THE CITY OF PROVIDENCE

STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS

RESOLUTION OF THE CITY COUNCIL

No. 185

Approved April 19, 1968

WHEREAS, the Engineering firm of Charles A. Maguire & Associates was heretofore engaged to prepare a preliminary report on the construction and development of reservoirs and other waterworks improvements on the Big River watershed located on the south branch of the Pawtuxet River and Wood River in the Pawcatuck basin, and

WHEREAS, said engineering firm has presented to the Water Supply Board of the City of Providence its report and recommended program for the development of said reservoirs and waterworks improvements, and

WHEREAS, the City of Providence is now urgently faced with the necessity of developing an additional source of water supply as the present supply will reach the limits of its estimated safe yield by the year 1981, and

WHEREAS, the most desirable sites for a new surface supply are the Big River watershed, and Wood River in the Pawcatuck basin, and

WHEREAS, the Water Supply Board has accepted and approved the report and recommendations submitted by the engineering firm of Charles A. Maguire & Associates and does hereby recommend that this Honorable body do likewise,

NOW THEREFORE, BE IT RESOLVED that:

1. The City of Providence does hereby find that it is necessary for said City of Providence to locate and develop an additional source of water supply.

RESOLUTION
OF THE
CITY COUNCIL

RESOLUTION OF THE CITY COUNCIL

No.

Approved

2. The City of Providence does hereby find that the most desirable sites for a new surface water supply are the Big River watershed located on the south branch of the Pawtuxet River and Wood River in the Pawcatuck basin.

3. The City of Providence does hereby find that it is necessary and in the public interest that it negotiate with the State of Rhode Island and its lawful representatives to the end that the said City of Providence acquire, by lease or otherwise, real estate and water rights owned by the State of Rhode Island and located on said Big River and Wood River watersheds for the purpose of obtaining a new water supply source.

4. The City of Providence does hereby accept and approve the aforesaid report and recommendations submitted to the Water Supply Board by Charles A. Maguire & Associates setting forth a program for the development of Big and Wood River reservoirs and waterworks improvements connected therewith, all as appears in said report and Appendix A thereto which accompanies it and a copy of which report and Appendix A accompanies this Resolution and is hereby incorporated herein and made a part hereof by reference.

5. The Mayor, the Chairman of the Water Supply Board, and the Chief Engineer of said Water Supply Board be and they are hereby authorized, for and in behalf of the City of Providence and in accordance with the provisions of Chapter 46-15 of the General Laws of Rhode Island, 1956, as amended, to file an application with the Water Resources Board of the State of Rhode Island requesting it to lease to the City of Providence land

RESOLUTION

OF THE

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No.

Approved

and water rights acquired by the State of Rhode Island pursuant to the provisions of said Chapter 46-15 of the General Laws of Rhode Island, 1956, as amended, or otherwise, for the development and construction of reservoirs and other waterworks at Big and Wood Rivers in the State of Rhode Island.

6. The Mayor, the Chairman of the Water Supply Board, and the Chief Engineer of said Water Supply Board be and they are hereby authorized and empowered for and in behalf of the City of Providence, to file with said application such plans, exhibits, maps, facts and such other proof and documents as may be required to establish the need of the City of Providence to increase its available water supply, the scope of the proposed project, with preliminary plans showing the works proposed to be constructed and the manner and means to be used to finance said project.

7. The Mayor, the Chairman of the Water Supply Board, and the Chief Engineer of the Water Supply Board be and they hereby are authorized and empowered to negotiate for and in behalf of the City of Providence with the Water Resources Board of the State of Rhode Island and such other agencies and departments of said State as may be necessary in accordance with law for the purpose of arriving at the terms of a lease or agreement which will carry out the purposes of this Resolution subject, however, to final approval of the Water Supply Board of the City of Providence and this Honorable body at a later date.

IN CITY COUNCIL

APR 18 1968

READ and PASSED

Russell J. Boyle
President

Vincent Vespia
Clerk

APPROVED

APR 19 1968

Joseph A. Doorley Jr.
MAYOR

RESOLUTION

OF THE

CITY COUNCIL

declaring the necessity of finding a new source of water supply, approving the program for the development of Big and Wood River Reservoirs submitted by Charles A. Maguire & Associates, authorizing the filing of an application with the Water Resources Board of the State of Rhode Island to lease land and water rights at Big and Wood Rivers and authorizing the mayor and chairman and chief engineer of the Water Supply Board to negotiate terms of a lease with the Water Resources Board subject to approval of the Water Supply Board and City Council

Councilmen McNulty and Pisaturo, by request

CITY OF

PROVIDENCE, RHODE ISLAND

SUMMARY REPORT

RECOMMENDED PROGRAM FOR THE DEVELOPMENT OF THE BIG AND WOOD RIVER RESERVOIRS AND WATERWORKS IMPROVMENTS FOR THE PROVIDENCE WATER SERVICE AREA

PREPARED FOR

WATER SUPPLY BOARD

JOHN A. DOHERTY — CHAIRMAN

EARL H. ASHLEY UGO RICCIO

JOHN J. TIERNEY DAVID R. McGOVERN

PHILIP J. HOLTON, JR. — CHIEF ENGINEER

MARCH 1968

CHARLES A. MAGUIRE & ASSOCIATES — ENGINEERS

Water Supply Board
City of Providence
552 Academy Avenue
Providence, Rhode Island

Gentlemen:

In accordance with our contract, we are pleased to submit our preliminary planning report on the construction of the Big River and Wood River Reservoir projects. This summary report outlines a proposed program for the development of the Big and Wood River Reservoir and other waterworks improvements for the Providence water supply system to provide for the future requirements of the system through the year 2015.

Under separate cover we have forwarded the back-up data and details, "Appendices to Summary Report", which were considered too voluminous in nature to present as part of this Summary Report. Also under separate cover but attached to this Summary Report is Appendix A, "Ground Water Situation". It was decided to attach this appendix because of the general interest in ground water in the State. Ground water availability for water supply purposes (as shown in Appendix A) provides only a minor amount of water for municipal usage, thus requiring development of surface water supplies such as Big and Wood Rivers to a maximum to meet the future needs of the Providence service area.

The recommendations outlined on pages 9 through 13 are presented in two sections - the "Immediate Program" which outlines the proposed improvements through 1980; and the "Future Program" which covers the period from 1981 to 2015. Recognizing that the water supply demands of the Providence service area in 1981 will exceed the available supply from the Scituate Reservoir, we cannot stress too strongly the urgency of initiating without delay the steps outlined in the "Immediate Program" on pages 10 and 11 for the development of the Big River Reservoir. Failure to comply with these recommendations will seriously restrict the future use of water to industrial, commercial and residential users within the Providence service area.

We have especially appreciated the cooperation of Mr. Philip J. Holton, Jr., Chief Engineer of the Providence Water Supply Board, in the preparation of the report and are indebted to him for the comprehensive data which have been made available. We are also appreciative of the cooperation received from the communities and water systems within and adjacent to the Providence service area.

We trust that the data and recommendations as set forth in this preliminary planning report will be of assistance in guiding the City of Providence in the matter of developing a program of waterworks improvements to meet the future needs of the system.

Very truly yours,

CHARLES A. MAGUIRE & ASSOCIATES

Harold Bateson

Harold Bateson - Partner

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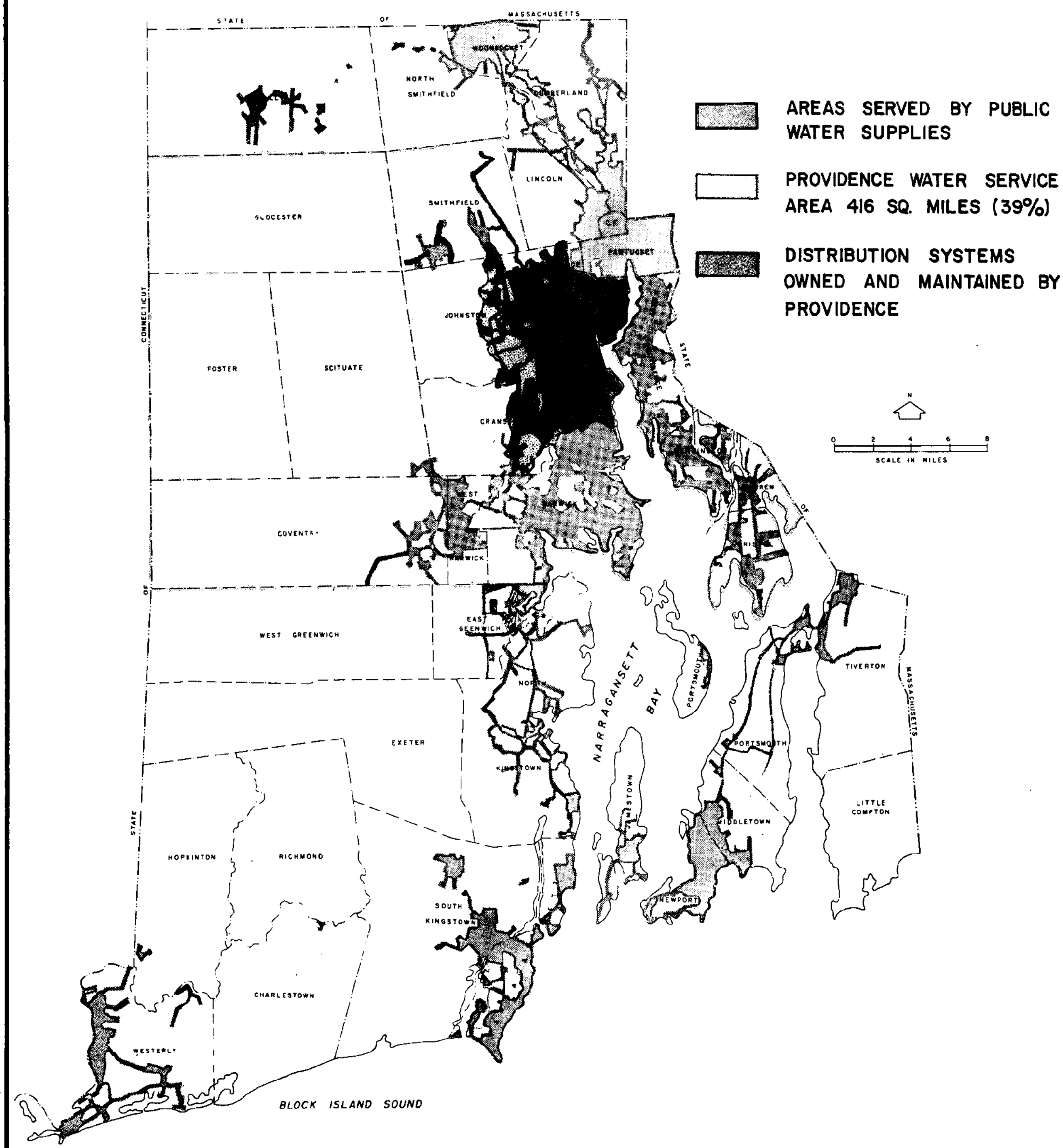
SECTION I - SUMMARY AND RECOMMENDATIONS

SUMMARY: Historically the City of Providence has played a leading role in the development of adequate water supplies in the State of Rhode Island, and today the Providence water supply system is acknowledged as one of the outstanding systems in the United States. Even as early as the 1870's and 1880's, Providence was serving parts of Warwick, Cranston, North Providence, Johnston and other adjacent areas. The Providence water service area has grown and changed since those early years and today it encompasses fifteen cities and towns that are entitled to receive water from the Scituate drainage basin which is the only present source of water supply for the Providence system. This service area, as shown on Figure 1, totals 416 square miles or 39 percent of the total State land area of 1,058 square miles, 5 percent greater than the total area served by all other public water supply systems in the State. The figure also shows the area that is served by the distribution system that is owned by the City of Providence which alone accounts for approximately 85 percent of the total water produced at Scituate. From a standpoint of total public water supplies in the State, Providence provides an estimated 50 percent of the total consumption and with the connection to East Providence and Bristol County expected in 1970 this will increase to over 60 percent.

The prominent role which Providence has played in the development of a regional water supply system is to be compared with the role played by such major cities as Detroit, Philadelphia, Cleveland and a host of others. That Providence has excelled in its job is evidenced by the high quality of water produced at Scituate and distributed to the system while still maintaining a low rate schedule.



BASE MAP BY R.I.D.C. 1962 UPDATED BY C.A.M. 1968

NOTE:
TOWNS AND CITIES SERVED BY PUBLIC WATER SYSTEMS OTHER THAN PROVIDENCE SERVICE AREA-373 SQUARE MILES 35% OF THE TOTAL STATE LAND AREA OF 1058 SQUARE MILES.

CITY OF PROVIDENCE WATER SUPPLY BOARD	
WATER SERVICE AREAS	
CHARLES A. MAGUIRE & ASSOC. ENGINEERS MARCH, 1968 PROVIDENCE, R.I.	FIGURE NO. 1

The wisdom of the long-range planning and capital investments of these early years has been justly proven in the ability of the Providence system to maintain its excellence of water supply and meet the system's demands to date and projected requirements until 1980. By 1981, however, a new source of supply will be required to augment the Scituate system. Our study has shown that the most desirable and feasible source of additional water supply is by the immediate development of the Big River Reservoir followed in 1997 by the Wood River Reservoir project, and in 2013 by the Moosup development. If Providence and the surrounding communities are to be assured of an adequate future water supply, they will have to depend on surface reservoirs such as the Big and Wood River developments. As stated in the letter of transmittal, the planning for the development of the Big River project should begin immediately to assure completion by 1980.

Our study of potential ground water developments as presented in detail in Appendix "A" - "Ground Water Situation" - has indicated that ground water development within and adjacent to the Providence service area will at best provide a limited source of water amounting to less than 11 mgd of a total requirement of the Providence service area in the year 2015 of 140 mgd.

If ground water were to be depended upon as a major source of water supply as has been suggested in several past reports, some of the streams would become dry during the summer months and in all probability many of the wells would become contaminated or polluted, and of course unsuitable for public water supplies. It is hoped that some of the confusion and misstatements which have been made on ground water usage and development in the State of Rhode Island in some prior reports will be clarified by Appendix A.

A most important phase of our study has been the projection of the population distribution within the service area (see Section II - Population and Water Consumption). To this end we have evaluated a mass of existing data on State and City growth considering the many factors such as fertility, mortality and migration, and other pertinent items. Figure 3 of this report summarizes our findings which indicate that the total projected population of the Providence service area is expected to be 765,000 in the year 2015 of which 744,400 is expected to be served by the Providence system. As shown by the curves this will be 55 percent of the State's total population estimated at that time to be 1,360,000. The population projections should be reviewed periodically in the future as a change in any one of the major factors upon which the projections have been made would necessitate a revision of the timetable of recommended improvements beyond the year 1980. The water usage or demand associated with the above projected populations is 140 mgd in 2015 of which 10 mgd is expected to be supplied from ground water, leaving a balance of 130 mgd to be supplied from surface water reservoirs. As the Scituate system is limited for water supply purposes to 72 mgd safe yield, new sources of supply will be needed to meet the projected year 2015 demands of the system totaling 130 mgd. The new sources of supply, fortunately, can be added periodically over the next 50 years as outlined in the following paragraph.

- <u>The Big River Reservoir, including treatment and transmission facilities will have to be completed by 1980</u>. Additional reservoir capacity will be required in 1997 (the Wood River development) and in 2012 (the Moosup River development). The three water resource development additions after satisfying riparian rights will ultimately add 64 mgd of safe yield to the present water supply at Scituate of 72 mgd for a safe yield for water supply purposes of the total system of 136 mgd (see Table 3). It is interesting to note that the proposed improvements through the year 2015, although of considerable magnitude, are not as large as the Scituate development that was built in the 1920's which provided a safe yield of 72 mgd. Several advantages of the proposed future reservoir construction as outlined in this report over the one single development such as Scituate are: (1) the actual time schedule of construction is mandatory to 1980 but can be adjusted thereafter to meet any change in predicted system growth and demands; and (2) the initial capital outlay is smaller than would be required if the total reservoir system were to be built in one period of time as was required for the Scituate Reservoir construction. Although the time schedule of construction beyond 1981 is flexible and can be changed subject to re-evaluation at the time of the projected system demands, we wish to stress the time schedule from 1968 to 1981 for the development of the Big River project must be strictly adhered to if the demands of the service area are to be met.

In connection with the Big River Reservoir development a 52 mgd flow capacity water treatment plant will be required. The quality of water from Big River is such that the treatment facilities will provide water meeting the same high standards as is presently produced at Scituate. The plant has been sited to provide expansion for the ultimate reservoir developments through the year 2015. With the construction of a new treatment plant, a new 90-inch transmission main will be required to connect the plant with the 102-inch aqueduct in West Warwick. The 102-inch aqueduct from West Warwick to Budlong in Cranston presently under construction has been sized from West Warwick to Cranston to take the proposed flow increase from the future Wood and Moosup Reservoir developments and no major improvements in transmission lines will be required beyond the West Warwick connection to Budlong Road. The only other improvement in the 1980's will be the increase in distribution storage. This will not be a major item as both the existing Aqueduct and Neutaconkanut reservoirs serving the lower service areas and the Longview high service area reservoir have been designed for such a contemplated expansion.

- In determining the future requirements of the Providence water service area an evaluation has been made of existing geological data within and adjacent to the Providence water supply service area to determine the present and future ground water potential. Where it was determined that ground water was available, recognition of this potential has been made and allowances credited as discussed in Section III-B, "Availability of Ground Water Supplies".

- Recognizing that the proposed reservoir developments at Big, Wood and Moosup will have a reserve capacity of about 6 mgd in 2015, consideration has been given to serving the fringe areas, both north and south, that are adjacent to the existing service area. These areas are discussed in some detail in Section V-B, "New Areas Considered for Expansion and Recommendations". The area north of Providence was evaluated, but the long length of transmission lines (20 miles) and associated hydraulic losses were such as to cause consideration of the areas to the south and easterly. A new transmission main could of course be provided to serve

Pawtucket but the construction through Cranston, Providence and Pawtucket would be extremely costly. Furthermore, the water would require continual pumping because of the difference in elevations of the two systems. In consideration of the above, our recommendation is that the future water requirements of both Pawtucket and Central Falls and other communities to the north be serviced from the Blackstone River drainage basin, wherein they are located. This basin has ample water resources for development and the recommendation is in conformance with several past reports.

The areas we have considered to be serviced to the south of the Providence service area are: West Greenwich, East Greenwich, Exeter and North Kingstown including the Navy facilities. Our ground water investigations have indicated that Exeter and West Greenwich will be able to provide for their projected water requirements from ground water but that East Greenwich will need to supplement their water supply in the 1970's probably through a new connection by Kent County Water Authority from the southern terminus of the proposed 36-inch Warwick main. The proposed 36-inch Warwick main should be reviewed as to capacity to take the additional flow to East Greenwich, including the Cowesett area of Warwick. An additional transmission main from the proposed Big River treatment plant, a distance of about 7 miles, will be required in 1990 to meet the projected deficiency in North Kingstown including the U. S. Navy installations, and to provide additional supply to the East Greenwich and Cowesett areas.

The purpose of this particular aspect of the study was to determine if the present Providence service area could be expanded and what new areas should be considered in such an expansion. It is well to point out that if East Greenwich (Kent County Water Authority) and North Kingstown including the U. S. Navy are to be served by the Providence system in the future, an agreement should be made at an early date to assure that planned water improvements within the two new areas recognize that the water supply will ultimately come from Big River. For example, all water supply improvements made in East Providence since 1960 have been designed in recognition of the eventual tie-in to the Providence system which is planned for 1970.

- As you are aware, the development of all future water supplies in the State - ground and surface - must be carried out with the approval of the recently created Water Resources Coordinating Board. Under the Act creating the Water Resources Coordinating Board, the City of Providence must file an application to this Agency if the City desires to develop the Big, Wood and Moosup Rivers for the purpose of meeting the requirements of the Providence water service area. We have, therefore, indicated in our recommendations that this report be submitted with a letter to the Water Resources Coordinating Board requesting their approval to have the City of Providence develop the three previously mentioned reservoir projects. The City of Providence should not be expected to undertake the proposed multi-million dollar expenditure for the development of Big River without also having approval from the Water Resources Coordinating Board to develop Wood and Moosup Rivers in the future.

- Recognizing that Providence will require an additional supply to augment the Scituate system by 1981 it is imperative that the field work and final planning phase be initiated by June of 1968 for the Big River project. Assuming that authorization is obtained by June 1968, it is estimated that the total time to engineer, construct and fill the Big River Reservoir will be 12 years, which means that the completed facility can be on the line on schedule. A delay at this time would have dire consequences should we experience a severe drought such as the 1962-1966 dry period.

Recognizing that Providence will require an additional supply to augment the Scituate system prior to 1981 we submit the following recommendations which will assure that this supply is obtained. Recommendations of future improvements beyond 1980 have also been presented so that Providence will have the time to adequately evaluate and plan for these improvements.

RECOMMENDATIONS: Based on the data and findings presented in this report we recommend that the following steps be initiated by the City of Providence to provide for the projected water supply requirements of its service area through the year 2015. The recommendations are presented in two sections - the "Immediate Program" and the "Future Program" of development. The "Immediate Program" outlines those steps that are urgently needed to be initiated from 1968 through 1980 and are a "must". The "Future Program" covers the period of proposed improvements from 1981 to 2015 and are more flexible in that the dates of proposed work in that period are subject to future re-evaluation of actual system growth and demands to that projected in 1968 by this report.

The recommended program of waterworks improvements for the Providence water service area through the year 2015 is as follows (see note below):

A. IMMEDIATE PROGRAM - 1968 THROUGH 1980 - FOR THE DEVELOPMENT OF THE BIG RIVER RESERVOIR PROJECT

	Date
(1) Approve this report and the recommendations contained herein	April 1968
(2) File an application with the State Water Resources Coordinating Board in accordance with the provisions of Chapter 46-15 of the General Laws of the State of Rhode Island 1956 as amended, to develop the Big, Wood and Moosup Rivers as set forth in this report.	May 1968
(3) Investigate all possible Federal Aid programs for assistance in the planning and construction phases of the Big River development project. File such applications as are applicable in connection with the proposed Big River project.	May 1968 and continuing
(4) Undertake the final planning and construction phases of the Big River project to assure completion by 1980.	
(a) Initiate the field work phase such as surveys, borings, geophysical work, pumping tests and related work which are necessary to provide final design criteria for the construction contracts of the Big River project.	June 1968

Note: To assist the reader in following the recommendations pertaining to construction we have prepared a map (Figure 2) showing the proposed improvements commencing with the Big River development by 1980 through to the Moosup River development in 2012. The map also shows the existing Providence system and indicates how it will be connected to the proposed future reservoir systems. Figure 10 shows schematically the proposed Big and Wood Rivers development and should also be referred to.

