SECOND PROGRESS REPORT

Interstate commission on the
Delaware River basin
1941

SECOND PROGRESS REPORT
regarding
A STUDY OF MULTIPLE PURPOSE DEVELOPMENTS
IN THE DELAWARE RIVER BASIN

December 16, 1941

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FOREWORD

This is the second progress report of the Incodel staff relative to its study of the possibilities of multiple-use development of the water resources of the Delaware River Basin. It supplements and supersedes the previous report dated July 25, 1941. The results set forth herein are tentative, and subject to further study and to revision.

A proposal designated Project Group No. 1 advanced in the "308" report of the United States Engineer Office of the War Department, published in 1934, has been used as the starting point for this investigation. The objective is to determine the value of this project for various water use purposes. Thus far, estimates have been developed for the following items: water supply, water power, and salinity. The methods of procedure, and the results of the appraisals, are set forth in detail in the body and appendices of this report under separate headings for each of the items investigated. An analysis of the value of the project for recreation is now under way but not completed. Other uses remaining to be studied include sanitation, flood control, navigation, and commercial fishing and oysteries.

SUMMARY OF FINDINGS AND CONCLUSIONS

1. The project would have no value as a source of domestic water supply during the period covering the next twenty-five years because other major projects for this purpose to meet the requirements of Philadelphia and New York City for such a period are under construction; and the necessary additional supply for northeastern New Jersey very obviously is going to be obtained from locally favored sources.

2. The project is economically unattractive for the development of power by private interest. Existing utilities can produce a comparable amount of power by steam at a cost at least $1,000,000 per year less than by the proposed project.

3. The value of the proposed project for the development of power by a public agency is estimated to be about $1,450,000 per year, but the annual cost to operate the project will approximate $1,913,000. A deficit of approximately $463,000 per year thus is indicated.

4. The value of the proposed project for the reduction of salinity in the section of the river bounding the highly industrialized areas between Philadelphia and the Pennsylvania-Delaware boundary line is estimated to amount to approximately $175,000 per year.

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I. BRIEF HISTORICAL REVIEW

In the past, many reports have been made advocating the construction of dams and reservoirs on the Delaware River and its tributaries. At least one was concerned primarily with development for municipal water supply; others have featured hydro-electric power. The most prominent of such reports are: "A Program for the Regulation and Conservation of the Delaware River" prepared for the City of Trenton, New Jersey, in 1929, by Robert E. Horton, Consulting Engineer; and "U.S. House Document No. 179, 73rd Congress, 2nd Session" prepared by the United States Engineer Office, War Department, pursuant to River and Harbor Act of January 21, 1927, House Document No. 308, 69th Congress, 1st Session. The Engineer Office report was published in 1932.

Horton's Report--1929

Horton's report, prepared prior to the Delaware River Diversion Case (283 U.S. 336) and apparently with the view of developing objections to the then proposed New York City diversion, deals primarily with water power and gives practically no consideration to water supply problems. When the program was offered in evidence in the Delaware Case, the Master, hearing the case for the Supreme Court, stated while it probably could be constructed from an engineering standpoint (provided legal limitations were removed) he was not convinced that the development of water power would be financially remunerative.

U. S. Engineer Office's "308" Report--1932

The Army Engineers "308" Report, on the other hand, was completed subsequent to the Supreme Court diversion controversy, and the pronouncement by the Court that "the highest use" of the waters of the Delaware River system is for municipal water supply. As a result it gives full recognition to the importance of water supply, developing a comprehensive program around two uses--water supply and water power.

The report makes the following general conclusions:

1. The improvement of the Delaware River for navigation above Trenton, New Jersey, is not economically justifiable under present or prospective conditions.

2. The Delaware River is of great value as a source of water supply for New York City and probably, at a future date, for cities in northeastern New Jersey and for Philadelphia.

3. Existing and potential hydro-electric values are substantial and power developments may be combined advantageously with storage and regulation for municipal water supply projects.

4. Federal participation in any present or prospective project above Trenton, New Jersey, does not appear justifiable.

5. Any development of the Delaware River, above Trenton, should be controlled by an interstate agency, competent to coordinate and supervise work under a comprehensive plan formulated in the interests of the States of New York, Pennsylvania and New Jersey.

The proposals advanced in the Army Engineers report have been used as the starting point for the present Incodel investigation. In it, two projects involving the coordination of water uses are advanced. One is called "Combined Project No. 1", and the other, "Combined Project No. 2".

