

Category I Basin Hydrology

THEN - The physical behavior of the Delaware River water system can be compared to a single pool being utilized for many purposes. If water is evaporated (at any location), the dynamics of the system change; water stored during periods of high runoff affects the degree to which sea salts are repulsed toward the ocean; the withdrawal of ground water, even if returned via waste treatment facilities to surface streams, alters the time / flow relationship of runoff in the Basin, and the absorptive / replenishment capacity of the natural underground reservoirs.

Level B Study, May 1981, p 9
DRBC

As in 1981, the physical behavior of the Delaware River system can still be compared to that of a single pool. Changes in one region can affect circumstances in another. The replenishment of both surface and ground waters is linked to weather and precipitation, soil and geology, human use and transport.

Natural Flows

Compared to many other river systems, the Delaware Basin is blessed with a relative abundance of water, realizing over 45 inches of rainfall on average in a year. In a natural system flows are variable, but unmanaged,

and dependent on precipitation and ground water base flows. Flow regimes, tracked as a hydrograph of flow volumes over time, reflect the effect of precipitation on streams. Flows on the River are the cumulative effects of flow from the tributaries; the Schuylkill and Lehigh Rivers are the two greatest contributors to Delaware River flows. Generally, the contribution of each tributary is proportional to the land area it drains—its watershed—but the magnitude of flows is also determined by the geology and soils of the watershed. Note the variability of base flows among the physiographic provinces as well as the

difference within the provinces during drought conditions as illustrated in Table 1.1.

Hydrographic Regions of the Basin

The Delaware River Basin lies in two significantly different hydrologic regions which correspond to the two major physiographic divisions in the northeastern US: 1) the Appalachian Highlands 2) the Atlantic Coastal Plain. While physiographic provinces do not follow watershed boundaries, they do help define the character of watersheds and influence flows and water quality.

1) **The Appalachian Highlands** are made predominantly of consolidated sedimentary rock. Surface water is in high-energy streams and rivers, many of which have been dammed for energy production and water supply. In general, consolidated rocks store and transmit much less water than the sediments of the Coastal Plain and ground water is found in fractures and

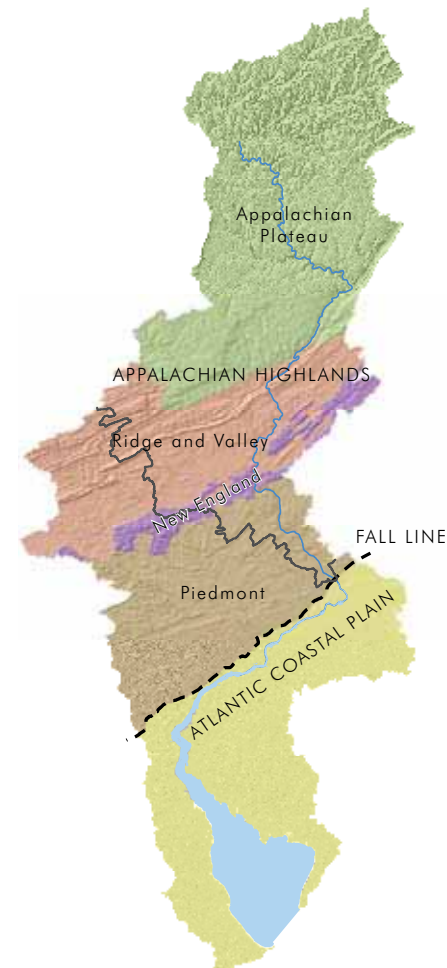


Fig. 1.1. Hydrographic Regions of the Delaware Basin.

1841

The "Bridges Freshet" sends ice choked floodwaters down the Delaware sweeping away 9 bridges and becomes the "landmark" deluge of the 19th century.

1931

US Supreme Court authorizes NYC to construct 2 reservoirs and divert 440 mgd for water supply; specifies flows at Port Jervis NY and Trenton NJ.

1954

US Supreme Court amends 1931 decree to increase NYC diversion to 800 mgd, specify flows at Montague NY, and approve 3rd reservoir at Cannonsville.

1955

NYC's Pepacton and Neversink Reservoirs go on line; Cannonsville added in 1964.

1961-67

Basin experiences record drought.

fissures, or in glacial deposits in some valleys. The Appalachian Highlands includes four provinces each of which has distinctive geology, landforms, and hydrologic characteristics. Two major tributaries, the Lehigh (Central Region) and Schuylkill (Estuary Region) Rivers, flow through all or most of the provinces of the Appala-

chian Highlands, which include four primary provinces:

- **Appalachian plateau.** The 1,000-to-4,000-foot-high uplands of this province form the Catskill & Pocono Mountains where rivers have carved deep and narrow valleys through gently folded shales and sandstone. Hydroelectric dams are interspersed throughout the province and New York City has a trio of reservoirs here for water supply. The Upper Region watersheds are almost exclusively within this province; and the Lehigh system originates in this province. The highest baseflow yields are found in the Appalachian plateau where, even in times of drought, baseflows may exceed those found

in some piedmont streams under normal conditions (Table 1.1). Water is abundant here, especially in glaciated valley aquifers, which are also vulnerable to pollution. The landform, especially in the northern reaches, is amenable to damming to create reservoirs for power generation and water supply. In general, the large reservoirs in this region serve distant populations, such as those of New York City, and local communities rely on ground water from wells. While encompassing one third of the basin, only about 3% of the population lives in the Appalachian Plateau. The natural beauty, availability of water, and access to distant employment centers is increasing development here.

- **Ridge and Valley.** The northern section of this province is a series of long, narrow forested mountain ridges oriented southwest to northeast characterized by extreme topographic relief; distances from

Hydrologic Terms:

- mgd = million gallons per day
- cfs = cubic feet per second
- ppm = parts per million

ridge top to valley bottom can reach 1200 feet. Developed land and agriculture dominate the valleys. Bedrock is principally sandstone and shale. Localized anthracite (coal) deposits have provided the resource for anthracite mining, a source of water quality impairment in the central portion of the Lehigh River (Central Region) and upper reaches of the Schuylkill River (uppermost region of the Estuary watersheds in Pennsylvania). At the southern end of the province is the Great Valley, a broad lowland with rolling hills and good agricultural soils overlaying a productive, but vulnerable carbonate aquifer. About 20% of the basin lies in this province and about 14% of the population lives here. Baseflows in the streams of the Valley and Ridge province provide yields comparable to the Appalachian plateau.

Table 1.1 Baseflow Values

BASEFLOW VALUES BY GEOLOGY IN GALLONS PER DAY PER MI ²		
PHYSIOGRAPHIC PROVINCE	NORMAL*	DROUGHT**
Appalachian Plateau	758,000	463,000
Catskill	727,000	478,000
Ridge & Valley	752,000	477,000
New England	671,000	373,000
Piedmont Uplands	539,000	291,000
Piedmont Lowlands	358,000	218,000
Atlantic Coastal Plain	738,000	450,000
* 1 in 2 year low flow ** 1 in 25 year low flow		

1962
DRBC approves its first Comprehensive Plan, which includes a dozen multi-purpose reservoir projects, including Tocks Island, a giant impoundment planned for the Delaware River main stem.

1971
Construction of Beltzville Reservoir is completed; Blue Marsh under construction.

1975
DRBC commissioners defer construction of the Tocks Island Dam project.

1976
Flood plain mapping completed for 119 basin municipalities to qualify for federal flood insurance.

1977
DRBC regulations restrict development in the 100-year flood plain and prohibit development in the floodway.

- New England.** Underlain by hard rock, this province is one of extensively forested hills and ridges drained by a network of steep, rocky streams. Less than 5% of the basin has this type of landscape and less than 3% of the population lives here. Known as the Reading Prong in PA and the Highlands in NJ, this province has been declared a landscape of national significance for its forested habitats and biodiversity. In 2006 New Jersey enacted legislation to protect the Highlands as an area of statewide significance, especially for water resources. The USDA Forest Service has characterized the attributes of the Pennsylvania portion of this province which cuts through the Lehigh (Central) and Schuylkill (Estuary) watersheds in Pennsylvania and the Central watersheds in New Jersey.
- Piedmont.** Extensive branching streams, rolling hills and prime agricultural soils cover low yielding sedimentary and crystalline rock in

the Piedmont. Less than 20% of the land area of the Basin lies in the Piedmont, but nearly 50% of the population lives here. Surface water is the source for nearly 90% of potable water supply. The Piedmont is the southern-most extension of the Appalachian Highlands hydrologic region, ending at the fall line where the Atlantic Coastal Plain begins.

2) The Atlantic Coastal Plain, in great contrast to the consolidated sedimentary rock of the Appalachian Highlands, is a great wedge of unconsolidated sediment. Alternating layers of sand, clay and gravel extend southeast from the fall line, thickening as they slope under Delaware Bay and the Atlantic Ocean. The coastal plain occupies the southern quarter of the basin and lies completely within the Estuary (Lower and Bay) Region. Great amounts of water are stored in these deposits which transmit water much more readily than the consolidated rocks

A major test of any water management plan is to determine whether it is compatible with the hydrologic cycle and related natural systems of the Basin – patterns of precipitation, streamflow, dependence on surface and ground water, ground water recharge and storage.

Level B Study, May 1981

of the other provinces. While ground water is widely available in the coastal plain, it may also be directly vulnerable to contamination. More than 33% of the basin's population lives in the Coastal Plain and ground water supplies are stressed in some areas.

More About Flow

Flows in all provinces vary seasonally, and are also affected by diversions and withdrawals of water for human uses, movement of water and wastewater within and among watersheds, and development that alters runoff and recharge patterns. Both high flows and low flows are important. High flows are associated with seasonal conditions in spring, as well as precipitation events and flooding. Low flows are associated with seasonal conditions of early autumn and can be exacer-

bated by diversions and withdrawals for human use. Low flows are also important because we use our waterways to assimilate waste water, and without minimum flows water quality problems can develop.

Flow Management

Although the Delaware River does not have a dam on its main stem, the flows of the River can be moderated to some extent through coordinated management of flows of reservoirs on the tributaries. A 1954 Supreme Court decree and subsequent modifications sanctioned the NYC reservoirs and the exports of up to 800 mgd of water to NYC and 100 mgd to New Jersey through the Delaware & Raritan canal. Conditions of the decree also require the maintenance of minimum flows at Montague NY (1,750 cfs) and

1981
DRBC releases Level B Study; water conservation and reservoir enlargement are key recommendations.

1983
"Good Faith" Agreement redefines state appropriations and establishes drought operating plan for basin reservoirs.

1985
DRBC adopts basin-wide well registration program as integral component of ground water management.

1985
Construction begins on Merrill Creek Reservoir, designed to provide make-up water for riverbank electric generating plants during low flow conditions.

1986
DRBC adopts regulations requiring the source metering of large water withdrawals.

1999
DRBC amends Southeastern PA Ground Water Protected Area regulations, placing withdrawal limits on 62 additional watersheds.

at Trenton NJ (3,000 cfs). In periods of low flow, this is accomplished through the cooperative management of New York City’s water supply reservoirs in NY, several multipurpose reservoirs in PA, and a privately-owned reservoir in NJ.

