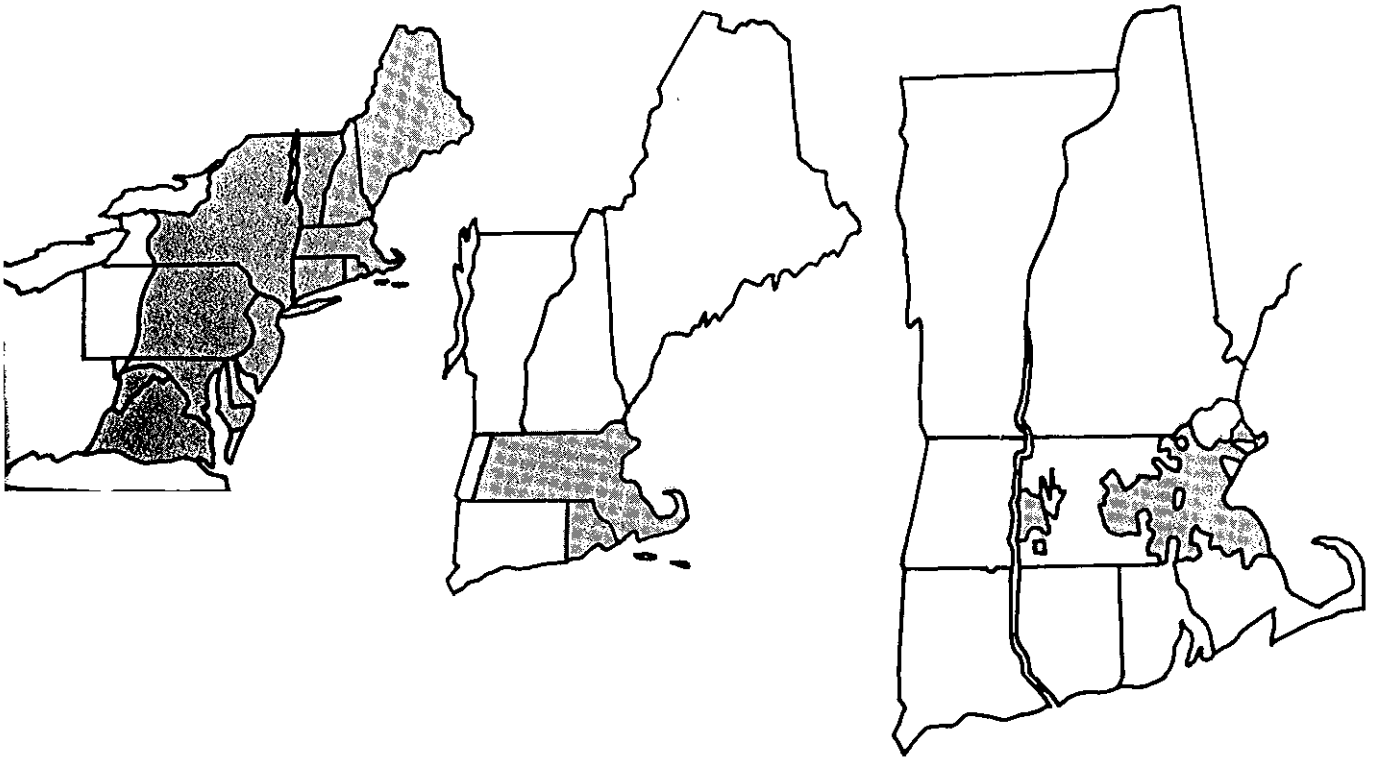
NORTHEASTERN UNITED STATES WATER SUPPLY STUDY

MILLERS RIVER BASIN WATER SUPPLY PROJECT

VOLUME II, APPENDIX A-H



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MILLERS RIVER WATER SUPPLY PROJECT

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APPENDIX A

ECONOMIC DEVELOPMENT

The purpose of this appendix is to provide background data concerning future economic development within the study area of this report. Data presented in this appendix are based on extensions of past relationships believed to have future relevance for the measures being projected. Underlying these extensions of past relationships are the assumptions that make the projections conditional forecasts. Thus, the projections are forecasts of what might occur if the particular assumptions were to materialize.

For water resource planning purposes, the assumptions underlying the OBERS projection method yield what is essentially a base line projection. That is, no explicit account is taken of the water resources endowments of a region.

It is assumed that water will play the same role in stimulating or depressing economic growth in the future as it has in the past. Thus, the major impact which the proposed project would have is insuring the provision of good, adequate water supply.

APPENDIX A

ECONOMIC DEVELOPMENT

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APPENDIX A
ECONOMIC DEVELOPMENT

1. Introduction

A. General

This Appendix examines the status of both the Millers River Basin and the greater Boston area economies today, discusses the historical forces that have been influential in shaping their present-day characteristics, and indicate what they are likely to be in the next fifty years. While economic and demographic information useful to water resources planning for both regions is provided, emphasis is placed upon the source area, the Millers River drainage area, with a more general look at the Greater Boston, or service area. This information includes historical and projected estimates of population, personal income, labor force, employment by industry group and output per employee. The historical years shown in this appendix are 1929, 1940, 1950, 1959, 1960, 1962, and in some cases 1970; projections are presented for each decadal year between 1970 and 2020. The areas for which projections and historical data are presented include the Millers River Economic Area, Franklin County, Massachusetts, the Connecticut River Water Resources Planning Area, the Lower Connecticut River Economic Area, the Boston Metropolitan Area, the Boston Economic Area, New England and the Nation.

B. Obers Projections

In carrying out this task, data prepared by the Office of Business Economics (OBE), Department of Commerce, and the Economic Research Service (ERS), Department of Agriculture were examined to determine their usefulness in providing meaningful bench mark projections. These projections, referred to as "OBERS Projections," are conditional forecasts of the future. They are based on extensions of past relationships believed to have future relevance for the measures being projected. Underlying these extensions of past relationships are assumptions that make the projections conditional forecasts. Thus, the projections are forecasts of what might occur if the particular assumptions were to materialize.

Certain assumptions regarding the structure and behavior of the economy are applicable to projections generally. Examples of these are:

1) The Federal Government will implement the policies needed to maintain relatively full employment;

2) Government and private policies will be successful in avoiding prolonged levels of inflation; and

3) The economy will be free of the distorting effects of a major military conflict during the 50-year projection interval.

For water resources planning purposes, the assumptions underlying the OBERS projection method yield what is essentially a "base line" projection. 1/ That is, no explicit account is taken of the water resource endowments of a region. It is assumed that water will play the same role in stimulating or depressing economic growth in the future as it has in the past.

C. Methodology

The analytical approach followed in this appendix was to compare the prospective trends for the Millers River Economic Area, the source area, to those of the Boston Metropolitan Area, the service area. Because both these regions differ area-wise from their enveloping OBE economic or water resource planning areas, separate projection series for personal income and employment were developed. These projections were based on the past historical series for the areas concerned and their relationships to the historical series of the enveloping OBE and water resource planning areas.

In developing data for the Millers River Economic Area, portions of Franklin and northwestern Worcester Counties, Massachusetts were examined for study as the source area. Where data from these two areas are combined, such as in population series, the Millers River Economic Area terminology is employed. On the basis of economic delineation rather than hydrologic considerations, however, these two areas are oriented to different geographic regions. In the OBERS projection series, for example, Franklin County is considered part of the Connecticut River Basin economic area, or more specifically, the Lower Connecticut, whereas northwestern Worcester County is more often tied to eastern Massachusetts economic areas. While both these areas of the Millers River drainage area are somewhat similar from an economic standpoint, Franklin County income and employment, being more easy to work with than the northwestern Worcester County data, are used to arrive at the percentage relationships necessary for the analysis employed in this Appendix.

As for the derivation of the OBERS projections, the general procedure followed was first to project national totals of each of the relevant economic measures and then to disaggregate these national totals to regional levels. Implicit in this procedure is the fact that national forces clearly dominate economic development throughout the nation. The national economy approximates a closed economy whereas the regional economies, within the United States are open. Goods and people

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1/ Part I, Appendix B, Economic Base, North Atlantic Regional Water Resources Study, prepared by the Office of Business Economics, Regional Economics Division, Department of Commerce for the NAR Water Resources Study Coordinating Committee. (May 1968), pp. 39-40.

move freely between regions. This assumption involving national forces is important for viewing the future economic growth of the Millers River and Metropolitan Boston areas which together account for an impressive share of the nation's economic activity and whose industries market their products beyond regional boundaries.

National projections of the overall economy were made in terms of benchmark aggregates such as gross national product, population, personal income and employment. From these summary measures were derived national totals of the economic series to be projected for local areas. Because of a lack of gross area product data that extend over a substantial time period, firm national-regional relationships of this measure could not be established. It is for this reason that population, personal income and employment were chosen as measures to be disaggregated to economic subareas for estimating the overall expansion of water resource requirements.

Furthermore, under contract to the North Atlantic Division for the Northeastern United States Water Supply Study, the Regional Planning Associates disaggregated the Water Resource Planning Area population projections to county level for dispersed, concentrated and most likely distribution patterns. The projections were then furnished to the New England Division by the North Atlantic Division for use in the Southeastern New England Water Supply Study. The most likely projections are used in this appendix to estimate water requirements for planning purposes.

In the particular case of northwestern Worcester County, a further disaggregation of the furnished Worcester County population figures was accomplished. In general, the method used in disaggregating the county total to sector level consisted of aggregating community projections provided by local agencies within a sector, totaling county sector values and comparing these to the controlling county total. The sector totals were then adjusted so as to reflect the county control figure. By use of this method the continuity of the population trend in the sector as expressed by the local groups' projections were maintained.

D. Major Findings

In general, the examined historical data and projections derived therefrom indicate that both the Millers River and Boston Metropolitan Area economies will continue to expand and prosper in the period 1970-2020. The projected rates of expansion for the two regions, however, differ markedly. In the process of expansion, both areas will continue to export valuable services and/or manufactured goods beyond their boundaries. Changes within and among the areas' various economic sectors are, of course, inevitable and will play a dominant role in determining

the regions' growth paths. Population, urbanization, employment, personal income, and the nature and composition of the industrial and business mix of the economies will all be of special relevance to the diverse water resource problems and needs of the two areas.

The major findings of this study are as follows:

1) Population in the Millers River Economic Area is expected to increase by a factor of 1.45 by the year 2020, although a decline is anticipated in relation to the total population of New England from 0.84 percent to 0.71 percent of the six-state figure. At the same time, population in the Boston Metropolitan Area is expected to increase by a factor of 1.7 by the year 2020. Here again, a decline is anticipated in relation to the total population of New England from 31.3 percent to 30.9 percent of the six-state figure.

2) Total personal income in the Millers River Economic Area is expected to rise by a factor of 4.9 by the end of the projection period. Since the region's population will be 1.45 times greater, per capita personal income will rise over threefold. At the same time, total personal income in the Boston Metropolitan Area is projected to increase by a factor of 6.3. Thus, per capita personal income in the Boston Area will increase closer to fourfold over the projection period.

3) The manufacturing sectors in both the Millers River Economic Area and the Boston Metropolitan Area are projected to decline relative to the nonmanufacturing sectors in importance as sources of employment. Employment in Franklin County's manufacturing industries is expected to drop from 33 percent of total employment in 1970 to roughly 25 percent by the year 2020. In the Boston Metropolitan Area, manufacturing employment as a percentage of total employment is projected to decline from 29 percent to 20 percent over the projection interval. By the year 2020, there will be more employees in nonmanufacturing jobs than in manufacturing positions in both areas. Employment in the services is expected to increase 93 percent by the year 2020 in Franklin County and 153 percent in the Boston Metropolitan Area. Expanding population and rising personal income indicate further advances for urban services such as finance, insurance, real estate, and medicine and health in the Boston Metropolitan Area. Thus, the projections of manufacturing and nonmanufacturing employment show the structural shifts which both economies are expected to experience.

4) The Upper Millers subregion is expected to be the fastest growing area within the Basin. Population in this subregion is projected to increase by 58 percent over the projection interval as opposed to 39 percent for the Lower Millers and 29 percent for the Middle Basin subregion.

2. Trends in Economic and Demographic Activity

A. General

The first part of this Chapter describes past changes in the economic growth of both the Millers River Economic Area and the Boston Metropolitan Region as compared to New England and national economic growth and discusses the historical forces that have been influential in shaping their present-day characteristics. This sets the stage for the second part which analyzes the future economic growth of the Millers River and Boston Metropolitan areas and compares this to projected national growth. In addition, this chapter serves as a point of departure for the analysis of future economic growth of the Millers River subregions which are discussed in the following chapter. The purpose of these chapters is to provide the necessary economic and demographic information essential for assessing the future demand for water and related land resource goods and services in the study areas.

In this Appendix, economic change is measured by a set of interrelated variables, namely population, labor force employment, personal income, and net output. These indicators express in economic terms the need for water resource development in an area. Especially important are the numbers of people projected to live in an area and any expected changes in industrial activity. Industrial output or activity at the national level is measured by gross national product. At the regional level, however, there are no official corresponding measures to the annual national output of goods and services. Therefore, employment data which is available in detail at the regional level is used to indicate changes in industrial activity and total personal income provides an overall measure of regional economic growth.

B. The Source Area

The Millers River Economic Area is a predominantly rural area with moderate elevations and a terrain consisting mostly of rolling hills. Beginning with the earliest settlements in the late 1600's, agriculture was the major industry with areas too steep for plowing used for sheep grazing. The plains yielded crops of wheat, tobacco and corn without too much difficulty, and by the late 1800's the region had grown to be the largest potato producing area in Massachusetts.

In these early days, however, every man's home was a factory in which plows, yokes, carts, scythes and household furniture were produced. At the same time, the women carded wool, spun and wove. Articles of prime necessity, such as iron, steel, brass and pewter utensils were imported. The first cutlery in America was made in the town of Greenfield, the eastern terminus of the famed Mohawk Trail.

The abundance of water was a prime factor in the early development of industry in the region. At present, the basin's industrialized areas are concentrated in the central and eastern sectors. Manufacturing, as it has throughout the early 1900's, now contributes the most to the economy of the region as measured by the number of persons employed. The next most important sector as a source of employment is services. In 1961, the five largest manufacturing groups, in order of importance as employers, were machinery, fabricated metal products, paper and allied products, textile mill products, and food and kindred products. 2/

C. The Service Area

One of the earliest settled areas of the United States, the central city and immediate surrounding cities and towns of the Boston Metropolitan Area have for many years experienced a high level of urbanization. Only in recent years, however, have the outlying towns of the area begun to feel the urban pressures which have been characteristic of the central core.

Like the Millers River Basin, farming was a principal occupation of the early settlers in this region. Here too, an abundance of water power was a vital factor in the colonization and industrialization of the area. Saw mills, grist mills and tanneries mushroomed, powered by the waters of inland streams. Differing from the Millers' region, however, were the marine resources of the Boston area. Good natural harbors and rivers gave impetus to the rapid rise of shipbuilding. The abundance of herring and cod in the offshore waters provided another industrial base and item of trade. And with the most logical, and safest mode of transportation in the early settlement days being by ship, this area soon became one of the most important commercial and trade centers on the east coast.

Today, the Boston Metropolitan Area is geographically and economically a part of the largest employment and population cluster in New England. This cluster is the northern terminus of "megalopolis," the Atlantic coastal strip between Washington and Boston in which live about 44 million people, approximately one-fifth of the United States population. Located in the area are the principal governmental, commercial, industrial, educational, medical, financial, insurance, and cultural institutions of New England.

The share of the total labor force employed in the manufacturing industries is higher than the national average. This manufacturing activity is quite diversified with some specialization occurring in the individual cities and towns. The area as a whole shows a degree of specialization in miscellaneous manufacturing, electrical machinery, textiles, professional services, trade and construction. The rapidly

2/ Massachusetts Department of Commerce. Monograph for Franklin County. (Revised Jan. 1963).

expanding electrical machinery industry has surpassed the textile industry in numbers as the leading employer in the manufacturing sector. Other manufacturing industries which are major employers include non-electrical machinery, apparel, food and kindred products, fabricated metals and printing and publishing. Also, in recent years the Boston area has experienced a remarkable growth in technologically-oriented industries which have located here in response to, or as spinoffs of, the concentration of advanced education and research facilities.

Boston, the central city, is the Massachusetts state capitol, the most populous city in New England, and the center of the eighth largest SMSA in the country. While only secondarily a manufacturing center, the city's primary function in the area is as a trade and finance center. It is a major national and international air terminal and port, and the hub for New England's rail, truck, and bus services.

D. Past Trends In Economic Growth

1) General. The prospect for future economic growth in any region is dependent on past trends and current conditions. First, past changes in the source and service area's population growth are described. As mentioned earlier, the need for water resource development in an area is primarily related to the number of people in an area. This then is followed by sections dealing with personal income and changes in employment labor force.

2) Trends in Population. Population in the Millers River Economic Area increased by 12.7 percent between 1929 and 1970, rising from a level of 86,600 to 97,600 persons (see Table 1a). The average annual rates of growth for the selected periods shown in Table 1c, however, were well below the respective rates for the Connecticut River WRPA, New England, and the nation, thus reflecting the region's loss of population through net outmigration. These population growth rates were also surpassed by those of the Boston Metropolitan Area for the respective periods, although the Boston rates were still below those for New England and the nation (see Table 5c). Population in the Boston Metropolitan Area increased by 32.3 percent between 1929 and 1970, rising from a level of roughly 2.76 million to 3.65 million persons (see Table 5a).

These lagging rates of population growth are also reflected in the areas' decreasing percentage shares of their enveloping water resource planning areas and New England populations. From a high of 34.0 percent of total New England population in 1929, the Boston Metropolitan Area's regional share had declined to 31.3 percent by 1970 (see Table 5b).

Likewise, the Millers River Economic Area's regional share of New England population declined from 1.07 percent in 1929 to 0.84 percent in 1970 (see Table 1b).

3) Trends in Personal Income. Reflecting population trends, personal income growth in both the Millers River and Boston Metropolitan Areas has also been slower than its national counterpart. Expressed in 1958 constant dollars, personal income in the nation increased from about $155 billion in 1929 to about $420 billion in 1962 (see Table 2a). This represents an increase of 171 percent, or an average annual growth rate of 3.0 percent (see Table 2c). Personal income in Franklin County, however, expanded at an average annual rate of 2.0 percent during the same period, or by 94.8 percent in total. And in the Boston Metropolitan Area, personal income increased by 89.3 percent, or at an average annual rate of 1.9 percent over the 33 year period (see Table 6a, c).

Although the long term average annual personal income growth rate for Franklin County has been slightly higher than that of the Boston Metropolitan Area, this relationship has not remained steady over the more recent 22 year period prior to 1962. In that period, personal income growth in the Boston area increased to an average annual rate of 2.5 percent while that in Franklin County increased to 2.2 percent (see Tables 2c and 6c). In the twelve year period prior to 1962, however, personal income growth in Franklin County dropped to an average annual rate of 1.8 percent while that in the Boston area increased to 3.1 percent. And in the three year period prior to 1962 the two growth rates once again approached one another.

From 1929 to 1962, the share of New England's personal income received in Franklin County declined from 0.47 percent to 0.43 percent (see Table 2b). During this period, however, the county's share reached a high of 0.53 percent in 1950. At the same time, the share of New England's personal income received in the Boston Metropolitan Area declined from 37.5 percent to 33.8 percent (see Table 6b). Thus, both the areas' lagging rates of personal income growth were reflected in their percentage shares of New England personal income.

4) Per Capita Personal Income. The critical interplay between population growth and growth in total income is reflected in the per capita levels of income which have always been higher in the Boston Metropolitan Area than in the nation but approximately the same as the nation in Franklin County (see Tables 2a and 6a). The higher levels of per capita income in the Boston Area have been attributed to higher rates of labor force participation, substantial property

income, and a larger-than-national share of employment in manufacturing (see Table 7). The Boston Area regional trend in per capita income, however, has been to converge somewhat toward the national level and that of Franklin County.

5) Trends in Industry Employment. Over the past 30 years, overall employment has grown slower in Franklin County than in the Boston Metropolitan Area and the nation. In the period 1940 to 1970 the labor force increased by 27.5 percent in Franklin County, 46.9 percent in the Boston Area, and by 74.0 percent in the nation (see Tables 3 and 7).

Based on the number of employees, and as noted previously, agriculture has been relatively more important in the Millers River economy than in the Boston Area economy (see Tables 3b and 7b). Manufacturing, construction, transportation, communications, and public utilities have also been more important employment-wise. In the heavily urbanized Boston Metropolitan Area, industries such as trade, finance, insurance, realestate, and government retained a larger share of total employment than they retained in the Millers River area. Franklin County's employment share in the general service industries, although somewhat less important during the 1940's and the 1950's than that in the Boston Area, increased by 1960 to a point where it was more important to the local economy.

E. Future Projected Economic Growth

1) General. Having reviewed past trends in both the source and service area economies, the prospect for future economic growth can be assessed.

2) Population. Population in the Millers River Economic Area is projected to increase by roughly 43,700 persons between 1970 and 2020 (see Table 1a). This represents a growth of 44.8 percent, or an average annual rate varying between 0.4 and 1.0 percent for the selected periods shown in Table 1c. These projected annual average rates are lower than those projected for the Connecticut River Water Resources Planning Area and New England till the year 2000 (see Table 1c). They are alos lower than the average annual rates projected for the Boston Metropolitan Area (see Table 5c). Population in the Boston Area is expected to increase by 67.7 percent, rising from a level of roughly 3.65 million in 1970 to 6.13 million in the year 2020 (see Table 5a). The average annual rates of population growth for both the source and service areas, however, are projected to remain below those of total population growth in the United States during the 1970-2020 period.

Increases in the above populations are based on the estimates of labor force needs to meet the requirements of expanding economies which the

local area labor forces cannot accommodate. A community is a place for earning a living and population settles or expands in a region primarily because of employment opportunities. Hence, a greater migration into the Boston Metropolitan Area is projected based on the assumption that labor shortages will be avoided and economic activity will not be curtailed.

In the Boston Area, population growth is projected to continue to lag behind that in the nation, but to surpass the New England rate by the year 2000 and more closely approximate the national rate. Thus, the area's percentage shares of United States and New England populations are expected to stop declining by the year 2000.

In the Millers River Area, population growth is also projected to catch up to the New England annual average rate and move closer to the national rate during the study interval. Thus, here too, the area's percentage share of New England population is expected to level off by the year 2000.

3) Total Personal Income. In line with past trends, personal income in Franklin County is projected to grow at a slower pace than that in the Boston Metropolitan Area, New England and the United States (see Tables 2c and 6c). Expressed in constant 1958 dollars, it is expected to rise by a factor of roughly 4.9 in the period 1970 to 2020. At the same time, personal income in the Boston Area is projected to increase by a factor of 6.3 by the year 2020.

In addition, the proportion of the enveloping Water Resources Planning Areas' and New England's personal income received in both the study areas is projected to further decline (see Tables 2b and 6b). By the year 2020, Franklin County's share of New England personal income is expected to decline to 0.35 percent from a 1970 level of 0.47 percent. The Boston Metropolitan Area's share of New England's personal income is projected to decline from 33.3 percent to 31.7 percent over the projection interval.

4) Per Capita Personal Income. With population in the Millers River Economic Area projected to increase by a factor of 1.45 and total personal income by a factor of roughly 4.9, per capita income will rise over threefold by the year 2020 (see Table 2a). In the Boston Metropolitan Area, however, per capita personal income will increase almost fourfold over the projection period (see Table 6a).

Although per capita income in the Boston Area is projected to remain higher than that of the nation as a whole, a regional trend to converge toward the national level is also expected to continue. From

a high of 1.14 in 1970, the index for the Boston Area per capita income relative to the United States average is projected to decline to 1.05 by the year 2020. This projection is based on a gradual maturing of more recently developed sections of the country and the concurrent lowering of regional differences in economic opportunities.

5) Industry Employment. The changing characteristics of both the source and service areas' economies are indicated by manufacturing and nonmanufacturing employment projections. While the Millers River area economy will still remain more dependent on manufacturing than the national and Boston Metropolitan Area economies, this sector is projected to decline relative to the nonmanufacturing sector in importance as a source of employment (see Tables 3b and 7b).

Employment in Franklin County's manufacturing industries is expected to drop from 33 percent of total employment in 1970 to roughly 25 percent by the year 2020 (see Table 3b). In the Boston Metropolitan Area, manufacturing employment as a percentage of total employment is projected to decline from 29 percent to 20 percent over the projection interval. At the same time, employment in both the areas' service industries is projected to increase its shares of total employment. Franklin County's service industries are expected to increase their share of total employment from 26 percent in 1970 to 37 percent by the year 2020. Likewise, the Boston Metropolitan Area employment in the service sector is projected to increase from roughly 26 percent to 38 percent of total employment (see Table 7b). Thus, by the year 2020, there will be far more employees in nonmanufacturing jobs than manufacturing positions in both areas.

Manufacturing or traditional industrial activity is still projected to be of greater importance to the Millers River economy than it will be to the national economy. In the Boston Area, however, it is projected to be of less importance. As indicated in Tables 4 and 8, economic production per employee in both areas is expected to dramatically increase over the projection interval. This will in great part be a result of the changing mix of manufacturing industries from the labor-intensive to the capital-intensive.

With the pronounced orientation toward the non-manufacturing sector, new concentrations of workers and occupational changes will occur. Finance, insurance, real estate, government, and business and private services stand out as the more important growth industries. As growing populations with higher per capita income spend a larger share of their income on non-commodity items, recreational activity, medical and health services, and educational services, employment in the services will grow faster than in any other industry group.

In essence, the projections of manufacturing and nonmanufacturing employment for both the source and service areas show the structural shifts which these economies are expected to experience. Both areas are projected to further move away from economies which are based on manufacturing toward economies which are based on services where employment growth in the service sectors will result from expanding population, increased general employment, and rising personal income.

3. Basin Subregion Profiles

A. General

This chapter describes the economic and demographic characteristics of the three subregions which comprise the Millers River Economic Area (see Plate No. A-1). The purpose of dividing the area into subregions is to provide more meaningful entities for planning than are represented at the county or economic area level.

In essence, each subregion is different from the others, confronted by its own problems, and having differing capabilities which influence its prospects for future growth. These differences relate primarily to the resources and production facilities in a region, the structure of its economic activity, and the characteristics of its population, work force, and industrial sectors.

For each subregion, a textual description of its present conditions is presented. Included in this discussion are agricultural activity, population, labor force, and industry activity trends. Analysis of the relationships among these variables in the subregion and comparisons to the entire Basin are also provided.

Probably the most significant factor in a subregion is the expectation for employment opportunities. As mentioned earlier, population settles or expands in a region primarily because of employment conditions. Employment developments not only affect the structural relationships in a subregion but also determine the overall size of the regional economy and its position in relation to other subregions.

B. Subregion I, The Lower Millers

1) Description.

The Lower Millers River subregion represents about 27 percent, geographically, of the entire area - 663 square miles. This area includes the towns of Deerfield, Erving, Gill, Greenfield, Montague, Northfield, and Wendell. Like the other subregions, the Lower Millers is sparsely populated relative to the rest of Massachusetts and includes only one large town, that of Greenfield, which had a 1970 population of 18,084. The area is a readily accessible year-round recreation area, with Interstate Route 91 and State Route 2 crossing it at right angles.

2) Present Conditions.

Agricultural Activity. Lying within the fertile Connecticut River Valley, the Lower Millers is extensively forested and has substantial

farmlands, much of which are devoted to dairy farming with some tobacco, fruit growing and poultry production.

Population. Measured in terms of population, the Lower Millers is the second largest subregion in the area. In 1970, over 35,000 people resided in this area, representing 36.7 percent of the entire basin population (see Table 9). Population density in 1970 was the highest in the area, with 199 persons per square mile. Since 1940, the average annual rate of population growth for the periods shown in Table 9d has been higher than that for the entire Millers area and thus, the subregion has increased its share of total area population (see Table 9c).

Employment. Compared with the other subregions for 1963, the employment pattern of the Lower Millers has centered somewhat less on manufacturing and somewhat more on the remaining industrial sectors (see Table 10). While manufacturing still contributes the most to the area economy based on employment, the trade sector also has an impressive share of total employment. In 1963, 52.5 percent of total employment in the subregion was in manufacturing and this was concentrated mainly in machinery, fabricated metal products, precision hand and electric tools, and paper and allied products.

3) Subregion I Communities.

Deerfield, Gill, Northfield, and Wendell. These four communities are primarily small agricultural-residential towns. General farming, fruit-growing, dairying, and poultry raising are among the principal agricultural pursuits. Those residents not engaged in agriculture and local industry find employment in the more industrialized towns of Erving, Greenfield, and Montague.

In addition, the towns of Deerfield and Northfield both make unique contributions to the subregion. While Northfield has become a small year-round resort community, Deerfield's chief industry is its schools. Deerfield Academy, one of the oldest boarding schools in the country, Eaglebrook, a preparatory school for boys, and Bement, co-educational, all add a college town flavor to the area.

Erving, Greenfield, and Montague. As in other towns in the Basin, agriculture was the sole occupation of the inhabitants of Erving, Greenfield, and Montague for many years. Fron an early date, however, the water power of the Connecticut and Saw Mill Rivers was utilized in the building of paper and saw mills in Montague. Today, the town still has a considerable amount of industrial activity concentrated mostly in the manufacture of paper and its allied products.

It wasn't until the early 19th century that industrial firms began operations on a large scale in Greenfield. Today, both Greenfield and Erving are primarily industrial communities, although Greenfield still maintains some of its agricultural characteristics. In both communities manufacturing is the largest source of employment with concentrations in metal working machinery, fabricated metal products, and precision hand and electric tools.

C. Subregion II, The Middle Millers

1) Description.

The Middle Millers River subregion is the largest in terms of land area, representing about 41 percent of the entire area. This subregion includes the towns of Athol, New Salem, Orange, Petersham, Phillipston, and Royalston. For the most part, the subregion is agricultural and residential in nature with manufacturing centered in Athol and Orange.

2) Present Conditions.

Agricultural Activity. Like Subregion I, the Middle Basin is extensively forested and has substantial farmlands. General farming, dairying, market-gardening, poultry-raising, and fruit-growing have become the chief agricultural activities in the subregion.

Population. Measured in terms of population, the Middle Millers is the smallest subregion in the area. In 1970, over 20,000 people resided in this area, representing roughly 21 percent of the entire area population (see Table 9). Population density at 76 persons per square mile was the lowest average of the Millers area.

As opposed to the Lower and Upper Subregions, the average annual rate of population growth for the Middle Basin has been somewhat lower (see Table 9d). During the most recent 1960-70 period, the rate was negative while remaining positive for the other subregions. These lower average annual rates are reflected in the subregion's declining share of the total area's population (see Table 9c).

Employment. Compared to the Lower and Upper Millers subregions, the employment pattern of the Middle Millers has centered more heavily on manufacturing (see Table 10b). This sector was the largest in terms of employment in 1963 with 72.5 percent of total subregion employment and was followed, as in the other subregions, by the trade sector. Within the manufacturing sector, firms engaged in the machinery industry were the leading manufacturers as measured by the number of employees.

3) Subregion II, Communities.

New Salem, Petersham, Phillipston, and Royalston. These four communities are primarily small agricultural-residential towns with their labor force commuting to nearby industrialized Athol and Orange for employment.

Athol and Orange. Both these towns are important manufacturing centers in the subregion. The leading manufacturing industries measured by the number of employees are machinery (excluding electrical), shoes, toys, sporting and athletic goods, and lumber, furniture and wood products.

D. Subregion III, The Upper Millers

1) Description.

The Upper Millers River subregion represents roughly 32 percent, geographically, of the entire area. This subregion includes the towns and/or cities of Ashburnham, Gardner, Hubbardston, Templeton, Westminster, and Winchendon, all of which are in Worcester County. The area is sparsely populated and includes only one large city, that of Gardner, which had a 1970 population of 19,513.

2) Present Conditions.

Agricultural Activity. Like the two other subregions, the earliest occupation of the Upper Millers' inhabitants was agriculture. Because of the rocky surface in many areas of the subregion, farming was never profitable, but dairying, fruit-growing, and poultry raising are still carried on.

Population. In 1970, over 41,000 persons resided in the Upper Millers subregion, representing 42 percent of the entire Basin population (see Table 9). Thus, while being the second largest subregion area wise, it was the largest population wise. In terms of density, the subregion average of 194 persons per square mile was slightly less than that for the Lower Millers.

Like the Lower Millers, the subregion has experienced a positive average annual rate of population growth since 1940. Moreover, during the most recent 1960-70 period, this rate was higher than that of the Lower Millers (see Table 9d).

Employment. Like the Lower and Middle subregions, the employment pattern of the Upper Millers is centered more heavily on the manufacturing sector, followed by trade (see Table 10). Manufacturing is by far the largest source of employment with concentrations in the manufacture of furniture and fixtures, toys, sporting and athletic goods,

fabricated structural metal products, and office and store machines and devices.

3) Subregion III, Communities.

Ashburnham, Westminster, and Hubbardston. Ashburnham is a rural suburban community bordering on the Fitchburg-Leominster Standard Metropolitan Statistical Area, with a small amount of manufacturing devoted almost exclusively to furniture and wood products, machinery, rubber and the fabricated metal fields. Because of the town's rocky surface, agriculture has never been profitable, but dairying and fruit-growing are carried on.

The town of Westminster, for the most part a residential suburban community where trade is the leading industry measured by the number of persons employed, lies within the Fitchburg-Leominster Metropolitan Area. Those not employed in local trade and manufacturing find employment in this bordering metropolitan area and also in Gardner.

Hubbardston is a typical New England town with a mixture of manufacturing and agriculture.

Gardner, Templeton, and Winchendon. Manufacturing is by far the largest source of employment in all three communities. Agriculture was the principal occupation of the settlers in Gardner for over fifty years until the first chair factory was started in 1805 and there is still some dairying, poultry farming, and fruit-growing carried on in Templeton and Winchendon.

Today, Gardner is known as "the chair city of the world." In all three communities the manufacture of furniture and lumber products was the leading industry in 1963. Other important manufacturing plants in Gardner were those engaged in the production of toys, sporting and athletic goods, fabricated structural metal products, and office and store machines and devices.

E. Future Prospects For Subregion Growth

1) Future Subregion Population Growth. Population in the Millers River subregions is projected to increase by roughly 43,790 persons between 1970 and 2020 (see Table 9a). This represents a growth of 44.8 percent, or an average annual rate varying between 0.4 and 1.0 for the selected periods shown in Table 9d.

The largest segment of this growth is expected to be in the Upper Millers subregion in northwestern Worcester County which lies adjacent to the Fitchburg-Leominster Metropolitan Area. Population in this

subregion is projected to increase by 58 percent as opposed to 39 percent for the Lower Millers and 29 percent for the Middle subregion. In absolute numbers, this represents a growth of 23,770 persons as opposed to 13,900 and 6,000 for the Lower and Middle subregions respectively.

The projected average annual rates of population growth are reflected in the increasing and decreasing subregional shares of total future Basin population. While the Upper Millers subregion is projected to increase its share of total Basin population from 42 percent to roughly 46 percent by the year 2020, the two remaining subregions are expected to experience slight decreases in their respective shares (see Table 9c).

The increase in population projected for the Upper Millers River subregion is based on the labor force needs to meet the requirements of the Fitchburg-Leominster and Gardner economies which the local regional labor force cannot accommodate. Since population settles or expands in a region primarily because of employment opportunities, a migration into the area is projected based on the assumption that labor shortages will be avoided and economic activity will not be curtailed.

Thus, in view of the Upper Millers subregion communities' positions surrounding Gardner, their closeness to the industrialized Fitchburg-Leominster Metropolitan area for commuting, and also the open land avialability, this subregion is projected to experience the largest population increase in the Millers River Economic Area.

2) Future Employment. The Millers River Economic Area has always had a strong tradition of hand-craftsmanship which has never been entirely displaced. Today, this craftsmanship is primarily concentrated in the machinery, fabricated metals, and furniture and lumber products industries located in Greenfield in the Lower subregion and Gardner in the Upper subregion. The area's labor force was never as heavily involved in textiles as that in eastern Massachusetts, except for some concentration in textile mill machinery, although there was some pockets of concentration in the shoe industry in Athol in the Middle subregion.

Total employment in the Millers River Economic Area has always been unbalanced with manufacturing favored at the expense of general services, finance, insurance, and real estate. On balance, this employment structure has remained quite stable in recent years. For the future, however, manufacturing employment in the area is expected to follow regional, State, and New England trends and undergo a decline relative to services and allied fields which are expected to be the fastest growing employment divisions.

Within the manufacturing division in the subregions during the 1960's, the fastest growing employment sectors were food products, chemicals, and electrical machinery. Most recently, the significant change in the structure of subregion manufacturing employment has been the increase in the electrical machinery industry and relative decrease in the furniture and lumber products group. For the future, subregion employment in the machinery sector is expected to increase slightly or remain stable along with that in the furniture and lumber products group. At the same time, employment in electrical machinery and chemicals is expected to grow at a greater rate. All in all, it is expected that the future structure of manufacturing employment in the subregions will not deviate greatly from past trends in that the machinery and furniture and lumber products industries will continue to be much more significant in the region than in Massachusetts or New England as a whole.