Combined Project No. 1

Combined Project No. 1, consisting of three reservoirs on the Delaware River between Port Jervis and Easton--designated as Tocks Island, Belvidere and Chestnut Hill--and having a total useable storage capacity of 24.3

billion cubic feet, or 182 billion gallons, is claimed to incorporate the most attractive power sites. The entire flow of the Delaware River is used for this purpose excepting 440 million gallons per day authorized for New York City and provision for 548 million gallons daily for Philadelphia to be taken from the Tocks Island reservoir.

The Tocks Island project would be located at a site on the river about five miles above Delaware Water Gap. The dam, 2400 feet long and 150 feet high, would back water up to Port Jervis, New York. The normal surface of the reservoir is at Elevation 420 and the effective reservoir capacity, 176 billion gallons.

The Belvidere plant is located one mile above Belvidere, New Jersey. During maximum floods, this dam, 90 feet high and 950 feet long, would back water up to the Tocks Island Dam. The effective capacity of the reservoir, at Elevation 280, would be five and one-half billion gallons.

The Chestnut Hill dam, 65 feet high and 900 feet long, is located about two and one-half miles above the highway bridge connecting Easton, Pennsylvania and Phillipsburg, New Jersey. It would back water up to the Belvidere dam during high floods. The effective storage capacity of the reservoir is one-half billion gallons and the normal surface elevation is 200.

The general location of the proposed developments which make up Project Group No. 1 is shown on Plate I. Table 1, a reproduction of Table 16 of the "308" Report presents a summary of statistics relative to the development of water power at the proposed hydro-electric power plants.

Combined Project No. 2

Combined Project No. 2 consists of 21 reservoirs including those which comprise Project No. 1, in addition to existing power developments on the Wallenpaupack and Mongaup rivers and to the reservoirs for the authorized 440 million gallons per day supply for New York City. It provides for water supply needs until about 1980: 400 million gallons per day for New Jersey, 548 for Philadelphia, and 800 million gallons daily for New York City in addition to the presently authorized 440 million gallons. The "308" Report admits this project represents a situation many years in the future and is less attractive for the development of water power than Project No. 1. For these and other reasons, which will be brought out later, the present study has been confined to Project Group No. 1.

Appraisal of Values

Using the Army Engineers Project Group No. 1 as the starting point in this investigation of the possibilities of a multiple purpose development, an appraisal has been made of its value for various purposes, including water supply, water power, recreation, salinity control, sanitation, flood control, navigation and irrigation. Discussion of each of these subjects is given under their respective headings.

II. WATER SUPPLY

A point of uppermost importance definitely established by the U. S. Supreme Court in the Delaware River Diversion Case, and also in the Connecticut River Diversion Case, is that the highest use of interstate waters in the eastern part of the United States is for drinking and other domestic purposes. Water supply comes first; it has precedence over all other uses. This being an established principle, any suggestion for the development of multiple purpose projects on the Delaware, of necessity, must give first consideration to the problem of water supply, or to the effect of the operation of the project for other purposes upon present or prospective water supply situations.

As is well known, any regionally significant use of the waters of the Delaware River Basin for domestic water supply purposes will depend upon the prospective requirements for New York City, Philadelphia, and north-eastern New Jersey. Analyses of the problems in these areas, therefore, have been made in order to determine future probabilities.

New York City now has under construction, or design, the projects already authorized by the United States Supreme Court on the Neversink River and the East Branch of the Delaware River for an additional supply of 440 million gallons of water per day. This water added to present and additional local sources probably will meet New York City's requirements for the next twenty to twenty-five years.

Philadelphia, until 1940, because of the decrepit condition of its water works plant and because of the unsatisfactory quality of its sources, almost annually for many years had been creating boards and commissions to study its water supply problem. Several of these had advocated the development of new supplies from the Upper Delaware Basin. However, in 1940 the

City engaged a consulting engineering firm which recommended the expenditure of $18,000,000 for the rehabilitation and improvement of its present facilities. This program has been approved and the work is under way. Upon its completion, Philadelphia will not be required, or probably disposed--in view of its prospective concurrent sewage collection and treatment program--to seek new sources for at least twenty-five years, if then.

