Carvin's Cove Water Supply Project for Roanoke, Va.

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THE bringing in of the Carvin's Cove water supply will terminate thirty years' experience with periodically recurring inadequacy at Roanoke. The initial development will add 150 per cent to the safe yield of the present supplies and, with comparatively minor additional expenditure, this can be extended to 300 per cent. This development will provide Roanoke with an unexcelled water supply with a hardness of approximately 20 ppm. and located at such an elevation as to be available by gravity.

In order to assist in a better understanding of the Carvin's Cove development, this discussion will briefly review some of the factors affecting the design, such as the population growth of the past and that projected for the future, the future water requirements, the capacity of the present sources of supply and their deficiencies, and the additional capacity needed to provide adequately for the future water requirements of Roanoke. Brief reference will also be made to the various alternative sources of increased water supply available to Roanoke and the factors which influenced the selection of the Carvin's Cove supply over the other available sources.

Population Growth

Inasmuch as the use of water depends primarily upon the growth in population, consideration was first given to the past and probable future population growth at Roanoke (Fig. 1). In the 40-year period prior to 1930, Roanoke experienced a rapid and sustained population growth. Like most other cities its population growth in the next decade was practically zero. This was followed by the war period with its effect upon population concentration in cities. It is believed that following the termination of the war the normal upward trend which was affected by the depression and the war will be resumed and that the present population of approximately 76,000 will increase to 85,000 by 1950, 100,000 by 1960 and 130,000 by 1980.

Water Consumption

Based upon the forecasted population and study of the water consumption for average and maximum days, a forecast of water requirements for the future was made. A study of the past consumption disclosed that there were a number of periods during which restrictions on use affected particularly the maximum rates and the ratio of maximum to average. The average day's use was also affected by a waste survey made in 1931 which reduced the pumpage nearly 1 mgd. and the fact that the Norfolk & Western Railroad, about 1920, had found it necessary to develop an independent supply in order to be assured of adequate water for its needs.

The forecast for the future should, of course, be based upon the assumption that an adequate supply will be available. On that assumption it is

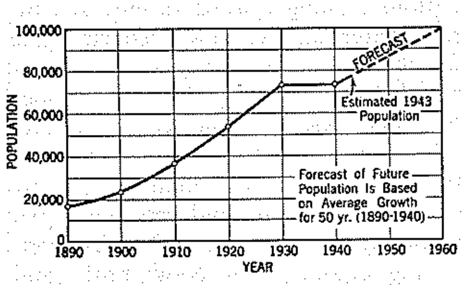

FIG. 1. Chart Showing Past and Estimated Future Population of Roanoke, Va., Including Vinton, Va.

estimated that the average day will increase to: 7.2 mgd. in 1950, 9.0 mgd. in 1960 and 12.2 mgd. in 1980, with the maximum day 50 per cent above these figures.

The forecast of the average and maximum days up to 1960, together with the recorded experience of the past, is shown on Fig. 2.

Present Sources of Supply

The safe yield of any water works is measured by its ability to deliver during periods of minimum availability. The present water supply of Roanoke is obtained from a number of widely scattered sources. The principal supply is secured from Crystal Springs, located not far from the center of the city, which has a dependable dry weather flow of somewhat less than 4 mgd. During the dry period of 1945, Crystal Springs yielded but 3.6 mgd.

Additional springs, known respectively as Muse, River and Smith, are used as auxiliary supplies. These are scattered about the city and in 1937 were estimated to have a total dependable yield of about 1.3 mgd.

About 30 years ago the Vinton water supply was merged with the Roanoke supply. Impounding dams on Falling and Beaver Creeks northwest of Roanoke are able to deliver a safe yield of 1.5 mgd. into the system by gravity. This water passes through pressure filters and marble beds for stabilization in order to reduce corrosion.

In a further effort to increase the supply the private water company drilled wells near Crystal Springs. There are two such wells which, pumped jointly, have a safe yield of 400,000 gpd. The water which they furnish is high in iron and very hard.