	Date
(b) Begin preparation of construction contracts for the various phases of work - i.e. final design plans and specifications.	January 1970
(c) Submit for bid the first construction contract for development of the Big River project.	January 1972
Subsequent construction contracts to follow.	
(d) Completion of construction of the dams, dikes and related work on the reservoir.	1976
(e) Filling of Big River Reservoir.	1977-1980
(f) Completion of other construction work - i.e. 52 mgd treatment plant and 42,000 feet of 90-inch aqueduct from treatment plant to West Warwick.	1972-1980
Big River project completed and water delivered to system	1981
Total Estimated Cost of Big River project (see Section IV)	$26,800,000
(5) During the period 1969-2015 construction should be phased to service western areas of Cranston and Johnston with the initial phase in general accordance with prior reports.	1969-1980

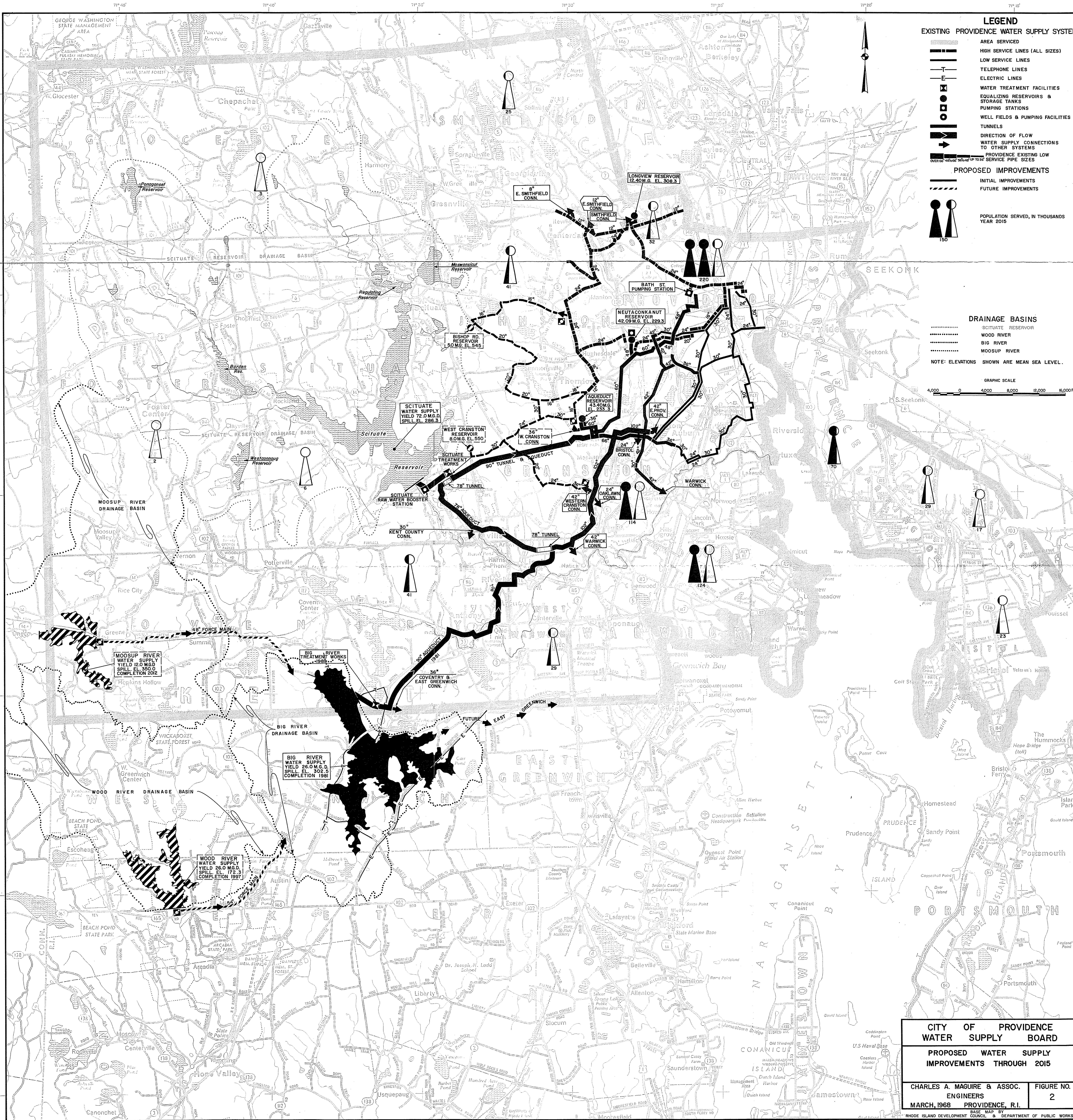
B. FUTURE PROGRAM OF DEVELOPMENT - 1981 TO 2015
FOR THE DEVELOPMENT OF WOOD RIVER RESERVOIR IN 1997
AND THE MOOSUP RIVER IN 2012

Date

(Dates presented are based on projected demands made in this report in 1968.) (A re-evaluation of these dates should be made in 1981 based on actual growth as compared to projections made in this report and a revised time schedule prepared based on available data at that time.)

(1)	Re-evaluate the recommended development program outlined herein in view of actual growth and system requirements and develop a more detailed and revised time schedule for the 1981-2015 system demands.		1981
(2)	Continue to expand the water system in the western section of Cranston and Johnston.		1981-2015
(3)	Expansion of the existing low service distribution storage at the Aqueduct and Neutaconkanut Reservoirs and of the high service at Longview Reservoir.		
	High service - Longview	11 mg	1980
	Low service - Aqueduct	40 mg	1990
	Low service - Neutaconkanut	40 mg	2010
(4)	Wood River development including pumping station and force mains, and 52 mgd expansion of the Big River water treatment plant.		1997

		Date
(5)	Construction of new transmission line from the Big River treatment plant east to serve East Greenwich and North Kingstown including the U. S. Navy (providing it has been determined to expand the existing Providence water service area). Legislation will have to be introduced to expand the existing service area as was recently done for East Providence and Bristol County Water Company.	1990
(6)	Moosup River development including pumping station, force main and 24 mgd expansion of the Big River treatment plant.	2012



LEGEND
EXISTING PROVIDENCE WATER SUPPLY SYSTEM
AREA SERVICED
HIGH SERVICE LINES (ALL SIZES)
LOW SERVICE LINES
TELEPHONE LINES
ELECTRIC LINES
WATER TREATMENT FACILITIES
EQUALIZING RESERVOIRS & STORAGE TANKS
PUMPING STATIONS
WELL FIELDS & PUMPING FACILITIES
TUNNELS
DIRECTION OF FLOW
WATER SUPPLY CONNECTIONS TO OTHER SYSTEMS
PROVIDENCE EXISTING LOW SERVICE PIPE SIZES
PROPOSED IMPROVEMENTS
INITIAL IMPROVEMENTS
FUTURE IMPROVEMENTS
POPULATION SERVED, IN THOUSANDS YEAR 2015
DRAINAGE BASINS
SCITUATE RESERVOIR
WOOD RIVER
BIG RIVER
MOOSUP RIVER
NOTE: ELEVATIONS SHOWN ARE MEAN SEA LEVEL.
GRAPHIC SCALE
LONGVIEW RESERVOIR 12.40 M.G. EL. 308.3
8" E. SMITHFIELD CONN.
12" E. SMITHFIELD CONN.
SMITHFIELD CONN.
BATH ST. PUMPING STATION
NEUTACONKANUT RESERVOIR 42.09 M.G. EL. 229.3
BISHOP RD. RESERVOIR 5.0 M.G. EL. 545
AQUEDUCT RESERVOIR 43.40 M.G. EL. 233.3
SCITUATE WATER SUPPLY YIELD 72.0 M.G.D. SPILL EL. 286.3
WEST CRANSTON RESERVOIR 8.0 M.G. EL. 550
36" W. CRANSTON CONN.
42" E. PROV. CONN.
24" BRISTOL CONN.
SCITUATE TREATMENT WORKS
SCITUATE RAW WATER BOOSTER STATION
90" TUNNEL & AQUEDUCT
78" TUNNEL
78" AQUEDUCT
24" OAKLAWN CONN.
42" WESTERN CRANSTON CONN.
WARWICK CONN.
30" KENT COUNTY CONN.
42" WARWICK CONN.
MOOSUP RIVER DRAINAGE BASIN
48" FORCE MAIN
MOOSUP RIVER WATER SUPPLY YIELD 12.0 M.G.D. SPILL EL. 350.0 COMPLETION 2012
BIG RIVER TREATMENT WORKS 1981
90" AQUEDUCT 1981
36" COVENTRY & EAST GREENWICH CONN.
FUTURE EAST GREENWICH
BIG RIVER DRAINAGE BASIN
BIG RIVER WATER SUPPLY YIELD 26.0 M.G.D. SPILL EL. 302.5 COMPLETION 1981
WOOD RIVER DRAINAGE BASIN
WOOD RIVER WATER SUPPLY YIELD 26.0 M.G.D. SPILL EL. 172.3 COMPLETION 1997
SCITUATE RESERVOIR DRAINAGE BASIN
CITY OF PROVIDENCE WATER SUPPLY BOARD
PROPOSED WATER SUPPLY IMPROVEMENTS THROUGH 2015
CHARLES A. MAGUIRE & ASSOC. ENGINEERS
MARCH, 1968 PROVIDENCE, R.I.
FIGURE NO. 2
BASE MAP BY RHODE ISLAND DEVELOPMENT COUNCIL & DEPARTMENT OF PUBLIC WORKS

SECTION II - POPULATION AND WATER CONSUMPTION

II-A. POPULATION: A most important phase then of our study has been a competent review of existing information and development of reliable population forecasts including allowances for industrial growth.

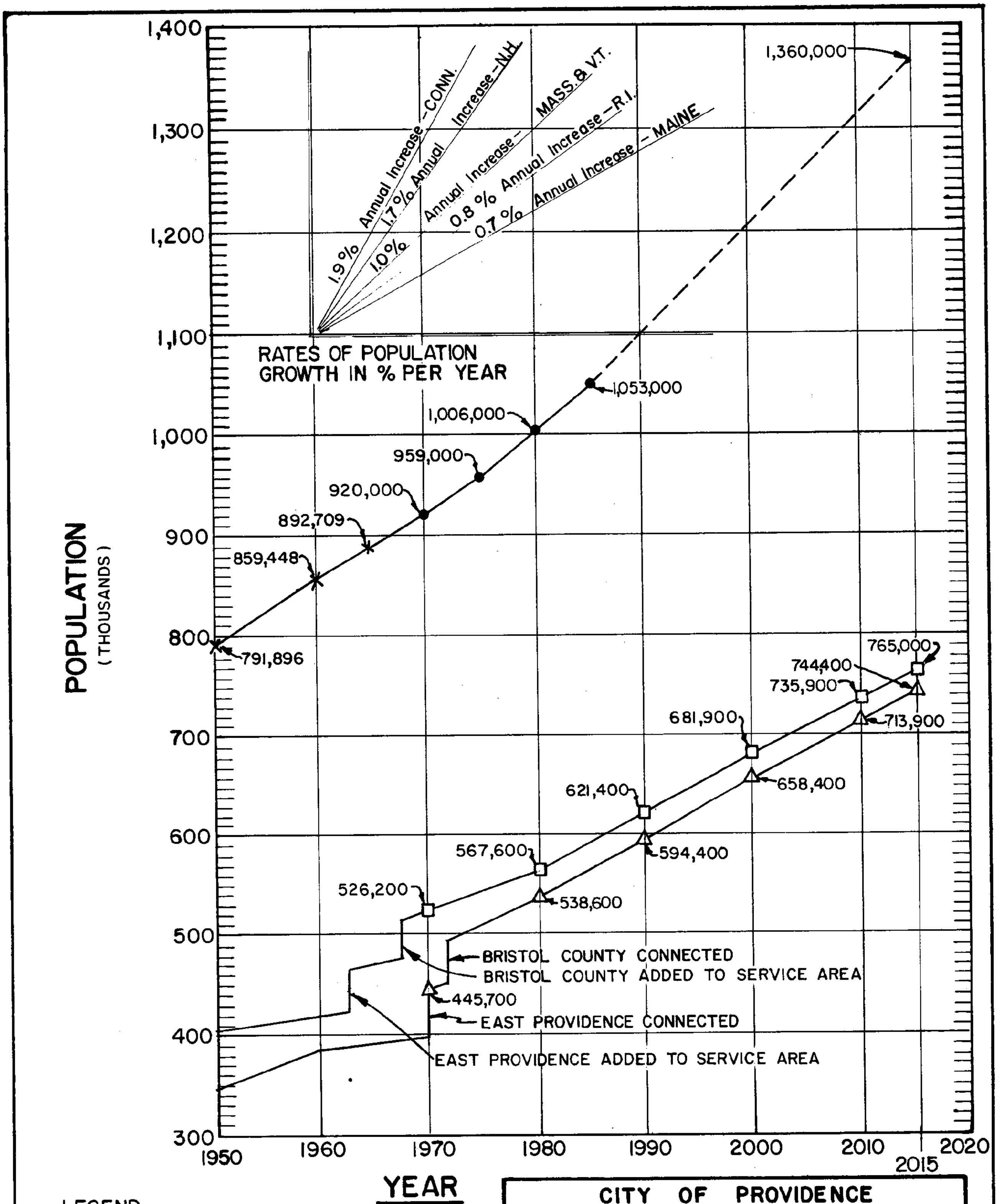
In arriving at a population to be served in the future by the Providence water service area, the problem reduced itself into determining first, the projected population of the State, followed by the distribution of that population within the service area. The service area being defined as the following 15 municipalities: Providence, Cranston, Johnston, Smithfield, North Providence, Warwick, West Warwick, Coventry, Scituate, Foster, Glocester, East Providence, Barrington, Bristol and Warren. It is interesting to note that these 15 municipalities comprise approximately 58 percent of the State population and 39 percent of the total land area of the State. The data necessary to compute projected populations such as births, deaths, migration and immigration are available in substantially more detail on the State basis and therefore, the projections of the State's population are more reliable than on an individual municipality basis. The problem thereafter is a matter of distribution of that growth within the State into the various cities and towns. This distribution of population is at best a difficult assignment which is dependent on local conditions such as zoning, present land use, transportation routes, industrial, commercial and business growth which determine daytime population demands, the saturation population or holding capacity of the municipality and the extent of water and sewer systems.

Numerous studies have been undertaken on population forecasts for Rhode Island and include engineering studies on the various communities for fallout shelters, sewerage, water, highways, etc. as well as Statewide studies devoted solely to population forecasts. In 1965, a report entitled "Rhode Island Statewide Traffic Study - Report No. 10, Forecasted Population and Socio-Economic Estimates" was conducted by the Rhode Island Department of Public Works. Following that, in 1966, Report No. 7 entitled "Population Projections for the State of Rhode Island and its Municipalities" was prepared by the Rhode Island Statewide Comprehensive Transportation and Land Use Program. The most recent report dated October 3, 1967 and incorporating the latest migration data was prepared by the U. S. Department of Commerce and is entitled "Revised Projections of the Population of States 1970 to 1985".

Differences in population projections between reports and particularly the magnitude of the differences were tabulated and reviewed. The review and final recommendations were made by a group of City and Town planners, a traffic engineer, a sociologist and staff engineers who have worked on many of the sewer and water projects in the State. Our forecasts were then compared with the Providence Water Supply Board data which were quite extensive based on detailed records of past years of water demand projections and differences between the population projections resolved or explained. One difference in projected growth was for the City of Providence where it was agreed to use the higher figure of 220,000 in 2015 recognizing that the sizing of the new transmission main from the Big River Reservoir was dependent to a large degree on the Providence requirements and a low estimate would result in a line of insufficient capacity in the future. All personnel were completely familiar through many years of experience with the areas' socio-economic aspects. Growth patterns and projections were made independently of each of the communities involved on an individual basis recognizing the many limiting factors such as zoning, trends, highway impact, saturation density, etc. Such then was the basis of determining the future populations of each of the municipalities within the Providence service area.

As stated in the Bureau of Census 1967 report "Population projections should not be regarded as predictions, but rather as indications of the population distributions which would develop on the basis of assumptions which were selected regarding fertility, mortality and migration.". There are many significant factors that could appreciably change these projections and future forecasts are therefore limited to this extent. Our proposed water development program has recognized this factor and the program as recommended is flexible to the extent that proposed time schedule of developments beyond 1981 can be adjusted to meet any significant differences resulting from changes in our future population estimates.

The results of our detailed population projections (Figure 3) for the State have been in general conformance with the 1967 Bureau of Census I-B curve which assumes migration rates will continue within the 1955-65 range and a moderate increase in fertility levels. This projection is somewhat under the II-C curve of the State report No. 7 which assumes a smaller migration figure.



LEGEND

—×— U.S. CENSUS PAST YEARS
—●— DEPT. OF COMMERCE PROJECTION SERIES I-B 1970–1985
C.A.M. PROJECTIONS
—□— POPULATION OF PROVIDENCE SUPPLY AREA
—△— POPULATION SUPPLIED BY PROVIDENCE SUPPLY SYSTEM
- - - STATE POPULATION PROJECTION

CITY OF PROVIDENCE
WATER SUPPLY BOARD

POPULATION ESTIMATES
RHODE ISLAND AND PROVIDENCE
WATER SERVICE AREA

CHARLES A. MAGUIRE & ASSOC.
ENGINEERS
MARCH, 1968 PROVIDENCE, R. I.

FIGURE NO.
3

The projected growth of Rhode Island as shown on Figure 3 is slightly higher than .8 percent per year which for information compares to projected growth rates of other New England States as follows: Maine .7 - Vermont 1.0 - Massachusetts 1.0 - New Hampshire 1.7 - Connecticut 1.9. For comparison and information, these rates have also been plotted on Figure 3.

The distribution of a portion of this State total into the Providence service area was made on a basis of study of each municipality in accordance with criteria previously discussed and accounts for over 57 percent of the State's total in 2015, of which 97 percent is expected to be served by the Providence water supply system.

The above evaluations of individual city and town population projections provided necessary background data for determining the requirements of additional reservoirs, aqueducts and storage facilities. The details of this phase of our study are presented in the Appendices Report.

II-B. WATER TRENDS AND FUTURE REQUIREMENTS: An important parameter for evaluating water trends and for projecting these trends into the future is the average water used in gallons per capita per day (gpcd). Determination of the gpcd requires the consideration of the following various water usages: Industrial, commercial, domestic, leakage within the distribution system, wash water at the treatment works, fire usage, and other unmetered usages. It is interesting to note that in our studies the existing gpcd trends varied from 68 to 177 gpcd*(with certain individual years being higher). Recognizing past trends and future requirements, the future increase of gpcd/year varies from 0.8 to 3.0 for the various communities, generally with the higher increase in the early years matching the current per capita (gpcd) trends.

*In 1965 the actual gpcd for Cranston was 220 reflecting a high industrial usage.

A careful evaluation of the water requirements of the fifteen municipalities entitled to receive water from the Providence Water Supply Board has been undertaken. Where municipalities were served by more than one water supply system, the number of services, population served and flows of each system have been studied. As an example, North Providence which is supplied by the Providence Water Supply Board, Pawtucket Water Department, the East Smithfield Water District and the Town of Smithfield Water Authority, was evaluated from 1950 to the present as to the number of services and persons served by each system to establish the per capita water trends. The future projections have been based on this information and other available data including population growth and estimated industrial and commercial growth through the year 2015. Other communities served by more than one water supply include Cranston with the Providence supply and Kent County Water Authority (West Warwick and Pawtuxet Valley Division), and Warwick with the Providence supply and Kent County Water Authority (West Warwick and Pawtuxet Valley Division as well as the East Greenwich Division).

The detailed review of all the water systems of the Providence service area revealed that the industrial usage in Providence and Cranston had a major impact on the gpcd. In Cranston, for example, in 1965 the industrial usage alone was 143 gpcd. These municipalities and the others of the Providence service area have been carefully reviewed individually and collectively as related to the overall water supply and usage. The total population of the Providence service area, the population served, the total usage and demand on the Providence supply have been summarized in Table 1 on pages 22 and 23.

The demand on the Providence supply water system in the next 50 years is expected to increase by 265 percent from 53 mgd in 1965 to 140 mgd in 2015 (see Figure 4), which compares to the 50 prior years' rate of increase of 17 mgd in 1915 to 53 mgd in 1965, or approximately 310 percent increase.

TABLE 1

WATER USAGE OF AREAS PRESENTLY ENTITLED TO RECEIVE WATER FROM PROVIDENCE WATER SUPPLY SYSTEM

	1965		1970		1980		1990		2000		2010		2015	
	Pop. Served	MGD[a]	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD
Providence	187,061	28.50	170,700	28.50	170,500	30.30	184,100	34.50	200,000	39.30	213,000	43.50	220,000	45.70
Cranston[b]	70,060	12.38	76,400	14.50	82,700	16.70	90,000	19.58	99,300	22.36	108,600	25.42	114,400	27.28
Johnston	14,555	1.10	16,900	1.46	21,400	2.16	25,600	2.96	31,700	4.15	38,500	5.63	41,000	6.27
N.Providence	16,840	1.44	19,300	1.83	22,500	2.47	25,000	3.12	27,500	3.85	30,000	4.67	31,200	5.05
Smithfield[c]	3,880	.33	4,800	.45	14,000	1.55	18,000	2.40	21,000	3.12	23,000	3.75	24,500	4.22
Warwick[d] (PWSB Only)	64,100	4,40	67,400	5.39	74,800	7.49	80,700	9.67	88,200	12.30	92,000	14.20	94,800	15.40
W.Warwick	21,500	1.74	22,000	1.98	22,700	2.50	23,800	2.98	25,500	3.56	27,100	4.20	28,900	4.68
Coventry	15,000	1.22	20,000	1.80	25,300	2.77	30,000	3.75	34,200	4.80	38,800	6.00	40,600	6.58
Scituate	1,000	.08	1,200	.11	2,300	.24	3,400	.41	4,300	.58	5,200	.77	5,700	0.89
Subtotal	393,996	51.19	398,700	56.02	436,200	66.18	480,600	79.37	531.700	94.02	576,200	108.14	601,100	116.07

a. Trend value derived from the average trend obtained by evaluation of annual water usage records.
b. Includes small areas served by KCWA in Oaklawn and Fiskeville.
c. Excludes Greenville Water District.
d. Includes portion of Warwick supplied by Providence Water Supply Board (PWSB).

TABLE 1 (Continued...)

WATER USAGE OF AREAS PRESENTLY ENTITLED TO RECEIVE WATER FROM PROVIDENCE WATER SUPPLY SYSTEM

	1965		1970		1980		1990		2000		2010		2015	
	Pop. Served	MGD[a]	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD	Pop. Served	MGD
E.Providence Connected 1970	--	--	47,000	6.20	52,500	8.00	57,500	9.60	62,500	11.40	67,500	13.00	70,000	13.80
Subtotal	393,996	51.19	445,700	62.22	488,700	74.18	538,100	88.97	594,200	105.42	643,700	121.14	671,100	129.87
Bristol Cty. Connected 1971	-- (39,950)	-- (3.65)	-- (44,360)	-- (4.29)	49,300	5.24	55,100	6.44	61,500	7.78	66,700	9.10	69,200	9.80
Subtotal	393,996	51.19	445,700	62.22	538,000	79.42	593,200	95.41	655,700	113.20	710,400	130.24	740,300	139.67
Foster	--	--	--	--	--	--	--	--	800	.10	1,300	.19	1,600	.24
Glocester	--	--	--	--	600	.06	1,200	.14	1,700	.22	2,200	.32	2,500	.38
TOTAL	393,996	51.19	445,700	62.22	538,600	79.48	594,400	95.55	658,200	113.52	713,900	130.75	744,400	140.29
gpcd		130		139		148		160		172		183		189

Trend value derived from the average trend obtained by evaluation of annual water usage records.

SECTION III - RECOMMENDED IMPROVEMENTS THROUGH THE YEAR 2015

III-A. ADDITIONAL SURFACE SUPPLIES: The Scituate Reservoir complex, the present source of water supplying the Providence water supply system, is currently being developed to its ultimate safe yield of 84 mgd of which 72 mgd is available for water supply purposes. On the basis of population estimates and projections (shown in Table 1), it appears that this supply will be sufficient to meet the water demands until about 1981. As additional communities entitled to receive water from the Providence system attain service, and as the population densities and per capita water consumption increase within the service area, additional water resources will have to be developed to satisfy the increasing water demands. The projected water demands and calculated surface water requirements through 2015 are presented in the following table. These figures reflect the available ground water potential of 10.4 mgd discussed in a subsequent section.

