WATER QUANTITY

Water quantity is the flow or volume of surface- and groundwater — the sources of which include but are not necessarily limited to rivers, streams, lakes, ponds, and aquifers; and the availability of such supplies for public, private, industrial, irrigation, and recreational purposes, and to sustain other organisms that depend on such supplies.

Characterization

The following characterization of water supply or quantity addresses available sources of water and the complementary water-supply systems and facilities serving public, industrial, and irrigation needs.

Climate, Geology, and the Hydrologic Cycle

Everywhere on Earth, climate is the single-most influential factor determining the amount of water received in a given area. New Castle County's climate is classified as mid-latitude, continental marine, which is characteristically humid with moderate temperatures and with, on the long-term average, a fairly even distribution of precipitation throughout the year. Precipitation does, however, vary considerably from normal, leading to extended dry or wet periods that may cause droughts and floods. The nearby Atlantic Ocean is the dominant climatic influence. Figures 7 and 8 illustrate the monthly variations in temperature and precipitation for the area. These data were collected from the National Weather Service Observatory at Greater Wilmington Airport. The mean-value precipitation is based on the 30-year, long-term normal period from 1950 to 1981. Mean-value temperature is based on a 103-year period of record.

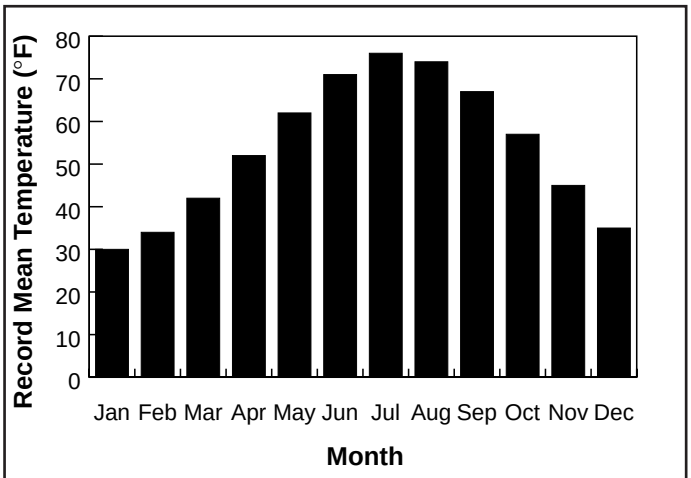
These climatic forces shape a characteristic hydrologic system and, accordingly, the types and occurrences of animal and plant inhabitants in conjunction with the geology of the area. The dynamics of this water-based system can be expressed in terms of the "hydrologic cycle."

Climate determines the net amount of water inflow into the local hydrologic system. Both climate and *weather* (or the temporal and spatial variability of climate in a given area), are also important factors influencing the discharge of water from the system in the form of evapotranspiration.

Evapotranspiration is the combination of evaporation and transpiration, or plant uptake of water. Evaporation varies annually according to the weather from near zero to a large amount of water that is intercepted. During periods of high rates of evapotranspiration, stream base flows recede and groundwater levels decline; the opposite occurs the remainder of the time. These cycles correspond to recharge and discharge periods. The remainder of the water at any given time is discharged either naturally or artificially. All water evapotranspired or otherwise discharged from the system eventually returns to the ocean, thus completing the cycle.

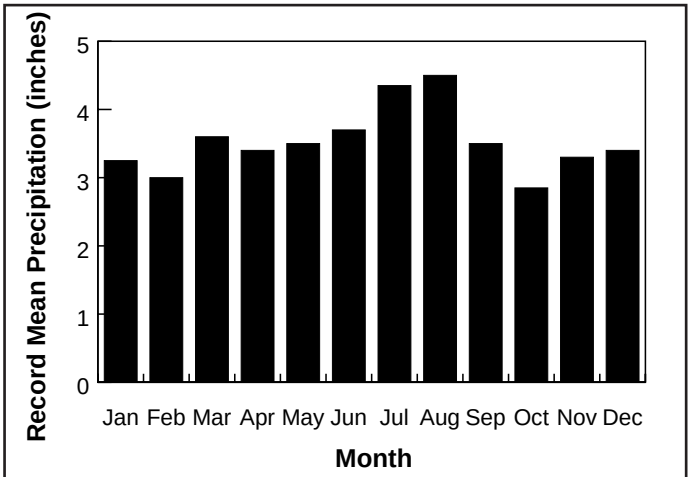
Short-term variations in inflow due to changing weather patterns lead to drought or flood events, which are more intensely expressed by changes in surface discharge. Groundwater systems, being more reflective of long-term

Figure 7
MONTHLY MEAN TEMPERATURE
WILMINGTON, DELAWARE



Source: National Oceanic and Atmospheric Administration, *Local Climatological Data, Annual Summary with Comparative Data,* Asheville, NC, 1988.

Figure 8
MONTHLY MEAN PRECIPITATION
WILMINGTON, DELAWARE



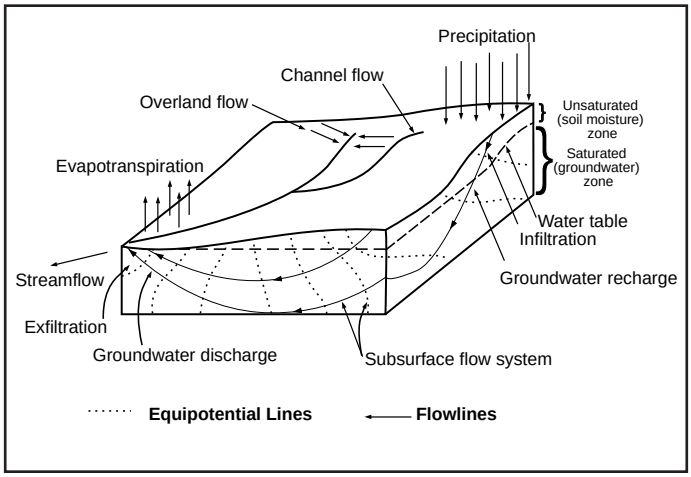
Source: National Oceanic and Atmospheric Administration, *Local Climatological Data, Annual Summary with Comparative Data,* Asheville, NC, 1988.

water availability, respond very slowly to these comparatively brief weather events. Thus, the surface waters are much more sensitive to swings in precipitation. As noted, precipitation in the Piedmont Basin has considerable variation, with period-of-record minimum and maximum annual totals of 29 inches and 62 inches, respectively. The standard deviation on the long-term normal annual precipitation of 42 inches is approximately 5 inches. This is significant in that drought conditions and water-supply shortages as determined by hydrologic indices and other indicators occur when precipitation totals fall 3 inches below normal over a six-month period. In other words, drought conditions exist statistically within one standard deviation of long-term normal precipitation, and thus drought events must be considered completely ordinary rather than uncommon events. In fact, drought recurs in this area to some degree of seriousness approximately three times each decade.

On an average or long-term basis, water-supply availability in the Piedmont Basin is a function of groundwater storage determined by the geologic controls that capture, store, and discharge water to the surface streams and through the ground systems. The *geology* of the area is, in fact, a more significant determinant than the weather in controlling the specific occurrence of water and the amount that is actually available for human uses (as well as the amount available to support all other living populations). These elements of the hydrologic cycle are shown schematically in Figure 9.

The other important factor in the occurrence and distribution of available water is human impact on natural systems. As discussed later in this section under "Sources of Impact," water usage by humans in the study area exerts significant stress on the environment at certain critical times.

Figure 9
SCHEMATIC REPRESENTATION OF THE HYDROLOGIC CYCLE



Qualitative Hydrology of Water Supplies

The Piedmont Basin has two major direct sources of water — which make up the hydrogeology of the area — surface supplies and ground supplies.

Surface-water supplies consist of rivers, streams, and several minor, man-made ponds and impoundments. The Christina River basin's drainage area, which actually extends beyond the Delaware portion referred to herein as the Piedmont Basin, is characterized as a low-order stream system with a dendritic drainage pattern established on basement-complex rocks. (Stream order indicates number of tributaries in a basin. While the Christina River is a third-order stream, a large, continental basin such as the Mississippi River would be a ninth-order stream.) This drainage pattern reflects the underlying geologic structure of faulted and folded rocks and the relationship of geology to the prevailing climate.

The stream network or drainage system can also be characterized by a parameter termed *drainage density*. As a rule, humid regions with consistent slopes and infiltration-resistant soils and rocks develop high drainage densities, or lengths of streams per unit area. The Christina River basin has a high drainage density value of roughly 1,000, reflected by close spacing of drainage ways. (In comparison, southern California has a drainage density value of 30).

Although the summit or highest relief at the perimeter of the Christina River basin stands 1,200 feet above sea level, the overall stream gradient is rather low. In the Christina River basin, a major geologic transition occurs from the Piedmont to the Coastal Plain and is demarcated along a line termed the "Fall Line." The minor tributaries in the Delaware River basin — Naamans and Shellpot creeks — differ from streams in the Christina River basin in that they flow directly from the Piedmont region to the Delaware River, traversing only narrow strands of riverbank deposits of recent origin.

Stream gradients above the Fall Line are somewhat steeper than those below, and flow decelerates downstream of this transition. Together, these parameters are indicative of an "old-age" drainage system. In the lower part of the basin, below the Fall Line, the drainage undergoes a transition to a meandering pattern with a slightly lower drainage density and gradient although discharge increases within these main-tributary segments, which have significantly larger cross-sectional area and depth compared to the Piedmont segments.

In these lower reaches, the streams are part of the Delaware River estuary and are thus under tidal influence. Due to the very low stream elevations relative to sea level, tidal influence extends considerably inland. The tide influences stream stages diurnally and extends 12 stream miles on the Christina River, where the tide is impeded at Smalley's

Dam; 8 stream miles on White Clay Creek, to near Delaware Park; and 3 stream miles on Brandywine Creek, to City Dam in Wilmington.

The basin is fairly complex geomorphically, and it should also be noted that all of these stream reaches have been considerably altered from their natural state. Significant alterations include sedimentation from erosion caused by urbanization of the area; channel engineering; changes in discharge, particularly during high-flow periods caused by increased runoff from impermeable surfaces; and inflow from stormwater sewers. For example, sections of the original stream channels in the Mill Creek drainage have been filled with over 10 feet of sediment this century.

Groundwater supplies are derived from aquifers and aquifer systems in the Piedmont and Coastal Plain. The American Geologic Institute defines an aquifer as a "a body of rock that is sufficiently permeable to conduct water and to yield economically significant quantities of water to wells and springs." This definition itself, however, requires further explanation due to the term "rock" being commonly misinterpreted to mean hardened geologic material. As defined by the American Geological Institute, rock is "an aggregate of one or more minerals" regardless of the degree of hardening of the material. With these definitions aside, the aquifers of each geologic province are distinctly different, reflecting the two major rock classifications in those two provinces, and this has a significant bearing on the amount of usable water that can be obtained.

Groundwater yield is determined by calculating a set of aquifer parameters by a variety of analytical techniques used to work on data collected primarily from aquifer tests. (These tests are colloquially called "pump tests," which is a misnomer since it is the aquifer, not the pump, that is being tested.) Of the several aquifer parameters, some represent the intrinsic, physical properties of the aquifer, while other parameters are derived. Intrinsic physical parameters include porosity and permeability. *Porosity* is defined as the ratio of void space to a unit volume of rock, while permeability is the rate of fluid flow in the rock. From these and other intrinsic parameters, several derived parameters have been established to determine hydraulic response of wells and aquifer yield. The two most important of these are *storativity,* which is the volume of water that can be released from a unit surface area of aquifer per unit decline in normal hydraulic gradient, and *transmissivity,* which is the volumetric rate of water release from an aquifer over time.

Piedmont aquifers are composed of ancient fractured rocks of igneous, meta-igneous, and meta-sedimentary genesis while rocks in the Coastal Plain, being far younger, are predominantly unconsolidated or soft and substantially underformed. Aquifers in the Coastal Plain typically yield an order of magnitude or more of water over a given unit size of aquifer material than do those in the Piedmont.

Piedmont formations contain porosity that has resulted from brittle deformation causing fractures, crevices, faults, and other discontinuities and defects (generically termed *strain*) occurring over the 600 million years of their existence. This type of porosity, also known as secondary porosity, comprises a very minor amount of void space for water to occupy. The void space that does exist is usually not well interconnected, and thus permeability is low and results in low bulk transmissivity values. Thus, Piedmont wells typically have very limited yield.

Groundwater flow is also complicated and often highly directional as a result of the orientation of the stresses and resulting strain in the rocks. Special exploratory and well-construction techniques can be used to both initially site and develop wells in the Piedmont that will yield more water than would otherwise be obtained. Several such wells in the Piedmont are important sources of public and industrial supply. In any location in the Piedmont, however, a well can be installed that will provide for at least the water needs of a single home.

A important function of groundwater in the Piedmont, arguably more so than as a source of water for wells, is as the source of base flow to streams during fair weather. A major portion of the net flow in the streams of the Piedmont comes directly from groundwater discharge in the form of continual leakage or seepage into the streambed overlying the various geologic formations. Local exceptions to the above exist, with the most notable in the Hockessin Valley. The Hockessin Valley merits special mention due to its unusual geology and hydrogeology for Delaware.

In that area, the underlying formation, called the Cockeysville Formation, is composed of the carbonate rocks including marble, dolomite, and dolomitic limestone. Rock that is highly resistant to weathering — predominantly the gneisses and schists that comprise most of the Piedmont — rim the Cockeysville Aquifer. The easier-to-erode Cockeysville has been removed at a faster rate.