TABLE A-1

Total Population, Millers River Economic Area,
Connecticut River Water Resource Planning Area,
New England and the United States

-1a. Population (in thousands)

	1929	1940	1950	1959	1960	1962	1970	1980	1990	2000	2010	2020
Millers River Economic Area	86.6	87.1	91.2	93.4	93.6	94.4	97.6	102.0	108.2	114.9	127.3	141.3
Connecticut River Water Resource Planning Area	1,178.9	1,219.2	1,383.6	1,629.4	1,640.4	1,677.2	1,845.3	1,959.4	2,184.4	2,389.0	2,646.0	2,940.8
New England	8,130.0	8,449.0	9,316.0	10,437.0	10,509.4	10,726.0	11,678.4	12,870.1	14,467.0	16,054.5	17,837.3	19,844.6
United States (in millions)	122.1	132.5	151.9	177.1	179.3	185.9	200.3	234.2	269.7	306.8	348.9	397.6

-1b. Millers River Basin Area Population as a Percent of New England Population

Percent of New England Population	1.07	1.03	0.98	0.89	0.89	0.88	0.84	0.79	0.75	0.72	0.71	0.71

TABLE A-1 (cont'd)

-1c. Average Annual Rates of Population Growth, Selected Periods

	1929-40	1940-50	1950-60	1960-70	1970-80	1980-2000	2000-2020
Millers River	0.1	0.5	0.3	0.4	0.4	0.6	1.0
Connecticut River WRPA	0.3	1.3	1.7	1.2	0.6	1.0	1.0
New England	0.4	1.0	1.2	1.1	1.0	1.1	1.1
United States	0.8	1.4	1.7	1.1	1.6	1.3	1.3

TABLE A-2

Personal Income, Franklin County, Connecticut River
Water Resource Planning Area, New England and the United States

-2a. Total Personal Income (in millions of 1958 constant dollars) and Per Capita Income

	1929	1940	1950	1959	1962	1970	1980	1990	2000	2010	2020
Franklin County	59.9	72.6	94.8	106.8	116.7	180.3	248.3	341.9	470.7	648.2	892.4
Per Capita	1,212	1,467	1,866	2,105	2,247	3,067	4,138	5,470	7,242	9,002	11,155
Relative to U.S.	0.95	1.13	1.03	0.99	1.00	1.01	1.01	1.02	1.01	0.95	0.90
Connecticut River	1,835.1	2,095.8	2,882.5	3,934.5	4,353.3	6,183.3	9,034.5	12,937.6	18,780.9	25,901.6	38,908.9
Per Capita	1,557	1,719	2,083	2,415	2,596	3,473	4,611	5,932	7,861	9,789	13,231
Relative to U.S.	1.22	1.33	1.15	1.13	1.15	1.14	1.12	1.11	1.10	1.03	1.07
New England	12,759.1	13,868.1	17,986.7	24,091.8	26,849.4	38,041.2	55,275.7	79,857.5	117,766.3	173,342.1	251,922.2
Per Capita	1,569	1,641	1,931	2,308	2,503	3,280	4,295	5,520	7,335	9,718	12,695
Relative to U.S.	1.23	1.26	1.07	1.08	1.11	1.08	1.04	1.03	1.02	1.03	1.02
United States (billions)	155.2	172.2	274.1	377.9	419.6	624.6	963.0	1,442.1	2,196.7	3,303.0	4,934.1
Per Capita	1,271	1,300	1,805	2,134	2,258	3,046	4,112	5,346	7,161	9,467	12,411

-2b. Franklin County's Personal Income as a Percent of Connecticut River Water Resource Planning Area and New England Personal Income

Percent of Connecticut River WRPA Income	3.27	3.46	3.29	2.72	2.68	2.92	2.75	2.64	2.51	2.50	2.29
Percent of New England Income	0.47	0.52	0.53	0.44	0.43	0.47	0.45	0.43	0.40	0.37	0.35

TABLE A-2 (cont'd)

-2c Average Annual Rates of Personal Income Growth, Selected Periods

	1929-62	1940-62	1950-62	1959-62	1970-2020	1980-2020	2000-2020
Franklin County	2.0	2.2	1.8	3.0	3.3	3.3	3.3
Connecticut River	2.7	3.4	3.5	3.4	3.7	3.7	3.7
New England	2.3	3.0	3.4	3.7	3.9	3.9	3.9
United States	3.0	4.1	3.6	3.6	4.2	4.1	4.1

TABLE A-3

Employment by Industry Divisions, Franklin County and the Lower Connecticut River Economic Area (OBE Economic Area 01005)

3a. Employment by Industry Divisions

Franklin County

	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agr., For., & Fish.	2,328	2,044	1,369	1,170	1,100	1,000	900	900	900
Mining	22	28	28	--	--	--	--	--	--
Contract Construction	803	1,221	1,226	1,422	1,500	1,600	1,700	1,900	2,100
Manufacturing	6,200	7,222	7,247	7,568	7,200	6,800	7,000	7,500	7,700
T.C.P.U.	1,426	1,677	1,459	1,422	1,300	1,200	1,000	1,000	900
Trade	2,348	3,207	3,168	3,532	3,700	3,900	4,200	4,600	5,000
F.I.R.E.	294	355	420	505	600	600	800	900	1,000
Services	3,734	3,570	4,774	5,962	7,000	7,800	8,700	10,100	11,500
Government	566	630	660	780	800	900	1,000	1,100	1,200
Military	0	12	28	--	--	--	--	--	--
Industry not reported	270	344	470	573	600	600	700	700	800
Total Employment	17,991	20,310	20,849	22,934	23,800	24,400	26,000	28,700	31,100
Participation Rate	.363	.385	.380	.39	.40	.39	.40	.40	.39

TABLE A-3 (Cont'd)

3a. Lower Connecticut River Economic Area

	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agr., For., & Fish	34,388	31,402	22,285	18,300	15,800	13,100	11,400	9,800	8,300
Mining	794	639	821	600	500	500	500	400	400
Contract Construction	32,523	46,496	54,418	66,400	77,600	87,700	100,200	113,100	125,500
Manufacturing	300,198	363,119	413,626	433,000	449,400	466,900	472,200	494,900	521,200
T.C.P.U.	36,933	48,498	50,653	53,200	55,800	57,900	57,700	58,000	59,000
Trade	110,640	145,083	163,609	188,200	215,700	241,500	269,700	299,400	332,500
F.I.R.E.	31,420	39,842	56,198	65,000	76,000	85,200	98,200	111,100	124,700
Services	129,627	141,959	195,221	270,700	352,600	426,500	530,400	634,300	743,500
Government	22,361	31,701	37,765	48,300	59,400	71,200	82,900	94,400	106,800
Military	1,578	11,185	21,357	17,500	16,900	16,900	16,900	16,900	16,900
Total Employment	700,462	859,924	1,015,953	1,161,300	1,319,700	1,467,400	1,640,100	1,832,500	2,038,800
Participation Rate	.39	.41	.40	.41	.42	.41	.42	.42	.41

3b. Percent Distribution of Employment by Industry Division
(United States Percentages are also included for Comparison)

	Franklin County								
	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agri., For., & Fish	12.9	10.1	6.6	5.1	4.6	4.0	3.5	3.2	3.0
Mining	--	--	--	--	--	--	--	--	--
Contract Construction	4.5	6.0	5.9	6.2	6.4	6.5	6.6	6.7	6.8
Manufacturing	34.5	35.6	34.8	33.0	30.2	28.1	27.2	26.2	24.6
T.C.P.U.	7.9	8.3	7.0	6.2	5.4	4.8	4.0	3.4	3.0
Trade	13.1	15.8	15.2	15.4	15.6	16.0	16.0	15.9	15.9
F.I.R.E.	1.6	1.8	2.0	2.2	2.4	2.6	2.9	3.2	3.2
Services	20.8	17.6	22.9	26.0	29.4	31.8	33.5	35.0	37.0
Government	3.1	3.1	3.2	3.4	3.5	3.7	3.8	3.9	4.0
Military	--	--	--	--	--	--	--	--	--
Industry not reported	1.5	1.7	2.3	2.5	2.5	2.5	2.5	2.5	2.5
Total Employment	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE A-3 (Cont'd)

Lower Connecticut River Economic Area

	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agr., For., & Fish.	4.9	3.7	2.2	1.6	1.2	0.9	0.7	0.5	0.4
Mining	--	--	--	--	--	--	--	--	--
Contract Construction	4.7	5.4	5.4	5.7	5.9	6.0	6.1	6.2	6.2
Manufacturing	42.9	42.2	40.7	37.3	34.1	31.8	28.8	27.0	25.6
T.C.P.U.	5.3	5.6	5.0	4.6	4.2	3.9	3.5	3.2	2.9
Trade	15.8	16.9	16.1	16.2	16.3	16.4	16.4	16.3	16.3
F.I.R.E.	4.5	4.6	5.5	5.6	5.8	5.8	6.0	6.1	6.1
Services	18.5	16.5	19.2	23.3	26.7	29.1	32.3	34.6	36.5
Government	3.2	3.7	3.7	4.2	4.5	4.9	5.1	5.2	5.2
Military	--	1.3	2.1	1.5	1.3	1.2	1.0	0.9	0.8
Total Employment	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
				United States					
Agr., For., & Fish.	19.1	12.5	6.7	4.7	3.5	2.6	2.0	1.6	1.2
Mining	2.1	1.6	1.0	0.8	0.6	0.5	0.5	0.4	0.4
Contract Construction	4.6	6.1	6.0	6.1	6.2	6.1	6.1	6.1	6.1
Manufacturing	23.7	25.8	27.5	26.5	25.2	24.1	23.1	22.2	21.6
T.C.P.U.	7.0	7.9	7.0	6.1	5.6	5.1	4.4	3.9	3.5
Trade	16.9	18.7	18.5	18.1	17.8	17.5	17.0	16.6	16.3
F.I.R.E.	3.3	3.4	4.3	4.5	4.7	4.8	4.9	5.1	5.1
Services	19.3	17.8	21.3	25.2	28.3	31.0	33.6	35.7	37.4
Government	3.3	4.4	5.0	5.6	6.2	6.6	6.9	7.1	7.3
Military	0.7	1.8	2.7	2.4	1.9	1.7	1.5	1.3	1.1
Total Employment	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE A-4

Economic Production per Employee (1958 Dollars)
Lower Connecticut River Economic Area (OBE Economic Area 005)

INDUSTRY	1960	1970	1980	1990	2000	2010	2020
Food	7,958	11,059	15,363	20,384	27,003	36,113	48,756
Textiles	5,514	8,265	11,833	16,626	23,592	33,350	47,174
Paper	8,048	10,853	13,789	17,259	21,734	27,225	34,487
Chemicals	10,760	17,815	27,823	42,676	69,652	99,419	134,884
Petroleum	7,877	20,927	42,601	82,160	155,544	280,485	503,065
Primary Metals	9,642	13,527	17,653	22,335	27,990	35,331	45,666

TABLE A-5

Total Population, Boston Metropolitan Area (Essex, Middlesex, Norfolk, Plymouth and Suffolk Counties), Narragansett Water Resources Planning Area (WRPA 01009) and New England

-5a. Population (in thousands)

	1929	1940	1950	1959	1960	1962	1970	1980	1990	2000	2010	2020
Boston Metropolitan Area	2,760.8	2,825.8	3,062.4	3,337.0	3,356.8	3,389.8	3,652.0	3,954.5	4,382.9	4,831.7	5,427.7	6,126.0
Narragansett Water Resources Planning Area	3,848.3	3,955.9	4,285.5	4,669.2	4,695.3	4,747.5	5,065.5	5,576.7	6,206.7	6,840.4	7,580.6	8,432.1
New England	8,130.0	8,449.0	9,316.0	10,437.0	10,509.4	10,726.0	11,678.4	12,870.1	14,467.0	16,054.5	17,837.3	19,844.6

-5b. Boston Metropolitan Area's Population as a Percent of Narragansett Water Resource Planning Area and New England Population

Percent of Narragansett WRPA Population	71.7	71.4	71.5	71.5	71.5	71.4	72.1	70.9	70.6	70.6	71.6	72.7
Percent of New England Population	34.0	33.4	32.9	32.0	31.9	31.6	31.3	30.7	30.3	30.1	30.4	30.9

TABLE A-5 (cont'd)

-5c. Average Annual Rates of Population Growth, Selected Periods

	1929-40	1940-50	1950-60	1960-70	1970-80	1980-2000	2000-2020
Boston Metropolitan Area	0.2	0.8	0.9	0.9	0.8	1.0	1.2
New England	0.4	1.0	1.2	1.1	1.0	1.1	1.1
United States	0.8	1.4	1.7	1.1	1.6	1.3	1.3

TABLE A-6

Personal Income, Boston Metropolitan Area
(Essex, Middlesex, Norfolk, Plymouth and Suffolk Counties),
Narragansett Water Resource Planning Area (WRPA 01009),
New England and the United States

6a. Total Personal Income (in millions of 1958 constant dollars) and Per Capita Income

	1929	1940	1950	1959	1962	1970	1980	1990	2000	2010	2020
Boston Metropolitan Area	4,790.0	5,283.5	6,287.3	8,201.3	9,065.5	12,671.2	18,309.9	26,457.5	38,229.0	55,246.4	79,841.2
Per Capita	1,735	1,869	2,053	2,461	2,678	3,470	4,630	6,037	7,912	10,179	13,033
Relative to U.S.	1.37	1.44	1.14	1.15	1.19	1.14	1.13	1.13	1.10	1.08	1.05
Narragansett WRPA	6,558.9	6,876.8	8,466.5	10,969.1	12,166.7	17,010.5	25,125.9	36,162.1	53,342.7	77,484.8	112,168.1
Per Capita	1,704	1,738	1,976	2,349	2,563	3,358	4,506	5,826	7,798	10,221	13,303
Relative to U.S.	1.34	1.34	1.09	1.10	1.14	1.10	1.10	1.09	1.09	1.08	1.07
New England	12,759.1	13,868.1	17,986.7	24,091.8	26,849.4	38,041.2	55,275.7	79,857.5	117,766.3	173,342.1	251,922.2
Per Capita	1,569	1,641	1,931	2,308	2,503	3,280	4,295	5,520	7,335	9,718	12,695
Relative to U.S.	1.23	1.26	1.07	1.08	1.11	1.08	1.04	1.03	1.02	1.03	1.02
United States (in billions)	155.2	172.2	274.1	377.9	419.6	624.6	963.0	1,442.1	2,196.7	3,303.0	4,934.1
Per Capita	1,271	1,300	1.805	2,134	2,258	3,046	4,112	5,346	7,161	9,467	12,411

TABLE A-6 (Cont'd)

6b. Boston Metropolitan Areas' Income as a Percent of Narragansett WRPA and New England Personal Income

	1929	1940	1950	1959	1962	1970	1980	1990	2000	2010	2020
Percent of Narragansett WRPA Personal Income	73.0	76.8	74.3	74.8	74.5	74.5	72.9	73.2	71.7	71.3	71.2
Percent of New England Income	37.5	38.1	35.0	34.0	33.8	33.3	33.1	33.1	32.5	31.9	31.7

6c. Average Annual Rates of Personal Income Growth, Selected Periods

	1929-62	1940-62	1950-62	1959-62	1970-2020	1980-2020	2000-2020
Boston Metropolitan Area	1.9	2.5	3.1	3.4	3.8	3.8	3.8
Narragansett WRPA	1.9	2.6	3.1	3.5	3.8	3.8	3.8
New England	2.3	3.0	3.4	3.7	3.9	3.9	3.9
United States	3.0	4.1	3.6	3.6	4.2	4.1	4.1

TABLE A-7

Employment by Industry Division, Boston Metropolitan Area (Essex, Middlesex, Norfolk, Plymouth & Suffolk Counties) and the Boston Economic Area (OBE Economic Area 01004)

7a. Employment by Industry Divisions

Boston Economic Area

	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agr., For., & Fish.	19,518	18,355	12,491	7,304	6,500	5,400	4,000	2,200	2,500
Mining	926	1,034	897	--	--	--	--	--	--
Contract Construction	46,993	68,118	67,099	75,962	87,600	98,800	110,900	124,600	140,700
Manufacturing	314,185	381,207	414,356	423,634	421,600	420,500	416,000	445,100	502,300
T.C.P.U.	72,994	93,631	82,659	87,648	87,600	93,400	93,100	93,500	87,900
Trade	204,161	246,159	236,436	255,641	280,500	307,300	336,800	369,400	401,900
F.I.R.E.	48,874	60,110	72,157	81,805	94,000	104,200	116,900	133,500	150,700
Services	220,968	234,634	289,174	376,888	470,200	575,000	689,400	814,500	954,400
Government	45,239	65,129	69,737	84,727	102,100	116,800	132,700	153,500	175,800
Military	3,114	13,533	25,626	23,373	22,700	21,600	21,800	22,300	20,100
Industry not reported	17,714	13,908	68,846	43,824	48,600	53,900	59,400	66,800	75,300
Total Employment	994,686	1,195,818	1,339,478	1,460,806	1,621,400	1,796,900	1,981,000	2,225,400	2,511,600
Participation Rate	.352	.390	.399	.400	.410	.410	.410	.410	.410

Boston Economic Area
(OBE Economic Area 01004)

	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agr., For., & Fish.	47,086	43,605	29,503	24,800	21,500	18,900	16,800	14,800	12,700
Mining	1,538	1,491	1,370	1,000	800	800	700	600	600
Contract Construction	80,144	114,489	118,847	141,400	160,400	178,200	199,800	221,700	245,700
Manufacturing	651,787	764,861	823,329	828,400	860,900	891,600	929,100	974,000	1,027,000
T.C.P.U.	108,435	140,336	130,290	134,300	140,200	144,700	143,400	143,400	145,100
Trade	318,968	388,895	395,048	435,500	486,900	534,000	585,300	639,400	698,700
F.I.R.E	66,645	83,326	107,593	123,300	142,700	159,700	183,600	297,300	232,100
Services	346,841	366,301	470,281	642,200	823,500	983,300	1,211,900	1.438,400	1,673,400
Government	67,563	100,053	116,078	145,600	175,800	207,000	241,600	273,800	307,700
Military	8,122	35,701	66,416	54,400	52,400	52,400	52,400	52,400	52,400
Total Employment	1,697,129	2,039,058	2,258,755	2,530,900	2,865,200	3,170,500	3,564,600	3,965,800	4,395,500
Participation Rate	.357	.394	.398	.400	.410	.410	.410	.410	.410

TABLE A-7 (Cont'd)

7b. Percent Distribution of Employment by Industry Division
(United States Percentages are included in Table 3b for Comparison)

Boston Metropolitan Area

	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agr., For., & Fish.	2.0	1.5	0.9	0.5	0.4	0.3	0.2	0.1	0.1
Mining	--	--	--	--	--	--	--	--	--
Contract Construction	4.7	5.7	5.0	5.2	5.4	5.5	5.6	5.6	5.6
Manufacturing	31.6	31.9	30.9	29.0	26.0	23.4	21.0	20.0	20.0
T.C.P.U.	7.3	7.8	6.2	6.0	5.4	5.2	4.7	4.2	3.5
Trade	20.5	20.6	17.7	17.5	17.3	17.1	17.0	16.6	16.0
F.I.R.E.	4.9	5.0	5.4	5.6	5.8	5.8	5.9	6.0	6.0
Services	22.2	19.6	21.6	25.8	29.0	32.0	34.8	36.6	38.0
Government	4.6	5.5	5.2	5.8	6.3	6.5	6.7	6.9	7.0
Military	0.3	1.1	1.9	1.6	1.4	1.2	1.1	1.0	0.8
Industry Not Reported	1.8	1.2	5.1	3.0	3.0	3.0	3.0	3.0	3.0
Total Employment	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Boston Economic Area

	1940	1950	1960	1970	1980	1990	2000	2010	2020
Agr., For., & Fish.	2.8	2.1	1.3	1.0	0.8	0.6	0.5	0.4	0.3
Mining	0.1	0.1	0.1	--	--	--	--	--	--
Contract Construction	4.7	5.6	5.3	5.6	5.6	5.6	5.6	5.6	5.6
Manufacturing	38.4	37.5	36.4	32.7	30.1	28.1	26.1	24.6	23.3
T.C.P.U.	6.4	6.9	5.8	5.3	4.9	4.6	4.0	3.6	3.3
Trade	18.8	19.1	17.5	17.2	17.0	16.9	16.4	16.1	15.9
F.I.R.E.	3.9	4.1	4.8	4.9	5.0	5.0	5.1	5.2	5.3
Services	20.4	18.0	20.8	25.4	28.7	31.0	34.0	36.3	38.1
Government	4.0	4.9	5.1	5.8	6.1	6.5	6.8	6.9	7.0
Military	0.5	1.7	2.9	2.1	1.8	1.7	1.5	1.3	1.2
Total Employment	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE A-8

Economic Production Per Employee (1958 Dollars)
Boston Economic Area (OBE Economic Area 004)

INDUSTRY	1960	1970	1980	1990	2000	2010	2020
Food	6,952	10,053	14,357	19,378	25,997	35,107	47,750
Textiles	4,602	7,353	10,921	15,714	22,680	32,438	46,262
Paper	7,365	10,170	13,106	16,576	21,051	26,542	33,804
Chemicals	9,232	16,287	26,295	41,148	68,124	97,891	133,356
Petroleum	7,573	20,623	42,297	81,856	155,240	280,181	502,761
Primary Metals	9,322	13,207	17,333	22,015	27,670	35,011	45,346

TABLE A-9

Population, Millers River Economic Area and Subregions (defined by Town boundaries)
Selected Years

9a. Population

	1940	1950	1960	1970	1980	2000	2020
Lower Basin	30,563	33,227	33,951	35,769	36,870	40,730	49,700
Middle Basin	19,791	20,559	20,999	20,784	21,050	22,380	26,800
Upper Basin	36,785	37,428	38,643	41,010	44,060	51,790	64,780
TOTAL	87,139	91,214	93,593	97,563	101,980	114,900	141,280

9b. Population Density, Persons per Square Mile

Lower Basin	170	185	189	199	205	266	276
Middle Basin	73	75	77	76	77	82	98
Upper Basin	174	177	183	194	209	245	307
TOTAL	131	137	141	147	154	173	213

9c. Subregion Population as Percent of Total

Lower Basin	35.1	36.4	36.3	36.7	36.2	35.4	35.2
Middle Basin	22.7	22.5	22.4	21.3	20.6	19.5	19.0
Upper Basin	42.2	41.1	41.3	42.0	43.2	45.1	45.8
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE A-9 (Cont'd)

9d. Average Annual Rates of Population Growth, Selected Periods

	1940-70	1950-70	1960-70	1970-80	1980-2000	2000-2020
Lower Basin	0.5	0.4	0.5	0.3	0.5	1.0
Middle Basin	0.2	0.1	Neg	0.1	0.3	0.9
Upper Basin	0.4	0.2	0.6	0.7	0.8	1.1
TOTAL	0.4	0.3	0.4	0.4	0.6	1.0

TABLE A-10

Employment by Industry Division in the Millers River Economic Area and its Subregions, 1963

10a. Employment by Industry Division

	Lower Basin	Middle Basin	Upper Basin	TOTAL
Agriculture & Mining	51	8	--	59
Construction	340	74	346	760
Manufacturing	4,788	4,009	7,064	15,861
Trans., Comm., & Public Utilities	532	115	287	934
Trade	2,265	847	1,669	4,781
Fin., Ins., & Real Estate	283	135	205	623
Services	856	343	617	1,816
Total Employment	9,115	5,531	10,188	24,834

10b. Percent Distribution of Employment by Industry Divisions

Agriculture & Mining	0.6	0.1	--	0.2
Construction	3.7	1.3	3.4	3.1
Manufacturing	52.5	72.5	69.3	63.8
Trans., Comm., & Public Utilities	5.8	2.1	2.8	3.8
Trade	24.8	15.3	16.4	19.3
Fin., Ins., & Real Estate	3.1	2.4	2.0	2.5
Services	9.4	6.2	6.1	7.3
Total	100.0	100.0	100.0	100.0

APPENDIX B

FUTURE POPULATION AND WATER DEMAND STUDIES

The purpose of this appendix is to show the development of the future water requirements for the potential service areas. Included is the disaggregation of projected population data to the community level, development of per capita usage curves, and estimates of future industrial water needs. Utilizing this data, together with estimates of potential safe yield of each community, a study was made to determine what cities and towns might join an expanded Quabbin - Wachusett system. Demands were then forecast for the various service areas. In the main report, these demands were used to determine the deficit and how the water made available by implementation of the project would affect this deficit.

APPENDIX B

FUTURE POPULATION AND WATER DEMAND STUDIES

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APPENDIX B

FUTURE POPULATION AND WATER DEMAND STUDIES

1. Population Studies

A. General

As described in the previous appendix, regional population and economic projections for Water Resource Planning Areas throughout the country recently have been prepared by the Office of Business Economics, U. S. Department of Commerce for the year 1980, 2000, and 2020. These projections have been prescribed for use by the Corps of Engineers in its planning.

Under contract to the North Atlantic Division for the Northeastern United States Water Supply Study, the Regional Planning Associates disaggregated these Water Resource Planning Area population projections to county level for dispersed, concentrated and most likely distribution patterns. The most likely projections are shown graphically on Plate No. B-1. These county level projections were then furnished to the New England Division by the North Atlantic Division for use in this report and it is to these totals that all sub-county projections are controlled.

The most likely projections were used in this report to estimate water requirements for planning purposes and it is to these water needs that the alternative solutions are keyed. The dispersed and concentrated projections were used to formulate a band of future needs, to illustrate the effect which future growth following these patterns would exhibit upon the various alternative schemes.

B. County Disaggregation

During the preparation of this report, it soon became evident that a more detailed breakdown than afforded by county level was required in most areas. Thus, a further disaggregation of the furnished county figures to the community level was accomplished for those areas deemed necessary.

Recognizing the large amount of work which has been accomplished by various local planning agencies, it was decided that the county disaggregation should reflect the population trends within county as indicated by the local projections, with the furnished most likely county totals acting as controls.

In general, the method used in disaggregating the county totals to community levels consisted of aggregating community projections provided by local agencies and comparing these to the controlling county totals. The community totals were then adjusted so as to reflect the county control figure. By use of this method, the continuity of population trends in the various sectors as expressed by the local group's projections was maintained.

Since most local planning agencies population projections were estimated only through the year 1990, the direct ratio method was utilized to estimate populations for 2000. Use of this community delineation for the year 2020, however, was not used because of the many uncertainties in projections of that time length over such a small area. Thus, for this study, county totals only were used at the 2020 target date. The projections used in this study, on a county level, are given in Table B-1.

2. Future Water Demands

A. General

The approach used to estimate the future water demands on the Quabbin-Wachusett-Sudbury Reservoir system consisted of determining what cities and towns would probably be required to join this system by 1990. In addition to these municipalities, an investigation was also made of communities which have as a feasible alternative connection to the supply system.

The future water demands of these two groups and the existing MDC communities were then estimated by two different methods to provide a range of probable supply needs. The first method computed the water demands from population by determining a per capita usage for domestic, commercial, and minor industrial users while the requirement for heavy water using industry was determined from projected industrial output.

The second method estimates the future water demands based on the Water Resources Council (WRC) per capita usage increase as described in its First National Assessment on the Nation's Water Resources.

B. Methodology

1) Population Based Water Demand (NEWS)

The large coverage of the study area for this report precluded a community level analysis of future per capita demands. Thus, the approach used in this report was the development of a "study area" per capita consumption curve.

The method used to develop this curve consisted of selecting a representative grouping of 26 communities in which industrial water use was not a significant factor. These communities' consumption patterns were then studied for the period 1950-1965, this period being considered as a most likely trend upon which future usage might follow (i.e. no wars or depression). The average increase experienced during this period was calculated to be some 1.3 gallons per capita per year. Using these communities' historical trends, a curve reflecting increasing per capita future demands at a decreasing rate was then drawn.

The curve thus developed was next compared to a number of independent estimates prepared by consulting engineering firms for other water supply studies in the New England area. These studies covered most of the communities: in the Eastern Massachusetts region, in the Springfield-Chicopee-Holyoke Metropolitan area, in the Hartford, Connecticut area and the entire State of Rhode Island. The NEWS curve developed for this report was found to compare quite favorably with these independent engineering estimates.

The resulting curve, shown on Plate No. B-2, thus is felt to represent the expected per capita increase which will prevail within the study area for domestic, commercial, and minor industrial demands. In utilizing the per capita consumption curve the actual per capita usage minus water supplied to major industries was determined for the base year 1965. The increased per capita demand through 1990 as defined by the curve was then added to the base year per capita

consumption. The service population was then multiplied by its respective per capita consumption value and a total water use for this component derived.

2) Industrial Water Demands (NEWS)

Information pertaining to industrial water demands both present and future within the study area was found to be quite limited on a detailed basis. It was ascertained that although various consulting engineering firms had conducted surveys for their respective clients, no wide range canvas of the study area's industrial water needs had been performed. As a result of this data gap, most of the data and estimates presented in this section was obtained and developed by the NEWS group.

The first step in development of the industrial water need estimates was the physical location of major water using industries within the study area. The four-digit industrial groupings suggested in the Cornell University Report, "Industrial Water Use Estimates, North Atlantic Region", as major water users were adopted. The location and size of these selected industrial groups were then obtained from the 1968 Massachusetts State Industrial Directory.

Once the actual location of the plants had been established, a telephone survey was conducted of those municipalities which appeared to have significant industrial concentrations and apparent high per capita consumption levels. The yield from this survey thus enabled the study to locate and quantify the industrial use from public water supply systems within the study area.

The study team next approached the problem of preparing estimates of future industrial water requirements. Two approaches were initially suggested; namely, relating future needs to employment populations and/or to production (output) projections. After study it was felt that output projections provided a more direct correlation to future water needs than did use of employment, thus the estimates prepared in this report relate future industrial water demand to industrial output.

Economic output projections prepared for the North Atlantic Regional Study currently underway by the Corps of Engineers were adopted

for use in this study. These projections estimate output for six two-digit major water using industries; namely, Standard Industrial Classification (SIC), 20 Food and Kindred Products, 22 Textile Mill Products, 26 Paper and Allied Products, and 28 Chemicals and Allied Products, 29 Petroleum and Coal Products, and 33 Primary Metal Industries. Since SIC 29 is not recorded as a major water using industry within the study area, the remaining five groupings furnished the basis for the estimates presented in this report. These 5 SIC categories constituted some 63 percent of total fresh water use in 1967 within Massachusetts and for purposes of the report were considered to represent major water using industries. Other industries future requirements were considered minor and their needs are considered included in the curve developed for the population based water demand.

Utilizing the forementioned North Atlantic Regional Study output projections, factors were derived relating projected economic activity for 1990 as a function of the recorded 1960 output values. These factors were then combined with "hard data" on water use for product value for each of the five selected SIC groups from the 1963 Census of Manufacturers, U. S. Department of Commerce, to develop estimates of future industrial usage. The estimates thus obtained corresponds to the industrial water demand which could be expected if the 1964 water use per dollar output were to continue into the future (i. e. if no technological changes were made in production or use techniques).

A disaggregation of these SIC totals to County level was then made, based on the assumption that future industry will choose to locate in the future as they have located in 1968, utilizing the data contained in the Massachusetts Industrial Directory.

Since many apparent pressures are being exerted upon industry; such as, increasing public water costs and pollution abatement programs, a move to reducing water use by these industries by economical technology seems in order. In this report, reuse data developed by Cornell University in their study Industrial Water Use Estimates, North Atlantic Region were adopted. These technological change rates were developed by Cornell by considering the changes in water reuse which occurred during the period 1954 to 1964 as

published in the Census of Manufacturers, Water Use in Manufacturing Reports. These historically recorded use rates were then assumed to continue in the future (i.e., basically an exponential curve). The use change rates thus developed were applied to the industrial water use estimates described in the preceding paragraphs. The result of this application thus represents estimates of future industrial water requirements with the effect of the estimated technological changes.

It is recognized that use of historic trends as a basis for future technological activity is open to debate. The Cornell group itself has expressed reservations on the application of these reuse rates to small geographic areas; however, there is little other available data on this subject.

Once the water use efficiency factors had been prepared the next question which arose was that of separating public from privately supplied industrial needs. For purposes of this report, it has been assumed that future industrial demands will be drawn from public and private sources in the same proportion as indicated in the 1963 Census of Water Using Manufacturers. There is little evidence to dispute this assumption one way or the other. However, it appears reasonable to assume that a privately supplied industry would implement all available economical technology to its processes before it connected to the public system. If then this was the case, the effect of privately supplied industries joining the public system is small with a maximum departure of some 20 percent from estimated county (1) total water requirements in 2020 for the worse case. Based on these calculations it appears that the assumption to continue the present privately-publicly supplied proportion into the future is a reasonable approach.

Because of the major assumption regarding technological advantages in industrial water usage which this study was obliged to make in estimating future demands, a testing of the significance of these water demand values upon total water requirements was made. These "sensitivity tests" indicate the magnitude of change in the estimates of publicly supplied water would be insignificant if the future industrial consumption values followed trends other than that presented in this report.

3) Water Resource Council Projections

The second method of forecasting future demands utilizes the information contained in "The First National Assessment of the Nation's Water Resources" which was prepared by the Water Resources Council in 1968.

In this report, Table 3-1-2 gives the population for 1960 and projects the population for the years 1980, 2000, and 2020 for the North Atlantic Region. Table 4-1-4 lists projections of municipal water requirements for the years 1965, 1980, 2000, and 2020 for the North Atlantic Region. Using these tables, the curve shown on Plate No. B-2 was developed for the GPCD use of public water supplies through 2020. The curve shows a 10.4 GPCD increase from the 1965 consumption rate to 1990. This increase was then added to the 1965 consumption rate for each sub-county sector multiplying this derived 1990 consumption rate by its associated population yields the total estimated water demands for 1990.

C. Future Water Requirements

1) Average Daily Demands

A community by community study was made to determine what cities and towns might join the expanded Quabbin-Wachusett system. Review of engineering reports as well as personal interviews with State and regional officials were made. A number of key communities were also contacted to determine their needs, problems, and possible solutions. The communities were then placed in one of four categories; those who are presently being serviced by the MDC; those communities whose only reported feasible alternative is to join the Quabbin-Wachusett system; communities who have as one of their feasible alternatives connection to the Quabbin-Wachusett system and those who either can meet their 1990 demands from local sources or appear beyond the apparent economic boundary, which can be reasonably serviced by the Quabbin-Wachusett system. The cities and towns in each group are shown on Plate No. B-3.

In estimating the potential which the municipalities might impose on the Quabbin-Wachusett system, the safe yield of each community

was taken as the 1965 reported safe yield plus the resource potential reported upon in community and regional planning studies. The estimated demand to be met from the regional system thus would be the total community demand minus the existing and reported potential community safe yield.

Instead of computing each community's 1990 water demand individually, they were grouped together along sub-county or county lines. Using a ratio of populations, the water demands of the service communities within the given sub-county sectors were determined. The individual city or town's population used were estimated by local planning agencies but adjusted to agree with the OBE projected county population as described in the preceding section on population. The demands of each group are, thus, estimates of the 1990 water demand on the Quabbin-Wachusett system for the three groups of communities which may be served by the Quabbin-Wachusett Reservoir system. As described earlier two methods were employed in preparing the estimate. The first method used both per capita increases and industrial water use while the second method only used forecast per capita increased as prepared by the Water Resources Council.

The forecast demands estimated by using the first method (NEWS) yielded a 1990 water demand of about 410 mgd for the presently serviced communities. If the municipalities reported as having no other option were served the total demand on the system could be about 441 mgd. Communities in this category include the eastern third of Norfold County and the southwestern quarter of Middlesex County.

If those municipalities who have other options desired to and were granted entrance to the system, the estimated 1990 demand would be about 519 mgd. If all these communities were served, than the Quabbin-Wachusett system would be supplying water to all or a major portion of Middlesex, Suffolk, and Norfold Counties; the southern half of Essex County; the northern third of Plymouth County; the central portion of Worcester County and the eastern half of Hampshire County.

Utilizing the second methodology (WRC), estimates based on per capita usage increases, yields a 1990 demand of 310 mgd for the

existing system; 320 mgd including those municipalities with no reported other supply options and 360 mgd if all communities listed as possible applicants were to be serviced. Use of the two methods of forecasting provides a rather large range of possible demands on the Quabbin-Wachusett system.

The demand estimates derived by use of the Water Resources Council estimates of per capita increases appear to be lower than might be expected within the study area based on historical evidence. Utilizing the Water Resources Council estimates the forecast demand for the existing MDC system in 1990 is 310 mgd. In 1971, the actual experienced demand on the system was about 322 mgd. Based on this actual observed demand on the system, it does not appear that use of the Water Resource Council estimates portray the future supply quantities which may be needed within this report study area. Therefore, demands estimated by the first method (NEWS) using both per capita increases and industrial water demand, was used to develop the future needs for the project.

3. Peak Loading Criteria

A. General

Variations in water demands due to seasonal weather changes have always been important considerations in the design of water supply systems in the northeastern United States and particularly in New England. Historically, summer drought periods have promoted exceptionally high water demands which quite often last for several weeks. In most cases these peak demands must be met by the water supply system since storage within the distribution system itself cannot usually be economically constructed to handle these peak loads.

B. Maximum Day Considerations on the Expanded Quabbin-Wachusett System

The ratio of the maximum day demand to the average daily demand is directly related to the type and character of the development within the community or communities to be served. Communities with a large amount of commercial and industrial development and/or with high population densities have considerably lower maximum

day ratios than do suburban residential communities. This can be attributed to the use of large quantities of water by the suburban communities during summer periods for the filling of swimming pools, lawn and shrub watering and similar seasonal activities.

The MDC system, as it now exists, services 32 member communities within the greater Boston area. Twenty-five of the communities depend wholly upon the system to supply their water needs while the remaining seven communities make maximum use of their own sources and only rely upon the MDC system to supply their peak demands. The 25 wholly supplied communities range from completely residential in character to those with industrial and commercial development. During the recent drought of the 60's, the ratio of the maximum day demand to the average daily demand for the city of Boston reached a high of 1.24, while the ratio for the total 25 communities reached 1.65. This difference has been attributed to the effect of the suburban communities peak demands upon the system. If the regional system continues to expand its service area to meet the future demands of the Metropolitan Boston area, it will be adding suburban communities which are largely residential in nature. Thus, the maximum daily demand ratio can be expected to increase above the present high figure of 1.65. The amount of increase will, of course, depend on what portion of the total water demand upon the system the new members demand represents.

