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THE GEOGRAPHY OF NEW YORK CITY'S WATER SUPPLY: A STUDY OF INTERACTIONS

ANASTASIA VAN BURKALOW

A CITY must often look outside its own boundaries for its water. Smaller communities can usually obtain an adequate water supply from local ground or surface waters, and even a large city can meet its water needs from local sources if it is near a large river (London, Philadelphia, Washington, Pittsburgh, and St. Louis) or lake (Chicago and Buffalo). New York City, however, has no nearby lake and no usable river; for the Hudson River, being an estuary, is brackish.[1] And early in the nineteenth century the city began to outgrow its local ground and surface water supplies. It has therefore had to go gradually farther and farther afield, eventually as much as 125 miles, to tap the surface waters of other watersheds.

New York first did this as early as 1842, when the Croton water system went into operation. This ended the use of local wells and ponds for public supply in Manhattan (New York City did not then include the other boroughs), though some Manhattan industries still use water from their own private wells. Other parts of the present city continued to depend on local sources for a longer time: the Bronx until it was annexed to the city in 1874 (west Bronx) and 1895 (east Bronx); Richmond until it received Catskill water in 1917; parts of Brooklyn until 1947, when pumping for public supply was stopped because of depletion of the ground water; and parts of Queens even today.[2] However, the inadequacy of the local sources

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[1] Farther up the Hudson a layer of fresh water, brought in by tributary streams, floats on top of the brackish water, and from that fresh surface layer some Hudson Valley communities (Poughkeepsie, Rensselaer, and Waterford, for example) take their public water supplies. Treatment is necessary, of course, to counteract the fairly heavy pollution. In the early 1950's, when the most recent expansion of New York City's water supply was being planned, some citizens' groups favored a Hudson River source instead of the Cannonsville Reservoir. However, the nearest the city has come to using Hudson River water was to build a temporary pumping plant near Chelsea, 10 miles south of Poughkeepsie. This plant, capable of pumping 100 million gallons per day (mgd) of river water into the city system, was authorized by the state Water Power and Control Commission for emergency use only, in case of shortage before completion of the first two stages of the Delaware system, and was not to be used after 1957. It was never needed and has now been demolished.

[2] Wells of the Jamaica Water Supply Company and the New York Water Service Corporation provide the public supply for parts of Queens, furnishing an average of nearly 50 mgd in recent years, which is about 3½ per cent of the average daily consumption of the entire city. Little additional ground water is now used in the city for public supply. City-owned wells in Brooklyn have long been out of use, and those in Queens and Nassau Counties, with a dependable yield of 70 mgd, and in Rich-

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was felt in Brooklyn and Queens as early as the 1890's, and it is said that need for additional sources of water helped influence Brooklyn, at least, to become part of Greater New York in 1898.[3] One of the first concerns of the Greater City was to add to its water supply, which by then consisted of an enlarged Croton system and the Bronx-Byram watershed.[4] Construction of the Catskill system, authorized in 1905, was begun in 1907, and in late 1915 Catskill water first reached the city. By the time this system was completed in 1927, plans were already being discussed for the Delaware system. Construction was finally begun in 1937 (court action and the depression had delayed it) but was interrupted by World War II. Finally, in 1951, the Rondout Reservoir was completed.[5] It was followed by the Neversink in 1952 and the Pepacton (East Delaware watershed) in 1955. The final stage, the Cannonsville Reservoir (West Delaware watershed), now under construction, is slated for completion in 1962.

Thus New York City now depends on seven distant watersheds, Croton, Bronx River, Esopus, Schoharie, Rondout, Neversink, and East Delaware, and is developing an eighth, the West Delaware. Their dependable yields are given in Table I, and their locations are shown on the map, Figure 1. Within their combined area of 1969 square miles, half again as large as Rhode Island, water is taken from more than a thousand streams, big and little. It is stored in 27 reservoirs and controlled natural lakes and is brought to the city through more than 350 miles of aqueducts and tunnels (Fig. 1).

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mond County, with a dependable yield of 5 mgd, have been kept as stand-bys in recent years. They were used extensively only in the dry period of 1949–1950 (see N. M. Perlmutter and Theodore Arnow: Ground Water in Bronx, New York, and Richmond Counties, With Summary Data on Kings and Queens Counties, New York City, New York, *New York State Dept. of Conservation, Water Power and Control Commission, Bull. GW-32,* Albany, 1953) and in 1957–1958 while the Delaware Aqueduct was closed for cleaning. Now that Delaware water is available, the Long Island well water is not considered necessary, and the city plans to sell its Long Island wells (see the *New York Times*, Feb. 2, 1958).

[3] Russell Suter: Engineering Report on the Water Supplies of Long Island, *New York State Dept. of Conservation, Water Power and Control Commission, Bull. GW-2,* 1937, p. 35.

[4] This consisted of the Bronx River watershed above Kensico Dam, from which water still enters the city's water-supply system, and the adjacent Byram River watershed. From its Byram Lake and Wampus Pond a dependable yield of 5 mgd could be led into the Bronx River by a tunnel and open channel. However, since April 12, 1955, none of this water has been allowed to enter the New York City system. In 1958 Byram Lake was bought by a resident of Mt. Kisco and presented to that village, which had for many years met about half of its public water-supply needs by buying that very water from New York City.

The Bronx-Byram watershed, too small to be shown clearly on Figure 1, lies close to the southeastern edge of the Croton watershed, near the New York–Connecticut boundary.

[5] Water from the Rondout Reservoir, on Rondout Creek, reaches the city via the Delaware Aqueduct, but Rondout Creek is a tributary of the Hudson River, not of the Delaware. Strictly speaking, therefore, it is not part of the Delaware system, and it was not subject to the limitations set up in 1931 by the United States Supreme Court.