In New Jersey, an urgent need exists to supplement the present supply for the northeastern New Jersey metropolitan area. There have been and still are differences of opinion as to its source. One group advocates a high level project from the upper portions of the Raritan River, and of the Musconetcong, a tributary of the Delaware. Another has strongly supported the so-called Chimney Rock project, a development entirely within the Raritan watershed which would deliver water by gravity only to the lower portions of the district. A third plan was advocated in 1938 by ex-Governor Moore. This involves the development and utilization of the Delaware and Raritan canal and feeder as a right-of-way for an aqueduct to convey water from the Delaware River from a location about twenty miles above Trenton to the North Jersey area. The Army Engineers proposal presents still another possible source. However, because it depends upon a huge program involving the development of power and the necessity of cooperative undertaking by Pennsylvania and New Jersey and possibly New York, or of a federal project, New Jersey has expressed itself as not being interested in this possibility. The obstacles are obvious. Even if it were more desirable and less expensive than the other alternatives, it could not be started for many years. It is apparent, therefore, New Jersey will obtain its additional water from one of its three most favored sources. When it does, it will have no need for additional supplies for many years.

In view of the above circumstances, as far as the present or near future water supply situations are concerned, there is no immediate interest in the development of the proposed Tocks Island group project by any of the states; and therefore for approximately the next twenty-five years no value can be assigned to the project for water supply purposes.

In the more distant future, it is probable that the states again will be confronted with the problem of supplying more adequate or suitable sources of supply for their metropolitan areas. An appraisal of the value of the proposed development for this contingency has not been made at this time. It is reserved for later study.

III. WATER POWER

Development By Private Interests

The potential use of water for power is given high ranking in importance by the United States Engineer Office. According to its report, as is shown on Table 1, the operation of Project Group No. 1, before any allowance is made for water supply except that authorized for New York, would produce 44,100 kilowatts of firm power. On the assumption of a 25 per cent load factor installation, the Engineers estimate this would result in the total annual production of 689 million kilowatt-hours of energy, of which 324 million would represent primary power. This has been valued at $3,840,000. The estimated annual charges against this project, consisting of costs assumed to accrue under private ownership and operation, are $3,198,000. This indicates an annual profit of $642,000.

The Commission's study does not verify these estimates. We believe that under the most favorable conditions the value of power from such a development would not exceed $3,339,000 and likely would be much less. The annual costs of the project, if constructed and operated by private agencies, probably would amount to at least $4,337,000 leaving a deficit of $1,000,000 a year.

Our estimate has been determined by comparing the cost of the power produced by the proposed hydro-electric plants with the cost of producing the same amount by steam. It accepts the Army Engineers' estimate of the amount of power and energy which would be produced, although these are obviously too high since the water conditions in 1930-31 (which were not available at the time of Engineers' study) were lower than for any comparable period of record used in making the forecast. Furthermore our estimate has been premised upon the assumption that completely new steam stations would be constructed. This is favorable to the hydro-development as it must be realized that the only markets for the output of the proposed project--New York City, northeastern New Jersey and eastern Pennsylvania--are now being adequately served by existing power systems. Two of these districts, northeastern New Jersey and eastern Pennsylvania, are closely interconnected by transmission facilities, and their peak demands are supplied by the existing hydro-electric developments on the Susquehanna River. New York City also is interconnected by a transmission line to hydro-electric developments in northern New York State and its peak demands are being skimmed off by these existing hydro-projects.

As the demand load of these areas grows, the first additional requirements would be met by the serving utility companies through the installation of additional generating capacity in the existing steam or hydro-electric plants. Such extensions would require a considerably smaller outlay of funds than to supply the additional capacity by constructing entirely new steam generating plants, as was assumed for the purpose of arriving at the above estimate. The cost differential, between providing additional power by the construction of the proposed Delaware River project versus the construction of additions to existing plants, we believe, would approximate $2,000,000 per year.

Under such conditions, it is obvious that the Delaware project is economically unattractive as far as its construction and control by private agencies is concerned. Incidentally, the three water power sites suggested in this group, by the Army Engineers, have been considered by representatives of the utility companies engaged in supplying electricity in the Delaware watershed and by many other interests for a long period of time and their development never has been deemed economical.

Development by Public Agencies

The development of a hydro-electric project on the Delaware River by a public agency--the Federal Government, an Authority created by the Delaware River Basin states, or by any of the individual states constituent to the Basin--presents a somewhat different economic picture. In contrast to a private corporation, a public agency could secure capital at more favorable interest rates; it might be exempted from a portion of taxes; it could apportion a part of project costs as benefits to other uses; it would not have to show a profit.

Since there are various ways in which the proposed reservoirs could be operated for the production of power it becomes necessary to determine which of them probably would be most desirable. The method assumed by the Army Engineers in its study completely utilizes the available storage by drawing down the reservoirs during periods of drought. This has the advantage of producing the greatest possible amount of primary power and of providing larger releases into the river below. It would be definitely disadvantageous to recreation, however, because of the fluctuation and depletion of the reservoirs. Another method might be to use the reservoirs principally for pondage--at least during the summer vacation period--thus involving only slight variations in water surface elevations. The amount of primary power produced in this manner would be less than under the previous alternative but there would be an appreciable benefit to recreation. Consideration has been given to both of these possibilities.

