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INVESTIGATIONS AND STUDIES FOR THE RICHMOND TUNNEL TO BE CONSTRUCTED UNDER NEW YORK HARBOR

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THE average daily consumption of water by New York City for the year 1961 is estimated now to average about 1270 million gallons daily with peak summer daily rates of about 1550 m.g.d. By the year 2000 the average rate is estimated to average about 1800 m.g.d.

These enormous demands have been and will be met from upland surface water supplies developed since 1905 by the Board of Water Supply and flowing by gravity into New York City. The Croton system built by the City prior to 1893 still furnishes up to about 150 m.g.d. without pumping and the needs of low service areas can theoretically increase that amount, without pumping, to the total yield capacity of the watershed to about 330 m.g.d. The Catskill supply consisting of Ashokan and Schoharie Reservoirs furnishes a safe yield of 565 m.g.d. and the Delaware Supply will furnish a safe yield of 800 m.g.d., of which 490 m.g.d. capacity is now obtainable from the recently completed Rondout, Neversink and Pepacton Reservoirs and the remaining 310 m.g.d. capacity will be available by 1965 from the Cannonsville Reservoir, now under construction.

The waters from the Croton reservoirs are fed into Jerome Reservoir in the Bronx through the Croton Aqueduct. The waters from the Catskill reservoirs are fed into Kensico Reservoir about 15 miles from the City and Hill View Reservoir at the City line by the Catskill Aqueduct and from the Delaware reservoirs by the Delaware Aqueduct into Kensico and Hill View Reservoirs. The Neversink tunnel joins