Permanent storage capacity in tributary reservoirs totals over 410 billion gallons; 68% of this storage is held in the three New York City water supply reservoirs in the Upper Basin. Of the 24 reservoirs in the Basin, nine are dedicated for water supply, two generate hydropower, three are solely for flood loss reduction, one is strictly for flow augmentation. Nine are dual or multi-purpose, providing water for a combination of water supply, flow augmentation, and flood loss reduction. Enhancement of fish and wildlife habitat and recreational opportunities are additional benefits of many of these reservoirs.

Since the Delaware River is subject to tidal influence as far north as Trenton NJ, one purpose of the 3,000 cfs flow target at Trenton has

historically been to maintain the salt line—where salt concentration is 180 parts per million (ppm)—at River Mile (RM) 98, safely downstream of intakes for public supply.

Reporting

Hydrologic indicators included in this report are:

- Flows at Trenton NJ
- Salt line location
- Water use
- Water supply sources
- Areas of ground water stress
- Floods and flood damage

Each indicator supplies a look at one piece of the complex hydrologic puzzle. A feature on predicted changes to climatic conditions and the challenges they pose to water resource management concludes this section.

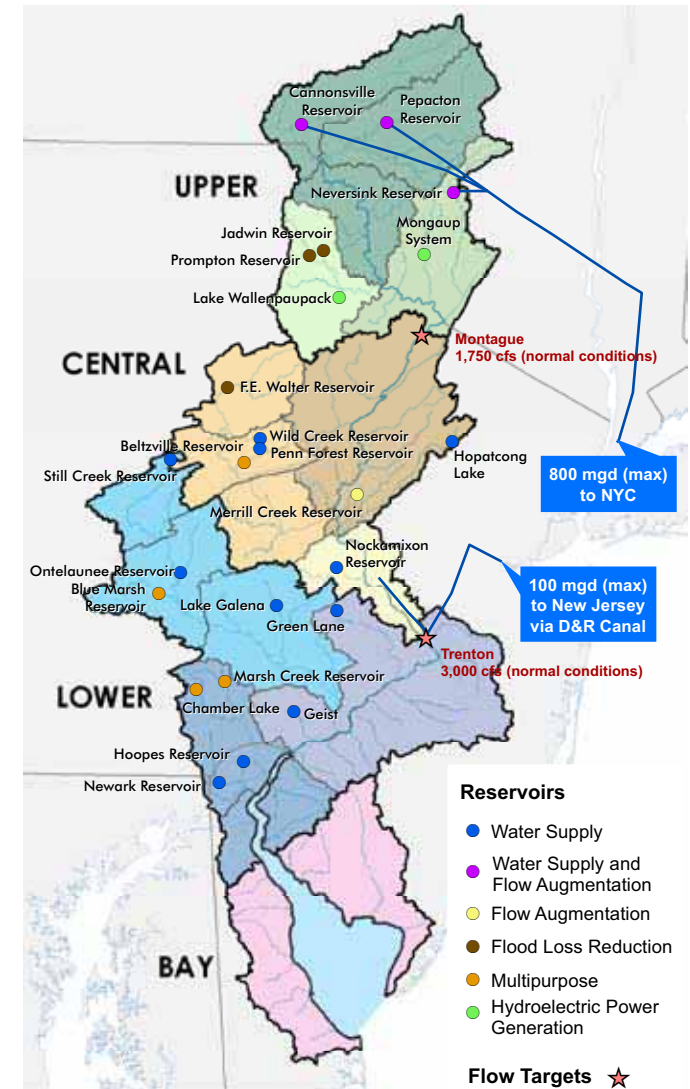


Fig. 1.2. Reservoirs of the Delaware River Basin.

1999
Hurricane Floyd delivers 6 to 10 inches of rain in 18 hours to the lower basin; tributary flooding causes extensive damage to roads and bridges and casualties among motorists.

2001
Tropical Storm Allison generates 10 or more inches of rain in 24 hours causing loss of life and property damage in PA counties.

2001
Basinwide drought emergency declared for only the 3rd time since 1980; combined storage in NYC’s Delaware reservoirs drops to a record-low 23% of capacity by Dec 15, 2001. 2002 sets new drought of record for DE.

2003
In the wake of Hurricane Isabel, a series of storms drop 2-3 inches of rain on saturated areas of the basin; flash floods affect towns in PA and DE.

2004-2006
Excessive rainfall in the basin is primary reason for 3 major flood events in 18 months. The worst flooding since 1955 causes evacuations, bridge and road closures, and millions of dollars in damages.

Indicator • Flows at Trenton

Indicator Description

Maintenance of average daily flows and minimum low flows at Trenton, NJ are vital for the protection of drinking water uses and maintenance of fresh water flows to the estuary for living resource health.

Desired Condition

Maintenance of minimum flows at Trenton, NJ (2,500 – 3,000 cfs based on drought status) to protect public water supplies from salt water intrusion (BP Goal 1.3; CCMP Action W6).

Status and Trend

Good: Flow target maintained 95% of the time.

Reservoirs provide a means of maintaining minimum flows at target gages. During the period from 1980 to the construction of the last large reservoir in the Basin in 2007, the 3,000 cfs normal flow target at Trenton NJ has been maintained 95% of the time compared to 87.5% of the time for the period prior to reservoir construction (1913–1949). Occasions when the flow target is not met may be due to reductions in watershed baseflow, the multi-day travel time to Trenton from the reservoirs in the Upper and Central Basin and the uncertainty of precipitation forecasts. The data used

to develop the following graphs only include the flows measured at Trenton.

Figure 1.3 presents the mean annual flow at Trenton from 1913–2007, including the drought of record in the 1960s. Note that mean annual flows in 1996 and 2003 exceeded those of any other year in the 84-year historic record.

A flow duration curve shows the probability of a specific flow, being exceeded. The flow duration curves for average daily flow at Trenton NJ (Fig. 1.4) show the increase in high, medium, and low flow conditions in recent years. The higher flows at the left of the graph occur only 0.1% of the time, where the lower flows on the right of the graph are almost always exceeded. Both curves represent similar management practices since the records used are post-reservoir construction. The blue curve represents 1980–2002 and the red curve represents 2003–2007.

Comparison of the two flow duration curves

shows the flows that occurred from 2003–2007 are greater than flow from the 1980–2002 for the same exceedence probability. Therefore, flows were higher and less reservoir releases were needed to meet the Trenton target in recent years.

The largest differences are seen at the 0.1% and 50% to 80% probabilities. This indicates that the highest flows between 2003 and 2007 were 80% higher than the highest flows between 1980 and 2002. Normal flows (those likely to happen 25 and 75 percent of the time) are approximately 45% to 63% larger in recent years than during the years 1980–2002. Low flows (those

exceeded 95–99.9 % of time) can be managed more easily with reservoirs than high flows. The two curves are closer together at low flow values, but the low flows of recent years are still 14%–27% larger than those of 1980–2002.

A review of precipitation records for the post reservoir time period shows the median precipitation during the 2003–2007 period was 22 percent greater than during 1980–2002 time period (Fig. 1.5). Greater flow from increased precipitation has implications for water resource management issues in the Delaware River Basin. Streams that are less dependent on ground-water contributions are more

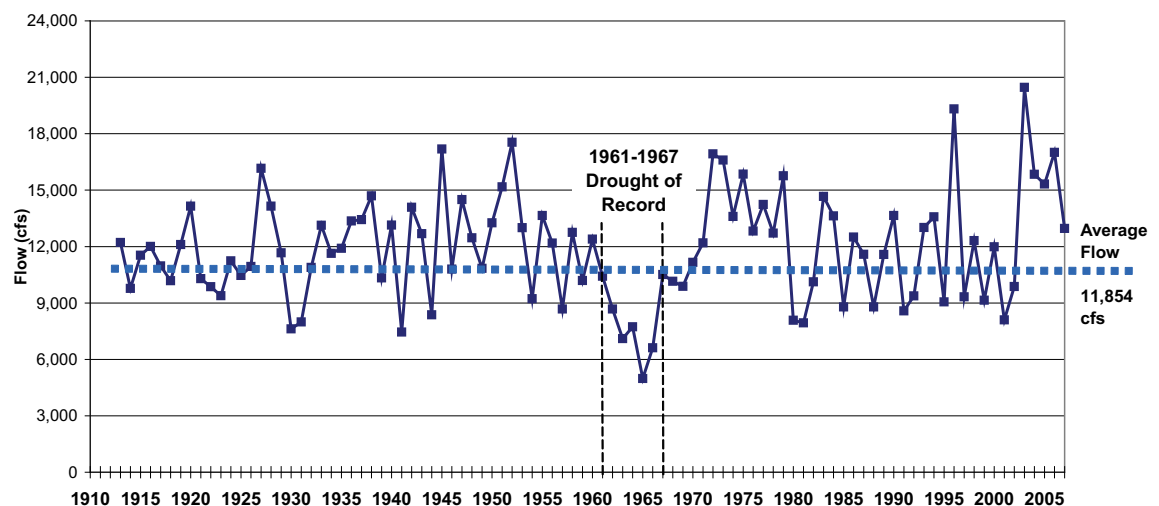


Fig. 1.3 Mean Annual Flow at Trenton NJ. USGS gage #01463500

sensitive to increases in precipitation.

Climate experts are predicting greater climate extremes, including warmer, wetter weather patterns and more severe droughts. Wetter weather would lead to increases in the probability and duration of reservoirs being at full capacity due to increased runoff and reduced discharges to meet instream needs and minimum flow targets at Montague and Trenton. More severe droughts would require more storage in the basin to meet water demands.

Actions and Needs

- Reservoir management, including the potential development of multi-purpose reservoirs for flood control and water supply, will be an integral part of adaptive responses to maintain minimum flows during changing climatic conditions.
- Stormwater management and other land-based strategies are also necessary to maintain normal flow patterns.