A third scheme also has been studied. It provides for a supplementary reservoir to be located on Flat Brook about five miles above its confluence with the Delaware with the water in the Tocks Island reservoir backing up to the Flat Brook dam. The purpose of the supplementary reservoir would be to supply sufficient water to maintain a full reservoir at Tocks Island

and the other two Delaware River sites during the summer, while at the same time permitting the production of an amount of primary power approximately equal to that produced under the first alternative. Because of the limited drainage area above the Flat Brook dam, there would not be sufficient run-off, however, to refill this reservoir following a period of depletion and in order to overcome this condition, the scheme provides for pumping equipment to replenish the reservoir, when necessary, from flows into the Tooks Island reservoir during periods of flood.

Based upon an extensive study of stream flows such as occurred during the period between July, 1930 and February, 1931 (the lowest of available record) it has been determined that the amounts of continuous firm power which can be developed under the three above methods are 31,600, 24,300, and 31,000 kilowatts, respectively. In arriving at this estimate allowances also were made for a succession of unusually low spring and summer flows.

During the period which existed in 1930-1931, the reservoir at Tocks Island, if it had been in operation, would have been drawn down six feet on September 21, under the first alternative, and none under the second and third. However, the period of low flows in the summer of 1923, while of shorter duration was more severe than 1930. By the middle of September of 1923, the amounts of draw-down would have been 12 feet and two and one-half feet under Schemes 1 and 2. Under all three methods, there would be no appreciable draw-down in the Belvidere and Chestnut Hill reservoirs since it has been assumed they are to be utilized primarily for pondage to meet daily fluctuations in demand.

Under each scheme, after September 21, it has been considered permissible to draw down the then available storage in Tocks Island, if necessary, in order to reduce the degree of salinity in the tidal estuary, to lessen the effects of pollution, and for other purposes. In each case, the maximum total draw-down has been limited so as not to exceed 120 billion gallons by March 1, it not being considered good practice to use the total available storage.

Economically, the results of the operation of Project Group No. 1 for the production of power under the three alternative methods are as follows:

Estimated Annual Profit or Deficit
(No reserve capacity provided)

	25% Load Factor	50% Load Factor
Scheme 1	Profit -- $ 254,000	Deficit -- $ 258,000
Scheme 2	Profit -- 22,000	Deficit -- 463,000
Scheme 3	Profit -- 25,000	Deficit -- 500,000

In arriving at the above figures, no provision was made for the installation of reserve generating capacity nor for reserve transformation and transmission facilities. The following summary gives a similar comparison with provision for twenty-five per cent reserve generating capacity and for reserve transformation and transmission facilities.

Estimated Annual Profit or Deficit
(With provision for 25% reserve capacity)

	25% Load Factor	50% Load Factor
Scheme 1	Profit -- $ 251,000	Deficit -- $ 189,000
Scheme 2	Profit -- 60,000	Deficit -- 373,000
Scheme 3	Profit -- 36,000	Deficit -- 416,000

It will be noted that while there is not a great deal of difference between the two sets of results the installation of reserve capacity appears to be profitable. This is because the additional annual expense involved is more than offset by the revenue received from the sale of the additional secondary energy produced. For the purpose of the study it has been assumed that there will be a market for approximately two-thirds of all secondary energy generated. This may not be entirely reasonable, and is obviously favorable to the hydro-electric project and to the reserve capacity alternative.

It will be noted that the above comparisons are based upon load factors of 25 and 50 per cent for primary power. The 25 per cent figure represents the opinion of the Army Engineers as to the position which the proposed power could occupy in relation to the demands upon the utility companies facilities. It is an extremely favorable rating and one which we are unable to support. We believe a rating much better than 50 per cent could not very well be expected and the estimates shown for a 50 per cent load factor represent our estimate of the results of the operation of the proposed project for power purposes. However, we have determined the figures not only for both of the above factors but for others as well. The results are shown graphically upon Diagrams A and B, and in tabular form on Tables 2 and 3.

The details supporting the above estimates have been assembled in Appendix B; and only a brief discussion of certain factors to which it is desired to call special attention is included herein.