A total of 12 communities which may join the MDC system by the year 1990 and for which peak loading information was available were analyzed. The communities consist of:

Avon	Natick
Braintree	Randolph-Holbrook
Dedham	Stoughton
Lincoln	Weymouth
Medfield	Wellesley
	Woburn

The peak maximum day ratio for the 25 wholly served MDC members was, as previously stated, 1.65. The peak ratio for the total 32 member communities was synthetized by pro-rating the peak maximum day ratio of the 7 partially served communities based on the ratio

of their estimated 1990 average daily demand on the MDC system to the estimated 1990 average daily demand of the wholly supplied communities. This computation yielded a peak maximum day ratio for all member communities of 1.67. Using this as a base figure and the assumption that the peak maximum day demands of the individual comminities would not increase significantly by 1990, the peak maximum day ratio for the member communities and the 12 communities listed above was synthesized, as before, and resulted in a peak ratio of 1.70. Since maximum day information was available on nine other eastern Massachusetts communities who probably will not join the MDC system but who have the same characteristics as the remaining 13 communities who have no other option but to join the MDC system; these nine communities were pro-rated in the same manner as before to the existing and twelve possible MDC members resulting in a ratio of 1.71. Therefore, for purposes of this study, a maximum day ratio of 1.70 was adopted as the maximum day loading criteria.

A comparison of this figure to other available historic and projected maximum day data for large systems in the Northeastern United States was also conducted. A review of this comparison is given in the following paragraphs:

1. Metcalf and Eddy-Hazen and Sawyer in the feasibility report on Alternative Regional Water Supply Plans for Northern New Jersey-New York City - Western Connecticut Metropolitan Area for the NEWS Study suggested a maximum day to average day ratio of 1.5 for New York City and major municipalities in New Jersey and 2.0 for suburban communities.

2. Metcalf and Eddy-Hazen and Sawyer in the Comprehensive Public Water Supply Study for the city of New York and County of Winchester indicate that the peak maximum day demand from 1955 to 1965 was 1.42 and that for 12 of the 22 supply systems in Westchester County the maximum day ratio varied from 1.37 to 2.72 and the weighted average of maximum day of these communities was 1.68.

3. Hazen and Sawyer in a report to the Regional Planning Council, Baltimore, Maryland on a plan of Regional Water Supply to the year 2020 indicated that the maximum day ratio varied from

1.25 to 1.41 in Baltimore from 1961 to 1967 and estimated an increase to 1.68 by the year 2020.

4. In an article in Water and Wastes Engineering by D. M. Watt and Norman. E. Jackson (June 1970) entitled "Washington's Water Supply" the ratio of the Maximum day to the average day for the District of Columbia was estimated to be 1.82 by the year 2010.

5. A cooperative State-Federal Report on Municipal facilities communities of 25,000 population and over, United States and Possessions as of January 1, 1964 shows maximum day to average day ratios for eight major systems in the northeast varying from 1.19 to 1.64.

TABLE B-1

HISTORIC AND PROJECTED COUNTY POPULATIONS

COUNTY		1960[1]	1970[1]	1980	1990[2]	2000	2010[2]	2000
	Concentrated			590.4	666.4	742.4	854.6	966.9
Essex	Most Likely	568.8	631.0	660.7	725.2	790.0	895.0	1,000.0
	Dispersed			707.6	805.0	902.4	1,045.5	1,188.6
	Concentrated			1,185.3	1,344.2	1,503.2	1,731.0	1,958.8
Middlesex	Most Likely	1,238.1	1,388.1	1,379.2	1,564.6	1,750.0	1,883.0	2,016.0
	Dispersed			1,530.4	1,747.5	1,964.6	2,276.7	2,588.8
	Concentrated			815.4	832.4	849.3	874.6	900.0
Suffolk	Most Likely	791.3	721.2	748.7	739.4	730.0	720.0	710.0
	Dispersed			684.9	657.2	619.4	575.4	531.3
	Concentrated			885.3	999.2	1,113.2	1,281.5	1,449.8
Norfolk	Most Likely	510.2	605.4	728.7	810.2	911.7	1,205.8	1,500.0
	Dispersed			634.6	717.0	809.3	937.6	1,066.0
	Concentrated			531.4	599.8	668.2	774.2	870.3
Plymouth	Most Likely	248.4	328.9	437.2	543.5	650.0	775.0	900.0
	Dispersed			309.0	351.5	394.0	456.5	519.0

(1) Federal Census (2) Interpolated Value

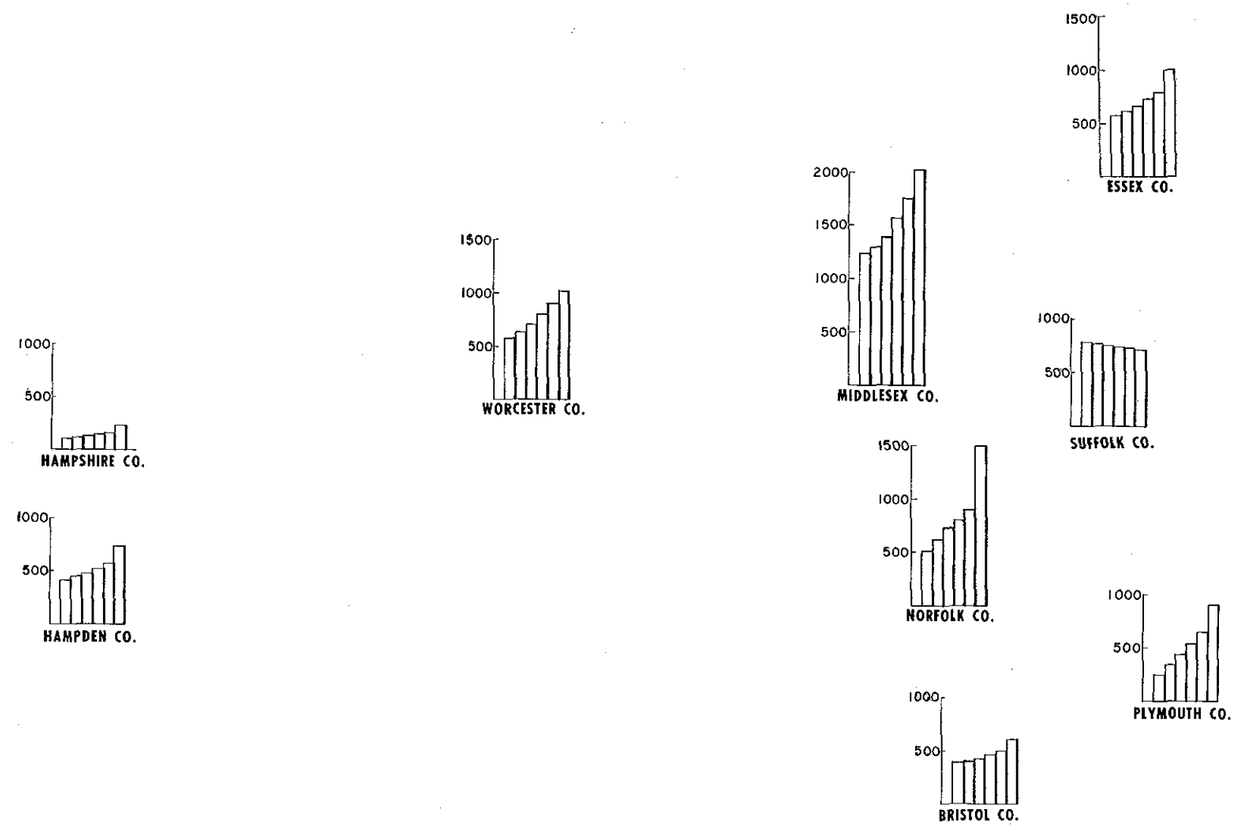
TABLE B-1 (cont'd)

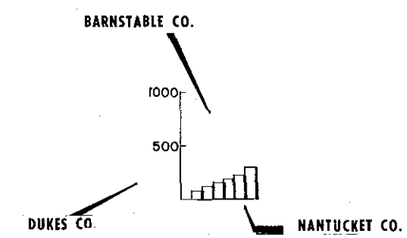
HISTORIC AND PROJECTED COUNTY POPULATIONS

COUNTY		1960(1)	1970(1)	1980	1990(2)	2000	2010(2)	2000
	Concentrated			354.2	399.8	445.4	512.8	580.2
Bristol	Most Likely	398.5	441.1	417.6	543.8	490.0	545.0	600.0
	Dispersed			495.5	563.8	632.0	732.4	832.4
	Concentrated			700.0	800.0	900.0	959.2	1,018.5
Worcester	Most Likely	583.2	633.8	700.0	800.0	900.0	959.2	1,018.5
	Dispersed			700.0	800.0	900.0	959.2	1,018.5
	Concentrated			52.6	56.6	60.6	67.0	73.3
Franklin	Most Likely	54.8	58.9	60.0	62.5	65.0	72.5	80.0
	Dispersed			65.4	71.0	76.6	88.2	99.8
	Concentrated			151.3	162.8	174.3	192.6	210.9
Hampshire	Most Likely	103.2	122.6	125.0	140.0	155.0	192.5	230.0
	Dispersed			122.9	133.5	144.1	165.9	187.7
	Concentrated			493.6	545.9	598.2	690.1	782.0
Hampden	Most Likely	425.3	453.5	480.0	530.0	580.0	640.0	740.0
	Dispersed			468.4	515.1	561.8	630.4	699.1
	Concentrated			5,759.5	6,407.1	7,054.8	7,937.6	8,810.7
Totals	Most Likely	4,921.8	5,384.5	5,737.1	6,459.2	7,021.7	7,888.0	8,794.5
	Dispersed			5,718.7	6,361.6	7,004.2	7,867.8	8,731.0

(1) Federal Census (2) Interpolated Value

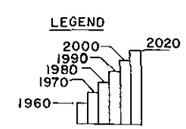
CORPS OF ENGINEERS U. S. ARMY





NOTE:

FRANKLIN COUNTY LESS THAN 100,000 PEOPLE THROUGH 2020

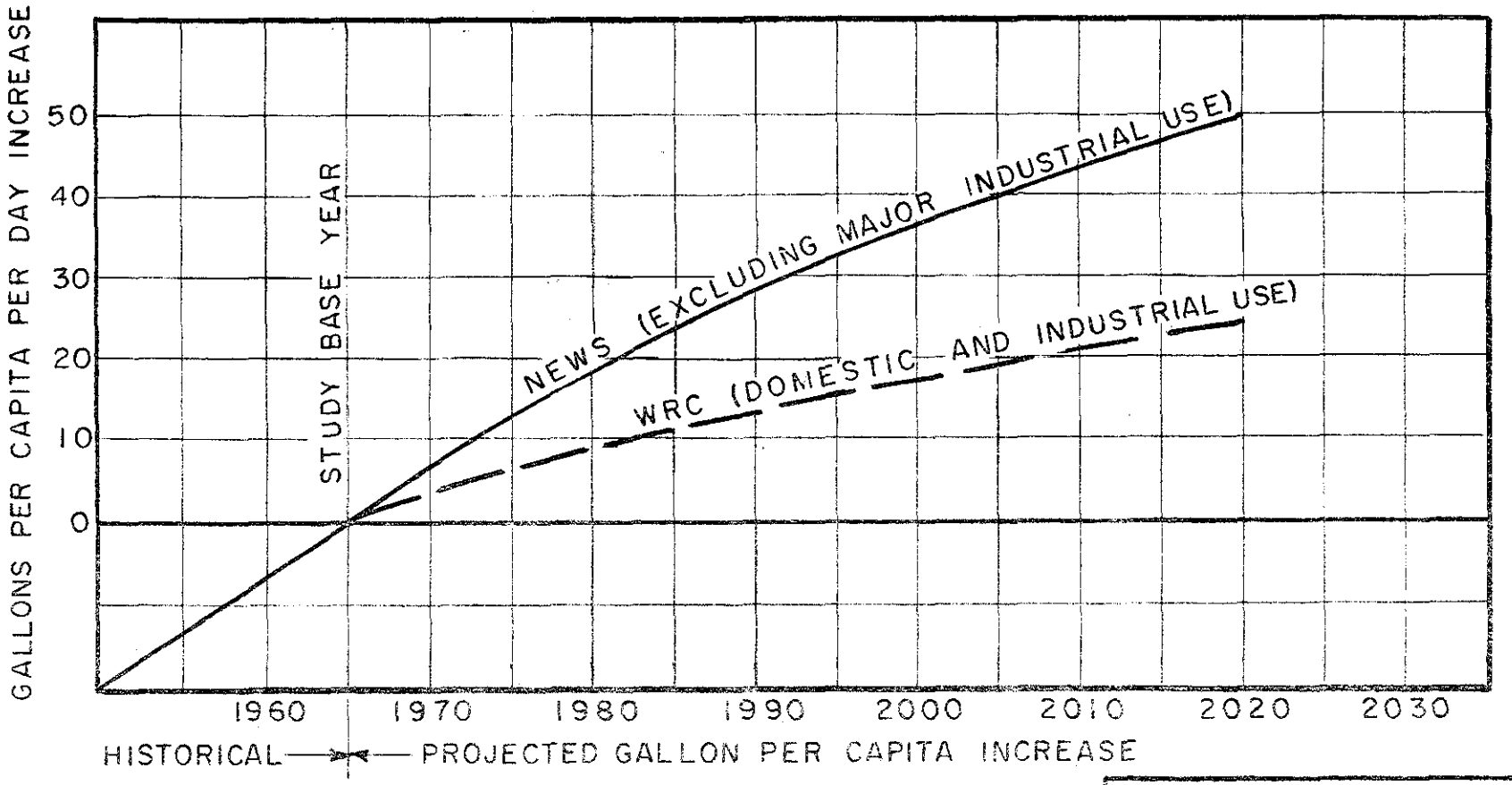


NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

FUTURE COUNTY POPULATION TRENDS

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

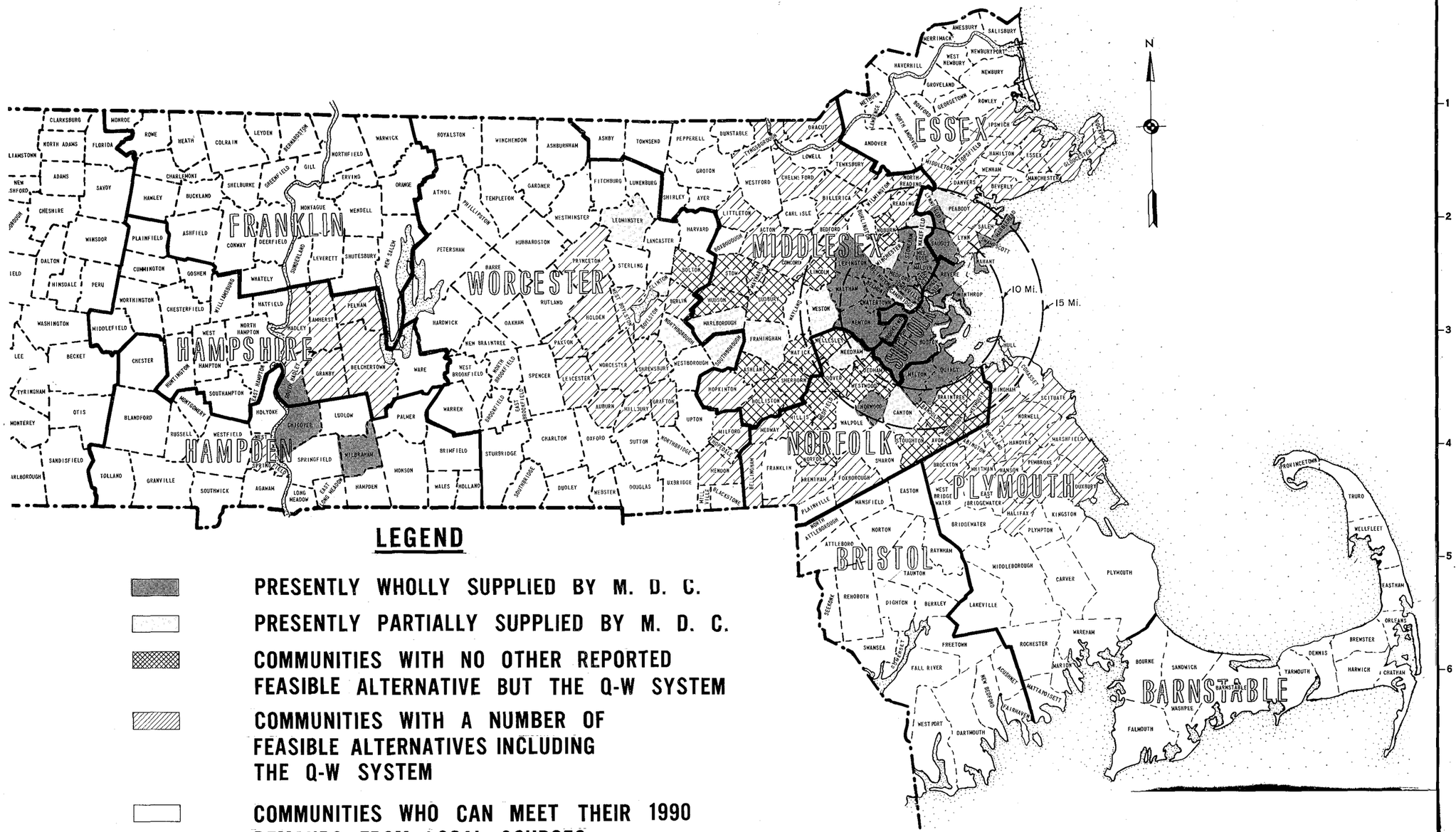
PLATE B-1



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
MILLERS RIVER BASIN

PROJECTED GALLON PER CAPITA INCREASE

PLATE B-2



LEGEND

- PRESENTLY WHOLLY SUPPLIED BY M. D. C.
- PRESENTLY PARTIALLY SUPPLIED BY M. D. C.
- COMMUNITIES WITH NO OTHER REPORTED FEASIBLE ALTERNATIVE BUT THE Q-W SYSTEM
- COMMUNITIES WITH A NUMBER OF FEASIBLE ALTERNATIVES INCLUDING THE Q-W SYSTEM
- COMMUNITIES WHO CAN MEET THEIR 1990 DEMANDS FROM LOCAL SOURCES OR OTHER REGIONAL SYSTEMS
- EXISTING Q-W SERVICE AREA
- PROBABLE 1990 Q-W SERVICE AREA
- POSSIBLE 1990 Q-W SERVICE AREA

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
QUABBIN – WACHUSETT
WATER SUPPLY SYSTEM
EXISTING AND FUTURE SERVICE AREA

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORP OF ENGINEERS
WALTHAM, MASS.

APPENDIX C

HYDROLOGY AND HYDRAULICS

This appendix presents the hydrologic and hydraulic data necessary for the development of the various alternatives. Included are the climatology and stream flow for the area, a simulation model to determine the yield of each alternative, determination of design floods, and hydraulic parameters necessary to design the facilities. Information contained in this appendix was used by the planners and designers to design the intake and outlet works and the diversion dams and tunnels.

APPENDIX C

HYDROLOGY AND HYDRAULICS

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APPENDIX C

HYDROLOGY AND HYDRAULICS

1. Introduction

This appendix presents the hydrology and hydraulics pertaining to the alternate plans for augmenting the existing Quabbin-Wachusett water supply system by diversion from the Millers River basin. Included are sections on climatology, streamflow, basin descriptions and hydrologic analyses and hydraulic design of the proposed plan.

2. Existing Quabbin-Wachusett System

A. General

The existing Quabbin-Wachusett-Ware River System consists of three watersheds and two reservoirs interconnected by a concrete-lined deep rock tunnel. Quabbin Reservoir on the Swift River, Connecticut River basin, has a drainage area of 186 square miles from which flows are diverted by gravity to the Wachusett Reservoir on the Nashua River, Merrimack River basin, which in turn has a drainage area of 1,077 square miles. Between the two reservoirs, excess flows from the Ware River, Connecticut River basin, with a watershed of 96.8 square miles, are diverted into the interconnecting aqueduct. Because of the relative height of the Ware River intake, flows can be diverted from this point to either Quabbin or Wachusett Reservoirs. Further description of this system is presented in section V of the main report. Following is a list of pertinent hydrologic data:

B. Quabbin Reservoir

1) Drainage area - 186 square miles

2) Water surface area - 38± square miles

3) Storage capacity -

	Elevation (msl)	Billion Gallons
Full pool	524	412
Minimum pool	422	10
Ground storage		15
Total usable storage		417

4) Downstream flow requirements - Between 1 June and 30 November when Connecticut River flow at Montague City is less than 4,650 cfs, the minimum Quabbin release is 110 cfs. When the flow is between 4,650 and 4,900 cfs the minimum release is 70 cfs. The minimum release at all other times is 31 cfs.

5) Transfer capacity to Wachusett -

925 cfs maximum with full pool (elevation 524 feet msl)

528 cfs minimum with minimum pool (elevation 422 feet msl)

C. Wachusett Reservoir

1) Drainage area - 107.7 square miles (includes 20.7 square miles controlled by Worcester)

2) Water surface area - 6.5± square miles

3) Storage capacity -

	Elevation (msl)	Billion Gallons
Full pool	389	65.0
Minimum pool	324	9.4
Total usable storage		55.6

4) Downstream flow requirements - 12/mg/week (3 cfs)

5) Transfer capacity to Boston - 775 cfs

D. Ware River Intake

1) Drainage area - 96.8 square miles

2) Storage capacity - negligible

3) Downstream flow requirements - No diversion permitted between 15 June and 15 October. Diversion of flows above 131 cfs permitted at all other times.

4) Transfer capacity -

1,590 to Quabbin
1,590 to Wachusett

3. Millers River Basin

A. General

The Millers River rises in Ashburnham, Massachusetts and flows in a general westerly direction for about 45 miles through Winchendon, Athol, and Orange to its confluence with the Connecticut River at Montague and Erving, Massachusetts. It has a total drainage area of 392 square miles and a total fall of approximately 900 feet. The upper reaches of this river are fed by a number of small brooks, flowing in a southerly direction from the towns of Rindge and New Ipswich, New Hampshire. Important tributaries on the Millers River are East and West Branches Tully River, Priest Brook, Tarbell Brook and Otter River. There are two existing Corps of Engineers flood control dams and reservoirs in the Millers River basin, namely, Birch Hill on the Millers River about 27.5 miles above its mouth, and Tully on the East Branch Tully River 4 miles above its mouth. A general plan of the Millers River basin is shown on plate C-1. Those tributaries of primary concern in this study are discussed in the following paragraphs.

B. Tarbell Brook

Tarbell Brook rises in the town of Rindge, New Hampshire and flows in a general southerly direction through Pearly Pond and Damon Reservoirs for a distance of 6.1 miles to its confluence with Sip Pond Brook. The Tarbell Brook flows eventually enter the Millers River and pass through the Corps' Birch Hill flood control project. One proposed plan for water supply is to direct Tarbell Brook flows westerly to Priest Brook by pumping from Tarbell at a site about 0.8 mile downstream from its confluence with Sip Pond Brook.

C. Priest Brook

Priest Brook rises in the town of Rindge and flows in a general southerly direction (it is known as Scott Brook until it reaches the State line 8.2 miles from its headwaters). The basin has a total drainage area of 22.7 square miles and a total vertical fall of 480 feet. Priest Brook is also a tributary to the Corps' Birch Hill project. The plan for water supply from this brook is to build a small temporary retention reservoir on Priest Brook at a site about 2.3 miles downstream from the New Hampshire State line in the town of Winchendon, Massachusetts. This point of diversion is located approximately 2.8 miles above the brook's confluence with the Millers River and the total drainage area at the site is 19.4 square miles. From the Priest Brook Reservoir flows would be diverted to the existing Tully Lake.

D. East Branch Tully River

The East Branch Tully River rises in the town of Richmond, New Hampshire where it is known as Tully Brook. It flows in a general southerly direction for approximately 6.2 miles to its confluence with Falls Brook just below the New Hampshire-Massachusetts State line where it forms the East Branch Tully River. From here it continues in a southerly direction for 4.8 miles through Long Pond to the confluence of Lawrence Brook and then to Tully Lake 1.1 miles downstream. Lawrence Brook has a drainage area of 26.6 square miles and constitutes 52.7 percent of the drainage area of Tully Lake. From Tully Lake the East Branch flows 3.1 miles to its confluence with the West Branch in Orange, Massachusetts to form the Tully River.

Some of the plans for water supply would use the Corps' Tully Lake project in Athol, Massachusetts as a point of diversion and for short term reregulating storage.

E. West Branch Tully River

The West Branch rises in the town of Warwick, Massachusetts where it is also known as Tully Brook. It flows in a general southerly direction for approximately 8.6 miles to its confluence with the East Branch in Orange where it becomes the Tully River. This basin has a total drainage area of 18.9 square miles and a total fall of approximately 630 feet.

One of the proposed plans is to divert West Branch flows easterly by pumping to the conduit leading from Tully Lake to Quabbin Reservoir. The diversion site would be located approximately 500 feet above the confluence of the two Tully Branches.

F. Birch Hill and Tully Projects

Following is a list of pertinent data on the Corps two single-purpose flood control reservoirs in the Millers River watershed, Birch Hill on the Millers River in South Royalston, Massachusetts and Tully Lake on East Branch, Tully River in Royalston.

	Birch Hill	Tully
Operational Date	December 1941	January 1949
Drainage Area (sq. mi.)	175	50
Capacity at Spillway Crest (acre-feet)	49,900	22,000
Spillway Elevation (feet, msl)	852	668
Spillway Length (feet)	1,100	255
Spillway Design Discharge (cfs)	56,000	32,700
Outlet Works		
Invert Elevation (feet, msl)	815	626
Gates	Four - 6'x12'	Two - 3.5'x6'
Conduits	Four - 6'x12'	One - 6' Diameter

4. Climatology

A. General

The Millers River region in north-central Massachusetts and southwestern New Hampshire has an average annual precipitation of about 40 inches. The area has a variable climate characterized by frequent but generally short periods of heavy precipitation. It lies in the path of the "prevailing westerlies" and is exposed to cyclonic disturbances that cross the country from the west or southwest. The area is also subject to coastal storms that travel up the Atlantic Seaboard in the form of hurricanes of tropical origin and storms of extratropical nature, often called "northeasters." The temperature within the area ranges from a summertime high in the 90's to subzero, occurring for short periods in the winter. Spring melting of the winter snow cover occurs generally in March or early April.

B. Temperatures

The mean annual temperature in the basin averages about 47° Fahrenheit, with an average monthly temperature varying from about 72° in July to near 21° in January. Extremes in temperature range from highs slightly in excess of 100° Fahrenheit to lows in the minus 20's.

Mean, maximum and minimum monthly temperatures recorded at four National Weather Service stations in the area are summarized in table C-1.

C. Precipitation

The mean annual precipitation averages about 40 inches. The greatest annual rainfall recorded in the area was 60 inches in 1954 and the minimum annual amount was 26 inches in 1965. Table C-2 summarizes monthly precipitation records in the area.

D. Snowfall and Cover

The average annual snowfall in the area is 62 inches. Mean monthly and annual snowfall at stations in the region are listed in table C-3. Snow cover measurements taken by the New England Division Corps of Engineers during the latter part of the winter at various locations in the study area since 1949 are summarized in table C-4. The average water equivalent of the snow cover reaches a maximum of about 3.6 inches in mid March.

5. Streamflow

A. General

The average annual runoff in northwestern Massachusetts is approximately 22 inches or about 55 percent of the mean annual precipitation. A summary of streamflow records at six stations in the Millers River basin published by the U.S. Geological Survey is shown in table C-5. A summary of runoff at other stations pertinent to the existing Quabbin-Wachusett system and the main stem Connecticut River is also summarized in table C-5. The mean, maximum and minimum monthly streamflow, plus annual runoff at selected stations in the region, are shown in table C-6. A plot of annual runoff at the Priest Brook USGS gage for the period of record is shown on plate C-2.

B. Droughts

The long term normal streamflow in northeastern Massachusetts of approximately 22 inches is actually the average of many highs and lows. When rainfall is below average for a period of time the area experiences a drought, a drought in this case being defined as a period of shortage in streamflow. The recent drought of the sixties in southeastern New England, for its duration, was the greatest ever experienced in the area based on over 200 years of record. The drought of the 1960's was more severe in the interior

TABLE C-1

MONTHLY TEMPERATURE

Month	Turners Falls, Mass.			Fitchburg, Mass.		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	23.4	66	-27	24.8	68	-21
February	24.3	65	-30	25.0	68	-21
March	34.4	85	-21	34.5	86	- 8
April	46.2	91	4	46.1	92	6
May	57.9	96	24	57.7	97	26
June	66.9	103	31	66.4	100	35
July	71.7	104	36	71.5	103	41
August	69.3	103	34	69.2	102	35
September	62.1	99	25	62.1	101	27
October	51.3	92	18	51.3	91	16
November	39.5	82	0	39.9	81	- 2
December	27.2	66	-24	28.4	71	-16
Annual	47.9	104	-30	48.1	103	-21

Month	Keene, New Hampshire			Birch Hill Dam, Mass.		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	21.4	66	-32	22.1	62	-34
February	22.5	65	-32	24.0	64	-25
March	32.8	85	-21	32.1	73	-18
April	44.5	91	1	44.9	88	6
May	55.8	95	21	55.3	92	20
June	64.5	98	27	64.6	97	29
July	69.4	104	34	68.8	96	36
August	67.0	102	27	66.6	99	30
September	59.9	101	19	59.2	98	20
October	49.3	90	10	49.5	85	13
November	37.6	80	-15	38.6	79	3
December	25.3	64	-29	25.9	62	-25
Annual	45.8	104	-32	46.0	99	-34

TABLE C-2

MONTHLY PRECIPITATION

Month	Turners Falls, Mass.			Fitchburg, Mass.		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	3.22	6.63	0.69	3.44	7.78	0.84
February	2.77	6.22	0.51	3.27	8.33	0.34
March	3.37	8.10	0.22	3.63	12.15	T
April	3.31	6.04	0.57	3.41	9.91	0.57
May	3.57	7.77	0.44	3.55	8.25	0.57
June	3.50	8.04	0.67	3.63	11.56	0.09
July	3.71	15.39	0.84	3.64	12.68	0.46
August	3.62	12.11	0.65	3.68	10.72	0.17
September	3.61	12.94	0.39	3.58	14.04	0.19
October	2.85	8.55	0.00	3.42	13.01	T
November	3.69	7.89	0.66	3.80	7.63	0.38
December	3.27	7.92	0.40	3.41	8.46	0.58
Annual	40.49	55.18	27.66	42.46	60.23	27.45

Month	Keene, New Hampshire			Birch Hill Dam, Mass.		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	2.86	6.50	0.76	2.91	5.95	0.78
February	2.66	7.02	0.60	2.76	5.12	0.88
March	3.13	7.60	0.04	3.00	6.49	0.85
April	3.14	6.65	0.35	3.17	5.04	0.77
May	3.31	7.02	0.79	3.08	6.67	0.93
June	3.40	7.73	0.41	3.35	7.64	0.59
July	3.72	11.09	1.07	2.91	6.86	0.79
August	3.59	8.96	1.05	3.20	10.44	0.80
September	3.52	10.39	0.20	2.92	7.73	0.64
October	2.74	7.84	0.23	2.72	7.07	0.47
November	3.36	7.67	0.52	3.96	7.06	1.32
December	3.10	6.70	0.51	3.36	5.99	0.76
Annual	38.53	51.20	27.12	37.34	50.49	25.91

TABLE C-3

AVERAGE MONTHLY SNOWFALL
(In Inches)

Month	Turners Falls Massachusetts	Fitchburg Massachusetts	Keene New Hampshire	Birch Hill Dam Massachusetts
January	15.6	15.6	16.3	15.2
February	15.2	17.5	16.6	18.0
March	9.1	11.4	11.3	14.5
April	2.1	2.5	3.2	2.5
May	-	-	-	0.2
June	-	-	-	-
July	-	-	-	-
August	-	-	-	-
September	-	-	-	-
October	-	-	0.1	0.3
November	2.7	3.4	3.6	3.2
December	10.4	11.7	12.2	12.5
Annual	55.1	62.1	63.3	66.4

TABLE C-4

WATER EQUIVALENTS OF SNOW COVER
MILLERS RIVER BASIN
1949 - 1972

Date	Minimum (inches)	Mean	Maximum
1 February	0.3	2.0	4.2
15 February	0	2.7	5.6
1 March	0	3.4	7.6
15 March	0	3.6	7.7
1 April	0	2.3	8.2
15 April	0	.4	4.9

TABLE C-5

STREAMFLOW RECORDS
MILLERS RIVER BASIN

Location	Drainage Area (sq.mi.)	Period of Record	Mean Discharge CFS	Mean Discharge MGD	Mean Discharge CFS/ Sq. Mi.	Mean Discharge MGD/ Sq. Mi.
Tarbell Brook near Winchendon	18.2	1916-1969	28.7	18.5	1.57	1.01
Millers River near Winchendon	83.0	1916-1969	139	89.8	1.67	1.08
Priest Brook near Winchendon	19.4	1916-1969	32.0	20.7	1.65	1.06
Millers River at South Royalston	187	1939-1969	302	195.2	1.61	1.04
East Branch Tully River near Athol	50.4	1915-1969	79.9	51.6	1.58	1.02
Millers River at Erving	375	1914-1969	607	392.4	1.63	1.03

TABLE C-6

MONTHLY RUNOFF (CFS)
MILLERS RIVER BASIN

	Millers River at Erving, Mass. DA = 375 square miles 1915 - 1966			Priest Brook near Winchendon, Mass. DA = 19.4 square miles 1917 - 1966		
Month	Mean	Maximum	Minimum	Mean	Maximum	Minimum
January	601.6	1,288	83.3	28.8	79	1.2
February	550.4	1,486	132.1	23.8	81	5.3
March	1,137.6	3,989	364.0	64.4	199	13.6
April	1,575.9	3,584	631.6	95.5	225	27.6
May	816.9	1,652	288.4	42.1	91	12.8
June	490.4	1,641	92.5	23.7	124	2.5
July	296.3	1,118	61.7	11.7	62	1.0
August	231.2	1,052	52.6	9.2	68	0.5
September	285.5	3,030	43.2	12.5	177	0.3
October	286.6	1,286	74.0	13.6	62	0.6
November	476.9	1,617	79.7	27.6	124	1.4
December	581.5	1,543	82.5	30.7	94	4.7
Annual	608.0			31.9		

than along the coast. The accumulated deficiencies in rainfall at Amherst, Massachusetts for the period 1961-1968 was 63 inches, which is equivalent to 1.5 years of average rainfall.

A statistical frequency analyses was made of 50 years of Priest Brook streamflow records using procedures described in ER 1110-2-1450, "Hydrologic Frequency Estimates." This analysis indicated that the 1964 climatological year low flow, the lowest single year of record, had a frequency in the order of once in 250 years. The frequency curve developed from this study is shown on plate C-3.

C. High Flow

The maximum annual runoff in northeastern Massachusetts, using Priest Brook as an index, has exceeded the long term average by as much as 69 percent, and streamflow often remains above normal for several successive years as illustrated on plate C-2. In addition to annual variations in runoff, the rivers of the region also experience a high flow period within each year during the months of March, April and May. About 50 percent of the average annual runoff occurs during these months due to the melting of snow cover.

D. Floods

Major floods in New England, particularly on the larger rivers, often result from a combination of heavy rainfall and snowmelt such as the March 1936 event. However, many of the peak discharges to date have resulted from high intensity rainfall alone, such as experienced in August 1955. Heavy precipitation associated with storms of tropical or extratropical origin normally occur during the summer and fall seasons. Floodflows on smaller tributary streams also result from local summer season thunderstorms produced by convective action.

The Millers River basin escaped the brunt of the disastrous New England storm of August 1955, and the two greatest floods of record in the basin remain those of March 1936 and September 1938. The floods of March 1936 were the result of two storms on 9-13 and 16-22 March. Recorded hydrographs at the gaging stations in the area show two peaks separated by a marked recession. The first peak was produced by rainfall and melting snow, whereas the second and greater peak was the result of mostly rainfall on ground with high antecedent moisture. The total rainfall for the period 9-22 March, as measured at Winchendon, Massachusetts, was 6.51 inches. Peak 1936 discharges recorded in the basin are listed in table C-7.

TABLE C-7

FLOODS OF RECORD

Station	Drainage Area (sq.mi.)	March 1936 (cfs)	September 1938 (cfs)
Tarbell Brook near Winchendon, Mass.	18.2	1,430	2,630
Priest Brook near Winchendon, Mass.	19.4	1,491	3,000
East Branch Tully River, Athol, Mass.	50.4	3,700	5,140
Millers River at Erving, Mass.	375	19,700	29,000
Connecticut River at Montague City, Mass.	7,865	236,000	195,000

The record flood in the basin occurred as a result of the September 1938 hurricane which brought a total storm rainfall of about 15.3 inches over the basin. Resulting peak runoff rates from this storm are also listed in table C-7.

6. System Analyses

A. General

As discussed in the main report, the plan for augmenting the existing Quabbin Reservoir is to transfer water from the Millers River basin. The three schemes or "alternatives" under consideration in this report are the following:

1) Alternative "1"

Diversion from the main stem Millers River in Athol.

2) Alternative "2"

Diversion from both the East Branch Tully River and Millers River via a common aqueduct from Tully Lake to Athol to Quabbin.

3) Alternative "3"

Diversion entirely from upstream tributaries, namely, Tarbell Brook, Priest Brook and West and East Branches Tully River.

Details of various components of the plans are discussed in the Hydraulic Design Section of this appendix, and schematics of the three alternatives are shown on plate C-4.

Analyses of the system operations were made with the aid of a computer and numerical simulation models. All system analyses were made using historical flow records for the period 1919 through 1968 with severity and timing of droughts as actually occurred. Maximum yield of a source was defined as the greatest yield which could be supplied continuously for the period of years of historical flow records.

