, 1984; Andres, 1986; Talley, 1987; Phelan, 1987; Andres, 1987, and Andres et al., 1990).

The “lower sand” ranges in depth from approximately 106 feet below sea level at Lewes in the northern portion of the Basin to 244 feet below sea level at Fenwick Island in the south.

Sparse data from wells along the coast indicate the following aquifer characteristics:

- Transmissivity: 8000 ft^2/day (maximum); 1,850 – 3,700 ft^2/day (average);
- Specific capacity: 8.1 gpm/ft;
- Yield: 257 gpm; and
- Storativity: 0.00037 (estimated).

The “upper sand” of the Pocomoke Aquifer ranges in thickness from 5 feet near Five Points, where it is approximately 112 feet below sea level, to approximately 30 feet thick between Indian River Inlet and Bethany Beach, where it is approximately 136 feet below sea level.

Very limited data from wells on the barrier island suggest the following aquifer characteristics:

- Transmissivity: 414 ft^2/day in the south near Fenwick Island to an estimated 1,000 – 2,000 ft^2/day to the north between Indian River Inlet and Bethany Beach;
- Specific capacity: 1.3 gpm/ft in the south to 5.9 gpm/ft northward;
- Yield: 36 gpm in the south to 228 gpm to the north; and
- Storativity: 0.0002 (estimated).

In the Inland Bays/Atlantic Ocean Basin, approximately 23 percent of the major public wells withdraw water from confined aquifers. With the exception of Frankford and Millsboro, which have public wells drawing water from the Pocomoke and Manokin aquifers, respectively, most confined wells are located along the coast (*Table 2.2-4*).

The Manokin and Pocomoke aquifers are mostly undeveloped in the inland portions of the Basin and are believed to have additional capacity for withdrawals without any

Table 2.2-4

PUBLIC WELLS WITHDRAWING WATER FROM CONFINED AQUIFERS

TOWN/SUBDIVISION	AQUIFER
Sussex Shores	Pocomoke
Town of Bethany Beach	Pocomoke/Manokin
Sea Colony	Manokin
Fenwick Island	Pocomoke
South Bethany	Pocomoke

Source: Phelan, 1987

adverse effects (Talley, 1987). A modeling analysis performed by Hodges (1984) simulating pumping increases through the year 2004 indicates that yearly average water levels in eastern Sussex County would not be affected by increased withdrawals from these confined aquifers in most areas. An exception is in the Lewes area where the simulation indicated that water levels could drop below sea level and could result in saltwater intrusion along the coast.

Well-withdrawal data for confined aquifer wells within the Inland Bays/Atlantic Ocean Basin indicate that municipal wells were withdrawing approximately 400,000 gallons per day in 1976. Hodges (1984) estimated that water use from the confined aquifers would increase by at least 34 percent by the year 2000. Based on this, water yield from the confined aquifers is currently at least 520,000 gallons per day. This value is likely low since several new subdivisions along the coast are obtaining water from confined aquifers.

The Columbia/Pocomoke Aquifer refers to that portion of the unconfined aquifer that is composed of Bethany Formation sands. The Columbia/Pocomoke Aquifer is most extensive in the southern portion of the Basin where it attains a maximum thickness of approximately 100 feet near Millville.

Columbia Aquifer

Fine- to coarse-grained sands of the Beaverdam Formation comprise most of the Basin's unconfined or water-table aquifer system, which is also referred to as the Columbia Aquifer. *Map 2.1-1* shows the surficial geological formations in the Basin and the outcrop area of the Beaverdam Formation. The Delaware Geological Survey defines the Columbia Aquifer as all the interconnected sands that lie above the first encountered confining layer found below the Beaverdam Formation (Andres, 1987). Therefore, underlying Bethany and Manokin sands are included in the Columbia Aquifer where these formations are devoid of a confining layer as is the case in the Pocomoke subcrop area in the southwestern portion of the Basin. In the Omar area, well-log information indicates that major confining layers are essentially missing or are very discontinuous throughout the Manokin and Bethany formations. The water-table aquifer system may attain thicknesses greater than 300 feet in this area (Talley, 1987).

The unconfined-aquifer system is the thickest and most productive aquifer in the Basin. It ranges in thickness from approximately 90 – 100 feet in the westernmost portions of the Basin to approximately 250 feet near Millville. The base of the Columbia Aquifer is shown in *Map 2.1-3*.

Hydrologic characteristics of the Columbia Aquifer are:

- Transmissivity ranges from 22,590 feet per day in the Pocomoke subcrop area near Oak Orchard (Talley and Andres, 1987) to 1,500 feet per day near Millsboro (Johnston, 1973);
- Specific capacity values range from 2 gpm/ft near Old Landing to 46 gpm/ft near Millsboro. An average specific capacity for the Basin is 15 gpm/ft (Talley and Andres, 1987);
- Yields from the Columbia Aquifer range as high as 1,250 gpm at the City of Rehoboth Beach, but an average yield is closer to 240 gpm; and
- Storativity value of 0.15 is representative for the Columbia Aquifer (Groot, 1983).

Nearly all domestic, irrigation, and agricultural wells draw water from the Columbia Aquifer (Andres, 1987). Approximately 77 percent of the major public wells in the Basin draw water from the unconfined aquifer. Major public wells include community, non-transient non-community, and transient non-community public wells. *Map 2.2-1 Locations of Public, Irrigation, Industrial, and Domestic Wells* shows the locations of public, domestic, irrigation, agricultural, and industrial wells found in the Basin. *Table 2.2-5* lists the total number of wells of each type in the Basin.

Hodges (1984) reports an equivalent population in coastal Sussex County in 1975 of 72,122 persons. An equivalent population is a total population that accounts for year-round residents and tourists. In 1976, average daily water-use volumes for the Inland Bays/Atlantic Ocean Basin were as shown in *Table 2.2-6*.