This differential weathering of adjacent formations is primarily responsible for creation of the Hockessin Valley and the geomorphic features within it, all of which are a type of terrane termed *karst*. Karst develops in carbonate formations exposed to humid climates and creates aquifers whose porosity is caused primarily from chemical dissolution of the rocks. Because the Cockeysville is part of the Piedmont, fracture-induced porosity is present in the Cockeysville as well. This results in exceedingly complex flow regimes and other notable geologic features such as sinkholes.

While sinkholes have been documented in Hockessin, caves that open to the atmosphere, which are common in other karst areas, do not exist here. Karst aquifers have the capability to yield considerable quantities of water to wells. Another karstic feature of the area is that streams crossing it

lose flow rather than gain flow. Mill Creek in the Hockessin Valley does just that; it leaks water *into* the ground, rather than the reverse, as is typical of the Piedmont. This leakage of water from Mill Creek contributes, on an annual average, 22% of the groundwater supply extracted from the aquifer. The creek flows at a perpetual 100-year drought condition.

Another occurrence of the Cockeysville Formation also exists in the White Clay Creek watershed near the intersection of Pike Creek and Paper Mill roads. This area has not been developed as a major water supply source but remains as a source of supply for homes and a school.

The Cockeysville Formation in Hockessin is a major source of water supply and requires considerable care in management of point and nonpoint discharges in Mill Creek and the surrounding tributaries since contaminants can directly enter the groundwater system and be transmitted to wells in unpredictable ways. Due to this sensitivity of the hydrologic system in Hockessin, New Castle County has adopted a special resource protection ordinance to further control land use in the valley and protect water supplies. (For more information, see "Groundwater.")

In contrast to Piedmont aquifers, Coastal Plain aquifers are composed of granular material whose pore space is a much larger percentage of the volume of rock and more continuously interconnected. The result is aquifers with high transmissivity values (greater than 50,000 gallons per day per foot of saturated aquifer thickness). In qualitative terms, the aquifers have "moderate" to "high" yield capability. Yields from individual wells of several hundred thousand gallons per day are obtainable in certain locations.

In the Coastal Plain, the rocks have not yet been transformed into hardened material and undergone major deformation. Thus, the portions of the formations that remain (after some erosion) are nearly intact as originally deposited. This results in so-called *layer-cake geology,* where formations are stacked, in beds, one upon the other in relatively even, sheet-like fashion.

As always, real geology is never quite as simple as a layer cake. Of the two formations in the Coastal Plain, the uppermost Columbia is expressed as a fairly regular sheet deposit at the surface, but at depth is irregularly deposited on the older, eroded surface of the Potomac Formation. This causes great local variation in thickness of the Columbia where in a lateral distance of several feet, the formation can vary in thickness by up to 100 feet. The Columbia Formation contains the namesake water-table aquifer.

The underlying Potomac Formation is substantially more consistent in thickness in a given area than is the Columbia; however, its internal composition is extremely variable and the entire formation is not level with the land surface but is warped downward slightly in a southeasterly direction. This warp or tilt is called *bedding dip.*

Overburden weight in the Potomac Formation has helped cause it to subside, creating the dip. In general, the greater the dip, the more material is deposited. Compaction does thin the sediments somewhat after burial, but downwarping also accelerates the rate of deposition so an increasing amount of accumulation occurs down-dip and the formation grows progressively thicker.

An important implication of the concept of dip is its relation to aquifer recharge. Dip along with erosion has caused the Potomac Formation and the aquifers within it to be exposed or nearly exposed at the surface at their northwestern end, forming *outcrop areas.* Where buried by the Columbia in the up-dip portion, the Potomac forms *subcrop* areas. The outcropping and subcropping areas of the aquifers are also the recharge areas where the aquifers receive the most water inflow from precipitation. The Columbia, of course, receives its recharge directly since it is the surficial aquifer, although variable permeability at the surface of the Columbia has areas where the potential for recharge is greater than in others, and these areas are designated recharge areas as well.

Any substances that may be in that water such as contaminants clearly put the aquifer at risk of damage. The bulk of the water in the Potomac is extracted outside the Christina basin; however; as explained above, the source is from within the basin. Accordingly, the need for protection of aquifer recharge areas should be apparent for all recharge areas. Historical contamination events have rendered many parts of these aquifers unusable, resulting in a loss of water supply.

In the down-dip portions of the Potomac Formation, the aquifers become bounded above and below by relatively impermeable, fine-grained sediments forming confined aquifers. These aquifers are more protected from contamination than water-table aquifers, but some level of protection is still required, particularly for proper well-construction techniques.

Rates of recharge and discharge are also functions of the composition of the deposits along with their spatial orientation. At the contacts of these various formations, flow boundaries exist. At the Fall Line, some minor inter-flow does occur between the two provinces although it is insignificant in terms of net flow in the basin system. This is a no-flow boundary.

As stated above, Coastal Plain rocks steadily thicken in a southeasterly direction from a "feather edge" at the Fall Line to several hundred feet. As a result, most of the Coastal Plain groundwater system is simply not in contact with the streams. The limited portions of the Coastal Plain

rocks that are in contact with the streams are mostly isolated from them by fine-grained sediments, which inhibit flow between the systems. Thus, the surface- and groundwater systems in the Coastal Plain are primarily a no-flow boundary, but local variation exists.

Groundwater in the Coastal Plain aquifers flows predominantly in a southeasterly direction (the direction of dip) with natural discharge ultimately going to the Delaware River and Atlantic Ocean at slow flow velocities on the order of inches per day. This flow is part of a large, regional flow system that extends along much of the middle Atlantic seaboard. No-flow and low-flow boundaries occur within Coastal Plain formations in the form of silt and clay layers, which act to separate internal aquifers from each other. Although complex, these systems are intensively used for water supply and have been afforded a large amount of study including digital models and therefore are fairly well understood.

In the Piedmont, the aquifers are in extensive contact with the surface systems and a significant amount of natural groundwater discharge is to streams rather than into a deep, regional flow system. The meager amount of groundwater discharge in the Piedmont expressed by low well yields would appear to contradict the fact that the streams are important water-supply sources. The reason the opposite is true is that the stream flow is derived from accumulated groundwater discharge from the much larger upper basin in Pennsylvania.

The above descriptions are necessarily abbreviated and simplified since the actual systems are much more complicated than can be described with any ease. Plan-view and cross-sectional maps are useful for general depictions of the systems, but it must be understood that the systems are dynamic, three-dimensional, and highly heterogeneous and can only be understood at the site-level with careful study.

There are very few consistently similar characteristics of the various hydrologic systems in the basin, and about the only commonality they share is the same climate. As explained by the geology, this is why, despite receiving an equal amount of precipitation, the characteristics of the systems are remarkably different.

Based on quantitative analysis of the various drainage and yield parameters for the Christina basin, overall it has a limited water-supply capacity in comparison to the intensity of its use as a source of fresh water. The consequence of this is that while the Christina basin is still the major source of supply for the area, other sources have been developed to augment this supply. Namely, reservoirs have been constructed to store runoff for periods of low flow and water is imported from outside the Christina River basin and in fact from outside the Delaware River basin.

The vast majority of these augmented supplies exist in and are for use by Pennsylvania, but Delaware does receive a small increment of that water. Our supplies are primarily based on those that are naturally available. Thus, nearly 70% of the public water in the area is derived directly from the surface sources, which also support aquatic habitat and a variety of other primary and secondary uses. Use of the surface water is becoming increasingly competitive.

Even with the limitations of the surface sources, they are more accessible than groundwater sources and were developed early in the settlement of the area. Later, as additional supplies were needed, groundwater was exploited. Overall, the groundwater systems in the study area are the most complicated and variable in Delaware. Still, aquifers supply about 25% of the total water for the area, and in the relatively small watershed of 100 square miles, 50% of the groundwater pumped in the entire state for drinking water is produced from the Christina River basin. Put another way, the concentration of the population and the demand it imposes on supplies has resulted in both ground- and surface-water supplies being at nearly 100% development.

Quantitative Hydrology of Water Supplies

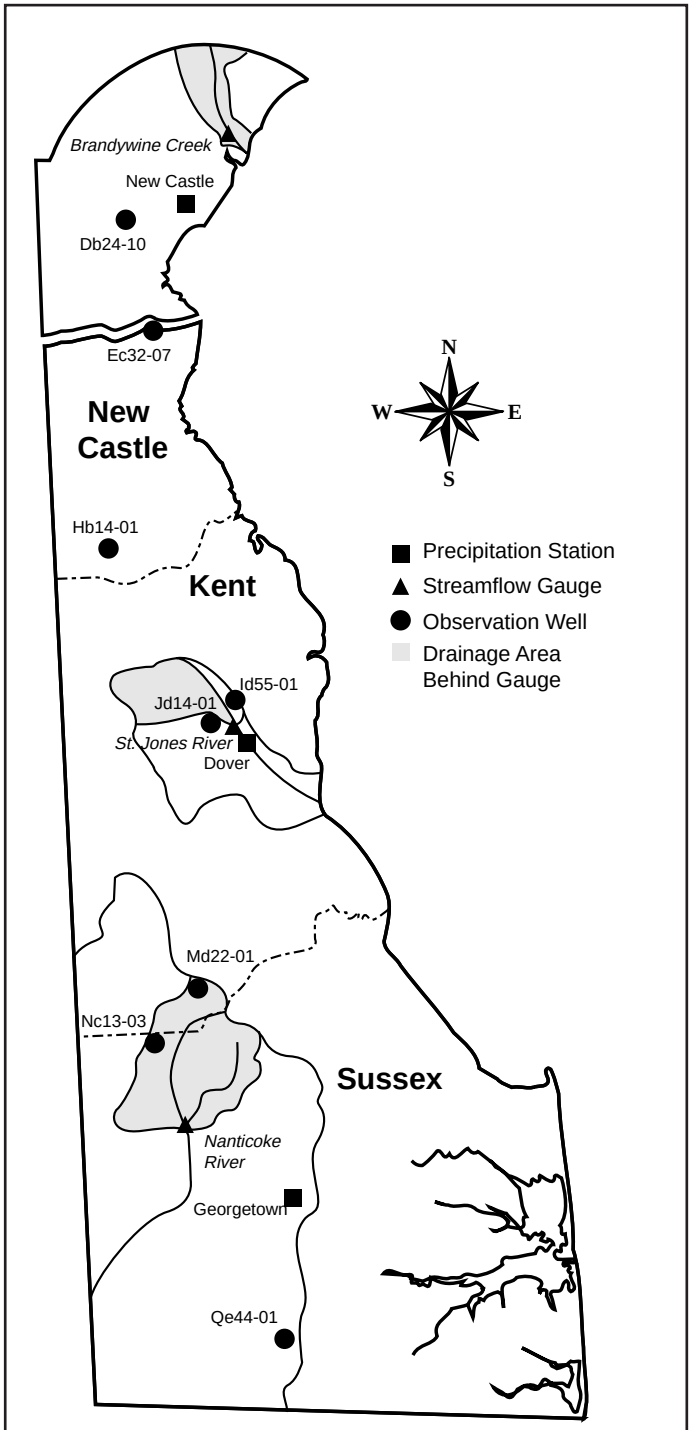
Surface-Water Resources

Data for stream flow is collected routinely via a system of stream-gauging stations operated and maintained by the U.S. Geological Survey and reported annually in their Water Resources Data publications for each “water year.” The water year starts October 1 and ends September 30, and the Water Resources Data contain records for the previous year. For example, the 1995 Water Resources Data covers the period October 1, 1994, through September 30, 1995. These publications are usually distributed in July of the calendar year following the reported water year, in this case July 1996. The locations of these stations are shown on Figure 10.

Data from only those gauging stations in operation during that year are reported. Data from discontinued stations can be obtained on-line from the U.S. Geological Survey’s central computer database, WATSTORE, in Reston, Virginia.

The report for each gauge consists of descriptions of its location, basin drainage area, period of record, gauge type, qualifying remarks, and any factors that can influence flow such as diversions upstream, extreme flows, and tabulations of mean daily flows and monthly totals. Beginning in 1993, in addition to the tabulated data, rudimentary statistics were added for each month of the reported water year as well as for the period of record. A hydrograph of the water year was also added. See Figure 11. Some of the important statistical data that are available are recurrence interval flows. Note that these recurrence intervals are not

Figure 10
MAP OF LOCATIONS OF HYDROLOGIC MONITORING STATIONS



Acknowledgments: U.S. Geological Survey, National Weather Service, Delaware Division of Highways,University of Delaware, City of Dover, City of Lewes, City of Wilmington, Daniel and Connie Swartzentruber.

Source: Delaware Geological Survey Summary of Water Conditions in Delaware for July, August, and September 1996.