B. Simulation Models

The operation of the Millers River system was simulated using a daily time increment and Priest Brook flows as a runoff index. The system model consisted of several individual site programs

directed by a main line program which controlled the overall system operation. For each time interval, the system was scanned and basic operating routines were performed at each site in the prescribed system. The basic steps were: (1) compute inflow and transfer in, (2) determine downstream requirement, (3) determine transfer out, and (4) determine any adjustment in storage. The results of the simulation were accumulated and printed out on a monthly basis. Results were also stored on computer disks for later retrieval and/or analysis. A sample computer printout for the Millers River simulation is shown on plate C-5. The input data for this run is not representative of any particular plan but rather for illustrative purposes only. Downstream requirements at Quabbin and allowable Ware River transfers were similarly determined on a daily basis and accumulated monthly.

Both the existing and augmented Quabbin-Wachusett system were simulated with the aid of a second computer model using a monthly time increment. In this simulation, historical records of monthly flows on the Swift River and Nashua River were used in conjunction with the retrieved monthly results of the Millers River system simulation. In this simulation, a priority routine was used for determining the amount of water transfer from Quabbin to Wachusett each month. With this routine, Quabbin and Wachusett are assigned a variable storage priority relationship and each month up to 10 trial transfers are made from Quabbin to Wachusett, using a modified binary search procedure to attempt to balance the priorities of the two systems. For example, Wachusett was assigned an increasingly high priority as storage rose, so that no water would be transferred from Quabbin unless it too had a high priority and was on the verge of spilling. Similarly, when Wachusett storage fell, it was given an increasingly high priority to transfer water from Quabbin, even to the point of draining Quabbin empty. The maximum transfer capacity from Quabbin to Wachusett, a function of the head in Quabbin, was related to the current storage in Quabbin and computed each month.

C. Downstream Flow Requirements.

In the operation of all the alternatives, two restraints were applied with respect to downstream flow requirements; (1) diversion from any site was made only when the Connecticut River was above some selected control flow, and (2) diversion was made of only those inflows in excess of the local downstream flow requirements. It is noted that downstream low flows on the Millers River were not augmented from available water in storage at diversion sites. When inflows were below the desired downstream flow, outflow was made equal to inflow. Downstream flow requirements at sites in the Millers basin were

established on a cfs per square mile drainage area using information on minimum desired flows from both the Environmental Protection Agency and the Fish and Wildlife Service of the Department of Interior. The adopted low flow requirements are listed in table C-8.

Various low flow controls on the Connecticut River were studied to determine the relative effect on system yield as described in the following paragraphs. The Connecticut River control flow used in the proposed plan was 17,000 cfs at Montague City, Massachusetts.

Present law requires that downstream flows be augmented from Quabbin storage during certain low flow conditions on the main stem Connecticut. The minimum legal release at the existing Quabbin, Wachusett and Ware River projects were described in paragraph 2 of this appendix.

D. Transfer and Storage Capacities

The yields from the diversion rights in the Millers basin are a function of several parameters: drainage area, downstream flow requirements, temporary storage capacity at the site, and transfer capacity. The first two parameters are fixed or specified, but the latter two are design variables requiring comparative studies. For these studies, yield versus storage and transfer capacity relationships were developed for each site by a series of computer simulation studies using a test period 1919-1968. An example of the developed yield versus storage and transfer capacity curves is shown on plate C-6.

These curves were later used by planners to arrive at the economical optimum combination of storage and transfer capacity. The resulting storages and transfer capacities selected at each of the individual sites are shown in table C-10.

With the proposed plans of diversion, a major portion of the diversion would be during the months of March, April and May with lesser amounts in wet periods during the fall and winter months. The reduction in daily flows on the Connecticut River at Montague City and various locations in the Millers River basin for an average year (1943) and a dry year (1965) are shown on plates C-7 thru C-14, respectively. Reductions in average monthly flows are similarly illustrated on plates C-15 and C-16.

TABLE C-8

LOW FLOW REQUIREMENTS
MILLERS RIVER TRIBUTARIES
MASSACHUSETTS

Month	Minimum Flow (cfs/sq. mile)
January - March	0.50
April - June	1.25
July	2.00
August	1.00
September - November	0.75
December	0.50

E. System Yields

1) Existing System

The existing Quabbin-Wachusett-Ware River system has a maximum yield of approximately 300 mgd. A simulation of the system for the 50-year period 1919-1968 demonstrated that Quabbin Reservoir has sufficient storage to buffer all experienced deviations in runoff and the maximum yield is therefore equal to the long term average runoff of the watersheds less downstream flow releases. Table C-9 is a tabulation of the incremental yield of each of the system's watersheds.

Sudbury Reservoir, another reservoir in the existing Metropolitan District Commission's system, with a drainage area of 22.3 square miles and storage capacity of 21,481 acre-feet, has an additional potential yield of 20 mgd for a total potential system yield of 320 mgd.

2) Alternative Yields

Each alternative was simulated for the test period 1919-1968 and the results are presented in table C-10. Simulations further determined that Quabbin and Wachusett have sufficient reserve regulating storage to buffer yearly variations. Therefore, the increase in yield of the system by the addition of any of the alternatives is equal to the long term average yield of the alternative under study.

3) Northfield Mountain

Simulation studies were also made with further augmentation of Quabbin with the planned diversion from the Connecticut River via the Northfield Mountain pumped storage project. It is noted that Quabbin and Wachusett still had reserve regulating storage enough for these transfers as well as the Tully-Millers River transfers, resulting in a minimum of spillage during prolonged wet periods. Therefore, the incremental safe yield provided by the planned Northfield Mountain project is equal to the long term average annual transfer. The proposed system will divert at a rate of 580 cfs when Connecticut River flows are above 15,000 cfs at Turners Falls (17,000 cfs at Montague City). This occurs an average of 23 percent of the time, resulting in an average annual transfer of about 130 cfs or 84 mgd.

TABLE C-9

QUABBIN-WACHUSETT-WARE RIVER YIELDS

Watershed	Average Runoff (cfs)	Test Period	Average Downstream Requirement (cfs)	Maximum Yield CFS	Maximum Yield MGD
Quabbin	287*	1919-1968	45	242	156
Wachusett	187	1919-1968	3	148**	96
Ware River	160	1919-1968	90	70	45
Total Yield				460	297

* The long term average of 292 cfs was reduced by 5 cfs to correct for the absence of evaporation losses from Quabbin prior to 1939. The average net reduction in yield from the watershed due to evaporation is 10 cfs based on data from U. S. Geological Survey Hydrologic Investigations Atlas Ha-7.

** Reduced by 36 cfs for Worcester water right.

TABLE C-10

MILLERS RIVER BASIN

	Site	Drainage Area (Sq. Mi.)	Transfer Capacity (cfs)	Storage (Ac.Ft.)	Average Annual Yield (MGD)	System Yield (MGD)
Alternative 1	Millers River Intake	200	730	0	68.4	68.4
Alternative 2	Tully Lake (alone)	50.4	490	0	24.2	
	Tully Lake (in system)	50.4	490	0	7.4	
	Millers River Intake	200	730	0	68.4	75.8
Alternative 3	Tarbell Brook	25.6	90		8.6	8.6
	Priest Brook	19.4	120	4,100	9.0	17.6
	Tully Lake	50.4	375*	5,400	24.7	42.3
	West Branch Tully	18.6	90		5.9	48.2
	Total Tully System	114.0		9,500		48.2

* Transfer capacity from Tully with no diversion from West Branch = 357 cfs. Maximum combined transfers from Tully and West Branch = 379 cfs.

F. Design Floods

Design floods at the respective diversion sites were determined through the development of a representative unit hydrograph and the application of selected design rainfall. Derived floods were used in the design of the diversion structures at Tarbell Brook, Priest Brook and West Branch Tully.

Analysis of experienced Priest Brook runoff and rainfall using computer program 23-J2-L211 of the Hydrologic Engineering Center, Davis, California, produced a 3-hour unit hydrograph with a peak of 680 or 35 cfs per square mile for the 19.4 square mile drainage area. The peak of the derived unit graph was comparatively low, based on experienced runoff from other basins in New England under more intense rainfall, therefore the peak was increased 40 percent to reflect the increased runoff rates that would be expected under standard project storm rainfall conditions. The resulting adopted 3-hour unit graph for Priest Brook had a peak discharge of 950 cfs, equivalent to 50 cfs per square mile for the drainage area of 19.4 square miles. This same unit graph was adjusted by direct ratio of drainage areas and adopted for the similar watersheds of Tarbell Brook and West Branch Tully.

Applying both standard project and maximum probable storm rainfall, as determined from EM 1110-2-1411, to the adopted unit graph resulted in a standard project flood discharge of 350 cfs per square mile and a maximum probable discharge of 800 cfs per square mile. The runoff rate for the SPF is equivalent to 2.3 times the runoff rate experienced from Priest and Tarbell Brooks during the record flood of September 1938.

The Priest Brook and Tarbell Brook diversion sights are just upstream of the existing Birch Hill flood control dam and the West Branch site consists of a relatively low weir. Because of the smallness of the reservoirs, the relatively low height of the dams and their location with respect to existing reservoirs, it was concluded that the spillways would be designed for the standard project flood discharge in accordance with procedures set forth in EC 1110-2-27, "Policies and Procedures Pertaining to Determination of Spillway Capacities and Freeboard Allowances for Dams," and EM 1110-2-1101, "Design Criteria for Systems of Small Dams."

Plate C-17 presents the surcharge-length curves used in studies of alternate spillway plans at Priest Brook. Similar curves were employed at the Tarbell and West Branch Tully sites.

7. Hydraulic Design

A. General

The hydraulic design features of the various components of the proposed plan are discussed in the following paragraphs. Hydraulic analysis made during plan formulation was general in scope. More detailed analysis, probably including model studies of some of the more complex hydraulic structures, will be required in final design.

B. Tarbell Brook Diversion

A structure will be required across Tarbell Brook at the point of diversion to provide a shallow depth of water from which flows can be diverted. The diversion structure on Tarbell Brook will have a concrete weir 75 feet in length at elevation 840 feet msl, approximately 9 feet above the channel invert. The weir will be centered on the stream with short nonoverflow embankment sections at each end of the weir tying into the natural high ground. The top of the nonoverflow sections will be at elevation 854 feet msl, 2 feet above the spillway crest of the downstream Birch Hill Dam. The surcharge on the weir for the design SPF flow of 9,000 cfs with no backwater effect from the Birch Hill pool would be 10 feet assuming a discharge coefficient "C" of 3.8 in the weir flow equation $Q = CLH^{1.5}$. With Birch Hill flood control storage filled to spillway crest (elevation 852) the Tarbell weir will be 12 feet submerged.

Stilling blocks will be provided on the downstream apron of the weir to assist in the stilling of low flows over the low weir section. During higher flows, spillage will be stilled by the resulting downstream tailwater.

Flows for diversion will be drawn off just upstream of the weir through an inlet located in the right abutment of the weir and discharged to the pumping station also located on the right abutment of the weir structure. A 36-inch diameter gated outlet is also located in the right abutment for the passage of downstream low flows and to permit draining the small pool during the summer season if desired. A plan and sections of the proposed Tarbell diversion structure are shown on plate C-18.

C. Priest Brook Dam

The dam to be built on Priest Brook will create a reservoir for the short term reregulation of flows from Priest Brook along with

diverted flows from Tarbell Brook. The top of the embankment will be at elevation 890 feet msl. A concrete weir spillway located on rock in the left abutment will have a crest at elevation 875 feet msl, 30 feet above the channel invert, and a length of 65 feet.

The outlet works will consist of a 42-inch diameter gated pressure conduit with a regulating gate at the outlet and an emergency gate at the entrance. Flows for diversion to Tully will be withdrawn from the outlet works conduit on the downstream side of the dam and piped to a pumping station which will also be located just downstream of the dam.

The reservoir at spillway crest will have a total storage capacity of about 4,100 acre-feet and a surface area of 400 acres. The spillway will consist of a low concrete weir 65 feet long located on bedrock in the left abutment of the dam. The maximum surcharge on the crest with a design standard project flow of 6,800 cfs will be 9 feet assuming a discharge coefficient "C" of 3.8 in the weir formula $Q = CLH^{1.5}$.

The spillway discharge channel will be located on bedrock for a distance of about 400 feet, dropping to the approximate downstream invert elevation of 865 feet msl and then continuing on a near level grade to its confluence with the downstream channel. A plan and sections of the Priest Brook dam are shown on plate C-19.

D. West Branch

The West Branch diversion structure will consist of a nonoverflow embankment section and a 50-foot long ogee-shaped overflow spillway. The spillway at elevation 525 feet msl is 11 feet above the normal invert of the river. With a design SPF discharge of 6,500 cfs, the surcharge will be 10.5 feet above spillway crest assuming a coefficient of 3.8 in the standard weir formula. Discharges will be stilled by a conventional stilling basin. The top of dam will be at elevation 540 feet msl resulting in a freeboard of 4.6 feet above design surcharge. The reservoir area created by this structure will be small, generally less than 13 acres in area and not more than 75 acre-feet in volume. Flows for diversion will be drawn off through an inlet on the left abutment of the spillway and conveyed through the dam in a 36-inch diameter pipe to a pumping station. Provisions will be made for discharging flows from this pipe back to the downstream channel and this pipe will also provide a means for emptying the diversion pool during the summer season if such is desired. A plan and sections of the West Branch diversion structure are shown on plate C-20. Pertinent hydraulic data for all the diversion sites are shown in table C-11.

TABLE C-11

PERTINENT HYDRAULIC DATA
FOR DIVERSION DAMS

ALTERNATIVE 3

	Tarbell Brook	Priest Brook	West Branch
Drainage Area (sq. mi.)	25.6	19.4	18.6
Spillway Elevation (ft. msl)	840	875	525
Spillway Length (ft.)	75	65	50
Top of Dam (ft. msl)	854	890	540
Channel Invert (ft. msl)	831	845	514
SPF Discharge (cfs)	9,000	6,800	6,500
Surcharge (ft.)	10	9	10.5
Freeboard (ft.)	4	6	4.5
Outlet Size	36" Dia.	42" Dia.	36" Dia.
Depth of Impoundment (ft.)	9	30	11

E. Tully-Quabbin Tunnel

The 8-foot diameter deep rock tunnel from Tully to Quabbin Reservoir will be 8.5 miles in length, and flow will be by gravity with a minimum hydraulic head differential of 102 feet. This head differential is based on an entrance head at elevation 626 feet msl and the tailwater at the Quabbin full pool level at Elevation 524 feet msl.

Hydraulic capacity determinations were made using methods outlined in EM 1110-2-1602. Capacity was based on entrance and exit loss coefficients of 0.2 and 1.0, respectively. Friction in the concrete-lined tunnel was computed using a Manning's "n" of 0.015. With the design transfer capacity of 379 cfs, the average velocity in the 8-foot diameter tunnel will be 7.5 feet per second. The hydraulic gradient in the tunnel will be higher than the West Branch diversion site, therefore flows from that site will be pumped into the tunnel. With diversions of 289 cfs from Tully and 90 cfs from West Branch, the hydraulic gradient in the tunnel at the point of entrance of the West Branch flow will be elevation 611 feet msl.

F. Tunnel Inlet

The tunnel inlet will be a 22-foot morning glory drop inlet located on bedrock adjacent to the existing Tully Lake outlet channel. A plan of the inlet and associated structures are shown on plate C-21.

An 8 x 30-foot bascule gate will be located across the existing outlet channel for control of hydraulic head on the tunnel inlet. During nondiversion periods, the bascule gate will be down and the three 8 x 8-foot gates will be opened and the bascule gate raised, creating a stilling pool for flows emerging from the lake outlet while raising the water level above the lip of the inlet. The lip of the inlet is 6 feet above the chamber invert and design head above the lip will not exceed 2 feet.

With an assumed maximum diversion rate of 500 cfs, velocities in the existing outlet tunnel would be about 20 feet per second. Velocities through the 8 x 8-foot gates would be about 3 feet per second and approach velocities to the morning glory would be 1 to 2 feet per second.

G. Millers River Intake

This proposed intake would be located approximately one mile upstream from the center of Athol on the right bank of the main stem of the Millers River. A plan of the inlet and associated structures is shown on plate C-22.

A 5 x 70-foot bascule gate will be located across the existing channel for control of hydraulic head on the tunnel inlet. During nondiversion periods, the bascule gate will be down and the three 8 x 8 foot gates to the inlet chamber closed. When diversion is initiated, the 8 x 8-foot gates will be opened and the bascule gate raised to divert flows over a 50-foot weir on the right bank at elevation 626 and into the inlet chamber. The lip of the 10-foot diameter morning glory tunnel inlet is 4 feet above the chamber invert and the design head above the lip will not exceed 2 feet.

Under design, the velocity of approach to the 50-foot weir will be 2.8 fps. Velocities through the gates and approach to the morning glory spillway will be 5.2 fps and 2.0 fps, respectively.

This structure is designed to create a minimum restriction to floodflows. During such periods, flows would pass over both the lowered 80-foot bascule gate and the 50-foot water supply weir.

H. Tunnel Outlet

The proposed tunnel outlet structure at Quabbin Reservoir is the same in plan and design for both the 10-foot diameter tunnel as described in Alternative 1 and 2, and the 8-foot diameter tunnel described in Alternative 3. The tunnel outlet is designed for discharging to the reservoir with the pool at varying stages.

The outlet will consist of a vertical riser transitioning onto a horizontal apron with an invert at elevation 514 feet msl, 10 feet below Quabbin full pool. On the apron, the flows pass through twin 8-foot wide passageways and then, when the Quabbin pool is down, the flows will discharge down a chute into a stilling basin at elevation 500 feet msl. From the stilling basin the flows will be conveyed in a rip-rapped channel about 800 feet across a swamp to the original Middle Branch Swift River channel leading to the base of the reservoir.

When Quabbin Reservoir is completely filled to elevation 524 feet msl, the outlet apron will be submerged by the backwater and discharge from the outlet into the pool will be direct.

With a maximum discharge of 380 cfs for Alternative 3, and a low Quabbin pool, the hydraulic gradient over the riser would be at about elevation 518 feet msl and the depth of flow and velocity through the passageways would be 2.6 feet and 9 feet per second, respectively. With Quabbin filled, the elevation at the outlet

would be at the full pool level of 524 feet msl and velocity through the submerged passageways, with a flow of 380 cfs, would be approximately 3 feet per second.

With a maximum discharge of 730 cfs for Alternatives 1 and 2, and a low Quabbin pool, the hydraulic gradient over the riser would be at about elevation 519 msl and the depth of flow and velocity through the passageways would be 4.1 and 11.4 feet per second, respectively. With Quabbin filled, the elevation at the outlet would be at the full pool level of 524 feet msl and the velocity through the submerged passageways, with a flow of 730 cfs, would be approximately 5 feet per second.

The passageways are equipped with 8 x 8-foot gates to permit closing off and pumping out the structure, if required, with Quabbin filled to capacity.

A plan and sections of the outlet structure are shown on plate C-23.

I. Hydraulics of Other Tunnel Plans

During project formulation, the hydraulics of many plans with respect to location and size of tunnel were analyzed. Procedures used in the analyses were the same as those previously described. A listing of the plans and their associated capacity and average annual yield is presented in table C-12.

Following are the assumed hydraulic head elevations at various locations used in computing hydraulic capacities.

	Elevation
Tully Dam	626
Millers River Intake	605*
Swift River	570
Quabbin Reservoir	524

* These cases only

Brief descriptions of the various tunnel plans are as follows:

1) Alignment 1

A direct tunnel from the Tully system to a point on the Swift River approximately 2 miles upstream from Quabbin Reservoir.

2) Alignment 13

A direct tunnel from the Tully system to Quabbin Reservoir entering at Gays Hill.

3) Alignment TMAX

A theoretical tunnel from the Tully system capable of carrying all flows above the minimum requirements to Quabbin Reservoir.

4) Alignment 2

A direct tunnel from the Millers River at an intake site just upstream of the town of Athol. Water diverted at this site would be only that in excess of Connecticut River and downstream Millers River requirements. Tunnel diameters ranging in size from 10 to 16 feet were investigated.

5) Alignment MRMAX

A theoretical tunnel from the Millers River to Quabbin capable of diverting all flows above the minimum requirements to Quabbin Reservoir.

6) Alignment 7+2

In this plan water from the Tully system is diverted to the Millers River intake and then further augmented by flow from the Millers River.

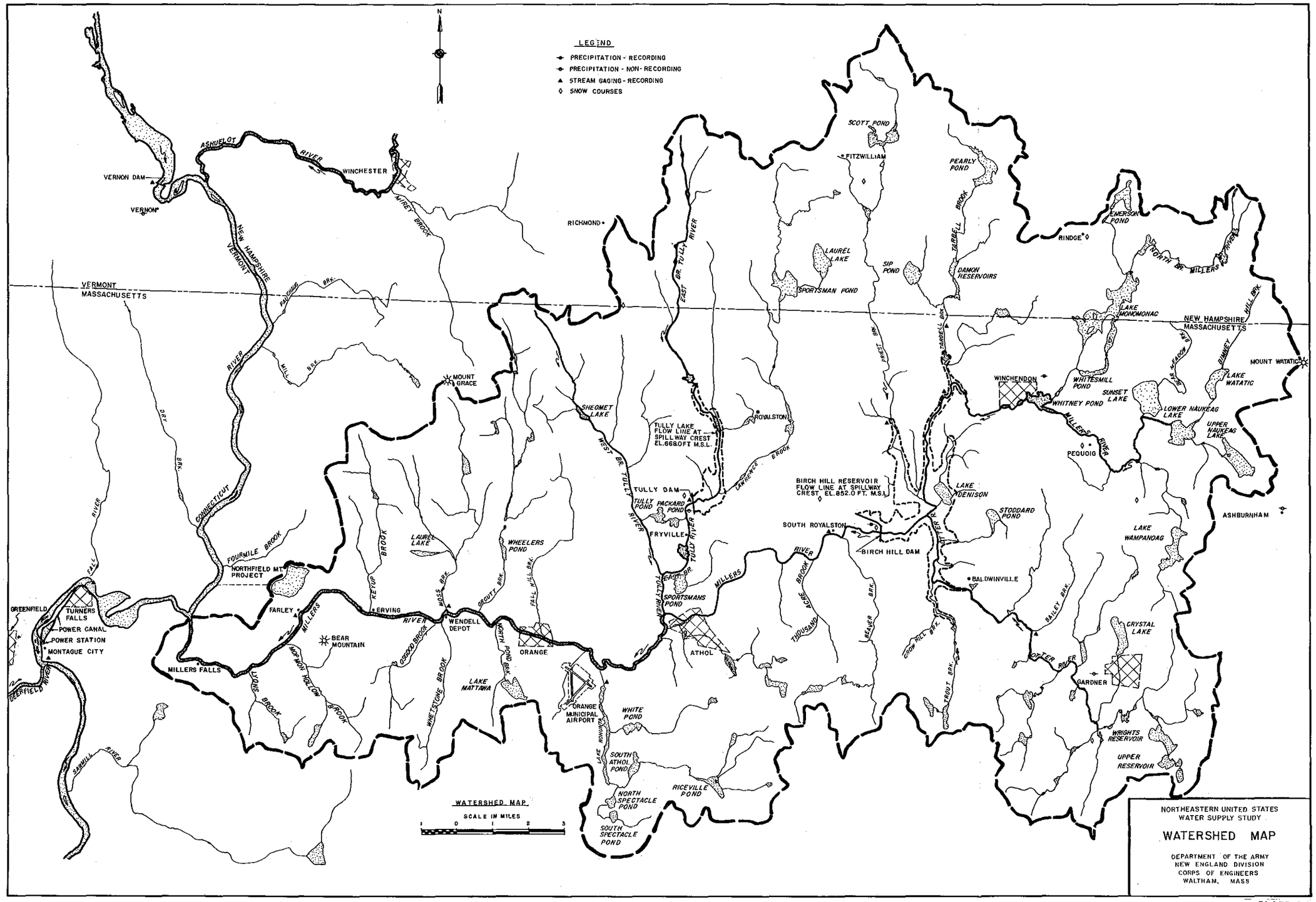
7) Alignment TMRMAX

A theoretical tunnel from the Tully system to the Millers River intake to Quabbin Reservoir capable of diverting all flows above minimum requirements to Quabbin Reservoir.

TABLE C-12

SUMMARY OF PLANS

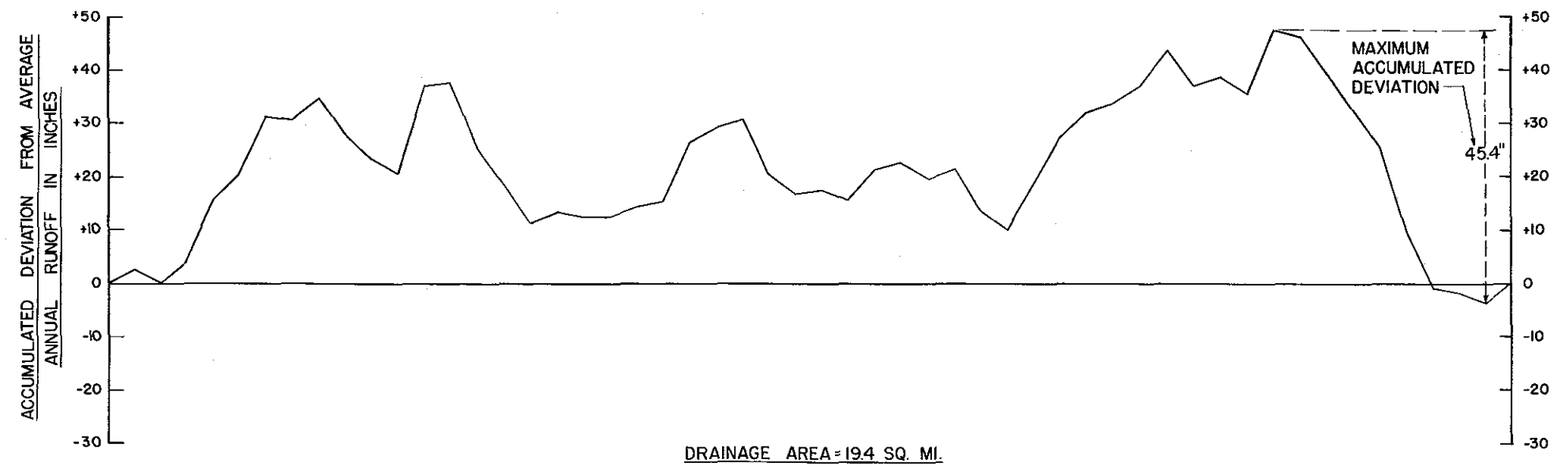
Plan	Alignment	Diameter (ft)	Capacity (cfs)	Yield (mgd)
TULLY				
Tully to Swift River	1-A	8	312	44.9
	1-B	10	553	48.0
Tully to Quabbin Reservoir	13-A	8	373	46.5
	13-B	10	661	48.2
Maximum Possible Yield	TMAX		infinity	58.5
MILLERS RIVER				
Intake Alone to Quabbin	2-A	10	675	65.3
	2-B	11	864	73.1
	2-C	12	1096	79.1
	2-D	14	1646	85.4
	2-E	16	2351	87.6
Maximum Possible Yield	MRMAX		infinity	89.2
TULLY & MILLERS RIVERS				
Tully to Millers River to Quabbin Reservoir	7 + 2A	10 - 10	573-675	78.9
	7 + 2B	10 - 11	573-864	90.9
	7 + 2C	10 - 12	573-1096	101.0
	7 + 2D	10 - 14	573-1646	113.4
	7 + 2E	10 - 16	573-2351	117.8
Maximum Possible Yield	TMRMAX		infinity	147.7

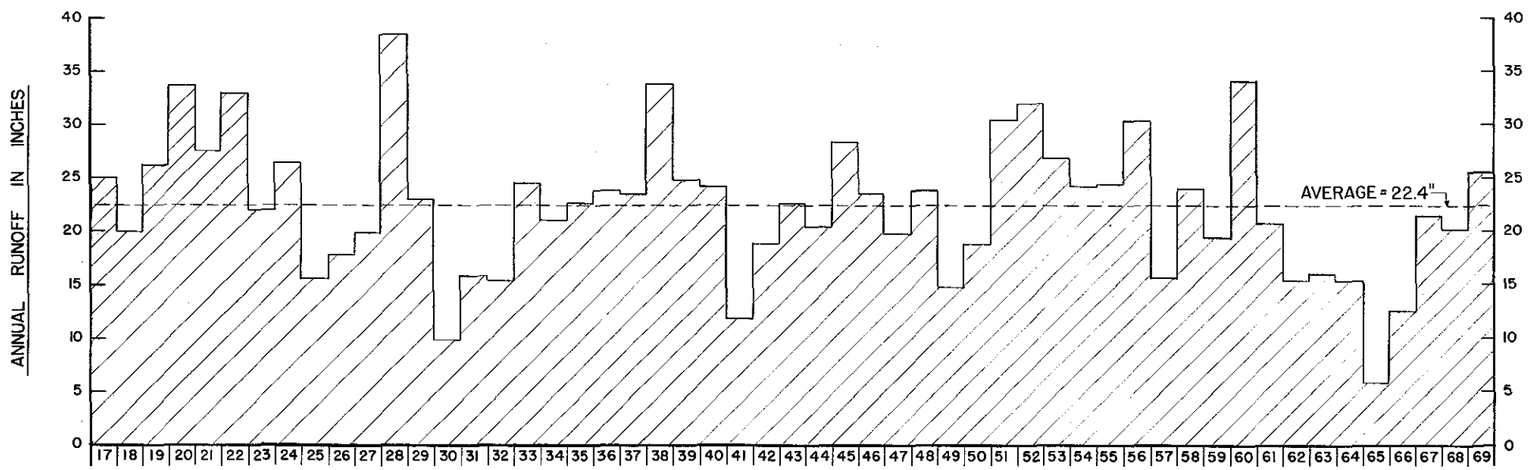


NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

WATERSHED MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS



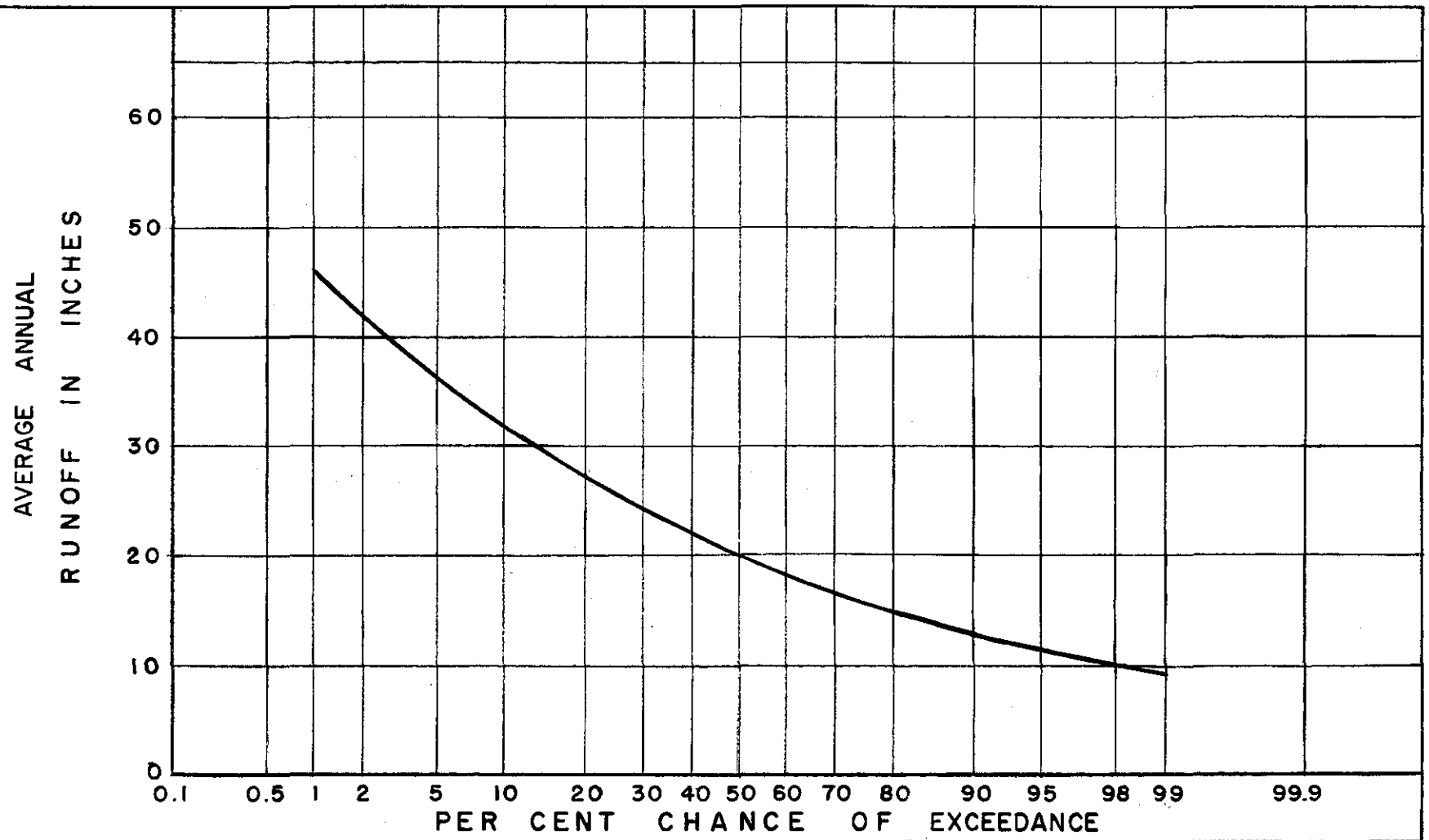


WATER YEARS 1917-1969

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

PRIEST BROOK RUNOFF

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS



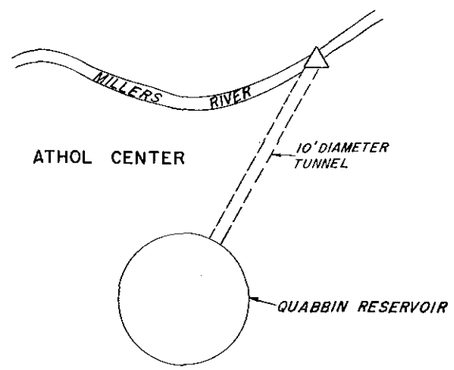
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

PRIEST BROOK

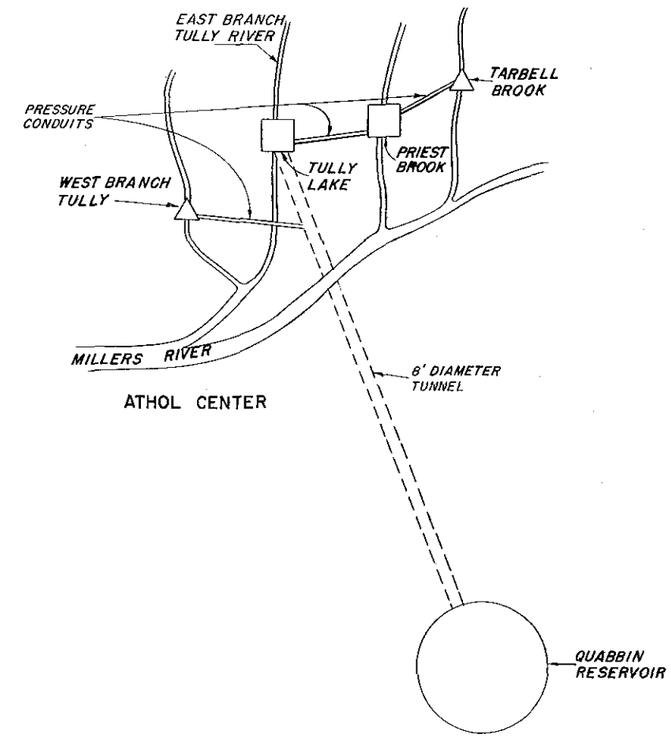
AVERAGE ANNUAL RUNOFF CURVE

PLATE C-3

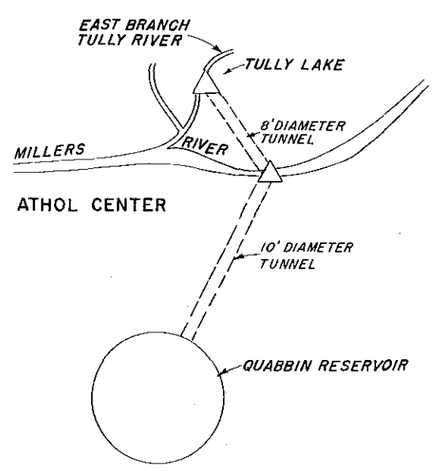
CORPS OF ENGINEERS U. S ARMY



ALTERNATE NO. 1
MILLERS RIVER DIVERSION
NOT TO SCALE



ALTERNATE NO. 3
TULLY COMPLEX DIVERSIONS
NOT TO SCALE



ALTERNATE NO. 2
TULLY - MILLERS RIVER DIVERSION
NOT TO SCALE

LEGEND

RIVER INTAKE

INTAKE WITH STORAGE

RESERVOIR

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

SCHEMATIC OF ALTERNATIVES

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS

TOTAL TRANSFERS TO QUABBIN---VIA MILLERS RIVER---TULLY SYSTEM HAS PRIORITY---POINT 19

CONN. RIVER CONTROL=17000. CFS

	DRAINAGE AREA	TRANSFER CAPACITY	MIN STORAGE	MAX STORAGE
TARBELL BROOK	25.60 SM	90. CFS		
PRIEST BROOK	19.40 SM	120. CFS	0. CFS-DAYS	2064. CFS-DAYS
TULLY RES.	50.40 SM	357. CFS	0. CFS-DAYS	2710. CFS-CAYS
W.BRANCH TULLY	18.60 SM	45. CFS		
MILLERS RIVER	200.50 SM	675. CFS		

TRANSFERS IN CFS-MON

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEARLY TRANSFER	ACCUM TRANSFER
1919	22.3	0.0	567.3	560.2	411.5	90.2	0.0	0.0	1.0	0.0	239.5	228.7	2120.6	2120.6
1920	0.0	0.0	391.9	675.0	572.3	73.7	0.0	0.0	0.0	159.2	10.0	488.6	2370.7	4491.4
1921	8.1	0.0	609.7	590.1	221.9	0.0	14.2	0.0	0.0	0.0	46.4	123.7	1614.0	6105.4
1922	0.0	0.0	522.6	638.2	384.4	307.9	300.5	0.0	0.0	0.0	0.0	0.0	2153.5	8259.0
1923	0.0	0.0	150.6	564.3	421.6	9.2	0.0	0.0	0.0	30.2	135.0	488.1	1799.0	10058.0

MEAN MONTHLY FLOWS IN CFS

6.	0.	448.	605.	402.	96.	62.	0.	0.	37.	86.	265.