The total safe yield of all existing supplies is 6.8 mgd., a figure which fails by more than 2.5 mgd. to meet the maximum demand of the present time, and which would only be one half of

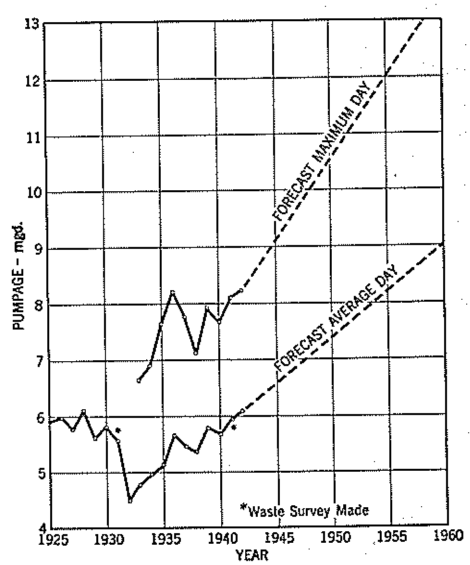

FIG. 2. Chart Showing Past and Estimated Future, Average and Maximum Days of Pumpage—Roanoke, Va.

the maximum demand reasonably anticipated fifteen years hence.

Additional Capacity Required

In comparing the forecasted requirements and the safe yield of the existing supplies it is apparent than an increased supply is urgent. On the assumption that all of the existing supplies would be retained in service, the capacity of a new development need be sufficient only to supply the difference between the maximum day's demand and the maximum safe yield of all the present supplies. It is believed, however, that with the development of an adequate supply of high quality the wells, and quite probably the springs, other than Crystal Springs, will eventually be abandoned. With the assured adequacy and the 20-ppm. hardness of the new supply it is also hoped that the Norfolk & Western Railroad may find it to its advantage to purchase water again from the public supply.

It was recommended that additional capacity be provided at the present time to the extent of at least 6 mgd., which, it was estimated, would be adequate to as late as 1960. It was, however, recognized that in the selection of the future supply for Roanoke, at this time, the more remote future must also be considered.

Available Sources of Supply

Although Roanoke has long suffered from severe periodic inadequacies, the deficiency has largely been due to the failure to develop the water resources of the area rather than to the lack of availability. The area has an average rainfall of approximately 40 in. per year. There are numerous watersheds within reasonable distance of Roanoke which could be developed for Roanoke's needs. Possibly it was this abundance of supplies which to some measure delayed the ultimate development. Both the city and the private company (for the water works system of Roanoke was privately owned until 1938) had made a number of investigations looking toward an enlarged future water supply. Two reports made for the city some 20 years ago recommended taking water from the upper Roanoke River. The company had selected Carvin's Cove, first brought to the attention of the management by Charles E. Moore, and reported upon favorably by Sanborn & Bogart, consulting engineers of New York, and Dr. Chas. P. Berkey of Columbia University, who reported upon geological features as affecting storage and dam construction. It should be stated that prior to 1932 there were no accurate U.S. topographic maps of the area available and it was probably for that reason that Carvin's Cove had escaped attention for so long.

In 1936 the private company authorized Alvord, Burdick & Howson to make a study of all practicable sources and to advise relative thereto.

The map, Fig. 3, shows the various practicable sources of supply available to the city of Roanoke and their relationship geographically to the city itself and to each other.

Each of these supplies was investigated as to water yield, cost of construction and annual cost of operation, as well as to the quality of water that would be delivered.