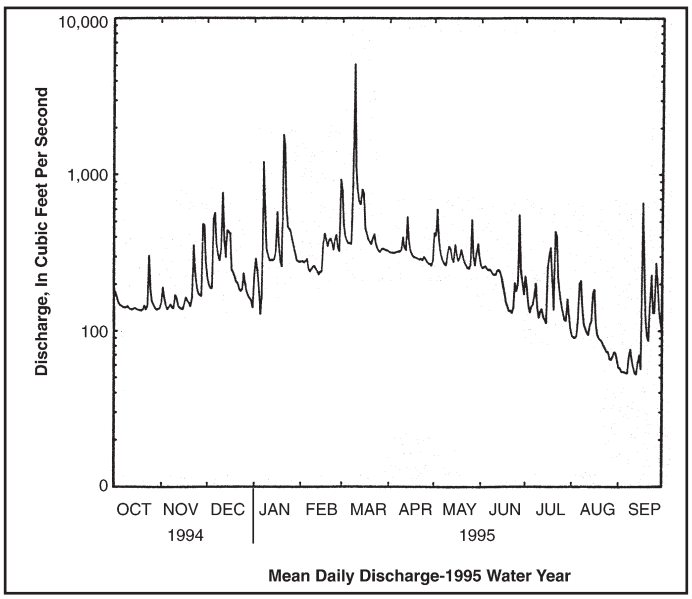
actual flows but statistical derivations, and they should not be misconstrued as predictors of when a given flow event will occur. For instance, the recurrence of a certain flow every 50 years does not mean such a flow will occur regularly every 50 years. Instead, such a flow may occur two years back to back and not again for 100 years.

Conversely, the possibility of flows above or below extremes of record must be acknowledged in light of the limited period of record for most stations (several decades) compared to the age of the streams (thousands of years). Therefore, new extremes will occur that will alter the record. For instance, a 50-year-flood flow may occur three times in 50 years. Still, recurrence flow data are useful for assessing stream behavior and the various application of such data for water resources management. One type of recurrence flow of wide importance is one termed "the Q7-10 statistical low-flow." It is used as a standard for maintaining stream water quality. The standard requires that a minimum flow equal to the Q7-10 low-flow must be maintained in the stream otherwise water-quality standards will be violated. This subject is covered in more detail in "Positive Initiatives."

Other information not reported in the Water Resources Data can also be obtained from the U.S. Geological Survey for both operating and discontinued stations. These data include detailed statistics derived from gauging-station flow records.

Published data are not organized by the U.S. Geological Survey for entire basins but rather for those stations within a

Figure 11
U.S. GEOLOGICAL SURVEY WATER RESOURCES DATA, MARYLAND AND DELAWARE, 1995



given district. If the district includes all stations for a particular drainage basin, such data would be found within one Water Resources Data publication. Otherwise, data covering an entire watershed would need to be obtained from Water Resources Data published by two (or more) different districts. This is the situation with the Christina River basin. Reports from the Maryland and Delaware district would be needed along with that of the southeast Pennsylvania district in order to obtain data for the entire watershed.

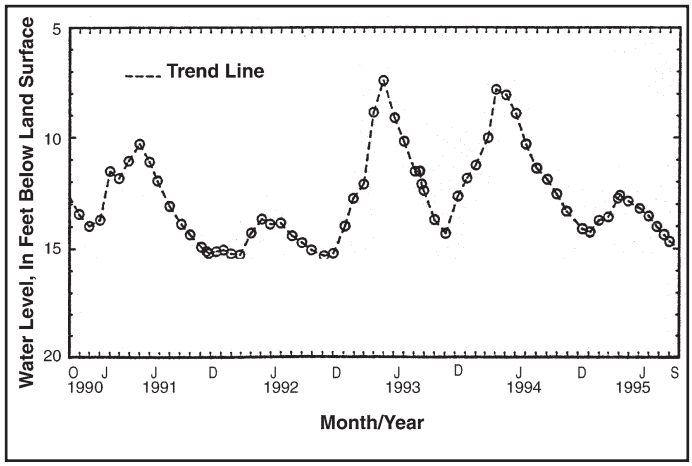
Real-time, or instantaneous, discharge data can be obtained automatically at continuous recording stations at which a sufficiently long history of flow data has been collected. Such data is analyzed by hydrologists using various computational techniques which also are used to determine the various statistical flows mentioned above. These data are used to establish rating curves for the gauges. The rating curves allow translation of stream level, or stage, to discharge measurements. Note that all flow data are reported in cubic feet per second.

Instrumentation in the gauging station is calibrated to read stream levels every 15 minutes (or more often if necessary) and record the stage measurement. Some stations are accessible remotely and can transmit in simulated voice or by electronic signal a stage reading, which can be translated manually to a discharge measurement by reference to the rating curve for the gauge. Only authorized personnel are permitted to access gauges remotely to both minimize maintenance cost associated with activating the instrumentation and to avoid busy telephone lines for use by authorized personnel. This is not an inconvenience to persons interested in these data as instantaneous reading could be obtained upon request by asking Delaware Geological Survey staff. Water-quality data are collected at some gauging stations. Only discharge data are collected at gauging stations in Delaware.

Stream gauges require regular maintenance since channel shifts from storms and sedimentation will alter the stage readings and thus give erroneous discharge measurements. Readings are not absolute but are subject to fluctuations due to tides, up-stream diversions, and other influences. These variations are routinely factored out to produce corrected discharge measurements.

In some instances, however, uncorrected discharge readings become more than a problem with the data simply being in error. One such problem occurred in 1995 when Marsh Creek Reservoir in Chester County, Pennsylvania, failed to make required water releases to the Brandywine Creek because its control gauge at Kennett Square was reading a higher flow than actual. Once this problem was detected, it was remedied minimizing the amount of deprived releases. Routine maintenance of this particular gauge was being neglected, and it is suspected that this

Figure 12
FIVE-YEAR HYDROGRAPH
OCTOBER 1, 1990, THROUGH SEPTEMBER 30, 1995



was at least partially due to government services cutbacks. Gauges in Delaware are supported in a cooperative program by both public and private contributors. While the program in Delaware is relatively strong, some stations have had to be discontinued for lack of available funds to keep them operational. Similar problems with gauge operation and maintenance should be expected as service and funding cutbacks continue.

Groundwater Resources

Companion to the surface discharge records, the U.S. Geological Survey also publishes data on groundwater levels in key observation wells throughout the state. Five of the twelve wells in the observation network are present in the Christina River basin, and all are within the lower Christina watershed, as shown on the Water Resources Data well location map in Figure 10. As with the surface gauging network, data are presented for the water year (see above for explanation), and each well has descriptions of location, hydrologic unit, station characteristics, remarks, and extremes of record. In addition, each well has a hydrograph plot of the previous five years of records. Figure 12 shows records for a representative water-table observation well. The U.S. Geological Survey does not routinely collect groundwater-quality data in the study area.

The Delaware Geological Survey also maintains a groundwater network similar to that of the U.S. Geological Survey using a different set of observation wells in the basin. These data are reported in the Summary of Water Conditions report on an as-needed basis. The last available report is shown in Figures 13 through 15. Only one well, Db24-10, a key water-table observation well, is located within the Christina basin, in the lower Christina watershed. The report also contains stream-flow data for Brandywine Creek (collected by the

U.S Geological Survey) and precipitation data (collected at the National Weather Service Observatory at the Greater Wilmington Airport). The Delaware Geological Survey also compiles more detailed data during droughts.

As noted, various hydrologic data originate from single sources but are frequently reported by various agencies using different formats depending on the purpose of the report. The single source of basic hydrologic data are weather data from the National Weather Service at the Greater Wilmington Airport. This is the source of official long-term normal temperature and precipitation records.

Other unofficial weather observatories exist within the basin at the City of Wilmington's Porter Reservoir off Concord Pike and at the University of Delaware's College of Agricultural Sciences in Newark, and at some casual observation sites maintained by private citizens.

The U.S. Geological Survey is the source of all streamflow data. Both the U.S. and the Delaware Geological Survey maintain separate but overlapping networks for groundwater data. See the references for special project reports on groundwater quality conducted by both agencies in the Christina basin.

All routinely collected surface- and groundwater-quality data in the basin are collected and reported by DNREC. The Department of Health and Social Services, Division of Public Health, also collects water-quality data from public water suppliers.

Water Systems

Northern New Castle County is reputed to be the most highly interconnected system of public water suppliers in the country. The degree of connection of the five major water suppliers resulted in great part from recommendations from the Water 2000 reports issued by the Water Resources Agency for New Castle County as the major outcome of the county's water-supply planning effort in the mid-1980s. It was recognized that until a major new water-supply facility could be constructed, the mutual reliability of the systems could be increased substantially by making provisions for both ongoing and emergency transfers of water among the utilities.

Two key principles enable these transfer projects to be successful. One is that even in a relatively small geographic area, none of the systems experiences peak demand situations simultaneously due to the unique characteristics of each system's customer and plant base. Therefore, excess pumping and treatment capacity is almost always available to permit sharing of supplies. Also, the advantage of conjunctive use of sources is made by exploiting a variety of different supplies. For instance, if one particular source, say groundwater, becomes unusable due to contamination or stream flows are low due to drought, alternate supplies available to the unaffected utilities can be used to back up the systems. Alternate supplies also include imported water from Pennsylvania via two interconnections with the Chester Water Authority, which draws its supply from the Susquehanna River. Backup supply from other river basins is a wise management approach given the low probability that water shortages would simultaneously affect two entire river basins. These transfer arrangements are patterned after the long-used practice of the electric utilities in their "grid" systems for peaking and emergency backup.

The increase in reliability of supplies provided by these transfer arrangements comes with several costs. First, customers pay a premium to have water imported or transferred between utilities within the state. This is not that such projects are inherently more expensive to construct than normal service-extension projects; they are not. Rather, the supplier providing the water usually imposes considerable surcharges for the privilege and requires minimum purchases. These costs are passed on to consumers. Second, transfers may be interrupted at the discretion of the supplier. Still, transfers are an effective way to increase supplies and are invaluable in emergency situations.

To date, 23 interconnections exist, with several new, smaller connections and expansions and a final major transmission line project between the City of Wilmington and United Water Delaware to be completed by 2000. Artesian Water Company is also pursuing and is expected to secure an extension and increase its transfer contract with Chester, now set to expire in 2002. At that point, virtually every practical transfer arrangement within the county would have been exploited, and the systems would be fully optimized. The remaining potential transfer project would then consist of large-scale importation from Pennsylvania. Such a project is under consideration as a county-wide option under the New Castle County Water Supply Plan, as described in "Positive Initiatives."

Because of the interconnections, however, it is neither a practicable nor a very straightforward task to determine water distribution or usage patterns on the basis of watersheds as defined in the study area. Interestingly enough, though, the service areas of the four utilities in the Christina River watershed do correspond to watershed drainages, which reflects the system engineering considerations for lifting water over major drainage divides. Map 15, of Public Water Service System Areas of New Castle County, shows the present arrangement of the utilities.

Wilmington occupies the Brandywine Creek and lower Christina River watersheds. Newark, Artesian, and United Water all occupy to some extent the upper Christina, while Artesian also has rights to the remainder of the White Clay Creek not controlled by Newark, and all of the Red Clay

Figure 13

DELAWARE GEOLOGICAL SURVEY SUMMARY OF WATER CONDITIONS IN DELAWARE FOR JULY, AUGUST, AND SEPTEMBER 1996

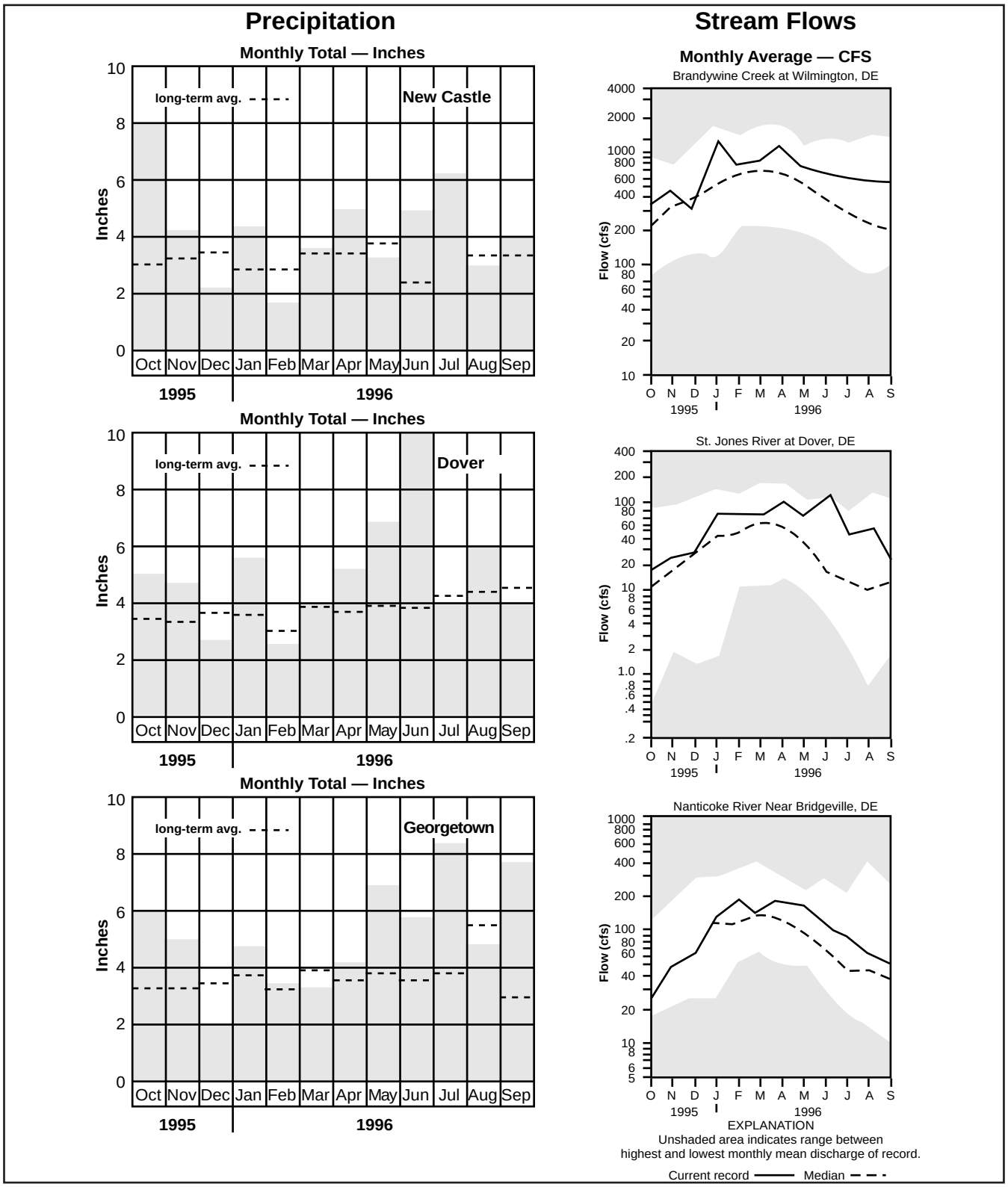


Figure 14
DELAWARE GEOLOGICAL SURVEY SUMMARY OF WATER CONDITIONS IN DELAWARE FOR JULY, AUGUST, AND SEPTEMBER 1996 — CONT'D.

