

**Additional Notes for Merguerian's Distinguished Faculty Lecture at Hofstra University on  
the Geology of the NYC Aqueduct System - 27 September 2000**

**HISTORY AND CONSTRUCTION OF WATER SUPPLY SYSTEM**

The population of NYC by 1664 had reached 1,500 people and by 1667 the first public well was dug in front of the old fort at Bowling Green. This was followed by a well at Chatham Square (Tea Water pump), renowned for its water quality. The Collect Pond (Criminal Courts Building) also served as a source of water throughout this early period. Before the beginning of the American Revolution (1776) the population increased to 22,000 and a distribution system from the Collect Pond was built by Christopher Colles consisting of hollow logs which fed into a reservoir at the intersection of Broadway and White Streets. By 1800 with the population at 60,000 the Collect Pond had collected pollutants and the water supply became insufficient. Aaron Burr founded the Manhattan Company, sinking a deep well and building an iron tank at the corner of Reade and Center Streets, thus providing water (700,000 gpd) using twenty miles of wooden pipes to 1,400 homes.

By 1830, a public water supply system was in place when an elevated 220,000 gallon tank was erected at Broadway and 13<sup>th</sup> Street. The tank was charged by a 12 hp pump from a 112 foot deep, 16 foot wide well that was in solid rock for 98 feet. It fed two galleries that were 25 and 75 feet long. The water supply, which fed two 12" cast iron distribution mains that ran along the Bowery to Chatham Square and along Broadway to Canal Street, soon proved inadequate.

In 1832, DeWitt Clinton, recommended use of the Croton river which he estimated would yield 20,000,000 gpd by gravity feed. In 1834 the State Legislature allowed NYC to venture beyond its borders for water and Major D. B. Douglas surveyed both the Bronx and Croton rivers, recommending the later for water-supply use.

Between 1837 and 1842 a fifty-foot high rock-filled, timber crib dam was constructed (Old Croton Reservoir) with granite masonry. By 1881, after extensive repairs and strengthening, a capacity of 95 mgd (million gallons/day) was achieved. The reservoir with a flow-line elevation at 166.2 feet was used until 1907 at which time the New Croton or Cornell Dam was put into service. In its day, the brick-lined masonry Old Croton water supply (which crosses the Harlem river at High Bridge) fed the reservoirs at Central Park on southward to Bryant Park. Parts of the Old Croton system, now with replaced piping, are still used in a limited fashion today. The Central Park Reservoir was abandoned in 1925 and the Bryant Park Reservoir was discontinued in 1890.

In 1873, to supplement the Croton supply, the Boyds Corner Reservoir in Putnam County was constructed and in 1878 the Middle Branch Reservoir was added. By 1884 the Kensico Dam was constructed and a small dam was built on the Byram River to divert flow coming from Byram Lake and Wampus Pond through a tunnel and open channel (Bear Gutter) into Kensico Lake. Here it flowed into the former Williamsbridge Reservoir (now a park and playground).

By 1880, after a survey by W. J. McAlpine indicating use of the Ramapo and Neversink rivers in New Jersey, attention was turned to sources of water west of the Hudson. He suggested that 600 mgd and another 250 mgd could be acquired from these watersheds, respectively. In 1883 the Croton Aqueduct Commission was enacted and construction of the New Croton System was begun in 1885. By 1890/91 water was delivered to the Central Park Reservoir but the New Croton Dam was not completed until 1907. The New Croton Dam was begun in 1892 at a site (Quaker Bridge) downstream from the old dam and was faced with the Peekskill granite. The New Croton system was mostly underground (tunnel) with part at grade and part a pressure tunnel and crossed the Harlem River just south of High Bridge. Construction was a nightmare as badly decayed rock beneath the river forced the tunnel invert to be built at -300 feet (instead of the original plan [-126.6 on east bank and -150 feet on west bank]). As a part of this new system, the Jerome Park Reservoir supplied about 285 mgd. Usage jumped from 102 mgd to 170 mgd, still within the capacity limit of the system (200-300 mgd) but things were to change quickly.

The consolidation of Kings, Queens, Richmond, and parts of Westchester counties into New York City in 1898 brought under jurisdiction of the city the disparate water supplies (and problems) of these contiguous regions and increased the population served by the water system to 3.5 million (overnight). Thus, with the increase in consumption, by 1899, the limits of the system had been reached. At this point a private company, the Ramapo Water Company, secured a charter with the state and sought to control all available dam and reservoir sites. Public outcry led to the revocation of that charter. The Comptroller employed John R. Freeman to investigate the sources of supply and prepare a report. By 1900, his report recommended usage of the Housatonic and Ten Mile rivers and suggested a reservoir on the East Branch of the Delaware at Margaretville, as well as the Neversink and other branches of the Delaware.