Analyses of the Carvin's Cove water showed a total hardness of 20, methyl orange alkalinity of 10 and an iron content of 0.1 ppm. The Roanoke River sources showed a hardness of approximately 145 ppm., with methyl orange alkalinity from 100 to 120, color normally ranging from 5 to 18 and

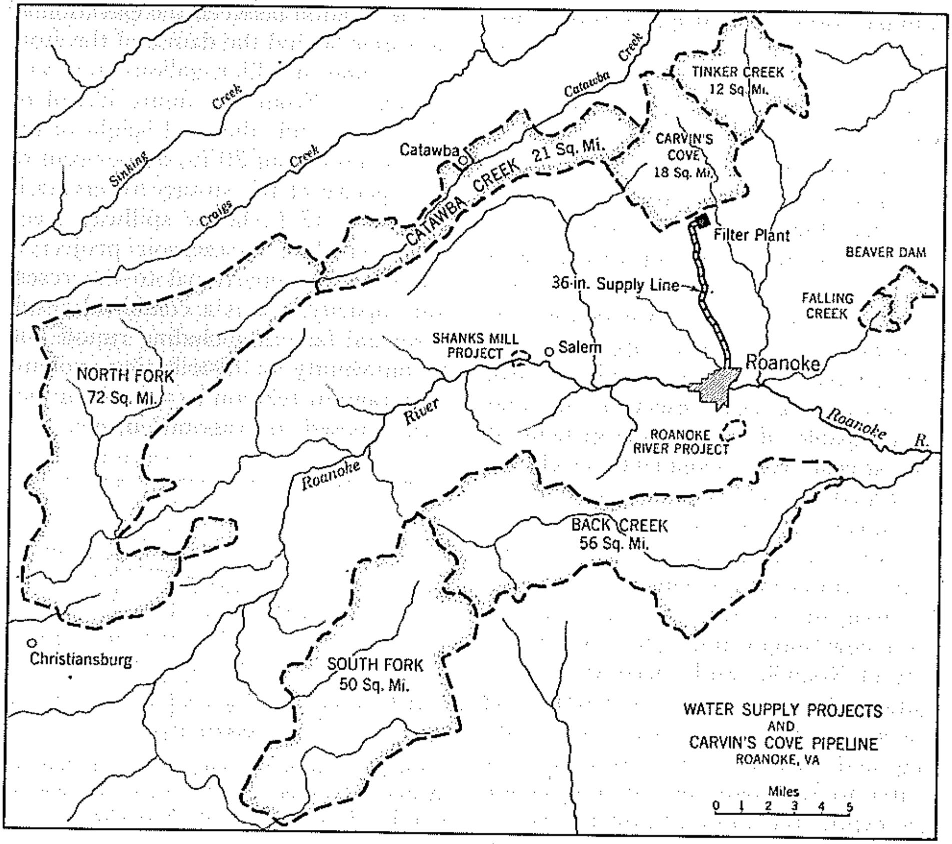

FIGURE 3

iron from 0.17 to 0.30 ppm. North Fork had the hardest water at 220 ppm.

The estimated construction and annual costs of these projects are:

Project	Construction Cost	Annual Cost
Carvin's Cove	$1,908,242	$149,600
North Fork	3,251,000	279,600
South Fork	3,606,100	291,300
Back Creek	1,811,700	206,000
Shank's Mill	1,530,500	178,100
Roanoke River	712,000	134,400

The estimated construction costs varied from $712,000 for Roanoke River, developed at a site in Roanoke, to $3,600,000 for South Fork, with Carvin's Cove intermediate at $1,900,000, of which $600,000 had previously been spent by the company, leaving the additional expenditure of $1,300,000 to bring the water to the city. In annual costs, which include interest and depreciation as well as operating cost, Roanoke River at Roanoke and Carvin's Cove were approximately one-half that of North Fork, South Fork or Back Creek, and materially less than Shank's Mill on the Upper Roanoke River.

The Roanoke River (at Roanoke) project, while lowest in both first and annual costs, was dropped from consideration because the sewage of Salem and much of the sewage of Roanoke entered the Roanoke River above the water works pumping station and would continue to do so through storm water overflows even though the dry weather flow were intercepted.