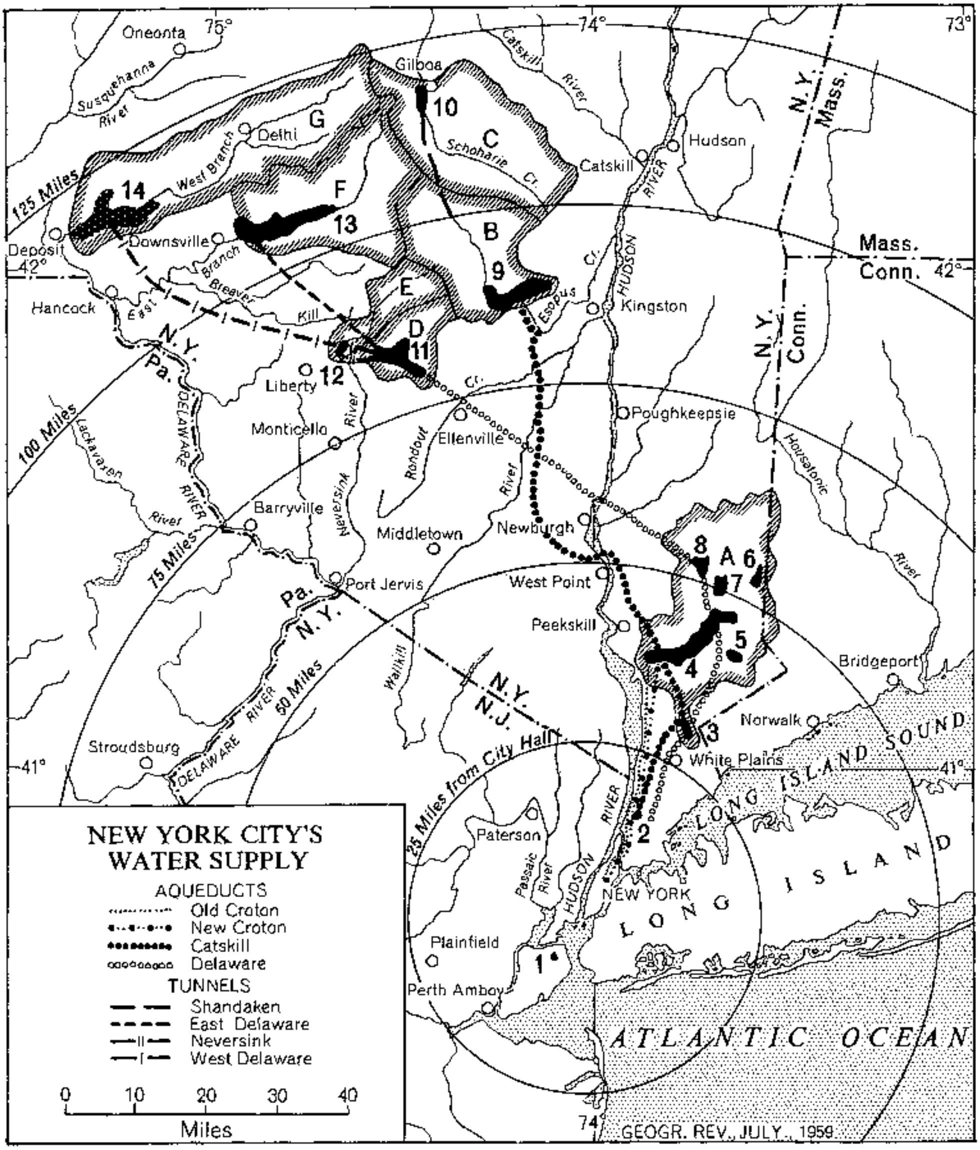

FIG. 1—The sources of New York City's water supply. Watersheds are shown by heavy boundary; key: A, Croton; B, Esopus; C, Schoharie; D, Rondout; E, Neversink; F, East Delaware; G, West Delaware. Reservoirs are shown in black; key: 1, Silver Lake; 2, Hill View; 3, Kensico; 4, Croton; 5, Cross River; 6, East Branch; 7, Middle Branch; 8, West Branch; 9, Ashokan; 10, Schoharie; 11, Rondout; 12, Neversink; 13, Pepacton; 14, Cannonsville (under construction). Adapted from map in "The Water Supply of the City of New York" (see text footnote 13 below), pp. 40–41.

TABLE I—NEW YORK CITY'S WATERSHEDS

WATERSHED	AREA (*sq. mi.*)	DEPENDABLE YIELD (*mill. gal. daily*)	WATERSHED	AREA (*sq. mi.*)	DEPENDABLE YIELD (*mill. gal. daily*)
Croton	375	325	Neversink	93	115[b]
Bronx River	13	5	East Delaware	372	375[b]
Esopus	257	345	West Delaware[a]	450	310[b]
Schoharie	314	220			
Rondout	95	120[b]	TOTAL	1,969	1,815[c]

[a] Under construction.

[b] Additional water must be held to replenish the stream in dry weather (see text, p. 385).

[c] To this must be added the 5 mgd dependable yield that can be drawn from wells in the Borough of Richmond if necessary, which will make a total dependable yield of 1820 mgd available in 1962.

Source: "Brief Descriptive Outline of New York City's Water Supply Works" (Board of Water Supply, City of New York, June, 1958).

TABLE II—WATERSHED PRECIPITATION
(*In inches*)

WATERSHED	AVERAGE	MINIMUM	YEAR	MAXIMUM	YEAR
Long Island	43.22[a]	29.90	1931	56.50	1889
Croton	47.68[b]	32.29	1935	63.76	1901
Esopus	49.32[c]	33.70	1957	73.08	1928
Schoharie	42.68[d]	30.68	1911	60.35	1928
Rondout	49.03[c]	33.65	1941	73.54	1928
Neversink	51.55[e]	37.36	1941	71.24	1938
East Delaware	43.79[e]	33.38	1957	54.43	1938
West Delaware	41.74[e]	33.22	1957	51.53	1938

Averages are for (*a*) 78 years; (*b*) 89 years; (*c*) 51 years; (*d*) 50 years; (*e*) 20 years. All periods end with 1957.

Sources: *52nd Ann. Rept. New York City Board of Water Supply, 1957; Ann. Rept. New York City Dept. of Water Supply, Gas and Electricity, 1951* (for Croton's maximum and minimum).