TABLE 2

SURFACE WATER REQUIREMENTS FOR THE PROVIDENCE SERVICE AREA

Year	Total Demand (mgd)	Available from Ground Water (mgd)	Required Surface Water (mgd)
1970	62.2	3.0	59.2
1980	79.5	9.5	70.0
1990	95.6	8.6	87.0
2000	113.5	10.2	103.3
2010	130.8	10.4	120.4
2015	140.3	10.4	129.9

After careful analysis and study of the water resources available and the future surface water requirements, it is recommended that the following sources of supply be developed in stages: the Big River watershed with a large storage reservoir to be completed by 1981; the Wood River watershed with a smaller storage reservoir required by 1997; and the Moosup River watershed utilizing a small flood control reservoir which will be necessary by 2012. The exact year of development beyond 1980 will depend on the actual rate of growth of projected water demands. A summary of the safe yield or dependable daily draft for water supply and the sequence of development of each resource is tabulated below, followed by a further discussion of each stage of development. For water requirements beyond 2015, consideration has been given to the development of the Flat River Reservoir and watershed with a safe yield of 18 mgd and the development of Bucks Horn Brook Reservoir with a safe yield of 5 mgd.

TABLE 3

SUMMARY OF SURFACE WATER RESOURCES

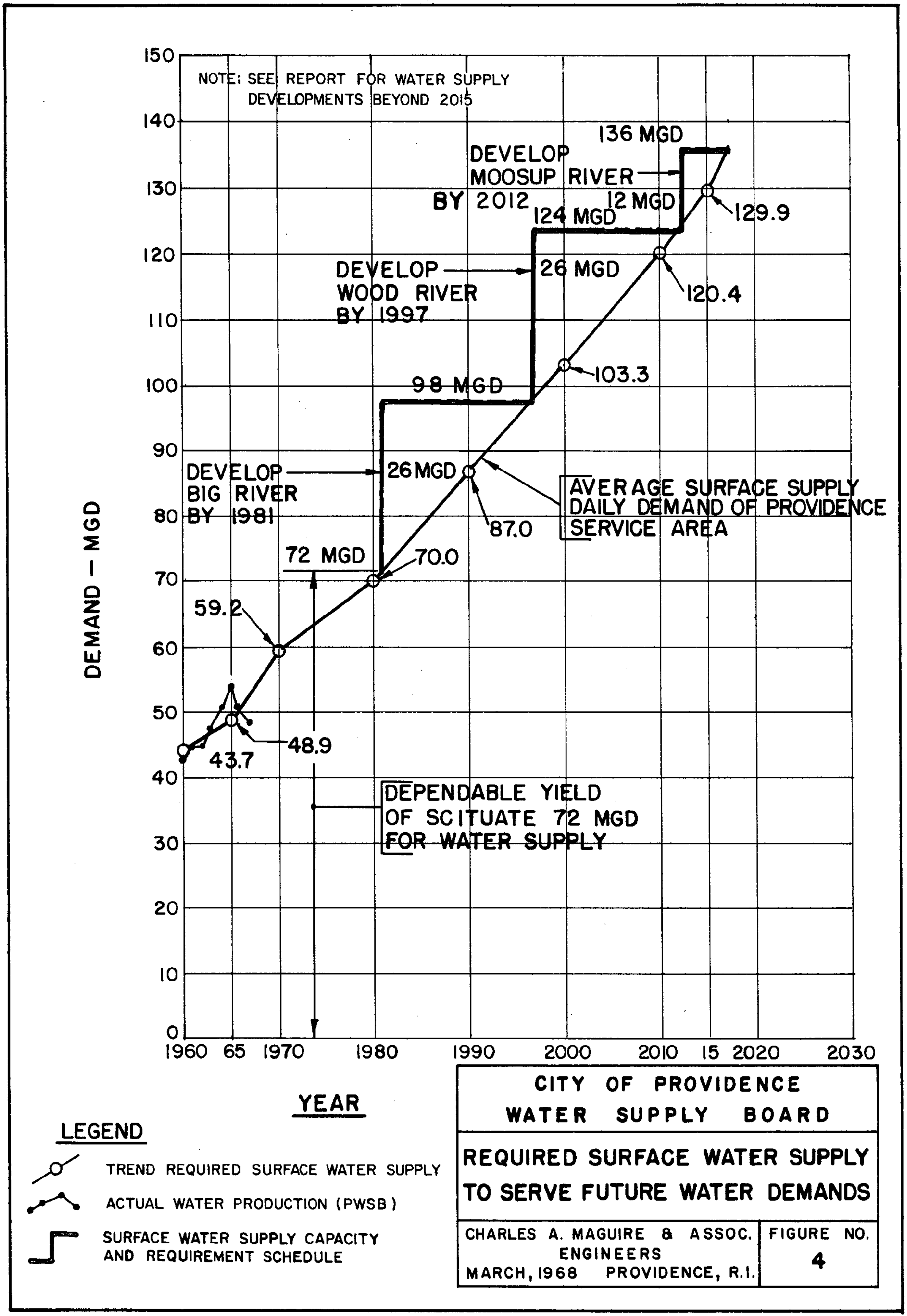
Source of Supply	Watershed Area sq.mi.	Available Storage Capacity mg	Safe Yield mgd	Available Water Supply Yield* mgd	Year Developed By	Total mgd
Scituate Reservoir and watershed	92.8	39,746	84.0	72	1926	72
Big River Reservoir and watershed	29.7	30,000	30.2	26	1981)	
Wood River Reservoir and watershed	36.0	5,965	31.1	26	1997)	64
Moosup River and watershed flood skimming	34.2	--	--	12	2012)	
					Total	136

*After deduction of water released to satisfy downstream riparian rights.

Big River Development: The development of the Big River watershed is the most advantageous first step for two reasons, because of its geographic location resulting in more economical transmission mains, and because of its large storage capability which makes a central major storage reservoir practical. This reservoir will be used, therefore, as the central impoundment in the new reservoir complex and will have a spillway elevation at 302.5 msl. It will be required to store the runoff from its immediate watershed plus the water pumped from the Wood River and the Moosup River following their subsequent development. The watershed area is 29.7 square miles and the water surface will be 5.9 square miles.

The safe yield of the watershed is based on USGS gauging data on the South Branch of the Pawtuxet River and on the long-term records of the Abbott Run and Scituate watersheds. The total safe yield of the watershed is 30.2 mgd, 4.2 mgd of which is to be released for riparian stream rights, leaving an available water supply safe yield of 26.0 mgd. The quantity of water to be released for riparians is an estimate based on Scituate requirements. The actual figure will have to be determined more accurately in the future by a detailed analysis of legal requirements. The available water supply yield of 26 mgd when coupled with the Scituate supply will make available 98 mgd (72 + 26), enough to meet the water needs until 1997 as shown on Figure 4.

Wood River Development: A cost analysis has shown that the development of the Moosup River watershed would be about one and one-half times more per mgd than the development of Wood River. For this reason Wood River was chosen as the most advantageous second stage of development.


NOTE: SEE REPORT FOR WATER SUPPLY DEVELOPMENTS BEYOND 2015
136 MGD
DEVELOP MOOSUP RIVER BY 2012
12 MGD
124 MGD
129.9
DEVELOP WOOD RIVER BY 1997
26 MGD
120.4
103.3
98 MGD
DEVELOP BIG RIVER BY 1981
26 MGD
AVERAGE SURFACE SUPPLY DAILY DEMAND OF PROVIDENCE SERVICE AREA
87.0
72 MGD
70.0
59.2
48.9
43.7
DEPENDABLE YIELD OF SCITUATE 72 MGD FOR WATER SUPPLY
DEMAND — MGD
YEAR
LEGEND
TREND REQUIRED SURFACE WATER SUPPLY
ACTUAL WATER PRODUCTION (PWSB)
SURFACE WATER SUPPLY CAPACITY AND REQUIREMENT SCHEDULE
CITY OF PROVIDENCE WATER SUPPLY BOARD
REQUIRED SURFACE WATER SUPPLY TO SERVE FUTURE WATER DEMANDS
CHARLES A. MAGUIRE & ASSOC. ENGINEERS
MARCH, 1968 PROVIDENCE, R.I.
FIGURE NO. 4

The storage requirements would be limited since the bulk of the flow would be pumped to the Big River Reservoir for storage. The spillway elevation of the Wood River Reservoir has been set at 172.3 msl. Since the Wood River watershed will operate in conjunction with the Big River watershed, they should be considered as a whole. The watershed area of the combination is 65.66 square miles. The total safe yield of the two watersheds is 61.3 mgd minus 9.3 mgd for riparian rights or 52 mgd available for water supply purposes. Wood River watershed therefore adds 26 mgd (52 - 26) of available safe yield. The total available water supply, by adding Wood River, would be 72 mgd from Scituate, 26 mgd from Big River and 26 mgd from Wood River or 124 mgd, a sufficient quantity according to the demands plotted in Figure 4 until 2012.

Moosup River Development: The third stage of development would be the Moosup River watershed and diversion works. The water would be flood skimmed from a small flood control reservoir at Elevation 350 to 356 msl, planned as a future project for the area by the State of Connecticut. Flood skimming consists of collecting and diverting the excess runoff on the watershed. The water pumped at the diversion works will be delivered to the Big River Reservoir for storage. Planning on the development of the Moosup project should be coordinated with the State of Connecticut in the near future.

The water supply safe yield gained by developing the Moosup River is 12 mgd. The total available water supply yield for the Providence system by 2012 would be the sum of the safe yields of the above developed supplies, or 72 mgd from Scituate, 26 mgd each from Big River and Wood River and 12 mgd from Moosup River for a total of 136 mgd. In comparing this 136 mgd supply with the projected demands plotted of Figure 4, it can be seen that this quantity of water would be sufficient until 2018.

With the completion of the above development program there will be available 136.0 mgd for water supply as mentioned above. The projected demand of the areas entitled to receive water is estimated to be 129.9 mgd in 2015. There will, therefore, be a reserve of 6.1 mgd available in 2015.

The figures used above for water released to riparian stream owners are based on the records of releases from Scituate Reservoir. For the purposes of this report, these estimates are quite adequate, but a legal study of riparian requirements should be made prior to the development of those resources to avoid legal conflicts.

Other Sources of Supply: For water needs beyond 2018, consideration has been given to the development of the Flat River Reservoir and watershed and the Bucks Horn Brook Reservoir. The development of the Flat River would consist of alterations to improve the watershed and provision of diversion works at the existing reservoir. Flood skimming the watershed would make available 18 mgd of dependable yield. The earlier development of the Flat River as a source of supply has been eliminated as an alternative due to poor water quality arising as a result of the relatively heavily inhabited watershed including considerable reservoir shore development. The development of Bucks Horn Brook Reservoir as a flood skimming operation operating in conjunction with the Moosup River flood skimming would make available an additional 5 mgd. This development would also require pumping and diversion works. Development of Bucks Horn Brook has not been considered as feasible prior to 2015 because of the high cost per mgd of available yield gained as compared to other sources.

The use of ocean water as a source of water supply utilizing the salt water conversion process has been suggested for municipal water supply. At the present level of technology within this field, the desalinzation process is approximately two to three times as costly as surface supplies. Even with the development of a more favorable and economic method of salt water conversion, the physical plant life expectancy of such a process of only thirty years does not compare favorably with the useful life of a large surface water supply system of over one hundred years. It appears that desalinated water will not be competitive to surface supplies in the Rhode Island area in the foreseeable future.

III-B. AVAILABILITY OF GROUND WATER SUPPLIES

GENERAL: This section of the report summarizes the ground water situation in the Providence Water Supply Board service area and in the immediately adjoining areas to the north and south. A more detailed analysis is found in Appendix "A".

Of key importance in determining the projected requirements of surface water supplies by the Providence system are the ground water supplies which may supplement them. For this reason, the ground water available for development for long-term yields for municipal water supply within the service area of the Providence water supply system has been reviewed in detail. The analysis of the historical development of the ground water in Rhode Island points out that published yields have been calculated too high and have not been properly limited to conform to long-term safe yields. Should the amount in past published yields be actually pumped and the water removed from the basins, the streams would dry up in summer and fall, except during periods of high flows. High or increased iron and manganese concentrations, reduction in yield, encroachment of well fields by residential, industrial and commercial development, and pollution from nearby streams, all are factors in limiting acceptable well field locations and capacities.

The safe yields of the various surface water supplies and ground water supplies have been summarized in Table 2 for the Providence service area. These safe yields have been studied in detail based upon geological conditions and the nature of deterioration of wells within the basins. The safe yields of the ground water basins have been subdivided into a community and water supply system basis in order to determine the requirements of surface water supply and transmission facilities.

GEOLOGY: The only geologic unit capable of yielding significant supplies of ground water in Rhode Island is the stratified silt, sand and gravel (called "outwash") deposited by the melting glaciers. Outwash is usually restricted to the stream valleys, where it is often 50 feet thick or more. Properly developed wells in outwash may yield 10 to 500 gpm, occasionally more.

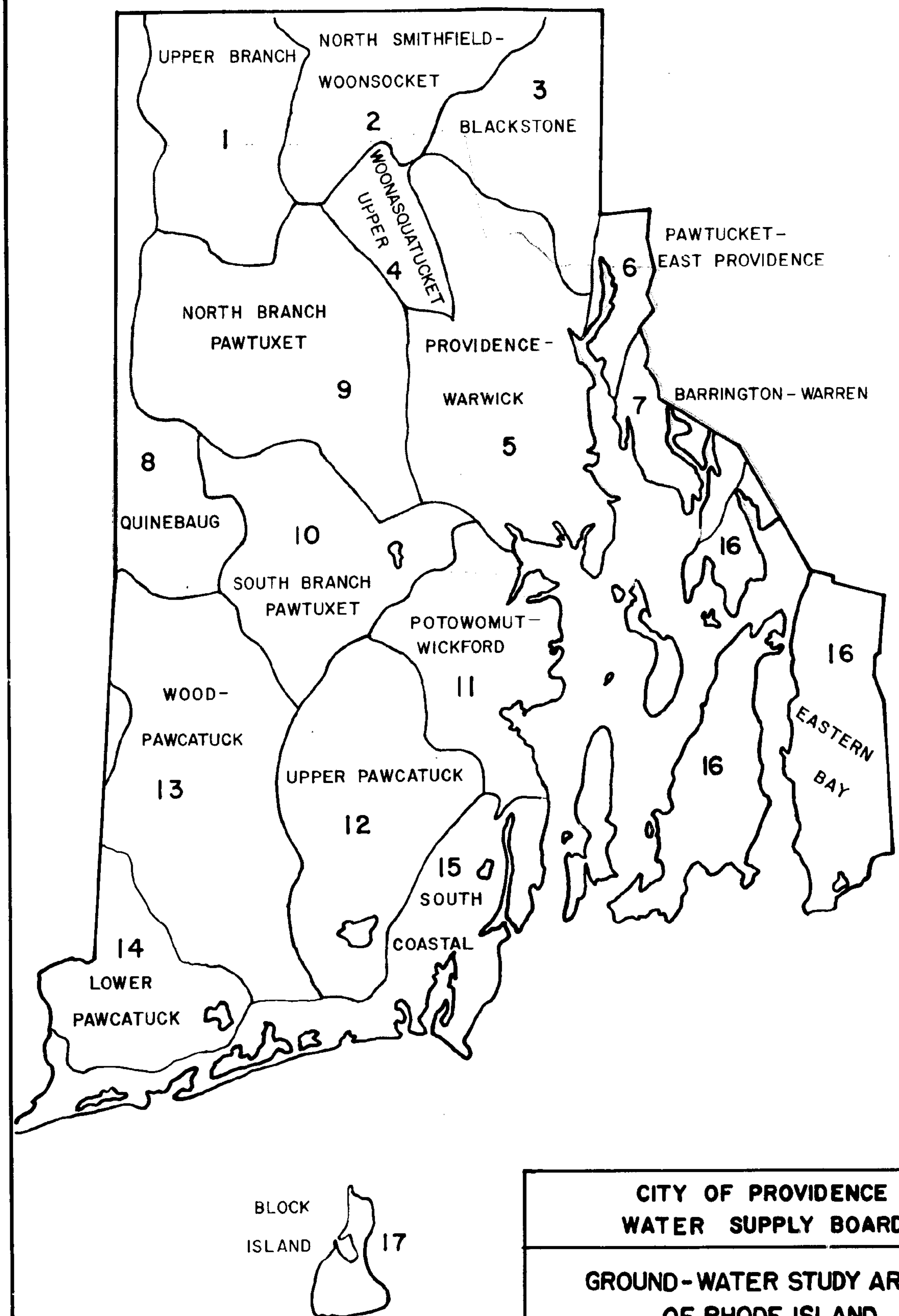
The hills and uplands of Rhode Island usually consist of bedrock (called "ledge") made of hard metamorphic rocks, which are thinly veneered with a poorly sorted soil (called "till"). Neither the bedrock nor till is very permeable compared to outwash. For this reason the outwash is hereafter referred to as the aquifer.

AQUIFER YIELDS: For the purpose of ground water studies, the U. S. Geological Survey divided the State of Rhode Island into 17 ground water basins, as shown in Figure 5. The most common method of determining a long-term yield of ground water from these basins assumes that the amount of water available equals the amount of water that naturally recharges the aquifers from precipitation falling directly on the aquifers. This is approximately one mgd/square mile. This method is usually modified to account for storage in the aquifer and induced infiltration from streams and ponds.

There are several reasons why the theoretical computations of the long-term yield as described above should not be used. They are far too optimistic in predicting a realistic yield of ground water for future supplies for the following reasons:

1. Permeability: Within the aquifers the actual productive lenses of coarse sand and gravel may be few and far between. Considering the available sites within a basin for drilling wells, it may be difficult to develop the aquifers at all. For instance in 1958 the City of Pawtucket drilled 36 exploratory holes in outwash. Most of the material encountered was fine sand. Only five holes penetrated material coarse enough for the development of permanent wells.

2. Land development: Rhode Island has the densest population in the United States. Currently the State requires a 400-foot minimum protective radius around a municipal well. As land development continues, such sites become increasingly hard to find. In addition, the natural recharge to aquifers from precipitation is diminished by streets, paved areas and storm sewers.



CITY OF PROVIDENCE
WATER SUPPLY BOARD

GROUND-WATER STUDY AREAS
OF RHODE ISLAND

CHARLES A MAGUIRE & ASSOC.
ENGINEERS
MARCH, 1968 PROVIDENCE, R.I.

FIGURE NO. 5

3. Water quality: Many wells in southeastern New England have a history of going "sour" due to high iron and/or manganese concentrations. The geochemistry of this process is poorly understood, and hence any prediction of ground water yield should be conservative to allow for some iron and manganese areas. The classic example of a town that tried to use cheaper ground water as an alternative to surface water is Lowell, Massachusetts (population 92,000). The history of the development of that city's water supply is briefly outlined as follows:

(a) In 1862 the City of Lowell obtained its water from the Merrimac River. No treatment was used and typhoid epidemics were traced to this water supply.

(b) In 1890 a well system was installed. Six hundred and eighty driven wells and a complicated vacuum pump ("air lift") and steam engine system supplied 6 mgd when new. Over the years the system deteriorated due to rising iron and manganese in the water and corrosion of the equipment.

(c) In 1914 an iron removal plant was constructed. It could not handle the increasing iron content in the well water, however.

(d) Nine gravel-packed wells were installed in 1940. These wells also yielded high iron, averaging 4.0 ppm.

(e) In 1950 eight new gravel-packed wells were installed in other areas. Four of these became contaminated, while four are still in use, supplying an average of 2.0 mgd.

(f) Finally in 1960, after complaints about iron and manganese from the townspeople, the decision was made to go back to the Merrimac River. In 1963 a new treatment plant was put into operation utilizing Merrimac River water. An average of 7.0 mgd is presently withdrawn from the river and treated by modern techniques such as flocculation, filtration, activated charcoal and chlorination. The water now has excellent quality.

Other Massachusetts towns such as Billerica, Lawrence, Franklin, Newton and Brookline, have had similar histories of well failure. In Rhode Island many municipalities such as East Providence, Pawtucket, North Kingstown and Barrington have had similar well water quality failures.

4. Legal considerations: If all the recharge to an aquifer is utilized, as in the long-term yield method described above, and is pumped to areas outside the basin, there will no longer be any discharge from these aquifers. It is this ground water discharge to streams that under natural conditions supports the "base flow" of streams. Therefore, if the long-term yield values are actually used, the streams will probably dry up in the aquifer areas during the summer and fall months except for the occasional storm flows. This prospect is not only aesthetically unappealing, but is illegal according to the riparian stream laws of Rhode Island. An example of the effects of induced infiltration is the University of Connecticut well field in Mansfield, Connecticut. According to the USGS, 7 mgd of ground water is the long-term yield in this area. Presently one mgd is withdrawn by the University well field, and

this pumpage causes the nearby Fenton River to dry up a portion of the time for half a mile. Clearly 7 mgd could not be withdrawn without seriously drying up the Fenton River.

Similarly, water level declines during the summer and fall months, when ground water storage is being consumed, may affect other landowners' wells. This act would probably be viewed as illegal.

SAFE YIELD:* Because of these limitations of the theoretical long-term yield, predicting a safe yield is difficult. Each basin represents a unique case. For purposes of this report, the safe yield is defined as the maximum rate of pumping over a sustained period of time from an aquifer, in mgd, without detrimentally depleting the aquifer or stream flow, inducing poor quality water, or infringing on other landowners' legal rights. It is then the amount of water that can safely be withdrawn from the ground for purposes of water supply to communities. For instance, in the Upper Pawcatuck Basin (area 12), the long-term yield according to a recent USGS investigation, is 25.0 mgd (8.0 from Chipuxet and 17.0 from Usquepaug-Queen). This theoretical maximum figure is based on an optimum well spacing, assumes no poor or deteriorating water quality or allowance for lowering stream flow below permissible levels, potential pollution, etc. A detailed evaluation of the hydrogeology of this basin revealed that there are definite limiting factors as to existing water quality, potential quality deterioration and minimum stream levels. This detailed analysis of Area 12 shows that iron, manganese and contamination will be a major problem in the Chipuxet ground water reservoir where an 8.0 mgd long-term yield has been theorized. In the Usquepaug-Queen ground water reservoir,

*Refers to ground water safe yield.

the 17.0 mgd theoretical long-term yield if unlikely to occur because the ground water discharge from this area is only 13.0 mgd during the driest year in ten years, the theoretical optimum well spacing and pumping rates could not be practically achieved because of land availability and the non-homogeneous aquifer, and the theoretically induced infiltration capacity on stream bed (40 gpd/square foot) has been estimated too high. Based upon these and other pertinent factors related directly to this basin, the long-term safe yield for water supply purposes for this basin based upon the above definition has been estimated as 8.0 mgd. Using the same criteria analyses, we have evaluated the potential ground water areas within and adjacent to the Providence service area and determined the safe yield available for water supply.

Table 4 shows the values of the safe yield for the basins in central Rhode Island where it would be practical to develop ground water supplies. The total safe yield is estimated to be 62.3 mgd. Since the present use of ground water in these same areas is 35.3 mgd, the amount of ground water available for future development in the Providence service area and immediately adjoining areas is 27.0 mgd.

For the Providence water supply service area shown on Figure 5, the safe yield equals 24.0 mgd (see Table 5). Within this service area, certain ground waters are more subject to danger from pollution, and therefore, the ground water in the municipalities of Providence, Cranston, Warwick and East Providence should be reserved for industrial use. Therefore, only Smithfield, Coventry, Glocester and Bristol County have good quality ground water where long-range supplies can be developed. The safe yield for these four areas as shown on Table 5 is 11.0 mgd of which 10.4 mgd will be utilized by 2015 as shown in Table 2. (See note C, Table 5.)

This quantity then is available for use to supplement the water surface supplies to meet the future demands of the Providence service area. This 10.4 mgd, deducted from the year 2015 total demands of 140.3 mgd, leaves 129.9 mgd to be available from surface supplies.

In 1981, when the recommendations of this report are again reviewed, the ground water situation should be reappraised based on additional data.

We understand that the Water Resources Coordinating Board is hopeful of conducting more detailed ground water studies which should define more specifically where and how such ground water can be successfully developed. Until this study is completed it is our opinion that a conservative evaluation of ground water potential such as we have presented is justifiable when considering long-term water supplies for municipal use.