The Carvin's Cove supply was, therefore, the next in line from the standpoint of both cost of construction and annual cost. As that supply was of lowest hardness and Carvin's Cove possessed the best reservoir site and was capable of future enlargement at lowest cost, its development was clearly indicated as the best solution of the Roanoke water supply problem.

The city of Roanoke acquired the water works by condemnation in 1938. Nothing further was done with respect to a new supply until 1943, when the city of Roanoke authorized an investigation for the purpose of determining the most practicable means of purifying and bringing the Carvin's Cove water to Roanoke and, in conjunction therewith, the most advantageous extent and location of storage reservoirs to improve distribution and pressures throughout the city. The report was completed in October 1943.

In making this investigation a more detailed study of the ultimate capacity of the Carvin's Cove project was undertaken. The concrete dam had been built in 1928. Much of the land which would be flooded at pool stage had not been acquired at that time. The reservoir when filled to the spillway level would store 6,470 mil.gal. at elevation 1,170 ft., which is 34 ft. above Mill Mt. reservoir which now floats on the city distribution system. This amount of storage is very large in proportion to the 17.88 square miles of drainage area tributary above Carvin's Cove dam.

The relation between the elevation of the water behind the dam and the storage volume in billion gallons is shown in Fig. 4. From this figure it will be noted that, while the total height of the dam is more than 70 ft., 50 per cent of the capacity of the storage reservoir is in the top 15 ft. below spillway level.

The yield of a reservoir project is not directly proportional to the reservoir capacity. It is a combined result of several factors, including runoff and its uniformity of distribution, volume of storage in relation to runoff, surface area exposed to evaporation, etc.

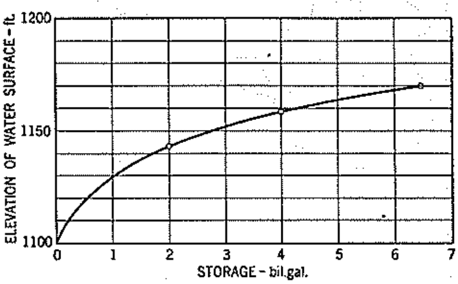

Fig. 4. Chart Showing Relation Between Water Elevation and Storage Volume of Carvin's Cove Reservoir—Roanoke, Va.

There were no records of runoff from Carvin's Cove itself and, accordingly, engineering studies were made of the runoff characteristics of 24 streams located within a radius of 125 miles of Roanoke and for which flow records were available through the United States Geological Survey. The daily, monthly and annual average flows were studied and from these the coefficient of variation from the mean of flows in this general area was computed. Using these data by means of the Hazen method of comparing such records it was determined that in the driest year likely to occur once in a cycle of 20 years the yield of the Carvin's Cove project would be not less than 10 mgd. after allowance for evaporation and all other losses. For all other years a much larger yield can be obtained.

The yield of 10 mgd. is estimated with the full 6,470 mil.gal. of storage available. With a smaller storage the yield would be less but it would not be decreased in anything like the proportion to the reduction in storage. For illustration, as indicated on Fig. 5, if the storage volume was but 4,000 mil. gal. instead of 6,470, the yield would still be 9 mgd. or but a 10 per cent reduction below that at full capacity. If the storage was but 2,000 mil.gal. the yield would still be 7.5 mgd. over the driest period to be expected once in a 20-year cycle. Reducing the reservoir capacity by the 70 per cent which is provided by the Carvin's Cove dam reduces the yield but 25 per cent.

These facts suggested the study of the practicability of bringing in water through diversion from other watersheds without the necessity of providing storage on those watersheds but rather by utilizing the Carvin's Cove storage to greater advantage.