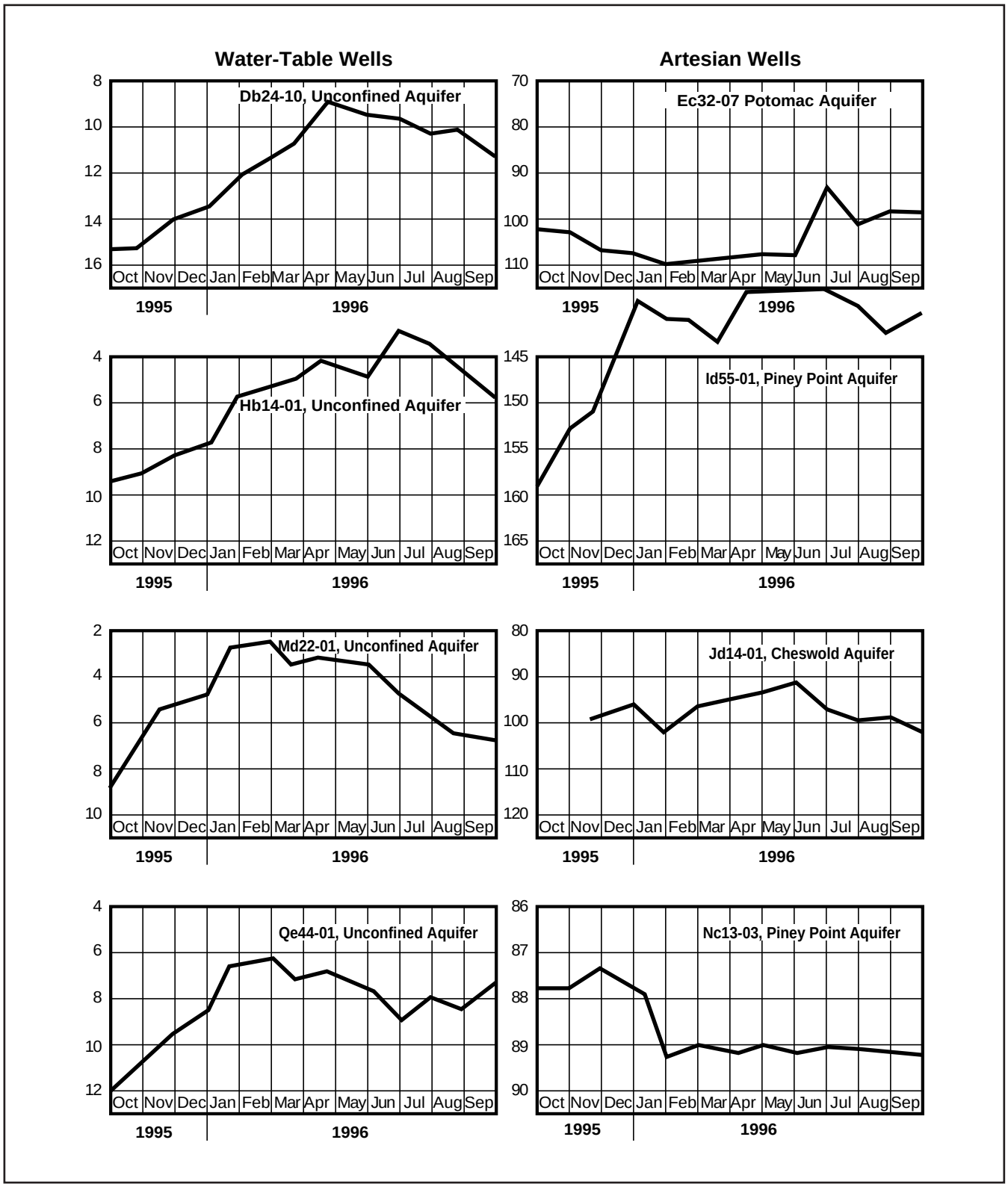
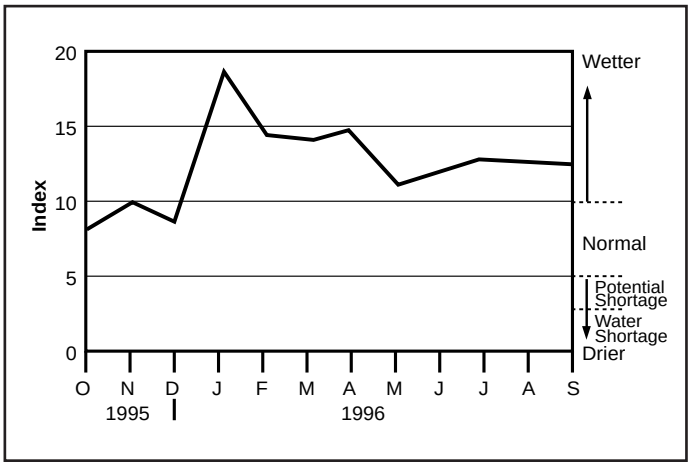


Figure 15
WATER CONDITIONS INDEX FOR
NEW CASTLE COUNTY



Water Conditions for July, August, and September 1996

Precipitation during July was generally above normal throughout Delaware with totals ranging from 8.32" (225% of normal) at Georgetown to 3.84" (93% of normal at Dover. August was somewhat drier than July with rainfall above normal at Dover, normal at New Castle, and slightly below normal at Georgetown. Precipitation was generally above normal during September with over 7" of rain at Georgetown. An exception was New Castle, where precipitation was slightly below normal.

Precipitation for the three-month period ranged from 20.77" (8.2" above normal) at Georgetown to 13.35" (2.29" above normal) at New Castle.

Precipitation for the 1995 – 1996 Water Year was significantly above average and much greater than during the 1994 – 1995 Water Year, with totals ranging from 65.13" (141% of normal) at Wilmington to 50.99" (125% of normal) at New Castle. For the 1994 – 1995 Water Year, precipitation was 36.05" at Wilmington and 31.25" at New Castle.

OCT 1, 1995 SEPT. 30, 1996	NEW CASTLE (NWS)	WILMINGTON (PORTER RES)	DOVER	BRIDGEVILLE-GREENWOOD	GEORGETOWN	LEWES
Total Precipitation	50.99"	65.13"	59.00"	54.68"	61.89"	56.44"
Normal Precipitation	40.84"	46.06"	44.14"	44.36"	43.79"	44.31"
Departure	+10.15	+19.07	+14.86"	+10.32"	+18.10"	+12.13"
Percent of Normal	125%	141%	134%	123%	141%	127%

Monthly mean stream flows were generally above normal during the reporting period and were significantly higher than those recorded during the corresponding period one year ago when drought conditions prevailed. Surface-water flows were more than adequate to meet public water-supply demands.

Although groundwater levels in three shallow water-table wells declined seasonally during the period, they remained in the normal to above normal range for this time of the year. Water levels exhibited a rise in well Qe44-10 near Trap Pond and a record high water level was established in September.

Water levels in the deeper artesian observation wells exhibited little change during July, August, and September. Water levels during September 1996 were approximately 23 ft. higher than during the corresponding period a year earlier.

The Water Conditions Index for New Castle County changed very little and remained in the lower end of the "wetter" range during the reporting period. Overall, water-supply conditions are very good to excellent for this time of the year.

Source: Delaware Geological Survey. *Summary of Water Conditions in Delaware for July, August, and September 1996.*

Creek. United Water Delaware controls the Naamans and Shellpot Creek basins. Curiously, United Water Delaware serves no customers within miles of its main Stanton Treatment Plant; instead Artesian has the service rights.

This illustrates a point regarding service territories and rights of service. A utility franchise denotes only the authority to serve, not the right to withdraw water. Other users can withdraw within other service areas. Another point is that *service area* does not automatically equate with *service provision*. Large tracts of land in some of the utilities' service areas do not have water service extended there, and water is provided by private wells. Utilities often exercise "first right of refusal" so that customers cannot force extension of service that would be an operating loss for the utilities. This is the case with the City of Wilmington's area in the Greenville vicinity and Artesian's area in the southwestern portion of the county. When sufficient demand exists in those areas to make service extension economical, it will be provided. By the same token, when service is extended, existing private wells are not normally required to hook up to the public system, and owners can retain full or partial usage of their system through negotiation with the utility and via permit from DNREC.

The City of Wilmington system is fully self-sufficient and feeds within its corporate limits and some adjacent areas. The City of Newark draws on supplies primarily within its corporate boundary but relies on steady transfers from United Water Delaware, a private utility, to meet demand. The cities' systems are not expected to undergo any significant growth in the foreseeable future, and may, in fact, decline.

Wilmington is expected to become a larger water exporter, however, when the transfer project with United Water Delaware is completed. Although not in the basin, the City of New Castle Board of Water and Light Commissioners transfers a small amount of water into the basin.

The private, investor-owned utilities of Artesian Water and United Water Delaware will absorb the majority of demand increases due primarily to residential housing for the next several decades in addition to some incremental commercial demand with an unknown measure of increasingly aggressive marketing to expand their water service.

Acquisition of whole or parts of public utilities by the investor-owned companies is not out of the question within the next 10 or so years as municipal systems continue to struggle to maintain operations under restrictive budgets, aging customer bases, and business flight. This has already occurred in southern New Castle County and in nearby Chester County, Pennsylvania.

Water Usage

Quantities and proportions of these various sources of supply for public water are shown in Table 16.

Tables 17 through 23 give breakdowns by utility on current and projected water usage. Again, all categories of usage are expected to remain flat or decrease slightly for the planning period with the exception of residential supply. Numerous tables are available from the New Castle County Water Supply Plan study reports giving extensive detail on usage projections, facility capacities, and other water-supply data.

In addition, Tables 24 through 28 provide a breakdown of major freshwater uses within the public suppliers' service areas and include basic information consisting of owner, location, water source (aquifer or stream), facility capacity, and withdrawal allocation limits. Excluded are the cooling water intakes of the large industries along the Delaware River. Some facilities outside of the basin are included also, owing to the categorizing of the information by utility.

While accurate at the time of compilation, the lists may not be complete or accurate at any given time due to continuous changes in the systems. Also, actual usage varies and will typically be less than the listed permit limits. Wells, in particular, are taken in and out of service regularly, or are abandoned and sometimes replaced by new facilities. A committee called the Resource Protection Area Technical Advisory Committee — consisting of DNREC and New Castle County agencies and other advisors — was created, in part, to track new wells designated by the EPA as "Community Water Systems." The DNREC Water Supply Section (phone: 302-739-4793), the Water Resources Agency for New Castle County (phone: 302-831-4925), and system owners must be consulted for current information on water-supply system facilities and water-use data. Information on drinking water quality for the public supplies is available from the Division of Public Health, Office of Drinking Water (phone: 302-739-5410).

As noted earlier, under certain critical conditions, naturally available water supply in the Delaware portion of the Christina River basin cannot meet demand. New sources of supply will be required at some time in the future in order to meet normal demands. During droughts, naturally available supply is much less than demand. Various projects are under development or evaluation in order to increase conservation and water-use efficiency and to provide for additional supply.

Water-Supply Regulation

Regulation of all water facilities and water withdrawals is administered by DNREC, and by the Delaware River Basin Commission (for withdrawals in excess of 1 million gallons per day, averaged over 30 days). Regulation is provided through the Well Construction and Water Allocation programs in DNREC and through DNREC's administrative agreement with the Delaware River Basin Commission.

Table 16

SOURCES OF PUBLIC WATER SUPPLY

	SURFACE WATER	GROUNDWATER	IMPORTS	TOTAL
STATE	50 MGD (54%)	40 MGD (43%)	3 MGD (3%)	93 MGD
NCC	50 MGD (68%)	20 MGD (27%)	3 MGD (4%)	73 MGD
N. NCC	50 MGD (69%)	19 MGD (26%)	3 MGD (4%)	72 MGD

The systems are regulated in terms of maximum daily, monthly, and yearly withdrawal. For groundwater withdrawals from confined aquifers, a maximum allowable draw-down limit is stipulated for each well to prevent groundwater mining. As described earlier, regulations are being developed to provide for additional, needed protection of in-stream flow, and this will apply to all stream withdrawals in the area. Permittees are required to submit water usage reports annually — or more often, at DNREC's request — and must prove compliance with the operational limits.