TABLE 4

SUMMARY OF GROUND WATER AVAILABILITY (IN MGD)

IN AREAS PRACTICAL FOR DEVELOPMENT FOR CENTRAL RHODE ISLAND

Ground Water Basin	Area No.	Present Use	Estimated Safe Yield	Estimated Availability
(a) Blackstone River	3	5.5	7.0	1.5
(b) Up. Woonasquatucket	4	0.9	2.0	1.1
(c) Providence-Warwick	5	9.0	12.0	3.0
(d) Pawtucket-E. Providence	6	3.0	3.0	0.0
(e) Barrington-Warren	7	2.0	2.0	0.0
(f) S. Br. Pawtuxet R.	10	3.7	8.0	4.3
(g) Potowomut-Wickford	11	6.3	8.3	2.0
(h) Up. Pawcatuck R.	12	3.9	8.0	4.0
(i) Wood-Pawcatuck	13	1.0	12.0	11.0
Total		35.3	62.3	27.0

TABLE 5

GROUND WATER SUPPLIES

AREAS PRESENTLY ENTITLED TO RECEIVE WATER FROM PROVIDENCE WATER SUPPLY SYSTEM

Municipality	Basin	Safe Yield mgd	Present Usage Total	Present Usage Municipal	Available for Development Total	Available for Development Municipal
Smithfield	4	2.0[c]	0.9	0.9	1.1	1.1
Scituate	9	0	0	0	0	0
Johnston	5	0	0	0	0	0
N. Providence	5	0	0	0	0	0
Providence	5	4.0	4.0	0	0	0
Cranston	5	4.0	2.0	0	2.0	0
Warwick	5	4.0	1.0	0	3.0	0
W. Warwick	5	0	0	0	0	0
(KCWA)	10	0	0	0	0	0
Coventry	5	0	0	0	0	0
(KCWA)	10	6.0[a,c]	3.7	3.1	2.3	2.3
E. Providence	6	1.0	2.4	2.4[b]	0	0
Bristol County (Barrington, Warren)	7	2.0[c]	2.0	1.0	0	0
Foster	9	0	0	0	0	0
Glocester	1	1.0[c]	0	0	1.0	1.0
	9	0	0	0	0	0
Total		24.0	16.0	7.4	9.4	4.4

a. Total safe yield for Basin 10 is 12.0 mgd with 4.0 mgd allotted to Big River development. 6.0 mgd is available for Coventry and 2.0 mgd is available for West Greenwich.

b. To be abandoned due to poor quality when system is connected to the Providence water supply system supply. The present pumpage has exceeded the safe yield (see safe yield column).

c. Areas within Providence water supply service area where good quality ground water can be developed. The sum of these four municipalities' safe yield equals 11.0 mgd. To match Glocester's future demand the 11.0 mgd figure has been reduced to 10.4 mgd and is the figure used in Table 2.

III-C. WATER TREATMENT PLANT: Because of the similarity in water quality between the Big River and the streams tributary to the Scituate Reservoir, the treatment processes employed at the proposed Big River works should be similar to those now being used so successfully at the Scituate Water Purification Works. Thus ferric sulphate and slaked lime should be used as coagulants to remove the impurities from the water, and the overall treatment should include aeration, chemical flocculation, sedimentation, filtration, chlorination and fluoridation.

In evaluating the water quality of the Big River near the proposed dam site, reference was made to the data collected over the past decade by the Water Purification Works Laboratory in Scituate. Consideration was given to recent conditions by averaging the analytical results of samples tested during the last two years. In the table below are shown the most recent water quality data for two sampling points on the Big River and 22 points on those streams contributing to the Scituate Reservoir.

TABLE 6

AVERAGED WATER QUALITY DATA FOR YEARS 1966-1967

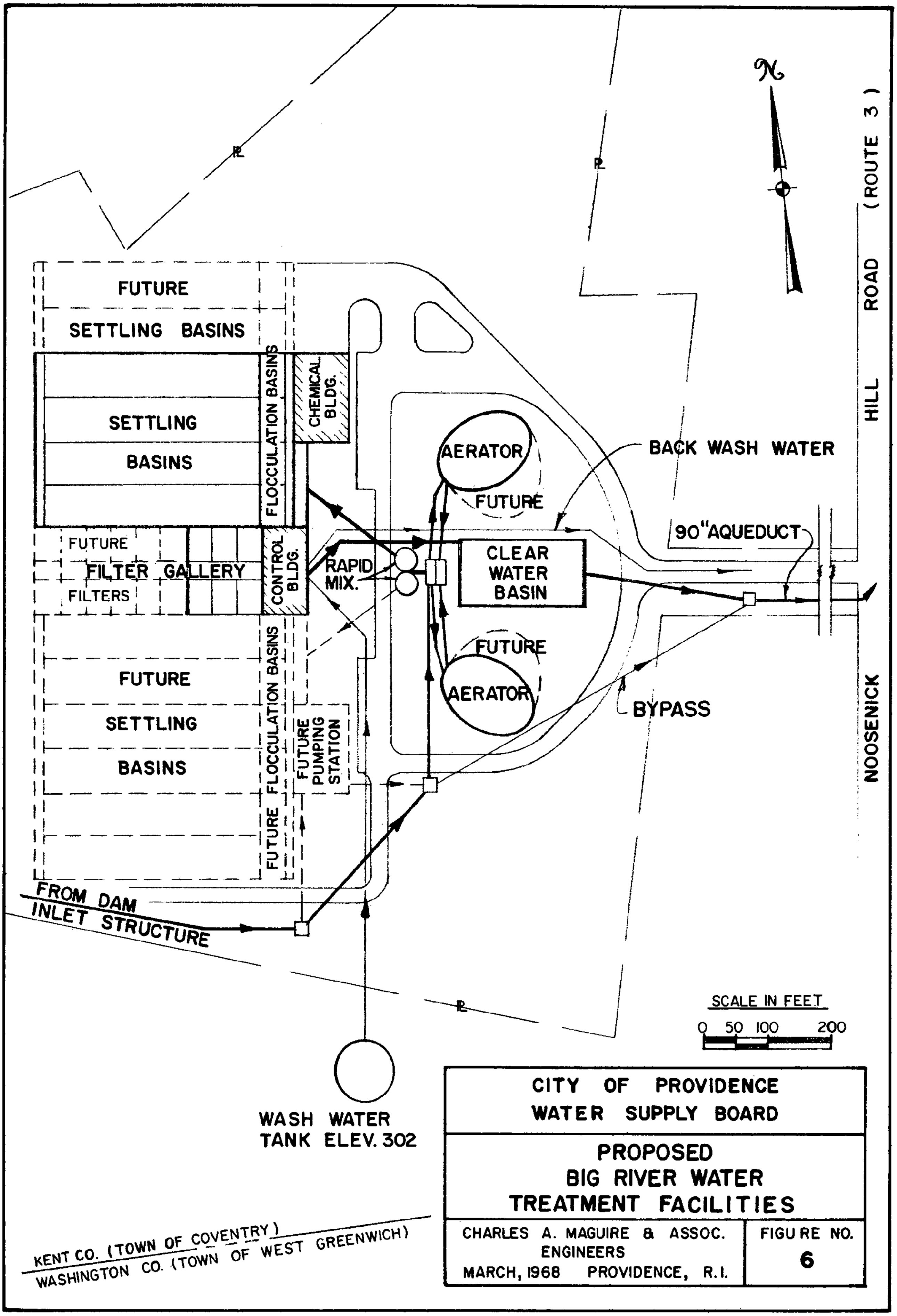
BIG RIVER AND TRIBUTARY STREAMS TO SCITUATE RESERVOIR

Chemical Constituent	Big River: Route 3 Bridge	Big River: Harkney Hill Road	Tributary Streams To Scituate Reservoir
Hydrogen-ion (pH)	5.9	5.9	5.9
Carbon dioxide	5.2	5.4	5.0
M.O. alkalinity	3.9	4.1	4.9
Color	51	50	40
Iron	0.30	0.30	0.24
Manganese	0.015	0.018	0.026
Turbidity	0.46	0.42	0.26
Chlorides	5.97	5.94	--

All values except pH are expressed as mg per liter.

It is quite clear that the chemical composition of the water in the Big River is similar to that in the waters that flow into the Scituate Reservoir. A study of the available laboratory data on the Scituate water showed that the long retention of the waters impounded by the Gainer Dam at Scituate afford the natural forces of time to carry out the physical, chemical and biological changes that result in the removal of many of the chemical impurities from the influent waters effecting the improvement of water quality. It can be expected that the Big River Reservoir will be able to bring about the same degree of purification of its influent waters, and that the raw water reaching the proposed treatment works at Big River will be similar to the raw water at the Scituate plant.

The treatment works will be located on an area lying to the northeast of Hungry Hill between the proposed dam site and Nooseneck Hill Road. This land is quite level and is at an elevation that will keep excavation costs at a minimum. The area is accessible from the highway and is reasonably higher than lowlying areas nearby so that all structures can be easily drained. The site is relatively near the dam so that the required length of raw water conduit will be minimal. Gravity flow through the treatment plant will be possible except when the water in the reservoir is at a very low level. A low-lift pumping station will be required when Wood River development takes place in 1997. A preliminary layout of the plant has been developed and is shown in Figure 6. Final layout and design will be based on more detailed field data. It is expected that controls and mechanization to the same degree as is practiced at Scituate will keep operational costs to a minimum.


FUTURE
SETTLING BASINS
SETTLING
BASINS
FLOCCULATION BASINS
CHEMICAL BLDG.
FUTURE
FILTER GALLERY
FILTERS
CONTROL BLDG.
RAPID MIX.
AERATOR
FUTURE
CLEAR WATER BASIN
BACK WASH WATER
90"AQUEDUCT
FUTURE
AERATOR
BYPASS
FUTURE
SETTLING
BASINS
FUTURE FLOCCULATION BASINS
FUTURE PUMPING STATION
FROM DAM
INLET STRUCTURE
WASH WATER
TANK ELEV. 302
NOOSENICK HILL ROAD (ROUTE 3)
SCALE IN FEET
0 50 100 200
KENT CO. (TOWN OF COVENTRY)
WASHINGTON CO. (TOWN OF WEST GREENWICH)
CITY OF PROVIDENCE
WATER SUPPLY BOARD
PROPOSED
BIG RIVER WATER
TREATMENT FACILITIES
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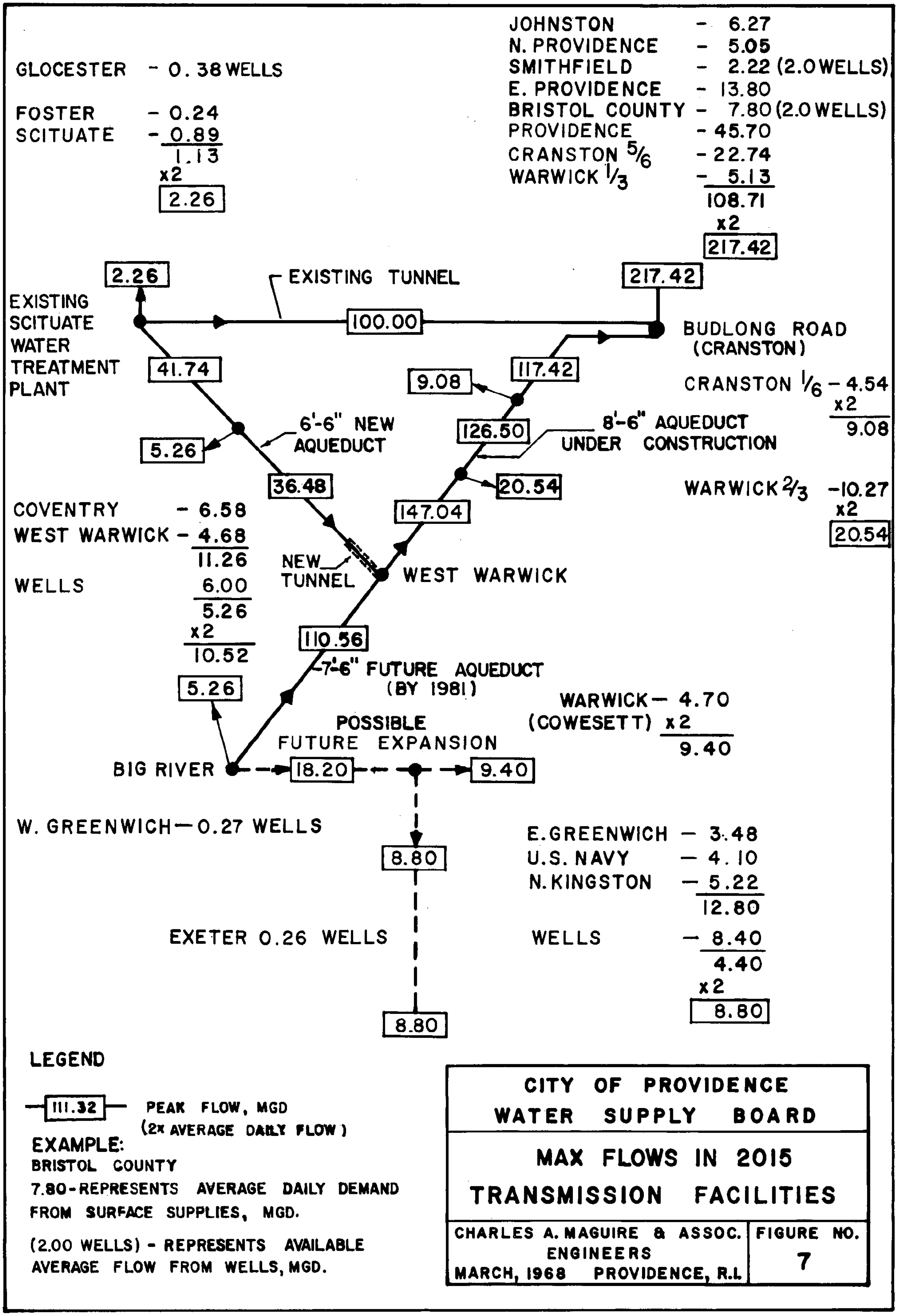
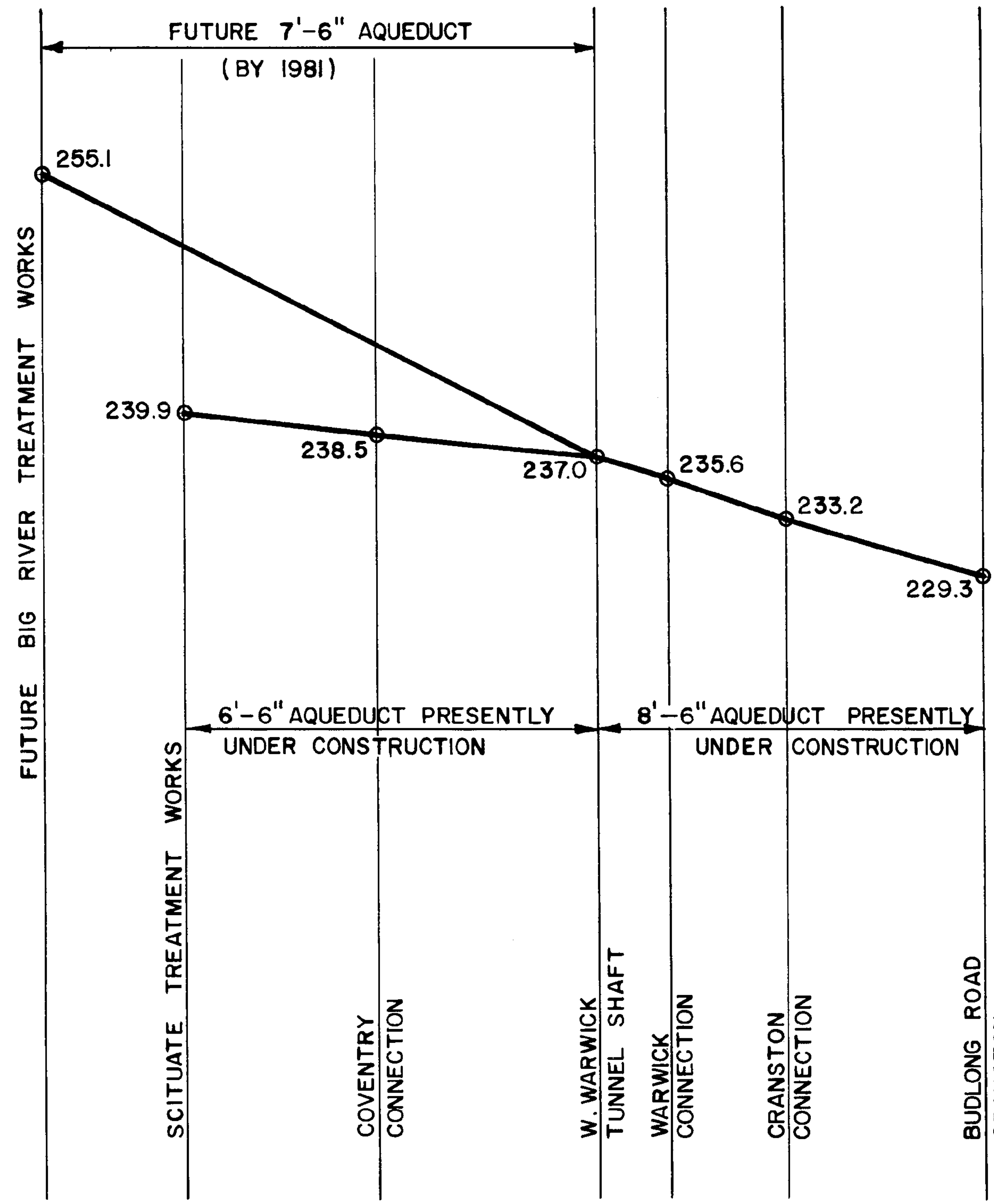
MARCH, 1968 PROVIDENCE, R.I.
FIGURE NO.
6

III-D. TRANSMISSION AND STORAGE FACILITIES: Expansion of the existing transmission facilities (from Scituate to Budlong Road in Cranston) is currently under construction. This expansion consists of an aqueduct installation, the first section of which from the Scituate treatment works to a junction shaft at the West Warwick Golf Course is 6 feet 6 inches, and the second section which is 8 feet 6 inches from West Warwick to the vicinity of Budlong Road in Cranston. In designing the aqueduct, the development of the Big River Reservoir project was fully anticipated with respect to size and layout of the new conduit.

The construction of a 7-foot 6-inch gravity feed transmission line will be required to connect the proposed Big River treatment works with the new aqueduct at West Warwick junction shaft. A schematic sketch, Figure 7 illustrates the relative location and maximum design flow (based on twice the average day demand) of the completed transmission system. The design flow for the new 7-foot 6-inch conduit from Big River Reservoir development to West Warwick is 111 mgd. The design flow in the 8-foot 6-inch aqueduct from West Warwick to Budlong Road in Cranston ranges from 147 to 117 mgd.

A hydraulic profile of the transmission system has been plotted on Figure 8. It can be seen from this profile that a 7-foot 6-inch conduit from the Big River treatment works to the West Warwick junction shaft would require the clear well elevation of the new treatment works to be set at Elevation 255 msl.


GLOCESTER - 0.38 WELLS
FOSTER - 0.24
SCITUATE - 0.89
1.13
x2
2.26
JOHNSTON - 6.27
N. PROVIDENCE - 5.05
SMITHFIELD - 2.22 (2.0 WELLS)
E. PROVIDENCE - 13.80
BRISTOL COUNTY - 7.80 (2.0 WELLS)
PROVIDENCE - 45.70
CRANSTON 5/6 - 22.74
WARWICK 1/3 - 5.13
108.71
x2
217.42
2.26
EXISTING TUNNEL
217.42
EXISTING SCITUATE WATER TREATMENT PLANT
100.00
BUDLONG ROAD (CRANSTON)
41.74
9.08
117.42
CRANSTON 1/6 - 4.54
x2
9.08
6'-6" NEW AQUEDUCT
126.50
8'-6" AQUEDUCT UNDER CONSTRUCTION
5.26
36.48
20.54
WARWICK 2/3 -10.27
x2
20.54
147.04
COVENTRY - 6.58
WEST WARWICK - 4.68
11.26
WELLS 6.00
5.26
x2
10.52
NEW TUNNEL
WEST WARWICK
110.56
7'-6" FUTURE AQUEDUCT (BY 1981)
5.26
WARWICK - 4.70
(COWESETT) x2
9.40
POSSIBLE FUTURE EXPANSION
BIG RIVER
18.20
9.40
W. GREENWICH - 0.27 WELLS
8.80
E. GREENWICH - 3.48
U.S. NAVY - 4.10
N. KINGSTON - 5.22
12.80
WELLS - 8.40
4.40
x2
8.80
EXETER 0.26 WELLS
8.80
LEGEND
111.32 PEAK FLOW, MGD (2x AVERAGE DAILY FLOW)
EXAMPLE:
BRISTOL COUNTY
7.80 - REPRESENTS AVERAGE DAILY DEMAND FROM SURFACE SUPPLIES, MGD.
(2.00 WELLS) - REPRESENTS AVAILABLE AVERAGE FLOW FROM WELLS, MGD.
CITY OF PROVIDENCE
WATER SUPPLY BOARD
MAX FLOWS IN 2015
TRANSMISSION FACILITIES
CHARLES A. MAGUIRE & ASSOC. ENGINEERS
MARCH, 1968 PROVIDENCE, R.I.
FIGURE NO. 7



<u>NOTE:</u> ELEVATIONS SHOWN ARE MAXIMUM FLOWS (2 X AVERAGE FLOWS) INDICATED IN FIGURE NO. 7

MSL DATUM

CITY OF PROVIDENCE
WATER SUPPLY BOARD

HYDRAULIC PROFILE IN 2015
TRANSMISSION FACILITIES

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MARCH 1968 PROVIDENCE, R.I.

FIGURE NO.
8

By setting the treatment plant at a relatively high elevation, gravity flow is possible from the treatment plant through the aqueduct for ultimate flows including the development of Wood River and Moosup River watersheds. Supply by gravity flow under the extreme conditions for maximum flows coupled with minimum Big River Reservoir elevation of 278 msl can be maintained until such time as the Wood River development is completed. The use of a 7-foot 6-inch aqueduct, therefore, eliminates the necessity of a pumping station at Big River Reservoir prior to 1997 when the addition of Wood River water would require utilization of greater storage capacity, which would be possible by intermittent pumping during periods of drought.

In evaluating the type of transmission facility required, it was estimated that an aqueduct would be generally more economical than a tunnel. The aqueduct from Big River would have to be completed by 1981 to coincide with the completion of the Big River Reservoir and treatment works.

STORAGE FACILITIES: As the additional communities entitled to receive Providence system water are served, the storage requirements of the expanded system will increase. The provision of storage facilities to meet the needs of these additional communities will become the responsibility of the communities themselves. The future storage requirements of the areas presently served can be met by expansion of the existing facilities. East Providence, for example, has recently completed an 8 mg storage tank, and Warwick and Kent County Water Authority are planning new storage facilities for their systems.

The capacity of the present storage facilities consisting of Aqueduct, Neutaconkanut and Longview Reservoirs is 97.9 mg. Comparison of the projected water demands for the years up to 2015 with the available storage capacity has demonstrated the need for expansion of the storage facilities. It is estimated that between 1990 and 2010 the existing low service system storage should be expanded by 80 mg. Since both Aqueduct and Neutaconkanut Reservoirs have been designed with provisions for economical future expansion, it is recommended that an additional 40 mg storage be added to Aqueduct Reservoir about 1990 and Neutaconkanut Reservoir be expanded by 40 mg about 2010. It is further recommended that about 1980 the existing high service system be expanded by 11 mg by adding to the storage protection afforded by Longview Reservoir.

The additional storage of 91 mg and the existing storage of 97.9 mg would provide 188.9 mg which would be adequate until after 2015. In the year 2015 the storage required to meet the maximum day demand of 168.6 for one day and the average demand of 84.3 for two days will be 168.6 mg.