Several aspects of the physical and cultural geography of the source areas have affected the amount and quality of the water available to New York City and the construction problems encountered in building the dams and aqueducts. And the development of this extensive water-supply system has left its imprint on the physical and cultural geography of the source areas and also of still more distant areas in the lower Delaware Valley. It is with these interrelationships that the present paper is concerned.

HOW THE GEOGRAPHY OF THE WATERSHED AREAS AFFECTS THE CITY'S WATER SUPPLY

FACTORS THAT INFLUENCE THE AMOUNT OF WATER AVAILABLE

Precipitation. In the watersheds the average precipitation is well over 40 inches a year, but the amount received in individual years may vary a good deal from the average (Table II).

It is the amount of water available in the driest year on record that is the dependable yield of a watershed, the minimum with which a city might have to get along and below which consumption should be kept. Unfortunately, in many cities of the United States consumption equals or exceeds dependable yield, and no reserve is left for emergencies or for future growth of the city.[6] As a result there are water shortages from time to time, when the use of water must be curtailed. This is what happened in New York in 1949. Consumption was about 25 per cent greater than dependable yield of the then existing facilities,[7] and a severe drought in the summer and fall caused a serious water shortage. Disaster was prevented only by an intensive water-saving campaign, which in about three months reduced the consumption by nearly 25 per cent.[8] Completion of the Rondout, Neversink, and Pepacton Reservoirs has increased the dependable yield (now 1510 million gallons per day, counting ground-water resources on Staten Island but not on Long Island) comfortably beyond current consumption (1153 mgd in 1958),[9] and completion of the Cannonsville Reservoir will give a total dependable yield of 1820 mgd, which it is thought will be adequate until about the end of the century.[10]

In the rainiest periods the reservoirs cannot hold all the available water, and large amounts spill over the dams and are lost. Carrying capacity of the aqueducts also limits the amount of water that can reach the city. Thus nature determines the minimum amount of water available to the city, but man has determined the maximum, because the reservoirs and aqueducts he has built will not accommodate nature's maximum.

Interstate Character of the Delaware River Drainage Basin. In the Delaware system man has placed still another limit on the maximum supply available to the city, this time by court decree. The Delaware River serves as boundary first between Pennsylvania and New York and then, for many miles, between Pennsylvania and New Jersey, and its broad estuary lies between Delaware and New Jersey. Its headwaters, however, from which New York City takes water, are in New York State, and when the Delaware plan was first announced in 1928, the approval of the Water Power and Control Commission of New York State was granted. Residents of New Jersey, Pennsylvania, and Delaware were at once concerned lest they be deprived of water

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[6] In 1955 this was true of 42 per cent of the country's major public water-supply systems, according to a survey made by the Water and Sewerage Industry and Utilities Division of the Business and Defense Services Administration of the United States Department of Commerce (see the *New York Times*, Apr. 7, 1955).

[7] *45th Ann. Rept. New York City Board of Water Supply, 1950.*

[8] *Ann. Rept. New York City Dept. of Water Supply, Gas and Electricity, 1950*, p. 108.

[9] Letter from Department of Water Supply, Gas and Electricity, City of New York, Jan. 22, 1959.

[10] K. R. Kennison: The Development of the Delaware Projects, *Municipal Engineers Journ.*, Vol. 40, 1954, 4th quarterly issue, pp. 131–168; reference on p. 152.

for their needs. Accordingly, in 1929 New Jersey went to the United States Supreme Court to enjoin New York City from taking any water from the Delaware River or its tributaries. Pennsylvania acted as intervener. The Court decision in May, 1931, permitted the city to take 440 mgd, enough only for the first two stages of the Delaware plan (Neversink and Pepacton Reservoirs), instead of the 600 mgd originally proposed. Efforts were made to provide for the third stage, the Cannonsville Reservoir, as part of an interstate development of the river, proposed by the Interstate Commission on the Delaware River Basin (Incodel) for power development and control of floods and pollution as well as for water supply. New York, New Jersey, and Delaware accepted the plan, but in 1952 Pennsylvania rejected it. Thereupon New York City reopened the original case before the Supreme Court and asked for an additional 50 mgd from the Neversink and Pepacton Reservoirs and 310 mgd from the proposed Cannonsville Reservoir. This request was granted by a decision in 1954. In both Court decisions the city was directed to release water from its reservoirs in dry periods, to maintain a certain minimum flow in the main valley.[11]

Factors That Influence the Quality of the Water

Geology. In the Westchester watersheds there are long, narrow outcrops of metamorphosed limestone, a soluble rock, but most of the area is underlain by relatively insoluble schist and gneiss. In the Catskill and Delaware watersheds most of the rocks are dark sandstones and shales, also insoluble.[12] As a result the water is soft, with only 17 parts per million of dissolved matter in the Catskill and Delaware water and 40–50 ppm in the Croton water.[13] Both home and industrial users are thus relieved of the expense and difficulties caused by hard water.

Because of the composition of the rocks in the watersheds, New York City's water contains little or no dissolved fluorides.[14] It has been widely recognized by dental and medical authorities that about 1 ppm of fluorides in the drinking water makes teeth more resistant to decay (but only if such water is drunk in early childhood while the permanent teeth are forming).

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[11] For a good summary of the Court decisions and the Incodel effort here described, see Kennison, *op. cit.*

[12] C. P. Berkey: Engineering Geology of the City of New York, *in* New York City and Vicinity, *Internatl. Geol. Congr., 16th Sess., United States, 1933, Guidebook 9,* Washington, 1933, pp. 77–123. Plate 9 is a simplified geological map of the Westchester and Catskill watersheds.

[13] "The Water Supply of the City of New York [Origin and Achievements of the Board of Water Supply, City of New York]," 1950, p. 92.

[14] Anastasia Van Burkalow: Fluorine in United States Water Supplies: Pilot Project for the Atlas of Diseases, *Geogr. Rev.,* Vol. 36, 1946, pp. 177–193; see especially Plate I.