An important component of these regulations concerns water conservation and drought emergency plans, which the suppliers must implement and update regularly. As a result of these planning efforts, the utilities and other systems operate at a generally much higher efficiency than comparable systems in the area and are well prepared for drought response. A good indication of system efficiency is conveyance loss or leakage, usually expressed as a ratio of production to sales. The difference from 100% is termed *unaccounted for usage*. The majority of unaccounted for usage is leakage. This is a major problem for older systems, in particular, where leakage can approach 40% of production or more. The overall leakage rate for the county's public water systems varies between 10% and 12%, which is considered "tight" and as efficient as practical under current water utility economics.

As seen in Table 29, there are 140 individual supply facilities in the study area with a combined capacity from ground- and surface-water sources of 130 million gallons per day. Surface-water sources are known to be over-allocated since naturally available supply is inadequate to meet prevailing demand at all times. Groundwater sources are at virtually full development, but evaluation of monitoring data and actual production records indicate that withdrawals are within a "safe," sustainable level and have not been overdrafted.

Table 17
ARTESIAN WATER COMPANY
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY[1] (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	20.55	16.60	0.00	0.00	16.60	-3.95
1995	21.38	16.60	0.00	6.00	22.60	1.22
2000	22.14	16.60	0.00	6.00	22.60	0.46
2005	22.84	16.60	0.00	0.00	16.60	-6.24
2010	23.69	16.60	0.00	0.00	16.60	-7.09
2020	24.90	16.60	0.00	0.00	16.60	-8.30
2030	26.33	16.60	0.00	0.00	16.60	-9.73
2040	27.67	16.60	0.00	0.00	16.60	-11.07

[1]*Includes DNREC allocations and pending allocations.*
Source: Metcalf & Eddy, 1991.

Table 18
WILMINGTON SUBURBAN WATER CORPORATION
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	DNREC ALLOCATION MAXIMUM DAILY GROUNDWATER PRODUCTION CAPACITY (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY[1] (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	26.93	0.00	36.00	2.00	38.00	11.07
1995	26.80	0.00	36.00	2.00	38.00	11.20
2000	27.07	0.00	36.00	2.00	38.00	10.93
2005	27.30	0.00	36.00	2.00	38.00	10.70
2010	27.42	0.00	36.00	2.00	38.00	10.58
2020	28.81	0.00	36.00	2.00	38.00	9.19
2030	30.00	0.00	36.00	2.00	38.00	8.00
2040	31.15	0.00	36.00	0.00	36.00	4.85

[1]*Total combined surface- and groundwater treatment capacity. Assumes the existence of adequate raw water supply.*
Source: Metcalf & Eddy, 1991.

Table 19
CITY OF WILMINGTON
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY[1] (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	35.76	0.00	50.00	0.00	50.00	14.24
1995	33.41	0.00	50.00	0.00	50.00	16.59
2000	34.24	0.00	50.00	0.00	50.00	15.76
2005	31.65	0.00	50.00	0.00	50.00	18.35
2010	31.18	0.00	50.00	0.00	50.00	18.82
2020	31.95	0.00	50.00	0.00	50.00	18.05
2030	32.35	0.00	50.00	0.00	50.00	17.65
2040	32.76	0.00	50.00	0.00	50.00	17.24

[1]*Total combined surface and groundwater treatment capacity. Assumes the existence of adequate raw water supply.*
Source: Metcalf & Eddy, 1991.

Table 20
CITY OF NEWARK
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY[1] (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY[2] (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	5.79	4.80	0.00	0.00	4.80	-0.99
1995	5.32	4.80	3.00	0.00	6.00	0.68
2000	5.12	4.80	4.00	0.00	7.00	1. 88
2005	4.94	4.80	5.00	0.00	8.00	3.06
2010	4.80	4.80	5.00	0.00	8.00	3.20
2020	4.96	4.80	5.00	0.00	8.00	3.04
2030	5.06	4.80	5.00	0.00	8.00	2.94
2040	5.16	4.80	5.00	0.00	8.00	2.84

[1]*DNREC allocation for maximum daily withdrawal.*
[2]*Total combined surface and groundwater treatment capacity. Assumes the existence of adequate raw water supply. Some groundwater must be treated at a treatment plant.*
Source: Metcalf & Eddy, 1991.

Table 21
NEW CASTLE BOARD OF WATER AND LIGHT
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY[1] (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	0.83	1.67	0.00	0.00	1.67	0.84
1995	0.85	1.67	0.00	0.00	1.67	0.82
2000	0.85	1.67	0.00	0.00	1.67	0.82
2005	0.85	1.67	0.00	0.00	1.67	0.82
2010	0.86	1.67	0.00	0.00	1.67	0.81
2020	0.90	1.67	0.00	0.00	1.67	0.77
2030	0.95	1.67	0.00	0.00	1.67	0 72
2040	0.99	1.67	0.00	0.00	1.67	0.68

[1]*DNREC allocation for maximum daily withdrawal.*
Source: Metcalf & Eddy, 1991.

Table 22
SELF-SUPPLIED SYSTEMS NORTH OF THE C&D CANAL
WATER SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	ESTIMATED 1988 MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	18.86	18.74	0.00	0.00	18.74	-0.12
1995	18.95	18.74	0.00	0.00	18.74	-0.21
2000	19.11	18.74	0.00	0.00	18.74	-0.37
2005	19.31	18.74	0.00	0.00	18.74	-0.57
2010	19.64	18.74	0.00	0.00	18.74	-0.90
2020	20.21	18.74	0.00	0.00	18.74	-1.47
2030	20.78	18.74	0.00	0.00	18.74	-2.04
2040	21.35	18.74	0.00	0.00	18.74	-2.61

Source: Metcalf & Eddy, 1991.

Table 23
NEW CASTLE COUNTY NORTH OF C&D CANAL
WATER-SUPPLY FACILITIES SURPLUS/DEFICIT

YEAR	PROJECTED MAXIMUM DAILY DEMAND (MGD)	MAXIMUM DAILY DEVELOPED GROUNDWATER PRODUCTION CAPACITY[1] (MGD)	SURFACE-WATER PRODUCTION CAPACITY (MGD)	IMPORTED WATER FROM OUT OF COUNTY (MGD)	TOTAL MAXIMUM DAILY PRODUCTION CAPACITY[2] (MGD)	WATER SUPPLY FACILITIES SURPLUS/ DEFICIT (–) (MGD)
1990	109.08	42.16	86.00	2.00	130.16	21.08
1995	107.09	42.16	89.00	6.00	135.36	28.27
2000	107.13	42.16	91.00	6.00	137.36	30.23
2005	107.25	42.16	91.00	2.00	133.36	26.11
2010	107.95	42.16	91.00	2.00	133.36	25.41
2020	112.09	42.16	91.00	2.00	133.36	21.27
2030	115.83	42.16	91.00	2.00	133.36	17.53
2040	119.47	42.16	91.00	0.00	131.36	11.89

[1] *Includes DNREC allocations and pending allocations for public purveyors and estimated 1988 withdrawals for self-supplied water users.*
[2] *Total combined surface and groundwater treatment capacity. Assumes the existence of adequate raw water supply. Some groundwater must be treated at a treatment plant.*
Source: Metcalf & Eddy, 1991.

Table 24
1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	LOCATION	BASE SOURCE	FACILITY SOURCE	Facility Source Pumping Capacity		DNREC Allocation Mil. Gal. Per	
				GPM	MGD	DAY	MONTH
(AWC cont.)							
INDUSTRIAL							
Crown Advanced Films•	New Castle	Potomac	2 Wells	720	0.20	0.20	6.00
E. I. du Pont	Glasgow Site	Columbia**	3 Wells	330	0.42	0.42	12.70
NVF	Yorklyn	Red Clay Creek	2 Intakes	4490	3.50	3.50	96.00*
Hercules Inc.	Wooddale	Wissahickon	14 Wells	453	0.55	0.55	14.00
Hercules Research Cent.	Wooddale	Red Clay Creek	1 Intake	625	0.90	0.90	22.00*
Army Creek Landfill• *(Recovery Wells)*	New Castle	Upper Potomac	15 Wells	2,500	3.60	0.00	0.00
RECREATIONAL							
Hercules Country Club	Wooddale	Red Clay Creek	1 Intake	350	0.50	0.50	5.00*
Delcastle Golf Club	McKennans Church Road	Pond #2	1 Intake	750	0.26	0.26	5.20
		Wissahickon	1 Well	50	0.07	0.07	1.50
Three Little Bakers CC	Wilmington	Pond #1	1 Intake	1,000	0.24	0.24	7.20
Cavalier's Country Club	Newark	Pond #1	1 Intake	1,000	0.59	0.59	8.15*
		Christina River	1 Intake	400	—	(combined total)	
Samuel Beard	Wilmington	Red Clay Creek	1 Intake	100	0.03	0.03	0.93
			Subtotal	**23,293**	**22.93**	**19.02**	**573.30**

•*Out of Basin*
**Water Table Aquifer*

Table 25

1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	LOCATION	BASE SOURCE	FACILITY SOURCE	Facility Source Pumping Capacity GPM	Facility Source Pumping Capacity MGD	DNREC Allocation Mil. Gal. Per DAY	DNREC Allocation Mil. Gal. Per MONTH
Artesian Water Co.							
PUBLIC							
	Airport Industrial Park•	Potomac	2 Wells	400	0.49	0.72	21.60
	Artisan Village•	Upper Potomac	3 Wells	2,110	3.02	3.02	90.72
	Caravel Farms	Potomac	1 Well	200	0.25	0.29	8.64
	Castle Hills•	Upper Potomac	3 Wells	800	0.98	1.37	42.41
	Collins Pk.	Potomac	1 Well	300	0.46	0.46	12.96
	Fairwinds•	Upper Potomac	4 Wells	1,100	1.35	2.00	60.00
	Glendale	Columbia**	2 Wells	450	0.62	0.50	15.00
		Upper Potomac	3 Wells	900	0.94	1.30	39.03
	Hockessin	Cockeysville	6 Wells	1,800	2.20	1.90	100.00
	Jefferson Farms•	Upper Potomac	2 Wells	700	0.79	1.30	38.88
	Llangollen Ests.•	Upper Potomac	5 Wells	1,400	1.55	2.00	60.00
	Midvale•	Potomac	2 Wells	300	0.30	0.58	17.28
	Old County Road	Potomac	2 Wells	1,700	2.45	2.45	69.00
	Wilmington Airport	Lower Potomac	3 Wells	525	0.43	0.86	25.92
	Wilm. Manor Gardens•	Columbia**	2 Wells	450	0.55	0.49	15.25
			Subtotal	**13,135**	**16.38**	**19.24**	**616.69**

****Water Table Aquifer.** *Source:* DNREC, 1997.
•Out of Basin.

Table 26

1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	LOCATION	BASE SOURCE	FACILITY SOURCE	Facility Source Pumping Capacity GPM	Facility Source Pumping Capacity MGD	DNREC Allocation Mil. Gal. Per DAY	DNREC Allocation Mil. Gal. Per MONTH
United Water Delaware							
PUBLIC							
North Service Area	Red & White Clay Creeks	Red & White Clay Creeks	Stanton WTP	20,835	30.00	pending	
River Road System	Smalley's Pond (Christina River)	Christina River	Christina WTP	4,165	6.00	pending	
INDUSTRIAL							
Standard Chlorine•	Red Lion	Columbia**	5 Wells (1)	240	0.35	0.36	10.80
Star Enterprise•	Delaware City	Columbia**	4 Wells (1)	200	0.22	0.22	6.48
		Holocene**	Inter. Trench	400	0.10	0.10	3.00
		Lower Potomac	8 Wells	5,000	6.00	6.00	180.00
		Potomac	1 Well			(combined total)	
		Red Lion Creek	1 Intake	900	1.30	1.30	38.90
		Dragon Run	1 Intake	1,300	1.87	1.87	56.20
ICI Americas•	New Castle	Lower Potomac	1 Well	500	0.61	3.92	60.00
		Colum./M. Potomac	4 Wells	2,225	2.71	Note: Total DNREC allocation	
IRRIGATION							
Marvin Hershberger	Smalley's Pond Headwaters	Christina River	1 Intake	60	0.02	0.02	0.35
			Subtotal	**35,825**	**49.17**	**13.79**	**355.73**

***Listed under Middle Potomac in Summary Table.**
****Water Table Aquifer. (1) Extraction Well.**
•Out of Basin.

Table 27
1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	LOCATION	BASE SOURCE	FACILITY SOURCE	Facility Source Pumping Capacity GPM	Facility Source Pumping Capacity MGD	DNREC Allocation Mil. Gal. Per DAY	DNREC Allocation Mil. Gal. Per MONTH
City of Wilmington							
PUBLIC							
	Brandywine WTP	Brandywine Creek	Brandywine P.S.	13,890	20.00	pending	
	Porter WTP	Brandywine Creek	Wills P.S.	16,670	24.00		
INDUSTRIAL							
Wilmington Finishing	Wilmington	Brandywine Creek	Intake #1 & #2	3,600	1.00	1.00	25.00
RECREATIONAL							
Dupont Country Club	Wilmington	Brandywine Trib.	1 Intake	550	0.36	0.36	11.00*
		Brandywine Creek	1 Intake	250	0.36	0.36	11.00*
Ed Oliver Country Club	Wilmington	Pond #1	1 Intake	1,250	0.45	0.45	8.00*
Wilmington Country Club	Kennett Pike	Brandywine Trib.	1 Intake	1,800	1.30	1.30	24.40
		Brandywine Trib.	1 Intake	300	0.43	(combined total)	
		Wissahickon	3 Wells	200	0.14	0.14	4.32
		Brandywine Trib.	1 Intake	50		(combined total)	
		Wissahickon	2 Wells	100	0.14	0.14	1.20
Brandywine Country Club	Shipley Road	Pond #1	1 Intake	500	0.51	0.51	7.00*
		Wilmington Comp.	1 Well	200	0.15	0.15	2.00*
			Subtotal	**39,360**	**48.84**	**4.41**	**93.92**