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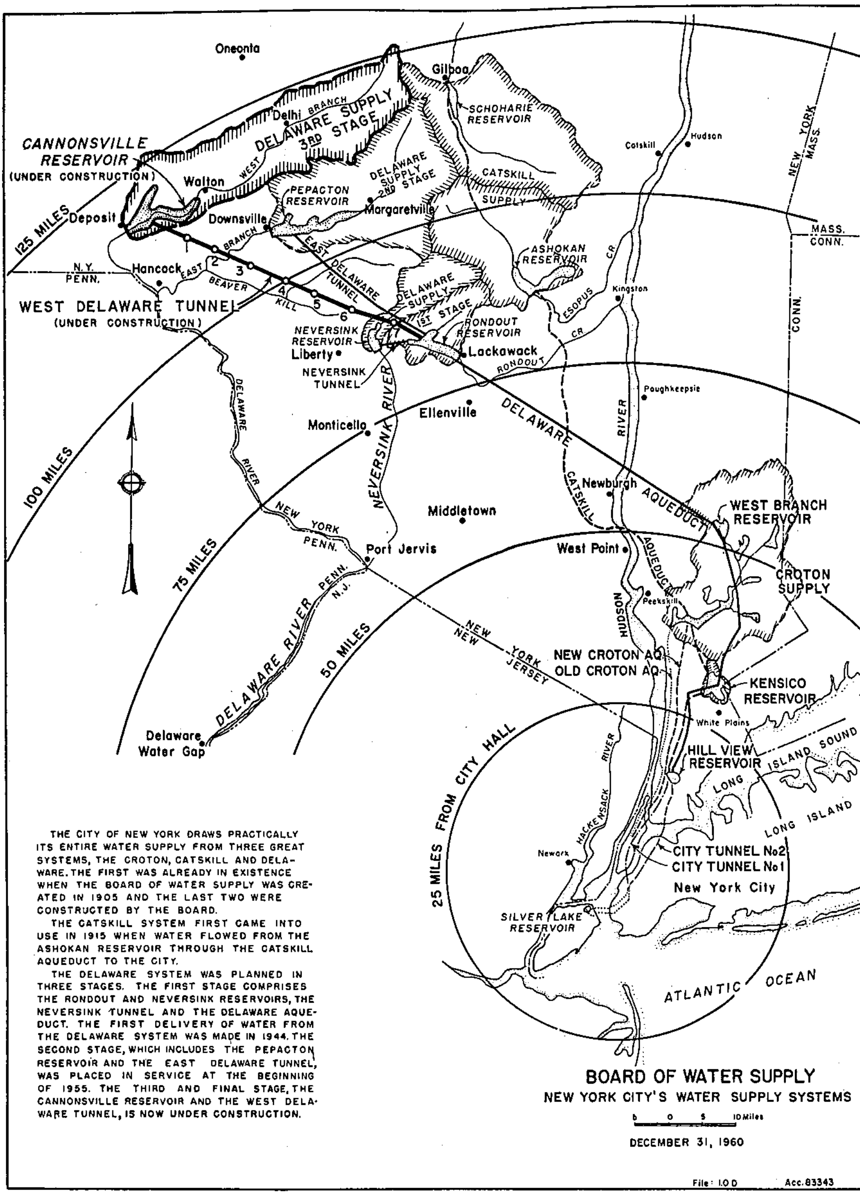
Oneonta
Gilboa
SCHOHARIE RESERVOIR
DELAWARE SUPPLY 3RD STAGE
Delhi
WEST BRANCH
CANNONSVILLE RESERVOIR
(UNDER CONSTRUCTION)
Walton
PEPACTON RESERVOIR
DELAWARE SUPPLY 2ND STAGE
Margaretville
CATSKILL SUPPLY
Downsville
Deposit
125 MILES
EAST BRANCH
EAST DELAWARE TUNNEL
ASHOKAN RESERVOIR
Hancock
N.Y.
PENN.
BEAVER KILL
DELAWARE SUPPLY 1ST STAGE
WEST DELAWARE TUNNEL
(UNDER CONSTRUCTION)
NEVERSINK RESERVOIR
RONDOUT RESERVOIR
Liberty
Lackawack
NEVERSINK TUNNEL
RONDOUT
ESOPUS CR
Kingston
Catskill
Hudson
NEW YORK
MASS.
CONN.
Poughkeepsie
DELAWARE RIVER
NEVERSINK RIVER
Monticello
Ellenville
DELAWARE AQUEDUCT
100 MILES
Middletown
Newburgh
CATSKILL AQUEDUCT
WEST BRANCH RESERVOIR
NEW YORK PENN.
Port Jervis
West Point
CROTON SUPPLY
75 MILES
PENN. N.J.
Peekskill
HUDSON RIVER
DELAWARE RIVER
50 MILES
NEW YORK NEW JERSEY
NEW CROTON AQ.
OLD CROTON AQ.
KENSICO RESERVOIR
White Plains
Delaware Water Gap
25 MILES FROM CITY HALL
HILL VIEW RESERVOIR
LONG ISLAND SOUND
HACKENSACK RIVER
LONG ISLAND
Newark
CITY TUNNEL No2
CITY TUNNEL No1
New York City
SILVER LAKE RESERVOIR
ATLANTIC OCEAN
THE CITY OF NEW YORK DRAWS PRACTICALLY ITS ENTIRE WATER SUPPLY FROM THREE GREAT SYSTEMS, THE CROTON, CATSKILL AND DELAWARE. THE FIRST WAS ALREADY IN EXISTENCE WHEN THE BOARD OF WATER SUPPLY WAS CREATED IN 1905 AND THE LAST TWO WERE CONSTRUCTED BY THE BOARD.
THE CATSKILL SYSTEM FIRST CAME INTO USE IN 1915 WHEN WATER FLOWED FROM THE ASHOKAN RESERVOIR THROUGH THE CATSKILL AQUEDUCT TO THE CITY.
THE DELAWARE SYSTEM WAS PLANNED IN THREE STAGES. THE FIRST STAGE COMPRISES THE RONDOUT AND NEVERSINK RESERVOIRS, THE NEVERSINK TUNNEL AND THE DELAWARE AQUEDUCT. THE FIRST DELIVERY OF WATER FROM THE DELAWARE SYSTEM WAS MADE IN 1944. THE SECOND STAGE, WHICH INCLUDES THE PEPACTON RESERVOIR AND THE EAST DELAWARE TUNNEL, WAS PLACED IN SERVICE AT THE BEGINNING OF 1955. THE THIRD AND FINAL STAGE, THE CANNONSVILLE RESERVOIR AND THE WEST DELAWARE TUNNEL, IS NOW UNDER CONSTRUCTION.
BOARD OF WATER SUPPLY
NEW YORK CITY'S WATER SUPPLY SYSTEMS
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the Neversink Reservoir into the Delaware system, the East Delaware tunnel joins the Pepacton Reservoir into such system and the recently driven West Delaware tunnel will join the Cannonsville Reservoir into that system.