Lack of natural fluorides can easily be offset by addition of the desired amount, as has been done in many community water supplies. Whether or not New York City's water will be so treated has yet to be decided. Some groups strongly oppose this so-called "mass medication."

In the Catskill and Delaware watersheds especially, the banks of the streams and reservoirs consist in some places of easily eroded glacial clays. During heavy rains these are washed into the water and temporarily increase its turbidity.[15]

Vegetation. In the Catskill and Delaware watersheds large areas have been set aside as state parks and forest preserves, within which most of the surface is covered with trees. Because the forests retard soil erosion, and therefore siltation in the reservoirs, the useful lifetime of the reservoirs is prolonged, and there is little need to treat the water for turbidity. In Westchester a smaller part of the watershed is forested, but here, as in the Catskills, the land close to the reservoirs has usually been planted with evergreens (Fig. 3). These are used instead of deciduous trees because the thin, broad leaves of the latter would tend to blow into the water, where they would clog outlets, discolor the water as they decayed, and so on. For these tree belts a program of planting, pruning, thinning, and insect control is carried on by the Department of Water Supply, Gas and Electricity as part of the maintenance of the water-supply system.[16]

Population Density. In 1950 the population densities per square mile in the various watersheds were as follows:[17] Bronx-Byram, 184; Croton, 128; Esopus, 17; Schoharie, 26; Rondout, 17; Neversink, 19; East Delaware, 18; West Delaware, 30. Except in the Westchester area (Bronx-Byram and Croton) these densities are very low, and there is relatively little danger of pollution of the water. Where this danger exists, the city builds and operates sewage-disposal plants.

Size of the System. The large size of New York City's reservoirs, due both to nature's potentialities and to man's decisions, makes it possible for water to remain in them for a long time—in the Catskill reservoirs for as much as six months, in Kensico (the Westchester storage reservoir for the Catskill and Delaware systems) for about three weeks. This permits natural purification of the water before it finally enters the aqueducts on its way to the

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[15] See Berkey, *op. cit.* [see footnote 12 above], p. 93.

[16] Two city agencies are responsible for the water supply: the Board of Water Supply, which develops new sources of water and builds the necessary dams and aqueducts; and the Department of Water Supply, Gas and Electricity, which maintains and operates the system built by the Board and builds, maintains, and operates the distribution system within the city.

[17] "Future Water Sources of the City of New York: Report of Engineering Panel on Water Supply to Mayor's Committee on Management Survey of the City of New York, July, 1951," p. 28.