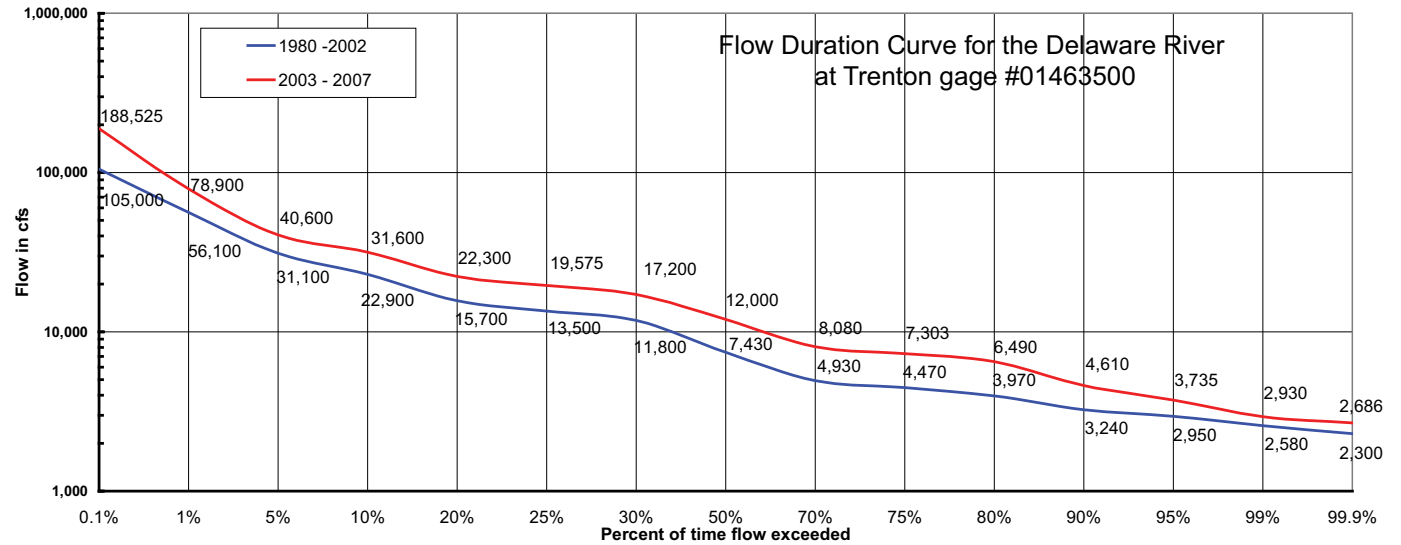


Fig. 1.4 Flow Duration Curves for Trenton NJ comparing two time periods: 1980–2002 and 2003–2007 indicates that recent flows (2003–2007) are higher than historical flows (1980–2002)

A flow duration curve is a cumulative frequency curve showing the percentage of time specified flows are equaled or exceeded.

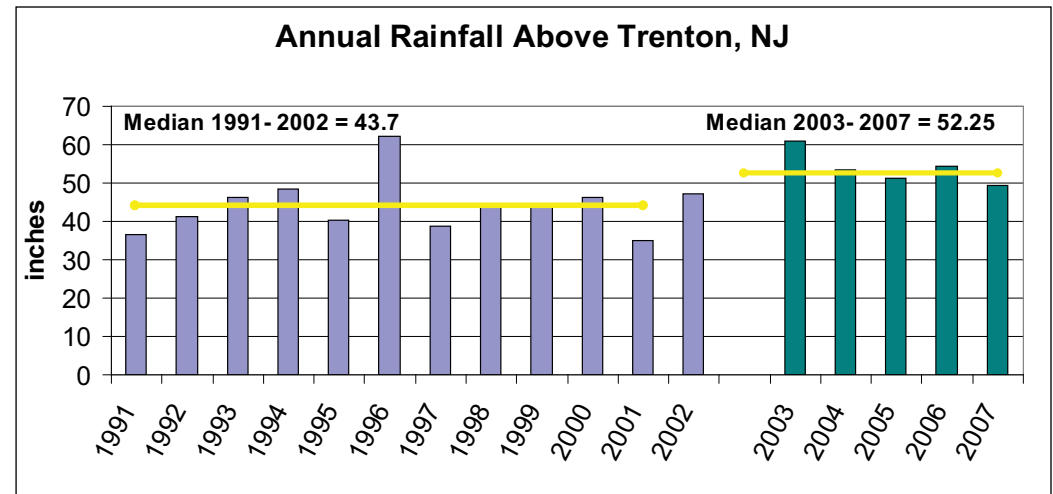


Fig. 1.5 Annual Rainfall Above Trenton, NJ. The median of annual total rainfall above Trenton, NJ was 22% greater during the years 2003–2007 than it was in 1991–2002. Precipitation data from the National Weather Service.

Indicator • Salt Line Location

Indicator Description

The salt line is an estimation of where the seven-day average chloride concentration equals 250 ppm along the tidal Delaware River. The salt line location plays an important role in the Delaware River Basin water quality and drought management programs because upstream migration of brackish water from the Delaware Bay during low-flow and drought conditions could increase sodium chloride concentrations in public water supplies, presenting a public health concern.

upstream reservoirs to augment flows and meet a daily flow target of 3,000 cfs at Trenton NJ. The program has worked well. Since 1970 low flows that once occurred 10% of the time now occur only 1% of the time. The salt line has been successfully repelled below drinking water intakes, protecting drinking water supplies in the most urban area of the Basin.

Actions and Needs

- Investigation of additional sources of chlorides, such as from road salts and runoff, is warranted.
- Documented sea level rise and increasing variability in flow from climatic change may create additional challenges for management of the salt line in the future.

Desired Condition

Ensure an adequate and reliable supply of suitable quality of water to satisfy public needs (BP Goal 1.3; CCMP Action W6).

Status

Very good: Drinking water intakes in the tidal River are effectively protected.

The salt line naturally advances and retreats with each tidal cycle and with seasonal variations in freshwater flow. For most of the year, the location of the salt line is between the Commodore Barry Bridge (RM 82) and Reedy Island (RM 54). During droughts and periods of very low flow, a management program directs releases from

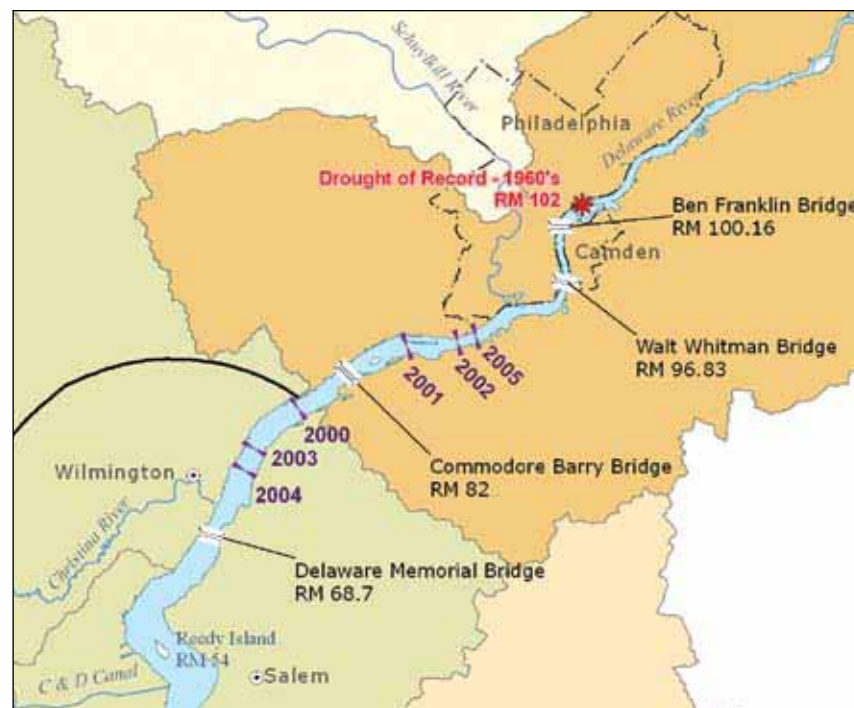
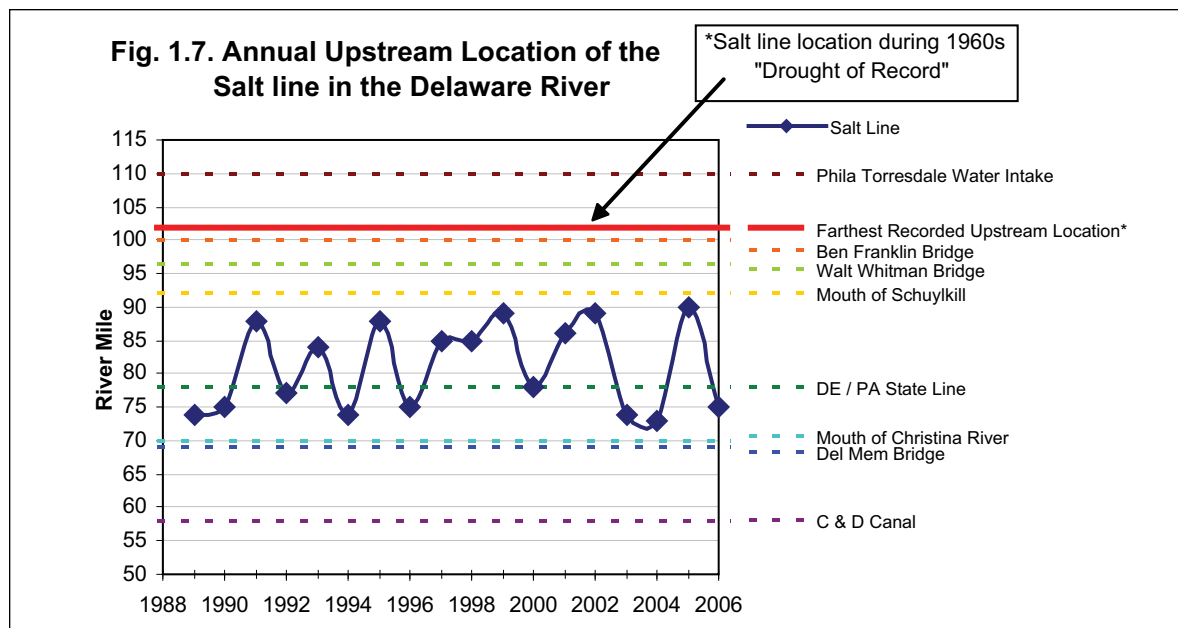


Fig. 1.6. Map of Historic Salt Line Locations.



Indicator • Water Use Efficiency

Indicator Description

In managing water resources it is desirable to have some measure of water supply efficiency, that is, where water use may be higher or lower in relative terms. This efficiency is measured through *Per Capita* and Consumptive Use.

Per Capita Use normalizes total water use for a given population. *Per capita* water use has been calculated as follows:

$$\frac{\text{Domestic (residential) well use} + \text{Public Water Supply}}{\text{Population}}$$

Water use from other sectors has not been included in the calculation in order to allow for a more meaningful comparison. However, public water supply may include some commercial and industrial use.

Consumptive Use measures water that is not returned to the watershed and ultimately lost, via evaporation or transfer, to immediate use within the water resource system. It is calculated both as a volume and as a percentage of total water withdrawals; the data reflect water use by all water use sectors.

Desired Condition

Decreasing or stabilized rate of water use per capita to balance demands on limited water resources (BP Goal 1.1) and the use of water conservation

techniques by water utilities (CCMP Action W3).

Status

Fair: Average per capita use is 133 gallons per capita per day (gpcd) and ranges from 90 to 190 gpcd.

Regional differences among the sub-basins are shown in Figure 1.8. The Schuylkill Valley subbasin shows the highest *per capita* use with a value close to 200 gpcd.

The basin average for consumptive loss in public water distribution systems is approximately 10%. In terms of absolute consumptive use the Upper Estuary has the highest, as many power generating and industrial facilities are located along the Delaware River in this subbasin (Fig. 1.9). When expressed as a percentage of water withdrawals, however, consumptive use is relatively low in this subbasin. The Delaware Bayshore watersheds have the highest percentage of consumptive use (nearly 30%) relative to total withdrawals (about 45 mgd), which is a function of the significant amount of agricultural activity in this region.