The Carvin's Cove project is unique in that it lends itself to progressive development by diversion from adjacent streams to such an extent that the water requirements for Roanoke can be met for the indefinite future. Investigations showed that by the construction of a small diversion dam built across Tinker Creek (Fig. 3), whose drainage area adjoins Carvin's Cove on the east, and a tunnel through the dividing ridge, the runoff from this additional drainage area of 12 square miles can be diverted into Carvin's Cove and with no change in the existing dam or reservoir capacity the yield can be increased thereby from 10 to 15 mgd. (Fig. 5).

By further similar construction of a low diversion dam on Catawba Creek whose drainage area adjoins Carvin's Cove on the west, the runoff from an additional 21 square miles can likewise be diverted into Carvin's Cove, thereby increasing the yield of the present reservoir another 5 mgd., making the total yield of the three watersheds using

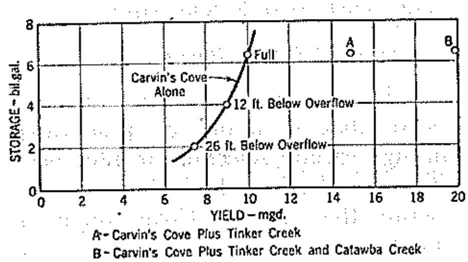

FIG. 5. Chart Showing Storage vs. Yield—Carvin's Cove Project—Roanoke, Va.

Carvin's Cove storage 20 mgd. This yield will be available 19 years out of 20 after allowing for evaporation and permitting a small dry weather flow to pass through the diversion dams on Tinker Creek and Catawba Creek at all times.

When combined with the present sources of supply, the total yield of the Carvin's Cove-Tinker-Catawba development would amount to 27 mgd., an amount four and one-half times the average requirements of the present and twice the estimated average annual requirements of 1980. The present supplies of Carvin's Cove alone, without the Tinker-Catawba addition, will provide materially more water than will be required by Roanoke till 1980.

It is apparent that the water requirements of Roanoke can be met with no enlargement of the present reservoir capacity for a time well beyond any date for which it is reasonable to forecast. This results from the fact that it was practicable in the construction of

Carvin's Cove dam to build a structure in a narrow gorge at reasonable expense and to obtain thereby the elevation necessary for gravity flow to Mill Mt. The over-development of storage was somewhat incidental to getting the elevation. The wisdom of that concconstruction becomes apparent in connection with the development being made nearly two decades later.

Location of Filter Plant

It is apparent from what has preceded, that it would be practicable, through careful selection of filter plant site and selection of pipeline sizes, to operate the Carvin's Cove supply by gravity most of the time. Therefore, in selecting the site of the filter plant, a careful study was made of the topography between Carvin's Cove dam and the city. A site was selected which is located at approximately elevation 1,150, at a level about half way between the full reservoir stage at Carvin's Cove and the distribution reservoir full stage on Mill Mt. The city acquired an entire farm of approximately 85 acres on which this site was located.

The project consists of a 36-in. pipeline from the Carvin's Cove dam to a 6-mil.gal. filter plant located approximately 3,000 ft. south of the dam. From the filter plant a 36-in. main will connect to the city distribution system, including a 24-in. feeder connecting to an existing 16-in. main which will feed in both directions one line leading directly to Mill Mt. reservoir.

The project includes a reinforced concrete roof over the present Mill Mt. reservoir, the construction of an additional 2-mil.gal. reservoir at City Farm in the southwest section of the city, and the construction of a 2-mil. gal. steel standpipe located in the northwest section of the city. In effect, including the 2-mil.gal. clear well at the filter plant, there will be a storage reservoir of approximately 2 mil.gal. located at each of the four corners of the distribution system.

The filter plant is of the conventional mechanical gravity type of 6-mgd. capacity. The water from Carvin's Cove which provides "oversize storage" should be of very low turbidity. Filters are designed on 2 gal. per sq.ft. rating, with all hydraulic design based on operating at 50 per cent overload.

The storage in the top 12 ft. of Carvin's Cove reservoir will be available to the plant by gravity after it is once filled. That storage will amount to over 2,500 mil.gal. and when once filled will provide a minimum yield of about 9 mgd. There will therefore be no necessity for low-lift pumping for many years after the reservoir is filled.