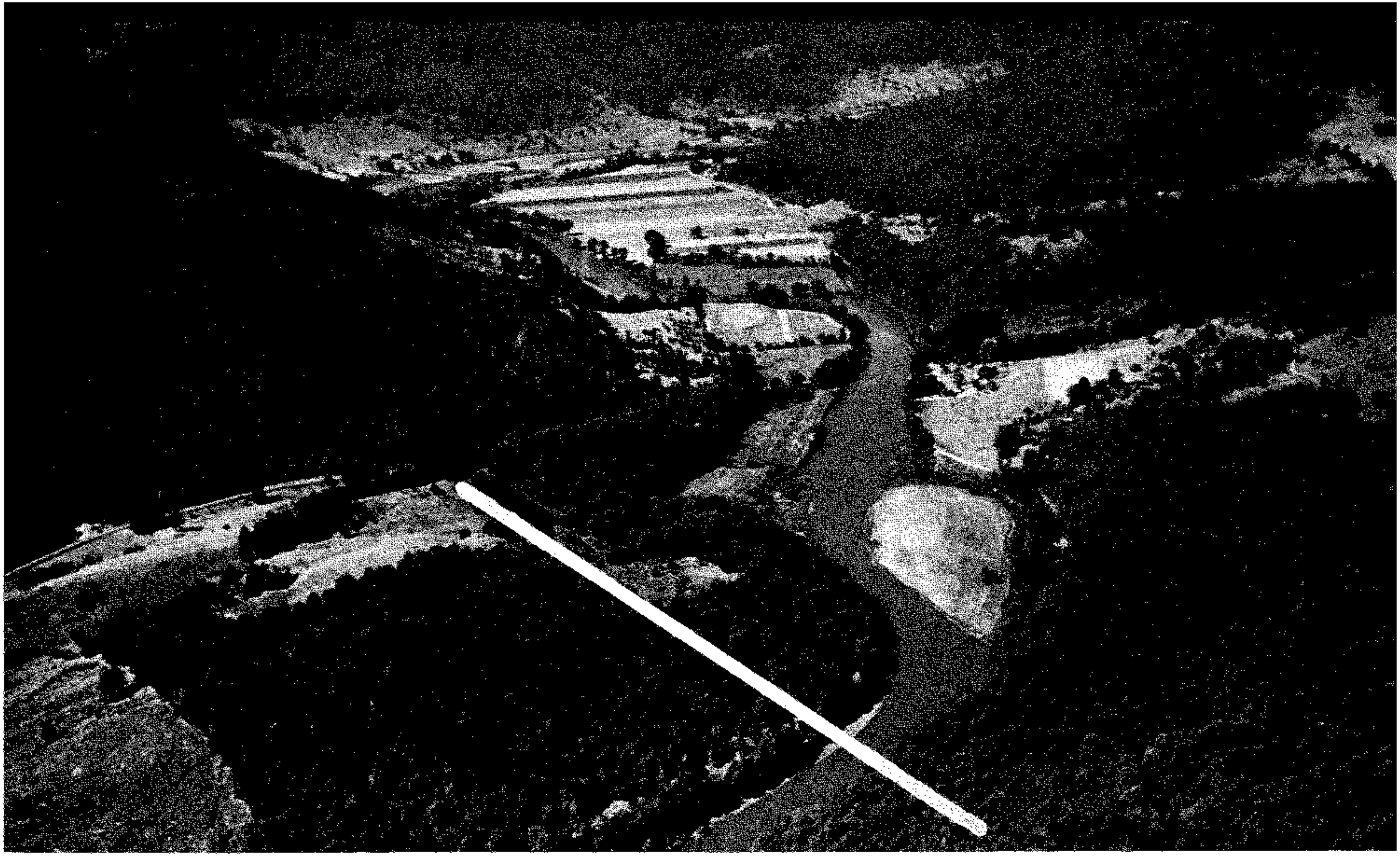
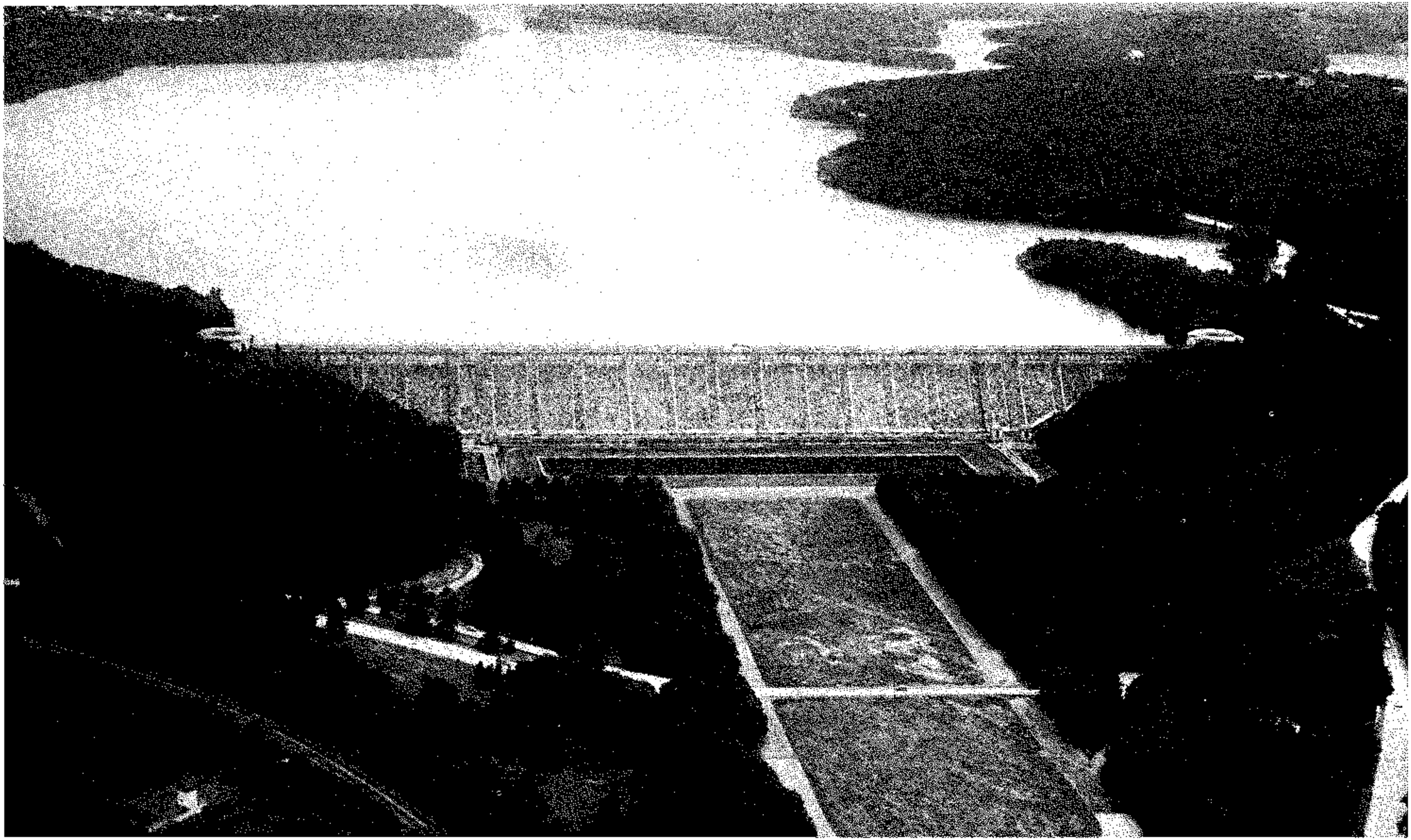


Fig. 2—Site of the Cannonsville Dam and Reservoir (now under construction) along the West Branch of the Delaware River. Gross reservoir capacity will be about 97.4 billion gallons. The elevation is 1150 feet. (Photograph courtesy Board of Water Supply of the City of New York.)

Fig. 3—Kensico Reservoir and Dam in Westchester County, 30 miles north of New York City. The reservoir is capable of storing 30.6 billion gallons, fed to it by the Catskill and Delaware watersheds and part of the Croton watershed. (Photograph courtesy, Board of Water Supply of the City of New York.)



consumers. In 1954, for example, it was found that the period of storage in Ashokan Reservoir reduced turbidity 62 per cent and bacterial count 71 per cent.[18]

FACTORS THAT INFLUENCED THE CONSTRUCTION OF THE DAMS AND AQUEDUCTS

Geology. The nature and general condition of the surface materials and bedrock in which dams and aqueducts are to be built determine the kind of structure required and the cost. Geological information, gained by surface exploration and test drilling, is therefore necessary during both planning and construction. With foreknowledge of the difficulties that will be met it is often possible to plan the route of an aqueduct or the location of a dam so as to avoid some of them. Where they cannot be avoided, construction can be planned to deal with them.