THE DOWNSTREAM REQUIREMENTS FOR THE TULLY SYSTEM IN CSM ARE

0.50	0.50	0.50	1.25	1.25	1.25	2.00	1.00	0.75	0.75	0.75	0.50

THE DOWNSTREAM REQUIREMENTS FOR THE MILLERS RIVER INTAKE IN CSM ARE

0.50	0.50	0.50	1.25	1.25	1.25	2.00	1.00	0.75	0.75	0.75	0.50

THE AVERAGE OVER THE PERIOD OF RECORD IS 108.3 MGD

NORTHEASTERN UNITED STATES

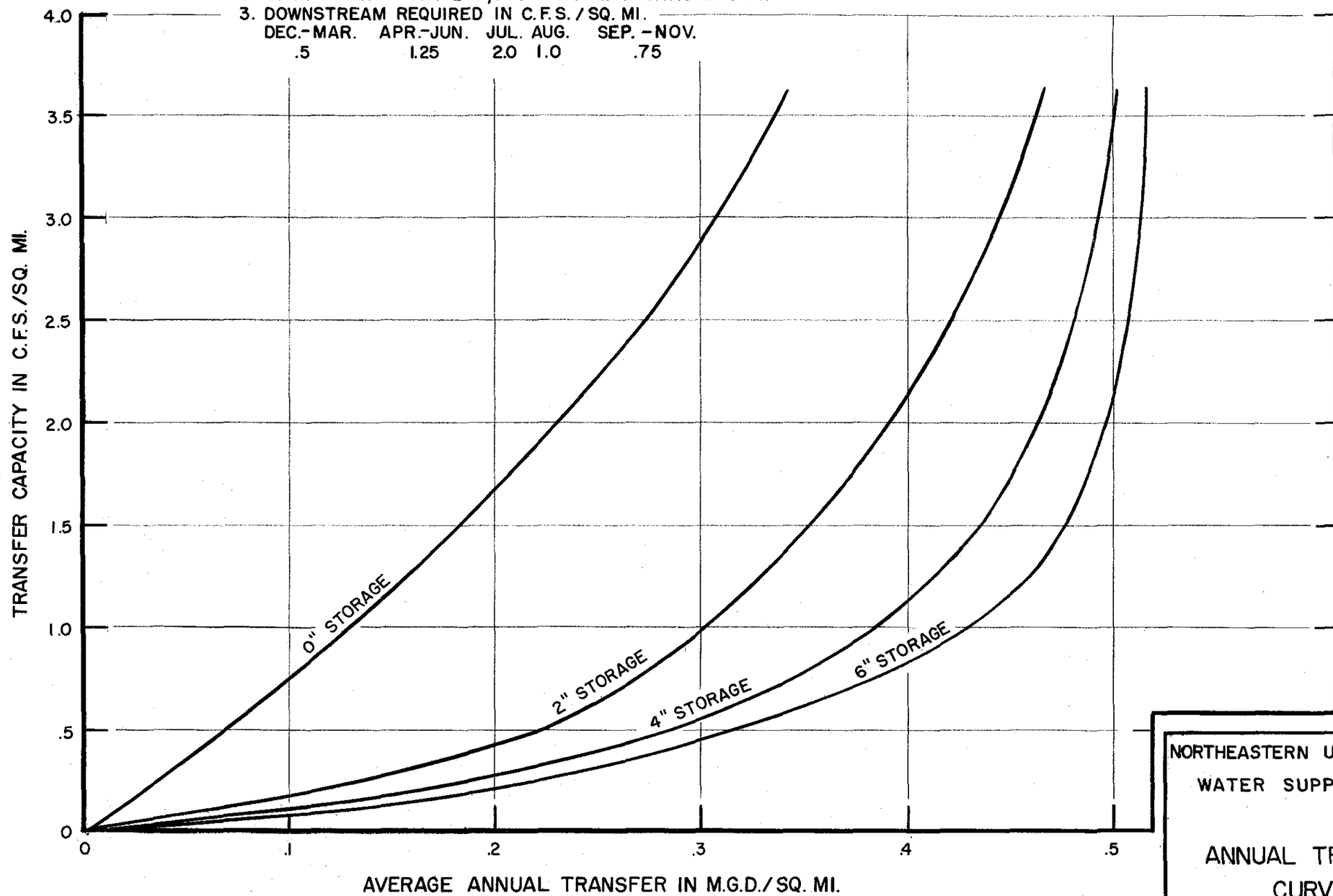
WATER SUPPLY STUDY

SAMPLE OUTPUT

NOTES:

1. INDEX STATION: PRIEST BROOK D.A. = 194 SQ. MI.
2. CONN. RIVER CONTROL: 17,000 C.F.S. AT MONTAGUE CITY.
3. DOWNSTREAM REQUIRED IN C.F.S. / SQ. MI.

DEC.-MAR.	APR.-JUN.	JUL. AUG.	SEP.-NOV.
.5	1.25	2.0 1.0	.75



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

ANNUAL TRANSFER
CURVES

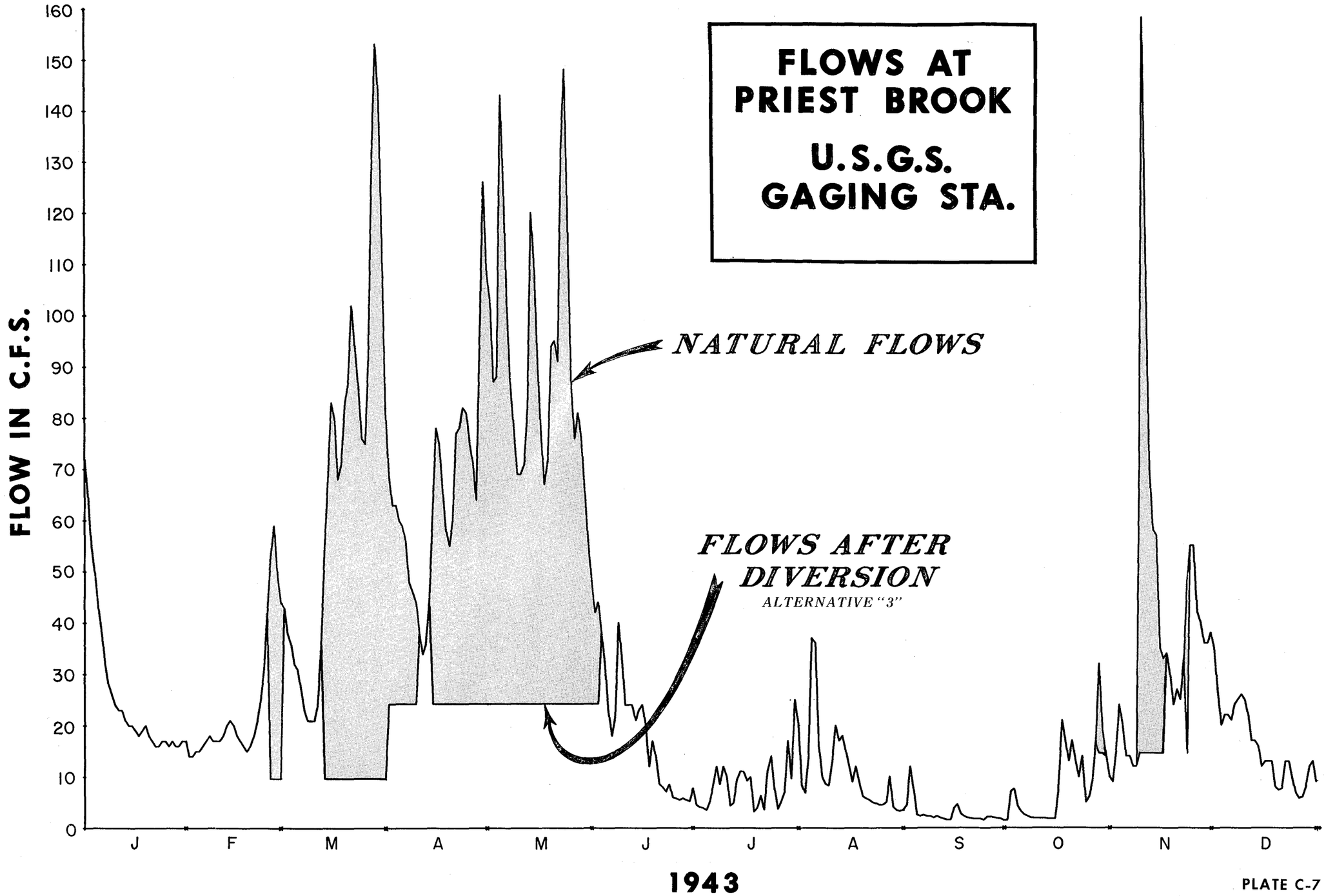

FLOWS AT
PRIEST BROOK
U.S.G.S.
GAGING STA.
NATURAL FLOWS
FLOWS AFTER
DIVERSION
ALTERNATIVE "3"
FLOW IN C.F.S.
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
1943

PLATE C-7

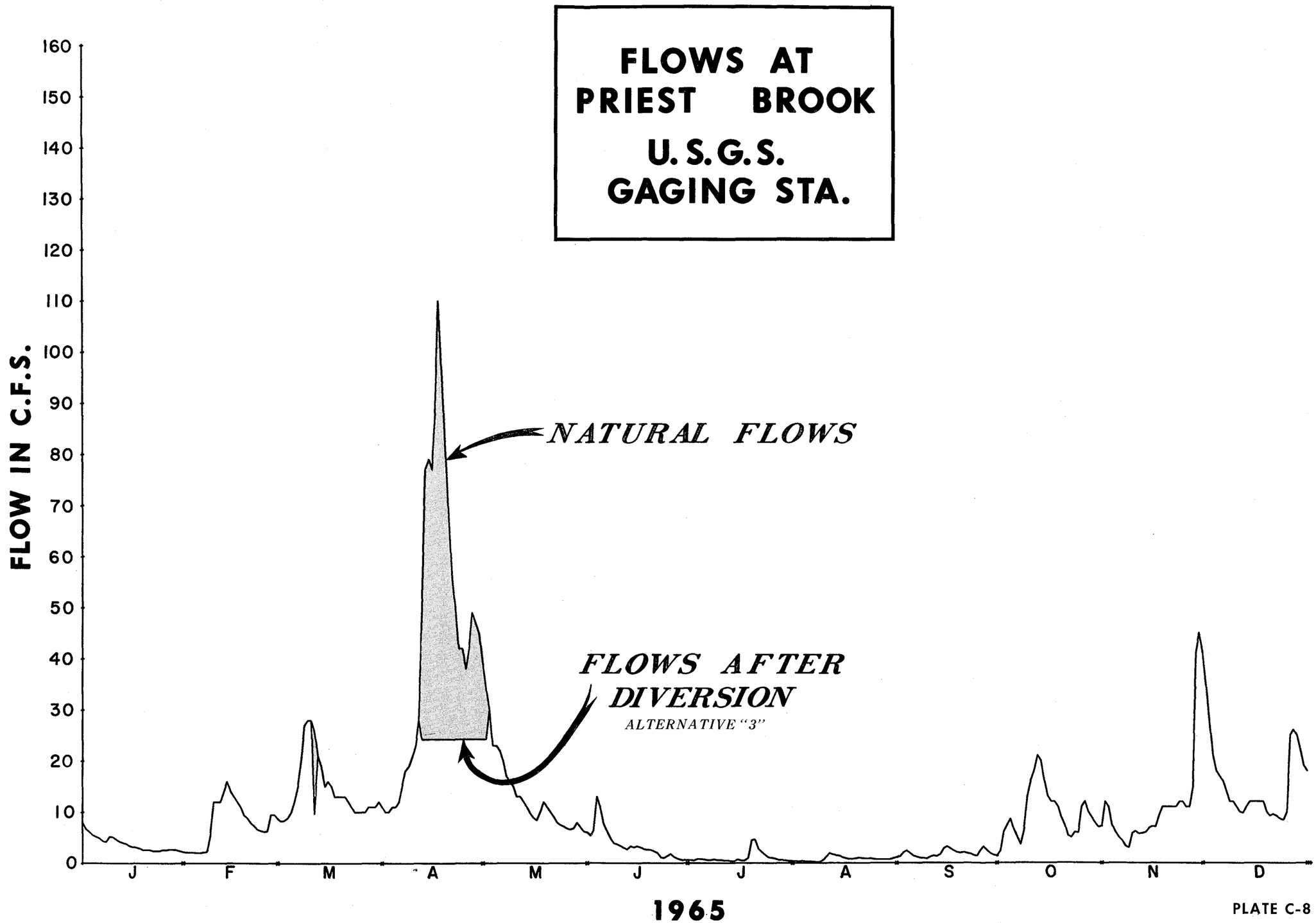

FLOWS AT
PRIEST BROOK
U.S.G.S.
GAGING STA.
FLOW IN C.F.S.
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
NATURAL FLOWS
FLOWS AFTER
DIVERSION
ALTERNATIVE "3"
J
F
M
A
M
J
J
A
S
O
N
D
1965

PLATE C-8

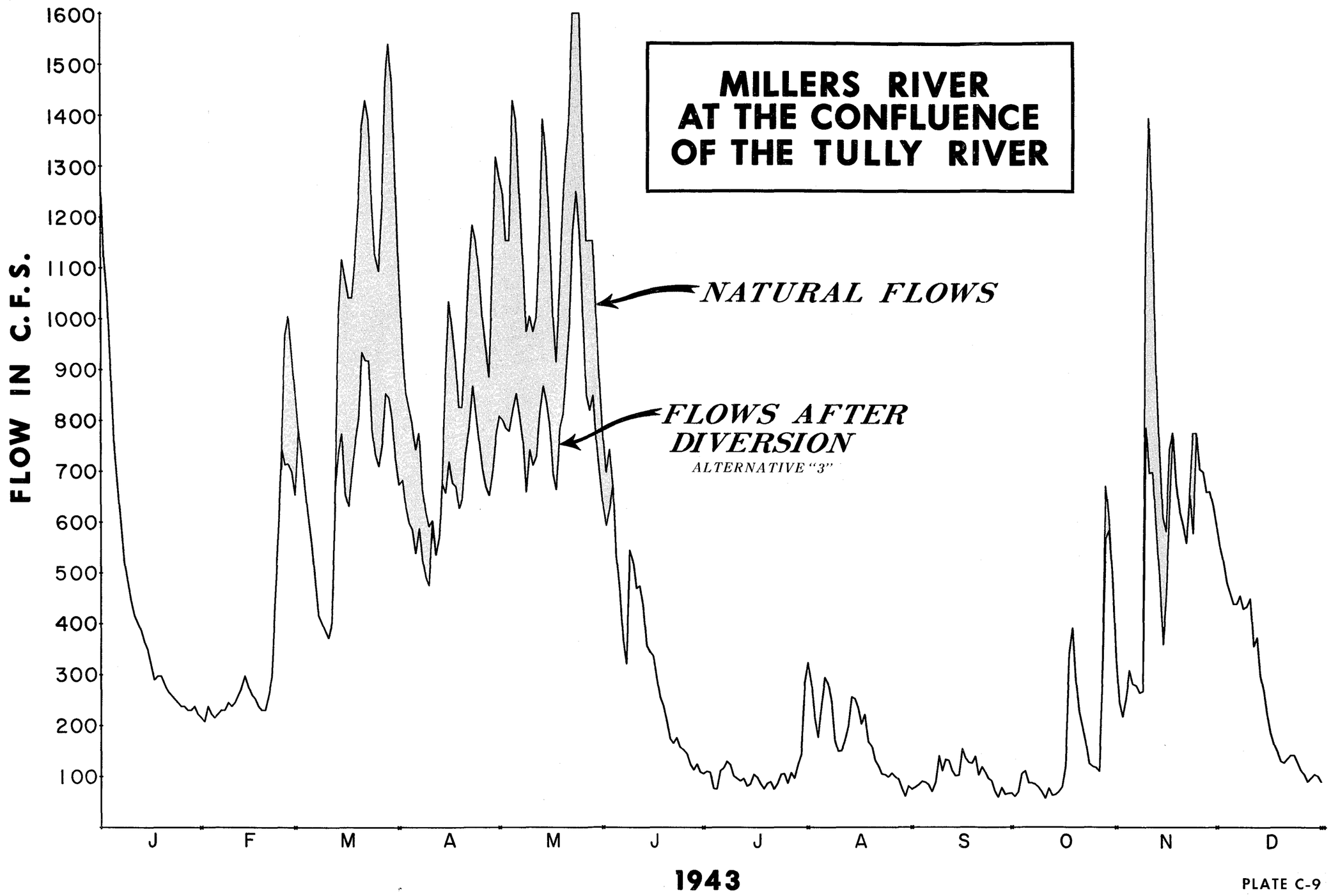

MILLERS RIVER
AT THE CONFLUENCE
OF THE TULLY RIVER
NATURAL FLOWS
FLOWS AFTER
DIVERSION
ALTERNATIVE "3"
FLOW IN C.F.S.
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
J
F
M
A
M
J
J
A
S
O
N
D
1943

PLATE C-9

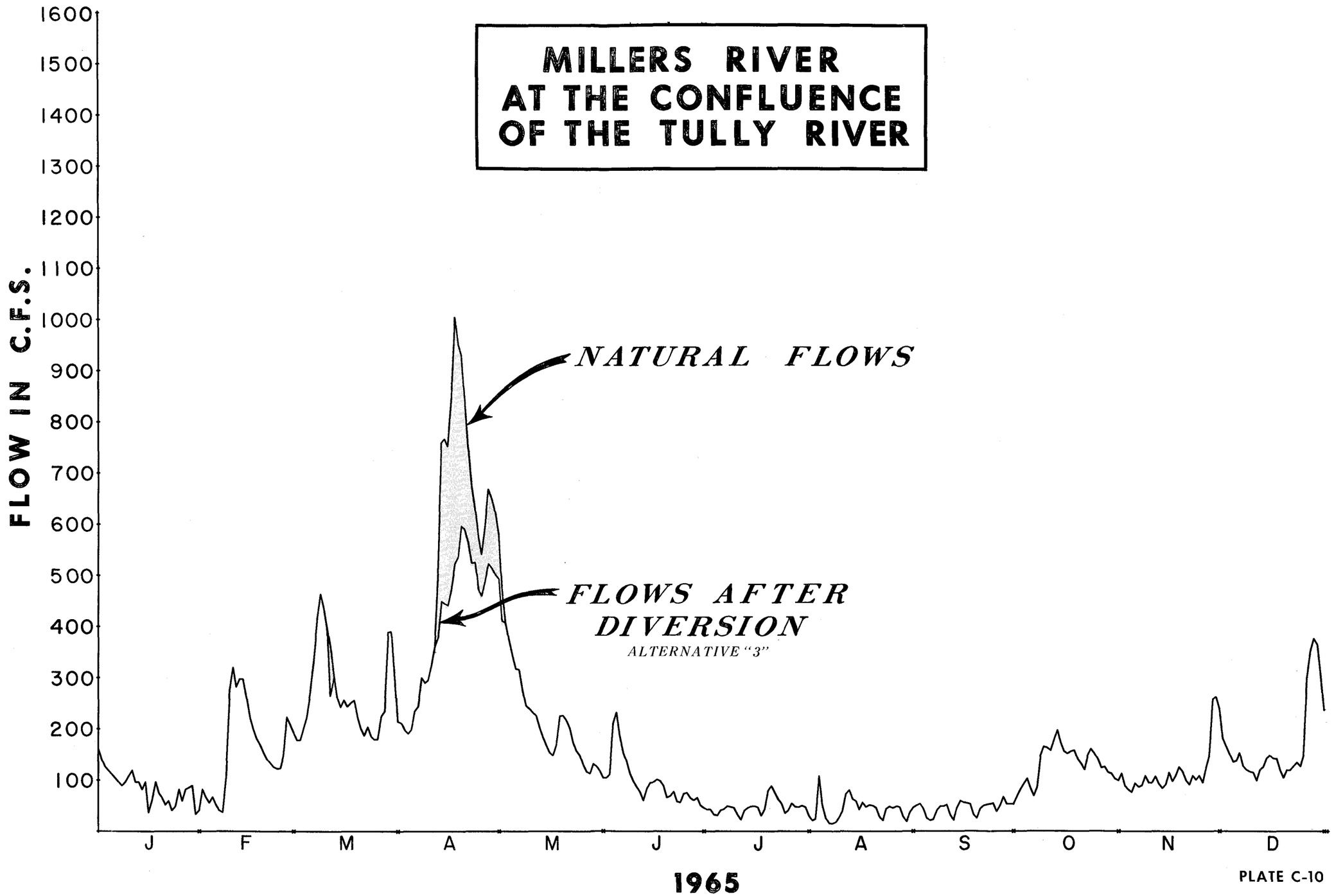

MILLERS RIVER
AT THE CONFLUENCE
OF THE TULLY RIVER
FLOW IN C.F.S.
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
NATURAL FLOWS
FLOWS AFTER DIVERSION
ALTERNATIVE "3"
J
F
M
A
M
J
J
A
S
O
N
D
1965

PLATE C-10

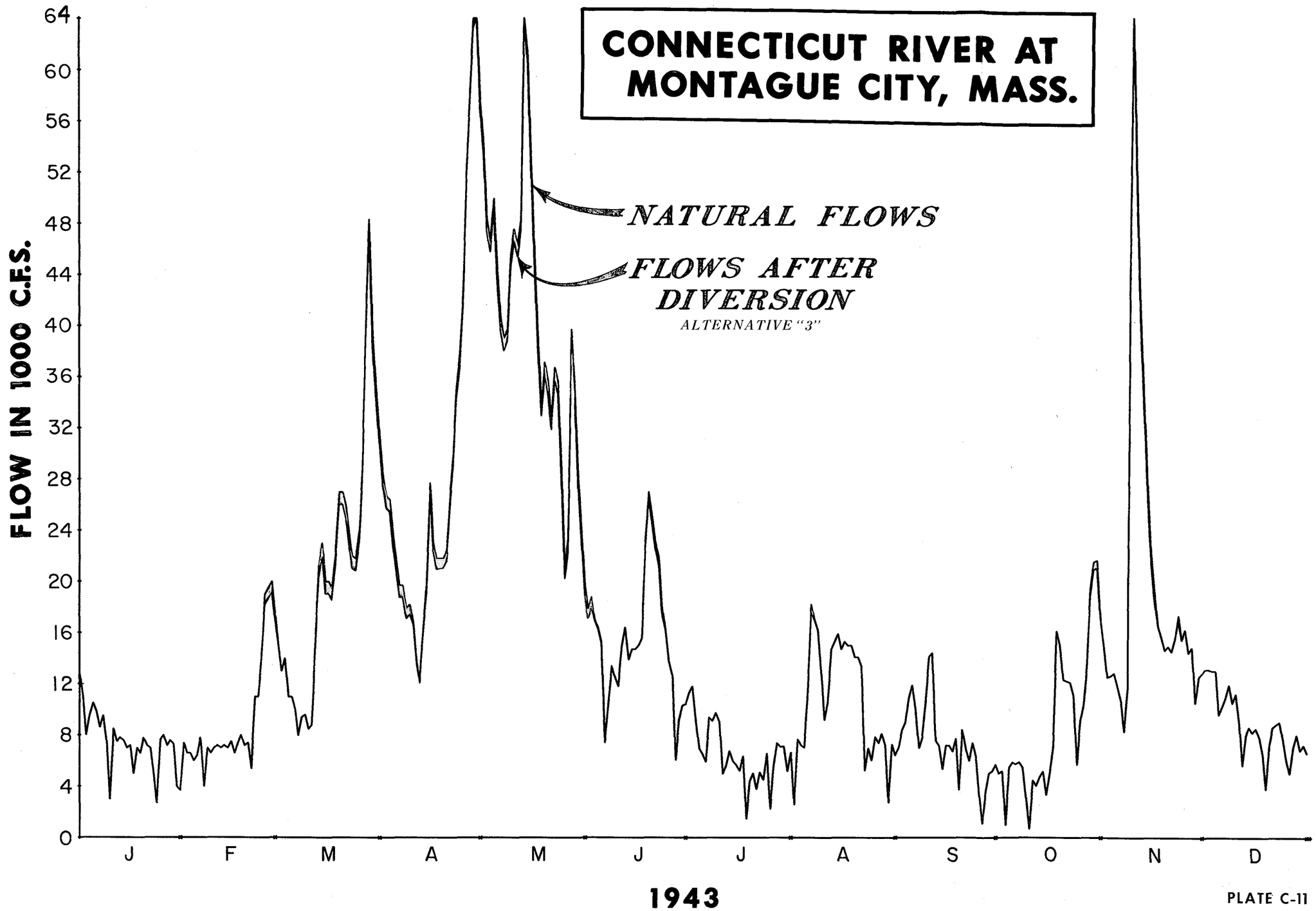

CONNECTICUT RIVER AT MONTAGUE CITY, MASS.
NATURAL FLOWS
FLOWS AFTER DIVERSION
ALTERNATIVE "3"
FLOW IN 1000 C.F.S.
64
60
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
J
F
M
A
M
J
J
A
S
O
N
D
1943

PLATE C-11

CONNECTICUT RIVER AT MONTAGUE CITY, MASS.

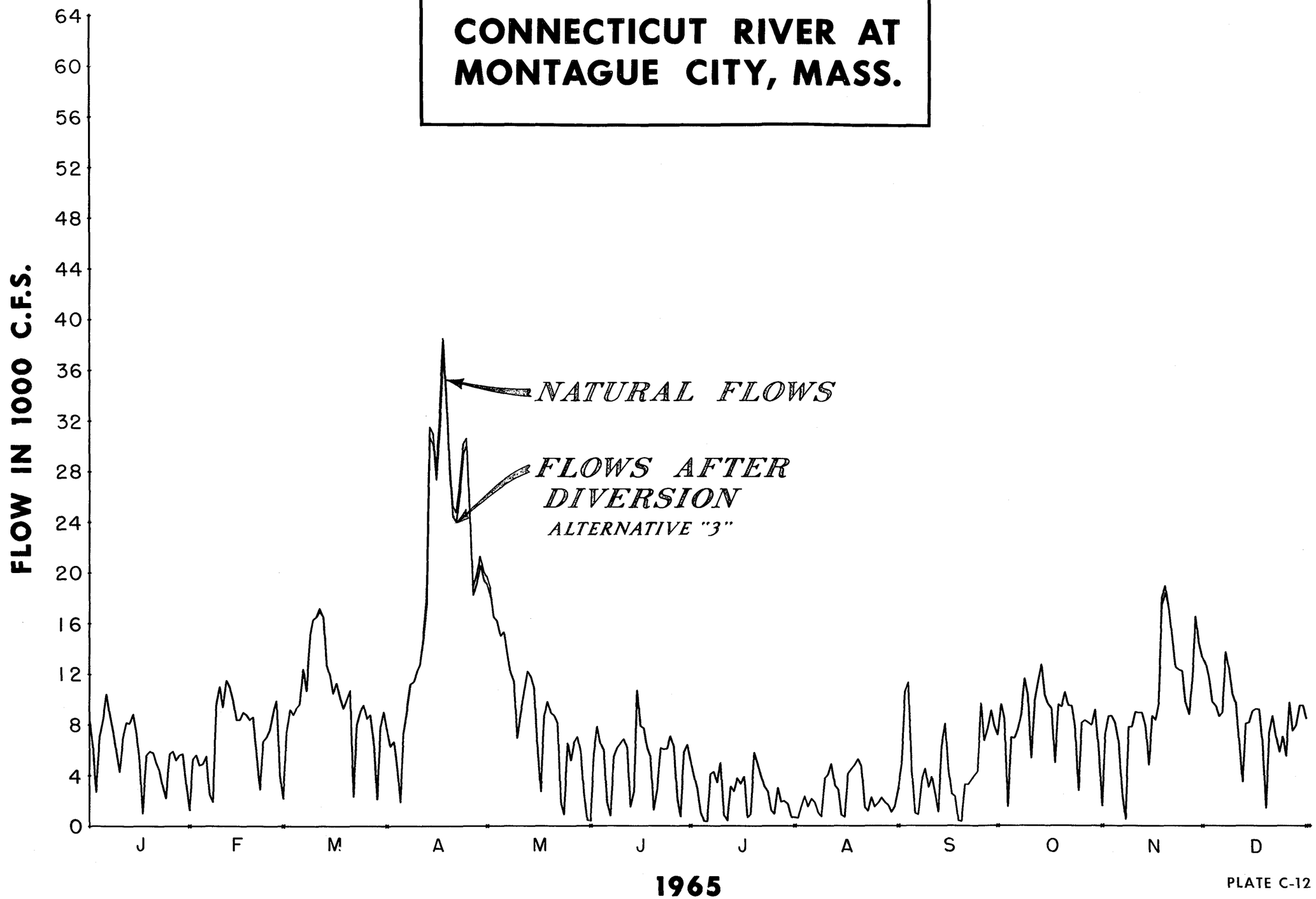


PLATE C-12

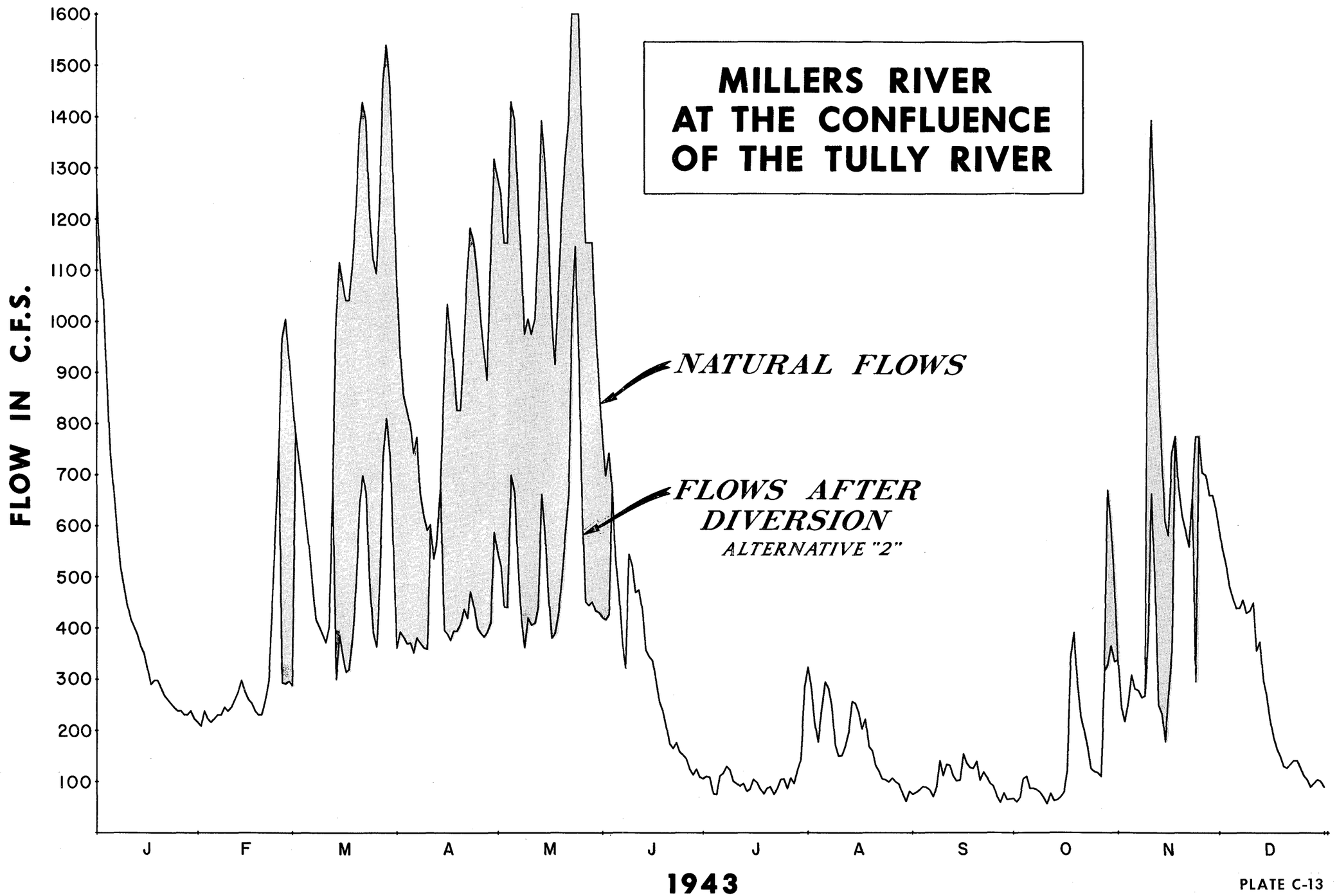

MILLERS RIVER
AT THE CONFLUENCE
OF THE TULLY RIVER
NATURAL FLOWS
FLOWS AFTER
DIVERSION
ALTERNATIVE "2"
FLOW IN C.F.S.
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
J
F
M
A
M
J
J
A
S
O
N
D
1943

PLATE C-13

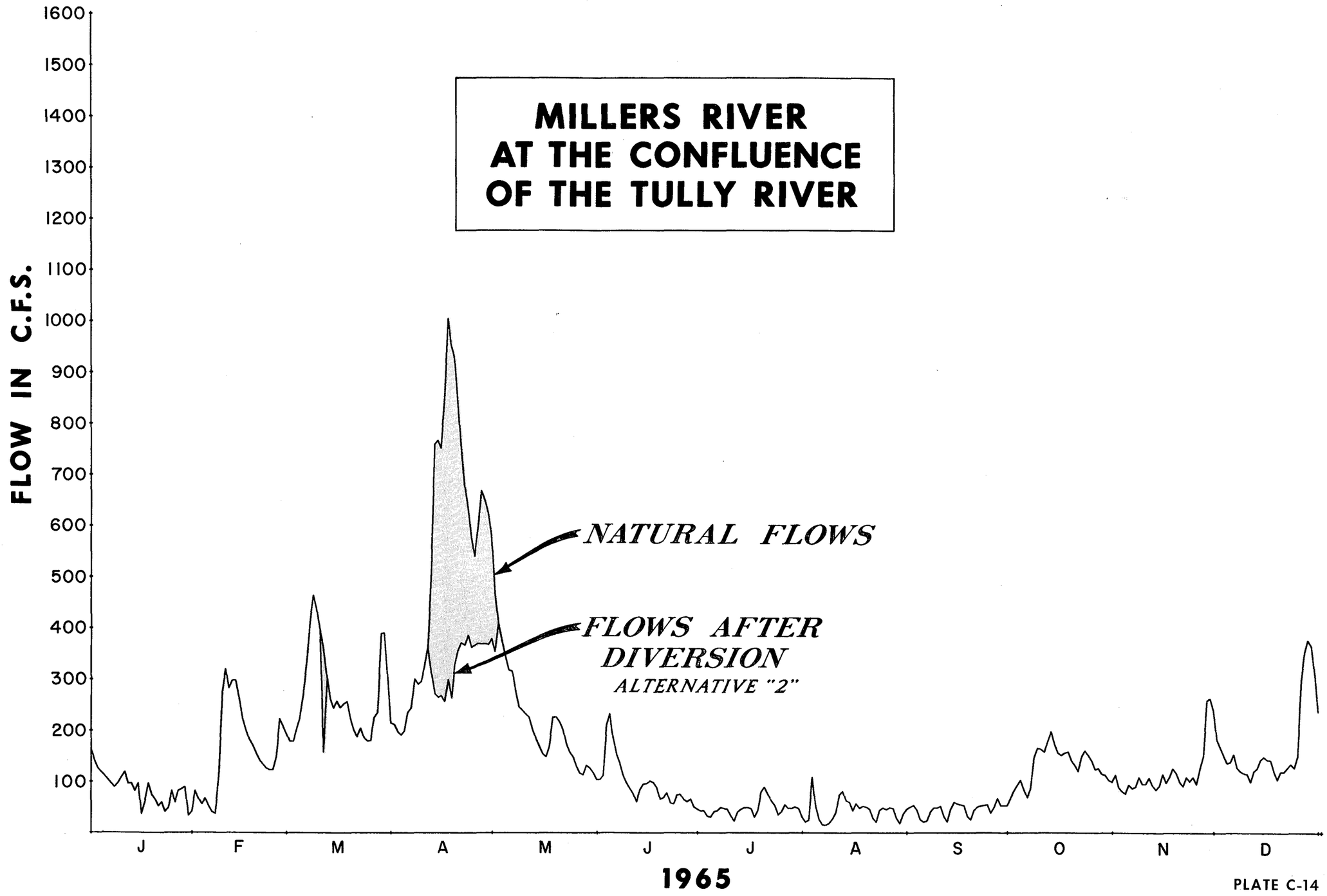
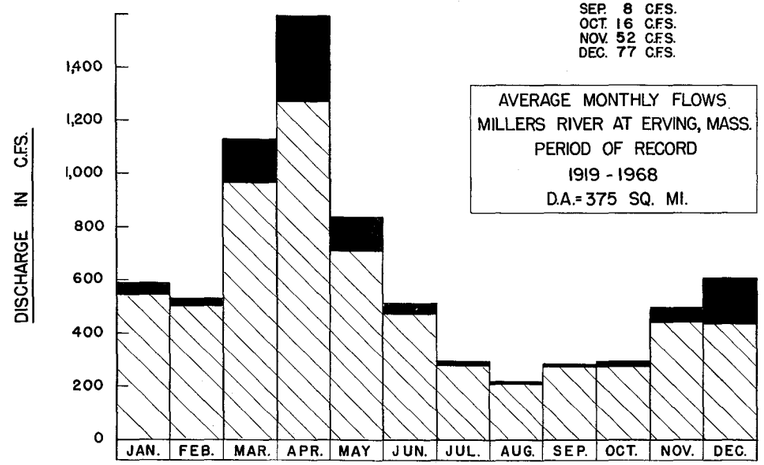

MILLERS RIVER
AT THE CONFLUENCE
OF THE TULLY RIVER
FLOW IN C.F.S.
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
NATURAL FLOWS
FLOWS AFTER
DIVERSION
ALTERNATIVE "2"
J
F
M
A
M
J
J
A
S
O
N
D
1965

PLATE C-14

AVERAGE MONTHLY TRANSFERS

JAN. 49 C.F.S.
FEB. 30 C.F.S.
MAR. 145 C.F.S.
APR. 303 C.F.S.
MAY 159 C.F.S.
JUN. 37 C.F.S.
JUL. 10 C.F.S.
AUG. 3 C.F.S.
SEP. 8 C.F.S.
OCT. 16 C.F.S.
NOV. 52 C.F.S.
DEC. 77 C.F.S.