Actions and Needs

- Better tracking of water transfers—how water is moved in pipelines from one location to another—would

There are problems in comparing water use at large scales and among different development types. Differing socio-economic and demographic characteristics can result in vastly different water use patterns. For example, largely suburban watersheds may have a greater per capita consumption than highly urbanized watersheds due to lawn irrigation and household size. And where power generation or agricultural uses dominate water use, consumptive use is also noticeably greater. As long as these limitations are acknowledged, such indicators of water use can be used for general comparison.

provide for more accurate and comparable estimates of water use efficiency. New Jersey DEP has developed and populated a water tracking model which may be applicable for use in other portions of the basin.

- Improved measurement and reporting of residential water use separately from other uses—such as commercial and industrial—within a public water system would provide a better idea of per capita water use efficiency. Pennsylvania DEP currently collects data in this manner. Achieving this across the basin would permit more realistic comparisons of *per capita* use.

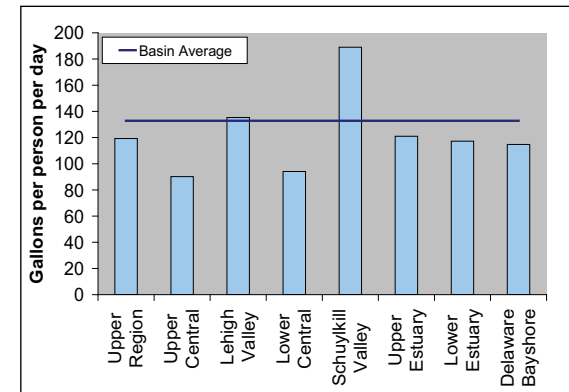


Fig. 1.8. Regional Per Capita Water Use.

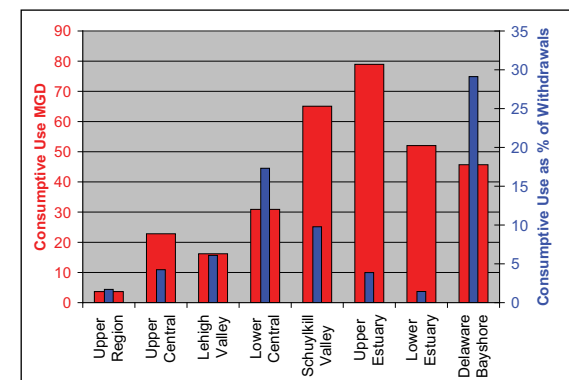


Fig. 1.9. Regional Consumptive Water Use.

Indicator • Water Use

Indicator Description

How water is used for potable supply and commerce is one indicator of the necessity and value of water to society. Accurate and comprehensive water use information enables the proper assessment, planning and management of water resources.

As reporting of water use improves, so does our accounting and our understanding of the need for water among various use sectors. The data set used in this analysis reflects water withdrawals and use in 2003.

Desired Condition

An adequate and reliable supply of suitable quality water to sustain human and ecological needs (BP Goals 1.2, 1.3, 1.4).

Status

Good: Human needs are being met; ecosystem needs are being investigated for consideration in management options.

The dominant use sectors, in the basin and regionally, are shown in Figures 1.10 and 1.11.

Nearly 15 million people rely on water from the Delaware basin for their daily water needs. On average over 8.7 billion gallons of Delaware basin water are put to use each day. These numbers include an average of

736 million gallons of water exported for populations in New York City and northeastern New Jersey, which account for approximately 8% of the total amount of water withdrawals.

A system of reservoirs in the Upper basin store water for export to New York City and make compensating releases to maintain water temperatures and flows for wildlife and downstream uses. New Jersey exports water from the basin via the Delaware and Raritan canal.

Uses related to power generation dominate both basin and regional water use patterns. However, which sectors use the water may not be as important as whether or not the water is ultimately returned to the system. For example, hydroelectric power generation is a dominant use in the Upper and Central region, accounting for 68% of water use (617 mgd). Hydroelectric power generation is non-consumptive and therefore the water is available for use downstream.

In contrast, thermoelectric power generation dominates both the basin and the Lower and Bay Region statistics at nearly 80% of total withdrawals (5,682 mgd). While it has a low consumptive loss rate (1.6%) the sheer volume of water used ensures a substantial water loss to the hydrologic system through evaporation. These plants are generally placed where

Fig. 1.10. Daily Water Withdrawals, Exports and Consumptive Use in the Delaware River Basin

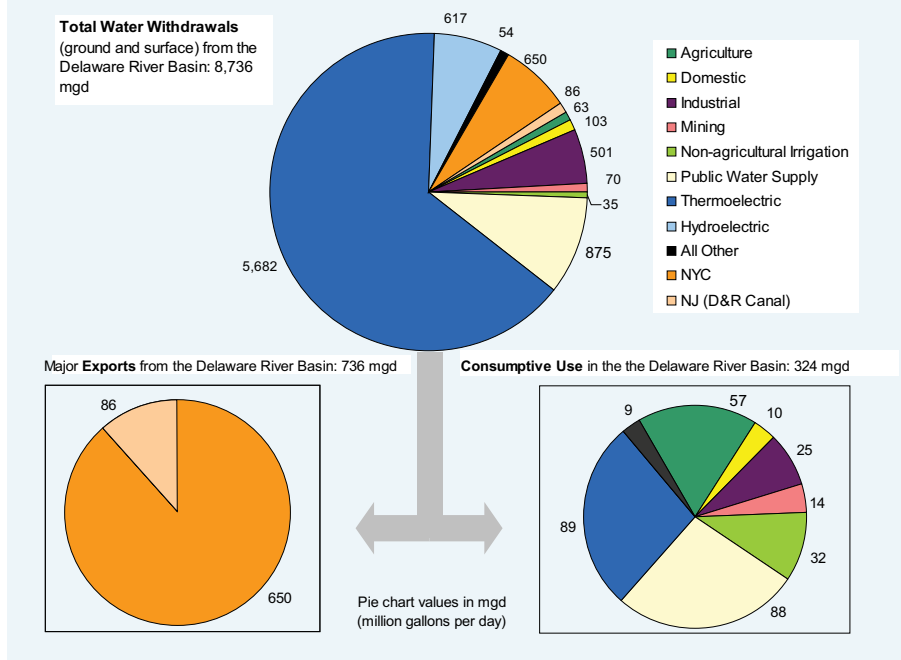


Table 1.2. WATER USE FACTS

Values - based on 2003 water use records

Population using Delaware basin	Approximately 15 million people
Water exported out of basin	736,000,000 gallons per day • 8% of total withdrawals • 45% of regional withdrawals
Water withdrawn for use in the Basin	8,000,000,000 gallons per day
Basin per capita water use	133 gallons per day per person
Dominant in-Basin uses	• 65% Thermoelectric power generation • 10% Public water supply • 7% Hydropower • 6% Industrial
Dominant uses in Upper and Central Regions	• 68% Hydroelectric power • 16% Public supply • 5% Domestic wells
Dominant uses in Lower and Bay Regions	• 79% Thermoelectric power generation • 10% Public water supply • 7% Industrial

water supply needs can be met with a less significant hydrologic impact. In addition, Merrill Creek reservoir in New Jersey was built by a consortium to offset power-related consumptive loss in the basin. When necessary, this reservoir can release flows to protect drinking water supplies.

Overall, 90% of all water withdrawn from the Delaware basin is diverted from surface water flows. Potable water in the basin is supplied from surface water diversions (64%) and ground water withdrawals (36%). Nearly 90% of all potable supply for commercial and residential use is through public water supply systems; only 10% is from domestic (household) wells. The basin average for consumptive loss in public water distribution systems is approximately 10%.

Our knowledge of the volumes of water used for irrigation is sparse and numbers reported here are based in part on estimates. Although the amount of water withdrawn for agricultural water use is relatively small (63 mgd basin-wide), the highly consumptive nature of irrigation means that this sector accounts for nearly 1/5 of the total consumptive water use.

Trends

Thermoelectric power generation, and the water demands for this sector, have shown a steady increase in recent decades and are projected to continue to increase.

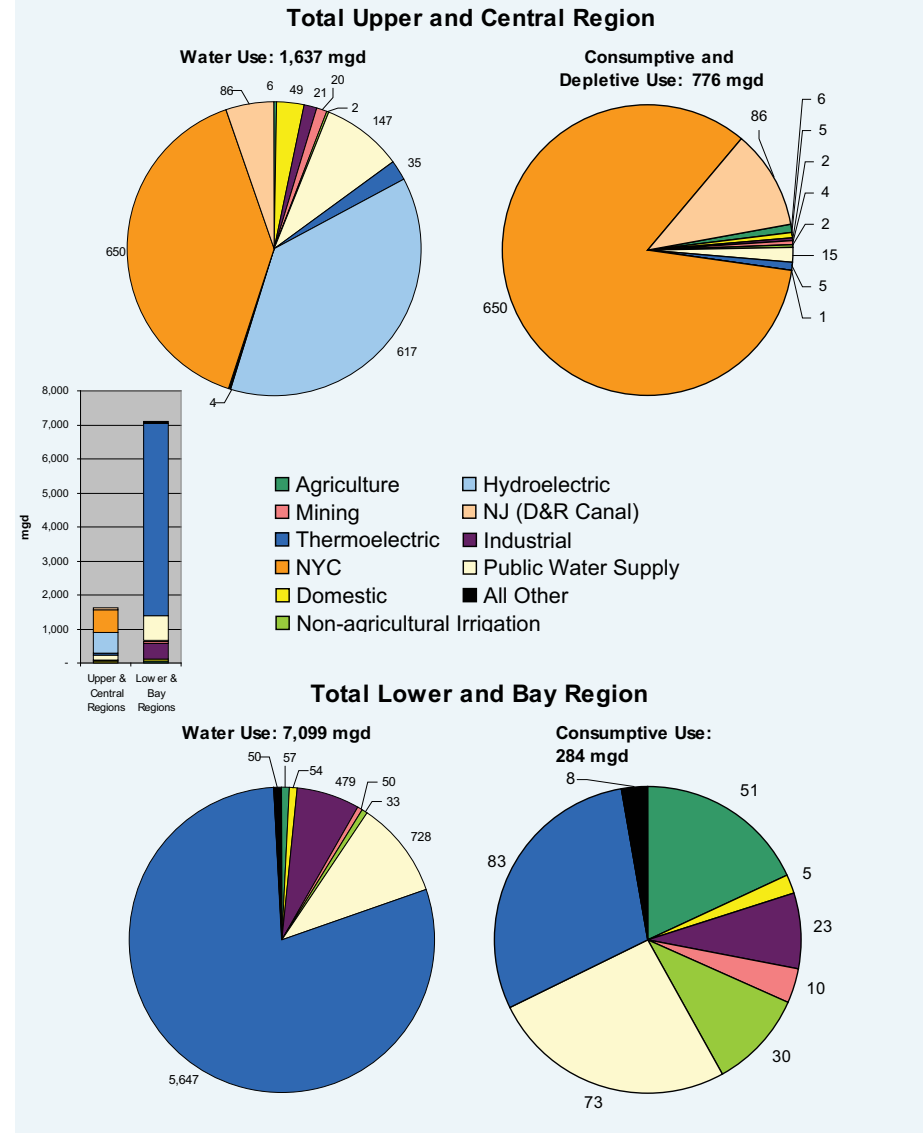
The data suggest that in the past decade, basin-wide water use has remained fairly constant. An increase in population has been offset by a decline in industrial water use and benefits attributable to conservation. Reliable data on agricultural use are generally not available, a situation that hampers efforts to plan for reliable supplies for all sectors.