Based on census data from Cassell and Meals (1999), an equivalent population of roughly 100,532 residents lived in the Inland Bays/Atlantic Ocean Basin during 1996 – 1998. But this value is low because these authors did not include the Iron Branch, Buntings Branch, and Lewes-Rehoboth Canal watersheds in the census count. Multiplying this residential population by a per capita water use of 50 – 75 gpd (Sundstrom and Pickett, 1969)

Table 2.2-5

NUMBER OF WELLS BY TYPE IN THE INLAND BAYS/ATLANTIC OCEAN BASIN

WELL TYPE	TOTAL	NUMBER OF ALLOCATED WELLS
Public	696	82
Irrigation	247	39
Industrial	88	16
Domestic	14,810	N/A

Table 2.2-6

AVERAGE DAILY WATER USE IN THE INLAND BAYS/ ATLANTIC OCEAN BASIN DURING 1976

WELL TYPE	TOTAL DAILY VOLUME IN GALLONS
Municipal Wells	2,482,400
Rural/Domestic	1,818,300
Agricultural/Irrigation	2,553,900
Industrial	3,327,700
Total	**10,182,300**

Source: Hodges, 1984

gives an estimated total daily drinking-water use of 5,026,000 – 7,540,000 gallons.

Sundstrom and Pickett (1969) estimated that as much as 100 million gallons per day can be developed from the unconfined aquifer in eastern Sussex County without causing serious adverse impacts to the quality of the aquifer and other current uses. Total water use in the Columbia Aquifer is not currently known, but based on population and average per capita water-use data, this value is believed to be less than 25 million gallons per day.

2.2.5 WATER QUALITY

2.2.5.1 Surface Water

Because Rehoboth Bay, Indian River Bay and Little Assawoman Bay dominate the Basin, discussions of surface water tend to focus on these three bays and their major tributaries, including Indian River, Pepper Creek, Herring Creek, Love Creek, and Dirickson Creek.

Section 10 of the State of Delaware Surface Water Quality Standards, as amended, designates the following specific uses for the waters of the Indian River, Indian River Bay, and Rehoboth Bay (Weston, 1993):

- ◆ Fish, aquatic life, and wildlife;
- ◆ Primary contact recreation;
- ◆ Secondary contact recreation;
- ◆ Industrial water supply;
- ◆ Waters of exceptional recreational or ecological significance (ERES Waters); and
- ◆ Harvestable shellfish waters.

Note: Only parts of the Indian River, Indian River Bay, and Rehoboth Bay are designated as ERES waters or harvestable shellfish waters.

Applicable Water-Quality Standards

The following sections of the State of Delaware Water-Quality Standards provide specific narrative and numeric criteria concerning the waters of the Inland Bays (Weston, 1993):

- ◆ Section 3 provides general guidelines regarding the Department's Antidegradation policies.
- ◆ Section 7 provides specific narrative and numeric criteria for controlling nutrient over-enrichment in waters of the state.
- ◆ Section 9 provides specific narrative and numeric criteria for toxic substances.
- ◆ Section 11 provides specific water quality criteria for the surface waters of the state.

Water-quality standards applicable to Indian River, Indian River Bay, and Rehoboth Bay are:

- ◆ Dissolved oxygen: 5.0 mg/L daily average (June – September); 4.0 mg/L minimum;
- ◆ Phosphorus during submerged aquatic vegetation growth season (March 1 – October 31): 0.01 mg/L dissolved inorganic phosphorus;
- ◆ Nitrogen during submerged aquatic vegetation growth season (March 1 – October 31): 0.14 mg/L dissolved inorganic nitrogen;
- ◆ Total suspended solids during submerged aquatic vegetation growth season (March 1 – October 31): 20 mg/L;
- ◆ *Enterococcus* bacteria: 10 colonies/100 ml; and
- ◆ Temperature: 86°F maximum daily; 84°F mean daily; maximum increase above natural conditions four degrees Fahrenheit.

Map 2.2-2 Total Suspended Solids and *Map 2.2-3 Chlorophyll A* provide general water-quality information for the Inland Bays.

In addition to the above narrative and numeric criteria, Section 11.5 of the State Water-Quality Standards provides general policies and criteria for Waters of Exceptional Recreational or Ecological Significance (ERES Waters). The Section requires that ERES Waters, which are considered as special natural assets of the state, shall be accorded a level of protection in excess of that provided for most other waters of the state. Furthermore, it calls for restoring ERES Waters, to the maximum extent practicable, to their natural condition by adopting pollution control strategies that will take appropriate action to cause systematic control, reduction, or elimination of existing pollution sources.

Water-quality data for the period of 1993–97 for STORET stations in the Inland Bays were retrieved and analyzed for compliance with Delaware Water Quality Standards and Department guidelines for assessment of eutrophic conditions. Most data were first averaged for the period of March through October each year and for the entire period. Dissolved oxygen data were averaged for the June through September period in each of those years separately, as the standards are written for those months. The results are found in *Table 2.2-7*.

For the five-year period, there were 39 stations that had data for at least one year. The Department uses total nitrogen above 1.0 mg/l, total phosphorus above 0.01 mg/l and chlorophyll at concentrations above 20 µg/l as indicator guidelines of waters that are undergoing excessive eutrophication. Ten of the reporting stations met the guidelines for average nitrogen concentrations. No stations met the average phosphorus guideline. Ten stations reported five-year average concentrations for chlorophyll a above the 20 µg/l level. Twenty-seven stations did not meet similar guidelines for total suspended solids of 20 mg/l. *Enteroccus* (bacteria indicative of fecal waste contamination) levels were elevated at 27 stations. Nine stations had dissolved oxygen levels that did not meet the standard for the five-year period. As can be predicted from the above information, there were numerous individual sampling events in which water-quality standards may not have been met. In addition, there were a number of stations that did not meet the annual averages although they did meet the five-year averages. Based on sampling

Table 2.2-7
AVERAGE CONCENTRATIONS OF SELECT PARAMETERS DURING MARCH TO OCTOBER, 1993–1997

STATION	DO MG/L	CHLOROPHYLL a (µG/L)	ENTEROCOCCI #/100 ML	DISSOLVED INORGANIC P	TOTAL SUSP SOLIDS MG/L	TOTAL N MG/L
305011	3.6	9.88	146.18	0.09	23.83	1.35
305061	3.6	12.5	227	0.11	24.5	1.29
305071	64.25	165.33	0.02	22.5	1.86	
306061	4.9	5.5	1	0.02	22.6	1.05
306071	5.3	9.8	9.62	0.03	30.23	0.95
306081	5.7	5.5	1.8	0.01	26.2	0.83
306091	5.9	7.5	1.46	0.06	28.69	0.77
306101	4.5	4	1.2	0.01	18	0.86
306111	5.4	4.8	2.31	0.08	22.38	0.65
306121	5.7	11.09	3.23	0.06	22.93	0.84
306131	5.6	22.27	5.23	0.06	23.64	1.18
306141	5.1	10.33	8.33	0.02	26.5	1.56
306151	2.8	17.5	5.2	0.02	32.4	1.42
306161	6.2	37.2	93.77	0.04	26.07	1.64
306171	5.5	71.5	84.4	0.02	34.34	1.75
306181	6.4	55.9	174.38	0.03	29.46	3.41
306191	5.4	63	147	0.07	32.48	3.52
306321	5.0	4.2	3.5	0.01	22.63	0.82