In 1903, the Burr-Hering-Freeman Commission was appointed and to avoid possible interstate litigation attention was focused on New York State water sources, abandoning the use of tributaries of the Delaware, Housatonic, and Ten Mile rivers. This led to the creation of the Board of Water Supply of the City of New York by the State Legislature in 1905. The BOWS made ample use of geological guidance from its inception. The late Professor James Furman Kemp provided useful data (as Consulting Geologist) when construction of the New Croton Dam was planned and executed. Kemp provided geological input on siting the Ashokan dam, the Catskill region, and Storm King crossing of the Hudson River. W. O. Crosby joined the geological consultant staff and his work was employed on proposed new supplies from the Catskills and Long Island. Kemp was loyal to his students and his protege Charles P. Berkey was enlisted to carry on Kemp's original work. The work of Mather, Dana, Merrill, Fettke, Gordon, Berkey and Rice, Holzwasser, Colony, Sharpe, Balk, Darnell, Fluhr, and others helped mold the approach of the BOWS to the problem of constructing a large enough water tunnel to supply the extant and future needs of New York City.

### **The Catskill Aqueduct System**

One of the first major construction works carried out by the Board of Water Supply, in 1907, was construction of the Catskill Aqueduct System, based upon the recommendations of the

Burr-Hering-Freeman Commission. The Geological Consultants (Kemp, Crosby, and Berkey) organized a team of geological specialists to examine the bedrock along the proposed aqueduct course. Their combined efforts with the engineering staff resulted in the Catskill Aqueduct System which is over 214 km long and consists of several large dams and reservoirs. It traverses a geologically diverse region that varies in elevation from 300 m above MSL in the headwaters to the City of New York. The Catskill system, which involved the use of 67 shafts varying in depth from 174 to 1187 feet, includes:

Three masonry dams

Several miles of earth dikes

Over 163 miles of aqueduct consisting of:

55 miles of cut and cover aqueduct

28.5 miles of grade tunnel

35 miles of pressure tunnel

6 miles of steel pipe siphons, and,

39 miles of pipe conduit.

Continuous construction in the early part of the century resulted in 1916 with the first supply of water to reach New York City. The Catskill Aqueduct System was completed in 1924.

Two distribution tunnels feed the system at present and a third tunnel is under construction to facilitate repairs to City Water Tunnels #1 and #2 and prepare for long-term needs of population. New York City boasts a gravity-feed system with hydraulic head provided by 300 m difference in elevation between headlands and distribution area (NYC). The Board of Water Supply (BOWS) was created by an act of the State Legislature in 1905 and continued to function until 1978 when the Department of Environmental Protection (DEP) took over functions of the BOWS. The Water Supply Act still exists giving the DEP broad powers but is seldom invoked because of political reasons. Construction of the water supply system involved large dams of earth and masonry, shafts and tunnels, distribution chambers, and many other structures through geologically diverse territories.

### **City Water Tunnel #1**

City Water Tunnel #1 was completed in January of 1917 and begins at the southerly end of the Hill View Reservoir in Yonkers and follows the highest ground through The Bronx and Manhattan and crosses the Harlem River just south of High Bridge in the Inwood Marble formation. It traverses through the Manhattan Schist in Manhattan, southward beneath Central Park and continues into the lower east side passing, at the foot of Clinton Street, through tectonically thinned units of the Inwood Marble, Fordham Gneiss, and Brooklyn Injection Gneiss (and probably the Hartland formation). It crosses beneath the East River in the injection gneiss to Bridge Street in Brooklyn and terminates at Third Avenue and Schermerhorn Street. A branch tunnel beneath Flatbush Avenue further distributes the system under Lafayette Street to a terminal shaft at Fort Greene Park. Covered in most places by at least 150 feet of sound rock through its course in the city, the tunnel varies from 200 to 300 feet deep (from -50 to -200 feet

below sea level). City Water Tunnel #1 carries water under pressure for its total length and supplies about 500-600 mgd.

## **The Delaware Aqueduct System**

By the end of 1930, the city began to approach the reasonably dependable output of the Catskill system. Displaying great foresight, in 1921 the Board of Estimate and Apportionment authorized the Board of Water Supply to investigate additional supplies. The conclusions of these studies were that the necessary supply could best be handled by employing the watersheds of Rondout Creek and tributaries of the Delaware River. Preliminary geological investigations began in 1924 and test borings were made in 1927-1928. Actual construction began in the early part of 1937 and was totally completed in 1964. Total length of the system is 190 km.

### **City Water Tunnel #2**

City Water Tunnel #2 was constructed during development of Delaware Aqueduct system and put into use in March 1936. It's capacity ranges from 700-800 mgd and is in generally good repair. Yet, some leakages and difficulties in control systems have occurred.

### **City Water Tunnel #3**

City Water Tunnel #3 was proposed by the Board of Water Supply to then Mayor John V. Lindsay (as Chairman, Board of Estimate) in July of 1966 (with NYC population at 8 million) for the following reasons:

- 1) To increase delivery capacity needed in the far southerly and easterly areas of tunnels #1 and #2 of the city where increased demand had occurred.
- 2) To reduce high flows which periodically overloaded older tunnels.
- 3) To permit shutdown, inspection, repair, and modernization of older tunnels, and,
- 4) To provide alternate delivery in the event of disruption in older tunnels.