Construction Costs

An authoritative scientific estimate of the construction costs of the three dams and reservoirs involved in the Army Engineers proposal cannot be made without the expenditure of much time and money for a study of geological conditions at the dam sites and for the preparation of design plans based upon such information. Some borings have been made but not enough to give reasonable assurance as to sub-surface conditions. The character of the surface strata at the proposed site of the dams and reservoirs consists of sandstones and limestones--in which there may or may not be cavernous conditions. It is possible that some of the dam sites would be entirely unsuitable.

For the purpose of this preliminary study, however, it has been assumed that the sub-surface conditions are such as do not involve unusual conditions which require undue expenditures. On this basis, we are of the opinion that the Army Engineers' estimate of $19,807,000 for the construction of the three dams and reservoirs is reasonable.

Power House and Equipment

We have compared the costs given by the Army Engineers for the construction of Power House and Equipment with expenditures for similar facilities incurred in the development of other hydro-electric projects and believe them to be insufficient.

Transmission and Switching Station Facilities

To the cost of the hydro-electric plants must be added a cost for transformation and transmission operations necessary to bring the energy to its market. The Army Engineers make no provision for these facilities. While it may be contended that adequate facilities already are in existence, it must be remembered that they were designed and constructed for a particular program which obviously did not include a Delaware River project. Even though they probably might adequately handle the load, nevertheless they represent an investment which the proposed development should be required to share, for without them, unless and until new facilities were constructed, it would be impossible to bring the output of the project to the available markets. The cost to construct such facilities therefore--whether or not they would actually be built--either should be included as a part of the total construction costs or be otherwise reflected in determining the value of power.

Value of Power

The value of the hydro-electric power produced by Project Group No. 1 will depend upon what the utility companies are willing to pay for the quantity and quality produced. For the purpose of this study, it has been assumed that this would be equivalent to what it would cost the companies to produce the same power by steam. Actually this gives a value somewhat high as there would be no incentive or reason for the utilities to purchase the hydro-power unless its cost were less than the amount for which the companies could produce it.

IV. SALINITY

The Salinity Problem

The section of the Delaware River Basin adjoining the river in the navigable tidal reach between Trenton and Wilmington--one of the most important industrial areas in the entire United States--depends almost entirely upon the river for its water supply, domestic and industrial. Unfortunately, that part of this area below Philadelphia, particularly in the vicinity of Chester and Marcus Hook in which a large proportion of the industries is located, is confronted with a very serious water problem. The river in this zone normally is fresh water. Except in respect to pollution which can and is being abated, the water in this area is ideally adapted for industrial purposes, being relatively free of turbidity, and soft. But during periods of extended drought, ocean water pushes itself farther and farther up the river as the drought continues, changing the water of this area from a satisfactory source into a brackish mixture, totally unfit for use. Industrially, its high solid and chloride content causes troublesome and serious boiler feed and process water difficulties which are extremely expensive to overcome. Domestically, it is impossible to remove the brackish taste, forcing practically all the consumers to obtain water from springs and other sources, for drinking purposes.

The causes of the movement of salinity in the Delaware River have been intensively investigated. The drought of 1930, which occurred during the prosecution of the Delaware River Diversion Case caused brackish water to advance to Philadelphia and aroused great concern as to the possible effect of the proposed New York City diversion upon future salinity conditions. The outcome of this circumstance was the initiation of two separate investigations: one by the Delaware River Conservation Association, an organization of industrial interests in Philadelphia and Delaware County; the other by the Commonwealth of Pennsylvania.

In fundamental principle, both agencies reached the same conclusion, namely, that the degree of salinity at any point in the marginal zone between Philadelphia and Artificial Island depends primarily upon the amount of fresh water run-off into the river above the point under consideration. They differed, however, as to the rates of run-off which are required to prevent the advance of salinity up-stream. For example, the industrial association found that a flow of 4,520 million gallons per day (7,000 c.f.s.) into the river above the Pennsylvania-Delaware boundary line would be necessary to prevent the appearance of the presence of ocean borne salinity above this point. The State determined that 3,430 million gallons per day (5,300 c.f.s.) would accomplish this purpose.

The Incodel staff, in connection with its Quantity Committee's program to formulate rules under which water supply diversion projects may be operated, re-examined the two studies in order to make its decisions as to which set of results was more reliable. It concluded that the figures arrived at by the Delaware River Conservation Association were more accurate. The results of its examination of this problem are included in Incodel reports dated October 10, and October 21, 1940.