On reaching the filter plant the water will be flocculated for approximately 45 minutes after receiving the chemical dosage, and will then be settled in a two-compartment settling basin having a total detention period of three hours at the 6-mgd. rate.

From the settling basins the water will pass to the four 1.5-mgd. filter units, grouped two units on each side of a central gallery. The influent is at the back of the filters, as is the wash water duct, thus providing a very capacious pipe gallery with all equipment easy of access.

The effluent from the filters is through ducts which unite and discharge to the 2-mil.gal. clear well, the water being chlorinated on leaving the filters.

The 2-mil.gal. clear well is of 20 ft. depth, the mid-depth being at the same elevation as the full elevation of Mill Mt. reservoir. This elevation is such that when the filter plant is operating the top half will normally be in use and at times when Crystal Springs is furnishing the entire supply the lower half only will be available for storage.

Facilities for feeding alum, lime, carbon and chlorine are provided. Because the filter plant will be remote from railroad connections, chemicals will probably be received in containers and facilities for unloading and storage are provided on that basis.

The plant is so designed that it can be enlarged progressively as needed to the ultimate capacity of the Carvin's Cove development, namely, 18 mgd.

Selection of Pipeline Capacity

The size of pipelines from Carvin's Cove dam to the filter plant, and also from the filter plant to its connection to the present city distribution system, are influenced somewhat by the relative elevations of Carvin's Cove dam and existing facilities. Over 35 per cent of the storage in Carvin's Cove is in the top 12 ft. of the reservoir. This amount of storage will provide a safe yield of 9 mgd. in connection with the Carvin's Cove drainage area, from which it is apparent that once the reservoir is filled it can operate by gravity with no low-lift pumping required for the next 25 years more or less. With adequate clear water storage at the filter plant, the rate of flow between the dam and the filter plant will be the average rate for the 24 hours a day. Hourly fluctuations will be taken care of by storage in the clear water reservoir. A 30-in. pipeline would have been adequate for this 3,000 ft. but in order to make available by gravity more of Carvin's Cove water this line was made 36 in.

Between the filter plant and the Roanoke distribution system, the pipeline

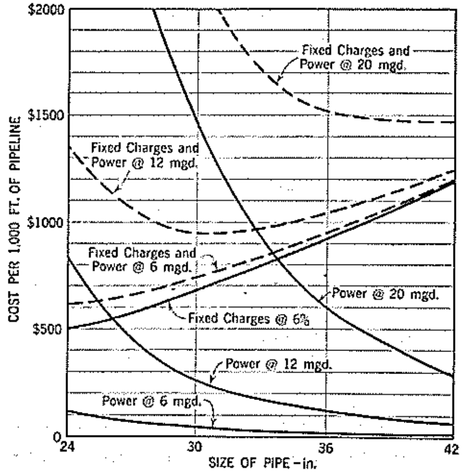

FIG. 6. Chart Showing Pipeline Fixed Charges vs. Power Costs—Roanoke, Va.

will be required to carry peak rates of draft except as modified by Mill Mt., City Farm and Carroll Avenue reservoirs. The distance is approximately 35,000 ft. A study of the economical size of pipeline for this reach was made and the results are shown on Fig. 6.

The annual cost of a pipeline consists of interest and depreciation on the investment, plus the cost of power required for pumping against the friction in the pipeline. Obviously the larger the pipeline the greater its initial cost and the greater the annual fixed charges. Also, the less will be the friction and the less the pumping cost.