AVERAGE MONTHLY FLOWS
MILLERS RIVER AT ERVING, MASS.
PERIOD OF RECORD
1919 - 1968
D.A.=375 SQ. MI.

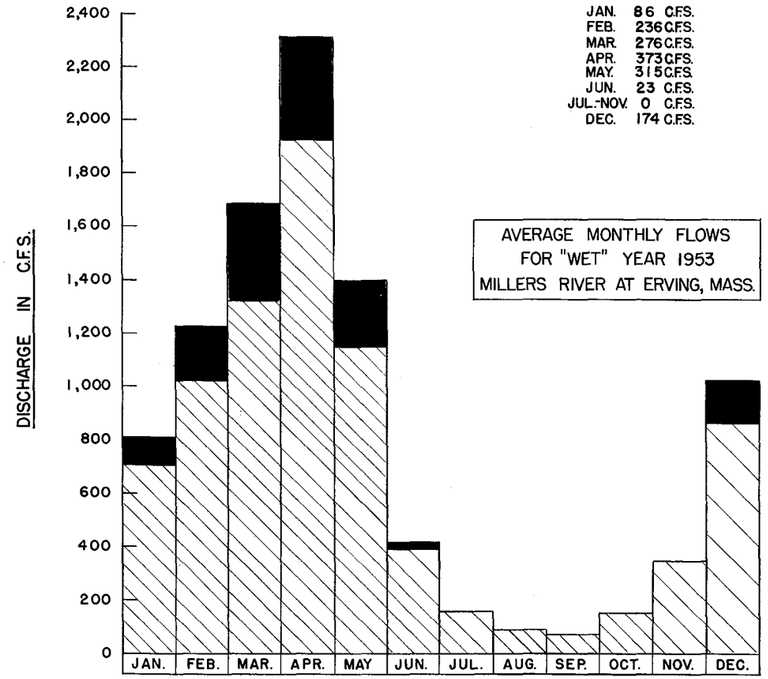


MONTHS OF YEAR

AVERAGE MONTHLY TRANSFERS

JAN. 86 C.F.S.
FEB. 236 C.F.S.
MAR. 276 C.F.S.
APR. 373 C.F.S.
MAY. 315 C.F.S.
JUN. 23 C.F.S.
JUL.-NOV. 0 C.F.S.
DEC. 174 C.F.S.

AVERAGE MONTHLY FLOWS
FOR "WET" YEAR 1953
MILLERS RIVER AT ERVING, MASS.

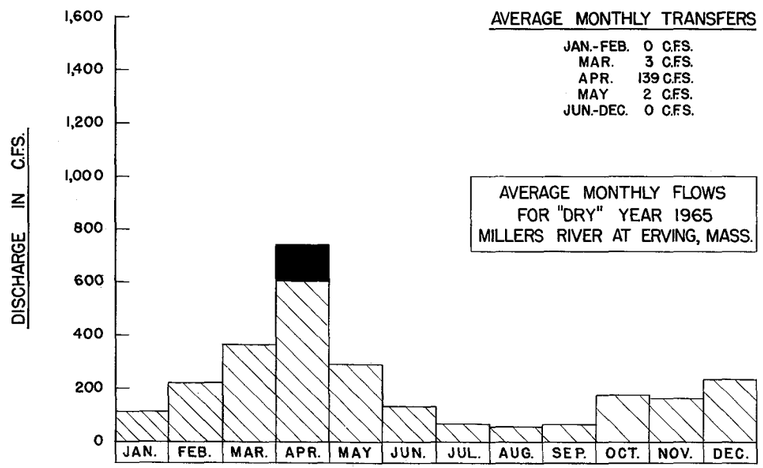


MONTHS OF YEAR

AVERAGE MONTHLY TRANSFERS

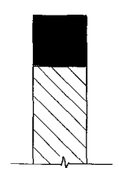
JAN.-FEB. 0 C.F.S.
MAR. 3 C.F.S.
APR. 139 C.F.S.
MAY 2 C.F.S.
JUN.-DEC. 0 C.F.S.

AVERAGE MONTHLY FLOWS
FOR "DRY" YEAR 1965
MILLERS RIVER AT ERVING, MASS.



MONTHS OF YEAR

LEGEND:



1. DENOTES MEAN MONTHLY DIVERSION TO QUABBIN RESERVIOR FROM THE TULLY SYSTEM

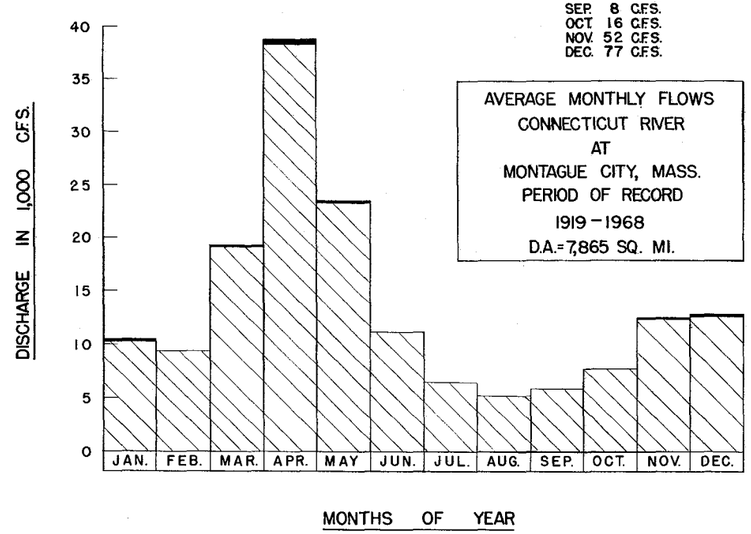
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

MEAN MONTHLY REDUCTIONS
MILLERS RIVER AT ERVING
ALTERNATIVE NO.3

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS

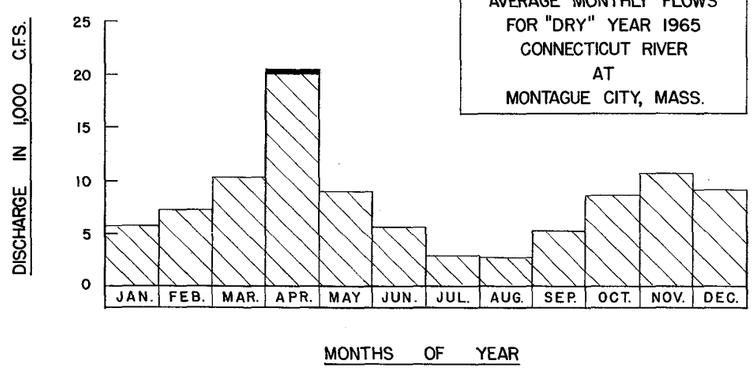
AVERAGE MONTHLY TRANSFERS

JAN. 49 C.F.S.
FEB. 30 C.F.S.
MAR. 145 C.F.S.
APR. 303 C.F.S.
MAY 159 C.F.S.
JUN. 37 C.F.S.
JUL. 10 C.F.S.
AUG. 3 C.F.S.
SEP. 8 C.F.S.
OCT. 16 C.F.S.
NOV. 52 C.F.S.
DEC. 77 C.F.S.



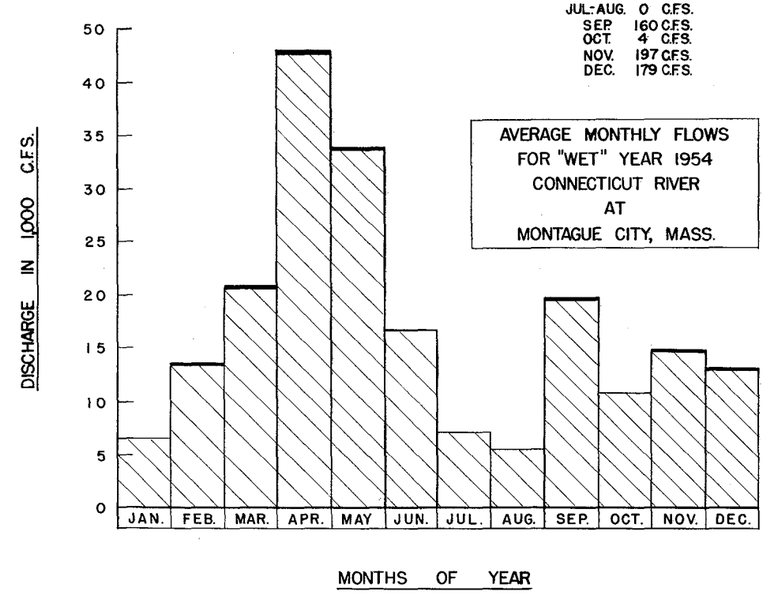
AVERAGE MONTHLY TRANSFERS

JAN.-FEB. 0 C.F.S.
MAR. 3 C.F.S.
APR. 139 C.F.S.
MAY 2 C.F.S.
JUN.-DEC. 0 C.F.S.

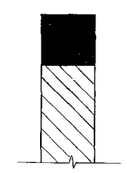


AVERAGE MONTHLY TRANSFERS

JAN. 0 C.F.S.
FEB. 94 C.F.S.
MAR. 250 C.F.S.
APR. 188 C.F.S.
MAY 295 C.F.S.
JUN. 23 C.F.S.
JUL.-AUG. 0 C.F.S.
SEP. 160 C.F.S.
OCT. 4 C.F.S.
NOV. 197 C.F.S.
DEC. 179 C.F.S.



LEGEND:

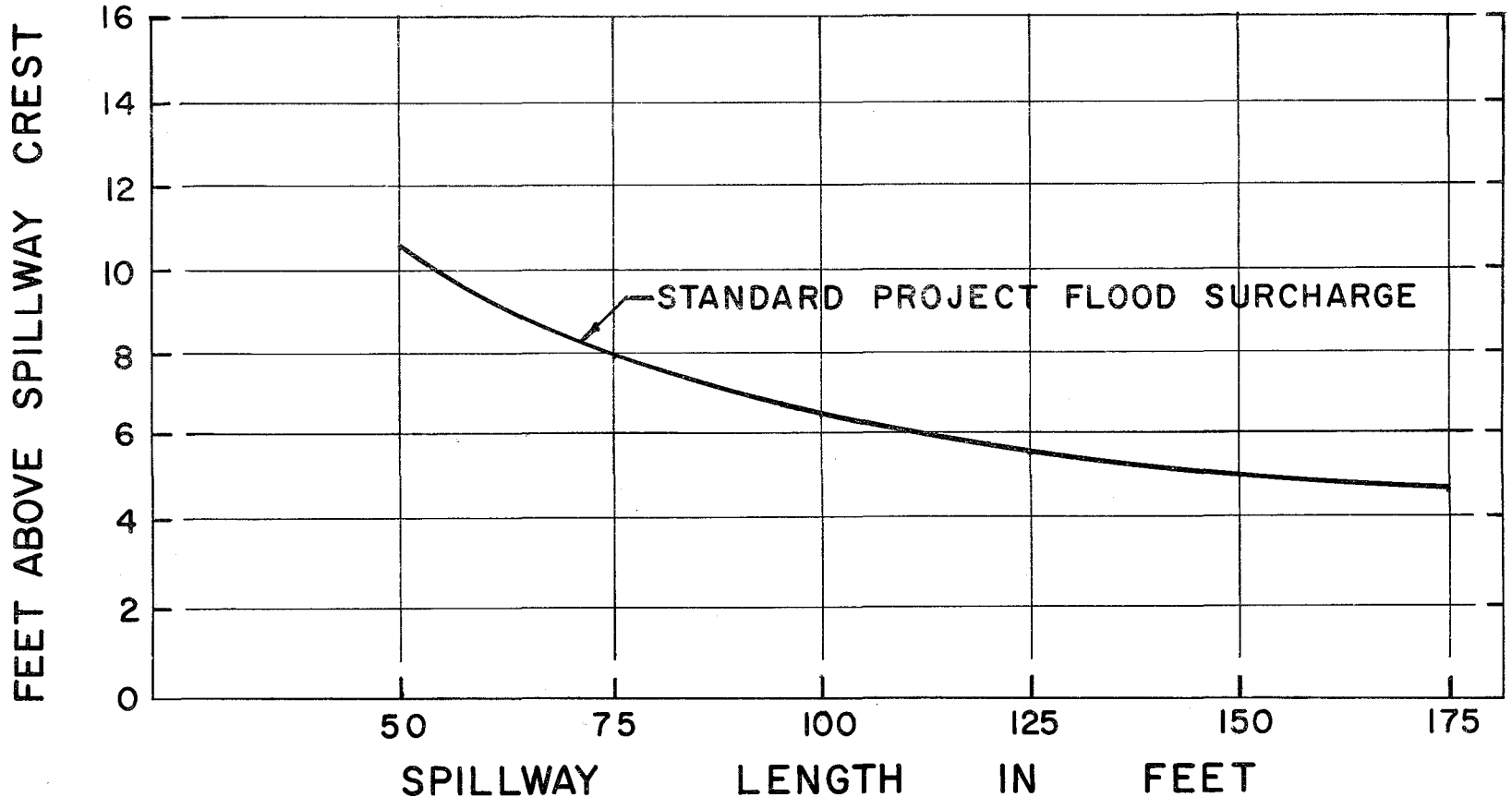


1. DENOTES MEAN MONTHLY DIVERSION TO QUABBIN RESERVIOR FROM THE TULLY SYSTEM

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

MONTHLY REDUCTIONS
CONNECTICUT RIVER AT MONTAGUE CITY
ALTERNATIVE NO. 3

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

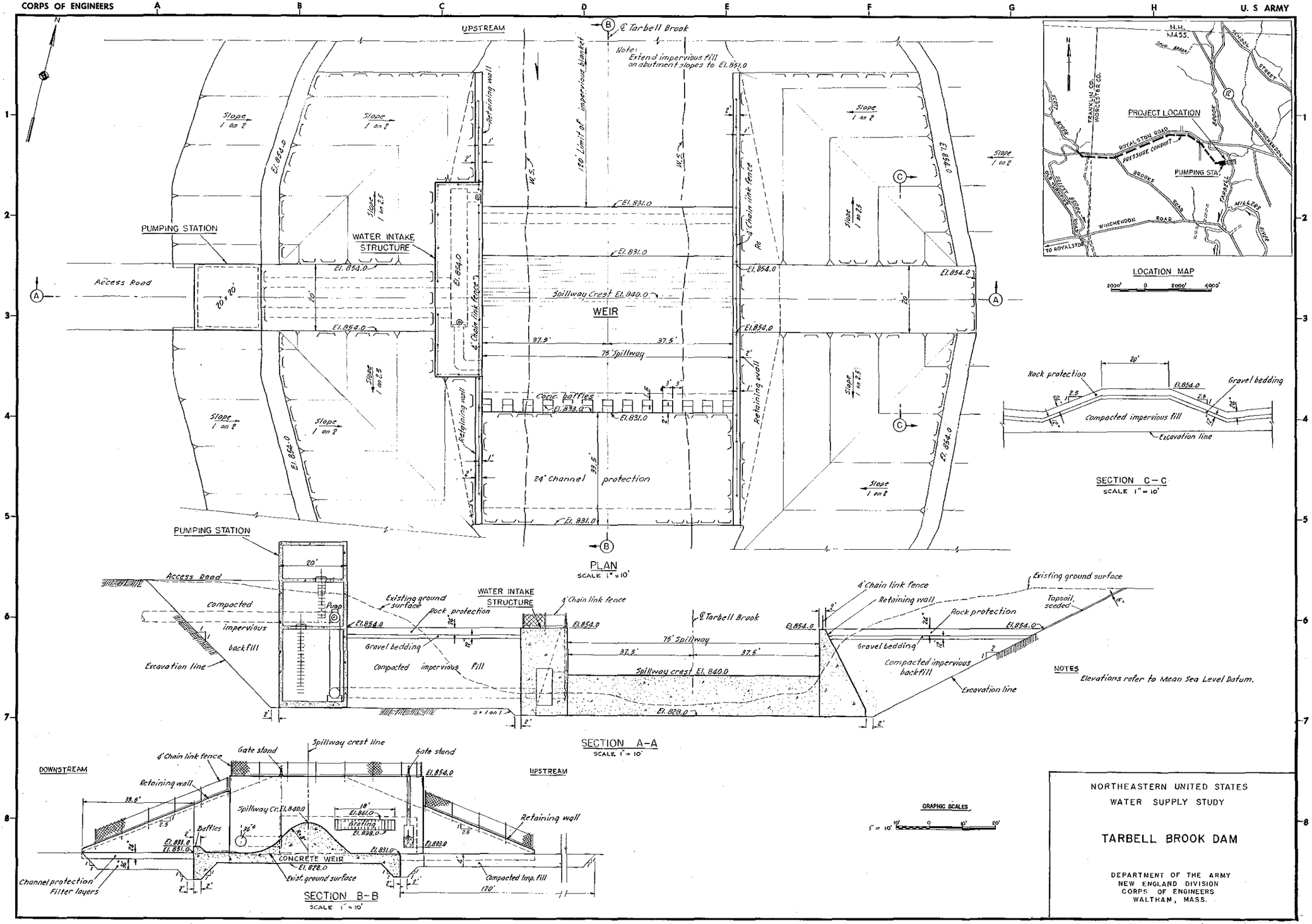
PRIEST BROOK RESERVOIR
SPILLWAY SURCHARGE

LENGTH CURVE

DRAINAGE AREA-19.4 SQ. MILES

PLATE C-17

CORPS OF ENGINEERS U. S ARMY



NOTES

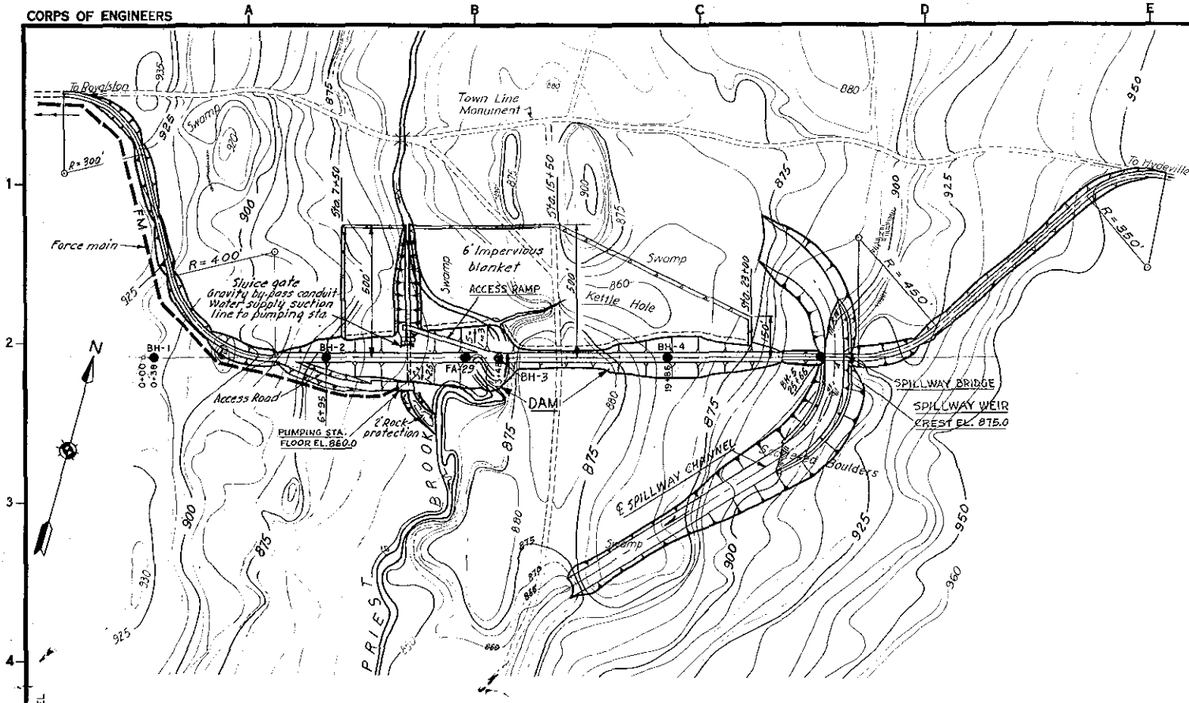
Elevations refer to Mean Sea Level Datum.

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TARBELL BROOK DAM

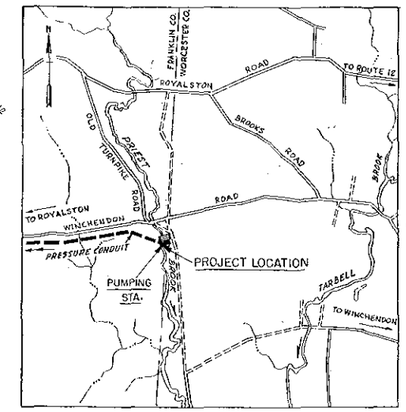
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE C-18

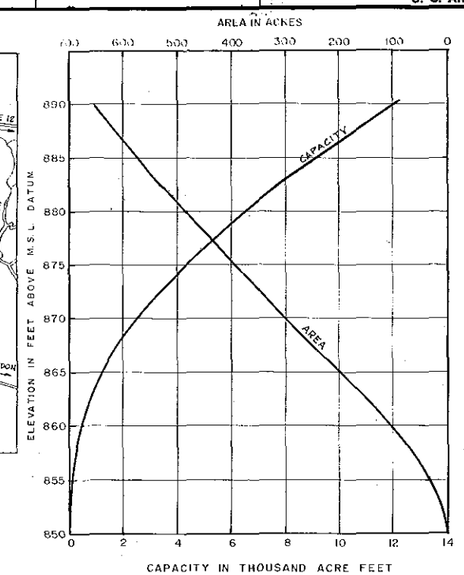


PLAN

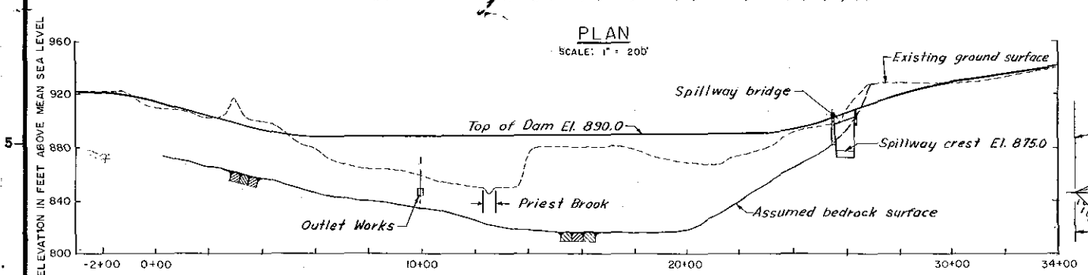
SCALE: 1" = 200'



LOCATION MAP

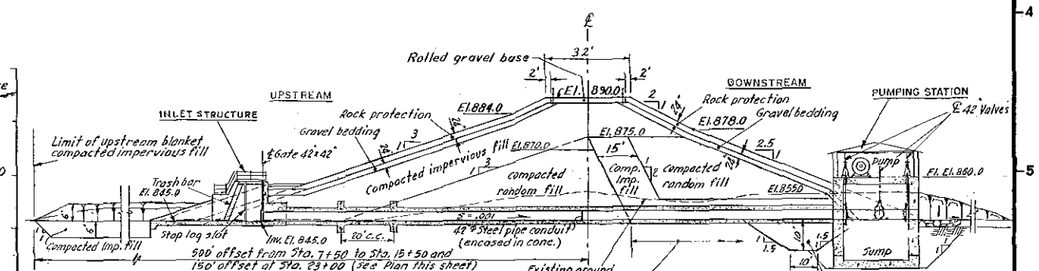


AREA-CAPACITY CURVE



℄ PROFILE

SCALE HOR 1" = 200' VERT 1" = 40'



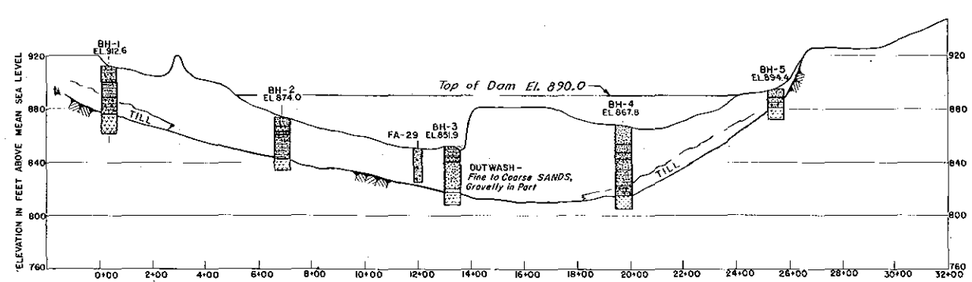
℄ OUTLET CONDUIT TYPICAL DAM SECTION

SCALE 1"=20'

STA. 6+00 TO STA. 22+00

NOTES

Elevations refer to Mean Sea Level Datum.



GEOLOGIC PROFILE ON ℄ OF DAM

SCALE HOR 1" = 200' VERT 1" = 40'

GRAPHIC LEGEND

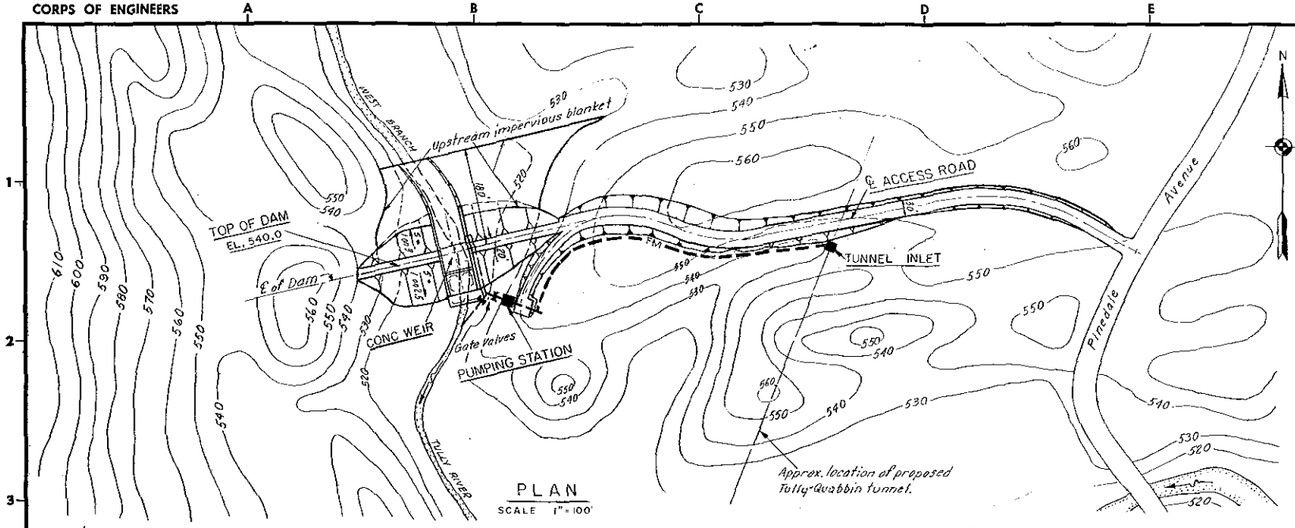
SAND
SILT OR ROCK FLOUR
CLAY
GRAVEL
GRANITE
WEATHERED OR FRACTURED ROCK
ROCK EXPOSURE
ASSUMED ROCK SURFACE
BH = TEST BORING-1936
FA = AUGER BORING-1931

GRAPHIC SCALES

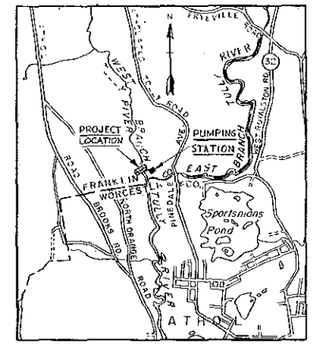
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

PRIEST BROOK DAM

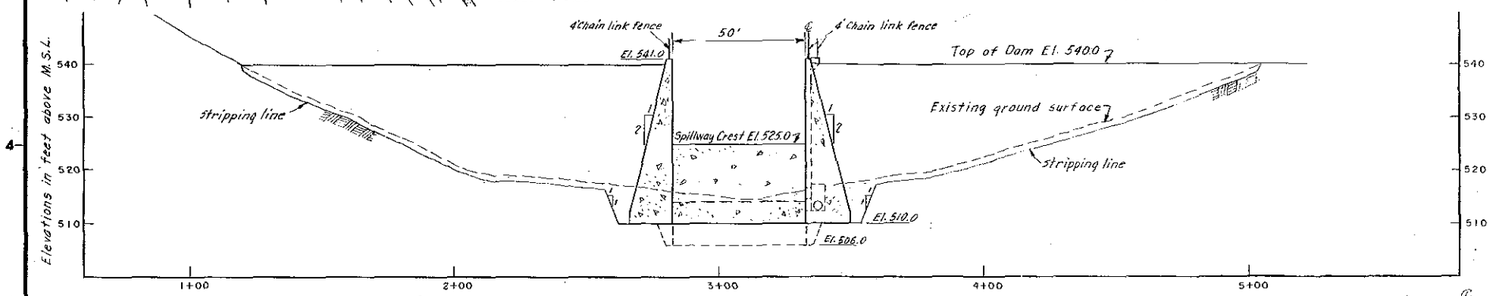
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.



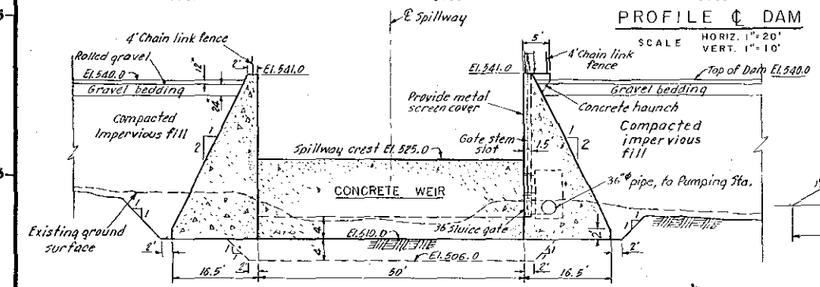
PLAN
SCALE 1" = 100'



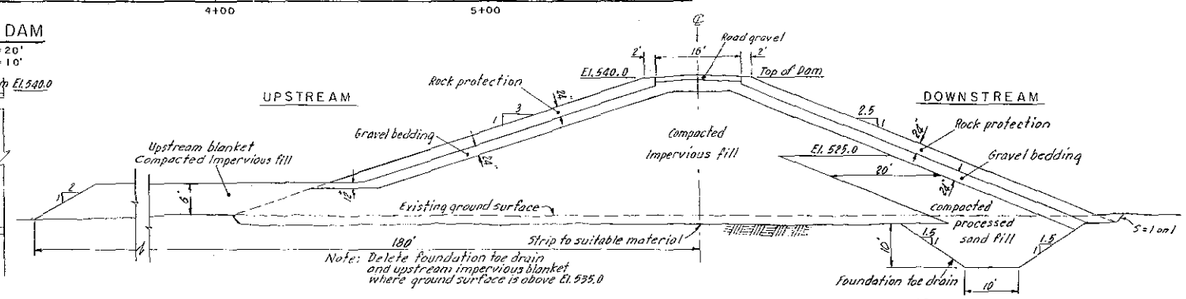
LOCATION MAP
SCALE 1" = 2,000'



PROFILE ℄ DAM
SCALE HORIZ. 1" = 20' VERT. 1" = 10'

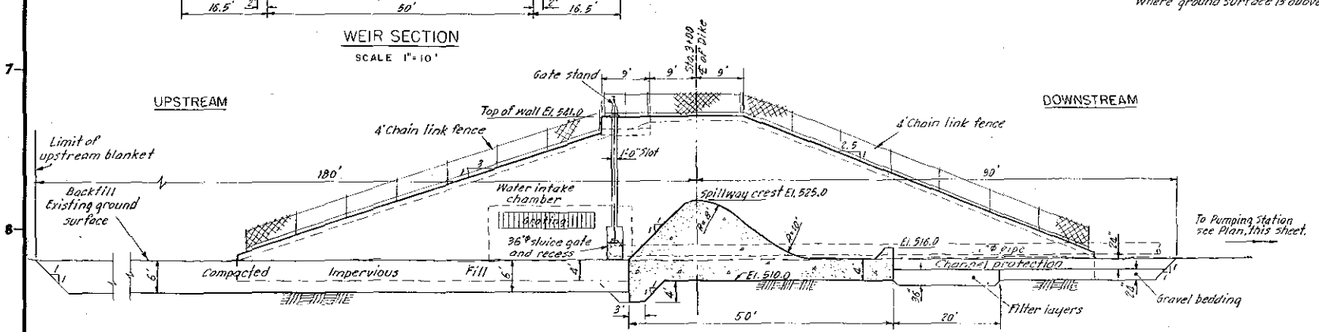


WEIR SECTION
SCALE 1" = 10'



TYPICAL DAM SECTION
SCALE 1" = 10'

NOTES
Elevations refer to Mean Sea Level Datum.



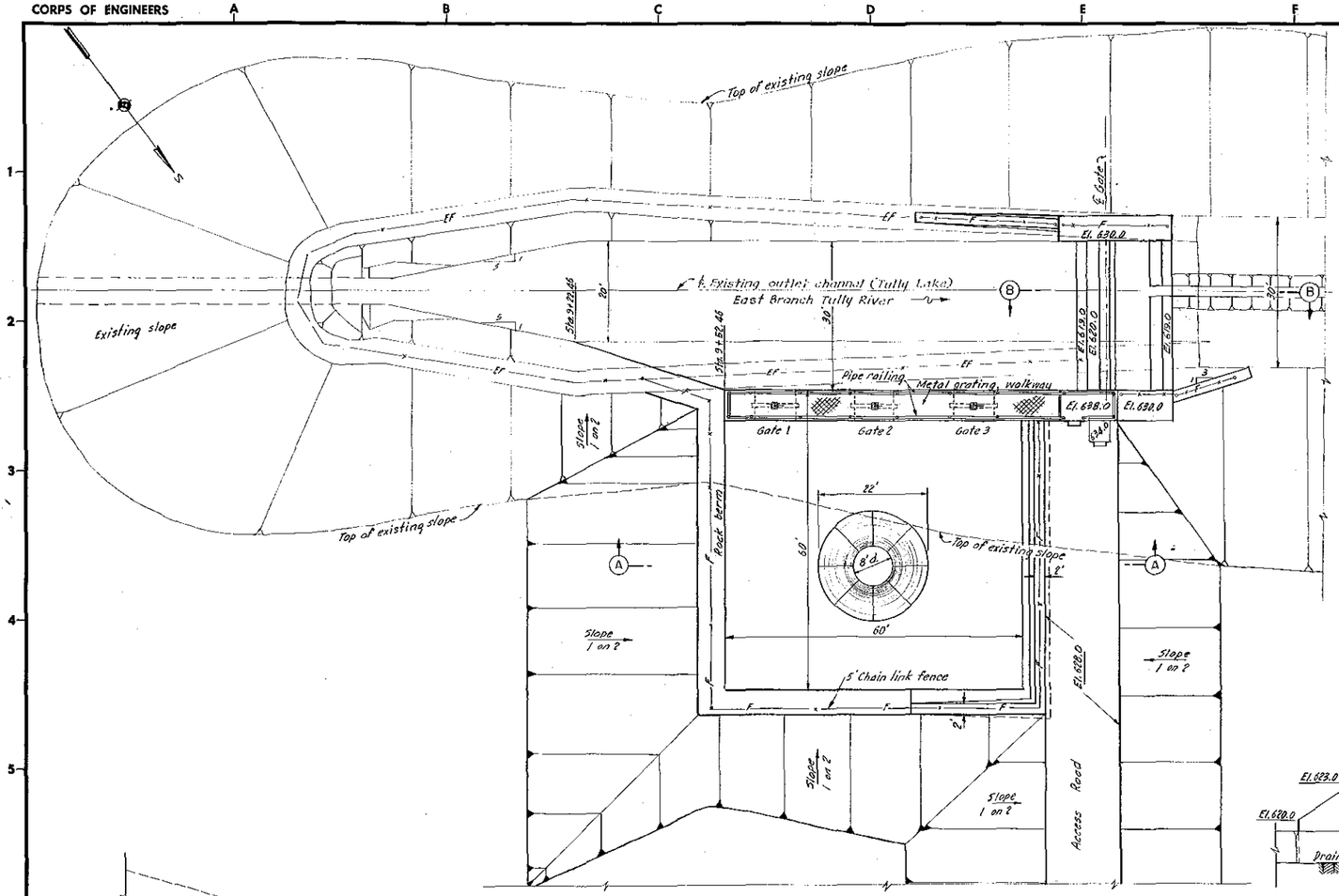
SECTIONAL ELEVATION
SCALE 1" = 10'

GRAPHIC SCALES
1" = 10' 10' 0 10' 20'
1" = 20' 20' 0 20' 40'
1" = 100' 100' 0 100' 200'
1" = 2,000' 2,000' 0 2,000' 4,000'

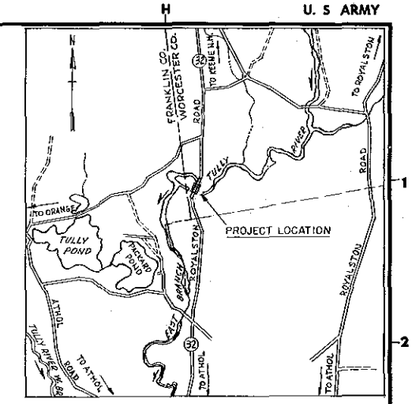
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

WEST BRANCH TULLY DAM

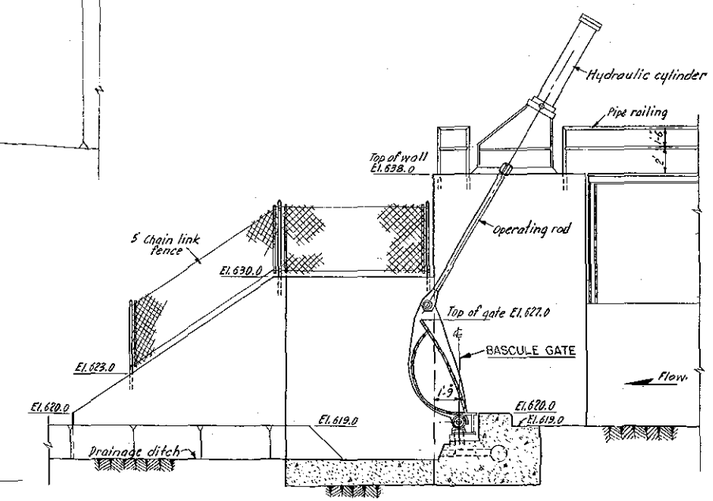
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.