Table 2.2-7
AVERAGE CONCENTRATIONS OF SELECT PARAMETERS DURING MARCH TO OCTOBER, 1993 – 1997 (CONTINUED)

STATION	DO MG/L	CHLOROPHYLL a (µG/L)	ENTEROCOCCI #/100 ML	DISSOLVED INORGANIC P	TOTAL SUSP SOLIDS MG/L	TOTAL N MG/L
306331	4.4	33.67	103.82	0.01	29.33	1.89
308031	7.1	17.38	59.73	0.01	7.63	1.12
308051	5.5	18.33	384.33	0.12	15.83	2.62
308071	9.3	12.07	78.89	0.02	7.48	3.16
308091	6.0	5.4	217	0.03	16.6	2.05
308151	4.9	3.75	411.4	0.03	12.63	3.65
308161	7.6	2.2	192.75	0.01	7.13	10.34
308291	5.4	4.31	44.6	0.01	3.13	1.69
308301	7.8	2.08	269.87	0.01	5.63	4.12
308311		51	156	0.08	137	29.11
309021	5.7	6	229	0.04	7.17	2.78
309041	7.1	5	364.33	0.02	19.5	2.61
310011	6.0	16.64	179.82	0.05	37.73	1.62
310031	4.6	16.75	607	0.06	27.75	2.65
310071	5.6	23.43	31.71	0.08	35	2.04
310101	5.3	30	421.82	0.07	15.82	2.84
312011	4.9	15.5	562.25	0.11	21.75	2.61
312041	4.0	10.18	297	0.06	22.73	1.85
402011	7.5	14.22	13.89	0.02	49.44	0.63
402021	5.9	9	91.4	0.02	31.5	0.69
402031	7.6	7.5	4.25	0.01	28.75	0.46

event timing, it is likely that dissolved oxygen standards were not met more often than noted above. Some standards, like temperature and pH, are relative to background conditions, so more study is required to determine if the possible violations were in fact violations. One station reported a number of possible violations of the standards for aluminum, lead, and mercury.

Trend Analysis Summary for the Inland Bays/Atlantic Ocean Watershed

To assess long-term changes in water quality of the Inland Bays/Atlantic Ocean Basin, the Department performed statistical trend analysis for 11 different constituents at 32 different sites in the Basin. The stations were chosen because they had a record of at least five years, and the most recent data occurred in the last five years. Two sets of analyses were completed for stations that had very long records. Those that had data from the 1970s had trend analysis completed for the period of record, then for the subset of data from 1980 forward. This technique allowed the earlier reductions in pollution discharge to be considered in the long-term trend, and the current trend to be assessed with regard to changes in water quality from the new “baseline” which started after reductions were in place. The results of the water-quality trend analysis, with regard to nitrogen, phosphorus, and dissolved oxygen, are summarized as follows.

Changes in Nitrogen

Nitrogen concentrations (as represented by total Kjeldahl nitrogen) showed slight downward trends for 16 of the 32 stations over the long term and showed downward trends at only 6 of the stations for the shorter term. Thus, for the most part, decreases in nitrogen concentrations occurred during the 1970s and early 1980s. Possible reasons for these reductions include improvements and upgrades to wastewater treatment plants, the use of agricultural Best Management Practices, and the implementation of the erosion and sediment control programs. Since the early 1980s, those reductions in nitrogen loads have likely been offset by changes in land use such as the conversion of forests and agricultural lands to residential and commercial developments, and the growth of animal agriculture industries, especially poultry, in the Basin. *Map 2.2-4 Total Nitrogen* shows the nitrogen distribution in the Inland Bays.

Changes in Phosphorus

Total phosphorus concentrations have only been measured for the short-term period. Concentrations of phosphorus (total phosphorus) have decreased slightly at 16 sites. The possible causes of these reductions include improvements to wastewater treatment plants, a detergent phosphorus ban, and the use of agricultural and urban Best Management Practices. *Map 2.2-5 Total Phosphorus* shows the phosphorus distribution in the Inland Bays.

Changes in Dissolved Oxygen

For the full record, 17 sites are showing statistically significant trends of change in dissolved oxygen concentrations. Only one of them is an upward trend. For the shorter record, 18 stations are showing trends; only one of them is positive (at the same location as above). It was observed that the short-term trends show greater negative trends in 12 of 18 stations that showed short-term trends. Thus, in those 12 stations, the rate of reduction of dissolved oxygen is actually increasing. *Map 2.2-6 Dissolved Oxygen* shows dissolved oxygen distribution in the Inland Bays.

Due to the failure of the Inland Bays waters to meet the Water-Quality Standards, Total Maximum Daily Loads (TMDLs) for nutrients have been developed for the tidal portions of the Indian River, Indian River Bay, and the Rehoboth Bay. TMDLs are regulations formulated under the Federal Clean Water Act of 1972 that set the maximum daily load of pollutants that may be discharged to a water body while still allowing the water body to meet water-quality standards. A Pollution Control Strategy is being developed for implementation of the TMDLs. Implementation of the TMDL is expected to bring dissolved oxygen concentrations into compliance with the standards.

Anoxia and Hypoxia

Dissolved oxygen (DO) is a fundamental requirement for the maintenance of balanced healthy populations of fish, shellfish, and other aquatic biota. The nature and extent of an organism's response to hypoxia (low dissolved oxygen concentrations) depend on several physical (e.g., temperature, salinity) and biological factors, including the concentration of oxygen dissolved in the water, the duration, frequency and nature of an organism's exposure to reduced oxygen, age and life stage, as well as the physiological condition of the organism. Most estuarine animals can tolerate short, infrequent exposure to reduced dissolved oxygen concentrations without apparent long-lasting adverse effects. Prolonged exposures to moderate hypoxia — DO less than 5 milligrams of oxygen per liter of water — may result in altered behavior, reduced growth, adverse reproductive or physiological effects, and possible mortality to sensitive species and juveniles.