SECTION IV - ESTIMATED COSTS AND TIMETABLE OF CONSTRUCTION

IV-A. GENERAL: This section summarizes the results of field and office studies directed toward the establishment of preliminary estimates of costs for the development of the Big River Reservoir, a 52 mgd treatment plant and 90-inch aqueduct from the treatment plant to West Warwick. The basis of cost estimate has been prepared on a preliminary geological reconnaissance survey of the proposed dam site, review of available boring data and limited seismic work, conceptual preliminary designs of major structures, USGS topographic data and evaluation of unit prices of cost in our area. In evaluating the unit items of cost, consideration was given to the ENR (Engineering News Record) Construction Cost Index which is a weekly barometer of construction costs throughout the United States. For the purpose of this report we have used the current ENR Cost Index of 1115. Projection of future costs can be made assuming an average annual increase of approximately 4 percent.

The methods and procedures utilized in our studies are believed to be sufficiently detailed to form a rational basis for the preliminary cost estimates. For a more accurate and detailed cost estimate, further information will be required and should include final detailed surveys; detailed subsurface explorations including borings, pumping and field tests; geophysical studies; and laboratory soil tests and analyses for each of the principal structures.

IV-B. ITEMS OF WORK: The principal items of work for which cost estimates have been made are as follows:

(1) Reservoir site improvements consisting of clearing, demolition of existing structures and burial graves and highway relocations. The existing area, required to be cleared below the proposed reservoir flow line of 302.5, is approximately 3,560 acres. Based on the USGS maps, 300 existing buildings will have to be demolished and a total of six cemeteries will be inundated requiring 180 burial grave sites to be moved. Roadway relocations involve 22,000 feet of secondary roads and 10,000 feet of minor roadways.

(2) A rolled earthfill dam with impervious core approximately 3,000 feet long and 60 feet high of cross-section as shown on Figure 9.

(3) A spillway and outlet channel having a crest width of 200 feet and length of 3,000 feet.

(4) A gate house and plant intake line.

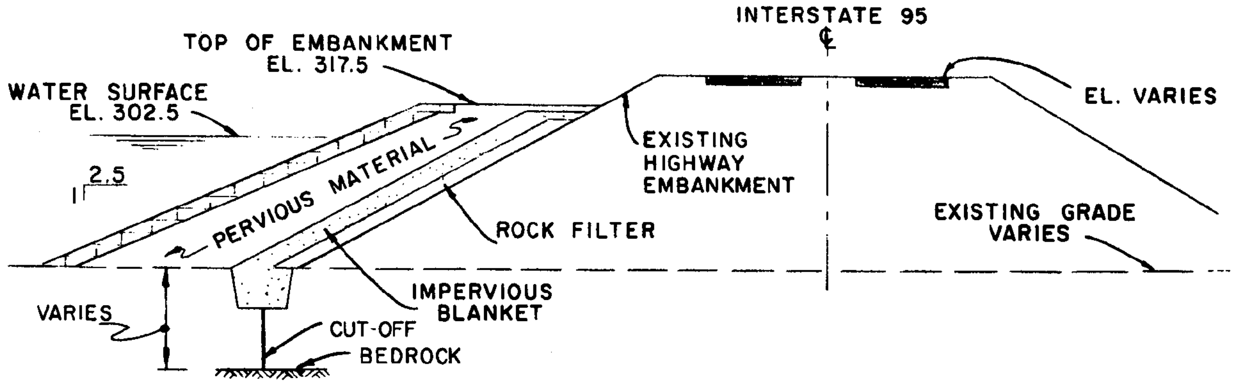
(5) A 52 mgd water treatment plant of conventional design similar to the Scituate plant designed for future expansion to 128 mgd by the year 2012.

(6) A 90-inch 42,000-foot long aqueduct to connect the flow from Big River treatment plant to the existing 102-inch aqueduct in West Warwick. A tunnel scheme was also evaluated but found to be more costly than the aqueduct plan.

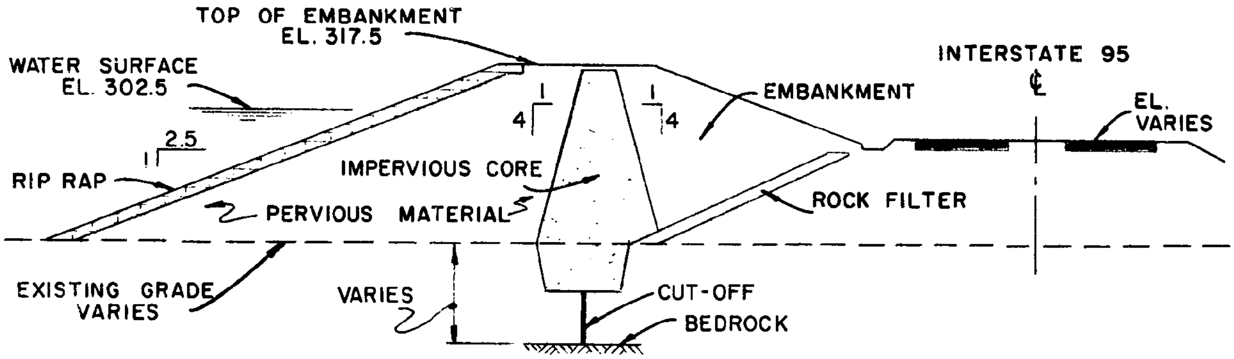
(7) Two major utilities - 934.5 KVA power line and a 600-pair telephone cable - will have to be relocated as part of the construction. The estimated cost of these two relocations is approximately $350,000. For the purpose of this report it has been assumed that the utilities will be relocated at the expense of the particular utility involved.

(8) Because of apparent granular nature of the soil along I-95 there would appear to be a problem of possible loss of water due to seepage when the reservoir is filled. This particular problem has been mentioned in prior report by our office. To control and cut off this seepage would require a cutoff barrier carried down to ledge or an impervious material. Because of lack of any soils information in this area and any exact knowledge of permeability of the soil it is impossible to determine the magnitude of this problem at this time. In final design borings and pumping tests will have to be carried out to determine the scope of the problem and evaluate various solutions. The cost of these necessary embankments and cutoff would conceivably cost three to four million dollars. Because of lack of any data we have not included this in the cost of the Big River project. The recently published report by Metcalf & Eddy mentioned this problem but estimated no cost for the control for apparently the same reason.

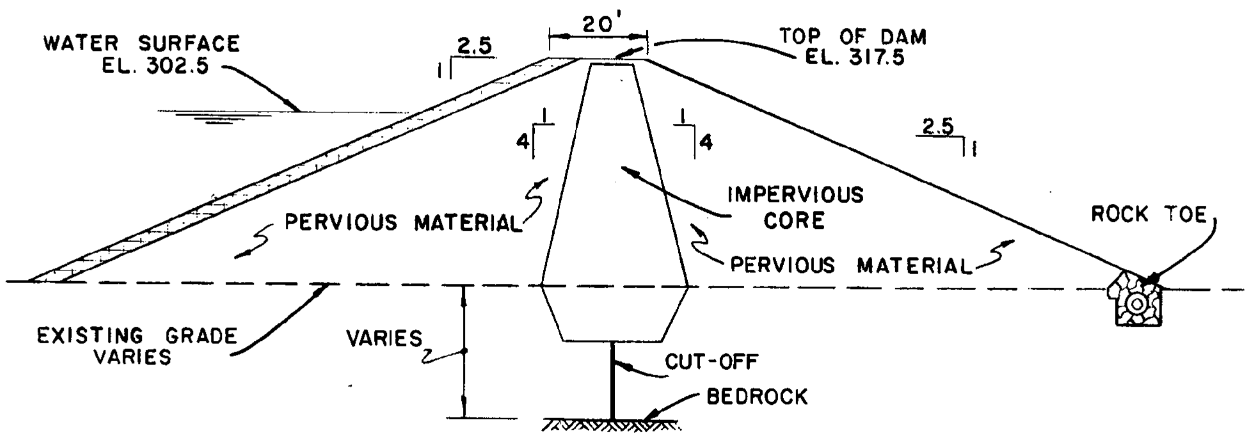
For purposes of clarification of what the major items of cost are, we have prepared a schematic plan (Figure 10) that shows the items mentioned in connection with the Big River project, and the major items of construction of the future Wood River development and future force main from Moosup River. In addition to this schematic plan the general plan (Figure 2) shows not only the proposed Big, Wood and Moosup Reservoir developments but also shows the existing Providence high and low pressure distribution systems which will help the reader in relating the proposed developments to the existing system.



TYPICAL EMBANKMENT CROSS-SECTION



TYPICAL DIKE CROSS-SECTION



TYPICAL BIG RIVER DAM CROSS-SECTION

NOTE:
ELEVATIONS ARE MSL

CITY OF PROVIDENCE
WATER SUPPLY BOARD

BIG RIVER RESERVOIR
EMBANKMENTS
AND DAM SECTIONS

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FIGURE NO.
9

IV-C. ESTIMATED COST: The estimated cost of construction of the Big River project based on the preceding criteria is presented in the following Table 7. The costs are based on a current ENR Cost Index of 1115 and include contingencies and engineering.

TABLE 7

ESTIMATED COST OF CONSTRUCTION OF THE BIG RIVER WATER SUPPLY DEVELOPMENT

Item No.[1]	Description of Work	Quantity	Unit Cost	Total	Estimated Cost
B-1	Reservoir Site Improvements				
	Clearing	3,560 acres	$500	$ 1,780,000	
	Demolition of struct.	300	600	180,000	
	Grave relocations	180	500	90,000	
	Highway relocations	--	--	1,500,000	
	Public utility relocations (by others)	--	--	--	$ 3,550,000
B-2	Dam and Spillway Construction				
	Dam			$ 2,000,000	
	Spillway and outlet channel			1,900,000	
	Diversion of water			200,000	
	Gate house			200,000	4,300,000
B-3	Plant intake and meter chamber				800,000
B-4	52 mgd treatment plant and appurtenances				6,700,000
B-5	90-inch connection to W. Warwick aqueduct - 42,000 ft. at $225/ft.				9,450,000
	Construction (including contingencies) Items B-1 through B-5				$24,800,000
	Engineering, surveys, borings, legal, administrative, misc.				2,000,000
	Total Items B-1 through B-5				$26,800,000

1. Item numbers refer to those shown on Figure 10. (No land costs have been included.)

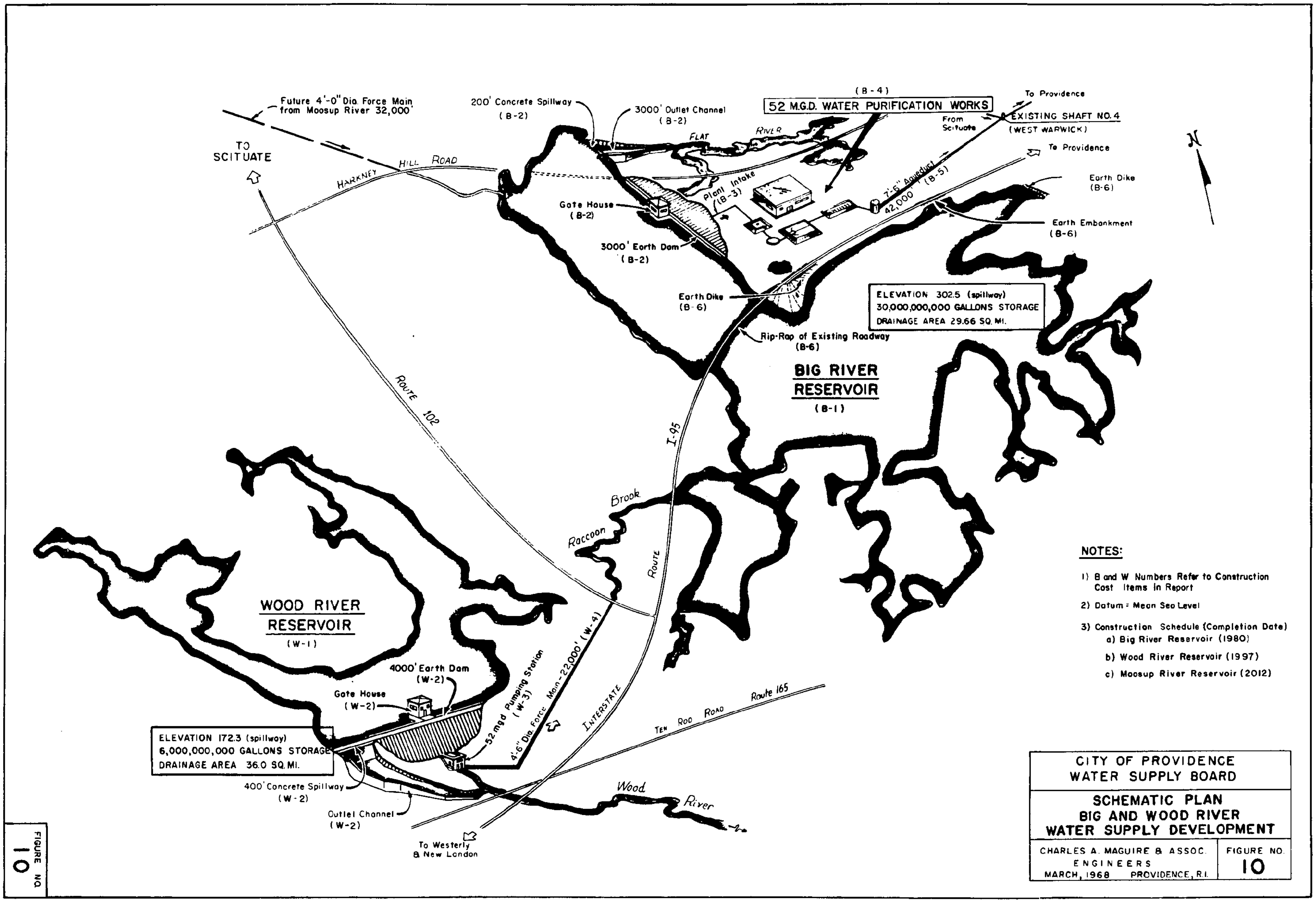
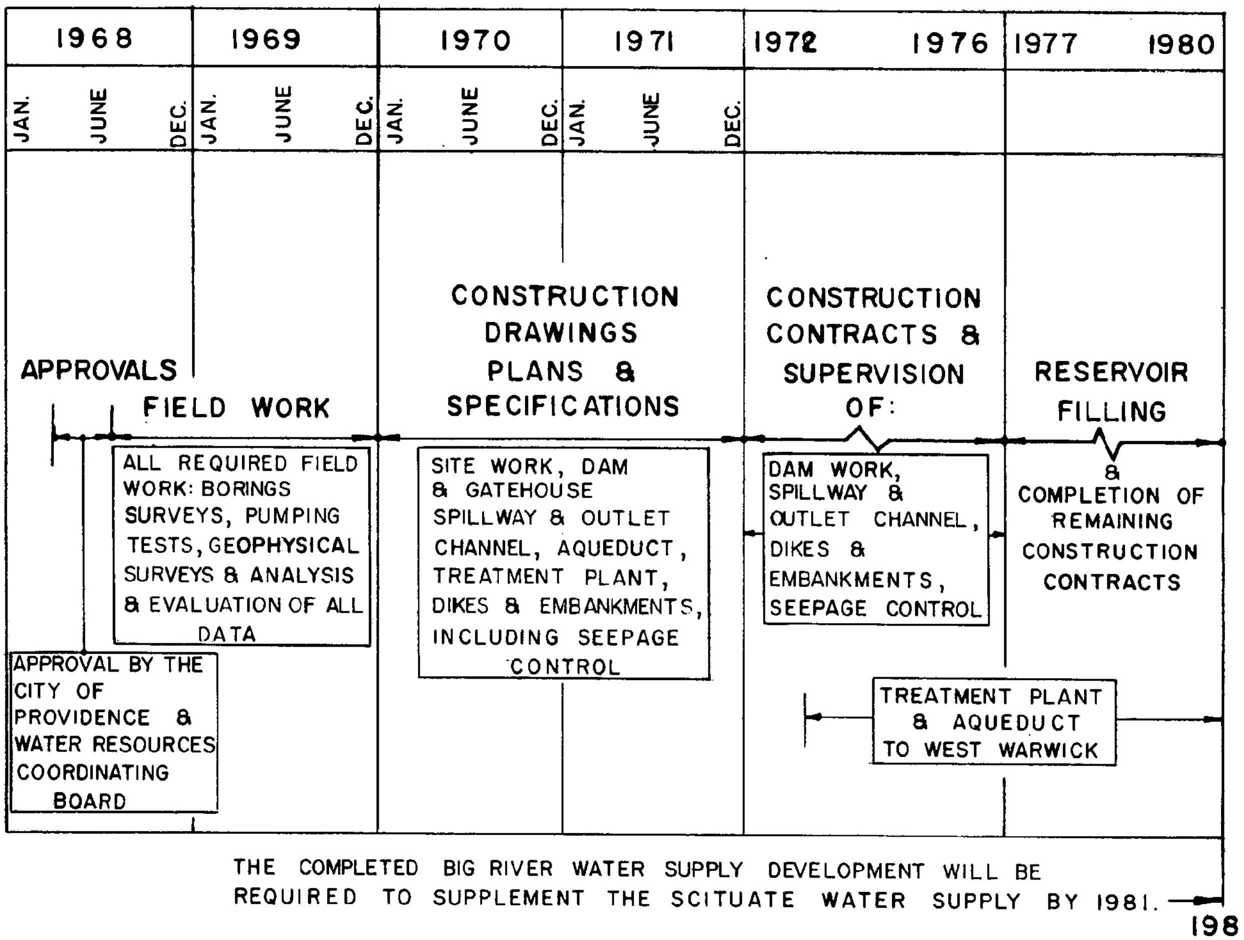

Future 4'-0" Dia. Force Main from Moosup River 32,000'
TO SCITUATE
HARKNEY HILL ROAD
200' Concrete Spillway (B-2)
3000' Outlet Channel (B-2)
FLAT RIVER
(B-4)
52 M.G.D. WATER PURIFICATION WORKS
To Providence
From Scituate
EXISTING SHAFT NO. 4 (WEST WARWICK)
To Providence
Earth Dike (B-6)
Earth Embankment (B-6)
Gate House (B-2)
Plant Intake (B-3)
7'-6" Aqueduct 42,000' (B-5)
3000' Earth Dam (B-2)
Earth Dike (B-6)
ELEVATION 302.5 (spillway)
30,000,000,000 GALLONS STORAGE
DRAINAGE AREA 29.66 SQ. MI.
Rip-Rap of Existing Roadway (B-6)
BIG RIVER RESERVOIR (B-1)
ROUTE 102
I-95
Raccoon Brook
ROUTE
WOOD RIVER RESERVOIR (W-1)
4000' Earth Dam (W-2)
Gate House (W-2)
52 mgd Pumping Station (W-3)
4'-6" Dia. Force Main-22,000' (W-4)
INTERSTATE
TEN ROD ROAD
Route 165
ELEVATION 172.3 (spillway)
6,000,000,000 GALLONS STORAGE
DRAINAGE AREA 36.0 SQ. MI.
400' Concrete Spillway (W-2)
Outlet Channel (W-2)
To Westerly & New London
Wood River
NOTES:
1) B and W Numbers Refer to Construction Cost Items in Report
2) Datum = Mean Sea Level
3) Construction Schedule (Completion Date)
a) Big River Reservoir (1980)
b) Wood River Reservoir (1997)
c) Moosup River Reservoir (2012)
CITY OF PROVIDENCE
WATER SUPPLY BOARD
SCHEMATIC PLAN
BIG AND WOOD RIVER
WATER SUPPLY DEVELOPMENT
CHARLES A. MAGUIRE & ASSOC.
ENGINEERS
MARCH, 1968 PROVIDENCE, R.I.
FIGURE NO. 10

FIGURE NO. 10

IV-D. TIMETABLE OF CONSTRUCTION: To assure that the Big River project is completed prior to 1981 it is imperative that a timetable of construction be worked out which recognizes the various facets of the project such as the filling of the reservoir and the problems that may be associated with the permeability of soil along I-95, or in the event that even a moderate "dry spell" occurs requiring extra time to fill the reservoir. As shown on Figure 11 the required field work such as borings, surveys, pumping tests and evaluation of data will take 18 months. Final design including construction drawings, specifications and bidding will take another 24 months, and construction 5 years, giving a total of 8-1/2 years prior to filling of the reservoir. Assuming a filling time of 3-1/2 years the total project time would be 12 years, which if started this year would mean completion by 1980, the time that the additional water will be needed to meet the requirements of the system.

As previously stated, a revised time schedule and estimated cost of construction should be prepared in 1981 for the 1981-2015 water development program as outlined in the Summary and Recommendations section of this report. To attempt to define more precisely the schedule of construction or estimate the costs for development of the 1981-2015 period at this time is not realistic recognizing the many variables and difficulties of forecasting even for a short time period. The updating of the development schedule in 1981 should recognize any changes in growth and water usage based on the latest census and water consumption data.



NOTES:

DURING THE 12 YEAR PERIOD, THE MATTERS OF ADMINISTRATION AND LEGAL WORK IN CONNECTION WITH THE PROGRAM INCLUDING RIPARIAN RIGHTS WILL HAVE TO BE RESOLVED. ANY ADDITIONAL LAND FOR EASEMENTS AND RIGHTS OF WAY WILL ALSO REQUIRE TIME.

A "PERT" PROGRAM WILL BE DEVELOPED AT THE EARLY PHASES OF DESIGN TO ASSURE COMPLETION OF THE RESERVOIR CONSTRUCTION CONTRACTS IN ACCORDANCE WITH THE DEMANDING TIME SCHEDULE.

CITY OF PROVIDENCE WATER SUPPLY BOARD	
BIG RIVER DESIGN AND CONSTRUCTION SCHEDULE	
CHARLES A. MAGUIRE & ASSOC. ENGINEERS MARCH 1968 PROVIDENCE, R.I.	**FIGURE NO. 11**

In addition, the population distribution and industrial growth patterns within the service area should be reviewed based on 1968-1980 data. At that time there will also be available further statistics on actual ground water developments and riparian rights which will assist in determining more precisely the safe yield available for water supply purposes, which is necessary in establishing a more exact timetable of future construction.

SECTION V - CONSIDERATION OF EXPANSION OF THE PROVIDENCE SERVICE AREA

V-A. GENERAL: The available safe yield for water supply purposes of the existing Scituate reservoir and proposed Big, Wood and Moosup developments will be 136 mgd in the year 2015. The surface water demands of the Providence service areas at that time are estimated at 129.9 mgd, leaving a surplus of 6.1 mgd. Consideration therefore has been given to the possibility of expanding the present Providence water service area to the north to the Pawtucket area and also to the areas to the south. Pawtucket is presently expanding its facilities by raising the Diamond Hill reservoir dam which will provide relief for the immediate future. Consideration of an ultimate source of water supply from the Big River development was evaluated but does not appear feasible because of the 20-mile length of the transmission line of which a considerable distance through Cranston and Providence would be difficult and expensive construction. Furthermore, the water would require continual pumping because of the difference in elevation between the Providence and Pawtucket systems.

In the remaining northern part of the State the principal water demand will be exerted by Woonsocket and northern Cumberland, which Metcalf & Eddy in their 1967 report recommended being supplied by the proposed Tarkiln and Nipmuc developments. We recommend, as has been suggested in past reports, that the development of these resources to serve Woonsocket and Cumberland be expanded and construction phased to also serve Pawtucket, Central Falls and southern Cumberland. The proposed transmission main from the Tarkiln development to Albion in Cumberland should also be enlarged and extended south, a distance of less than seven miles, to serve the Pawtucket-Central Falls area. All of these communities are within the Blackstone River drainage basin within which there is ample water resources, if properly developed, to serve them all.