From Hill View Reservoir, water is fed into New York City by Tunnels Nos. 1 and 2 put into service in 1917 and 1936 respectively.

The population served now is approximately 8 million, not including transients, and for the year 2000 it is estimated to be nearly 10 million. The average daily consumption is at present about 150 gallons per capita.

New York City corporately consists of five boroughs, Manhattan, Queens, Brooklyn, The Bronx and Richmond. The first four of these boroughs are serviced in addition to the Croton Supply, by shaft connections of City Tunnels Nos. 1 and 2 to the distribution mains. The borough of Richmond, which is Staten Island, is serviced by a 36-inch cast iron flexible joint pipe placed in operation in 1917 and 42-inch pipe of like design placed in operation in 1925. Each of these lines is laid in a trench in the muds and sands of the New York harbor bottom. These mains connect indirectly with City Tunnel No. 2 in Brooklyn and with the Silver Lake distribution reservoir on Staten Island.

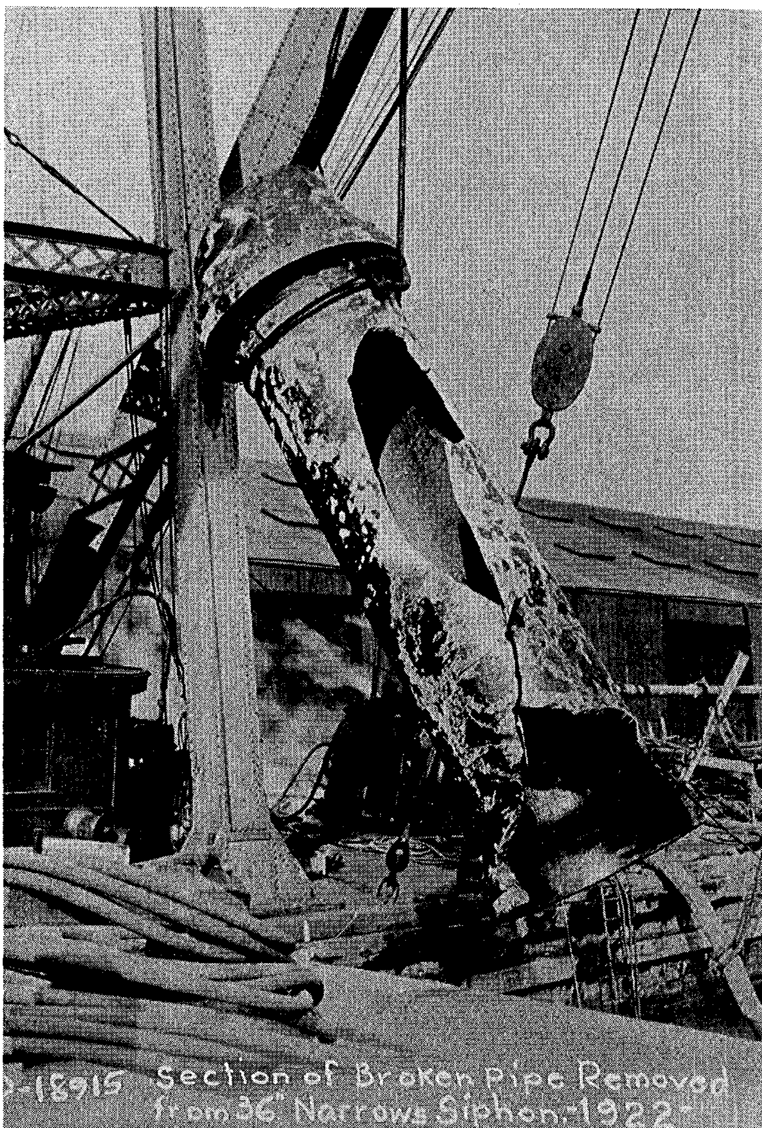
The Board of Water Supply, approaching completion of the Cannonsville Reservoir after years of effort in obtaining water from the East and West Branches of the Delaware River, an interstate stream, through decrees of the Supreme Court in 1931 and 1954 which provide for large compensating dry weather releases to the river below the reservoirs as well as for the diversions, turns its attention at the direction of the Board of Estimate upon joint request of the Department of Water Supply, Gas and Electricity and the Board of Water Supply, to plans and studies inherent with the transportation and delivery to the various boroughs for proper distribution in sufficient amounts at adequate pressures. At present the capacities of City Tunnels Nos. 1 and 2 are fully used and in times of peak demand undesirable pressure drops are experienced in parts of Manhattan, Brooklyn and Queens. There is no allowance for a temporary shutdown for emergency repairs to the shaft heads of either tunnel and each has now been in service about 30 years.