(1) Inactive

Table 28
1997 EXISTING WATER SUPPLY SOURCES BY WATER PURVEYOR SERVICE AREA

PURVEYOR	LOCATION	BASE SOURCE	FACILITY SOURCE	Facility Source Pumping Capacity GPM	Facility Source Pumping Capacity MGD	DNREC Allocation Mil. Gal. Per DAY	DNREC Allocation Mil. Gal. Per MONTH
City of Newark							
PUBLIC							
North	Academy St.		2 Wells	0	0.00	pending	
South	S. Chapel St.	Columbia**	6 Wells	1,000	1.30	1.60	47.70
		Potomac	4 Wells	950	0.90	1.40	41.00
Laird Tract	Creek Rd.	Wissahickon	2 Wells***	0	0.00	1.80	54.00
INDUSTRIAL							
Curtis Paper (1)	Newark	White Clay Creek	1 Intake		1.00	pending	
NVF	Newark	White Clay Creek	1 Intake	4,500	1.50	1.50	35.00*
E. I. du Pont	Louviers	White Clay Creek	1 Intake		0.29	pending	
RECREATIONAL							
Dupont Country Club	Louviers Golf Course	White Clay Creek	1 Intake	700	0.23	0.23	6.75*
			Subtotal	**7,150**	**5.22**	**6.53**	**184.45**

***Water Table Aquifer.*
****Out of Service.*
(1) Capacity based on reported maximum month.

The combined facility pumping-capacity is sufficient for future water supply needs. Overall water availability, however, is inadequate during times of high demand and low flow. Accordingly, DNREC will not issue new major allocations of either groundwater or surface water in the area without the addition of supplemental supply.

Trends

Water-supply protection is being given increasing attention as evidenced by the establishment of recharge and wellhead protection areas instituted by county ordinance. The protection area ordinance for recharge is an "overlay" zoning that specifies minimum lot sizes and maximum amounts of impervious surface in high-potential aquifer recharge areas. This helps allow for essential replenishment of groundwater supplies that are impacted by dense residential zoning and construction of paved surfaces. The wellhead protection areas are, likewise, overlay zoning measures; however, it must be noted that the wellhead protection areas do not regulate pre-existing conditions.

The ordinance provides no means to require remediation of known contamination in those areas. For instance, the City of Newark has contaminated wells within delineated wellhead protection areas. The Newark South Wellfield, in fact, is a classic example of the potential efficacy of wellhead protection. In the years following the development of the wellfield, the predominant zoning in the area (manufacturing and commercial) allowed development incompatible with the resource and eventually the wellfield became contaminated. With the installation of new wells, however, the potential source of contamination would be regulated to protect supplies. The protection areas are designated on the Water Resource Protection Area Map. (See Map 5.)

Other trends are toward the installation of high-efficiency plumbing fixtures and implementation of other water conservation measures. The statewide uniform plumbing code was, in fact, amended in 1991 and now specifies the installation of fixtures having specific flow rates that are considered conserving, as opposed to previous code standards that allowed considerably higher flows. Initial concerns from plumbing interests — such as inadequate drain-line carry and retrofitting to old waste systems — were unfounded. Some water managers expressed concern that disruption of the waste treatment process would occur due to insufficient flow; this problem did not materialize either.

One meritorious concern that has been expressed is the increased "tightening" or "hardening" of demand that results from making water use more efficient. To some degree, this concern is legitimate since less water will be available to save during a water shortage as the percentage of dwelling units and businesses with new standard plumbing will steadily increase over time. If the expectation is that large-demand savings can always be relied upon during drought times based on past experience — for instance the 25% demand reductions achieved during the 1995 drought — that water may not be available to "save," possibly leading to drought management problems. On the other hand, that argument must be rebutted by saying that water should not be wasted so that it can be saved during droughts. The eventual solution is to provide additional backup water supplies and to institute appropriate drought management measures as needed, with more emphasis on innovative approaches.

There are a variety of ongoing projects that are being implemented in the interest of enhancing water supply. To name a few, the aging diversion structures on the Brandywine and White Clay creeks could benefit from renovation to provide for better control of the diversion and reduce leakage losses. The Curtis Treatment Plant in

Table 29
FACILITY INFORMATION PER WATER SUPPLY SOURCE AND ACCOMPANYING ALLOCATED WITHDRAWALS

BASE SOURCE	FACILITY SOURCE	CAPACITY		ALLOCATION	
		GPM	MGD	MGD	MG/30
GROUNDWATER					
Piedmont					
Wissahickon Fm. + *Wilm. Complex.*	27 Wells	1,183	1.05	3.11	84.00
Cockeysville Fm.	6 Wells	1,800	2.20	1.90	100.00
Subtotal	29 Wells	2,983	3.25	5.01	184.00
Atlantic Coastal Plain					
Columbia Fm.	22 Wells	2,670	3.46	3.10	92.96
Potomac Fm.	52 Wells	21,140	22.71	24.81	678.93
Subtotal	83 Wells	25,967	27.28	29.02	804.73
GROUND TOTAL	**116 Wells**	**28,950**	**30.53**	**34.03**	**988.73**
SURFACE WATER					
Brandywine Creek	10 Intakes	37,860	53.90	53.90*	1,617.00*
Red Clay Creek	5 Intakes	5,565	4.93	4.93	147.90
White Clay Creek	6 Intakes	26,035	35.02	35.02	1,050.60
Christina River	4 Intakes	5,625	6.61	6.61	8.50
Impoundments	4 Intakes	3,500	1.46	1.46	27.40
SURFACE TOTAL	**24 Intakes**	**78,585**	**99.92**	**101.92**	**2,827.43**

**City of Wilmington unpermitted withdrawals included — capacity 44 MGD.*

Newark was completed in 1992; however, it incorporated the existing diversion works, raceway, and settling lagoons used by the Curtis Paper Company, installed in the late 19th century. The Wilmington Raceway is a registered historic structure, which may preclude renovation efforts that would alter its appearance.

One intriguing area of research in the water-supply industry is in the application of Artificial Storage and Recovery (or ASR, as it is commonly known). Simple in concept but complex in application, a suitable source of excess water is treated and injected into suitable aquifer systems, usually for withdrawal at a later time during high-demand periods. The technique can, however, be applied to meet a variety of resource management objectives, including to repel salt-water intrusion or other contamination of aquifers, or to provide an emergency water supply. A proposal to use this technology in a unique way has been offered by DNREC to implement a very large-scale application as a single source of future water supply for the entire county. Small-scale variations of this concept have been suggested as well.

Before any aquifer recharge project can be established as a reliable supply, extensive geological and hydrochemical test programs have to be performed. Installation of the infrastructure is relatively conventional. Opinions expressed by various experts in the field about the potential for a successful large-scale application of aquifer recharge range from doubtful to very optimistic. Only research and pilot studies will prove who is right. These studies will be undertaken in both the private sector and by DNREC over the next few years.

Innovative research by the University of Delaware has been conducted in the area of demand-side management. Three years of study on the effectiveness of pricing controls on the customers of Artesian Water Company revealed that customers, contrary to conventional thought, were highly sensitive to price increases and reduced demand in response to price increases by approximately twice as much as was presumed based on the results of other rate-impact studies.

In 1992, the Water Resources Commission of New Castle County was required by the General Assembly to investigate the feasibility and encourage the adoption of conservation-oriented water-rate structures for the utilities it regulates. This resulted in approval of a true conservation rate structure that was adopted by Artesian Water Company. However, the effort falls short since municipal suppliers — who provide most public water — remain unaffected, and only Artesian has a true conservation rate structure among the private utilities. There is no incentive for the utilities to continue to advance its usage.

Sources of Impact

Drought

New Castle County is a metropolitan-suburban area experiencing continued population growth and faced with contamination problems and periodic shortages of water supply during droughts. The area's water systems are not reliable in terms of adequate supply. This was brought into sharp focus in the Drought of 1995. For all of its inconveniences to the public and industry, the drought forced a firsthand look at the associated impacts and sharpened focus on the need to deal with water supply issues.

At the height of the drought, water quality had deteriorated to the point that it was estimated that 40% of the water in Brandywine Creek was composed of treated sewage effluent. The Water Quality Standards were waived. The effluent in the Brandywine originated in Pennsylvania and while it did help provide for augmented flow in the stream, it also made treatment for drinking water difficult. The City of Wilmington's water intakes were not built to operate at the low stream levels that occurred, and the intakes became partially inoperable. Fortunately, no primary drinking water violations were reported in the city's system; however, this was in great part due to the substantial use of Hoopes Reservoir water.

The situation at United Water Delaware's Stanton and Christina Treatment plants was also very problematic. High levels of chlorides and sodium were entering the distribution system due to excursion of brackish water from the Delaware River during low tide. The company issued a public health advisory for persons with diagnosed hypertension to consume bottled water. Certain industries also curtailed or ceased purchase of United's water due to the high dissolved solids content, which was incompatible with their processes.

The affected industries were able to continue operations only by activating idle sources of self-supplied water such as unused wells and by making dramatic improvements in water-use efficiency. (United continues to experience depressed industrial sales, which is believed to be the effect of residual conservation efforts by its large industrial customers.)

The groundwater-supplied utilities fared better in terms of both quality and quantity problems, with no unusual cases reported. While some additional groundwater supply was available during the drought, it was produced by the temporary waiving of draw-down limits. Since recovery from the drought, no impact to the groundwater system has been experienced by the temporary overdrafts.

The impact to the stream habitat was able to be investigated in some detail coincidental to the height of the drought. Biological studies consisting of fish species surveys and habitat evaluations that were already planned

before the drought by the Joint Task Force on In-Stream Flow Needs were conducted in late summer. These studies revealed that certain sections of the supply streams in the vicinity of the withdrawals were impacted in terms of insufficient depth, velocity, and dissolved oxygen. Withdrawals were essentially 100% of naturally available flow at the time. Comparison of the measured depths and velocities to habitat criteria for certain key fish species indicated that the habitat was definitely impacted, but the extent is still not known in the absence of any direct evidence such as fish kills. The best assessment of the amount of permanent damage to the ecosystem from the drought is that remarkably little occurred. This likely was the result of the drought having a relatively short serious period followed immediately by a strong recovery.

Arguably, the most severe impact from the drought was on human populations. Even with the successful management of the drought through conservation efforts from citizens and businesses, the economic impacts were substantial. Hard numbers on the economic losses due to the drought are not available. One golf course did, however, report turf damage repairs on the order of $50,000. Many landscaping companies laid off all laborers and went out of business for the season due to restrictions on watering. It is not unreasonable to assume that millions of dollars in lost business revenue in the "green industry," as well as private landscaping investments, were incurred due to the drought.

Contamination of Drinking Water Supplies

Aside from drought impacts, which are transient, other more frequent impacts on water supplies exist and are due to natural and man-made contaminants. Ultimately, this becomes a cost pass-down to the consumer.

Occasionally, contamination of water supplies represents a total, permanent *loss* of water supply. Other contaminants can be treated so the supply is not lost. One type of contamination not usually recognized as such but representing a major operating expense for the utility is highly turbid water that results from sediment-loading from erosional runoff. Highly turbid water carries organic matter in both the water column and adsorbed to sediment. In the disinfection process, organics or fine sediment containing organics that are not filtered react with the chlorine-based disinfectants commonly used in the water industry. These reactions produce toxic by-products in a class of compounds called trihalomethanes. More stringent regulatory requirements have reduced the allowable concentrations of these disinfection by-products and thus have necessitated changes in treatment processes. Treatment plant upgrades to comply with the more stringent rules for disinfection by-products have been in the multi-millions of dollars for the region's water utilities.

Spills represent a particular danger for utilities drawing on surface water. To prevent interception of contaminants in the streams after a spill, an emergency response network has been established throughout the basin. Numerous minor spills have occurred, affecting public water-supply systems. Some contaminants have been inadvertently drawn into the distribution systems, but with no known health effects due to rapid dilution in the distribution system. So far, the streams have purged themselves quickly of these spills, and service disruption has not been experienced. A major persistent spill of any particularly dangerous compound has not yet occurred, but is recognized as an event that would seriously cripple major portions of the area's water service.

Sodium chloride from road salting is a chronic and occasionally acute contaminant problem in the area. Alternatives to sodium chloride exist, but efforts to change to these alternatives have not been successful because of the cost issue even though the problem has caused the shutdown of the United Water Delaware water treatment plant at Smalley's Pond on the Christina River on several occasions.

Other contaminants particularly in the groundwater have also required advanced treatment, which again represents a cost for utilities and, ultimately, consumers. Some of these occurrences are from synthetic organic contaminants while others are elevated concentrations of dissolved solids in the raw water, usually iron and manganese. As marginal sources are brought into production and treatment processes have to be upgraded, the costs for public water will continue to rise. For more information, please see Maps 4, 5, 6, 14, and 15.