Some aquatic animals may avoid low dissolved oxygen waters. This behavior may result in increased predation and decreased access to preferred feeding areas or refuge and spawning habitat. In addition, recent research conducted in Delaware indicates aquatic populations exposed to low dissolved oxygen concentrations may be more susceptible to adverse effects from other stresses, such as disease and toxic substances. Severe prolonged hypoxia — DO less than 2 mg/L — results in death to most aquatic animals, especially during summer months when metabolic rates are high. Anoxia, the complete absence of oxygen, and toxic hydrogen sulfide production, result in death to organisms that cannot evade such waters.

Anoxia and hypoxia can occur for many reasons, the most common of which is elevated temperature or elevated nutrient levels. The amount of oxygen a given quantity of water can hold under normal conditions depends, in part, on the temperature of the water; the higher the temperature, the less oxygen the water can hold. Hypoxia can also occur as the result of excess nutrient enrichment (eutrophication) of our waterways. Excess eutrophication has long been identified as a serious problem in the Inland Bays. When waters are too rich in nutrients, excessive algal growth occurs. This excessive algal growth, referred to as blooms, results in massive plant biomass production that must be supported by large amounts of oxygen at night or during the day under low sunlight conditions.

During daylight hours, the algae are net producers, through the process of photosynthesis, of oxygen; thus oxygen levels are normal or can even be supersaturated. When light levels decrease at night or during overcast days, the algae become net consumers, by way of respiration, of oxygen along with other aquatic organisms. Therefore the flux, or input or removal, of oxygen during a daily day-night cycle can become extremely variable, whereby during a sunny day the DO can easily be supersaturated as contrasted to cloudy days or at night when levels of DO can reach critically low hypoxic and even anoxic levels. This was dramatically evident during the summer of 2000, a very rainy, cloudy and overcast period punctuated with the most separate fish kill events (12) ever recorded to date in the Inland Bays, killing over an estimated 5 million fish. Many of these fish kills occurred following a series of cloudy days in which the estuary's demand for oxygen was outstripped by plants' net ability to produce oxygen. Under such conditions, it is possible for the water to quickly change to a state of hypoxia or anoxia from one of hypersaturation. The changes in oxygen levels can be both dramatic and devastating. Prolonged periods of daily DO extremes, high and lows, have also been shown to suppress a fish's natural immune system, thereby allowing various bacteriological and fungal infections to infect an otherwise healthy fish. This may be an additional reason for the recent increased observance of lesioned or diseased fish in our estuarine systems.

The animals and plants that are in these hypoxic zones must be able to leave the affected area or die. Plants and animals that die undergo bacteriological decomposition that can further consume additional available oxygen, thus leading to extended periods, in the range of days, weeks, or months, of hypoxia and anoxia.

The Inland Bays have had a number of hypoxic or anoxic incidents in the recent decade. An algal bloom in the summer of 1998 killed thousands of menhaden. Water-quality testing showed elevated nutrient levels in the waters.

In another incident in 1998, large mats of sea lettuce — a type of macroalgae — washed into a shallow sandbar area over a mile long and several hundred yards wide, reducing water circulation and flushing. Conditions deteriorated quickly, characterized by severely depleted DO, and lasted over a period of weeks during which thousands of clams and other benthic organisms died. These same types of clam kills were documented again in 1999 and 2000, but to a somewhat lesser degree.

During the summer of 2000, it is believed that several different hypoxic or anoxic incidents resulted in the loss of over 5 million menhaden. Investigations into the cause of these deaths are still under way. When excessive algal blooms occur that result in fish or shellfish mortality, or by severely decreasing the ambient estuarine water quality such as by reducing DO levels or producing toxic gasses (hydrogen sulfide), they are considered a category of harmful algal blooms (HABs).

Harmful Algal Blooms

Algal blooms are an abundance of macroalgae or microalgae in amounts that are greater than what is the normal healthy background level for that particular algae. Harmful algal blooms (HABs) are a proliferation of harmful or nuisance algae that cause a negative impact to natural resources and/or humans.

HABs occur when microscopic or macroscopic algal species exceed normal population levels thereby adversely impacting ambient water quality resulting in mortality or impaired functioning of organisms and/or their habitat.

HABs occur in two broad categories:

- Those that are harmful because of the production of internal and/or external toxins (phycotoxins); and
- Those that are harmful due to their sheer relative numerical over-abundance, thus causing an adverse environmental/habitat impact.

HABs may be obvious, such as when large areas of discolored algae-laden water form apparent "red tides" and "brown tides"; or alternatively, they may not be visually detected, but are detected by special molecular probe test procedures or by screening for their toxins. An all-too-common form of HAB in the Inland Bays is the noxious sea lettuce blooms that in their excessive concentrations rob the water of oxygen and produce toxic hydrogen sulfide gas. HABs can cause impacts beyond the direct human health effects and damage to ecological resources. Economic costs can be high because of lost revenues immediately attributable to lost fisheries, consumers' fears of fish and shellfish contamination (real or perceived), and the effects of lost tourism and recreational use of the waters due to production of noxious by-products or fears of toxic exposure.

Pfiesteria piscicida

One recent harmful bloom that has occurred in the Inland Bays is the dinoflagellate *Pfiesteria piscicida*. A bloom of this organism in 1987 resulted in a fish kill of approximately 250,000 fish. Another smaller *Pfiesteria* bloom occurred in 1988.

Pfiesteria is a microorganism that generally feeds benignly on phytoplanktonic microalgae, but may attack fish and shellfish directly under certain, yet to be determined, conditions. The organism can release external (exotoxins) toxins into the waters at certain points in its life cycle that may cause lesions, tissue destruction, and hemorrhaging and even eventually death in fish and shellfish. Toxic-form *Pfiesteria* has been shown to be more common in phosphate-enriched and slow-moving estuarine waters where fish secreta seems to stimulate toxin production.

Human health can also be neurologically affected, sometimes severely, when people are exposed to *Pfiesteria* exotoxins in the water or in aerosol. Exotoxins can also affect wildlife. In fact, most toxic blooms first become evident when fish and wildlife kills occur.

In 1997, public interest in *Pfiesteria piscicida* and its possibly toxic effects peaked. On the nearby lower Eastern Shore of Maryland, fish kills in the Pocomoke River and apparent health effects on some people who were exposed to the river resulted in the temporary closure of the river on orders from Maryland's governor. Subsequent discoveries of fish with a high occurrence of skin lesions that, at that time, were thought to be typical of toxic *Pfiesteria* activity led to additional closures in a few other tributaries of Chesapeake Bay. As a result of this toxic event, millions of dollars of lost seafood revenues occurred due to unfounded public fears the finfish local to Maryland's waters were contaminated and harmful. Even a high-profile $500,000 public education and outreach advertising program failed to prevent these dramatic economic losses.