The Borough of Richmond is much smaller in population than any of the other four, but it has at present a population of about ¼ of a million people (about equal that of the City of Providence, Rhode Island). The borough has a surface area of 38,591 acres and is the third largest borough in area, only the Boroughs of Queens and Brooklyn being larger. Accordingly, its population density is considerably lower than the other boroughs being about 6 per acre against 116 for Manhattan, about 50 for The Bronx and Brooklyn and 25 for Queens. About 40 per cent of the gross acreage of Richmond is still free for future development. The Borough of Queens is developing more rapidly at present than any of the others. The growth on Staten Island has been hampered by lack of highway transportation to the mainland. Under construction is the Verrazano Bridge at the Narrows which is scheduled for completion by 1965 and there is every prospect of industrial development and a population explosion for Staten Island upon completion of that bridge. It is estimated that the ¼ million population will increase to 590,000 by 1975 and 700,000 by the year 2000.

Richmond is served by the 36-inch and 42-inch cast iron mains about 43 and 35 years old respectively, and the present summer demands exceed the total capacities of both mains. Only the large storage capacity of Silver Lake Reservoir prevents a summer shortage now. Injury, damage or failure of either main would be of serious consequence. The open Silver Lake Reservoir is subject to pollution from sea gulls. Thus the situation in Richmond is critical without the expected future growth which will be greatly enhanced by the completion of the Narrows Bridge. In November 1960 the Board of Water Supply submitted a report to the Board of Estimate based upon investigations and studies carried on over a period of years to determine a recommended solution to the above problem.

The investigations and studies indicate that a three stage construction program is needed, planned so that completion of the three stages will terminate simultaneously in about 5 years. Stage I will consist of a concrete-lined rock pressure tunnel from Brooklyn to Staten Island nearly five miles long constructed under New York Harbor in the bedrock foundations at an elevation about 900 feet below mean sea level. This tunnel will be about 10 feet in diameter and will connect a downtake shaft in the Red Hook section of Brooklyn with an uptake shaft in the Tompkinsville section of Staten Island, both shafts to be also constructed as part of Stage I as well as the connections in Brooklyn between Shaft 17A of City Tunnel No. 2

and the downtake shaft, which is located about 228 feet from Shaft 17A and in Richmond between the existing large distribution feeder and a connection chamber at or near the uptake shaft. Stage II will consist



of a large diameter pipeline (about 84″) laid through the streets of Richmond to form a connection between the new Richmond tunnel and the Silver Lake Reservoir area. Stage III will consist of the construction in Silver Lake Park of covered underground storage tanks, equivalent to about 100 million gallons capacity to protect the purity of the delivered water from pollution and to provide a higher flow line than is possible with the present reservoir, thus to create increased hydraulic benefit not only in Richmond but cross-harbor to Brooklyn, Manhattan and even Queens. With the completion of such a system, the Borough of Richmond for the first time will have a system of supply comparable to that of the remaining boroughs.

This program was approved by the Board of Estimate on February 9, 1961 and $31,100,000 total authorized; $24,170,000 for Stage I, $1,380,000 for Stage II and $5,550,000 for Stage III.