PLAN
SCALE 1" = 10'



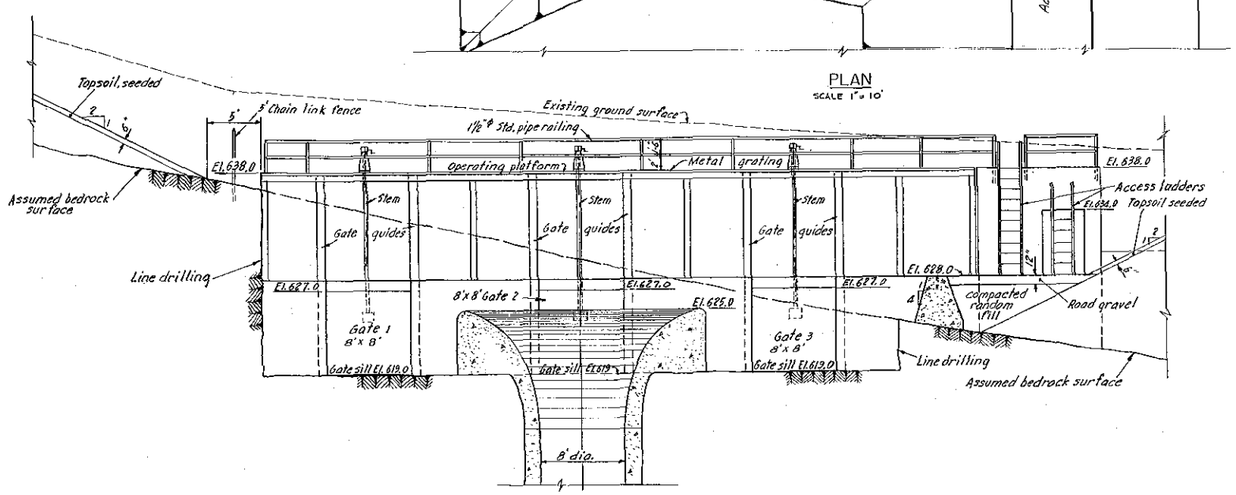
LOCATION MAP



SECTION B–B
SCALE 1/4" = 1'-0"

NOTES

Elevations refer to Mean Sea Level Datum.



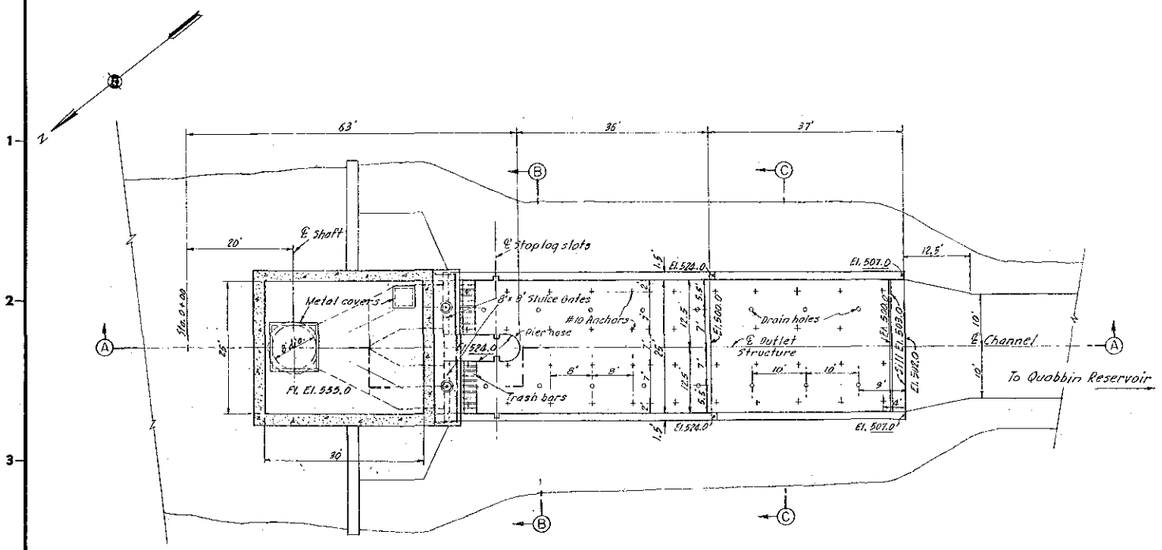
SECTION A–A
SCALE 1" = 5'

GRAPHIC SCALES

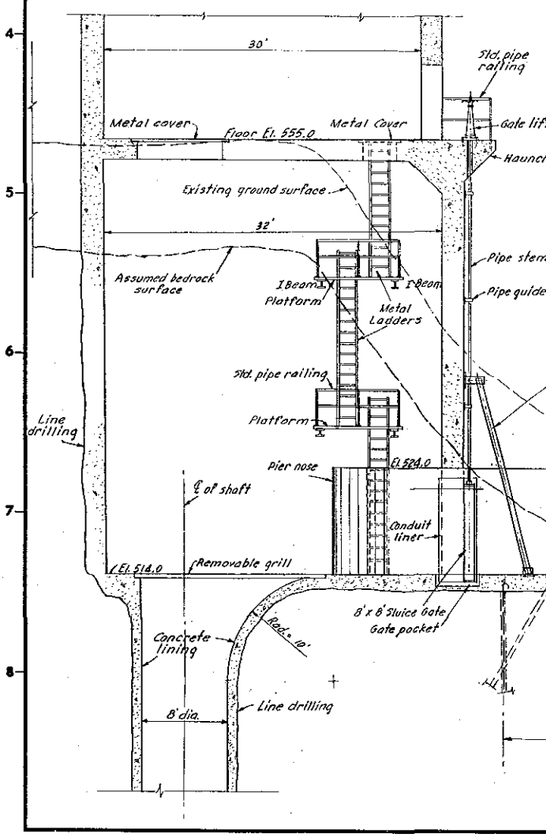
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

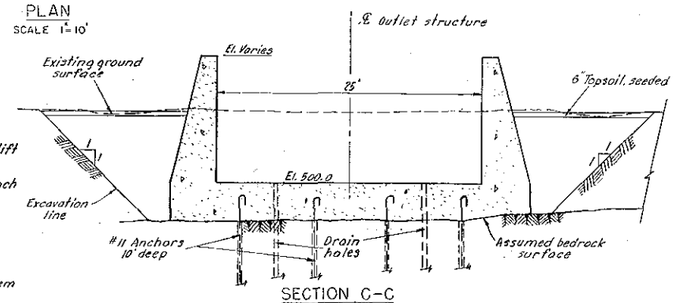
EAST BRANCH TULLY RIVER
TUNNEL INLET STRUCTURE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

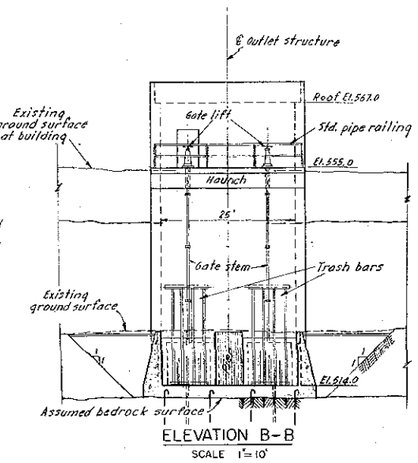


PLAN
SCALE 1" = 10'

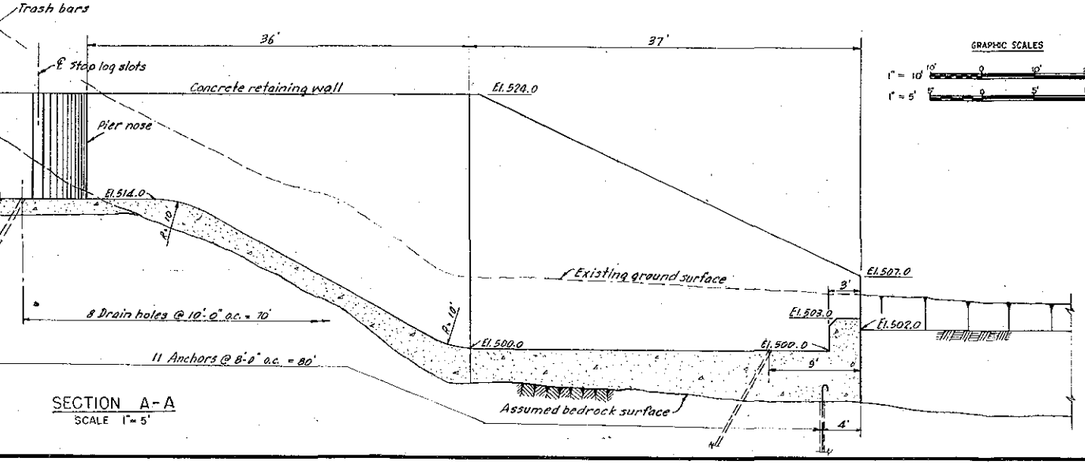




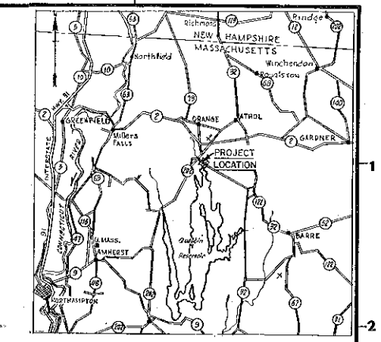
SECTION C-C
SCALE 1" = 5'



ELEVATION B-B
SCALE 1" = 10'



SECTION A-A
SCALE 1" = 5'



LOCATION MAP

NOTES

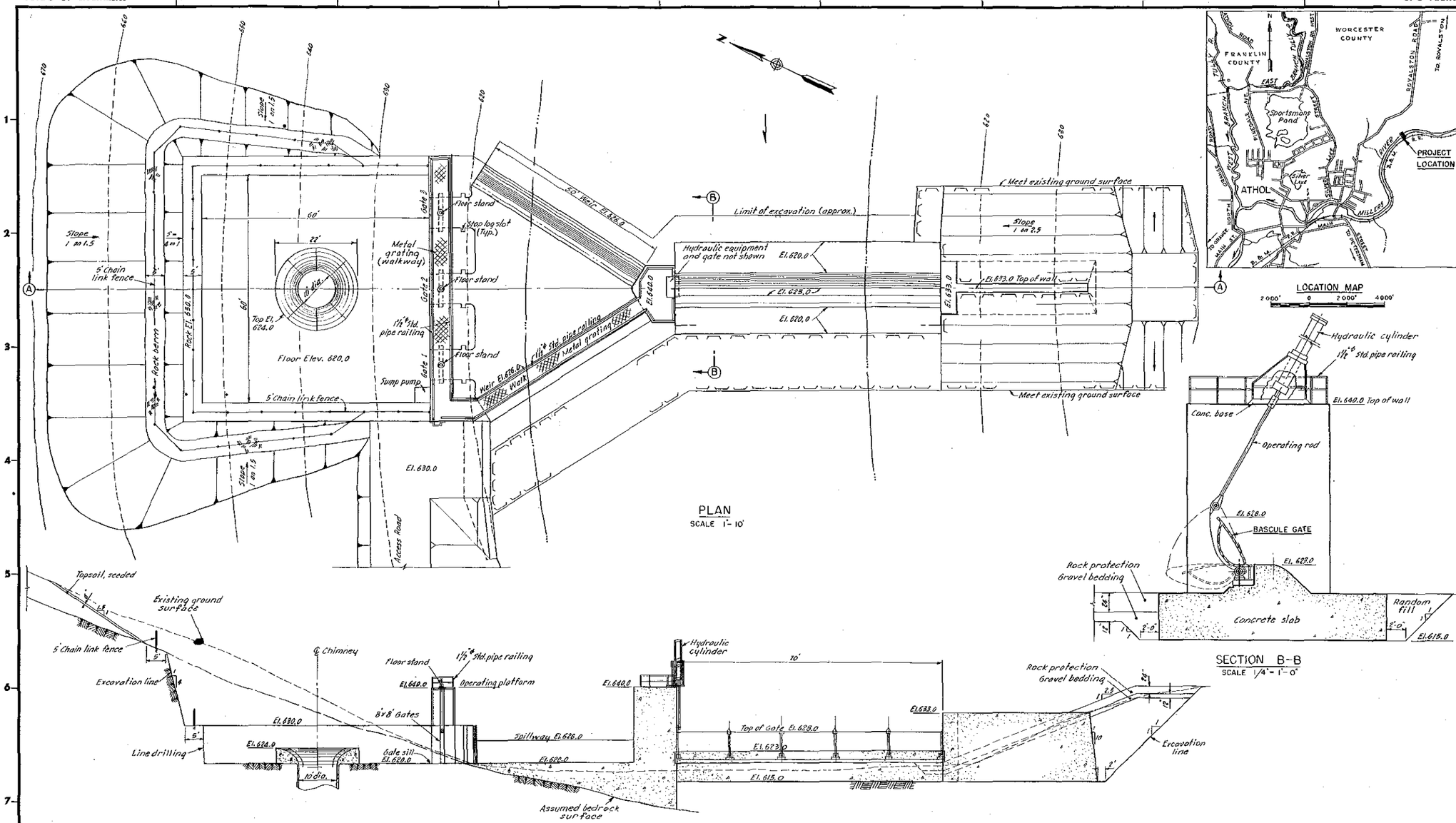
GRAPHIC SCALES
1" = 10'
1" = 5'

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

QUABBIN RESERVOIR
TUNNEL OUTLET STRUCTURE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

CORPS OF ENGINEERS U. S. ARMY



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

MILLERS RIVER
TUNNEL INLET STRUCTURE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE C-22

APPENDIX D

ALTERNATIVE PROJECT DESCRIPTIONS AND COSTS

This appendix describes the structural features necessary to implement each alternative. Facilities were designed to provide a safe structure for given conditions and hydraulic criteria. Detailed drawings and cost estimates for each structure are included. Costs are based on unit prices adjusted to July 1973 price levels using the Engineering News Record Construction Cost Index. This information serves as backup for the project description and costs sections of the main report.

APPENDIX D

ALTERNATIVE PROJECT DESCRIPTIONS AND COSTS

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APPENDIX D

ALTERNATIVE PROJECT DESCRIPTIONS AND COSTS

1. Alternative No. 1 - Millers River Diversion

A. General

In this alternative, water would be diverted from the mainstem of the Millers River above Athol, Massachusetts. Facilities required would include an inlet structure on the Millers River, a 10 foot diameter tunnel to Quabbin Reservoir and an outlet structure within the reservoir itself. Investigations conducted to date indicate that proposed pollution abatement plans by Massachusetts State Agencies include secondary treatment on all point sources of pollution. Additional treatment appears necessary to insure a good water supply source. Advanced waste treatment facilities, therefore, have been included as elements in this alternative.

B. Millers River Diversion Facilities

The diversion site would be located in the Town of Athol, about three miles upstream from the confluence of the Millers and Tully Rivers in Athol, Massachusetts. The location of the site is shown on Plate No. D-1.

The structure would consist of an inlet to the 10 foot diameter tunnel to Quabbin Reservoir controlled by a combination weir - bascule gate extending across the Millers River. The concrete control structure, 120 feet long, would extend across the river to provide a regulated pool for the inlet shaft. The bascule gate, 70 feet long and 5 feet high, would regulate the water height and velocity to the inlet. During diversion, the bascule gate would be raised creating a stilling pond and increasing the water level above the elevation of the 50 foot inlet structure weir. The 22-foot morning glory inlet, tapered to the 10 foot inlet shaft, would be located adjacent to the river channel in the middle of a 60-foot square chamber cut in rock. The three 8 x 8 foot gates to the inlet chamber would be opened only when diversions were occurring. By regulating these gates in conjunction with the bascule gates, any combination of diversion flow and downstream flow can be achieved. A plan of the diversion works is shown on Plate No. D-2. Costs are given in Table D-1.

Diversions would occur only when both the flows in the Connecticut River at the Montague City USGS gage and in the Millers River exceed their respective required flow rates. Water diverted from the river would enter the morning glory inlet and drop down the vertical 10-foot shaft into the connecting 10 foot diameter tunnel to Quabbin Reservoir.

C. Tunnel - Millers River to Quabbin Reservoir

The 10 foot diameter tunnel would run a distance of 7 miles from the inlet at Millers River to a point south of Gays Hill on Quabbin Reservoir. Plate No. D-1 shows the tunnel alignment. Costs as shown in Table D-2 are based on mole excavation methods and concrete lining the tunnel to a finish diameter of 10 feet. Vertical 10 foot diameter shafts would be provided at the inlet and outlet and would be used as construction shafts. The morning glory inlet at the Millers River has been described in Paragraph B. The tunnel profile is shown on Plates No. D-3 and D-4.

D. Quabbin Reservoir Outlet

The outlet at Quabbin Reservoir, shown on Plate No. D-5, would consist of an inclosed transition structure, a concrete stilling basin and a twenty foot wide trapazoidal channel leading to the Middle Branch of the Swift River in Quabbin Reservoir. The structure would be founded on bedrock and includes a wet well with two 8 x 8 foot gated passageways and a control building. The stilling basin would reduce outlet velocities from 11.4 feet per second to 5 feet per second, if Quabbin Reservoir was below elevation 503. However, if Quabbin Reservoir were filled, (Elevation 524), the entire stilling basin and passageways would be submerged and discharge would be directly into the pool. The riprapped channel would extend some 800 feet across a swampy area to the original Middle Branch of the Swift River channel. This channel makes its way to Windsor Dam.

The construction costs for the outlet are given in Table D-3.

E. Waste Treatment Facilities

An analysis was made on the present and projected loadings of waste discharges upstream from the diversion intake, present and planned treatment and present and planned waste effluents. The various status of the planned treatment facilities required a series of assumptions. In order to prepare cost estimates on a comparable basis, all advanced

waste treatment plants were established using the Corps of Engineers Study on the Merrimack River.[1] Cost estimates are shown on Table D-4.

Based on information available, it appears many of the pollution sources will require advanced waste treatment processes to insure a good quality supply for diversion. The final determination of this additional treatment need will, of course, be made during the Design Phase if this alternative is implemented. It is anticipated that during the Design Phase, the planned secondary treatment plants by the State will be in operation. Thus, the full operational effectiveness can be reviewed at that time. The following brief descriptions of the proposed treatment were taken from Appendix G, Environmental Protection Agency Report on Water Quality Studies.

1) Millers River Pollution Sources

a) South Royalston

South Royalston is a small rural community located on the banks of the Millers River. Municipal waste discharge from the town is presently discharged untreated into the Millers River. Planned treatment for the Town would consist of extended aeration with a design discharge rate of 0.039 mgd.

To the planned secondary treatment, additional facilities required for this alternative would consist of a 100,000 gallon stabilization pond followed by rapid sand filters.

b) Winchendon

Winchendon is a community of 6,635. Its waste load is characterized as municipal and its present treatment facilities are primary. The existing facilities must be upgraded under the State implementation schedule to the secondary level. Planned treatment facilities consist of aeration and settling tanks with an average design flow of 0.5 mgd.

Additional treatment which could be required subject to plant effluent evaluation would be nitrogen removal followed by rapid sand filtration.

---

[1] The Merrimack: Designs for a Clean River, a feasibility study prepared by North Atlantic Division, U. S. Army Corps of Engineers, September 1971.

2) Otter River Pollution Sources

a) Baldwinsville Products, Inc.

Baldwinsville Products' plant renovates waste paper products. Because of the processes involved, large quantities of water are used and subsequently returned as waste discharge to the river. At present, an average effluent flow of 3.5 mgd is discharged to the river untreated.

Planned treatment is secondary, but because of the large loadings from the plant, additional treatment beyond the planned processes is considered necessary. To insure a good quality effluent from this source, it is felt rapid sand filtration followed by granular carbon absorption would be necessary.

b) Seaman Paper Company, Inc.

This plant, as is the Baldwinsville Products operation, is located on the Otter River, a tributary of the Millers River. Waste from this plant averages 0.576 mgd and can be characterized as paper waste.

At present, waste discharges from the plant are subject to secondary treatment. If the Millers River were to be used as a water supply source, it is probable granular carbon absorption would also be necessary.

c) Gardner - Templeton

At present, the City of Gardner, population 19,748, treats its municipal waste at a secondary treatment facility. Because waste flow now exceeds the capacity of the plant, desired results are not being obtained. Presently, construction is under way to obtain secondary treatment on the city's waste. In addition, it has been reported that the Town of Templeton may also treat its waste at this facility.

It appears additional treatment beyond that presently under construction may be necessary. Proposed additional treatment could consist of nitrogen removal followed by carbon absorption.

d) Baldwinville

Baldwinville is a small community of 6,635 located on the Otter River. At present, raw municipal sewage is discharged to the river.

Planned treatment for this source consists of secondary with a design flow of 0.250 mgd. Additional treatment beyond that presently planned could consist of nitrogen removal followed by rapid sand filtration of final effluent.

F. Cost Summary

Table D-5 summarizes the costs for Alternative No. 1 - Millers River Diversion.

2. Alternative No. 2 - Tully-Millers River Diversion

A. General

In this plan, diversion from the Millers River Basin would be accomplished via withdrawals from the East Branch Tully River and the mainstem of the Millers River above Athol, Massachusetts. Facilities necessary for development would include a morning glory type inlet structure just downstream from the existing Tully flood control reservoir and an 8 foot diameter tunnel to the Millers River above Athol. At the Millers River, a second tunnel inlet would be constructed and from this location a 10 foot tunnel would be driven to Quabbin Reservoir where water would be discharged through an outlet structure. As in Alternative No. 1, waste treatment plants on six point sources of pollution would also be required. Plate No. D-6 shows the location of the proposed structures.

B. East Branch Tully River Diversion Facilities

The diversion site for this alternative is located at the existing Corps of Engineers flood control reservoir on the East Branch Tully River. However, no storage within the flood control reservoir would be used for water supply. The site is located about 4 miles upstream from the confluence of the Tully River and Millers River in Athol. The structure would consist of an inlet to the 8 foot diameter tunnel to the Millers River above Athol and an 8 foot high pelican gate attached to the existing Tully Lake outlet channel.

The existing outlet channel of Tully Lake would be enlarged to 30 feet wide for a distance of 1200 feet. A 30 foot long, 8 foot high pelican gate would regulate the water height and velocity in the outlet channel. During diversion, the pelican gate and the three 8 x 8 foot gates would

be raised creating a stilling pool and increasing the water level above the lip of the tunnel inlet. The 22-foot morning glory drop inlet would be located adjacent to the outlet channel in the middle of a 60 foot square chamber cut in rock. The three 8 x 8 foot gates to the inlet chamber would be opened only when diversions were occurring. By regulating these four gates and the gates at the existing dam, any combination of diversion flows and downstream flows can be achieved. A plan of the diversion works is shown on Plate No. D-7. The cost estimate for the inlet is given in Table D-6.

C. Tunnel - Tully Lake to Millers River Inlet

The 8 foot diameter tunnel would be driven a distance of 2-1/2 miles from the outlet of Tully Lake to a point upstream of Athol on the mainstem of the Millers River. Plate No. D-7 shows the tunnel alignment. Costs, as shown in Table D-7, are based on mole excavation methods and concrete lining the tunnel to a finish diameter of eight feet. Two vertical eight foot diameter shafts would be provided: one each at the Tully and Millers River inlets. The tunnel profile is shown on Plate No. D-8.

D. Facilities Required Millers River to Quabbin Reservoir

At the Millers River, water diverted from the East Branch Tully River would be augmented by diversion from the Millers River mainstem. To accomplish the diversion from the Millers, facilities required would be a weir-bascule structure across the river; a morning glory inlet to the tunnel connecting to Quabbin Reservoir; and an outlet structure at Quabbin. In addition, to insure adequate quality water at the Millers River intake, waste treatment plants would be required at six pollution sources upstream of the intake.

All of these required facilities would be similar to those needed in Alternative No. 1. Descriptions of the works are given in paragraphs B, C, D, and E, under Alternative No. 1 - Millers River Diversion.

E. Cost Summary

The construction costs and annual charges for Alternative No. 2 are summarized in Table D-8.

3. Alternative No. 3 - Tully Complex Diversion

A. General

This water supply plan for diversions from the Millers River Basin involves the construction of an 8-foot diameter tunnel from Tully Lake to Quabbin Reservoir, a dam on Priest Brook, and diversion structures on Tarbell Brook and West Branch Tully River. Water would be diverted in a pressure conduit from Tarbell Brook to the proposed Priest Brook ponding area. Pumping facilities at the Priest Brook Dam convey this water together with Priest Brook water to Tully Lake. A gravity feed tunnel would then divert water from the two brooks plus the East Branch Tully out of the basin to Quabbin Reservoir. Water from the West Branch Tully could then be pumped into the tunnel near the confluence of the East and West Branches of the Tully River. Recreation and wildlife management programs are also included at these diversion sites. Plate No. D-9 shows the location of the proposed structures.

B. Tarbell Brook Diversion Facilities

The diversion site is located in Winchendon, Massachusetts, about one-half mile upstream of the confluence of Tarbell Brook and the Millers River. The structure consists of a 75 foot long weir and pumping station. A 28 acre pool with a maximum depth of nine feet would be formed by the weir with a top elevation of 840 msl. The inundated area will be cleared and grubbed to improve its appearance once filled. The pool forms a sump so that water can be drawn off. The limits of this permanent pool are shown on Plate No. D-10.

The 75 foot long concrete weir, as shown on Plate No. D-11, would have a spillway crest elevation of 840 msl. The excavation necessary for placing the weir retaining walls and pumping station would be back-filled to elevation 854 msl with compacted impervious material. Twelve inches of gravel bedding and twenty-four inches of rock protection would then be placed on top of the back-filled material. The retaining wall on the left abutment and the water intake structure on the right abutment are formed integrally with the weir. The weir is designed for a 10 foot surcharge and a 6 foot freeboard. A 4 foot impervious blanket will be placed upstream of the weir to reduce the seepage velocity. A 36 inch diameter gravity by-pass will be included in the water intake structure in order to maintain the required downstream flow and provide complete pool drawdown. Two 36 inch diameter pipes would convey the water to the pumps. From these, a 42 inch diameter pressure conduit running beside Royalston Road would carry the water to Priest Brook ponding

area. The pumps and pipeline would be designed to carry a maximum of 90 cfs. Table D-9 gives the construction cost and annual charges for the Tarbell Brook Diversion Facilities.

C. Priest Brook Diversion Facilities

Priest Brook Dam is located on the Winchendon-Royalston town line, just south of Winchendon Road, some 2-3/4 miles from the confluence of Priest Brook and the Millers River. Some 19.4 square miles of drainage area would be affected by the 4500 acre-foot reservoir. The pool at spillway crest (Elevation 875 msl) would have a surface area of 400 acres and a maximum depth of 30 feet. The inundated area downstream of Royalston Road has to be stripped or covered with a gravel blanket to prevent degradation of the water. A river located upstream of Royalston Road would form a 40 acre wildlife pool at Elevation 865 msl. Regulation of this pool would occur, during the summer and fall, to maintain a shallow depth of water (approximately 5 feet). The main pool buffers the river flow and as such is intermittently filled and emptied. The limits of the reservoir are shown on Plate No. D-12.

The dam, with a top elevation of 890 feet msl, would be of rolled earth filled construction, approximately 1100 feet long including spillway and would have a maximum height of 45 feet above the stream bed. A chute spillway with a 70 foot long ogee weir at elevation 875 msl would be founded in rock on the left bank. The spillway is designed for a 9 foot surcharge and a 6 foot freeboard. A six foot impervious blanket will be placed upstream of the dam in order to reduce the seepage velocity. A 42 inch diameter gravity by-pass conduit located at Station 10 + 00 serves as an outlet and a water supply suction line. The intake to the conduit includes a trash rack, a stop log structure and a 42 x 42 inch emergency gate. The pool will be regulated from the downstream side at the pumping station, where water will be released downstream as well as pumped to Tully Lake. Winchendon Road will be relocated across the dam while Royalston and Old Turnpike Roads will be abandoned in the reservoir area. General details of the dam are shown on Plate No. D-13. The cost estimate of these facilities is given in Table D-10.

The pumping station would divert water through a 72 inch pressure conduit to Tully Lake. Depending on the amount of water available above the control flow, the diversion rate will vary up to a maximum of 120 cfs. This includes the water transferred from Tarbell Brook. The pressure conduit will run west beside Winchendon Road until it intersects a power line running northwest. The conduit then follows this easement to Long Pond on the East Branch of the Tully River.

D. East Branch Tully River Diversion Facilities

The diversion site is located at the existing Corps of Engineers flood control reservoir on the East Branch Tully River. The site is about 4 miles upstream from the confluence of the Tully River and Millers River in Athol. The structure consists of an inlet to the 8 foot diameter tunnel to Quabbin Reservoir and a 7 foot high pelican gate added to the existing Tully Lake outlet channel. Two inches of the 8.3 inches of runoff storage in Tully would be utilized from 15 September to 15 June for reregulating the flows diverted to Quabbin Reservoir. The remainder of the year, the pool will be held at Elevation 649 msl for recreation and no diversions from Tully would occur. The 620 acres inundated would be cleared, grubbed and stripped to improve water quality. Plate No. D-14 shows the limits of Tully Lake and the proposed improvements. The existing outlet channel of Tully Lake would be enlarged to 30 feet wide for a distance of 1200 feet. A 30 foot long, eight foot high pelican gate would regulate the water height and velocity in the outlet channel. During diversion, the pelican gate and the three 8 x 8 foot gates would be raised creating a stilling pool and increasing the water level above the lip of the tunnel inlet. The 22 foot morning glory drop inlet would be located adjacent to the outlet channel in the middle of a 60 foot square chamber cut in rock. The three 8 x 8 foot gates to the inlet chamber would be opened only when diversions were occurring. By regulating these four gates and the gates at the existing dam, any combination of diversion flows and downstream flows can be achieved. A plan of the diversion works is shown on Plate No. D-7. The construction costs and annual charges are shown in Table D-11.

Diversions would occur when both the flows in the Connecticut River at the Montague City USGS gage and in the East Branch Tully River exceed their respective required flows. However, water may be drained from storage and diverted into the tunnel at other times. Water entering the morning glory inlet would drop some 312 feet down the vertical 8 foot shaft into the tunnel. The 8 foot diameter tunnel would run horizontally at Elevation 300 msl for some 2.2 miles to the entrance shaft from the West Branch Tully River.

E. West Branch Tully River Diversion Facilities

Located in Athol, Massachusetts, about 800 feet upstream of the confluence of the East and West Branches of the Tully River is the diversion site. The structure consists of a 320 foot long earth-filled dam with a 50 foot wide spillway, a water intake chamber and a pumping station. The permanent pool would be held at spillway crest elevation of 525 msl,

inundating some 13 acres. This area would be cleared and grubbed. The pool forms a sump with a maximum depth of 11 feet, so that water can easily be diverted. Plate No. D-15 shows the diversion site and reservoir area.

The dam, shown on Plate No. D-16, with a top elevation of 540 msl would be of rolled earth-filled construction, approximately 400 feet long including the spillway and would have a maximum height of 25 feet above the stream bed. The 50 foot long ogee spillway weir would be founded on earth. Therefore, in order to reduce the seepage velocity under the dam, a 6 foot impervious blanket would be placed to 180 feet upstream of the dam centerline. The spillway is designed for a 10.5 foot surcharge and a 4.5 foot freeboard. The retaining wall on the right abutment and the water intake structure on the left abutment would be integrally formed with the spillway. The water intake chamber would have an 18 x 3 foot rectangle opening and a 42 inch diameter gated opening. A 42 inch pipe serves as both the pump suction line and the gravity by-pass which would be used to maintain the required downstream flows and provide complete pool drawdown. From the pumping station a 30 inch diameter pressure conduit would run beside the access road to the Tully-Quabbin tunnel. The pumps and pipeline would be designed to carry a maximum of 90 cfs. Construction costs are given in Table D-12.

F. Tunnel - Tully Lake to Quabbin Reservoir

The 8 foot diameter tunnel would run a distance of 8.6 miles from the outlet of Tully Lake to a point south of Gays Hill on Quabbin Reservoir. Plate No. D-9 shows the tunnel alignment. Costs, as shown in Table No. D-13, are based on mole excavation methods and concrete lining the tunnel to a finish diameter of 8 feet. Three vertical 8 foot diameter shafts would be provided: one each at the inlet and outlet and one at the West Branch Tully entrance. The morning glory inlet at Tully Lake has been described in Paragraph D. Water entering this inlet would drop vertically into the tunnel. The tunnel profile is shown on Plates No. D-17 and D-18. The entrance shaft from the West Branch Tully diversion facilities would be capped with an automatic pressure valve in order to prevent negative pressures and remove any air in the shaft when water is being pumped from West Branch Tully.

The outlet at Quabbin Reservoir, shown on Plate No. D-5, would be the same as the one for Alternatives No. 1 and 2, consisting of an inclosed transition structure, a concrete stilling basin and a 20 foot wide trapazoidal channel leading to the Middle Branch of the Swift River in Quabbin

Reservoir. The only difference from the outlet described in Section D of the Millers River Diversion Facilities is that the stilling basin would reduce outlet velocities from 9 feet per second to 3 feet per second if Quabbin Reservoir were below elevation 503. This is due to the smaller flow rate in the 8 foot diameter tunnel. The construction costs and annual charges for the outlet are given in Table D-3.

G. Cost Summary

The construction costs and annual charges are summarized in Table D-15 for Alternative No. 3 - Tully Complex Diversion.

4. Basis of Cost Estimates

A. General

Topographic maps of the U. S. Geological Survey as well as previous Corps of Engineers surveys were supplemented with centerline profiles of the dam sites. Geologic reconnaissance have been made at all the dam sites and tunnel routes. At the Priest Brook dam site, these investigations were augmented by previous subsurface explorations. Quantities of the principle construction items were estimated on the basis of a preliminary design which would provide a safe structure for given conditions and hydraulic criteria. A three-year construction period was assumed for purposes of determining the Federal investment.

B. Unit Prices

Unit prices are based on average bid prices, adjusted to July 1973 levels for similar work in the New England area. Tunnel costs were estimated by computer based on July 1973 labor, equipment and materials rates with profit and overhead added. Costs of lands, damages and easements required by the project are based on real estate studies and information from local officials, and reflect recent area values to which acquisition and contingency costs have been added.

C. Contingencies, Engineering and Overhead

A contingency allowance of 20 percent is included in the total construction cost. Costs of engineering and design, and supervision and administration are estimated on percentages of the total construction cost. These percentages are based on experience on similar projects in the New England area.