Actions and Needs

The key challenge is to manage supply to a growing population while ensuring adequate instream flows to satisfy ecological needs.

- Population growth hotspots, especially in the Pocono and select bayshore watersheds, compel attention. Additional demand may compete with the need to maintain seasonal flows for aquatic life needs.
- In groundwater-dependent areas where surface water is not an immediate option, additional planning for alternative sources, such as aquifer storage and recovery or beneficial reuse may be in order.
- A better understanding of irrigation water use, especially for agriculture is needed in order to improve planning and management.
- A study of the potential growth in water demand for the thermoelectric sector is required due to the impact that large power gener-

Fig. 1.11. Regional Water Withdrawals, Exports, and Consumptive Use



ating facilities can have on water resources. Water needs for other energy production (e.g. drilling) also needs investigation.

- Advances in quantifying the instream needs of aquatic ecosystems are necessary for achieving the desired water supply goals.

Indicator • Water Supply Sources

Indicator Description

Water for drinking, industrial uses, irrigation and power supply can come from surface sources, such as rivers, streams and reservoirs, or from sources in the ground (aquifers). The ability to draw from a mix of sources increases reliability, especially during times of drought. Knowledge about water supply sources is important in planning for growth, for water supply and waste water collection, treatment and discharge, and for maintaining hydrologic integrity in watersheds.

Desired Condition

An adequate and reliable supply of suitable quality water to sustain human and ecological needs, and to maintain hydrologic integrity (BP Goals 1.1, 1.2, 1.3, and 3.1).

Status

Good: Multiple potable supply sources available in many, but not all, regions of the basin; some source protections in place.

The ability to draw from a mix of sources increases reliability, especially during times of drought.

The source of potable supply varies across the basin. As illustrated in Figure 1.12, 64% of potable water in the Basin is supplied from surface water sources and 36% from ground water, a portion of which is domestic supply. Domestic supply refers to private household wells; reliance on domestic wells varies greatly across the Basin.

The Upper region is particularly dependent on ground water (nearly 80%) and domestic wells specifically (43%). Supply sources may vary within a region as well. Note that while 70% of the Estuary region relies on surface water to meet demand, the Bayshore region is totally dependent on ground water, 22% of which is from domestic wells.

Trend

Interconnections among public supply systems and the ability to use both ground and surface water to meet demand (conjunctive use) are measures of supply sustainability. Supplies need to be protected from depletive withdrawals and from quality impairments that could impact the long term viability of the source. Source water protection can be accomplished in several ways and is especially important in areas dependent on ground water as a sole source of supply.



Cannonsville Reservoir

R. FROMUTH, DREC

Sole Source Aquifer designation is one tool to protect drinking water supplies in areas with few or no alternative sources to the ground water resource, and where if contamination occurred, using an alternative source would be extremely expensive. EPA defines a sole source aquifer as one which supplies at least fifty percent (50%) of the drinking water consumed in the area overlying the aquifer. The designation protects an area's ground water resource by requiring EPA review of all proposed projects within the designated area that will receive federal financial assistance to ensure they do not endanger the ground water source.

The larger high-yielding aquifer systems in New Jersey have been designated as Sole Source Aquifers, since they are the sole source of drinking water for communities in that area. In addition to the aquifers, the designation includes review of projects in a stream flow source zone which lies

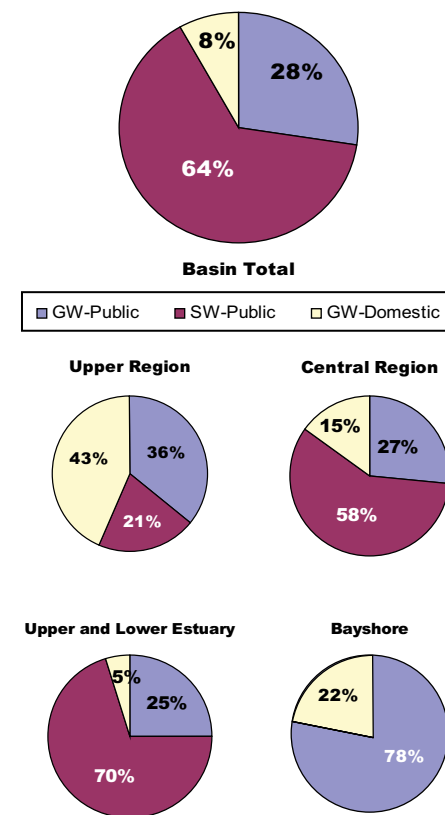


Fig. 1.12. Sources of Potable Supply

within two miles of the Delaware River in counties in NJ (Mercer, Hunterdon, Sussex and Warren), DE (New Castle); PA (Delaware, Philadelphia, Bucks, Monroe, Northampton, Pike and Wayne) and NY (Delaware, Orange and Sullivan).

State-designed **Wellhead Protection** (WHP) Programs offer local options to protect community supply wells, often through specialized zoning and development ordinances. All four basin states have adopted WHP programs in compliance with a federal mandate and may require some degree of protection as part of ancillary permitting processes. Delaware, as part of its Source Water Protection Plan, enacted a law in 2001 requiring large municipalities and counties to recognize WHP Areas in their Comprehensive Land Use Plans and to enact ordinances to protect WHPAs by December 2007. Pennsylvania, New Jersey and New York have voluntary WHP programs. Although a WHP program may recognize clusters of domestic wells as worthy of protection, state programs do not require it.

Actions and Needs

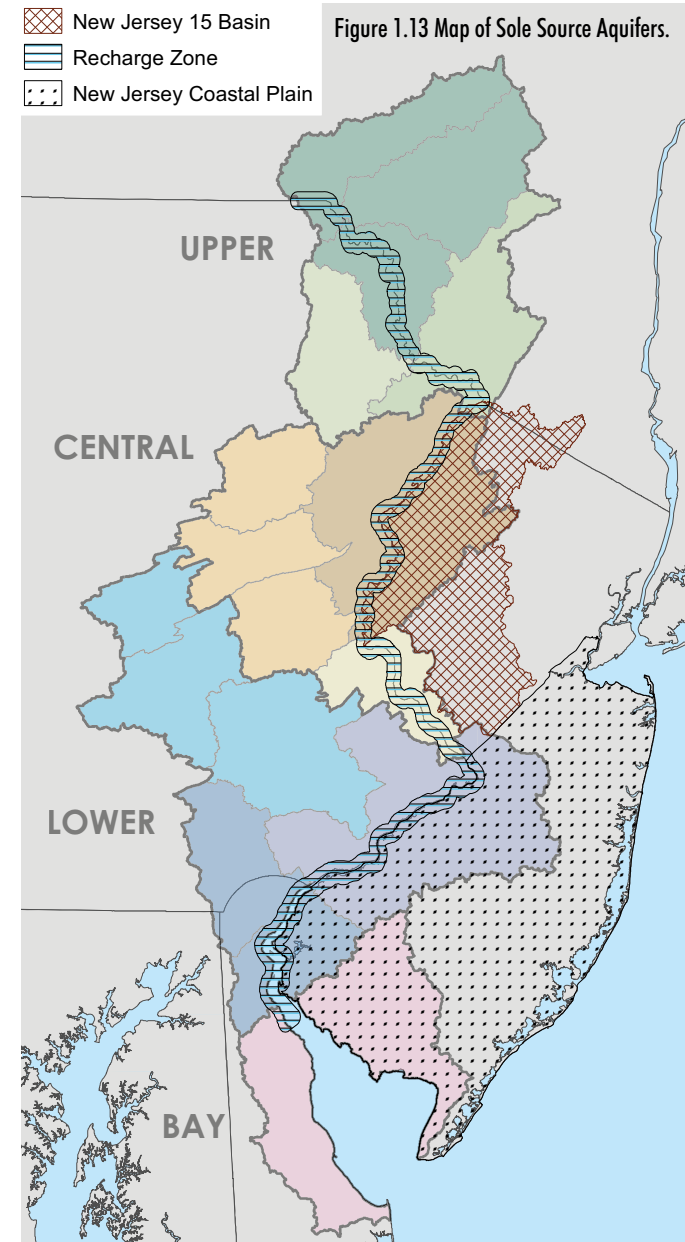
- Additional supply sustainability indicators should be identified; measures of system interconnection and source water protection should be considered.

The sole source aquifer determination for New Jersey's Coastal Plain Aquifer was made in part because more than 3 million coastal plain residents depend on this ground water to serve 75% or more of their drinking water needs.

- Additional information on the adoption of wellhead protection programs should be collected and reported.
- Further efforts for protection of locally significant ground water supplies, especially areas served by community wells and domestic well clusters, should be encouraged and supported.



Buckingham Twp. PA, public community supply well and water tower. The township owns the land surrounding this and other wellheads, effectively protecting the public water supply.



Indicator • Areas of Ground Water Stress



THEN - Ground-water overdraft, or “mining”, is a common practice in the western drylands, but is not likely to become a widespread practice in the Coastal Plain of the Delaware River region.

USGS Professional Paper No. 381, 1964

NOW - Some watersheds in the Coastal Plain and Piedmont hydrologic provinces have experienced ground water overdraft conditions and require special management.

Indicator Description

Stress on a water resource system can occur when withdrawals exceed natural recharge. Withdrawal of ground water by wells is a stress superimposed on a previously balanced ground water system. The response of an aquifer to pumping stresses may result in an increase in recharge to the aquifer, a decrease in the natural discharge to streams, a loss of storage within the aquifer, or a combination of these effects, and impacts may extend beyond the limits of the aquifer being monitored.

Two major areas within the watersheds of the Upper Estuary region show stress and are recognized as critical or protected areas: the Ground Water Protected Area in southeastern Pennsylvania, and Critical Area No. 2 in south-central New Jersey which overlays the Potomac-Raritan-Magothy (PRM) Aquifer (see Figure 1.14). New or expanded withdrawals

in both of these critical areas are prohibited or limited and managed subject to specific regulations which serve to allocate the resource on the basis of a sustainable long-term yield.

Desired Condition

An adequate and reliable supply of suitable quality water to sustain human and ecological needs (BP Goal 1) and decreased reliance on Triassic and PRM aquifers (CCMP Actions W1-W3).

Status

Fair: Conjunctive use and regional alternatives to local supplies are easing the stress in these two areas, but additional problem areas are emerging.

South Eastern PA Ground Water Protected Area (SEPA-GWPA).