A flow of 4,520 million gallons per day into the Delaware River above Marcus Hook, under normally uniform meteorological conditions over the basin watershed, represents a flow of approximately 2,750 million gallons daily (4,250 c.f.s.) into that part of the river which lies above Trenton. If, in the summer and fall, after the freshets have driven salinity down to about Artificial Island, the flows at Trenton fall below this rate for any appreciable period of time, in concurrence with low flows in the remainder of the watershed, salinity will advance above the Pennsylvania-Delaware boundary line. This advance will continue under a given set of low flow conditions until a state of stabilization (which depends upon such conditions) finally will be reached. As the presence of salinity advances upstream, its degree at any lower point increases proportionately.

Damages Caused by Salinity Invasions

In an attempt to appraise the value of the proposed multiple-purpose Project Group No. 1 in respect to the problems caused by salinity invasions, a study has been made to determine past damages in relation to run-off in the Delaware River at Trenton. It has been found that flows in the river during the summer and fall have fallen below those necessary to prevent salinity incursions above the Pennsylvania-Delaware boundary line in seven of the past eleven years--1929 to 1940. Two of these years, 1930 and 1931, were extremely severe; three--1923, 1936, and 1939--moderately severe; and one, 1929, relatively slight. The following tabulation gives, for each of these years, the extent of the period of salinity invasion above Marcus Hook; the average and maximum degree of salinity at Marcus Hook for the period; and the average daily rate of run-off in the Delaware River at Trenton.

Year	Period of Salinity Invasion		Degree of Salinity		Average Daily Rate of Run-Off in c.f.s.-Delaware River at Trenton
	Date	No. of Days	Average	Maximum	
1929	8/1 - 9/30	61	260	350	3270
1930	8/1 - 2/15	198	750	1,150	2670
1931	9/12-12/31	110	690	1,000	2960
1932	8/1 -10/6	67	725	1,100	2120
1933	None	0	0	0	0
1934	None	0	0	0	0
1935	10/10-10/30	21	100	250	2560
1936	8/1 -11/5	97	370	500	3460
1937	None	0	0	0	0
1938	None	0	0	0	0
1939	7/1 -10/31	123	420	650	2920
1940	None	0	0	0	0

It will be noted that no salinity invasion is indicated for 1933, 1934, 1937, 1938 and 1940. In three of these years, salinity actually did reach Marcus Hook, but only for a few days; its occurrence, therefore, has been ignored.

To correlate these data, a survey has been made during the past few months of the requirements, costs, and damages caused by salinity in supplying water in the affected area. Due to the absence of any appreciable amount of available information regarding the subject this was done mostly by means of conferences with representatives of the principal industries and of the Chester Municipal Water Authority. Particular assistance was given by Mr. W. D. Mason of the Sun Oil Company in arranging meetings for this purpose, not only with representatives of his own Company, but also with the American Viscose Corporation, Scott Paper Company, Aberfoyle Manufacturing Company, and the General Chemical Company. Representatives of the Chester Brewery and the Troy Laundry also were interviewed.

From this survey it has been found that from 50 to 250 million gallons of water daily are pumped from the Delaware River in this section for industrial and domestic purposes. Of this amount, on the average, only 28 million gallons are used for purposes which require a specific standard of quality or treatment. Approximately five million gallons are used for domestic and commercial purposes, and twenty-three million gallons for industrial use. Twenty of the twenty-three million gallons of industrial water are supplied by privately owned industrial plants; the remaining three millions by the Chester Municipal Water Authority which also supplies the five million gallons used for domestic and commercial purposes.

Of the 23 million gallons used by industry, about one-half is for boiler feed water and one-half for manufacturing processes. In each case, usually, such water is filtered, reduced to zero hardness, and should be practically free of salinity. Under normal conditions of flow these requirements are easily met. During periods of salinity invasion, however, difficulties arise. The first requisite, filtration, gives no trouble; the second, while possible to attain, becomes difficult and expensive. But there is no known practical method under the present development in the science of water treatment to remove salinity, in order to meet the third requirement. While this does not result in a breakdown in industrial processing, it does present extremely troublesome problems and causes much expense.

One of the greatest difficulties arises in the manufacture of steam for the production of power and for industrial processes. The salt in the water causes foaming, and it becomes necessary to "blow-down" the boilers almost continuously, requiring the use of large volumes of make-up water. This in turn greatly increases the amount of fuel required for heating. The salinity-high water also causes excessive corrosion in boiler tubes and other equipment, resulting in rapid depreciation and not infrequent breakdowns.