No fish kills occurred in Delaware in 1997, and there were no confirmed reports of lesions on fish that could be definitely linked to *Pfiesteria*. However, *Pfiesteria* cells were observed in water samples collected August 7, 1997, from the Indian River. Dr. JoAnn Burkholder of North Carolina State University examined these samples and concluded that three of the five samples contained 150 – 300 cells/ml of potentially toxic *Pfiesteria*-like organisms (PLOs). Dr. Burkholder considers 250 – 300 cells/ml to be a potentially lethal concentration based on aquarium bioassay studies. However, Dr. Burkholder also emphasizes that numbers of PLOs in excess of 5,000 cells/ml have been observed in a non-toxic state.

Samples of striped bass and Atlantic croaker subjected to pathological examination revealed a variety of bacterial infections, including Mycobacterium, Aeromonas, and the skin virus Lymphocystis.

Nonetheless, it appears that the potential for toxic *Pfiesteria* activity in the Inland Bays is real based upon the *Pfiesteria* cell counts from the summer of 1997 and highly suspicious factors associated with two major fish kills that occurred in Indian River during 1987 and 1988. At that time, *Pfiesteria* had not been identified in Delaware or anywhere else. Circumstances surrounding these fish kills (reports of mahogany-colored water, observations of relatively high levels of an unknown dinoflagellate in water samples, and the symptoms exhibited by the dying fishes) all strongly implicate *Pfiesteria* as the cause.

Further evidence that *Pfiesteria* may have been the cause of the 1987 fish kill (by an order of magnitude the larger of the two kills) emerged following the formal identification of the organism in 1991 by Dr. Burkholder. A sample of water that had been collected by the Department during the 1987 fish kill had since been stored under refrigeration. In 1992, this water sample was sent to Dr. Burkholder in North Carolina. She exposed fishes to this water in the laboratory; toxic *Pfiesteria* activity ensued and the fishes died. In addition, Dr. Burkholder also confirmed a sample of mahogany-colored water taken from Indian River in 1992 as containing potentially toxic concentrations of *Pfiesteria* although no fish kill was noted at that time.

Toxic Algal Blooms

Toxic algal blooms occur when toxic phytoplankton produce phycotoxins that either reside within their bodies (endotoxins) or are secreted outside the body (exotoxins) into the ambient waters. Many times the secreted exotoxins result in fish kills or die-offs of other types of wildlife. Some species of toxic algae can produce both forms of toxins. *Chattonella,* found in Delaware in 2000, is thought to produce both mechanistic types of toxins.

For those phytoplankton producing internal toxins (endotoxins) that are stored within their bodies, which are in turn then eaten by other organisms farther up the food chain, these toxins are passed along to their consumers. As these endotoxins are passed up the food chain, they are more concentrated at each trophic level (biomagnified) and at some point become lethal to the organism consuming them. This occurred recently in Florida when manatees died in mass after feeding on plants containing brevetoxins.

Another form of toxin impact occurs when toxic plankton produce toxins that are released outside their body (exotoxins) in the form of a waste secretion into the environment as a normal function of their metabolism. When in sufficient concentrations in the water, these exotoxins can result in fish, shellfish, and other wildlife kills. *Pfiesteria* is a local example of this type of effect.

Human health concerns can occur when filter-feeding shellfish like oysters, clams, and mussels take in endotoxic algae and concentrate toxins that are passed on in their flesh. Four syndromes can occur as a result of exposure to endotoxins:

- Paralytic shellfish poisoning (PSP);
- Diarrheic shellfish poisoning (DSP);
- Neurotoxic shellfish poisoning (NSP); and
- Amnesic shellfish poisoning (ASP).

Marine life in the Inland Bays/Atlantic Ocean Basin has been affected in the past by endotoxins. In 1987, over a hundred dead dolphins washed up on Delaware shores after they died from eating endotoxin-contaminated fish. Additionally, a number of potentially phycotoxic species have been identified in water samples from Delaware, but fortunately these numbers have been below levels of concern. Their presence dictates that a vigilant monitoring program should be continued to follow trends of these species of concern to protect public health and the safety of the recreational and commercial shellfish industry.

The wetter- and cooler-than-normal summer of 2000 saw the first documented case of brevetoxin production in the Inland Bays and the Atlantic Ocean area immediately around the Indian River Inlet. Brevetoxin is produced by a specific group of phytoplankton and is generally considered a Gulf of Mexico and Florida phenomenon. There has been only one recorded case of the brevetoxin being produced outside that area when a gyre of Gulf Stream water carrying the toxin producing *Gymnodinium breve* red tide as far north as Cape Hatteras, North Carolina.

The suspected brevetoxin-producing phytoplankton organism in Delaware was a previously undocumented species of the genus *Chattonella.* This was the first reported instance of this species to produce brevetoxin, and the only time it was found to such bloom concentrations (7 million and 29 million cells/liter in Bald Eagle Lagoon and Arnell Creek, respectively). To date, no solid confirmation has been made that this species of *Chattonella* produced the brevetoxin found in Delaware since laboratory cultures of the organism have not yet been induced to produce the brevetoxin or to yield the same concentration found in natural field conditions in 2000. This inability to produce laboratory verification of brevetoxin production is not at all unusual since it is very difficult, if not impossible, to reproduce field conditions in a laboratory setting and then induce pure cultures of an organism to produce brevetoxins.

Brevetoxin can consist of various chemical forms, with some being more toxic than others. The forms found in Delaware comprised the most toxic type and thus are of concern since this toxin can produce Neurotoxic Shellfish Poisoning (NSP) in humans if contaminated shellfish (bivalve filter feeders) are eaten. Shellfish bioassays conducted for the NSP brevetoxin in 2000 on Inland Bays-harvested shellfish resulted in negative findings, indicating that the shellfish were safe to eat and not a threat to the consuming public. It is unclear at this time as to whether this brevetoxin was a one-time event, the start of a new introduced species phenomenon to be monitored in the future, or a long-time, but undetected resident that will have to be considered in future estuarine management scenarios.

Currently research is being conducted to identify *Chattonella* monitoring techniques and molecular probes to enable wide-scale screening for the organism and to incorporate brevetoxin screening of ambient water samples.