To the south, the areas we have considered and studied include part of the City of Warwick (that served by the Kent County Water Authority), and the Towns of North Kingstown, East Greenwich, the U. S. Navy installations at Quonset and Davisville, West Greenwich and Exeter. Of these, as shown in Section III-B, the Towns of West Greenwich and Exeter have sufficient ground water available to meet their water requirements through 2015. The other areas, however, will be deficient prior to that time and will need to augment their ground water supplies. Since these areas are adjacent to the existing service area of the Providence water supply system and will need additional water supplies in the future, it makes economic sense to serve them with any surplus that may be available from the Providence system.

V-B. NEW AREAS CONSIDERED FOR EXPANSION AND RECOMMENDATIONS: As put forth above, the communities considered most feasible to serve with Providence system water, should the service area be expanded, are part of Warwick (served by Kent County Water Authority), North Kingstown, East Greenwich and the U. S. Navy installations at Quonset and Davisville. The surface water requirements of these communities and the total surface water requirements of an expanded system are listed in Table 8. According to this tabulation the surface water requirements by 2015 will increase from 129.9 mgd demand for the present service area to 139.0 mgd for an expanded service area.

TABLE 8

EXPANDED SERVICE AREA

SURFACE WATER REQUIREMENTS

		Additional Communities		Present Service Area	Expanded Service Area
Year	Total Demand	Available from Ground Water	Required Surface Water	Required Surface Water	Required Surface Water
1970	6.88	6.5	0.4[a]	59.2	59.2
1980	9.2	7.2	2.0[a]	70.0	72.0
1990	11.6	8.1	3.5[a]	87.0	90.5
2000	14.0	8.6	5.4[b]	103.3	108.4
2010	16.8	8.8	8.0[b]	120.4	128.4
2015	18.0	8.9	9.1[b]	129.9	139.0

a. Surface water through proposed 36-inch Warwick connection to KCWA (to serve East Greenwich and Cowesett area of Warwick. Other areas not deficient until 1990).

b. Surface water through a new connection from Big River treatment plant easterly to KCWA system to serve East Greenwich, Cowesett area of Warwick, North Kingstown and U. S. Navy.

As can be seen from the above tabulation these additional communities would require water from Providence water system starting in 1970. The slight change in construction schedule of the recommended development of future sources of supply presented earlier, and the eventual construction in 1990 of a transmission line from the Big River treatment plant easterly to serve this area.

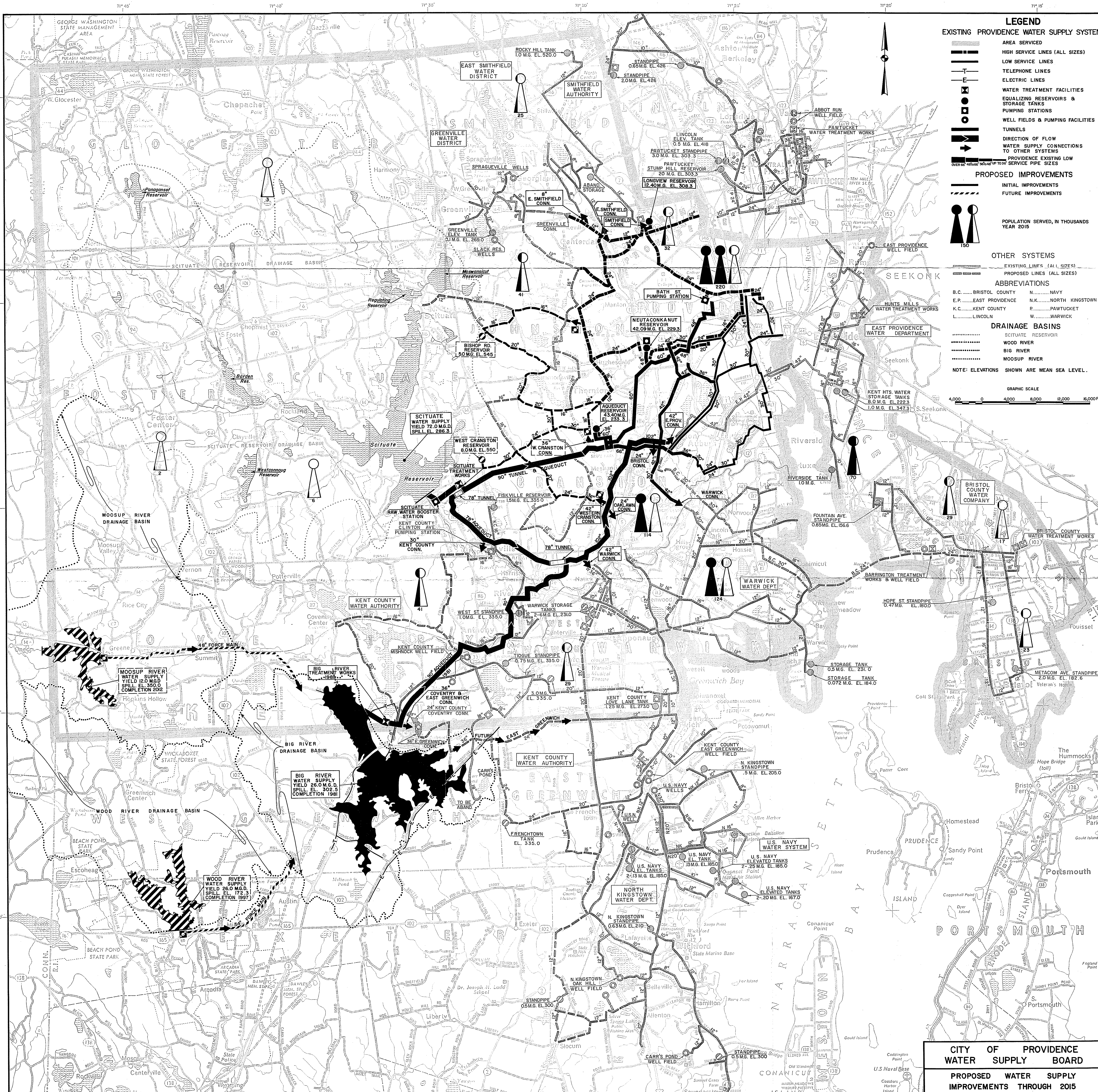
The development program would be changed as follows: The development of Big River watershed would be required one year sooner in 1980 instead of 1981, the development of Wood River Reservoir and watershed would be required two years sooner in 1995, the addition of Moosup River diversion works would be needed by 2008 rather than 2012, and an additional source of supply such as Flat River would have to be developed some five years sooner in 2013. The accelerated surface supply development would require concurrent treatment facility expansion.

As previously mentioned, a transmission line would be required in 1990 from the Big River treatment plant easterly to serve the southern areas, and is shown in Figure 12. The aqueduct would provide for a maximum flow of 18.2 mgd easterly, of which 9.4 mgd is for the Cowesett section of Warwick, while the remaining 8.8 mgd is for East Greenwich, the U. S. Navy installations and North Kingstown. To provide service to the East Greenwich and Cowesett areas prior to the construction of the new transmission main from Big River in 1990 consideration should be given to the enlargement of the proposed 36-inch Warwick line in Route 2 to which the Kent County Water Authority could connect. Improvements in the Kent County Water Authority system would also be necessary to provide for the increased flows.

Figure 12 which shows the major distribution systems of Providence and other water supply systems within and adjacent to the Providence service area, was used in our hydraulic studies. We have included it in this report and hope it will be of some assistance to those communities that at present are, or expect to be connected to the Providence water supply system.

As mentioned in the "Summary and Recommendations" section of this report, the detailed background information, which has been the foundation of this report, is available. A bound appendix to the report containing this information is on file in the office of the Chief Engineer of the Providence Water Supply Board.

END


LEGEND
EXISTING PROVIDENCE WATER SUPPLY SYSTEM
AREA SERVICED
HIGH SERVICE LINES (ALL SIZES)
LOW SERVICE LINES
TELEPHONE LINES
ELECTRIC LINES
WATER TREATMENT FACILITIES
EQUALIZING RESERVOIRS & STORAGE TANKS
PUMPING STATIONS
WELL FIELDS & PUMPING FACILITIES
TUNNELS
DIRECTION OF FLOW
WATER SUPPLY CONNECTIONS TO OTHER SYSTEMS
OVER 66" 48"to66" 36"to48" UP TO 36"
PROVIDENCE EXISTING LOW SERVICE PIPE SIZES
PROPOSED IMPROVEMENTS
INITIAL IMPROVEMENTS
FUTURE IMPROVEMENTS
150
POPULATION SERVED, IN THOUSANDS YEAR 2015
OTHER SYSTEMS
EXISTING LINES (ALL SIZES)
PROPOSED LINES (ALL SIZES)
ABBREVIATIONS
B.C. .... BRISTOL COUNTY
N. .... NAVY
E.P. .... EAST PROVIDENCE
N.K. .... NORTH KINGSTOWN
K.C. .... KENT COUNTY
P. .... PAWTUCKET
L. .... LINCOLN
W. .... WARWICK
DRAINAGE BASINS
SCITUATE RESERVOIR
WOOD RIVER
BIG RIVER
MOOSUP RIVER
NOTE: ELEVATIONS SHOWN ARE MEAN SEA LEVEL.
GRAPHIC SCALE
4,000 0 4,000 8,000 12,000 16,000 FT.
CITY OF PROVIDENCE
WATER SUPPLY BOARD
PROPOSED WATER SUPPLY IMPROVEMENTS THROUGH 2015
& MAJOR DISTRIBUTION SYSTEMS
CHARLES A. MAGUIRE & ASSOC.
ENGINEERS
MARCH, 1968 PROVIDENCE, R.I.
FIGURE NO. 12
BASE MAP BY RHODE ISLAND DEVELOPMENT COUNCIL & DEPARTMENT OF PUBLIC WORKS

GLOSSARY

gpcd	Water usage in gallons per capita per day
mgd	Flow of water in millions of gallons per day
Safe Yield	The maximum dependable draft which can be made continually upon a surface water supply during a period of extended drought when the greatest deficiency in runoff is likely to occur
Water supply safe yield	That portion of the safe yield available for water supply purposes after satisfying riparian rights
Ground water safe yield	The maximum dependable draft from a ground water aquifer which can be removed at a maximum rate of pumping over a sustained period from the aquifer without detrimentally depleting the aquifer or stream flow, inducing poor quality water or infringing on other landowners legal and riparian rights

Technical work on this study was performed by the following members of the staff of Charles A. Maguire & Associates:

Harold Bateson	Partner-in-Charge
K. Peter Devenis	Associate and Chief Hydraulics Engineer
Paul T. Carver	Senior Sanitary Engineer
Henry Campbell	Consultant - Water Supply
Dr. Perry Rahn	Consultant - Ground Water Hydrologist
Francis C. Pierce	Associate and Chief Soils Engineer
Stephen J. Madden	Hydraulics Engineer
James E. Ryan	Senior Highway and Traffic Engineer
Walter Schwaner	Senior Planner

CITY OF

PROVIDENCE, RHODE ISLAND

APPENDIX A

GROUND WATER SITUATION

RECOMMENDED PROGRAM FOR THE DEVELOPMENT OF THE BIG AND WOOD RIVER RESERVOIRS AND WATERWORKS IMPROVMENTS FOR THE PROVIDENCE WATER SERVICE AREA

PREPARED FOR

WATER SUPPLY BOARD

JOHN A. DOHERTY — CHAIRMAN

EARL H. ASHLEY UGO RICCIO

JOHN J. TIERNEY DAVID R. McGOVERN

PHILIP J. HOLTON, JR. — CHIEF ENGINEER

MARCH 1968

CHARLES A. MAGUIRE & ASSOCIATES — ENGINEERS

Water Supply Board
City of Providence
552 Academy Avenue
Providence, Rhode Island

Gentlemen:

As stated in our Summary Report we are submitting the back-up data and details of our water study on the Providence water supply system in a separate volume - "Appendices to Summary Report" - except for Appendix "A" - "The Ground Water Situation". This appendix, presented herewith, has been bound separately and attached to the Summary Report. It was decided to attach this appendix to the Summary Report because of the apparent interest in ground water in the State and it is hoped that some of the confusion and misstatements which have been made with respect to ground water in some past reports and articles will be clarified.

Please refer to the "Summary Report" for recommendations and summary of our findings. A bound volume of the "Appendices to Summary Report" is on file in the office of the Chief Engineer of the Providence Water Supply Board to which we refer the reader for detailed information on all phases of our study.

CHARLES A. MAGUIRE & ASSOCIATES

Harold Bateson

Harold Bateson - Partner

APPENDIX A

GROUND WATER SITUATION

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LIST OF FIGURES

LIST OF TABLES

APPENDIX A

GROUND WATER SITUATION

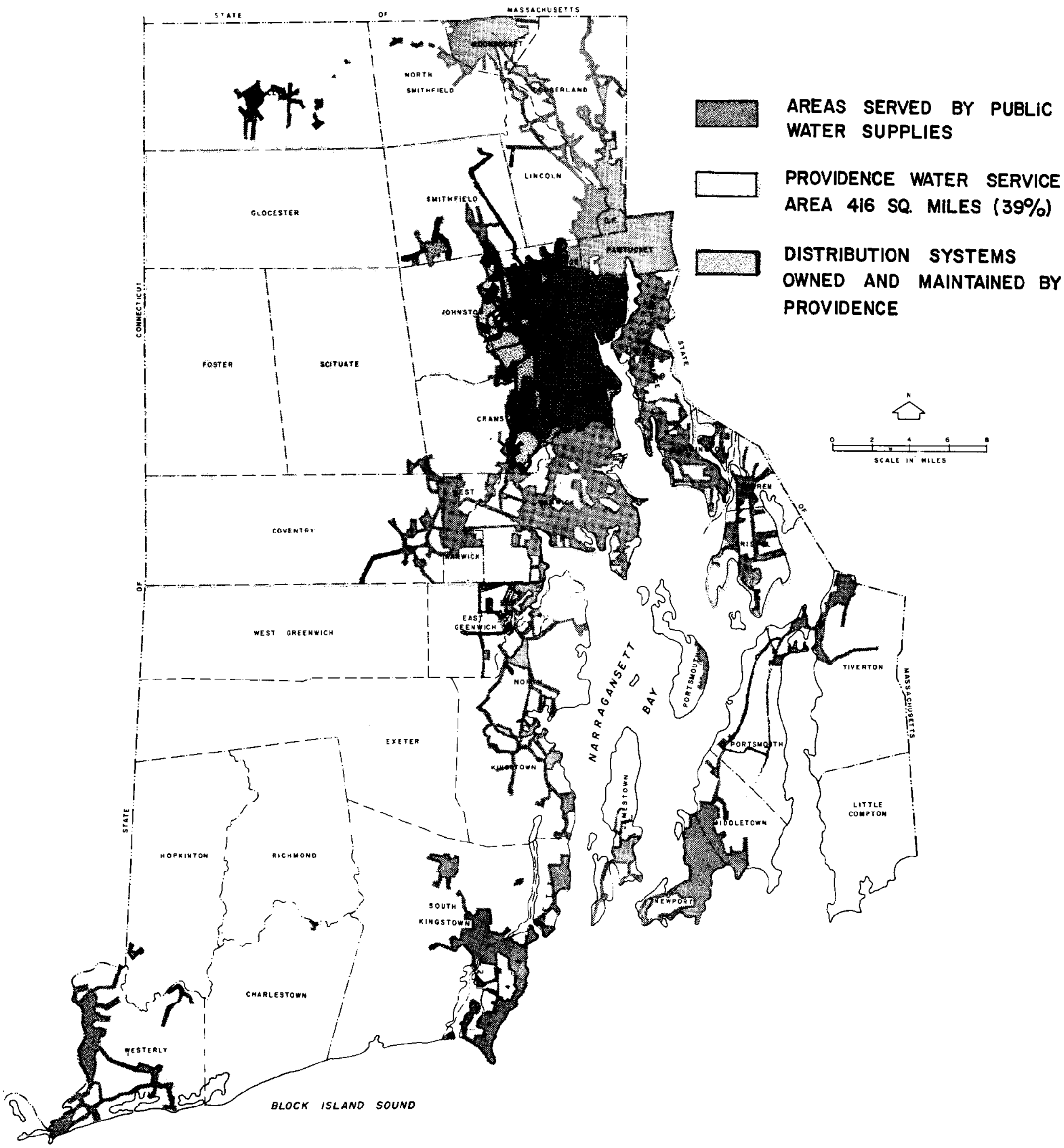
SECTION I. ABSTRACT

This phase of our report on the proposed waterworks improvements for the Providence service area summarizes the ground water situation within and adjoining the present Providence water supply system service area. The purpose of this phase of our study is to determine the present and future ground water potential of the area and make allowances for this supply in determining the additional requirements to be developed from surface water supplies.

To this end, the safe yield of ground water within this area has been evaluated and the quantity determined for purposes of calculating the total availability of water (including both ground and surface water) that can be depended on in the future for water supply purposes.

Usually ground water reports estimate the average daily "availability" or "long-term yield" of an aquifer. Analysis of the historical development of ground water in Rhode Island has been made including its limitations and it is our opinion that, in general, long-term yield estimations of ground water yields are too high. If the long-term yields are actually pumped and the water exported outside the basin, streams would dry up for a considerable period of time in the summer and fall. High iron and manganese in ground water, land development and induced infiltration considerations also suggest a much lower practical pumping value, or safe yield, especially in lieu of existing riparian water laws which prohibit the drying up of streams by induced infiltration, or the export of unreasonable amounts of water out of a basin to the detriment of local landowners.

For the purposes of this investigation, the "safe yield" of a ground water supply is defined as the maximum rate of pumping over a sustained period from an aquifer, in mgd, without detrimentally depleting the aquifer or stream flow, inducing poor quality water or infringing on other land-owners' legal ground water rights. The safe yields of the various ground water supplies have been summarized in Table 3 for the area within and adjoining the Providence service area. (See Figure 1 for delination of Providence water supply service area.) These safe yields have been studied in detail based upon geological conditions and the nature of deterioration of wells within the basins. The "safe yields" of the ground water basins have been subdivided into a community and water supply system basis as shown in Tables 4 and 5 in order to determine the requirements of surface water supply and transmission facilities.



NOTE:
TOWNS AND CITIES SERVED BY PUBLIC WATER SYSTEMS OTHER THAN PROVIDENCE SERVICE AREA-373 SQUARE MILES 35% OF THE TOTAL STATE LAND AREA OF 1058 SQUARE MILES.

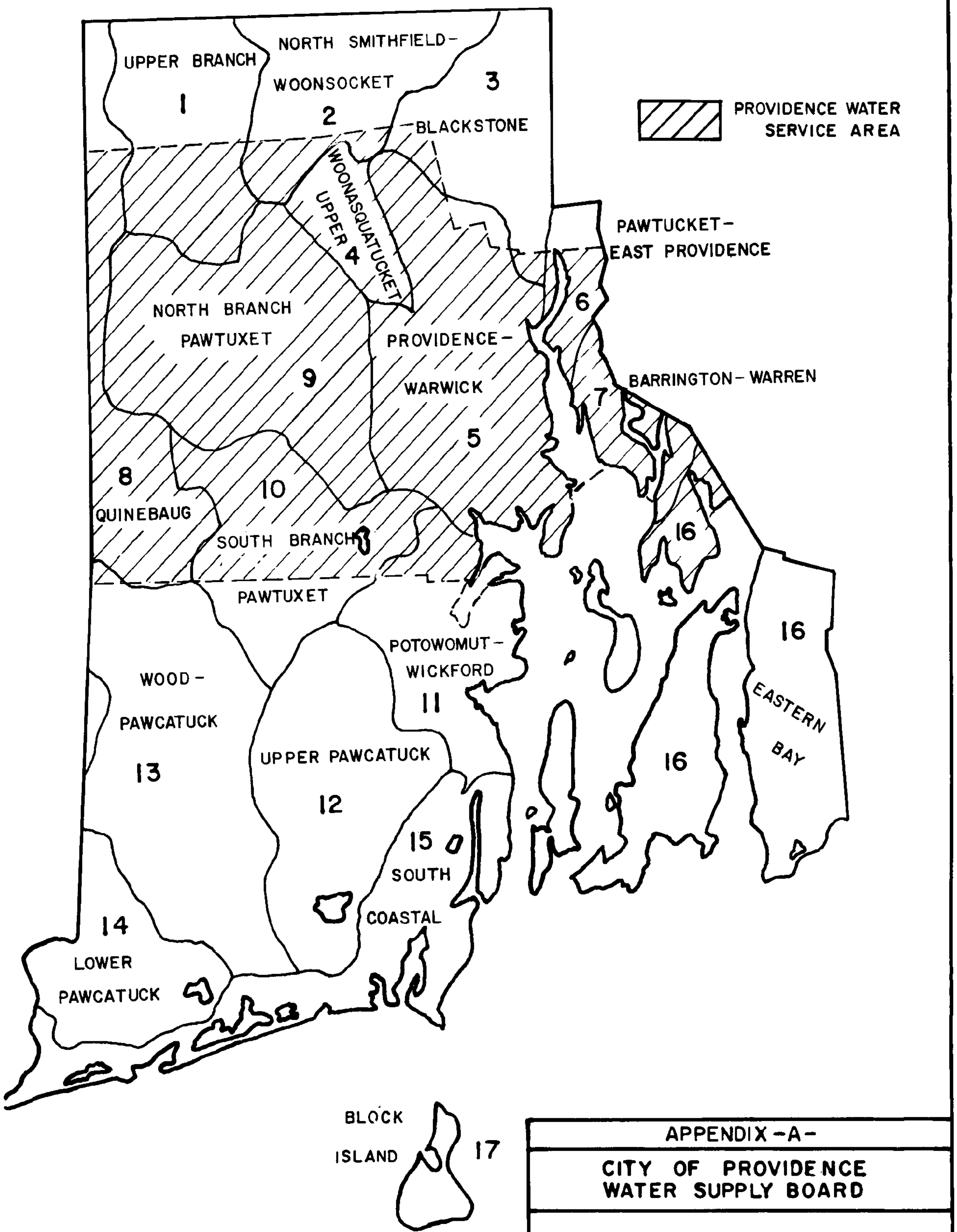
APPENDIX -A-

CITY OF PROVIDENCE
WATER SUPPLY BOARD

WATER SERVICE AREAS

CHARLES A. MAGUIRE & ASSOC.
ENGINEERS
MARCH 1968 PROVIDENCE, R.I.

FIGUIRE NO.
1



APPENDIX -A-

CITY OF PROVIDENCE
WATER SUPPLY BOARD

WATER STUDY AREAS
OF RHODE ISLAND

CHARLES A. MAGUIRE & ASSOC.
ENGINEERS
MARCH 1968 PROVIDENCE, R.I.