Because geological advice proved helpful in the construction of the New Croton Dam, completed in 1905, the city has employed geologists on the Catskill and Delaware systems from the earliest planning stages. Their careful exploratory studies have discovered, for example, places where ground water, seeping into the tunnels in large amounts, would complicate construction; caverns in limestone that might weaken tunnel walls; masses of deeply weathered rock, along faults or in places that had been protected from glacial erosion, that would require extra strengthening of tunnels; resistant rock formations that a tunnel should avoid; thick covers of glacial moraine filling deep preglacial or glacially eroded valleys that would require tunnels to be unusually deep to pass beneath them.[19]

Elevation of the Watershed Areas.[20] The Catskill water drops from 590 feet above sea level in the Ashokan Reservoir to 295 feet at the Hill View Reservoir (the distributing reservoir for both Catskill and Delaware water),

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[18] *Ann. Rept. New York City Dept. of Water Supply, Gas and Electricity, 1954*, pp. 71–72. See also F. E. Hale: Sanitation and Purification of New York City's Water Supplies, *Journ. New England Water Works Assn.*, Vol. 55, 1941, pp. 62–82. In spite of the naturally high quality of the water, some treatment is necessary: chlorination at least twice (but only four pounds of chlorine are needed per million gallons, as compared with 400 pounds per million gallons needed in many Midwestern cities); aeration to eliminate gases that cause unpleasant odor or taste; occasional addition of alum to precipitate sediments washed in by heavy rains. At three laboratories and in the field daily bacterial tests are made, totaling more than 30,000 a year.

[19] For detailed discussions of geological problems of this sort see Berkey, *op. cit.* [see footnote 12 above]; C. P. Berkey and T. W. Fluhr: Engineering Geology of the New York City Aqueducts, *in* Guidebook of Excursions, 61st Annual Meeting, Geological Society of America, 1948 (edited by Agnes Creagh; New York, 1948).

[20] Data in this section were taken from "The Water Supply . . . of New York" [see footnote 13 above], and Tobias Hochlerner: New York City's Water Supply to Outside Communities, *Journ. Amer. Water Works Assn.*, Vol. 37, 1945, pp. 754–764.

92 miles away, near the city line in Yonkers. Thus in the Catskill Aqueduct the water can move downhill under the influence of gravity. But since the drop is fairly slight, it was necessary to build about 80 per cent of the aqueduct with just enough slope to make the water flow. Where the surface is about at the level necessary for gravity flow, the aqueduct is a cut-and-cover structure—a channel cut into the surface and covered over with a mound of earth. In higher areas the gravity-flow level is maintained through tunnels. Where valleys cut below this level, the aqueduct goes under them in pressure tunnels.

Flow in the Delaware Aqueduct is by gravity also, and the drop from the outlet of the Rondout Reservoir, flow line 840 feet above sea level, to Hill View is even greater than that from Ashokan. However, this aqueduct is a deep pressure tunnel throughout its length, for reasons discussed below.

Incidentally, the elevation of the distributing reservoirs determines how and where the water will be delivered within the city. Catskill and Delaware water, distributed from the Hill View Reservoir, can flow by gravity to all parts of the city except the highest, where pumping is needed. In contrast, Croton water, distributed from the Jerome Park Reservoir, elevation about 133 feet, can reach by gravity flow only the parts of the city less than 40 feet in elevation. But since these consume only about one-third of the total Croton supply, the rest must be pumped to higher areas.[21] Long Island well water must always be pumped, of course.

Cultural and Physical Geography along the Delaware Aqueduct Route. The Delaware Aqueduct could have been constructed like the Catskill—a combination of cut-and-cover sections and tunnels (gravity and pressure). However, because of various conditions along the route it was built as a deep pressure tunnel throughout.[22] By the time it was built, in the late 1930's, villages, houses, roads, and other structures were much more numerous than they had been in the early years of the century, and property values had greatly increased. Building deep below the surface avoided conflict with these surface developments and eliminated the necessity of paying high taxes for surface rights of way. Only underground easements were needed. West of the Hudson the aqueduct crosses a number of deep valleys, under which pressure tunnels would have been required anyway, and a number of high ridges, under which deep tunnels were necessary (the deepest of these

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[21] The Delaware Aqueduct, connected with the West Branch Reservoir of the Croton system, can now carry about 100 mgd from the higher Croton reservoirs to Hill View, which reduces the cost of pumping Croton water from the Jerome Park Reservoir.

[22] See "The Water Supply . . . of New York" [see footnote 13 above]; Lawrence Ravitz: Delaware Watershed Connected with City through 85-Mile Underground Aqueduct, *Bull. General Contractors Assn.*, March, 1948, pp. 15–18; and "More Water for New York City," *ibid.*, March, 1937, pp. 46–55.

FIG. 4—Schoharie Reservoir and Gilboa Dam. The capacity of the reservoir is 19.6 billion gallons. The elevation is 1130 feet. (Photograph courtesy Board of Water Supply of the City of New York.)

is 2500 feet below the ridge crest). A deep pressure tunnel for the entire length was therefore simpler to build, and it will have lower maintenance costs and greater safety from damage. Choice of the exact route was often guided by surface conditions. For building the access shafts (there are 31 of these) room was needed on the surface, and both for this reason and to keep down the cost of the sites the more heavily built-up areas were avoided whenever possible.

EFFECT OF THE CITY'S WATER-SUPPLY SYSTEM ON THE SOURCE AREAS

Changes in Physical Conditions

The Upland Watersheds. Most obvious among the physical changes in the upland watersheds are the reservoirs—twelve in the Croton watershed, two in the Catskill system, and four in the Delaware. These, with their borders of pine trees (another change introduced by the water system), add greatly to the scenic beauty of the areas and to their recreational facilities. By state law the city must allow boating, fishing, and ice cutting on the reservoirs, subject to reasonable regulations.[23] Ice cutting is no longer carried on, of course. But permits for boating and for fishing, from shore or boat, are available free of charge from the Department of Water Supply, Gas and Electricity.

More localized is the change in Esopus Creek, which now carries, in addition to its own water, the water from the Schoharie Reservoir (Fig. 4), diverted southward under the mountain divide by means of the Shandaken Tunnel. Because of the resulting great increase in the volume and depth of Esopus Creek, some adjacent areas have been flooded.[24]

In the spring and summer of 1950 New York City tried to change conditions in the Catskill and Croton watersheds in still another way—artificial rain making.[25] As one of its efforts to ease the critical water shortage of 1949–1950 the city employed Dr. Wallace E. Howell, a meteorologist, to seed the clouds over the watersheds with silver iodide. In 31 weeks Dr. Howell carried out 36 seeding operations. During that period the rainfall in some months was greater than average, and in the watersheds it was 14 per cent greater than in surrounding areas that had not been seeded. Whether

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[23] T. De L. Coffin: Sanitation of the Croton Watershed, *Water Works Engineering*, Vol. 95, 1942, pp. 1440–1442 and 1462.