Seaweeds

Harmful algal blooms that are not toxin producing can still be hazardous to humans and aquatic life when there are macroalgae (seaweed) eruptions. Under normal non-enriched conditions, seaweeds (macroalgae) produce valuable aquatic habitat for many species of fish and wildlife. However, in nutrient-enriched waters, some macroalgae will respond with rapid vigorous growth, consuming significant amounts of available oxygen in the water when light is not available for photosynthesis, thus depriving other organisms of their life-sustaining oxygen. The seaweeds often form thick mats that limit or reduce the amount of light that penetrates to the bottom of the water column, thus crowding out other benthic algae and killing submerged aquatic vegetation. In addition, the physical structure of many densely packed seaweed masses inhibit or totally prevent the circulation of water carrying adequate levels of dissolved oxygen into the windrowed mat, further exacerbating the problem area.

If the problem persists for more than a few tidal cycles, the area generally goes hypoxic, and after a few days without relief, anoxic conditions generate hydrogen sulfide production from the decomposition process. At this point, the hydrogen sulfide is highly toxic to those species that cannot escape to healthier waters. Seaweeds do cause mass die-offs of bottom-dwelling organisms that are unable to leave the area when a bloom occurs. During the summer of 1998, there were several such events in the Inland Bays that killed hundreds of thousands of clams. This problem was repeated in 1999 and 2000, but to a lesser degree. There have been repeated outbreaks of seaweed die-offs in the Inland Bays in recent years that led to foul smells and calls from residents near the affected areas to remove the overgrown algae. Special harvesting equipment was rented in 1997 and bought in 1998 to remove the seaweeds.

Water Resource Protection Issues

Federal Clean Water Act Requirements

Section 303(d) of the 1972 Federal Clean Water Act (CWA), as amended, requires states to develop a list of water bodies that need additional pollution reduction beyond that provided by the application of existing conventional controls. These waters are referred to as "Water Quality Limited" and must be periodically identified by the Department or the U.S. Environmental Protection Agency (U.S. EPA).

Water Quality Limited waters requiring the application of Total Maximum Daily Loads (TMDL) are identified in a document commonly referred to as the "303(d) list." A TMDL is the level of pollution or pollutant load below which a water body will meet water-quality standards and thereby allow use goals such as drinking-water supply, swimming and fishing, or shellfish harvesting to be achieved. A state's 303(d) list must be reviewed and approved by the U.S. EPA by the first of April of every even-numbered year.

A full TMDL process determines the pollutants causing water-quality impairments, identifies maximum permissible loading capacities for the water body in question, and, for each relevant pollutant, assigns load allocations, Total Maximum Daily Loads, to the different sources, point and nonpoint, in the watershed.

The full TMDL process is an effective and important tool for achieving water-quality standards, but is time-consuming and labor-intensive. For this reason, TMDLs are currently pursued for high-priority waters, with the most severe water-quality problems, including the Inland Bays, Nanticoke River, and the Appoquinimink River. These waters are typically impacted by both point sources (e.g., sewage treatment plants, industrial facilities) and nonpoint sources (e.g., storm-water runoff from urban and agricultural lands).

The Clean Water Act (CWA) mandates that the U.S. EPA performs all of the responsibilities not adequately addressed by a state. To date, scores of Section 303 lawsuits across the country have been filed against EPA. Plaintiffs have prevailed in most of those cases, resulting in court-ordered TMDL development schedules as short as five years.

Citizen Groups Sue EPA Over Delaware Water Quality

In August 1996, James R. May, Esq., Director of the Environmental Law Clinic at Widener University School of Law, on behalf of the American Littoral Society (and its affiliate, Delaware River Keeper Network) and the Sierra Club, filed a federal complaint charging the U.S. EPA with "the failure to perform its mandatory duties to identify and then to improve the water quality of hundreds of miles of rivers, streams, and Atlantic coastline, and thousands of acres of lakes, reservoirs, ponds, bays, estuaries, and wetlands in the State of Delaware which fail to meet the fishable and swimmable water quality standard as required by the Federal Water Pollution Control Act, 33 U.S.C. _1251 et seq. (1988) commonly known as the Clean Water Act" (American Littoral Society et. al. v. United States Environmental Protection Agency et. al.; Civil Action No. 96-5920).

The Complaint asks the Court to order the EPA to:

- Comply with CWA requirements for Total Maximum Daily Loads (TMDLs) in Delaware on a short time line;
- Commit to updating Delaware's Continuing Planning Process (CPP), which serves as the overall framework for water resources management in the State;
- Not issue or approve any new or renewed National Pollutant Discharge Elimination System (NPDES) permits discharging into impaired waters for which TMDLs or Total Maximum Daily Temperature Loads have not been established;
- Cease any additional grant funding to Delaware to administer the 303(d) program until the state's 303(d) list meets the requirements of the CWA; and
- Administer the NPDES program for Delaware until the State has an EPA-approved Continuing Planning Process in place.
- The Department agreed to be present during a federally funded mediation process and assist the EPA with program and technical issues. A settlement was reached and an interagency Memorandum of Understanding (MOU) was signed, dated July 25, 1997.

Delaware's Total Maximum Daily Load Program

Delaware has completed a final TMDL for the Appoquinimink River and draft TMDLs for the Nanticoke River and Inland Bays (Indian River/Bay and Rehoboth Bay).

Delaware's 1996 303(d) list was approved in December 1996. The 1996 list indicates significant water-quality problems throughout the state.

Since the early 1990s, the EPA has urged states to adopt a watershed approach to water-quality management. The EPA issued a new TMDL guidance document in 1991 encouraging the development of TMDLs on a watershed basis. Delaware has implemented a watershed approach that includes the integration of the TMDL monitoring and assessment program for each watershed in accordance with the Department's Whole Basin Management Program schedule.

Plaintiffs demanded an accelerated schedule to ensure that TMDLs for all 1996-listed waters will be established by 2006. The Department and the EPA agreed to a schedule for completion of the TMDLs on a 10-year schedule.

Included in the settlement with the EPA, and in addition to the commitment to a 10-year schedule for TMDL development in Delaware, are commitments to prepare a supplement to Delaware's 1996 List of Impaired Waters to include waters impacted by habitat degradation from agricultural and urban activities, develop guidance documents regarding the use of biological and habitat data for listing waters in 1998, and develop protocols for assessing wetlands in Delaware. The Memorandum of Understanding (MOU) between the EPA and the Department sets forth the duties of the EPA and the Department that will serve as the framework for administering the TMDL program in Delaware.