This exhibit shows in diagrammatic form the annual cost, consisting of fixed charges and depreciation, and the power cost to pump against pipe friction and their use in determining the economical size of the Carvin's Cove transmission line. The diagram shows the total annual cost for 24-, 30-, 36- and 42-in. diameter pipe, under pumpage rates of 6, 12 and 20 mgd. The low point on each of the total annual cost curves shows the most economical size for that particular pumpage. For instance, the 6-mgd. curve is lowest at the 24-in. size, although nearly horizontal between the 24- and 30-in. The 20-mgd. rate is lowest at the 42-in. but not materially lower than for the 36-in. size. This type of analysis is applicable in evaluating gravity lines as well as those which are supplied by pumping, for obviously decreasing the pipe size will make gravity flow inadequate and pumping necessary.

As a result of this analysis, in conjunction with the requirements of maximum hour delivery on that part of the line from the filter plant to the city distribution system, the ultimate development of 18 mgd. and a consideration of the difficulties incident to the duplication of the line in the fairly remote future, it was recommended that the line be 36 in. in diameter.

Plans and Specifications

Complete plans and specifications were submitted to the War Production Board late in 1944, but, although the plans and specifications met with their entire approval, it was not until about the middle of 1945 that the board considered the war demands for critical materials sufficiently relaxed to authorize construction. The City Council then promptly called for bids for construction, and they were received on Aug. 20, 1945.

Filter Plant

The dimensions of the filter plant building were those dictated by utility requirements. The dimensions in plan and elevation having been determined, however, there was as always considerable latitude concerning the type of architecture to be selected. Several alternative designs were made, each built around the same measurements for the building proper and each costing substantially the same. The city selected a southern Colonial type believed particularly suitable for construction at the site on what is known as "Old Plantation Road."

Storage Reservoirs

The topography served by the Roanoke water works, aside from the central business district, varies 200 ft. or more in elevation. The distribution system is quite deficient in feeder mains. The wide variation in topography, coupled with the deficiency in feeder mains, has necessitated the construction of numerous booster stations. There are now seven such stations operating on the system.

An analysis of the relative costs and merits of additional feeder main construction and of strategically located reservoirs demonstrated that the most economical expenditure of funds for the correction of distribution deficiencies would be by means of the construction of additional reservoirs. Mill Mt. now provides 2 mil.gal. of storage in the southeast corner of the city. The new Carvin's Cove clear well, to the northeast of the city, will provide from 1 to 2 mil.gal., depending upon the direction of flow. It was decided to build a 2-mil.gal. reservoir at City Farm, near the southwest section of the city, and to construct a 2-mil.gal. steel standpipe at Carroll Avenue, near the northwest section of the city. The effect of these four reservoirs at the four corners of the distribution system on intermediate pressures is illustrated in Fig. 7. The installation of these reservoirs will make unnecessary the operation of two pumping stations under ordinary conditions at least.

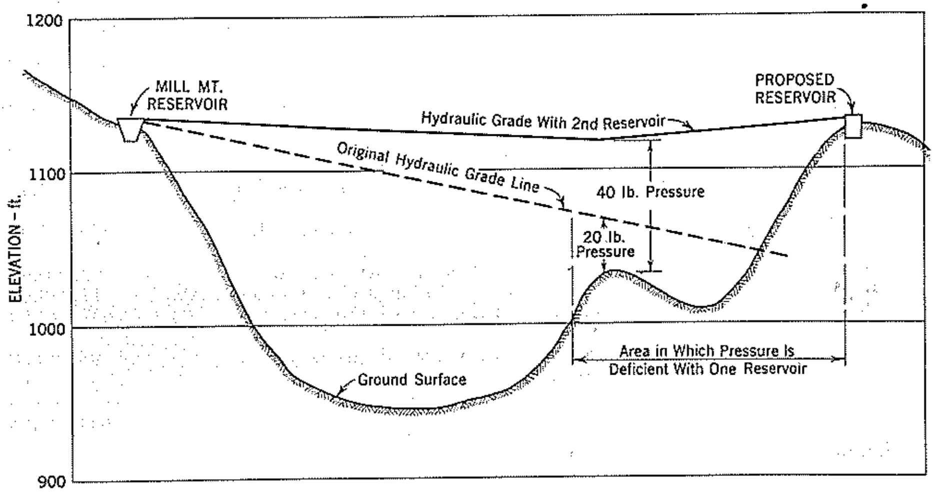

FIG. 7. Chart Showing Effect of Distribution Reservoirs on Pressures—Roanoke, Va.