[24] "The Water Supply . . . of New York" [see footnote 13 above], p. 15.

[25] *New York Times*, Apr. 25, 1954; H. T. Orville: Weather Made to Order? *Collier's*, May 28, 1954, pp. 25–29.

the increased rainfall was caused by the seeding can never be proved, of course, since natural variations in rainfall from year to year are marked.

The Long Island Water Table. When ground water is withdrawn more rapidly than it accumulates, the water table is lowered. Many parts of the country have been damaged in this way, some of them seriously; a notable example is western Long Island.[26] During the early decades of this century the water table here dropped rapidly because of the combined effects of (1) decreased replenishment as buildings and pavements covered more and more of the surface and (2) increased use. Water was withdrawn both for public use, from wells owned by the city and by several private water companies, and for industrial use, from wells owned by the industries themselves. How great the overwithdrawal was becoming was not realized until 1933, when a detailed survey of the island's ground-water resources revealed that the water table was below sea level, more than 15 feet below in some places, in an area of more than 40 square miles, including nearly all of Brooklyn and adjacent parts of Queens. Sea water was infiltrating into the wells and moving farther and farther inland each year.

It was because of this situation that in 1933 the New York State Legislature passed a law requiring that new Long Island wells yielding more than 100,000 gallons a day and not to be used for agriculture must be approved by the state Water Power and Control Commission. When such new wells are to supply water for industrial cooling and air conditioning, the water must be returned after use to the aquifer from which it was taken. This can be done by pumping the water back through a recharge well (the method commonly used in crowded Brooklyn and Queens because it requires little surface area) or by allowing it to accumulate in a recharge basin and soak back into the ground (the method often used in the more open areas of Nassau and Suffolk Counties). The returned water has been found to be 2°–20° F. warmer than when it was first pumped from the ground and is therefore less effective for subsequent cooling; however, only where there are numerous recharge wells close together is the effect marked. Nassau County has also provided eleven recharge basins for the accumulation and seepage of storm runoff discharged into the sewers.

In spite of these conservation measures, the water table continued to drop for several years and in the late 1930's reached levels as much as 35

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[26] See, for example, M. L. Brashears, Jr.: Artificial Recharge of Ground Water on Long Island, New York, *Econ. Geol.*, Vol. 41, 1946, pp. 503–516; A. H. Johnson and W. G. Waterman: Withdrawal of Ground Water on Long Island, New York, *New York State Dept. of Conservation, Water Power and Control Commission, Bull. GW-28*, 1952; N. J. Lusczynski and A. H. Johnson: The Water Table in Long Island, New York, in January 1951, *ibid., GW-27*, 1951; N. J. Lusczynski: The Recovery of Ground-Water Levels in Brooklyn, New York, from 1947 to 1950, *U. S. Geol. Survey Circular 167*, 1952.

feet below sea level. Recovery did not begin until about 1941 and was slow at first. An element of gradual change was the decrease in the number of plants manufacturing ice. As their business was curtailed by the increasing use of electric refrigerators in homes, their pumping of ground water decreased, from 18 mgd in 1936 to 4 mgd in 1947. A more abrupt change came in 1947. In that year net withdrawal of ground water in Brooklyn was reduced by more than half, because the city required the New York Water Service Corporation to stop pumping from its Flatbush wells, source of the infamous "Flatbush" water. Against this unsatisfactory public supply—brackish, corrosive, and hard—there had been public outcry for years, and the change in 1947 to Catskill water brought rejoicing. It also initiated a more rapid recovery of the water table, which by the early 1950's had been raised above sea level in the entire south half of Brooklyn. In the northwest, where there are large industrial wells that predate the conservation measures of 1933, heavy industrial use keeps the water table well below sea level. And in western Queens it stays slightly below sea level because of pumping for public supply by the Jamaica Water Supply Company and the New York Water Service Corporation.

EFFECTS ON PEOPLE AND COMMUNITIES

Displacement of People and Their Works. To strangers driving past, the city's reservoirs may look like natural lakes. Old-timers, however, cannot forget that they are man's work, in a sense a new cultural landscape blotting out the old one they remember so well. Inundated under many feet of water are hundreds of farms, among them prosperous dairy farms in the valleys tributary to the Delaware; resort hotels and camps that drew numerous summer visitors to the mountain valleys of the Catskill and Delaware watersheds; more than 20 villages, with their homes, churches, schools, and businesses; and more than 60 cemeteries. From these last some 10,000 bodies were removed for burial elsewhere. And from the farms and villages some 6000 permanent residents have been displaced.[27]

By state law the city is allowed to acquire the property it needs through condemnation proceedings, but it is also required to pay generously. As a matter of course it must pay the value of the property, buildings, and equipment taken—and this requires a separate negotiation for each piece of property, 557 of them in the Pepacton Valley alone, for example. But in

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[27] Exact figures for the areas covered by the Ashokan, Schoharie, Rondout, Neversink, and Pepacton Reservoirs are given in "The Water Supply . . . of New York" [see footnote 13 above], pp. 35 and 76. Some figures for the area that will be covered by the Cannonsville Reservoir are given in the *New York Times*, July 28, 1957.

addition the city must pay claims for business losses, loss of wages, and so on, both to those whose property has been taken and to people in nearby areas. In the Pepacton Valley there were 475 such claims.[28]

Benefits to Local Communities. To residents in the watershed areas the city water system brings several benefits: an easily available water supply if they wish to tap it; a real-estate tax income that may be sizable; and in many localities sewage-disposal plants at no cost.