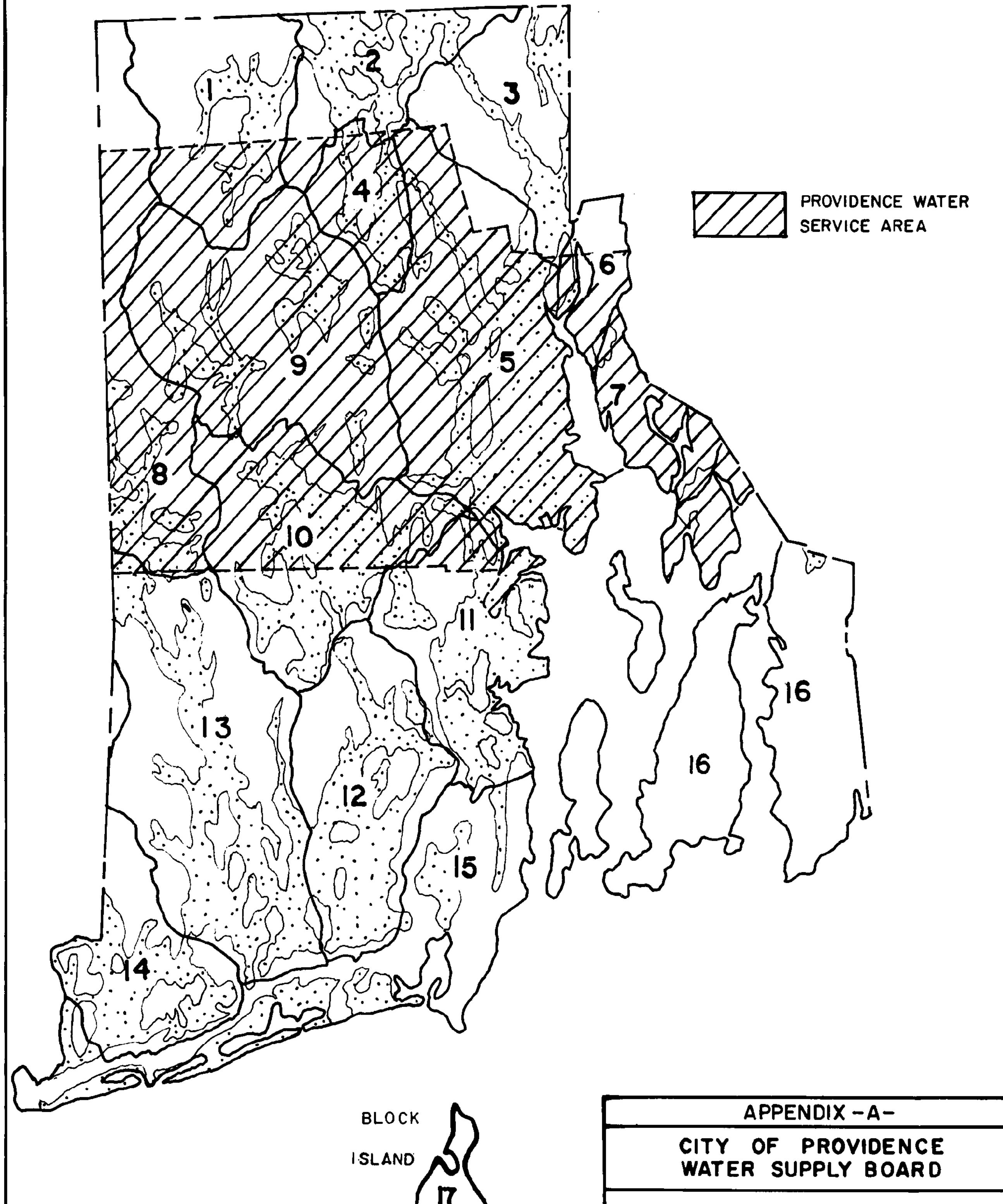
FIGUIRE NO.
2

promising areas. For the purpose of these studies, the State was divided into 17 study areas, which are identifiable ground water basins. Figure 2 shows these areas and their USGS designation. This report has also utilized these State drainage basin areas. The various basins have been further delineated as related to the communities within the Providence water service area.

Figure 3 shows the distribution of the outwash in the area of Rhode Island. This figure is a reduction of a 1:62500 map compiled especially for this report which was adapted from Land (1961) and several USGS basin and quadrangle reports that were used to evaluate the ground water conditions. The aquifers are usually confined to the valleys because outwash filled pre-existing valleys. The large areas between aquifers are bedrock , thinly covered with till.

<u>II-C</u>. <u>HYDROLOGIC SYSTEM</u>: Precipitation averages 45 inches per year in Rhode Island (Lang, 1961). From May to October plants consume much of this precipitation via the process of transpiration. Some water is also evaporated from streams, ponds and swamps; together the processes of transpiration and evaporation are called "evapotranspiration" (ET). In Rhode Island ET averages 21 inches per year (Randall, 1966), and is fairly constant regardless of the total precipitation.

Precipitation		= ET	+ Runoff
Average year:	45"	= 21"	+ 24"
Driest year in 10:	35"	= 21"	+ 14"
Wettest year in 10:	55"	= 21"	+ 34"



APPENDIX -A-

CITY OF PROVIDENCE WATER SUPPLY BOARD

AQUIFERS OF RHODE ISLAND

CHARLES A. MAGUIRE & ASSOC. ENGINEERS
MARCH 1968 PROVIDENCE, R.I.

FIGURE NO 3

Rainfall either runs off the land as surface water stream flow or infiltrates into the ground to become ground water. On the areas of outwash, most of the water infiltrates and the runoff from the drainage basin occurs as ground water runoff. On areas of till and bedrock, little water infiltrates and most of the runoff is surface water. For Rhode Island as a whole, considering the percent of the State that is underlain by outwash, the hydrologic budget can be approximated as follows:

Precipitation		= ET	+ Surface Water Runoff	+ Ground Water Runoff
Average year:	45"	= 21" +	14"	+ 10"
Driest year in 10:	35"	= 21" +	9"	+ 5"
Wettest year in 10:	55"	= 21" +	19"	+ 15"

Surface water runoff produces the high stream flows of winter and spring, and occasionally summer thunderstorm runoff. Ground water runoff discharges into the streams the year round supplying the "base flow" to streams. It is this base flow that maintains streams from May to November except for storm flows. Some ground water also discharges down through the aquifers as "underflow", which eventually discharges into the ocean.

SECTION III. CALCULATION OF SAFE YIELD OF AQUIFERS

III-A. LONG-TERM YIELDS: Ground water hydrologists have used the term "safe yield" in so many contradictory ways that presently the USGS no longer uses it at all. Currently the USGS in the Rhode Island-Connecticut area uses the term "long-term yield", which is an average annual yield of ground water for an aquifer and is a much higher figure than allowed for ground water supply purposes referred to as "safe yield" in this report. As a prerequisite for determining "safe yield", it has been necessary to calculate the "long-term yield" of the various ground water basins within Rhode Island. The "long-term yield" can be calculated in several ways, depending on the investigator. The four following methods are examples of how to calculate the long-term yield of an aquifer.

Method 1. Assume that the "long-term yield" equals the amount of annual ground water recharge to the aquifer from natural precipitation falling directly on the aquifer. If there is no surface runoff, this recharge rate will equal about one mgd/square mile in the average year and about 1/2 mgd/square mile in the driest year in 10 years. In some cases natural ground water underflow into the aquifer is also added to precipitation recharge on the aquifer.

Method 2. Assume the "long-term yield" equals the rate of ground water that can be taken from storage within the aquifer over the 180-day period of no precipitation recharge. The volume of the aquifer must be known, and some value of the "specific yield", or effective porosity, must be assumed, usually 0.1 to 0.3 for alluvium.

Method 3. Assume the "long-term yield" equals the "median" flow of the river in the aquifer area, or one-third the average flow of the river. It has been found (Lang, 1961) that the median flow of a stream approximates the base flow.

Method 4. In addition to "long-term yield" as developed by the previous three methods, occasionally the USGS adds the positive effect of any water coming from induced infiltration (Randall, 1966; Thomas, 1967).

Table 1 shows the 17 ground water basins of Rhode Island according to the USGS basin designation. For this report a "long-term yield" for each basin was calculated in the manner described above, using various sources of data, mostly USGS reports. These values were estimated by choosing the minimum of the first three methods described. The effect of induced infiltration (Method 4) has not been included in the development of the "long-term yield" within the study areas of this report for several reasons. These reasons generally include the fact that stream bed infiltration rates assumed by the USGS in past reports have been more than ten times too high (Rahn 1968) creating an impression of higher availability from stream flows than actually is the case. Further, the reliance on induced infiltration within the aquifer area may not be desirable, in that withdrawal of the base flow of a stream within the aquifer area may cause almost no stream flow during the dry months. In fact, induced infiltration from stream flows in some streams which may be transporting pollutants might make the ground water unfit for water consumption. The details of such limitations are presented in the body of the report.

TABLE 1

GROUND WATER USE AND "LONG-TERM YIELD"[a] IN

SEVENTEEN STUDY AREAS OF RHODE ISLAND

Water Basin Area No.	Ground Water Basin	Basin Area in R. I. (sq.miles)	Estimated[b] Use (mgd)	Estimated "Long-Term Yield" (mgd)
1.	Upper Branch River Area	59	1.5	12
2.	No. Smithfield - Woon. Area	40	1.0	18
3.	Blackstone River Area	49	5.5	14
4.	Upper Woonasquatucket R. Area	23	0.9	9
5.	Providence-Warwick Area	114	9.0	57
6.	Pawtucket-E. Providence Area	17	3.0	15
7.	Barrington-Warren Area	20	2.0	10
8.	Quinebaug River Area	61	0.5	10
9.	No. Branch Pawtuxet River Basin	105	0.5	14
10.	So. Branch Pawtuxet River Basin	75	3.7	37
11.	Potowomut-Wickford Area	59	6.3	20
12.	Upper Pawcatuck River Basin	70	3.9	23
13.	Wood-Pawcatuck Area	123	1.0	43
14.	Lower Pawcatuck River Area	47	3.4	23
15.	South Coastal Area	75	0.5	8
16.	Eastern Coastal Area	120	1.8	2
17.	Block Island	11	0.1	7

a. Utilized to develop "safe yield" of the aquifers - see Tables 3, 4 and 5.

b. Includes municipal, industrial and other private wells. Data from USGS reports and other sources.

III-B. LIMITATIONS OF THE CALCULATION OF THE LONG-TERM YIELD, WITH HISTORICAL EXAMPLES: In determining the ground water available for water supply purposes - i.e. "safe yield", the theoretical calculations of the "long-term yields" have been reduced, recognizing the following factors and limitations.

(1) Permeability: The aquifers within Rhode Island are not differentiated as to permeability. Thus, although the ground water may be present, there may be no practical way to get it out. Good wells in the well-sorted sand and gravel lenses within the aquifer yield large amounts of water. However, the poorly-sorted fine sand, silt and clay areas are tight, and do not yield much water to wells. Although the latest USGS report (Allen, 1966) attempts to delineate the coarser areas within the aquifers, the stratigraphy is largely unpredictable.

Case History No. 1: November 29, 1957 to February 3, 1958, the R. E. Chapman Company drilled 36 exploratory 2-1/2-inch test holes in accessible areas in the aquifer within the City of Pawtucket. Most of the material encountered was fine sand and was not worth developing. Only five out of 36 holes drilled in the accessible parts in the 10-square mile Pawtucket area were permeable enough to permit the developing of any permanent wells.

Case History No. 2: Although Rhode Island has numerous patches of sand and gravel, it is not very extensive, particularly in comparison to Long Island. Long Island is a large pile of stratified glacial drift which accumulated as the end moraine of the continental glaciers that covered New England. There is some bedrock underneath this sand and gravel, but it is unconsolidated sandstone of Cretaceous Age. Almost all the rain sinks into Long Island; it is recharged at a total rate exceeding one billion gallons per day (bgd) (McGuiness, 1963). There are practically no streams. There are scores of wells yielding more than 1,000 gpm and thousands of wells yielding 100 gpm. Ground water supplies all the needs of Long Island outside New York City Boroughs; the pumpage of ground water in Long Island in 1960 was about 310 mgd.

Thus the reason for the good development of ground water on Long Island is because of its geology. One cannot compare it to Rhode Island which has only patches of sand and gravel resting on hard metamorphic rocks ("ledge") of Paleozoic Age.

Even Long Island is not without problems, however. The heavy pumpage is causing salt water intrusion, particularly in western Long Island as well as areas in eastern Long Island. In 1947 the City of New York condemned the wells supplying the Flatbush section of Brooklyn. This western area now receives surface water from upstate New York. In many scattered localities the ground water has been polluted by sanitary and industrial wastes and effective methods of controlling this pollution are being initiated. Another "quality" problem is the rise in ground water temperature resulting from recharge of used cooling water in Brooklyn and Queens. In some places the ground water has become too warm to be effective in cooling. In eastern Long Island, almost all the potato farms have high capacity wells for irrigation, mostly over 500 gpm. Extended operation of these wells, where located within a mile of the shoreline, during periods of drought, have caused salt water intrusion forcing the farmers affected to utilize lower pumping rates.

(2) Land development: As Rhode Island becomes more populated, the areas which are available for acquisition for well sites are diminished. With suburban growth, additional limitations are imposed on available well sites because of the increase in septic tanks and polluted streams. Currently, the State requires a 400-foot minimum radius[1] for protection of a well for drinking water purposes.

The mathematical model solution of the ground water availability in the Upper Pawcatuck River Basin (Allen, 1966) by the USGS estimates that 25 mgd of ground water are available. However, such a solution requires a certain optimum spacing of wells which in all probability could not be practically realized. Further, such a model does not make allowance for pollution of wells through deterioration of water quality due to increases in iron and manganese as related to ground withdrawal and time considerations.

As fields and forests are converted into roads, houses and parking lots, the infiltration of the earth's surface is diminished so that the average ground water recharge rate of one mgd/square mile may not be as abundant in the future. In the built-up part of Providence and Cranston, for instance, much of the precipitation is collected and removed from the area in storm sewers (Lang, 1961). Therefore, the model solution should also include this decrease in recharge as related to urbanization.

(3) Water quality: The bedrock in Rhode Island is a manganese and iron rich metamorphic rock which is easily weathered chemically by ground water. Hence iron (Fe) and manganese (Mn) often present a problem in the development of ground water supplies. The iron and manganese rich areas are usually related to certain geologic formations within the metamorphic

1. Municipal well protection requirements have been set for the Kent County Water Authority and Navy wells located in the Hunts River basin, at 700-foot radius by the Town of East Greenwich.

rocks (Thomas, 1967) but are very unpredictable. In a study made by Poon (1967), it was shown that (page 26): "---biological reduction and transformation, organometallic complexation, together with the presence of carbon dioxide and the lowering of pH all have some effect on the solubility of manganese.".

Case History No. 3: The City of East Providence has four wells which average 0.28 mg/l Fe and 2.05 mg/l (milligrams per liter) Mn. Treatment to make this water acceptable to U. S. Public Health Service limits of 0.3 mg/l Fe and 0.05 mg/l Mn is costly. The ground water is also polluted by detergents. For these reasons East Providence is seeking to abandon its wells.

One exploratory well on Weedon Street in Pawtucket reportedly had 13 ppm Fe.

Bristol County Water Company has very expensive treatment facilities to remove Fe and Mn from its Barrington well field.

The amount of Fe and Mn in well water tends to increase the longer a well is pumped. This may be due to induced infiltration or overdraft. The problem of high iron and manganese in ground water cannot be ignored in computing long-term ground water availability as in recent reports by Farragut (1965) and Miller (1967).

Case History No. 4: In the Commonwealth of Massachusetts, where the geologic conditions for ground water are generally considered more favorable than Rhode Island, the ground water supply of the largest capacity over a long period of time is that of the City of Lowell (population 92,000). The following history leading to the development of Lowell's water supply system was supplied by Mr. Edward J. Tierney, Deputy Commissioner in charge of water, Department of Public Works, Lowell, Massachusetts.

(a) In the year 1862, the city began taking water from the Merrimac River, near the site of the present water treatment plant. Crude pits along the river edge were used to filter the river water, but no other treatment was used. Typhoid epidemics were traced to this water source and the Massachusetts Department of Health demanded a change in the water supply.

(b) Consequently in 1890, 680 shallow 2-1/2-inch diameter "driven wells" were installed. Six hundred wells were installed in the same site while 80 were installed about 4 miles away near Stony Brook (the "Cook Well Field"). The 80 wells proved to have high H_2S and in spite of the fact that a 20-inch main had been completed to this field, it was never used. The other 600 wells were operated by a complicated steam engine and vacuum pump ("air lift") system. When new, these wells supplied 6 mgd but over the years the yield decreased.

(c) In 1914, an iron removal plant was built utilizing hand-operated coke filters, settling basins and slow sand filters. The high iron and manganese of the well water over the years continued to increase and to deposit crusts on the well screens. These facts, in addition to the costly maintenance, degeneration of the equipment and increased population (Lowell reached a peak of about 120,000 during the textile manufacturing boom of the 1930's) eventually forced the abandonment of this old air lift well system.

(d) In 1940, the first modern "gravel-packed" wells were installed in the same area. But iron and manganese were still a problem. One well eventually reached 15 mg/l Fe and 1.0 mg/l Mn, and the entire field averaged 4 mg/l Fe. Eventually the treatment plant could not handle the high iron and manganese and consequently it was a common practice to not treat it at all. But because of complaints from the city (chlorine bleach tends to precipitate iron causing red stains in laundry, among other things), a new water source was considered.

(e) In 1950, 8 new gravel-packed wells were developed. These 8 wells consisted of 3 well fields of 2, 2 and 4 wells each, all located several miles from the Merrimac River. Two wells were located on leased land near a dump but soon had to be shut down because of contamination from the dump. The two other wells developed high manganese content and could not be used. The four other wells (the Black Brook well field) are still in use, having a maximum capacity of 3.0 mgd with no iron or manganese problems.

(f) In 1960, in order to supply the demand of 9 mgd for the city, and meet the requests for water of improved quality the decision was made to go back to Merrimac River. A 2.5 million dollar modern treatment plant was constructed and put into operation in 1963. The treatment consists of flocculation, rapid sand filtration, automatically changed activated carbon and pre- and post-chlorination. No special treatment is needed for iron and manganese. This water supply system has an average yield of 9 mgd (including 2 mgd from the four gravel-packed wells) and a maximum capacity of 16.5 mgd. The water has excellent quality except for certain taste and odor problems for two weeks in the fall caused by dying algae in the river. This problem should be rectified shortly.

In summary, the history of the water supply system for the City of Lowell has run a complete cycle - starting from surface water, substituting a cheaper ground water source to avoid treating the surface water, the subsequent deterioration of the ground water supply and the return to surface water.

Other Massachusetts communities, such as Billerica, Lawrence, Franklin, Newton and Brookline have had similar histories of having their wells go "sour", and have abandoned their wells in favor of water from the Metropolitan Water District or other surface waters.

(4) Induced infiltration: When a well is pumped, it creates a "cone of depression" in the water table. If this cone extends to a stream, swamp or pond, the normal flow of ground water from the ground to the surface water will be reversed. Water will move from the stream or pond into the well. This process is called induced infiltration. Since most aquifers are in the valley bottoms where streams are found, induced infiltration may be expected.

It should be pointed out that Method 1 of the "long-term yield" calculations assumes that the long-term yield equals the natural ground water discharge (base flow) to a river. This means the aquifer will no longer discharge water to the stream. Since it is this ground water discharge that supplies base flow to streams, all the streams in the aquifer area will be kept flowing only by virtue of base flow from the till and bedrock areas in the drainage basin (which is very small), and by flood flows. What little base flow is supplied to the stream by the till and bedrock areas in the drainage basin head waters will probably be consumed by induced infiltration as soon as it flows over the aquifer area. Thus, if the "long-term yield" data are in fact realized, we must accept the fact that our streams will be dry in the aquifer areas during the summer and fall except for storm flows, not a desirable condition.

Case History No. 5: The University of Connecticut pumps about one mgd from the Fenton River Valley. The Fenton River has a drainage area of 20 square miles. The USGS calculation of the long-term yield is 7 mgd (Thomas, 1967). Despite the fact that current pumping is only one-seventh of the long-term yield, about 1,000 feet of the Fenton River is dried up for about one week each summer (Rahn, 1968). This is the first documented case of induced infiltration drying up a stream in eastern United States. The cone of depression has also drawn down the water table 15 feet for about 500 feet across the river. It is debatable whether 7 mgd could ever be pumped from this area as the USGS suggests.

Case History No. 6: Pollution in streams will cause problems in wells inducing infiltration. Usually bacteria are filtered out, although a well near Slater Park in Pawtucket had to be abandoned because of high bacteria counts which probably are induced from the Ten Mile River. This well had no bacterial count originally, but after a year of operation it became polluted bacterial-wise. Wells are even more susceptible to virus pollution because virus are very minute, molecular in size, and travel through sand and gravel much like dissolved chemicals. The present-day methods of isolating virus in water supplies for control purposes have not been developed to the state where effective virus control for municipal water supplies is a reality (Berg, 1964, Standard Methods 1965, PHS Drinking Water Standards 1962). As such, the safe health aspects of well supplies are always more questionable in potential pollution areas.

Case History No. 7: Chemical pollution in streams will present a larger well contamination problem. The Naugatuck River near Waterbury, Connecticut is badly polluted by wastes from copper, rubber and other chemical factories (Dorrler, in preparation). As a result, wells inducing infiltration from the Naugatuck River have had concentrations of sulphate up to 130 mg/l, and chromate, copper and silver concentrations which make the ground water unsuitable. Presently, surface water supplies from Waterbury must be piped into these factories.

Case History No. 8: Sea water intrusion is a special case of induced infiltration. One well in Barrington pumping at one mgd during the recent drought developed chlorides over 250 mg/l (as well as an increase in iron) and had to be shut down. Numerous wells along the coast of Connecticut and Long Island also have become saline. For instance, at New Haven, Connecticut wells have reached 2,527 mg/l chloride content, forcing a reduction in ground water pumpage in New Haven from 4.4 mgd in 1950 to 3.4 mgd in 1960.

III-C. LEGAL ASPECTS AND CONSIDERATIONS: If all the recharge to an aquifer is utilized, as in the long-term yield method described above, and is pumped to areas outside the basin, there will no longer be any discharge from these aquifers. It is this ground water discharge to streams that under natural conditions supports the "base flow" of streams. Therefore, if the long-term yield values are actually used, the streams will probably dry up in the aquifer areas during the summer and fall months except for the occasional storm flows. This prospect is not only aesthetically unappealing, but is of questionable legality according to the riparian stream laws of Rhode Island. Similarly, water level declines during the summer and fall months, when ground water storage is being consumed, may affect other landowners' wells. Such an act would undoubtedly be viewed as illegal, based on the Annotated General Laws of Rhode Island, Chapters 636 and 638:[1]

> "No person owning any dam on any river or stream of water shall detain the natural stream thereof, at any one time, more than 12 hours out of 24 hours, except on Sundays, whenever he shall be requested by the owner of any dam within one mile below on the same stream to suffer the said natural run of said river or stream to pass his said dam." (Rhode Island General Laws, Chapter 636, paragraph 16.)

Although the law is designed to protect riparian stream owners from the misuse of another upstream or adjacent stream user, this law could probably be extended to an upstream or adjacent well field if the case ever came to court.

Concerning the laws on ground water per se, legal terminology classified ground water into "subterranean streams" and "percolating waters". To a hydrologist this terminology is absurd and confusing. However, theoretically a subterranean stream flows in a permanent underground channel whereas percolating water seeps underground in non-discernable ways.

(1) Subterranean streams: Since the aquifers outlined on Figure 3 are known, and the general ground water flow patterns are known, there is a good chance that a court would view these waters as subterranean streams. As such they are subject to the same rules applying to surface streams. The landowner may only use as much water as is reasonable so as not to interfere with the rights of others.

1. Also see Appendix G - "Rights and Liability of a Public Supplier of Water from Underground Sources".

(2) Percolating waters: Most of the ground water is thought to be of the percolating variety, whose circulation is unknown. An old English common law held that a person's ownership of land gave him the right to pump all the water that lay beneath or migrated into his land. In Rhode Island the case of Rose versus Socony Vacuum Corporation 54 Rhode Island 411 (1934), seems to uphold the defendent in that he had no liability for his oil percolating into the ground and polluting the plaintiff's well. This case seems to uphold the English common law. However, in this case it also stated that "In this state the rights to subterranean waters appear to be relative to the extent that they may not be purposely or negligently diverted.". Thus it appears that a municipal corporation cannot pump percolating water from land owned by it for distribution to distant inhabitants where the water is secured in such quantities as are unreasonable with respect to the owner of adjoining property.