Current TMDL Activities in the Inland Bays/Atlantic Ocean Basin

By Secretary's Order No. 98-W-0044, the Department has adopted TMDL regulations for nitrogen and for phosphorus for Indian River, Indian River Bay, and Rehoboth Bay. The effective date of the final Regulations was December 10, 1998, which meets the December 15, 1998 deadline.

Future Pollution Management Activities. Once a TMDL is promulgated, a Pollution Control Strategy (PCS) will be developed. A PCS will specify the necessary pollutant load reductions that need to occur such that loadings will be less than or equal to the TMDL. Plans are for reductions to be achieved through voluntary (for those activities that are voluntary now) and regulatory (for those activities that are regulated now) actions. However, TMDLs will provide watershed-wide pollution reduction targets that the Department and the EPA will be legally obligated to meet. This obligation will require new approaches for addressing point and nonpoint sources of pollution. Concepts such as "pollution trading" between different sources of pollution, geographic targeting, and pollution prevention will all be considered as part of the PCS. Meeting these targets may require regulation under existing law.

2.2.5.2 Ground Water

Although more than a dozen confined and unconfined aquifers and lesser water-bearing strata have been identified in Sussex County, for all practical purposes, ground water is withdrawn from four zones:

- The surficial, locally semi-confined Columbia Aquifer, which consists predominantly of the Beaverdam Formation;
- The Pocomoke Aquifer, which comprises the uppermost water-bearing zone of the Bethany Formation;
- The Ocean City Aquifer, which is an informal unit in the Bethany Formation and is present only locally; and
- The Manokin Aquifer.

Ground-water quality can vary widely between these four aquifers, but is generally well suited for most purposes.

Columbia Aquifer

The Columbia Aquifer may be considered in two parts:

- Well-drained upland region; and
- Surficial confined region.

The well-drained upland region is in the northern portion of the Inland Bays/Atlantic Ocean Basin and occupies approximately 40 percent of the Basin's land area. The well-drained upland region generally contains sandy and gravelly surficial sediments and well-drained soils. Rainwater readily moves through these sediments and replenishes (recharges) the ground-water system. Recharge potential is fair to good (refer to *Map 2.1-4*). According to Hamilton and others (1993), the well-drained upland region contains a median water-table depth of 8.9 feet below ground surface (BGS).

The surficial confined region occurs in the southern third of the Inland Bays/Atlantic Ocean Basin and occupies about 35 percent of the Basin's land area. Silty, clayey, organic, and poorly drained sediments are typical. Seasonal high water tables are considerably higher in this region than in the well-drained upland region. Rainwater does not readily infiltrate downward in this area.

Much of the recharge mapping has not been completed for the southern third portion of the Basin. A poor recharge rating has, however, been assigned to most of the area that has been mapped in the southern third portion of the Basin.

Nearly all fresh water in coastal Sussex county is obtained from the shallow-water-table Columbia Aquifer. Recharge occurs by downward percolation of precipitation and surface water from "losing" streams. The mineralogy of the overlying Omar and Beaverdam formations consists principally of quartz, with minor feldspar and clay minerals (Denver, 1989; Sundstrom and Pickett, 1969; Sundstrom et. al., 1975). This relatively uncomplicated aquifer mineralogy is reflected in the natural geochemical conditions of the Columbia Aquifer.

Water from the Columbia Aquifer is generally softer, more acidic, and has lower total dissolved solids (TDS) and alkalinity than water obtained from deeper, confined aquifers (Andres, 1991; U.S. Geological Survey, 1989; Woodruff, 1970). Dominant dissolved ions in ground water from the Columbia Aquifer are calcium, sodium, potassium, bicarbonate, sulfate, and iron (Denver, 1989; Woodruff, 1970). Increased concentrations of chlorides, fluorides, total dissolved solids, and alkalinity are observed in local areas where there is road salting, excessive pumping of fresh water that leads to saltwater encroachment in coastal areas, and application of certain agricultural nutrients.

Dissolved Metals

Concentrations of dissolved manganese and iron are high in ground water from the Columbia Aquifer. Dissolved iron concentrations in 131 ground-water wells in coastal Sussex County range from 3 mg/L to 80,000 mg/L, with a mean of 1,654 mg/L and a median value of 25 mg/L (Andres, 1991). Denver (1989) attributed the elevated iron in eastern and southern Sussex County ground water to the poorly drained soils and large amounts of organic matter, which result in highly reduced ground-water conditions.

Map 2.2–7 Iron Concentrations in Selected Wells shows the wells for which the Department has iron data. Average and maximum iron concentrations for the unconfined aquifers' surficial confined region in the Basin are 8.6 mg/L and 17 mg/L, respectively. In contrast, data from this map also indicate that the oxic ground water in relatively coarse-textured sediments of the well-drained upland region contains much lower iron concentrations, which average 1.8 mg/L.

Nitrate

Another characteristic of shallow ground water from the Columbia Aquifer is the presence of elevated nitrate, the most common contaminant in ground water in the Inland Bays/Atlantic Ocean Basin (Miller, 1972; Andres, 1991; U.S. Geological Survey, 1989). Andres (1991) identified nitrate levels ranging from <0.5 mg/L up to 34 mg/L, with a mean value of 6.33 mg/L. Nearly 23 percent of wells sampled in his study exceeded the EPA's Maximum Contaminant Level (MCL) of 10 mg/L. The highest nitrate concentrations were observed along State Route 26 east of Dagsboro and along State Route 5 west of the State Route 24 intersection. Nitrate concentrations are generally observed to decrease with depth.

High nitrate levels (>45 mg/L) are linked to methemoglobinemia in humans, which is most serious in babies less than one year old (Miller, 1972).

Map 2.2-8 Nitrate Concentrations in Selected Wells shows the wells for which the Department has nitrate data. Data from these wells indicate that nitrate generally averages less than 0.4 mg/L in the surficial confined region. In the well-drained upland region of the Basin, the average nitrate concentration in shallow monitoring wells from 17 non-hazardous waste sites averaged 6 mg/L. A maximum nitrate value of 85 mg/L was recorded at one of these sites. Data from 31 public wells in the well-drained upland region indicate that nitrate concentrations in the mid-depth to deep portions of the aquifer average 4.21 mg/L.