Positive Initiatives

Water Supply Plan for New Castle County, "Churchmans Marsh EIS"

Integrated Resources Planning has not yet been utilized for planning future water supplies. In fairness, Integrated Resources Planning methods were not in wide use when previous studies of future water supply were undertaken. Still, no matter the type of planning method used, the first and most fundamental element of any supply planning effort is the definition of future needs. Several studies going back as early as the 1950s resulted in recommendations for a new, large reservoir for the county. These proposals never materialized for a variety of institutional and regulatory reasons, with one of the main objections being that the reservoir was sized to meet a need that would not arise until far into the future and thus would be very costly to build.

Nonetheless, the need for additional supply has long been recognized by water resources officials and the problem remained largely unaddressed. With support from the state and the county water utilities, the Water Resources

Agency for New Castle County produced its ten-volume series of reports entitled *Water 2000* as a road map for securing future water supply. The study's major recommendation was the construction of a two-billion-gallon reservoir at Churchmans Marsh. DNREC subsequently adopted the *Water 2000* study as part of the state's water plan in 1985 followed by adoption into the comprehensive plan of the Delaware River Basin Commission later that year.

Thompson's Station Reservoir was selected as a secondary alternative since indications were given by DNREC that the wetlands issues associated with Churchmans Marsh were considerable and the project would have to overcome significant hurdles to receive approval. Reservoir projects in the Piedmont that had been proposed in the past also met with objection. The leading contender prior to the *Water 2000* report was a reservoir known as the "Newark Project." It was conceived as a four-billion-gallon reservoir on the main stem of White Clay Creek just north of Newark. The impoundment would have inundated several thousand acres of land, forming a pool extending into Pennsylvania. By the time *Water 2000* was issued, land that would have been inundated had begun being denoted to the state for dedicated open space as part of what is now White Clay Creek State Park and the Bi-State Preserve. Also, a review of previous demand projections for the "Newark Project" found they were over-estimated and such a large facility was unnecessary. Accordingly, the "Newark Project" was permanently dropped from the state's water plan in 1984 concurrent with the adoption of the Churchmans Marsh and Thompsons Station projects.

Since the proposed primary project was a reservoir and would be located in wetlands, the regulatory requirements of the National Environmental Policy Act of 1974 had to be addressed — involving the preparation of an Environmental Impact Statement. The U.S Army Corps of Engineers is the federal agency responsible for conducting an Environmental Impact Statement (EIS), and the Corps of Engineers coordinates the study along with the project applicant and the involved federal review agencies: the U.S. Environmental Protection Agency; the U.S. Fish and Wildlife Service; and the National Marine Fisheries Service of the National Oceanographic and Atmospheric Administration.

With the need established to conduct a formal Environmental Impact Statement, a voting Project Management Committee was formed, consisting of Artesian Water Company; Wilmington Suburban Water Corporation (now United Water Delaware); and New Castle County; and the Delaware Department of Finance, Delaware Economic Development Office, and DNREC (all represented by one vote). In 1995, the City of Newark joined, as the fifth voting member, and became the project sponsor. A Public Advisory Group and Technical Coordinating Committee were created as well, to provide for early public input into the process.

To engage the federal review process, an application was submitted in 1988 by New Castle County to the Corps of Engineers for a Clean Water Act, Section 401 permit for construction of a reservoir in Churchmans Marsh — concurrent with application to DNREC for an accompanying ("tidal") wetlands permit and subaqueous lands permit. These applications prompted the Corps of Engineers to require that an Environmental Impact Study be conducted to fulfill federal requirements. Such a study, when completed, becomes a U.S. Army Corps of Engineers document. The Project Management Committee contracted with a consultant to perform the supply-and-demand analysis, with the intent of leading into the preparation of an Environmental Impact Statement. Formal study began in 1989.

The consultant then started winnowing through the list of alternatives also evaluated in *Water 2000*, including 68 separate projects and 38 combination projects. In the intervening seven years, the study has slowly progressed with elimination of most proposed projects to enable detailed analysis of a core group of feasible alternatives.

A side note is that because the permit application to the Corps of Engineers names Churchmans Marsh as the application project, the subsequent study has been erroneously dubbed the "Churchmans Marsh EIS (Environmental Impact Statement)." This leads many to conclude that only Churchmans Marsh is being studied, and that a reservoir is to be constructed there upon completion of the study. The study requires comparative evaluation of feasible and practicable alternatives, and it must be understood that issuance of the required permits is not a given.

An important component of the federal laws for water-supply planning is the identification and evaluation of alternative projects for comparison of impact on the human community and ecological systems. The study is highly process-driven, and critical to the process is that all significant impacts from a proposed project must be identified in sufficient detail to enable comparison among alternative projects. The key decision-making guidelines on whether a project may be permitted are that it must be one that first *avoids* environmental impacts, or if unavoidable, *minimizes* such impacts, and as necessary provides *compensatory mitigation* for environmental impacts.

The specific review criteria that are being used in this study to evaluate and compare projects are technical, environmental, legal, institutional, neighborhood, and economic. (The resulting acronym is "TELINE.") Due to the variety of locales and the different media within each project, direct comparisons of the above criteria are not possible. For instance, each reservoir site would impact habitats of different qualities, values, and functions. Therefore, a consensus is developed on the way environmental impacts

are to be ranked. Some evaluation criteria are straightforward, such as cost to construct, provided projects are compared on the same design basis.

The study has proven to be an exceedingly difficult, expensive, and controversial undertaking. In fact, the study process is intentionally designed to pit diverse and usually opposing interests and subjects all projects and interest groups to intense scrutiny in order to emerge with a legally defensible justification for the decision the Corps must make on the permit application. Corps personnel in this Environmental Impact Statement have stated that it must be assumed that the decision the agency will make will result in a lawsuit being filed; therefore, the process needs to be able to stand severe legal tests.

Through the course of the study, most effort was expended on detailed field work for the reservoir projects since they represent the highest cost, and any determined not to be feasible would be eliminated to concentrate on a final select few sites. Up until this year, Churchmans Marsh was still considered a viable project. Other potential reservoir sites were eliminated due to various fatal flaws — any of a variety of site problems so severe they could not be compensated for. In April 1996, the Corps held its first public "scoping" meeting, and unexpected public concern was expressed over the just-released fish consumption advisory for Christina River in the vicinity of Churchmans Marsh. Throughout the study, cost estimates consistently placed Churchmans Marsh at the top of the list due to excavation requirements and for wetlands replacement. With the discovery of contaminated sediments in the marsh, the cost estimates increased further since expensive landfilling may be required for the excavated sediment rather than as use for cover material as originally proposed. These findings and other accumulating evidence showed that the environmental and economic impacts of a reservoir in Churchmans Marsh were so unfavorable the project was exceedingly unlikely to receive state or federal approval. Other less impacting projects were available.

A definitive decision has just been made to eliminate Churchmans Marsh from further study. As a result, the project will never be constructed unless it can be shown at some time in the future that no other alternative is available. The Project Management Committee will resubmit to the Corps of Engineers an application for Thompsons Station Reservoir as the new preferred alternative. To reiterate, the study is not to determine which project will be constructed but whether or not the Corps will issue a permit to construct the preferred reservoir project, which is now Thompsons Station.

If a reservoir is chosen for development, however, a variety of institutional issues will require resolution first, involving multiple-party project ownership and operation, certain regulatory decisions, and other technical and legal complexities that while they have been routinely handled in many other parts of the country, have no precedent in Delaware. Consultant services are being secured to recommend the best ownership and financing arrangement to carry the selected project forward once the Environmental Impact Statement is completed. This and the normal engineering design and construction schedules will likely place the development of any selected project past the year 2005.

As of this writing, five projects remain under review, consisting of the following:

- Thompsons Station Reservoir
- Artesian Marsh Reservoir
- Desalination
- Philadelphia Pipeline
- Chester County Pipeline

Detailed study is now being performed on the non-reservoir projects. Since the Artesian Marsh project shares many similar negative impacts as does Churchmans Marsh, as well as not being able to provide 100% of the supply need, this project will remain on the list of alternatives until definitive decisions are made on the other projects. If no others are found to be viable, Artesian Marsh will then be subjected to additional study as the third alternative reservoir site.

In-Stream Flow Needs Evaluation

Delaware has never set regulations for minimum in-stream flows relative to allocation of surface waters. Regulations exist that specify certain design flows for adequate assimilative capacity of wastewater discharges in order to protect aquatic habitat but make no provision for assuring such flows will exist.

When flow falls below critical levels, the Water Quality Standards are not expected to be met and are, in effect, suspended for the duration. The frequency of such suspensions is expected to occur no more often than the design flow. Among the several design flows, one, the Q7-10 low-flow value, is the most conservative and is the minimum flow value that is usually required.

Withdrawals for water supply obviously deplete available flow, and at certain critical times, if withdrawals are high enough and stream flow is low enough, the Water Quality Standards will not be able to be maintained. The frequency of this can occur more often than would occur naturally if withdrawal was being made. In this instance, the standards will be violated and protection of the aquatic habitat cannot be provided. This is the situation with the streams in the study area and is a direct result of over-allocation of the resource or, alternately, inadequate management. Existing regulation on this matter only states a requirement for in-stream flow in qualitative terms, rather

than in specific quantities. Numerous water-supply systems went into operation or continued to operate without required allocation permits, and in the absence of any standard for minimum in-stream flow, resulted in the available supplies not being reliable or inadequate to meet demand under some conditions. This topic is further detailed below.

In 1989, the water-supply needs analysis that prefaced the Churchmans Marsh study assumed two design criteria (of a different type and purpose) in determining the amount of available water supply from the four major water supply streams in northern New Castle County. The first assumption made was that the amount of surface water that would be available would be that which would occur during a 90-day drought of record. The drought of record for this area was at that time the drought of the mid-1960s, but has since been slightly surpassed by the Drought of 1995. This quantity of water is called the design flow. Current design flows for the supply streams are shown in Table 30. (Re-calculation of the design flows is likely to be required prior to the completion of the Water Supply Plan). Superimposed on this design flow was a certain amount of surface water that would be required to be left in-stream rather than be available for withdrawal. The amount of this flow was assumed to be Q7-10 low-flow as computed at the locations of the four surface-water intakes on White Clay Creek at Curtis Mill, White Clay Creek at Stanton, Christina River at Smalley's Pond, and Brandywine Creek at the Wills Pumping Station.

Q7-10 flow is that flow which is computed to occur over a continuous seven-day period once every ten years. (Q7-10 high-flow is also calculated for each stream.) This flow is calculated from gauging records collected by the U.S. Geological Survey. Gauging station locations where these data are collected are displayed on Map 16.

The rationale for selecting the Q7-10 flow is, as explained above, that it is the accepted design flow for the protection of aquatic habitat from discharges to streams from wastewater treatment plants, and it is set in regulation by DNREC's Water Quality Standards as well as the Delaware River Basin Water Code.

The assumption of this minimum in-stream flow proved controversial since it totaled 81 million gallons per day. This amount of water is actually *more* than currently used on an average demand day for the entire county. The consequence of assuming this large amount of water would not be allowed to be withdrawn and would remain in the stream to "pass by" the intakes is obviously significant in that it would have a deciding influence on the type and size of any future water-supply project that would be required. In other words, provision would have to be made to meet future water demands as well as to provide for in-stream flow. This was the first time Delaware was faced with dealing with this issue and several regulatory and policy considerations further complicated the matter, which will be discussed shortly.

For the purposes of water management and planning, there are three methods that could be used individually or in combination to provide for additional supply as well as to maintain a certain amount of in-stream flow. One is to construct a reservoir that would augment stream flow and provide supply. Another is to develop some other alternative supply project that would provide enough water to enable stream withdrawals to be curtailed to an equivalent amount such that Q7-10 flow could be maintained. These approaches are termed *supply-side management*.

Demand-side management could also be employed to curb demand for the same effect as adding water to the system. Usually, modern economics and regulatory requirements dictate that demand-side techniques be applied to supply-side project construction, although no standard approaches exist to do so and much controversy has arisen over how to integrate the two. Nonetheless, under the state's water management plan for drought, which is when critical low flows would occur, demand controls are a matter of law. Different supply-side approaches, reservoir versus non-reservoir, each have advantages and disadvantages. Obviously, an evaluation of in-stream flow needs and the potential outcomes this would have on determining the type of project selected for development is integral to the Water Supply Plan.

Adding to the impetus to conduct a formal study of in-stream flow needs were regulatory actions taken by the Delaware River Basin Commission on the City of Newark in 1991 and on Wilmington Suburban Water Corporation (now United Water Delaware) in 1993.

The history involved in this initiative is complex, but it is important to show the cross-cutting nature of water supply issues. The City of Newark approached DNREC in 1989 to construct a surface-water treatment plant at Curtis Paper Mill, which would have been the first new surface facility in Delaware since the 1940s. DNREC approved the allocation for a diversion of 5 million gallons per day from White Clay Creek. However, in the absence of a flow standard, none was imposed in the allocation issued by DNREC. However, recognizing the pre-existing diversion downstream of Newark on White Clay Creek at Stanton by Wilmington Suburban Water Corporation, DNREC required the city to cease withdrawal on White Clay Creek whenever flow was insufficient to meet prevailing demand at the Stanton intake.