Reductions in total annual ground water withdrawals have been observed since numerical withdrawal limits were

established for the GWPA. Between 1990 and 2003 total annual ground water withdrawals within the GWPA were reduced by approximately 2.5 billion gallons (6.8 mgd). However, while the GWPA has improved overall through reduced ground water withdrawals, there are still subbasins withdrawing ground water volumes that exceed the potentially stressed level. In the Warminster Subbasin, Little Neshaminy Creek (A), Newtown Creek (B), and Schuylkill-Trout Creek (C) are all withdrawing ground water in annual volumes that exceed the potentially stressed level (Figure 1.15).

New Jersey Critical Area 2. In 1996, implementation of Critical Area #2 by NJ resulted in a reduction in the use of the PRM aquifer system. Many of these municipalities are now served by surface water diverted from the Delaware River near Delran, NJ. As a consequence of conjunctive use of ground and surface water, aquifer water levels have increased

and appear to be stabilizing in most parts of Critical Area #2. An example is shown in the hydrograph from USGS Elm Tree 3 observation well (Fig. 1.16), over 700 feet deep in the Middle PRM aquifer in Camden County NJ.

Additional Problem Areas in the Lower Estuary and Bay Region. The PRM aquifer system extends under the Delaware River, through Delaware and into portions of Maryland. A 2007 draft report from the USACE on a ground water model developed for northern New Castle County DE concluded that ground water withdrawals in Delaware are dimin-

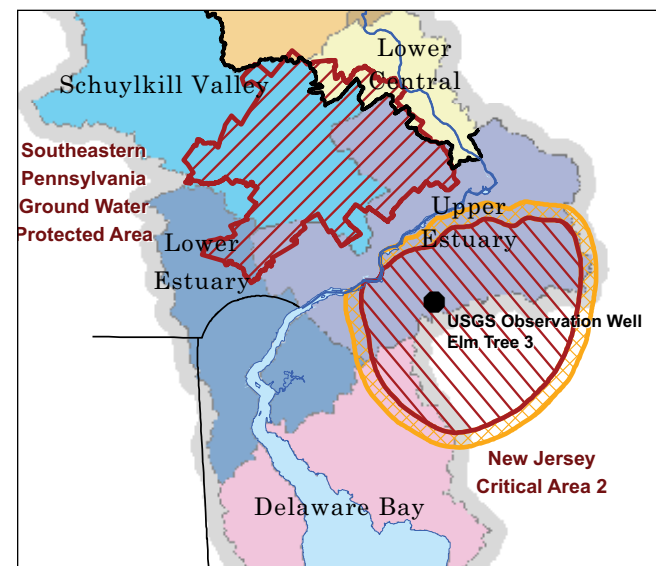


Fig. 1.14. Areas of ground water stress.

ishing stream base flows and forming cones of depression. The impact of these withdrawals extends into Maryland and New Jersey. Delaware has developed a program to provide surface water for northern New Castle County (see box).

Base flow declines are also a concern in the Salem-Gloucester area and the Maurice River basin of southern New Jersey. New and expanded allocations are being denied or restricted to limit adverse impacts on the aquifers and protect stream flows.

Trends

Since the creation of the protected areas, conjunctive use projects and regional alternatives have provided a measure of sustainability. However, depletive use in areas beyond these critical areas is emerging as a problem.

Actions and Needs

- Comprehensive information on stream flow and ground water conditions in the PA-GWPA would enhance the ongoing analysis of this region.

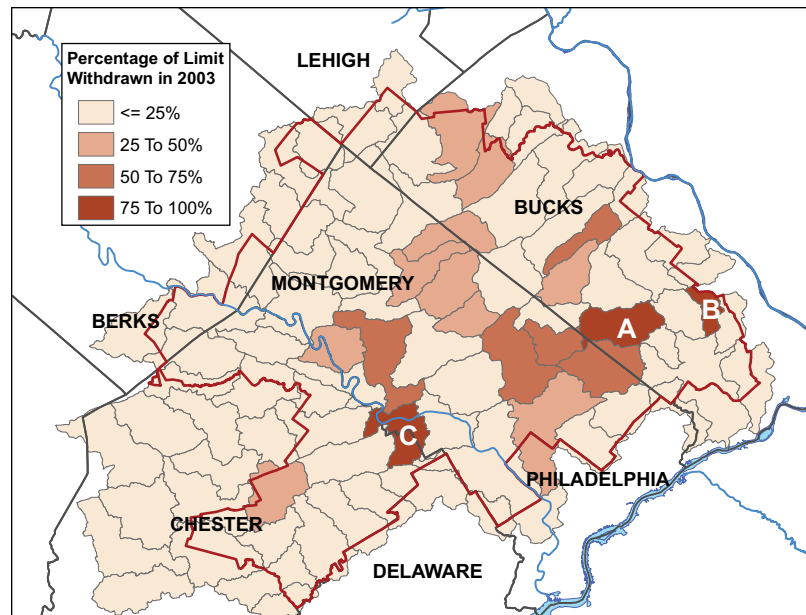


Fig. 1.15. Percentages of subbasin ground water withdrawal limits reached in 2003 in PA-GWPA. Mining withdrawals are not included. The withdrawal limit is defined as the 1-year-in-25 average annual baseflow rate as determined by the USGS for each subbasin.

New Castle County, DE

Delaware has responded to seven drought events in 25 years. Adaptive management resulted in a plan and facilities to “drought-proof” the state. In addition to an iron removal plant built in 2003 to treat ground water, a 300-million-gallon reservoir was built to augment supply from the White Clay Creek and make the City of Newark self-sufficient. The DE Water Supply Coordinating Council assembled an additional 2 billion gallons of water supply since 1999.

- A detailed study of projected demand, outstanding allocations and water availability are a necessary part of ongoing regional, state and basin-wide water supply planning efforts.

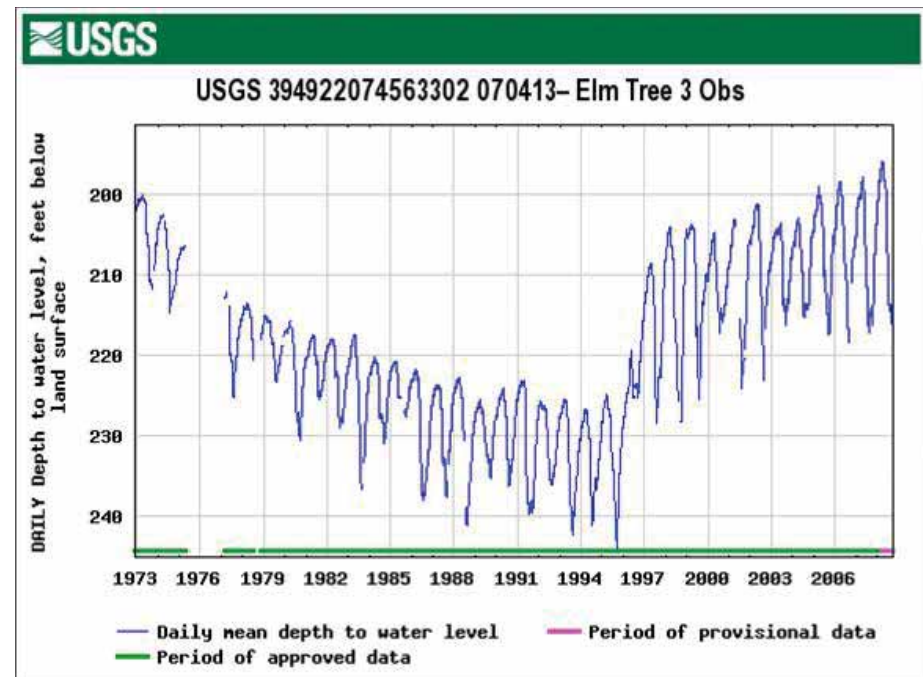


Figure 1.16 illustrates how water levels at a USGS observation well in NJ Critical Area 2 have rebounded.

Indicator • Flood Damage

Indicator Description

Flood insurance claims data have been collected and used as an indicator of flood damage since the start of the Federal Emergency Management Agency (FEMA)'s National Flood Insurance Program (NFIP) over 30 years ago. NFIP provides federally-backed flood insurance in communities that adopt and enforce floodplain management ordinances to help reduce future flood losses.

Repetitive loss is a useful indicator of flooding as a recurring economic and environmental problem. Repetitive loss is applicable to a property that endures two or more losses of at least \$1,000 for each loss. The two losses must be within ten years of each other and be at least 10 days apart.

While insurance claims can provide a general picture of flood damage, within the basin they reflect only a fraction of the total cost of property damage caused by flooding. In

addition to residential and commercial properties whose owners choose not to purchase flood insurance, much of our constructed infrastructure – including roads, bridges, canals and utility lines – suffer damages that are not captured by this indicator or by insurance program records.

Desired Condition

Prevention of flood-induced loss of life and property, and protection of floodplain ecology (Basin Plan Goal 2.1).

Status

Poor: Increased property loss and repetitive claims in recent years.

Approximately 1,372 square miles, or 11% of the basin, is located in the 100 year floodplain, or in areas that have a 1 in 100 chance at any time of being flooded. Nearly 20,000 flood insurance claim reimbursements totaling almost \$473 million have been

awarded in the Delaware Basin since the late 1970s.

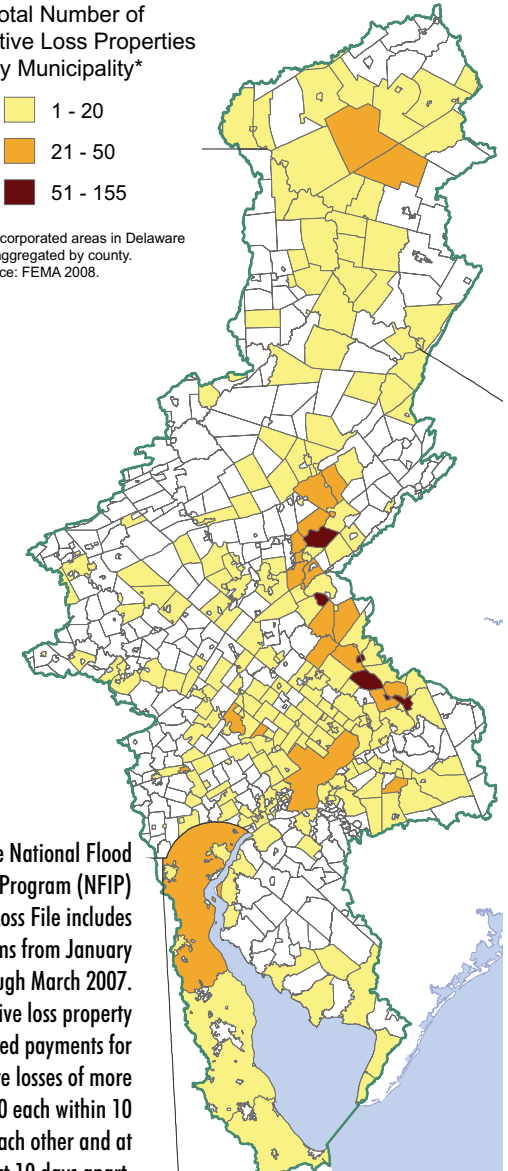
Prior to 2004, FEMA reported a total of 317 repetitive loss properties in the basin. Since then, three mainstem floods in 2004, 2005 and 2006 caused the addition of 1949 properties to this list. As of the end of January 2008, nearly \$235 million has been paid out to 2,266 repetitive loss properties. The counties with the highest concentrations of repetitive loss properties are Bucks, Montgomery and Northampton PA, and Warren, Hunterdon and Mercer NJ. New Castle County DE ranks 5th in

For more information on the Interstate Task Force and a complete list of recommendations, visit: www.state.nj.us/drbc/Flood_Website/taskforce.