Contracts

Bids were received for the construction on August 20, 1945. The work was divided under eight contracts. In general, it was found that the prices that were bid for materials and equipment were well in line with estimates previously made; the bids on filter plant structures were materially above the estimate and although but two bids were received for the pipe laying, these were from 50 to 75 per cent above the estimate of cost.

Alternate bids were taken on three materials for the 35,000 lin.ft. of main line from Carvin's Cove to the city limits, namely cement-lined cast-iron, steel cylinder reinforced concrete pipe, and steel pipe with bituminous spun lining and either bituminous coated or bituminous coated and wrapped exterior. Contract was awarded to the Lock Joint Pipe Co. for reinforced concrete pipe. Comparative prices were:

Steel cylinder reinforced concrete	$378,411.00
Steel coated and wrapped	$420,693.90
Steel coated only	$377,523.00
Cement-lined cast-iron	$450,811.30

In view of the fact that pipe would not be available for laying for 75 days after August 20, 1945, it was decided to readvertise the laying contract and endeavor to secure broader competition. New bids were taken on September 24. Six bids, varying from $637,742.50 to $658,704.37 were secured.

In view of the representative bidders submitting figures and the closeness of the figures submitted, the acceptance of the low bid was recommended in the belief that it fairly represented the cost of the work under existing labor conditions. Although the nearby Radford Ordnance Plant had recently released several thousand employees, contractors who thoroughly studied the situation were extremely pessimistic regarding the conditions under which labor would be available and the efficiency with which it would operate.

The amount of the contracts and the successful contractors for the entire work, other than Carroll Avenue standpipe and the covering of Mill Mt. reservoir, are as follows:

Contract	*Bidder*	*Amount of Bid*
A—Filter Plant Structures	Ralph E. Mills Co. and Blythe Bros. Co., Roanoke, Va.	$ 417,900.00
B—Filter Equipment	Roberts Filter Mfg. Co., Darby, Pa.	63,870.00
C—Pumping Equipment	Worthington Pump & Machinery Corp., Harrison, N.J.	4,260.00
D—Slow Mix Equipment	Jeffrey Mfg. Co., Columbus, Ohio	4,735.00
E—Pipe and Fittings (In City)	Lynchburg Foundry Co., Lynchburg, Va.	41,121.15
Pipe and Fittings (Carvin's Cove to City)	Lock Joint Pipe Co., East Orange, N.J.	378,411.00
F—Valves (Altitude)	Anderson Valve Corp., Scottdale, Pa.	2,290.00
Valves (Gate)	M & H Valve and Fittings Co., Anniston, Ala.	17,250.00
G—Pipeline Construction	Ralph E. Mills Co. and Blythe Bros. Co., Roanoke, Va.	637,742.50
H—City Farm Reservoir	Ralph E. Mills Co. and Blythe Bros. Co., Roanoke, Va.	96,700.00
	TOTAL	$1,664,279.65
Estimated cost of Carroll Ave. Standpipe		52,000.00
Estimated cost of Mill Mt. Reservoir Roof		60,000.00
	TOTAL	$1,776,279.00

Personnel

W. P. Hunter is City Manager of Roanoke. Charles E. Moore is Manager of the Water Works, a capacity in which he has served under both private and municipal ownership. Alvord, Burdick and Howson, Chicago, were consulting engineers for the water works project.

Acknowledgments

Acknowledgment is made of the fine co-operation by various local citizens and engineers, particularly W. P. Wiltsee, Chief Engineer of the Norfolk & Western Railroad, whose knowledge of construction conditions and service on committees in connection with the project were very valuable.