Contracts for Stage I are now in preparation and it is expected that this work will be advertised for bids this year. Stage III is planned for advertising about 1 year from now and Stage II in about 3 years from now, so that all construction will end simultaneously in 4 to 5 years hence.

All modern methods, some more feasible than others were investigated in the search for a proper, adequate and economical system to augment the supply of water of Staten Island.

Studies of Major Augmentation to Present Facilities

To meet the obvious need for major augmentation to the existing supply for the Borough of Richmond, several methods were studied and analyzed as follows:

(a). *Conversion of Saline Water*: Because Staten Island is entirely surrounded by salt water and because in recent years growing attention has been directed to extraction of fresh water from the masses available in the ocean, this method received due consideration. An additional reason for careful scrutiny of this method was that, if such a source could prove to be feasibly used for Staten Island, there were future possibilities of using such a development on Staten Island to furnish water for the future needs of the other four boroughs as well, which consideration might affect the thinking in connection with the aqueduct or aqueducts joining Richmond with the other boroughs.

In summary, it was found that the processes so far developed as well as other conversion processes under experimentation are not now in the realm of practicability for use on Staten Island and in addition it does not appear immediately that any suitable or adequate process of this nature for the problem at hand will be forthcoming for many years to come. The cost of development alone is prohibitive. In my opinion, conversion of saline water as a source of fresh water for Richmond should not be considered until all fresh water sources have been exhaustively utilized.

(b). *Surface Supplies*: The obtaining of water through the capture, storage and distribution of rainfall and runoff from surface areas is, next to that of well supplies, the most common of all water supply procedures. This requires terrain with broad and reasonably undeveloped watersheds for catchment purposes and suitable reservoir sites. The Richmond topography does not meet these requirements, and if it did the value of its acreage, in one of the world's most important metropolitan centers, would preclude its reservation for water supply purposes.

(c). *Ground Water Supplies*: Only a comparatively small part of Richmond is suited to well systems. The island has been thoroughly explored by well drills. A small area bordering the Atlantic Ocean of about 5 square miles in extent, and a second area of limited extent and depth in the center of the island, are at present exploited to the limit of the safe yield of these areas. The sinking of additional wells would only lead to excessive drawdowns in these aquifers, so that further wells should not be developed.

(d). *Large Feeder Connection to New York's Upland Supplies*: Barring the satisfaction of Richmond's development of sources of supply by other methods, there remains the augmentation of the Borough's supply by additional connections to the main supply feeders of the other four boroughs and the quantity of upland water developed and being developed by the City is adequate to so permit.

The matter then becomes a problem of dependable transportation and delivery. Many analyses and studies showed by the following three schemes seemed the most worthy of further consideration:

(1). The construction of additional siphons (cast iron or steel) across the Narrows, such to be similar in construction to those already in place.

(2). The construction of a submarine aqueduct, laid in the harbor bottom along the most direct route to be feasible.

(3). The construction of a tunnel from Brooklyn to Richmond deep in the bedrock formations under the harbor.

As a matter of interest, consideration was also given to the possibility of carrying supply feeders to Richmond over the proposed new bridge at the Narrows but the gradient of the bridge, the risk of carrying a rigid pressure line on an extremely flexible framework, and especially the very high cost, immediately ruled out further consideration of this type of aqueduct connection.