Fig. 1.17
Total Number of Repetitive Loss Properties by Municipality*

- 1 - 20
- 21 - 50
- 51 - 155

*Unincorporated areas in Delaware are aggregated by county. Source: FEMA 2008.



The National Flood Insurance Program (NFIP) Repetitive Loss File includes flood claims from January 1978 through March 2007. A repetitive loss property has received payments for two or more losses of more than \$1,000 each within 10 years of each other and at least 10 days apart.

Table 1.3. Repetitive Claims 1978 - 2008

County	Watersheds	No. of Properties	Repetitive Loss in \$Millions
Bucks PA	Delaware River & Neshaminy Creek	590	\$ 76.0
Montgomery PA	Schuylkill River & Perkiomen Creek	252	\$ 26.8
Northampton PA	Delaware River & Lehigh River	193	\$ 25.9
Warren NJ	Delaware, Pequest & Paulinskill Rivers	192	\$ 19.8
New Castle DE	Red Clay & White Clay Creeks, Christina River	51	\$ 12.9
Hunterdon NJ	Delaware River	155	\$ 12.7
Mercer NJ	Delaware River & Assunpink Creek	191	\$ 11.2

terms of the cost of repetitive losses (Table 1.3, Fig. 1.17).

Trends

The density of claims reflects population density, the degree of development in floodplains, the number of policy holders, and flooding frequency. The vast majority (86%) of the repetitive loss properties were added as a result of three major flood events between 2004 and 2006.

Typically, several factors contribute to flood events in the Basin including:

- antecedent soil moisture – how wet soils are before the storm event
- the duration and intensity of the storm event
- the number of storm events that contributed to precipitation within a given period of time
- the extent of the precipitation, i.e. how large an area was affected by the storm;

- snow pack , since snow melted by rain can contribute to flooding.

Figure 1.18 illustrates some of these factors. It compares the observed total monthly precipitation for recent years (2003–2006) to a historically wetter year (1996) and to average annual precipitation for 1971–2000; record flood events are highlighted.

A record amount of rain fell on the basin in October 2005, but it did not result in mainstem flooding due to antecedent hydrologic conditions: below normal precipitation in the preceding five months resulted in very low stream flow, soil moisture, ground water levels and reservoir storage. Conversely, the September 2004 flood event was preceded by two months of above-average rainfall which compromised the ability of soils to absorb additional rainfall.

The April 2005 flood also illustrates the importance of antecedent conditions, including a prior rain event in March and the contribution of a melting snow pack. Total rainfall in June 2006 included an especially heavy rain (up to 18”) over a 4-day period across the Lehigh, Schuylkill and Upper Basin.

In 2008, the Delaware River Basin Interstate Flood Mitigation Task Force (Task Force) developed a set of 45 consensus recomenda-

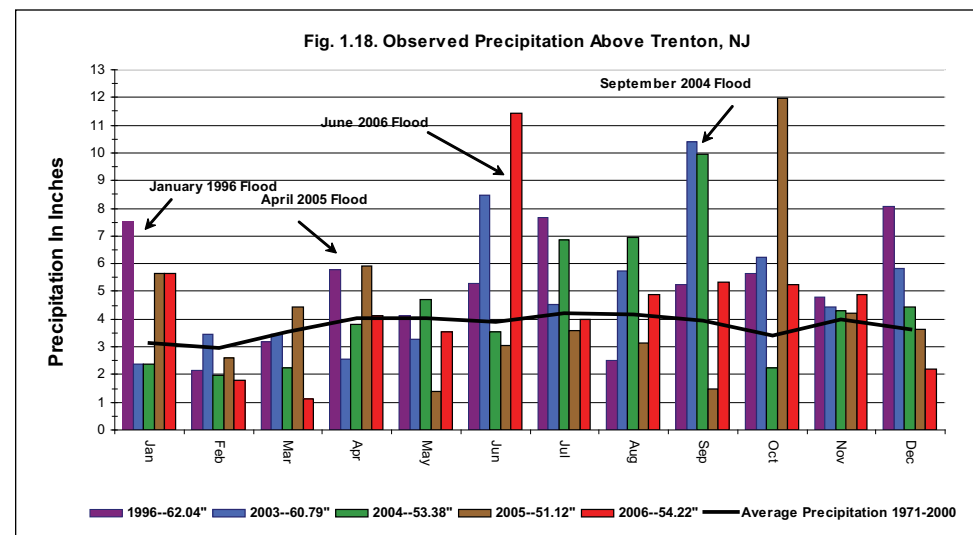
tions that address a wide variety of actions to improve conditions in the basin, including flood map modernization, improved regulations, and integrated watershed and floodplain management. The Task Force report is available at www.drbc.net.

Actions and Needs

- Additional indicators are needed to capture the ecological functioning and value of floodplains and to reflect the total cost of recurring flood damages to communities.
- Adopt policies to ensure that public funds do not support projects that create a further flood risk.
- Adequately fund planning and mitigation actions; flood prone communities often find that available funds are not sufficient for either acquisition or elevation of buildings that are repeatedly flooded.
- Evaluate the precipitation observing station and stream gage networks in the Basin to support improvements in flash flood forecasting capabilities.



PHOTO: J. SPINWOOD, DRBC, JUNE 29, 2006, HARDEY PA



Feature • Basin Hydrology Climate Change

Note: There is a wealth of information on climate change, some specific to the mid-Atlantic region. A copious number of sources were examined for this assessment, and while we refrain from mentioning them all, a few are worth noting, including: the Consortium for Atlantic Regional Assessment (CARA) and the Northeast Climate Impacts Assessment (NECIA). Since the products of these initiatives are generally available on the web, we have chosen to avoid the distraction of footnotes. Readers are encouraged to investigate.

Measuring climatic change impacts

There is general, but not unanimous, agreement that global temperatures are warming, sea level is rising, and the planet's climate is undergoing a possibly significant change. While the causes, the rate of change, and the degree of climate modification we can expect may be in debate, change from recent historic conditions is already occurring, and adapting to additional change will present a considerable challenge to water resource management.

Precipitation Patterns: Status and Trend

Temperature and precipitation are linked in the global climate system. Because warmer air holds more water vapor, atmospheric moisture will increase as surface temperatures increase, generating the potential for more frequent storms and precipitation. Storm intensity may also increase, as storms, especially hurricanes, are fueled as they pass over warmer waters.

Recent years have been some of the wettest on record and NJ precipitation records indicate an increase of 3.3 inches since 1970. The seven wettest calendar years of the last 113 years have all occurred since 1972, and October 2005 was the wettest on record in New Jersey (11.98 inches). It is unclear whether the long term trend is for continued increases in precipitation, but changes are expected in seasonal precipitation patterns and the severity and frequency of storm events. In contrast, the decade of the 1960s was the driest on record and even amid the wet conditions of recent decades there have been several times when water supplies approached dangerously low levels and drought emergencies were declared in the basin.

Wetter winters. Winter precipitation in the Northeast is forecast to increase by 20%-30% by the end of the century, and this is expected to be in the form of rain rather than snow. Figure 1.19 illustrates the predicted change to snowfall patterns. Rains, especially warm rains, on top of existing snow cover will accelerate snowmelt. Spring

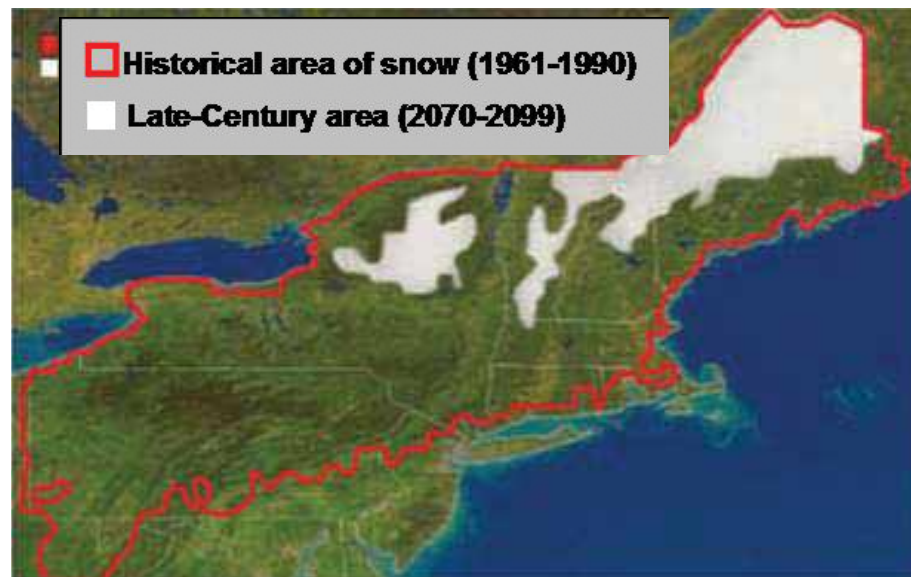
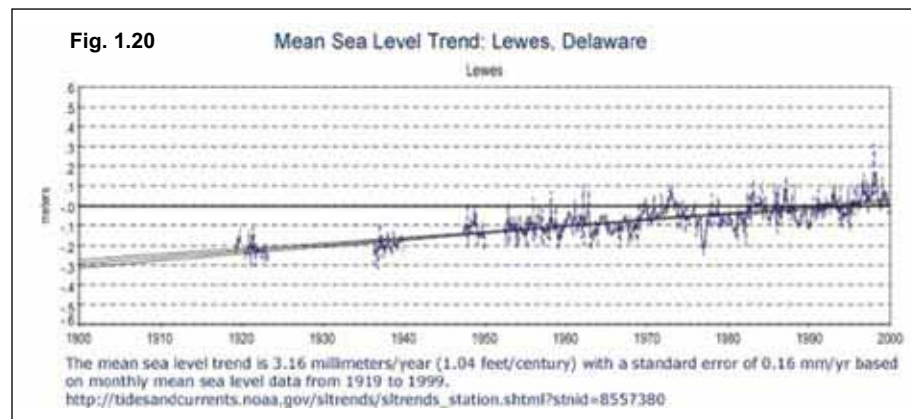


Fig. 1.19 The Changing Face of Winter. The area that typically sees at least a dusting of snow on the ground for at least 30 days during the winter may change by the end of the century under a higher emissions scenario. This suggests that without any reductions in greenhouse gas emissions, the Delaware River Basin may not have any substantial snowpack by the end of the century. From *Confronting Climate Change in the U.S. Northeast, 2007* Northeast Climate Impacts Assessment.



peak flows, which are now occurring about 7 to 14 days earlier than the long-term average, are expected to be occurring even earlier by the end of the century. While summer precipitation is not predicted to change dramatically, higher air and water temperatures could increase evaporation and reduce summer and autumn stream flows.