Following the issuance of the allocation to Newark, the city also applied for approval of the diversion to the Delaware River Basin Commission. The resulting docket decision also required that Newark curtail its withdrawal under certain conditions. That condition required a passing flow

of Q7-10 be maintained as long as naturally available, and if not available, all natural stream flow be allowed to pass the intake. As did the state's allocation permit, the docket specified that a certain amount be allowed to pass by to meet demand at the Stanton intake.

However, the amount the Delaware River Basin Commission decided would be needed for protection of downstream flow to Wilmington Suburban Water Company was based on a value of 16 million gallons per day, which is equal to the entitlement the commission issued to Wilmington Suburban Water Company in 1974. The commission under authority of its compact began charging water users under its jurisdiction in 1974. Water users who pre-dated the commission's formation were issued an "entitlement," which authorized those users to legally use a certain amount of water without paying water-use charges to the commission. The amount of water entitled this way was equal to the maximum pumping capacity existing at that time. In the case of the Wilmington Suburban Water Company that capacity was 16 million gallons per day. It must be emphasized that entitlements do not constitute a "right" or allocation to withdraw, only an exemption from water-use charges. The Delaware River Basin Commission's unwritten policy is that entitled users would not be required to obtain permits for their withdrawal unless the user has exceeded its entitlement, a policy generally termed "grandfathering." This was the situation with the Wilmington Suburban Water Company. In contrast, the City of Wilmington's Entitlement of 60 million gallons per day will likely never be exceeded, and thus the city would never be required to obtain the commission's approval for its withdrawal. State regulations do not authorize grandfathering although pre-existing uses are "recognized." As of this date, the City of Wilmington has no legal authority to withdraw water from the Brandywine Creek. Resolution of this matter may require adjudication.

Since 1974, Wilmington Suburban Water Company had almost doubled its plant capacity at Stanton to 30 million gallons per day, but without regulatory approval. The City of Newark obtained approval to "infringe" on the pre-existing diversion by Wilmington Suburban, which the Delaware River Basin Commission did not formally recognize at present capacity. By coincidence, the amount required to pass by Newark's intake as specified in both permits was almost the identical value, or specifically 14 million gallons per day.

To make matters worse, Wilmington Suburban eventually received an allocation permit from both DNREC and the commission in 1993, after Newark. This constitutes a final irony in that Wilmington Suburban had been established on White Clay Creek since the mid-1940s but because its permit to withdraw came after Newark's, Newark's withdrawal legally precedes Wilmington Suburban's and the subsequent permitting of Wilmington Suburban at present-day capacity resulted in White Clay Creek technically and legally being over-allocated. The commission's solution to this dilemma was to authorize Wilmington Suburban to use Hoopes Reservoir to provide flow augmentation for the pass-by requirement. However, this authorization was only permitted for three years, after which the company would have had to develop an alternative source of supply. This alternative will be discussed in the following section.

In light of the above permitting complexities and related issues raised in the Churchmans Marsh Environmental Impact Statement, DNREC initiated a formal study of in-stream flow needs. The goal of this study was to determine the adequacy of Q7-10 as a flow standard and to make recommendations on flows that would be established for the water-supply streams of northern New Castle County. In total, these activities, as difficult and controversial as they remain even today, are having the positive effect of forcing establishment of long-neglected in-stream flow standards.

The study concluded in early 1997 with the production of the second of two reports. The first one issued in 1995 concentrated on the basic hydraulics of the study reaches and determined tentative target fish species along with recommendations for a second phase of study to focus on habitat surveys, literature search, and refinement of target fish species. Map 16 shows the study area and stream reaches. The essence of the study approach has been to identify critical stream sections under various flow scenarios (analyzed by calibrated computer models) and compare stream depths and velocities to available habitat criteria for the target fish species. Some fish species had no criteria available but were adopted from similar species for evaluation purposes. It should be noted that target fish species were selected based on indigenous populations indicative of the health of the aquatic system, rather than commercial species such as stocked trout.

Preliminary results of the study are that generally the Q7-10 flow provides for at least the minimum of the various fish species criteria and in some instances exceeds that required for aquatic habitat. Thus, the Q7-10 standard appears to be appropriate for the supply streams and would prevail for water-quality purposes where fish habitat criteria were lower than Q7-10.

The opposite situation exists on one section of White Clay Creek above Newark which appears to be impacted by withdrawal during low flow, and certain habitat criteria are not supported by Q7-10 flow. A separate study of this situation will be conducted in conjunction with the renewal of the city's Delaware River Basin Commission docket which expired this year. In that section of the stream, a

higher than Q7-10 passing flow may be required. Promulgation of flow standards is on hold, pending additional study. For more in-formation contact the DNREC Division of Water Resources at (302) 739-4793.

Tidal Control Structure

As explained in the preceding section, the passing-flow requirement imposed on the United Water Delaware Stanton Treatment Plant in 1993 mandated that the company allow a Q7-10 flow to "pass by" its intake. In that section of White Clay Creek where the withdrawals are made, the Q7-10 flow equals 17.3 million gallons per day. Under "normal" conditions, the company would not be able to withdraw at full capacity 16% of the time, with operational difficulties anticipated for several weeks every year on average, usually in the dry months of September and October.

The first summer the passing-flow requirement was imposed, United Water had to obtain releases from Hoopes Reservoir in order to meet both the flow standard and demand. The company had an emergency release arrangement with the City of Wilmington since 1972, but invoked it for the first time in 1993 under authorization of the Delaware River Basin Commission. Again in 1994, Hoopes Reservoir releases were required as a result of the pass-by requirement. The next year during the worst part of the 1995 drought, at the time the Governor declared the drought emergency, flow in White Clay Creek at Stanton was as low as 12 million gallons per day while demand was running at 15 million gallons per day. White Clay Creek was actually being pumped at over 100% of available flow with some flow from reversal of ebb tide which entrained brackish water into the treatment plant. The rest of the supply shortfall was being made up again by releases from Hoopes Reservoir in addition to the considerable demand reduction of at least 25% of normal. Under such emergency conditions, waiving of the passing-flow requirement for the entire month of September was permitted to allow all available flow to be withdrawn for public water supply to protect public health and welfare.

While this action is appropriate during a water shortage emergency, it also raises the issue of frequency of allowing such waivers and the resultant effect on the stream ecology since flow in the stream should not be allowed to be depleted below the prevailing standard of Q7-10 more often than the design flow. Or, in other words, a flow of no less than 17.3 million gallons per day should occur for more than seven days every ten years as dictated under the state Water Quality Standards.

Accordingly, the flow standard was not upheld for weeks on end during the drought. Still, the issue lingered

Table 30
30-DAY DESIGN LOW-FLOWS

	MINIMUM STREAM FLOW[1]	30-DAY LOW FLOW					
		1966 DROUGHT		20-YEAR RECURRENCE INTERVAL		50-YEAR RECURRENCE INTERVAL	
	(CFS)	(CFS)	LESS 7Q10 (CFS)	(CFS)	LESS 7Q10 (CFS)	(CFS)	LESS 7Q10 (CFS)
Christina River @ Smalley's Pond	3.23	2.88	_	4.30	1.07	3.23	–
Red Clay Creek @ Stanton	11.18	11.10	_	11.77	0.59	9.76	–
White Clay Creek @ Stanton	17.46	15.80	_	18.03	0.57	13.79	–
Brandywine Creek @ Wilmington	76.28	86.2	9.92	80.03	3.75	69.66	–
Total (CFS)		**115.98**	**9.92**	**114.13**	**5.98**	**96.44**	**0**
Total (MGD)		**74.96**	**6.41**	**73.76**	**3.86**	**62.33**	**0**

[1]*Minimum Stream Flow* = 7Q10.
Source: Metcalf & Eddy, 1991.

of providing for adequate flow to support the stream habitat and avoid violating the Water Quality Standards. One approach would be to revise the Water Quality Standards to allow for lower passing flows and thus extend available supply. On several counts, this approach is not prudent. The standards were developed based on scientific criteria for protection of in-stream biota, and from a water management and policy perspective it would be difficult to recommend lower flow standards which would likely result in further, gradual degradation of surface water quality — the opposite of DNREC's objectives. From a practical standpoint, the difference between Q7-10 flow and a lesser standard of, say Q7-50, is only several million gallons per day. While this difference is proven to be critical for providing adequate flow for aquatic habitat, it is not significant for existing and future water supply.

To compound matters, Hoopes Reservoir was only allowed to be utilized under United Delaware's Delaware River Basin Commission allocation permit for a period of three years after the permit's issuance. The company was faced with complying with minimum stream-flow requirements, with the expectation that the Q7-10 standard would be used, and at the same time meet demand, all without having a county-wide storage project or other regional supply.

The innovative engineering solution to this dilemma was in fact conceived prior to the 1995 drought. This positive initiative is named the Tidal Control Structure. Now under development, the Tidal Control Structure will consist of an inflatable and deflatable heavy-gauge rubber dam constructed across White Clay Creek in the vicinity of the Metroform area. The concept of the project is simple: take advantage of the diurnal tidal inflow and capture it at maximum water-level elevation. This will be done by inflating the rubber dam at the correct time to coincide with flood tide and withdrawal from the pool behind the dam. Shortly before ebb tide, the dam will be deflated and the cycle repeated as necessary. As part of the design, enough water will also be captured to enable passing of the Q7-10 flow. The net result of the project is that the passing-flow requirement can be maintained at the same time the reliability of the treatment plant is improved.

Fish passage is the greatest concern for potential impact of the project, but is considered of minimal concern in the view of the Division of Fish and Wildlife. The structure will be operated only at times of low flow — typically five to six weeks out of the year.

Fish passage is of highest concern during the spring spawning season when the dam will not be in operation, so no impact is expected at that time and limited impact is expected during the times of operation when indigenous species "run" with the tide. Another concern is "back water" effects and potential aggravation of historical flooding problems in the nearby Glenville development. Since it is a "low-head" dam rising approximately 5 feet above the streambed, any excess runoff that may occur during storm events will easily flow over the dam if it is inflated at the time of highest stage. Thus, no flooding potential is expected. Hydraulic model runs have been performed which confirm these aspects.

As can now be further seen, there is extensive intermingling of issues common to the In-stream Flow Needs Study and the Churchmans Marsh Study. After numerous meetings with the regulatory agencies over these issues, United Water Delaware made a business decision to undertake development of a project that would allow them to meet the passing-flow requirement under almost all conditions while enabling them to meet prevailing demand as opposed to arguing for exemption or lessening of the flow standard. United's action will result in improvement of protection to the stream and needed security of the public water supplies, which extend to its customers and others throughout the county.

Christina River Basin Drought Management Committee

In the late 1980s after Delaware's Piedmont Basin and nearby Chester County, Pennsylvania, were exposed to two fairly serious droughts — one in 1981, another in 1985 — water management officials were prompted to propose creation of a new entity to address drought and other water-supply related issues separate from the Delaware River Basin Commission. The major situation that prompted this was the discontinuance of the drought declaration in 1985 that had been announced for the entire Delaware River basin based on improvement of storage conditions in the upper basin. Conditions in the lower basin, however, were substantially different, and the Pennsylvania portion of the Christina River basin remained in serious drought. Loss of cooperation with the drought management efforts resulted although finally conditions improved and supplies returned to normal.

The lesson was learned, however, and a new mechanism was desired for dealing with local drought events based on local conditions. Unfortunately, the commission refused to allow the Christina River basin to exempt itself from commission drought rules even if the Christina River basin's conditions did not indicate drought. (The commission refers to this policy as "equal hardship.")

The Christina River Basin Drought Management Committee was approved by the Delaware River Basin Commission in 1988 and incorporated into Pennsylvania's and Delaware's drought management plans. Its inaugural meeting was held December 18, 1991. The committee is composed of an equal number of public and private water utilities from both states along with the respective environmental agencies and representatives from the Delaware

Geological Survey, the Delaware River Basin Commission, and the two counties' water resources agencies. Chairmanship of the committee rotates annually between the two state agencies. (Ironically, all drought response action recommended by the committee so far has occurred only under Delaware's chairmanship.)

Key activities and responsibilities of the committee include continuous monitoring of hydrologic and water-supply conditions and coordinating drought response action in an advisory capacity to the state's governors. Two indices are used to measure and monitor water-supply conditions in Delaware: one is DNREC's Hydrologic Index, and the other is Delaware Geological Survey's Water Conditions Index. These indices are calculated using measures of precipitation, stream flow, groundwater levels, and population. Although the two indices use significantly different methods of calculating conditions, years of experience particularly during periods of drought or near-drought conditions show that they produce compatible results and are closely synchronous.

The two indices differ when conditions are approaching or are wetter than normal. In this case, DNREC's index lacks a clear indication of wet conditions; however, this reflects the primary function of the index as a drought management tool. In contrast, the Delaware Geological Survey's index was designed to register the full range of water conditions, dry through normal through wet. Figure 15 shows the most recently issued conditions graph.

A major initiative of the committee is to revise the operating plan of the largest reservoir in the basin at Marsh Creek. This action was prompted by the 1995 drought to allow for emergency stream-flow augmentation in Brandywine Creek under certain conditions. The proposal is for a three-year agreement based on presumption of a new water-supply project being developed in New Castle County by the year 2000. This agreement was signed by the Pennsylvania Department of Environmental Protection Secretary in 1997. More information regarding drought coordination and monitoring of water conditions can be obtained by calling the DNREC Water Supply Section at (302) 739-4793 or the Delaware Geological Survey at (302) 831-2833.