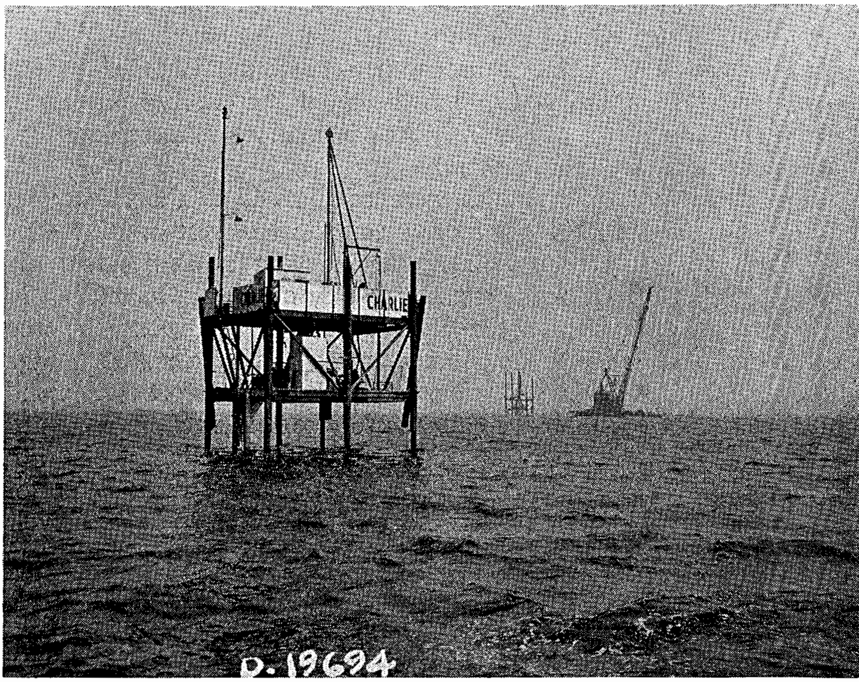
1. *Additional siphons across the Narrows*: This would consist of from one to ten additional 42-inch diameter flexible joint pipes installed progressively as the need increased or concurrently in the interest of reduced over-all cost. These would be fed by a 72-inch steel cylinder pressure concrete main from Shaft 17A to the Narrows. The over-all length of this route would be 46,000 feet. The cost alone of this method was too large even though several other disadvantages made it less desirable than the tunnel location. For example, the cost of one such 42-inch siphon with connections would be $17,300,000, two $22,100,000, three $26,900,000 etc. The troublesome location of the onshore connecting surface aqueducts and the more vulnerable locations of the siphons in the harbor muds and sands were two of the undesirable features.

2. *Single large diameter siphon along most feasible surface route.* This would consist of a 9 or 10 foot diameter steel cylinder reinforced concrete pipe of submarine type where laid in the harbor bottom. The complexity and magnitude of the surface conduit problems of Scheme 1 were also inherent in this one. In addition the cross water installation presented problems which might not be satisfactorily solved. The cost would be more than that of the tunnel by over $5,000,000.

3. *Tunnel from Brooklyn to Staten Island.* This would consist of a hard rock tunnel, lined with concrete, about ten feet in finished inside diameter extending directly in a straight line between Shaft 17A of City Tunnel No. 2 in Brooklyn to Staten Island. Careful and extended analyses indicated this method to be the most satisfactory, economical, feasible and dependable.

Investigations

The location of the Richmond Tunnel and appurtenances was investigated by 87 borings of which 60 located the surface of sound bedrock and 11 more penetrated deeply into the bedrock under the floor after locating the surface of sound rock. Being approximately 800 feet apart, the harbor borings produced a record of geologic formations across the waist of New York Harbor that had never before been attempted and the wealth of boring data obtained has furnished data for reports of Engineering Geologists of the Board—Frank E. Fahlquist and Thomas W. Fluhr—and has established the soundness and suitability of the rock floor between Brooklyn and Richmond along the chosen route, for the tunnel being proposed.



MAKING BORINGS FOR THE RICHMOND TUNNEL IN UPPER NEW YORK HARBOR

No program of borings can reveal everything concerning subsurface conditions, and uncertainties remain upon completion. There is no doubt that the excavations for the tunnel will pierce numerous joints, some of which will contain water seepage and some of which may be accompanied by crushed or decayed zones at the faults. However, the borings indicate that the formations involved for the most part are very hard and sound even though roof bolting or structural type of roof support may be required at many locations.

There exist the hazards of water inflows during excavation. Accordingly, the tunnel has been designed to be built 900 feet below sea level (about 700 feet below the rock surface as indicated by borings) in order to be conservative in the minimizing of the difficulties that might be encountered even though there appears to be no likelihood of a rock valley of any appreciable dimension existing between borings. Because of the hazards under which the tunnel will be excavated, even though it appears they will not be great, exploration by drilling in advance of driving the tunnel heading will be required. The soundness of the excavation can accordingly be anticipated and the number, size and seriousness of water bearing seams can be predetermined. Thus, where desirable, these conditions can be alleviated materially, permitting the tunnel heading to be driven into rock formations rendered sounder and drier by advance grouting.