Increased droughts. Drought can be classified as short-term (1-3 months), medium-term (3-6 months) or long term (more than 6 months) duration. The northeastern US typically experiences short-term droughts about once every 2-3 years and medium droughts once every 15 years in inland regions, but not at all in some coastal areas. In the Delaware basin, the most recent major drought lasted from 1961–1967, and is considered the basin *drought of record* for planning purposes. Dry conditions have triggered regional drought watches and warnings several times since the 1960s, notably in 1980-81, 1985, 1995, and 1999. More recently, portions of the basin experienced drought conditions in 2001–2002; Delaware has adopted 2002 as its planning drought of record. Under the more extreme climate change scenarios, droughts are expected to become more frequent, with short-term droughts potentially affecting areas of the Catskills and Adirondacks as often as once every year.

Precipitation: Impacts on Water Resources

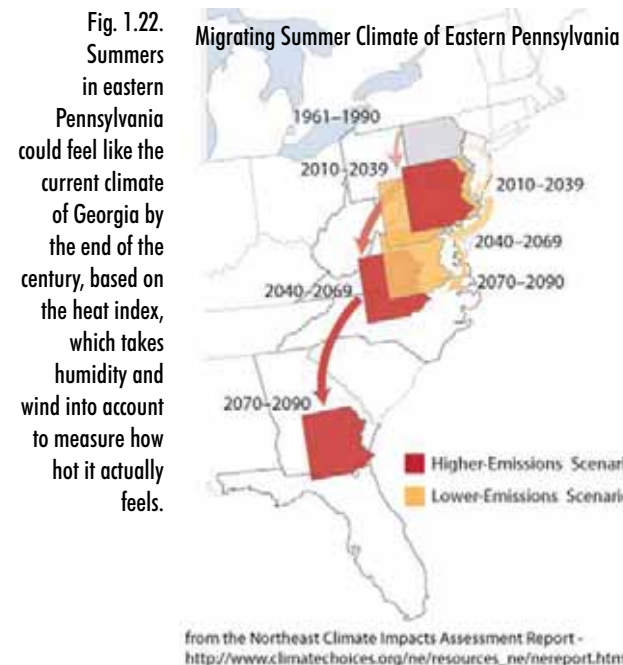
Water supply. Shorter, wetter winters with reduced snowfall and earlier peak flows will affect the water management system of the basin. Snowpack is depended upon for spring flows to reservoirs and for recharge of ground water to ensure stream base flows through the summer months. Without this natural attenuation, additional storage may be necessary. An increase in the frequency of drought would further stress the region’s water supplies and challenge current storage capacities.

More frequent, flashier storms will have an impact on water quality. Runoff carries non-point source pollution and sediment loadings, and additional pollutants would be added as overburdened storm and wastewater systems add untreated flows to rivers and streams.

Instream flows. Both reduction in flow and increases in extreme precipitation events pose threats to aquatic communities and to water quality. Extended periods of low flow may mean a reduction of the assimilative capacity of streams and the likelihood of increases in pollutant concentrations. Prolonged periods of low flow will also challenge our ability to maintain freshwater flows into the estuary. Fresh water flow helps repel the upstream incursion of salinity toward drinking water intakes and maintain a salinity gradient hospitable to aquatic life in the estuary.



Fig. 1.21. Aerial Photo of Maurice River Cove comparing 2001 shoreline to that of 1890. Photo courtesy of J. Gebert, U.S. Army Corps of Engineers, Philadelphia District



Flooding. In the near term, increased storm severity in late winter/early spring will also exacerbate flood risk as heavy rains and intense storms during that time are naturally compounded by snowmelt. In the longer term, snow will be replaced by rain, and winter flooding could be more common. In tidal areas, more severe storms could bring higher waves and storm surges, increasing coastal flooding and beach erosion.

More intense precipitation events are likely to cause increased frequency and magnitude of floods. Areas of the basin already at risk for flooding may find that risk increased and risk areas may be expanded, with commensurate increases in damages to individual properties and to community infrastructure.

Sea Level Rise: Status and Trends

The effects of sea level rise are especially important to Lower and Bay Regions of the basin. With its limited topography and generally low elevation, the coastal plain province is particularly vulnerable to increases in sea level. Many coastal areas are undergoing subsidence which exacerbates the effects of a rising sea elevation.

The trend in mean sea level at Lewes, DE from 1919 through 1999 (Fig. 1.20) shows an increase of 0.124 inches/year, the equivalent to one inch every eight years. The rate of increase at Philadelphia from 1900 through 1999 was 0.108 inches/year; or about one inch every nine years. Projections for sea level rise in the northeast US range from eight inches to three feet by the end of the century. Rising sea level is principally due to the expansion of the seas as temperatures increase. The rate at which the world's polar ice sheets melt could exacerbate the rate of sea level rise.

Sea Level Rise: Impacts on Water Resources

Increased salinity. It is projected that salinity will increase as a result of increasing temperatures and the incursion of saltwater into fresh as sea level rises. Increased salinity could threaten water supplies for public, industrial, and agricultural use in the tidal watersheds. In the Delaware estuary, freshwater flows from the river and streams naturally buffer against salinity incursions into fresh water. Sea level rise coupled with intermittent decreasing fresh water flows could compromise freshwater intakes and wells in aquifers vulnerable to salt water intrusion. Some coastal areas have already experienced salt water intrusion as a result of overdraft. For example, several wells in the lower Cape May peninsula have been abandoned due to salt water intrusion from overuse of the aquifer, and many homes and businesses are now dependent on desalinated well water; the process is costly. Communities with drinking water intakes along the River could be at risk, including Philadelphia, a city of 1.5 million people.



Fig. 1.23. Wastewater treatment plants in the area of Cape Henlopen DE are vulnerable to sea level rise. Using the 1962 storm flood elevation, this image shows that Lewes WWTP would be flooded and the facility at Wolf Neck would be nearly surrounded by water. Courtesy of David B. Carter, Coastal States Organization Climate Change Workgroup Co-Chair & Delaware Coastal Program Manager.

Erosion, flooding and habitat loss. Sea level rise is slowly inundating low lying areas along coastlines, causing significant erosion of beaches. In Salem County NJ, some bay beaches are currently fully submerged at high tide, and further sea level rise could eliminate them at low tide. Over time, a measurable loss of wetlands is predicted, especially where existing tidal marshes are caught between a rising bay and the hard, immovable edges of development. Wetland loss puts human settlements at risk. Wetlands buffer wind and tidal energy; their loss means that buildings and infrastructure take more insults from coastal storms. Figure 1.21 illustrates how erosion and sea level rise has altered the coastline of Cumberland County, NJ since 1890.

Loss of beaches and loss of wetlands means loss of habitat and breeding sites for many species. See for example horseshoe crabs and red knots as indicator species in the Living Resources section of this Report. Impacts to economically important finfish and shellfish species, such as oysters and weakfish, could be dramatic, with repercussions for recreation and employment in the region.

Infrastructure considerations. Rising sea level will cause problems for infrastructure in coastal areas. Roads and bridge approaches in low lying areas will first become vulnerable to flooding during storm events, and eventually be permanently inundated. Storm sewers in coastal areas will carry seawater onto town streets, rather than conveying stormwater away. Several coastal towns have experienced this already. Sea level rise will also render lower bridges too low for the safe passage of boats underneath. Costs to replace infrastructure can be expected to be many millions of dollars.

Wastewater treatment plants are at risk as is drinking water infrastructure. If water supplies are threatened, intakes and treatment plants may have to be relocated and alternative potable water supplies secured.

Temperature: Status and Trend

Temperatures in the northeastern US have increased by about 1.8°F since 1899. Since 1970 the region has warmed at a rate of 0.5°F per decade, with winter temperatures warming at the more rapid rate of 1.3°F per decade. We have experienced more days where temperatures surpassed 90°F and 100°F, fewer days with temperatures below 32°F, and more rain than snow in winter months with a commensurate decrease in snowpack. Earlier spring snowmelt and vegetation blooms have also been documented across the region.

Some predictions indicate that by 2040–2069 mean annual temperatures for the Delaware River basin will range between 2.5°F and 8.7°F warmer than experienced between 1971 and 2000. While the range of estimates depends on the degree to which greenhouse gas emissions are curbed or increased, northeast temperatures are expected to rise 2.5°F to 4°F in winter and 1.5°F to 3.5°F in summer regardless of any emissions reduction, simply because of residual concentrations of greenhouse gases in the atmosphere.

Temperature impacts on water resources

Increased ambient air temperatures will increase water temperature, compromising its ability to hold dissolved oxygen in suspension – a critical condition for aquatic life. Temperature also affects the ability of water to assimilate some pollutants and may cause violations of water quality criteria. Areas that are densely populated with significant areas of rooftops, roadways, parking lots and heat-generating emissions are vulnerable to even greater localized temperature increases and exacerbated impacts on water resources.

The current mix, distribution, and abundance of forests are likely to be altered by rising temperatures. Evergreen forests, because they require colder temperature regimes, will be especially vulnerable to replacement by deciduous species better adapted to warmer weather. Warmer temperatures tend to encourage parasites and diseases that attack vulnerable species; warmer temperatures may play a role in the proliferation of woody adelgid that attack hemlock forests. Major changes to forest cover can be expected to affect water resources.

There are numerous other impacts expected with increased temperatures, including human health effects from heat stress, worsening air quality, and infectious diseases; economic shortfalls from the loss of winter recreation and tourism; increased energy demand for cooling; and impacts on agricultural production, plant and animal life cycles and survival connected to disruption of seasonal phasing.

Actions and Needs

Adapting to changing conditions will be most successful if managers are well informed.

- More localized studies and accurate models are needed to better understand how climate change will affect regions of the basin.
- Close examination of the sufficiency and sustainability of existing water supply infrastructure is needed; current and future planning initiatives must address the reality of a changing climate.
- To predict the effects of sea level rise on wetlands, improved mapping and knowledge of land use at wetlands margins is necessary. The true extent of bulkheads, dikes and other barriers to wetland movement is necessary for the realistic development of policy alternatives.
- Expanded ground water monitoring may be warranted to ensure tracking of salt water intrusion.

Several state and local initiatives are currently investigating the effects of climate change on the basin. The New York City Department of Environmental Protection is involved in studies that examine the effects of climate change on the quality and sustainability of its water supply, and the Partnership for the Delaware Estuary was recently awarded a grant from the EPA to look at how climate change, specifically sea level rise, will affect the estuary. DRBC has filed a research plan with EPA to assess the consequences of climate change on dissolved oxygen, water supply intakes and oyster populations in the estuary. EPA is actively supporting efforts to identify and reduce vulnerability to climate variability and change.