The initial projected "hole in the ground" costs for Stage 1 of CWT #3 was \$238M and project was projected to be completed by 1975. Stages 2 through 5 (later modified to 4 stages) were to cost an additional \$180M and be completed by 1985. Rather, Stage 1 was essentially completed in the mid 1980s and total costs were about \$1B. Water is planned to be turned on by July of 1998 as 99% of the work has been completed. Stage 2 is presently nearing completion in the Brooklyn-Queens section. In Manhattan and all Stage 2 exploratory drilling is complete and shaft has been constructed at 10<sup>th</sup> Avenue and 30<sup>th</sup> Street but northward tunneling or additional shaft construction has been delayed, the result of fiscal problems.

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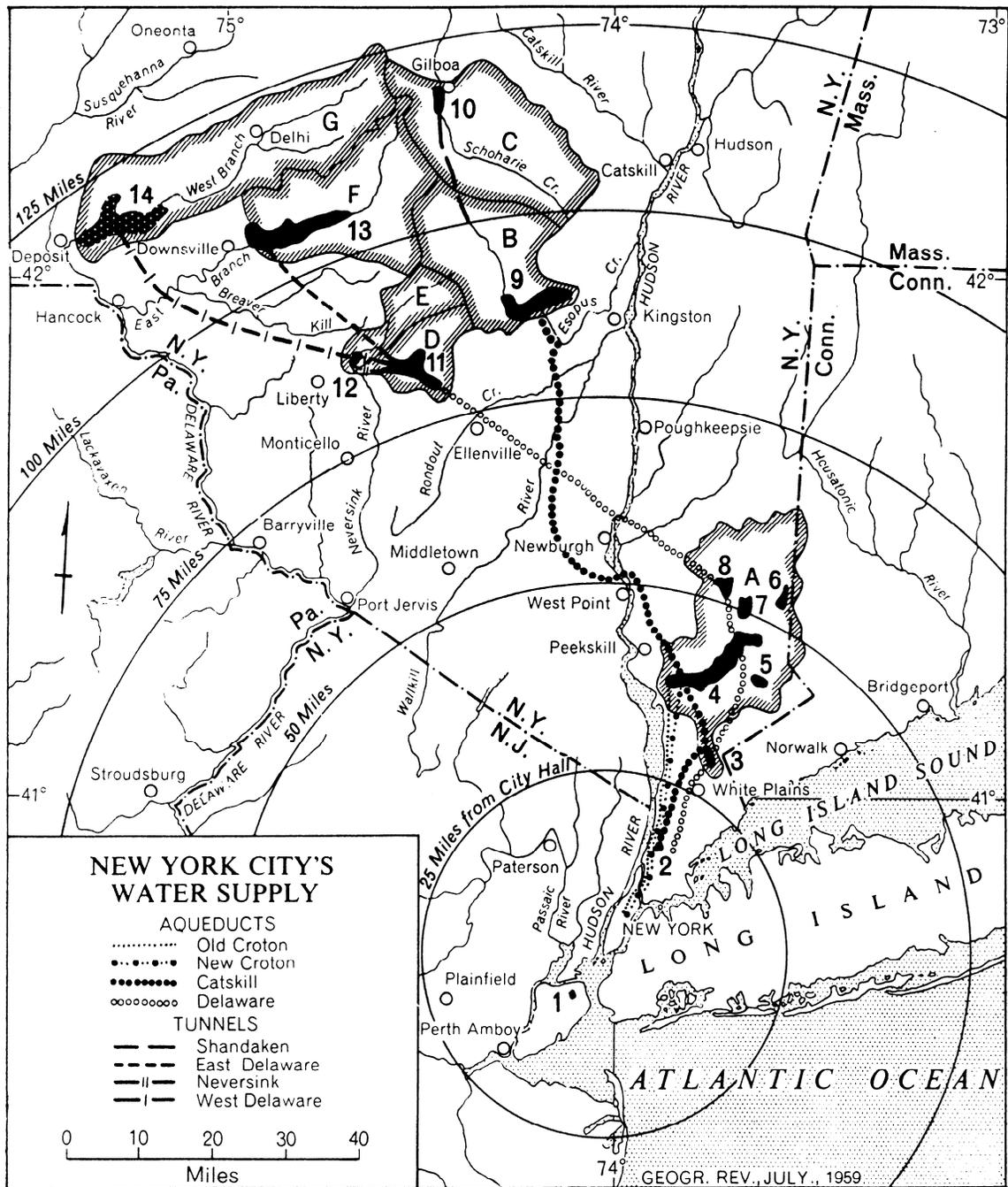


FIG. 1—The sources of New York City's water supply. Watersheds are shown by heavy boundary; key: A, Croton; B, Esopus; C, Schoharie; D, Rondout; E, Neversink; F, East Delaware; G, West Delaware. Reservoirs are shown in black; key: 1, Silver Lake; 2, Hill View; 3, Kensico; 4, Croton; 5, Cross River; 6, East Branch; 7, Middle Branch; 8, West Branch; 9, Ashokan; 10, Schoharie; 11, Rondout; 12, Neversink; 13, Pepacton; 14, Cannonsville  
Adapted from map in "The Water Supply of the City of New York"