III-D. SAFE YIELD: In view of the foregoing limitations, it is obvious that the "long-term yield" is not a realistic value to depend on in estimating the available ground water for purposes of municipal water supply of Rhode Island's aquifers. The problem is - how much should it be reduced? How safe should the "safe yield" be? Metcalf & Eddy (1967) divide their values of long-term yield by 4 to arrive at a safe yield which they call the "average daily yield". However, for the Fenton River, Connecticut a factor of 7 still causes the stream to dry up one percent of the time. For the purposes of this report, rather than divide the long-term yield by a constant factor, each basin has been considered separately. The estimates of the safe yield of each basin have taken into consideration the coarseness (permeability) of the aquifer, existing surface reservoirs and riparian rights, land acquisition problems, water quality considerations and other limitations as previously discussed. (Most ground water reports ignore these conditions completely.) For purposes of this report then, the "safe yield" is defined as the maximum rate of pumping over a sustained period of time from an aquifer, in mgd, without detrimentally depleting the aquifer or stream flow, inducing inferior quality water, or infringing on other landowners' legal rights. If the ground water which is withdrawn from the aquifers is returned to the stream or recharged into the aquifer, a larger safe yield may be expected; however, for this report the water is assumed to be exported outside the aquifer basin to meet municipal water requirement needs.

SECTION IV. SAFE YIELDS OF SELECTED AREAS

IV-A. SELECTED AREAS: The following basins are the only areas where sizable quantities of ground water could be developed in Rhode Island for the Providence water supply system. Areas 1[a], 2, 8[b], 14, 15 and 16 are too far removed to be important sources of supply for the Providence service area except as otherwise noted, and area 9 is already fully utilized by the Scituate Reservoir. The known large capacity wells producing more than 0.2 mgd referred to in the description below are summarized in Table 2. The well numbers are USGS terminology. A question mark indicates the USGS has not named the well yet.

(a) Blackstone River (area 3): Out of a total of 5.5 mgd withdrawal, 1.58 mgd comes from wells belonging to the Lincoln Water Department in the Blackstone River Valley, and an estimated 2.0 mgd from Pawtucket Water Department wells in Abbott Run. The long-term yield is calculated by Method 1 to be 14 mgd (Table 1). This should be adjusted to 7.0 mgd safe yield because of the prospect of contamination of wells by waste areas, induced infiltration from polluted rivers, and high natural Fe and Mn in ground water.

(b) Upper Woonasquatucket River (area 4): Presently four wells serve the Greenville Water Company with 0.3 mgd. The Greenville Water Company is exploring the abandonment of these wells in favor of Providence water. The quantity of ground water used in the basin for all purposes is in the order of 0.9 mgd. The long-term yield is estimated (Method 1) to be 9 mgd, but because of uncertainties in the thickness of the aquifer and the very rapid housing development, a figure of 2 mgd is estimated to be the safe yield.

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a. The Town of Glocester in Area 1 has a safe yield of 1.0 and a present use of 0.0.

b. Area 8, the Quinebaug River, drains into Connecticut. Although some of the head waters of the Quinebaug originate in Rhode Island, there is almost no sand and gravel present, and no present usage of ground water.

TABLE 2

WELL FIELDS IN THE PROVIDENCE SERVICE AREA AND ADJOINING AREAS

PUMPING GREATER THAN AN AVERAGE OF 0.2 MGD

Basin	USGS Well No.	Owner	Ave. Pumping Rate (mgd)	Max. Pumping Capacity (mgd)
3	Lin 342, Lin ? Lin ?, Lin ?	Lincoln Water Dept.	1.58	3.0 (well 342 inactive)
3	--	Pawtucket Water Dept.[b]	2.0	5.0
3	Cum 3	Owens-Corning Fiberglas	0.34	
3	Paw 10,11,13	Lorraine Mfg. Co.	0.43	
5	Pro 1112	Merchants Cold Storage	0.38	
5	Pro 144-146	U. S. Rubber Co.	1.09	
5	Pro 51	James Hanley Co.	0.24	
5	Pro 95	Providence Gas Co.	0.86	
5	Car 3,4,36	Narragansett Brewing Co.	1.97	
6	Epr 76-78	E. Providence Water Dept.	2.35	5.0
7	Bar 1	Crown Festner Corp.	0.36	
7	Bar ?	Bristol County Water Co.	1.0[a]	2.0
10	Cov 1-13,18-28,405,460	Kent County Water Authority	3.1	5.1
11	War 39,40; Egr 180	U. S. Navy	2.9	4.2
11	Egr 3;War 33,?	Kent County Water Authority	1.8	3.2
11	Nok 26, ?	N. Kingstown Water Comm.	1.3	3.0?
12	Exe 33,39	Ladd School	0.5	
12	Sok 92,138,888	University of Rhode Island	0.4	1.5
12	Sok 81,84,91	Wakefield Water Co.	0.8	1.2
13	Ric 8	Sun Chemical Co.	0.6	

a. 1965 - 0.92 mgd, 1967 - 0.40 mgd. 1.0 used for this study.
b. Abbott Run watershed well Nos. 1-11: Estimate by the Water Department includes ground water pumped to Abbott Run to supplement surface flow to treatment plant.

(c) Providence-Warwick (area 5): The area is covered with a lot of sand and gravel, and the long-term yield is estimated by Method 1 to be 57 mgd. Due to uncertainties of the thickness of these deposits, the fact that much of the area is built-up so that precipitation is collected and removed from the area by storm sewers in addition to other previously mentioned factors, we recommend a safe yield value of 12 mgd be assigned to the area. Presently about 9 mgd is being utilized, mostly by industries, including 1.97 mgd from three wells by the Narragansett Brewing Company.

(d) Pawtucket-East Providence (area 6): Presently 3 mgd are withdrawn from this area, and a long-term yield of 15 mgd is calculated by Method 1. However, because of proximity to salt water, and high Fe and Mn, it is recommended that the safe yield should not exceed the present use.

(e) Barrington-Warren (area 7): The Bristol County Water Company pumps one mgd from two[1] wells (Bar ?), and together with industrial and domestic ground water about 2 mgd is used in this area. Although the long-term yield is calculated by Method 1 to be 5 mgd, the high iron and manganese and the proximity to salt water suggest a safe yield not exceeding the present use. Lang (1961) reached the same conclusion (page 18): "----it is apparent that the safe yield of the outwash aquifer is being approached if it has not already been exceeded.".

(f) South Branch Pawtuxet River (area 10): The Kent County Water Authority had a well field (Cov 1-13, 18-28) of 2-inch wells on a vacuum system which was abandoned in 1966 in favor of more efficient gravel-packed wells. The new Kent County Water Authority wells (Col 405, Col 460), now pump an average of 3.1 mgd. The total ground water pumpage for area 10 is

1. The third well of the Barrington well field has a very high iron content and is held in reserve. Actual pumpage 0.92 mgd - 1965 and 0.40 - 1967.

about 3.7 mgd including small industrial, domestic and livestock supplies and the theoretical long-term yield is calculated by Method 1 to be 37 mgd. Based on the rapid population increase in this area, which threatened water quality and infiltration, the long-term yield of 37 mgd should be reduced to about 12 mgd. When the Big River Reservoir is constructed the safe yield would be reduced to about 8 mgd.

(g) Potowomut-Wickford (area 11): This area has a total usage of 6.3 mgd and a total long-term yield by a combination of Methods 1 and 2 of 20 mgd. This area can be broken down into two sub-basins - Hunts River and Wickford. The estimated safe yield for water supply purposes by Method 1 has been calculated at 8.3 mgd of which 5.0 is the Hunts River area and 3.3 mgd for the Wickford basin.

(1) Kent County Water Authority: Three wells in East Greenwich along the Hunts River of the Kent County Water Authority (Egr 3, War 33 and War ?) produced 1.8 mgd during 1967 but are capable of pumping up to 3.2 mgd. Bostitch's well produces 0.2 mgd.

(2) U. S. Navy: Three wells along the Hunts River belonging to the U. S. Navy Quonset Station (War 39, 40 and Egr 180) averaged 2.9 mgd in 1967.

(3) North Kingstown: The Town of North Kingstown withdrew an average of 1.3 mgd from two wells (Nok 26, Nok ?) near Belleville Pond in the Annaquatucket River Basin[1] of the Wickford sub-basin.

In view of the heavy pumping (presently 4.9 mgd) and the probability of increased pollution of the Hunts River, any further pumping in areas (1) and (2) above would probably exceed the safe yield.

1. In addition, North Kingstown pumped less than 0.1 mgd from the Pettaquamscutt River area near Carr's Pond to service the southeast area of North Kingstown. This river is in the "South Coastal Area 15".

(h) Upper Pawcatuck River (area 12): Presently the total withdrawal of this area is only 3.9 mgd, with the largest users being the Wakefield Water Company (Sok 81, 84, 89), 0.8 mgd; Ladd School (Exe 33, 39), 0.5 mgd; and the University of Rhode Island (Sok 92, 139, 888), 0.4 mgd. According to Allen, et al (1966), there are 25 mgd of ground water available in area 12. This long-term yield of 25 mgd is derived by a mathematical model assuming an optimum well spacing which in all probability would not be possible, due to land use, impermeable aquifer areas and poor quality in the Chipuxet Valley. These facts, in addition to the general limitations stated above, suggest a safe yield of about 8 mgd.

(i) Wood-Pawcatuck (area 13): The only large capacity well in this area belongs to the Sun Chemical Company (Ric 8), which uses 0.6 mgd. The long-term yield of 43 mgd (Method 1) should be reduced to 15 mgd, and further reduced to 12 mgd if the proposed Wood River surface reservoir is constructed. Area 13 appears to be one of the more promising in Rhode Island for ground water development.

IV-B. SUMMARY OF SAFE YIELDS: Table 3 shows the values of the safe yield for the basins in central Rhode Island where it would be practical to develop ground water supplies. This area generally represents the Providence service area and adjoining areas. The total safe yield is estimated to be 62.3 mgd. Since the present use of ground water in these same areas is 35.3 mgd, the amount of ground water available for future development in the Providence service area and immediately adjoining areas (referred to, for purposes of this report, as the Central Rhode Island Area) is 27.0 mgd. Figure 4, which is a map showing the ground water basins, also shows the estimated ground water available for future development.

TABLE 3

SUMMARY OF GROUND WATER AVAILABILITY (IN MGD)

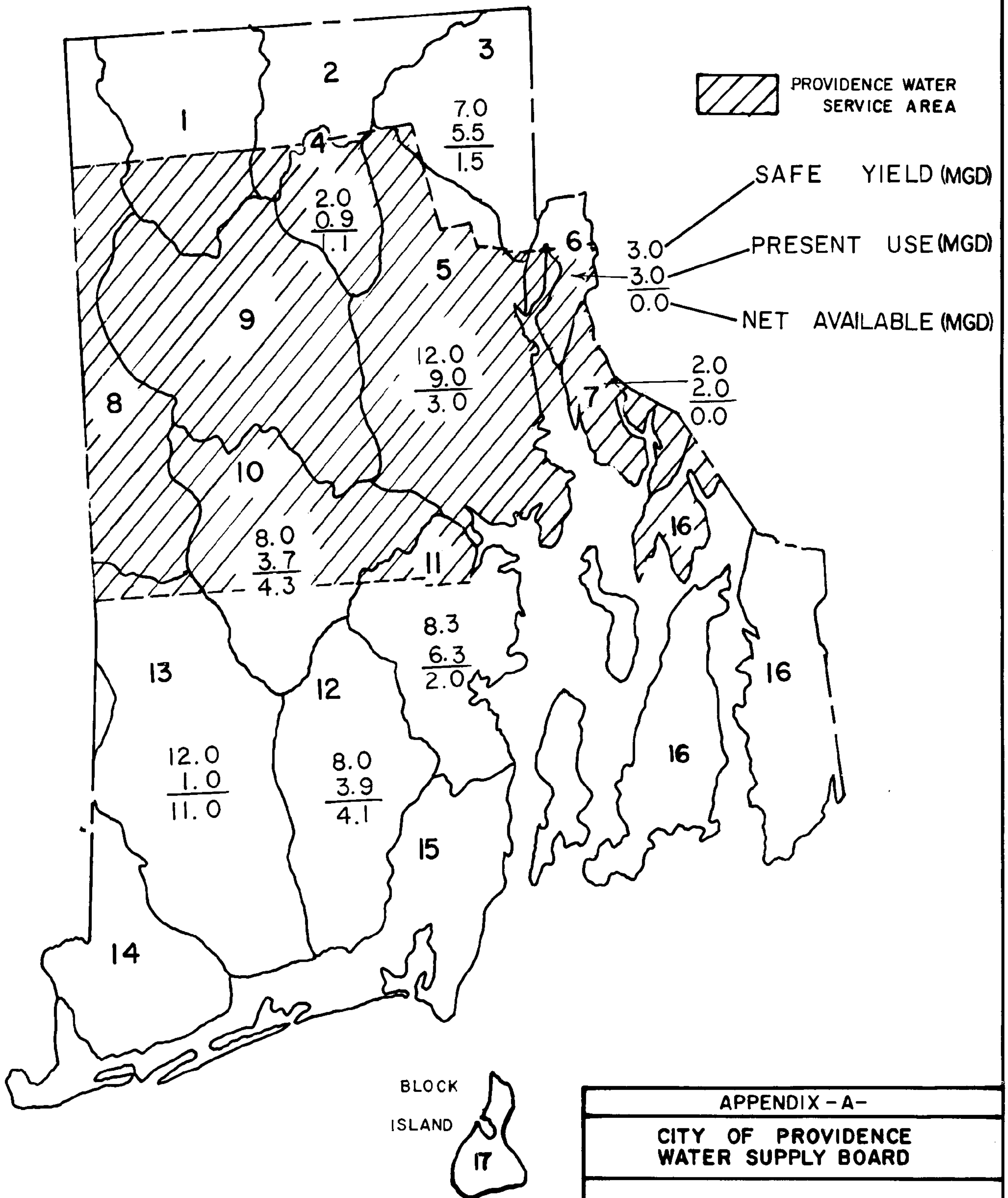
IN AREAS PRACTICAL FOR DEVELOPMENT FOR CENTRAL RHODE ISLAND

Ground Water Basin	Area No.	Present Use	Estimated Safe Yield	Estimated Availability[c]
(a) Blackstone River	3	5.5	7.0	1.5
(b) Up. Woonasquatucket	4	0.9	2.0	1.1
(c) Providence-Warwick	5	9.0	12.0	3.0
(d) Pawtucket-E. Providence	6	3.0	3.0	0.0
(e) Barrington-Warren	7	2.0	2.0	0.0
(f) S. Br. Pawtuxet River	10	3.7	8.0	4.3
(g) Potowomut-Wickford	11	6.3	8.3[a]	2.0
(h) Up. Pawcatuck River	12	3.9	8.0	4.1
(i) Wood-Pawcatuck	13[b]	1.0	12.0	11.0
Total		35.3	62.3 mgd	27.0 mgd

a. See text on Pettaquamscutt River of North Kingstown which lies within Basin No. 15.

b. Total safe yield of Basin 13 is estimated at 15.0 mgd which is reduced to 12.0 mgd by the Wood River surface water development.

c. See Figure 4 for map of ground water basins and estimated availability of ground water.



APPENDIX - A -

CITY OF PROVIDENCE
WATER SUPPLY BOARD

GROUND WATER AVAILABILITY

CHARLES A. MAGUIRE & ASSOC.
ENGINEERS
MARCH 1968 PROVIDENCE, R.I.

FIGURE NO. 4

SECTION V. CONCLUSIONS

V-A. SAFE YIELD: Because of the limitations of the theoretical long-term yield, predicting a safe yield is difficult as each basin represents a unique case. For purposes of this report, the safe yield has been defined as the maximum rate of pumping over a sustained period of time from an aquifer, in mgd, without detrimentally depleting the aquifer or stream flow, inducing poor quality water or infringing on other landowners' legal rights. It is then, the amount of water that can safely be withdrawn from the ground for purposes of public water supply. The pumping capacity of any particular well should not be confused with the safe yield. The American Society of Civil Engineers (Saville, 1945) defines well capacity as "The maximum rate at which a well will yield water under a stipulated set of conditions, such as a given drawdown, pump or motor size.". It is possible to install a well or a well field with pumps large enough to double the actual aquifer safe yield for a short period of time without serious effects, but this depends on hydrogeologic factors which cannot be determined with certainty before the installation of the wells. Using the same criteria analyses, we have evaluated the potential ground water areas within and adjacent to the Providence service area and determined the safe yield available for water supply purposes.

V-B. PROVIDENCE WATER SUPPLY SERVICE AREA: For the Providence water supply service area shown on Figure 1, the safe yield equals 24.0 mgd (see Table 4). For water supply and distribution purposes it is important to know where the ground water supply is available and as related to the trunk transmission systems and to the populations of the individual communities served.

Table 4 shows the distribution of these ground waters indicating those sources which may be expected to be reliable for municipal water supply purposes. Within the Providence water supply area, certain ground waters are more subject to danger from pollution and, therefore, the ground water in the municipalities of Providence, Cranston, Warwick and East Providence should be reserved for industrial use. Therefore, only Smithfield, Coventry, Glocester and Bristol County have the quality of ground water where long-range public water supplies can be utilized or developed. The safe yield of 11 mgd projected to be utilized by 2015 for these four areas are summarized below from Table 4 (see note c, Table 4).

Municipality	Safe Yield for Public Water Supplies (mgd)	Anticipated Future Use (mgd)
Smithfield	2.0	2.0
Coventry	6.0	6.0
Bristol County (Barrington, Warren)	2.0	2.0
Glocester	1.0	0.4
Total mgd	11.0	10.4

This quantity of 10.4 then, is available for use to supplement the water surface supplies to meet the future demands of the Providence service area. The 10.4 mgd, deducted from the year 2015 total demands of 140.3 mgd (see Section III of Summary Report) leaves 129.9 mgd to be available from surface supplies. (Also see Appendices C and D.)

TABLE 4

GROUND WATER SUPPLIES[d]

AREAS PRESENTLY ENTITLED TO RECEIVE WATER FROM PROVIDENCE WATER SUPPLY SYSTEM

Municipality	Ground Water Basin No.	Safe Yield	Present Usage Total	Present Usage Municipal	Available for Development Total	Available for Development Municipal
Smithfield	4	2.0[c]	0.9	0.9	1.1	1.1
Scituate	9	0	0	0	0	0
Johnston	5	0	0	0	0	0
N. Providence	5	0	0	0	0	0
Providence	5	4.0	4.0	0	0	0
Cranston	5	4.0	2.0	0	2.0	0
Warwick	5	4.0	1.0	0	3.0	0
W. Warwick	5	0	0	0	0	0
(KCWA)	10	0	0	0	0	0
Coventry	5	0	0	0	0	0
(KCWA)	10	6.0[a,c]	3.7	3.1	2.3	2.3
E. Providence[e]	6	1.0	2.4	2.4[b]	0	0
Bristol County (Barrington, Warren)	7	2.0[c]	2.0	1.0	0	0
Foster	9	0	0	0	0	0
Glocester[e]	1	1.0[c]	0	0	1.0	1.0
	9	0	0	0	0	0
Total mgd		24.0	16.0	7.4	9.4	4.4

a. Total safe yield for Basin 10 is 12.0 mgd with 4.0 mgd allotted to Big River development. 6.0 mgd is available for Coventry and 2.0 mgd is available for West Greenwich.

b. To be abandoned due to poor quality when system is connected to the Providence water supply system supply. The present pumpage has exceeded the safe yield (see safe yield column).

c. Areas within Providence water supply service area where good quality ground water can be developed. The sum of these four municipalities' safe yield equals 11.0 mgd. To match Glocester's future demand the 11.0 mgd figure has been reduced to 10.4 mgd and is the figure used in Table 1, Appendix D.

d. Small domestic well usage not included.

e. Basin area Nos. 1 and 6 include communities outside the Providence service area in addition to those communities indicated in this table. Yields and flows have been apportioned to the communities as shown.

V-C. AREAS ADJACENT TO THOSE PRESENTLY ENTITLED TO RECEIVE WATER FROM THE PROVIDENCE WATER SUPPLY SYSTEM: For the areas adjacent and south of the Providence supply service area which will experience a water supply shortage in the near future (see Section V of Summary Report), an evaluation of the ground water safe yields has been made and presented in Table 5. These yields have been utilized to analyze future potential needs from the Providence surface water supply system in Appendix C.

TABLE 5

GROUND WATER SUPPLIES[e]

AREAS ADJACENT TO THOSE PRESENTLY ENTITLED TO RECEIVE WATER FROM PROVIDENCE WATER SUPPLY SYSTEM

Municipality	Ground Water Basin No.	Safe Yield	Present Usage[a] Total	Present Usage[a] Municipal	Available for Development Total	Available for Development Municipal
West Greenwich	13[d,f]	0	0	0	0	0
	10	2.0	0	0	2.0	2.0
East Greenwich KCWA and Ind.[a]	11	2.1	2.0[b]	1.8	0.1	0.1
U. S. Navy	11	2.9	2.9	2.9(Navy)	0	0
North Kingstown	11	3.3	1.3	1.3	2.0	2.0
	15[f]	0.1	0.1	0.1	0	0
Exeter[c]	12	4.5	0.5	0.5 (Ladd School)	4.0	4.0
	13[d,f]	0	0	0	0	0
Totals in mgd		14.9	6.8	6.6	8.1	8.1

a. 1967 usage.
b. Includes Bostitch well 350 gpm capacity. Estimated average annual pumpage, spring 1966 was 0.24 mgd based upon information provided by Bostitch to the Rhode Island Division of Water Resources.
c. Exeter has sufficient ground water supplies to supply its needs until after 2015.
d. Total safe yield of Basin 13 is estimated at 15.0 mgd which is reduced to 12.0 mgd by the Wood River development, leaving 0.0 mgd ground water potential for Exeter and West Greenwich from this basin.
e. Small domestic well usage not included.
f. Basin area Nos. 12, 13 and 15 include communities outside the area of the communities listed in this table. The portion of the basin area yields and usage applicable to the communities and U. S. Navy are listed in the table.

V-D. SUMMARY: In summary, the ground water resources of Rhode Island are only of sufficient quantity to supplement surface water supplies. With the densest population in the United States, Rhode Island cannot afford to waste its rainfall by allowing flood flows to discharge into the sea without utilization. Recognizing that ground water aquifers retain such a small portion of the storm water flows, it is important that the surface water supplies be developed to their fullest and be supplemented by the available ground water safe yield to insure maximum utilization of the water resources of the State.

Many of the larger cities in the United States have had to convert from ground water to surface water resources for many of the reasons discussed in this Appendix. In the Detroit area, for instance, suburbs such as Birmingham and Pontiac originally obtained their municipal water from wells, but now must acquire water from Detroit whose source of supply is from the Great Lakes. Similarly, the well systems of the communities of East Providence, Barrington, North Kingstown, Coventry and East Greenwich will require surface water supplies to be made available by the City of Providence to meet their increasing system demands. New ground water supplies will not be as easy to establish in the future with suburbia rapidly taking over large land areas and even endangering present ground supplies from pollution and encroachment. An example of such growth is now taking place adjacent to the Hunts River in East Greenwich and North Kingstown.[1] Where ground water is contemplated to be used in the future for purposes of municipal water supply, these supply aquifers should be defined and sufficient land acquired to insure their future safe yield and prevent their loss by future encroachment and pollution.

1. The Hunts River is the ground water supply source for East Greenwich, Cowesett and Potowamut sections of Warwick and the U. S. Naval facilities at Quonset and Davisville in North Kingstown.

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USGS - U. S. Geological Survey.
APHA - American Public Health Association.
AWWA - American Water Works Association.
WPCF - Water Pollution Control Federation.
ASCE - American Society of Civil Engineers.

GLOSSARY

gpcd	Water usage in gallons per capita per day
mgd	Flow of water in millions of gallons per day
Safe Yield	The maximum dependable draft which can be made continually upon a surface water supply during a period of extended drought when the greatest deficiency in runoff is likely to occur
Water supply safe yield	That portion of the safe yield available for water supply purposes after satisfying riparian rights
Ground water safe yield	The maximum dependable draft from a ground water aquifer which can be removed at a maximum rate of pumping over a sustained period from the aquifer without detrimentally depleting the aquifer or stream flow, inducing poor quality water or infringing on other landowners legal and riparian rights

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