Extensive hydraulic studies were conducted, as the Richmond tunnel is at the southerly end of a complicated system of feeder aqueducts and distribution mains. The carrying capacities and the pressure gradients that might result, not only on Staten Island but in the Boroughs of Brooklyn, Manhattan and even Queens, by the construction of the new Richmond connection and by elevated storage on Staten Island were given serious consideration. As the Richmond tunnel will be completed well in advance of the construction of a third City Tunnel it will be possible, during peak demand periods, with storage of adequate elevation on Staten Island and with a tunnel of adequate cross-section, to lessen the draft on Hill View Reservoir north of the City and to develop higher pressures in the existing system in the southern parts of the City.

The consideration of the future needs of the Borough of Richmond, the results of the hydraulic analyses, and the economics of hard rock tunnel construction led to the conclusion that the size should be not less than 10 feet in finished inside diameter, particularly as such size approaches the minimum cost per foot.

Related studies indicated the advisability of furnishing underground storage of 100 million gallons capacity with a flow line of about Elevation 280, which is about 50 feet higher than the existing open Silver Lake reservoir of 450 million gallons capacity. The topography of the hillside at the existing site is such that the higher underground storage can be built adjacent to the site of the present reservoir.

The selection of shaft sites for the construction of the Richmond

Tunnel presented a challenge, but two sites were found and the borings verified their suitability. In the populated busy downtown section of Brooklyn, Block 521, roughly an acre of land, has been secured with relatively low costs and public inconvenience, one gasoline station and fourteen house lots were involved. Six houses of slum clearance calibre together with eight vacant lots existed in the block. Only thirty-three people were inconvenienced by being forced to find better quarters and only one business interest (the gasolne station) was disturbed. This block is only about 230 feet from Shaft 17A of City Tunnel No. 2. A land connection beneath Gowanus Parkway will be needed, but will be built at a time when a program for widening the parkway will be in progress, a year or more hence.

The second site selected, on Staten Island, is on City property under jurisdiction of the Department of Marine and Aviation. The site is about 340 feet from the harbor bulkhead line and is undeveloped at present although that department has plans for its future use in the projected development of port and pier facilities on Staten Island. Thus adequate area for shaft construction purposes is available before the development program can be initiated, and only a small area for shaft access will be needed beyond the construction period.

Reconnaissance and surveys were conducted to locate an 84 inch aqueduct connection between the Richmond shaft and the Silver Lake reservoir. The pipe line will, in general, follow the City streets and will be about 5000 feet in length. Borings disclosed the feasibility and suitability of making the connection. Such connection to Silver Lake Reservoir will also be joined with the existing surface distribution network in Richmond. Its construction will be complicated by its location under railroad tracks and main highways near the shaft site; by the crowded condition in some downtown streets in Tompkinsville; and by the steep hillside between the waterfront at the shaft location and the reservoir site on the hill.

The results of the investigations, studies and recommendations for the Richmond Project are included in a volume entitled "Reports on the Increased Water Supply for the Borough of Richmond by the Board of Water Supply, City of New York," which was adopted by the Board of Water Supply on November 15, 1960. The Board of Estimate approved the project for construction on February 9, 1961. President Arthur C. Ford, Commissioner Edward C. Maguire and Commissioner Herbert M. Rosenberg are the members of the Board of

Water Supply. Immediate investigations and studies for the Richmond Project were under the supervision of the Research and Development Department of the Board of Water Supply, over which Mr. Eugene E. Farnan, Deputy Chief Engineer, is in charge. His chief assistant is Mr. Vincent G. Terenzio, Division Engineer. They were aided in the field by Senior Civil Engineer Martin J. Barkin. The writing of specifications, preparation of contracts and the design of the tunnel and physical structures are under the supervision of Mr. LeRoy Ericson, Deputy Chief Engineer.