In the manufacture of viscose, of paper, and in dyeing operations, extended high salinity conditions invariably result in the production of a product much inferior to that normally produced. In fact, during 1941, the Aberfoyle Manufacturing Company, one of the largest yarn dyeing concerns in the country, actually had to discontinue its own dyeing, and "let" the work out to other companies. Aside from the obvious inconvenience and the consequent "headaches" incurred, this arrangement is understood to cost the company an additional ten cents for every pound of yarn dyed. This one item alone represents a loss of approximately $300.00 a day.

On November 3rd, 1941, the Scott Paper Company had to shut down part of its plant for the entire day in order to correct a condition caused by salinity. In the manufacture of its paper products, certain felts are used which cannot be cleaned in the normal manner when salinity exists. The shut-down required in order to do this put 1,000 people out of work for the day. It also, of course, interfered with production and added to maintenance costs.

Boiler tubes blew out in 1941 in at least one of the major oil company's plants and also in a plant which produces a catalytic agent used by the oil refineries.

The American Viscose Corporation not only produces the steam which it requires for processes, but also makes all of its own electric power. Its normal reserve facilities are greatly overtaxed during periods of salinity invasions; and its power lines are not interconnected with those of the electric utility company serving this area. Under such conditions, a power house failure, if it occurred, would result in a complete shut-down. The market value of the Viscose Company's plant products is approximately $600,000 per month. High salinity causes a marked deterioration of its product and under conditions such as existed in 1941 is understood to have depreciated this value by about five per cent.

On the basis of data furnished by the industries in the Chester-Marcus Hook area, particularly by the Sun Oil Company, it is estimated that when the water in the Delaware River at Marcus Hook reaches a state in which the salinity throughout the day averages 600 parts per million chlorides, the annual damage caused by the use of the consequently deteriorated water supply of this area, totalling 28 million gallons per day, amounts to approximately $62,000 plus $8,500 for each day that salinity of this degree exists. While this estimate, of necessity, is but a rough approximation, it is believed to be reasonably representative; and probably somewhat on the liberal side. It has been arrived at by estimating the additional cost for salt and other chemicals which are required in order to remove the additional hardness in the saline water; the cost for additional chemicals used in the already treated boiler feed water; the cost of additional fuel for heating; the cost for additional pumping; a charge for excessive depreciation and maintenance of equipment; and a sum to represent depreciation in the value of manufactured products. In addition there is also included an item to represent the cost of procuring bottled water for drinking purposes. The above factors make up the part of the cost--$8,500 per day for 600 parts per million salinity--which it is assumed will vary with the degree of salinity. For example, this charge would become $4,250 per day for 300 parts per million salinity and $17,000 for 1200 parts per million. The $62,000 item is a constant, representing annual fixed charges upon the estimated capital sum which would be required in order to construct the additional water softening plant capacity which is required during salinity invasions. The sum includes provision for softening domestic as well as industrial water because the losses due to the hardness of the domestic supply during salinity invasions are believed to be even greater than the cost which would be required to remove such hardness. The distributions of the items which comprise the estimate are as follows:

SUMMARY OF ESTIMATED DAMAGES TO EXISTING DEVELOPMENTS
CAUSED BY SALINITY INVASIONS IN THE LOWER DELAWARE RIVER
IN THE VICINITY OF CHESTER-MARCUS HOOK
(Use of water 28 M.G.D.-Degree of Salinity, 600 p.p.m. chloride)

	Annual Fixed Charges	Daily Variable Charges
Privately Owned Industrial Supplies:		
Water Softening--20 M.G.D.	$ 42,000	$ 1,930
Additional Fuel--Heat Losses		2,220
Depreciation and Maintenance of Equipment		1,110
Depreciation in Value of Manufacturing Product		2,220
Chester Municipal Water Authority:		
Water Softening--8 M.G.D.	20,000	220
Bottled Water for Drinking		800
TOTAL	$ 62,000	$ 8,500

The detailed breakdown for each of the items comprising the above estimate is given in Appendix C.

Based upon this unit cost estimate, the total amount of damages for the eleven years 1929 to 1940 has been computed to be $5,477,000. This is equivalent to an average annual sum of $456,000. As already pointed out, this estimate probably is somewhat high; first, because liberal assumptions have been made to cover the items of additional expense, and second, because it seems probable that the period studied has occurred in a relatively dry meteorological cycle. However, even if so, it is also recognized that the estimate does not give any economic weight to the many intangibles involved upon which it is impossible to place values. These no doubt would more than offset the liberalness of the above figure. The year by year estimate from which the above total and average annual charges have been determined are given in the following tabulation:

ESTIMATED DAMAGES TO EXISTING DEVELOPMENTS
CAUSED BY SALINITY INVASIONS 1929 to 1940

Year	ANNUAL AMOUNT OF DAMAGE		
	Fixed Charges	Variable Charges	TOTAL
1929	$ 62,000	$ 50,000	$ 112,000
1930	62,000	2,120,000	2,182,000
1931	62,000	985,000	1,047,000
1932	62,000	620,000	682,000
1933	62,000	0	62,000
1934	62,000	0	62,000
1935	62,000	13,000	75,000
1936	62,000	500,000	562,000
1937	62,000	0	62,000
1938	62,000	0	62,000
1939	62,000	445,000	507,000
1940	62,000	0	62,000
TOTAL	$744,000	$4,733,000	$5,477,000
AVERAGE	$ 62,000	$ 394,000	$ 456,000

Value of Multiple-Purpose Project

The effect of the operation of the multiple-purpose Project Group No. 1 upon salinity conditions and the damages caused thereby next was investigated.

On the tabulation given on page 4 are shown the average rates of run-off in the Delaware River at Trenton for each period of salinity invasion in the years 1929 to 1940. If the proposed hydro-electric project, and the authorized New York City water supply project had been in operation during this period these flows would have been increased and the modified values under each of the three power schemes studied would be as follows:

AVERAGE DAILY RATE OF RUN-OFF AT TRENTON IN C.F.S.			
Year	Actual	Under Scheme 1 and 3 31,000 K.W.	Under Scheme 2 24,000 K.W.
1929	3270	3820	3470
1930	2670	3630	3520
1931	2960	4310	4120
1932	2120	2930	2620
1936	3460	4580	4240
1939	2920	3680	3430

Having determined the modified flows, they then were used to find out what the average degree of salinity would have been under the altered conditions, using for this purpose the formula and charts developed by the Delaware River Conservation Association. The results of this analysis, compared with the conditions which actually existed are:

AVERAGE DEGREE OF SALINITY AT MARCUS HOOK			
Year	Actual	Modified	
		Schemes 1 and 3	Scheme 2
1929	260	50	100
1930	750	500	525
1931	690	250	350
1932	725	500	550
1935	100	50	50
1936	370	50	100
1939	420	200	250

The next step then was to ascertain the extent of damages under the modified conditions of flow. This analysis indicates the total for the 1929 to 1940 eleven-year period would have been $3,220,000 under Scheme 1 and 3, which produce 31,000 kilowatts of primary power and $3,599,000 under Scheme 2 which produces 24,000 kilowatts of primary power. These compare with $5,477,000 under actual conditions of flow. On an average annual basis, the damage would have amounted to $268,000 under Schemes 1 and 3, and $300,000 under Scheme 2. These compare with $456,000 under natural conditions. The benefits in respect to salinity reduction, as determined by the decrease in damages, therefore, would be $188,000 under Scheme 1 and 3 and $156,000 under Scheme 2. These sums represent the value of the proposed multiple-purpose Project Group No. 1 for the control of salinity. The details supporting these figures follow:

ESTIMATED DAMAGES TO EXISTING DEVELOPMENTS
CAUSED BY SALINITY INVASIONS, 1929 to 1940

Year	ANNUAL DAMAGES CAUSED BY SALINITY		
	Actual	Modified by Operation of Proposed Hydro-Electric Project	
		Schemes 1 and 3	Scheme 2
1929	$ 112,000	$ 62,000	$ 62,000
1930	2,182,000	1,477,000	1,547,000
1931	1,047,000	417,000	562,000
1932	682,000	489,000	532,000
1933	62,000	62,000	62,000
1934	62,000	62,000	62,000
1935	75,000	62,000	62,000
1936	562,000	129,000	197,000
1937	62,000	62,000	62,000
1938	62,000	62,000	62,000
1939	507,000	274,000	327,000
1940	62,000	62,000	62,000
TOTAL	$5,477,000	$3,220,000	$3,599,000
AVERAGE	$ 456,000	$ 268,000	$ 300,000
BENEFIT		$ 188,000	$ 156,000

One very definite conclusion which can be drawn as the result of this, and previous, studies of salinity is that it is impractical, if not impossible to eliminate the incursions of salinity above the Pennsylvania-Delaware boundary line. It appears that the only possibly practical way to overcome the effects of such salinity invasions will be to provide a supplementary source of water supply for use during such periods. Each water supply diversion project in the basin, however, if operated under proper regulations for releases, will improve conditions. But the effect of such improvement, economically, is not great. This study supports this conclusion beyond question.

In Appendix C are included supporting data and computations for this study.