Chlorides

Map 2.2-9 Chloride Concentrations in Selected Wells shows the wells for which the Department has chloride data. Chloride is a common constituent found in on-site wastewater associated with development. Chloride is also derived from potassium chloride fertilizers that are utilized in farming operations. Other sources include waste lagoons for animal operations and road salt used for highway deicing. In most areas of the Inland Bays/Atlantic Ocean Basin's unconfined aquifer, chloride concentrations are below the secondary drinking-water standard of 250 mg/L and are not problematic. Significant areas of the unconfined aquifer along the coast have, however, been severely degraded as a result of saltwater intrusion.

According to Denver (1986), natural ground water in the unconfined aquifer has chloride concentrations averaging approximately 5 mg/L. Chloride analytical data provided on *Map 2.2-9* reveal that much of the Basin's unconfined aquifer has been degraded with chloride in excess of natural levels. Chloride data from the map indicate that average chloride concentrations of 45 mg/L occur in shallow ground-water-monitoring wells located proximal to spray irrigation sites and large on-site septic sites. A maximum value of 940 mg/L was recorded at one of these sites. The average and maximum chloride concentrations found in deeper public wells were 16.6 and 32 mg/L respectively.

The difference between the average chloride concentrations within the Basin's surficial confined region and the well-drained upland region was not considered here. Since variations in surficial lithology and oxygen content do not affect the chemical form of this element, significant concentration differences likely will not exist between these two different regions.

Ocean City and Pocomoke Aquifers

The Ocean City and Pocomoke aquifers in the Bethany Formation represent areally limited overlapping sand lenses as opposed to discrete sand bodies that can be regionally correlated. Recharge of the aquifers occurs through leakage from the overlying Columbia. In most of eastern Sussex County, the Pocomoke (the uppermost of the two water-bearing units) is unconfined and subcrops immediately beneath the Columbia. Hydraulically, it is part of the water-table aquifer. The Ocean City Aquifer is limited in extent to the southeasternmost corner of the state and thickens towards the east. Westward of a line extending from Lewes southwestward to Gumboro, the confining beds separating the Pocomoke and Ocean City aquifers is missing and the combined strata are considered Pocomoke. Lithologically, the Ocean City and Pocomoke beds are very similar to the Columbia, although with perhaps a larger and more diverse suite of clay minerals, scattered lignite, and glauconite and an increase in shell material (Andres, 1986; Andres, 1991; Sundstrom and Pickett, 1969).

Generally, as one goes deeper, ground water becomes increasingly harder, less acidic, and has increased TDS, bicarbonate, and alkalinity. But in much of the Inland Bays/Atlantic Ocean Basin, it is difficult to differentiate water from different strata based on its quality because of the degree of interconnection between the aquifers.

Manokin Aquifer

The Manokin Aquifer represents the uppermost water-bearing strata in the Manokin Formation and generally the lowermost aquifer used for potable purposes in the Basin. Unlike the Pocomoke and Ocean City aquifers, it is areally continuous and occurs in subcrop in northern Sussex County and is artesian for most of the Inland Bays/Atlantic Ocean Basin. This aquifer provides much of the fresh water to Delaware's seashore communities (Hodges, 1984; Groot, 1983; Andres et al., 1990). Recharge occurs through leakage from the overlying strata in the subcrop area (Hodges, 1984). Lithologically, the aquifer is characterized as a nearly uniform layer of upward coarsening, grayish, medium to coarse quartz sand, with local lignitic, shelly clay/silt beds (Sundstrom and Pickett, 1969; Andres et al., 1990).

The distinctive lithology of the Manokin is reflected in its ground water, which differs somewhat from ground water in the overlying strata. Water quality is good, but becomes noticeably more saline and mineralized with increasing depth and proximity to the Atlantic Ocean (Andres, 1990; Talley, 1987; Groot, 1983). Manokin wells sampled by Hodges (1984), Andres (1990), and Sundstrom and others (1976) are characterized as relatively hard (up to 150 mg/L of $CaCO_3$) and alkaline (up to 225 mg/L), with higher sulfate (up to 54 mg/L) and chloride (up to 460 mg/L) than most unconfined (Columbia-Pocomoke-Ocean City) wells, and moderately high iron (up to 1500 µg/L) and manganese (27 µg/L) concentrations. Nitrate and phosphate concentrations are mostly non-detectable.

2.2.6 DATA GAPS AND RECOMMENDATIONS

1. Determine ground-water system lag time in various sites throughout the state. This could be very helpful in establishing timetables to see results of Pollution Control Strategies.
2. Develop a combined strategy to coordinate ground-water sampling and share analytical data.
3. Refine regional ground-water flow data with information from all possible sites.
4. Determine more accurate base-flow loading for impacted streams; Compare ground-water and surface-water data for interactions.
5. Analyze up-gradient well data from monitored sites to see if there are any regional trends in ground-water quality.
6. Delineate all source-water protection areas, such as wellhead areas and excellent recharge potential areas.
7. Establish wellhead protection ordinances, Best Management Practices, and/or regulations.
8. Identify intensive ground-water extractive use in areas that may have water availability issues.
9. Create and update coverage in the Department GIS of the location of all facilities with water allocations similar to the information developed for public supply wells.
10. Accurately define all sub-cropping aquifer areas to help protect the deeper portions of these aquifers.
11. Better mapping accuracy for surface-water intakes including all irrigational uses.
12. Develop a suite of aquatic resource benchmarks that will define living resource habitat/water-quality conditions (both status and trends) of the Inland Bays. These will consist of living resource keystone or resident important species (RIS) In addition, standard water-quality parameters as well as macrobenthic biometrics will be utilized in the overall assessment suite. (Look at what benchmarks are being used elsewhere, such as the Chesapeake Bay.) *Lead: Coastal Management & Center for the Inland Bays*
13. Develop and refine a plan to deal with excessive macroalgae. This would consist of early season macroalgae surveillance in order to determine the size and causal mechanisms that will lead to the development of a management plan to control excessive deleterious outbreaks. Harvesting of nuisance macroalgae should minimize by-catch of crabs and fish.
14. Promulgate regulations to prohibit new dead-end canals and all other man-made water bodies that do not possess those flushing and circulation characteristics that will maintain optimal water quality and habitat in order to maintain a healthy functioning aquatic biotic community.
15. Complete recharge-potential mapping for the rest of the state. This mapping shows areas where water and/or contaminants can rapidly enter the ground water.
16. Develop depth-to-ground water maps for the entire state that highlight areas with an extremely shallow water table.
17. Review irrigation well water-quality for nutrient loading. Incorporate in management plans.

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