By state law the city must allow communities and water districts in Delaware, Greene, Orange, Putnam, Schoharie, Sullivan, Ulster, and Westchester Counties to take water from city aqueducts or reservoirs, subject to reasonable regulation. The users must pay a reasonable rate for the water and all costs of their connections with the city system.[29] Use has been made of this privilege chiefly in Westchester, where 58 per cent of the water supplied by communities in 1957 came from the city system.[30] To these communities, and to a handful west of the Hudson, the city furnishes an average of nearly 50 mgd, for which it is paid more than $1.5 million yearly.[31]

Land owned by the city for water-supply use totals 73,000 acres, with an assessed value of about $75 million. The 1957 state, county, town, village, and school-district taxes on this land amounted to about $5.5 million.[32] In some localities the city's payments make up a large part of the total real-estate tax income—90 per cent, for example, in the little village of Olive in Ulster County, and 25 per cent even in the prosperous township of North Castle in Westchester County.[33]

By state law New York City can, with the approval of the state Health Department, set up sanitary regulations in its watershed areas.[34] This permits the city (at its own expense, of course) to improve sewage-disposal facilities on private property and, in villages with public water supplies, to build sewage-disposal plants, which it must maintain and operate forever. Such plants have been built in a number of places in all the city's watersheds, and one was built outside the watersheds at Port Jervis, N. Y., on the Delaware River, as directed by the United States Supreme Court in its decree of 1931.[35]

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[28] "The Water Supply . . . of New York" [see footnote 13 above], pp. 4–5.

[29] Hochlerner, *op. cit.* [see footnote 20 above], p. 755.

[30] *New York Times,* Mar. 9, 1958.

[31] *51st Ann. Rept. New York City Board of Water Supply, 1957.*

[32] See the *New York Times,* July 7, 1956, and February 2, 1958, and annual reports of the Department of Water Supply, Gas and Electricity.

[33] *New York Times,* July 5, 1956.

[34] Thaddeus Merriman: Sanitation on the Catskill Watersheds: Riparian Ownership Creates Interesting Problems, *Amer. City Mag.,* Vol. 31, 1924, pp. 119–120.

[35] See Kennison, *op. cit.* [see footnote 10 above].

EFFECT OF THE CITY'S WATER-SUPPLY SYSTEM ON MORE DISTANT AREAS

Control of Volume in the Delaware and Its Tributaries

Water diverted from the Delaware headwaters for use in New York City is permanently removed from the Delaware drainage system. And yet because of the diversion the headwaters below the dams and the main valley downstream from them have more water available for use, not less, as many residents of the valley feared would be the case.[36] Without the dams the volume of these streams varied greatly, from flood stage, when there was more water than could be used, to a mere trickle in the dry summer months. The dams help to reduce the volume of floods, with their destruction and waste of water, as was demonstrated in 1955 when Hurricane Diane brought heavy rains to the region. And the dry-season volume is increased by releases of stored water from the reservoirs. For the main valley these were ordered by the United States Supreme Court in its decisions of 1931 and 1954, in amounts great enough to maintain a specified minimum flow (according to the 1954 decision, 1525 cubic feet per second at the United States Geological Survey gauging station at Montague, N. J.). This is chiefly to provide adequate water for community water supplies, navigation, sewage disposal, and pollution control; however, camps and resorts in the upper valley and the shad-fishing industry downstream should also benefit. In the very dry summer of 1957 these releases made up about two-thirds of the average flow of the river. Within New York State the minimum volume of the streams below the dams is controlled in the same way (Rondout Creek, a tributary of the Hudson, is included), in accordance with regulations of the Conservation Department of New York State and the state Water Power and Control Commission. These releases, made whether or not any are needed for the main valley, are solely for conservation of fish. As a result, the streams are kept full even in droughts. In the dry summer of 1957, for example, 1201 million gallons of water were released daily from the Pepacton Reservoir, and 345 million from the Neversink Reservoir, at a time when the natural flow in the streams would have been only 133 and 83 million gallons daily.

Control of Salinity in Delaware Bay

Salinity of the water in Delaware Bay, of great importance to the oyster

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[36] Data in this section were taken from C. E. Heacox: Reservoirs vs. Drought, *New York State Conservationist*, Feb.–Mar., 1958, p. 7; "Report [to the Interstate Commission on the Delaware River Basin] on the Utilization of the Waters of the Delaware River Basin, Malcolm Pirnie Engineers, Albright and Friel, Inc., Consulting Engineers, August 1950."

industry, is affected by the volume of fresh water flowing in. The boundary line between fresh and brackish water surges upvalley at times of low stream flow and downvalley in floods. It is close to this boundary that the oysters flourish best; for there the salinity is too low for their chief enemies—oyster drills, starfish, and mussels. Some oystermen feared that New York City's withdrawal of Delaware River water would cause a permanent upvalley shift of the critical border zone, bringing saltier water to the oyster beds they were working. Instead, the decreased variation in stream volume will mean a decrease in the naturally great variation in salinity. This should benefit the oyster industry, which yields five million bushels a year here and is important to residents of both New Jersey and Delaware.[37]

The story of New York City's water supply is thus one of interactions: between various elements of the earth environment within the watershed areas; between man and the earth environment both locally and in more distant areas; between the city and individuals in the watershed areas; between the city and other political units or agencies (the United States Supreme Court, New York State and adjoining states, state agencies and departments, counties, townships, villages, school districts); and between man's resource needs and government regulations. On the one hand the amount and quality of the water available to the city have been affected by the physical and cultural geography of the watersheds and by the political organization of the main Delaware Valley. On the other hand the development of the city's water supply has affected the physical and cultural geography of the watersheds and of the Delaware Valley. In these more distant areas it has not influenced political organization, but the city's own political organization, resulting from the creation of the Greater City, may have been partly influenced by water needs and developments. And both locally (on Long Island) and in the Delaware Valley the utilization of water resources has resulted in government regulation, which in its turn has influenced the availability of water.

To understand the geography of New York City's water supply, we must know the locational facts of where the water comes from, where it is stored, and by what routes it reaches the city. And we must know descriptive facts about the source areas. But these facts, locational and descriptive, are only the raw materials of geography. From them must come an understanding of the interactions discussed above, a compound of physical, cultural, and political geography.

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[37] "Report on . . . the Delaware River Basin," p. 56.