TABLE D-1

DETAILED COST ESTIMATE

MILLERS RIVER INTAKE STRUCTURE

Item	Estimated Quantity	Unit	Unit Price	Estimated Amount
Reservoir Clearing	1	Job	L.S.	$ 5,800
Preparation of Site	1	Job	L.S.	5,800
Control & Diversion of Water	1	Job	L.S.	29,300
Unclassified Excavation Gen.	3,500	c.y.	1.80	6,300
Unclassified Excavation Rock	3,000	c.y.	5.50	16,500
Line Drilling	1,300	S.F.	5.90	7,670
Rock Surface Handcleaning	3	Sq	35.10	105
Rock Protection	500	c.y.	4.30	2,150
Gravel Bedding	300	c.y.	2.60	780
Comp. Random Fill	1,000	c.y.	.58	580
Concrete	1,500	c.y.	123.00	184,500
Cement	2,600	bbl.	7.70	20,000
Steel Reinforcement	200,000	lb.	.32	64,000
8' x 8' Lift Gates Complete	3	ea.	12,000	36,000
5' x 70' Mod. Bascule Gate Comp. w/hydraulic pump & Elec. Power	1	Job	L.S.	88,000
Sump Pump Complete	1	Job	L.S.	3,500
Steel Catwalk	1	Job	L.S.	11,000
Chain Link Fence	400	L.F.	4.90	1,960
Miscellaneous Metals	2,000	lb.	1.70	3,400
Topsoil	100	c.y.	8.50	850
Seeding	0.1	Ac.	1950.00	195
Access Road	1	Job	L.S.	47,000
Elec. Power	1	Job	L.S.	4,700
CONSTRUCTION COST				$540,090
Contingencies				108,910
TOTAL CONSTRUCTION COST				$649,000
Engineering & Design				146,000
Supervision & Administration				105,000
TOTAL PROJECT FIRST COST				$900,000

TABLE D-2

DETAILED COST ESTIMATE

MILLERS RIVER TO QUABBIN TUNNEL

(July 1973 Price Level)

LABOR	$ 12,221,000
EQUIPMENT	2,664,000
MATERIALS	3,038,000
CONSTRUCTION COST	$ 17,923,000
Contingencies	3,585,000
TOTAL CONSTRUCTION COST	$ 21,508,000
Engineering & Design	2,258,000
Supervision & Administration	1,734,000
TOTAL PROJECT FIRST COST	$ 25,500,000

TABLE D-3

DETAILED COST ESTIMATE

QUABBIN RESERVOIR OUTLET STRUCTURE

Item	Estimated Quantity	Unit	Unit Price	Estimated Amount
Preparation of Site	1	Job	L.S.	$ 5,800
Control & Diversion of Water	1	Job	L.S.	5,800
Earth Excavation General	2,900	c.y.	1.80	5,220
Rock Excavation	1,400	c.y.	5.50	7,700
Line Drill	2,700	S.F.	5.90	15,930
Concrete	550	c.y.	123.00	67,650
Cement	900	bbl.	7.70	6,930
Steel Reinforcement	82,500	lb.	0.32	26,400
Fence	750	lb.	4.90	3,650
Miscellaneous Metals	3,200	lb.	2.30	7,360
Topsoil	150	c.y.	8.50	1,275
Seeding	1/2	Ac.	1950.00	975
Access Road	1	Job	L.S.	7,000
8' x 8' Sluice Gate	2	ea.	12,000	24,000
Channel Exc.	3,700	c.y.	5.90	21,830
Rock Cleanup	35	Sq.	35.10	1,229
Drain Hole Slab - 10 ft.	16	ea.	175.00	2,800
Anchors	40	ea.	70.00	2,800
Control Building	1	Job	L.S.	35,000
CONSTRUCTION COST				$249,349
Contingencies				49,651
TOTAL CONSTRUCTION COST				$299,000
Engineering & Design				60,000
Supervision & Administration				41,000
TOTAL PROJECT FIRST COST				$400,000

TABLE D-4

DETAILED COST ESTIMATE

ADVANCED WASTE TREATMENT PLANTS

	Capital Cost	Annual Operating Cost
South Royalston	$ 100,000	$ 3,000
Winchendon	410,000	91,000
Baldwinsville Products, Inc.	2,176,000	264,000
Seaman Paper Company, Inc.	525,000	35,000
Gardiner - Templeton	2,900,000	264,000
Baldwinsville	240,000	55,000
CONSTRUCTION COST	$ 6,351,000	
Contingencies	1,270,000	
TOTAL CONSTRUCTION COST	$ 7,621,000	
Engineering & Design	955,000	
Supervision & Administration	724,000	
TOTAL PROJECT FIRST COST	$ 9,300,000	
TOTAL ANNUAL OPERATING COST		$ 712,000

TABLE D-5

SUMMARY OF FIRST COSTS AND ANNUAL CHARGES

ALTERNATIVE NO. 1 - MILLERS RIVER DIVERSION

(July 1973 Price Level)

PROJECT FIRST COSTS

POLLUTION TREATMENT	$ 9,300,000
MILLERS RIVER INTAKE	900,000
10' DIAMETER TUNNEL (MOLE)	25,500,000
QUABBIN OUTLET	400,000
REAL ESTATE COSTS	400,000
TOTAL PROJECT FIRST COST	$ 36,500,000
INTEREST DURING CONSTRUCTION	3,100,000
INVESTMENT	$ 39,600,000

ANNUAL CHARGES

INTEREST AND AMORTIZATION	$ 2,380,000
OPERATION AND MAINTENANCE	740,000
MAJOR REPLACEMENT	150,000
TOTAL ANNUAL CHARGES	$ 3,270,000

TABLE D-6

DETAILED COST ESTIMATE

TULLY INTAKE STRUCTURE

Dam and Roadway	Estimated Quantity	Unit	Unit Price	Estimated Amount
Preparation of Site	1	Job	L.S.	$ 5,800
Control & Diversion of Water	1	Job	L.S.	5,800
Unclassified Excavation Gen.	7,000	c.y.	1.80	12,600
Unclassified Excavation Rock	1,800	c.y.	5.50	9,900
Line Drilling	2,550	S.F.	5.90	15,045
Concrete	350	c.y.	123.00	43,050
Cement	620	bbl.	7.70	4,774
Steel Reinforcement	35,000	lb.	.32	11,200
8 x 8 Lift Gates Complete	3	ea.	12,000	36,000
8 x 30 Pelican Gate Comp. w/ Hyd. Pump and Elec. Power	1	Job	L.S.	59,000
Steel Catwalk	1	Job	L.S.	12,000
Chain Link Fence	300	L.F.	4.90	1,470
Miscellaneous Metals	3,200	lb.	2.30	7,360
Topsoil	150	c.y.	8.50	1,275
Seeding	0.2	Ac.	1950.00	390
Access Road	1	Job	L.S.	24,000
CONSTRUCTION COST				$249,664
Contingencies				50,336
TOTAL CONSTRUCTION COST				$300,000
Engineering & Design				60,000
Supervision & Administration				40,000
TOTAL PROJECT FIRST COST				$400,000

TABLE D-7

DETAILED COST ESTIMATE

TULLY TO MILLERS RIVER TUNNEL

(July 1973 Price Level)

LABOR	$4,117,000
EQUIPMENT	1,012,000
MATERIALS	796,000
CONSTRUCTION COST	$5,925,000
Contingencies	1,185,000
TOTAL CONSTRUCTION COST	$7,110,000
Engineering & Design	716,000
Supervision & Administration	574,000
TOTAL PROJECT FIRST COST	$8,400,000

TABLE D-8

SUMMARY OF FIRST COSTS AND ANNUAL CHARGES

ALTERNATIVE NO. 2 - TULLY - MILLERS DIVERSION

(July 1973 Price Level)

PROJECT FIRST COSTS

POLLUTION TREATMENT	$ 9,300,000
TULLY INTAKE	400,000
MILLERS INTAKE	900,000
8' x 10' DIAMETER TUNNEL (MOLE)	33,900,000
QUABBIN OUTLET	400,000
REAL ESTATE COSTS	400,000
TOTAL PROJECT FIRST COST	$45,300,000
INTEREST DURING CONSTRUCTION	3,800,000
INVESTMENT	$49,100,000

ANNUAL CHARGES

INTEREST AND AMORTIZATION	$ 2,970,000
OPERATION AND MAINTENANCE	740,000
MAJOR REPLACEMENT	150,000
TOTAL ANNUAL CHARGES	$ 3,860,000

TABLE D-9

DETAILED COST ESTIMATE

TARBELL BROOK DIVERSION FACILITIES

Description	Estimated Quantity	Unit	Unit Price	Estimated Amount	Total
RESERVOIR CLEARING	60	Ac	730.00	$ 43,800	
Contingencies				4,200	
SUB-TOTAL					$ 48,000
DAM AND ROADWAY					
Preparation of Site	1	Job	L.S.	$ 5,800	
Control & Diversion of Water	1	Job	L.S.	5,800	
Unclassified Excavation Gen.	31,000	C.Y.	2.40	74,400	
Imp. Borrow	6,300	C.Y.	3.50	22,050	
Rock Protection	2,300	C.Y.	9.40	21,620	
Gravel Bedding	1,700	C.Y.	2.70	4,590	
Comp. Imp. Fill	4,200	C.Y.	0.60	2,520	
Concrete	2,725	C.Y.	123.00	335,175	
Cement	4,770	bbls.	7.70	36,729	
Reinforced Steel	272,400	lbs.	0.32	87,168	
Access Road	1	Job	L.S.	47,000	
Seeded Topsoil	300	C.Y.	10.50	3,150	
Chain Link Fence	250	l.t.	4.90	1,225	
3' x 3' Gates	2	ea	4100.00	8,200	
Log boom	1	Job	L.S.	2,300	
Construction Cost				$ 657,727	
Contingencies				131,273	
SUB-TOTAL					$ 789,000
PUMPING STA., PIPELINE & EQUIPMENT					
Pumping Station	1	Job	L.S.	$ 291,000	
Electrical & Mechanical Equip.	1	Job	L.S.	318,000	
Pipeline --					
48" Pressure Conduit (7500')	1	Job	L.S.	560,000	
36" Conduit (4500')	1	Job	L.S.	168,000	
Construction Cost				$1,337,000	
Contingencies				268,000	
SUB-TOTAL					$1,605,000
TOTAL CONSTRUCTION COST					$2,442,000
Engineering & Design					450,200
Supervision & Administration					290,000
PROJECT FIRST COST					$3,182,200
REAL ESTATE COSTS					
Lands				$ 900	
Severance Damages				1,000	
Contingencies				6,100	
Resettlement				1,400	
Acquisition Costs				8,400	
SUB-TOTAL					$ 17,800
TOTAL PROJECT FIRST COST					$3,200,000

TABLE D-10

DETAILED COST ESTIMATE

PRIEST BROOK DIVERSION FACILITIES

Description	Estimated Quantity	Unit	Unit Price	Estimated Amount	Total
RESERVOIR CLEARING					
Clearing	300	Ac	730.00	$ 219,000	
Stripping	400,000	C.Y.	1.00	400,000	
Gravel Blanket	80,000	C.Y.	2.50	200,000	
Contingencies				81,000	
SUB-TOTAL					$ 900,000
DAM AND ROAD RELOCATION					
Preparation of Site	1	Job	L.S.	$ 25,000	
Control & Diversion of Water	1	Job	L.S.	18,400	
Unclassified Excavation Gen.	254,000	C.Y.	1.80	457,200	
Uncl. Excavation Imp. Borrow	225,000	C.Y.	2.50	562,500	
Rock Excavation	17,000	C.Y.	5.50	93,500	
Comp. Imper. Fill	186,000	C.Y.	0.55	102,300	
Comp. Perv. Fill	13,000	C.Y.	2.50	32,500	
Comp. Random Fill	45,000	C.Y.	0.50	22,500	
Rock Protection	22,000	C.Y.	4.30	94,600	
Gravel Bedding	16,000	C.Y.	2.60	41,600	
Rolled Gravel Base	7,000	C.Y.	3.90	27,300	
Comp. Processed Sand	16,000	C.Y.	6.70	107,200	
Cone Outlet Works	300	C.Y.	123.00	36,900	
Cone Weir & Spillway Br. Abut.	500	C.Y.	123.00	61,500	
Cement	1,300	bbls.	7.70	10,010	
Steel Reinforcement	70,000	lbs.	0.32	22,400	
42" & Steel Incased in Conc.	240	lt.	76.00	18,240	
42" x 42" Valves	3	ea	8200.00	24,600	
24" x 24" Water Supply Gate	1	ea	5800.00	5,800	
Staff Gages	1	Job	L.S.	4,900	
Spillway Bridge	1	Job	L.S.	59,000	
Guard Railing (Rd)	4,200	lt.	4.90	20,580	
Bit. Cone Surfacing	11,500	sy	2.50	28,750	
Chain Link Fence	500	lt.	4.90	2,450	
Log Boom	1	Job	L.S.	3,700	
Topsoil	3,000	C.Y.	8.60	25,800	
Seeding	4	Ac	1950.00	7,800	
Construction Cost				$1,917,030	
Contingencies				383,970	
SUB-TOTAL					$2,301,000
PUMPING STA., PIPELINE & EQUIPMENT					
Pumping Station	1	Job	L.S.	$ 274,000	
Electrical & Mechanical Equip.	1	Job	L.S.	518,000	
Pipeline --					
72" Pressure Conduit (25,000')	1	Job	L.S.	2,850,000	
36" Conduit (3,000')	1	Job	L.S.	750,000	
Construction Cost				$4,392,000	
Contingencies				878,000	
SUB-TOTAL					$5,270,000
TOTAL CONSTRUCTION COST					$8,471,000
Engineering & Design					1,059,200
Supervision & Administration					813,000
PROJECT FIRST COST					$10,343,200
REAL ESTATE COSTS					
Improvements				$ 124,500	
Lands				179,300	
Severance Damages				40,000	
Contingencies				68,800	
Resettlement				125,000	
Acquisition Costs				19,200	
SUB-TOTAL					$ 556,800
TOTAL PROJECT FIRST COST					$10,900,000

TABLE D-11

DETAILED COST ESTIMATE

EAST BRANCH TULLY RIVER DIVERSION FACILITIES

Description	Estimated Quantity	Unit	Unit Price	Estimated Amount	Total
RESERVOIR CLEARING					
Stripping	680,000	C.Y.	1.00	$ 680,000	
Gravel Blanket	165,000	C.Y.	2.50	412,500	
Construction Cost				$1,092,500	
Contingencies				109,500	
SUB-TOTAL					$1,202,000
DAM AND ROADWAY					
Preparation of Site	1	Job	L.S.	$ 5,800	
Control & Diversion of Water	1	Job	L.S.	5,800	
Unclassified Excavation Gen.	7,000	C.Y.	1.80	12,600	
Unclassified Excavation Rock	1,800	C.Y.	5.50	9,900	
Line Drilling	2,550	S.F.	5.90	15,045	
Concrete	350	C.Y.	123.00	43,050	
Cement	620	bbl.	7.70	4,774	
Steel Reinforcement	35,000	lb.	0.32	11,200	
8 x 8 Lift Gates Complete	3	ea	12,000	36,000	
8 x 30 Mod. Bascule Gate Comp. w/Hyd. Pump & Elec. Power	1	Job	L.S.	58,000	
Steel Catwalk	1	Job	L.S.	12,000	
Chain Link Fence	300	L.F.	4.90	1,470	
Miscellaneous Metals	3,200	lb.	2.40	7,680	
Topsoil	150	C.Y.	8.50	1,275	
Seeding	0.2	Ac	1950.00	390	
Access Road	1	Job	L.S.	24,000	
Construction Cost				$ 248,984	
Contingencies				49,016	
SUB-TOTAL					$ 298,000
TOTAL CONSTRUCTION COST					$1,500,000
Engineering & Design					375,000
Supervision & Administration					225,000
TOTAL PROJECT FIRST COST					$2,100,000

TABLE D-12

DETAILED COST ESTIMATE

WEST BRANCH TULLY RIVER DIVERSION FACILITIES

Description	Estimated Quantity	Unit	Unit Price	Estimated Amount	Total
RESERVOIR CLEARING	21	Ac	730.00	$ 15,330	
Contingencies				1,670	
SUB-TOTAL					$ 17,000
DAM AND ACCESS ROAD					
Preparation of Site	1	Job	L.S.	$ 25,000	
Control & Diversion of Water	1	Job	L.S.	18,500	
Unclassified Excavation Gen.	7,800	C.Y.	1.80	14,040	
Imp. Borrow	24,000	C.Y.	2.50	60,000	
Comp. Proc. Sand	3,000	C.Y.	6.70	20,100	
Rock Protection	2,500	C.Y.	4.30	10,750	
Gravel Bedding	2,000	C.Y.	2.60	5,200	
Rolled Gravel Base	900	C.Y.	3.90	3,510	
Concrete	1,420	C.Y.	123.00	174,660	
Cement	2,500	bbl.	7.70	19,250	
Steel Reinforcement	142,000	lbs.	0.32	45,440	
Sluice Gate	2	ea	12,000	24,000	
Gate Valves Complete w/ w. s. discharge pipes	2	ea	6,000	12,000	
Chain Link Fence	350	lf.	4.90	1,715	
Log Boom	1	Job	L.S.	3,500	
Construction Cost				$437,665	
Contingencies				87,335	
SUB-TOTAL					$ 525,000
PUMPING STA., PIPELINE & EQUIPMENT					
Pumping Station	1	Job	L.S.	$167,000	
Electrical & Mechanical Equip.	1	Job	L.S.	217,000	
30" Dia. Pressure Conduit (700')	1	Job	L.S.	26,000	
Construction Cost				$410,000	
Contingencies				82,000	
SUB-TOTAL					$ 492,000
TOTAL CONSTRUCTION COST					$1,034,000
Engineering & Design					250,000
Supervision & Administration					175,000
PROJECT FIRST COST					$1,459,000
REAL ESTATE COSTS					
Lands				$ 6,900	
Improvements				10,000	
Severance Damages				1,800	
Contingencies				3,800	
Resettlement				4,100	
Acquisition Costs				14,400	
SUB-TOTAL					$ 41,000
TOTAL PROJECT FIRST COST					$1,500,000

TABLE D-13

DETAILED COST ESTIMATE

TULLY TO QUABBIN RESERVOIR TUNNEL

(July 1973 Price Level)

LABOR COST	$12,999,000
EQUIPMENT COST	2,639,000
MATERIAL COST	2,661,000
CONSTRUCTION COST	$18,299,000
Contingencies	3,660,000
TOTAL CONSTRUCTION COST	$21,959,000
Engineering & Design	2,306,000
Supervision & Administration	1,735,000
TOTAL PROJECT FIRST COST	$26,000,000

TABLE D-14

SUMMARY OF FIRST COSTS AND ANNUAL CHARGES

ALTERNATIVE NO. 3 - TULLY COMPLEX DIVERSION

(July 1973 Price Level)

PROJECT FIRST COSTS

TARBELL BROOK	$ 3,200,000
PRIEST BROOK	10,900,000
EAST BRANCH TULLY	2,100,000
WEST BRANCH TULLY	1,500,000
QUABBIN OUTLET	400,000
TOTAL DIVERSION FACILITIES	$ 18,100,000
TULLY LAKE TO QUABBIN RESERVOIR 8' DIAMETER TUNNEL	26,000,000
REAL ESTATE EASEMENTS	300,000
TOTAL PROJECT FIRST COST	$ 44,400,000
INTEREST DURING CONSTRUCTION	3,700,000
INVESTMENT	$ 48,100,000

ANNUAL CHARGES

INTEREST AND AMORTIZATION	$ 2,890,000
ELECTRICAL CHARGES	120,000
OPERATION AND MAINTENANCE	60,000
TOTAL ANNUAL CHARGES	$ 3,070,000

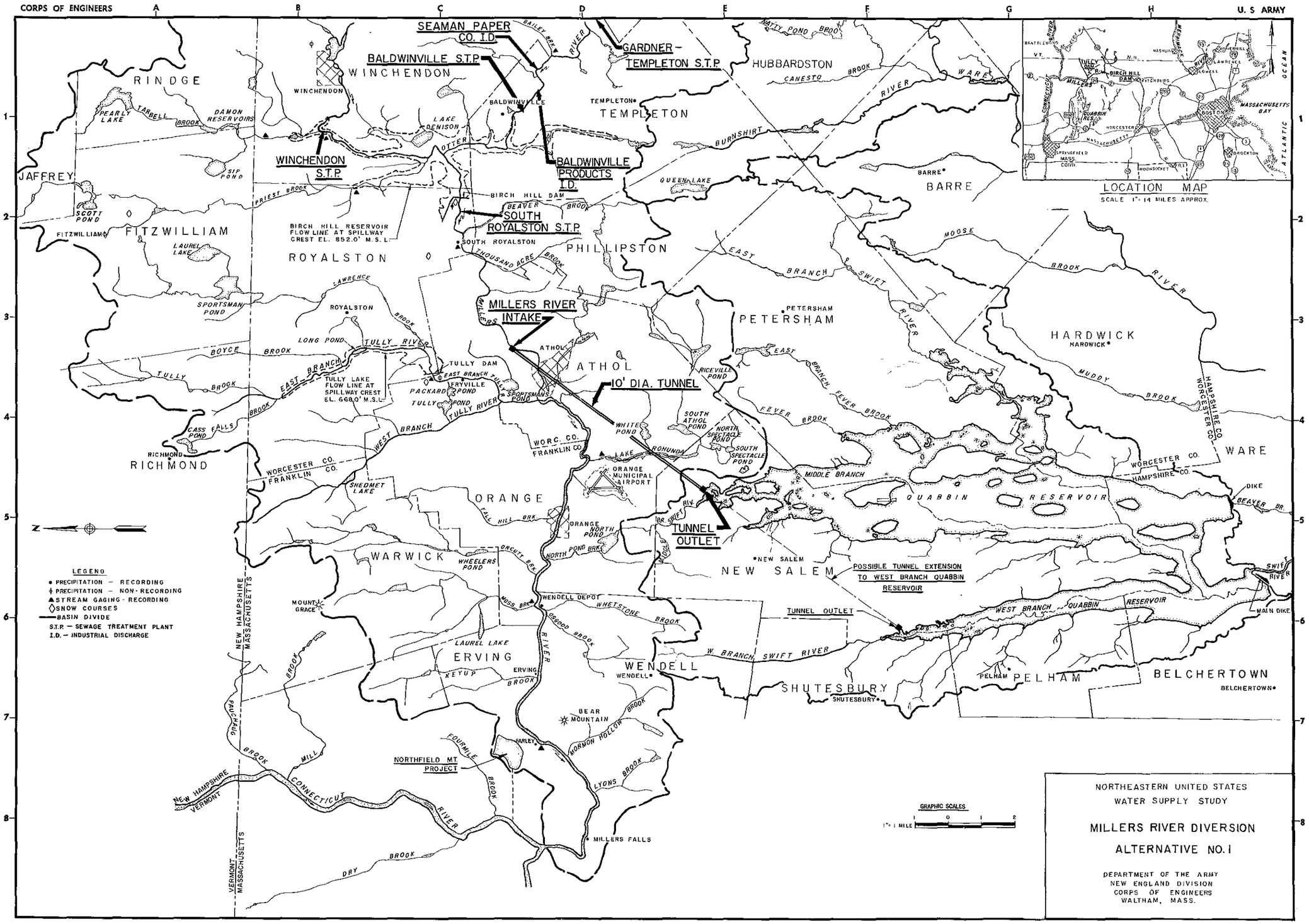
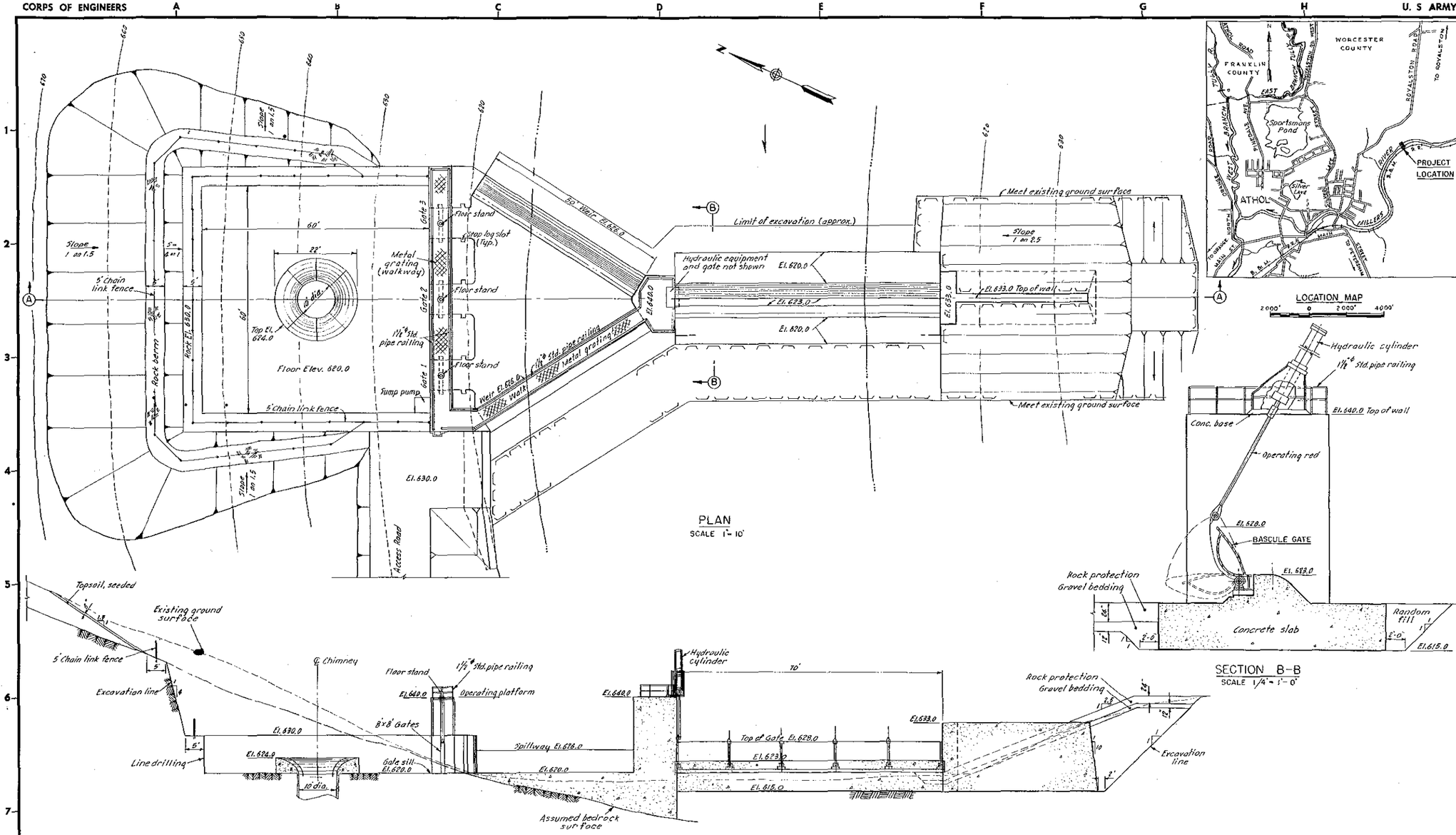

CORPS OF ENGINEERS
U. S ARMY
SEAMAN PAPER CO. I.D.
BALDWINVILLE S.T.P.
GARDNER-TEMPLETON S.T.P.
WINCHENDON S.T.P.
BALDWINVILLE PRODUCTS I.D.
SOUTH ROYALSTON S.T.P.
MILLERS RIVER INTAKE
10' DIA. TUNNEL
TUNNEL OUTLET
POSSIBLE TUNNEL EXTENSION TO WEST BRANCH QUABBIN RESERVOIR
NORTHFIELD MT PROJECT
RINDGE
WINCHENDON
HUBBARDSTON
TEMPLETON
JAFFREY
FITZWILLIAM
ROYALSTON
PHILLIPSTON
BARRE
PETERSHAM
HARDWICK
ATHOL
RICHMOND
ORANGE
WARE
WARWICK
NEW SALEM
ERVING
WENDELL
SHUTESBURY
PELHAM
BELCHERTOWN
QUABBIN RESERVOIR
LOCATION MAP
SCALE 1" = 14 MILES APPROX.
LEGEND
PRECIPITATION - RECORDING
PRECIPITATION - NON-RECORDING
STREAM GAGING - RECORDING
SNOW COURSES
BASIN DIVIDE
S.T.P. - SEWAGE TREATMENT PLANT
I.D. - INDUSTRIAL DISCHARGE
GRAPHIC SCALES
1" = 1 MILE
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
MILLERS RIVER DIVERSION
ALTERNATIVE NO. 1
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

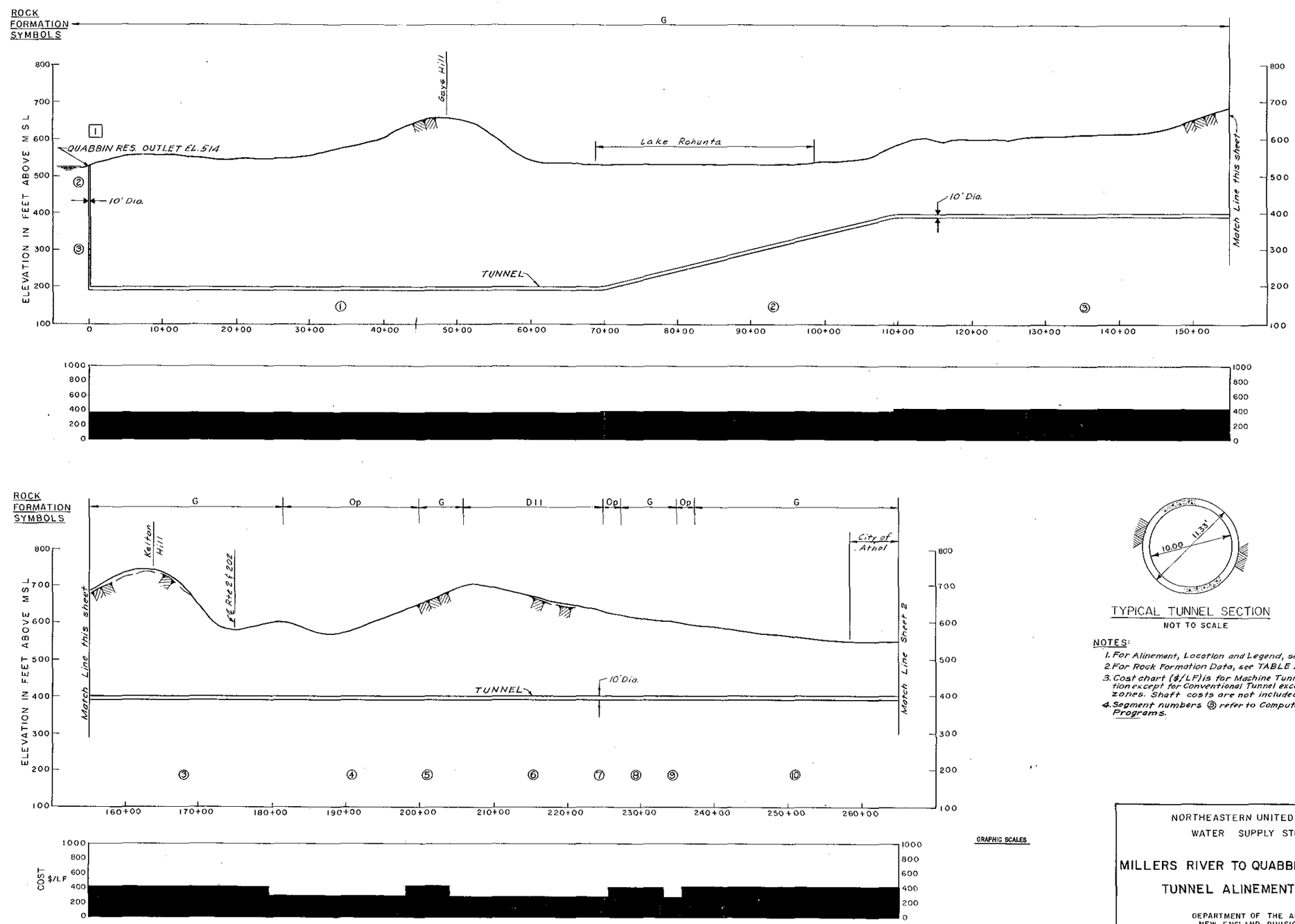
PLATE D-1



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

MILLERS RIVER
TUNNEL INLET STRUCTURE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.



TYPICAL TUNNEL SECTION

NOT TO SCALE

NOTES:

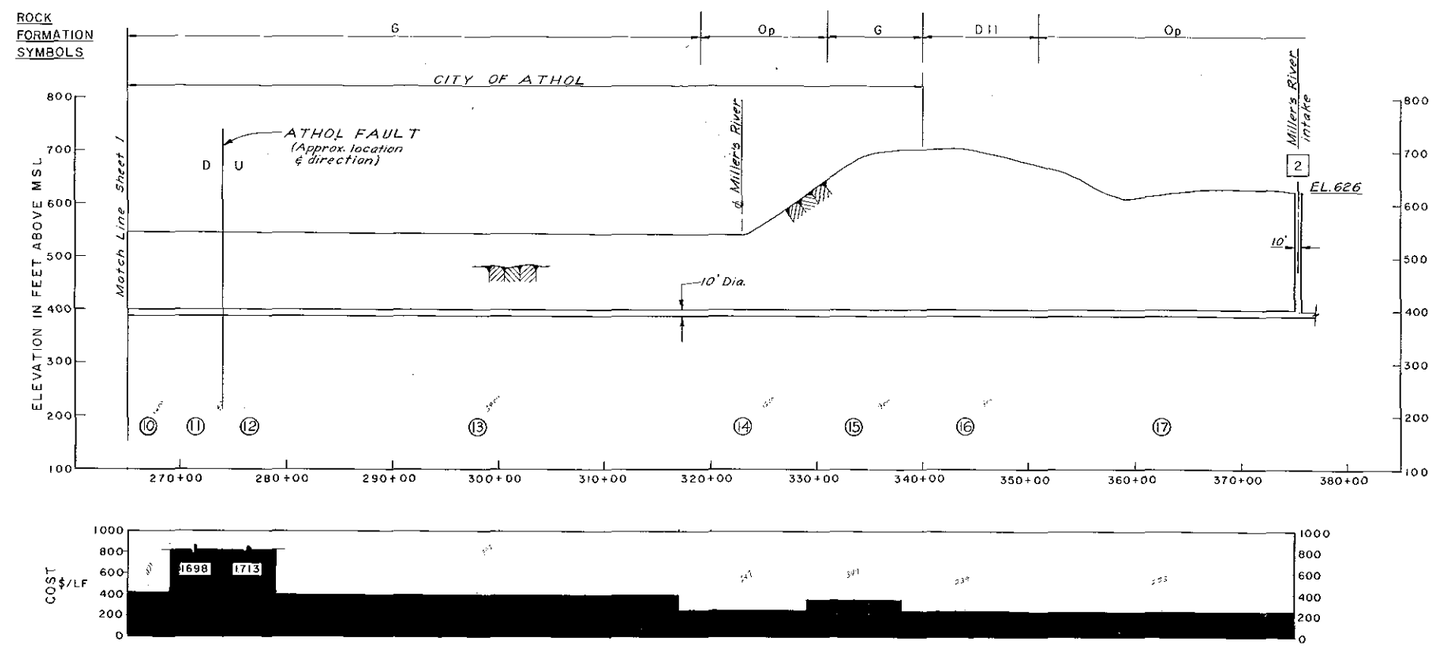
1. For Alinement, Location and Legend, see PLATE E-1
2. For Rock Formation Data, see TABLE E-1
3. Cost chart ($/LF) is for Machine Tunnel (Mole) Excavation except for Conventional Tunnel excavation in fault zones. Shaft costs are not included.
4. Segment numbers ③ refer to Computerized Cost Programs.

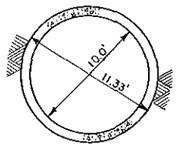
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

MILLERS RIVER TO QUABBIN RESERVOIR

TUNNEL ALINEMENT NO. 14

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.





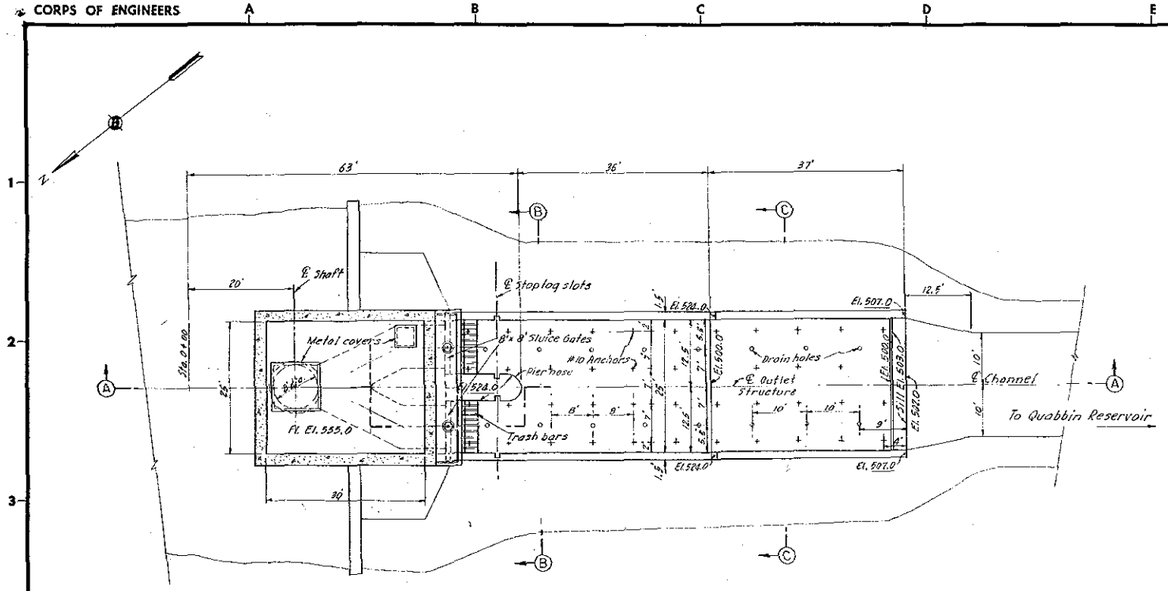
TYPICAL TUNNEL SECTION
SEGMENT NO. 13
NOT TO SCALE

NOTE:
See Sheet 1 for pertinent notes.

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

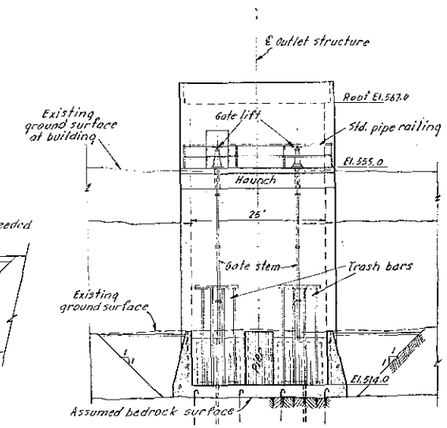
MILLERS RIVER TO QUABBIN RESERVOIR
TUNNEL ALINEMENT NO. 14

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

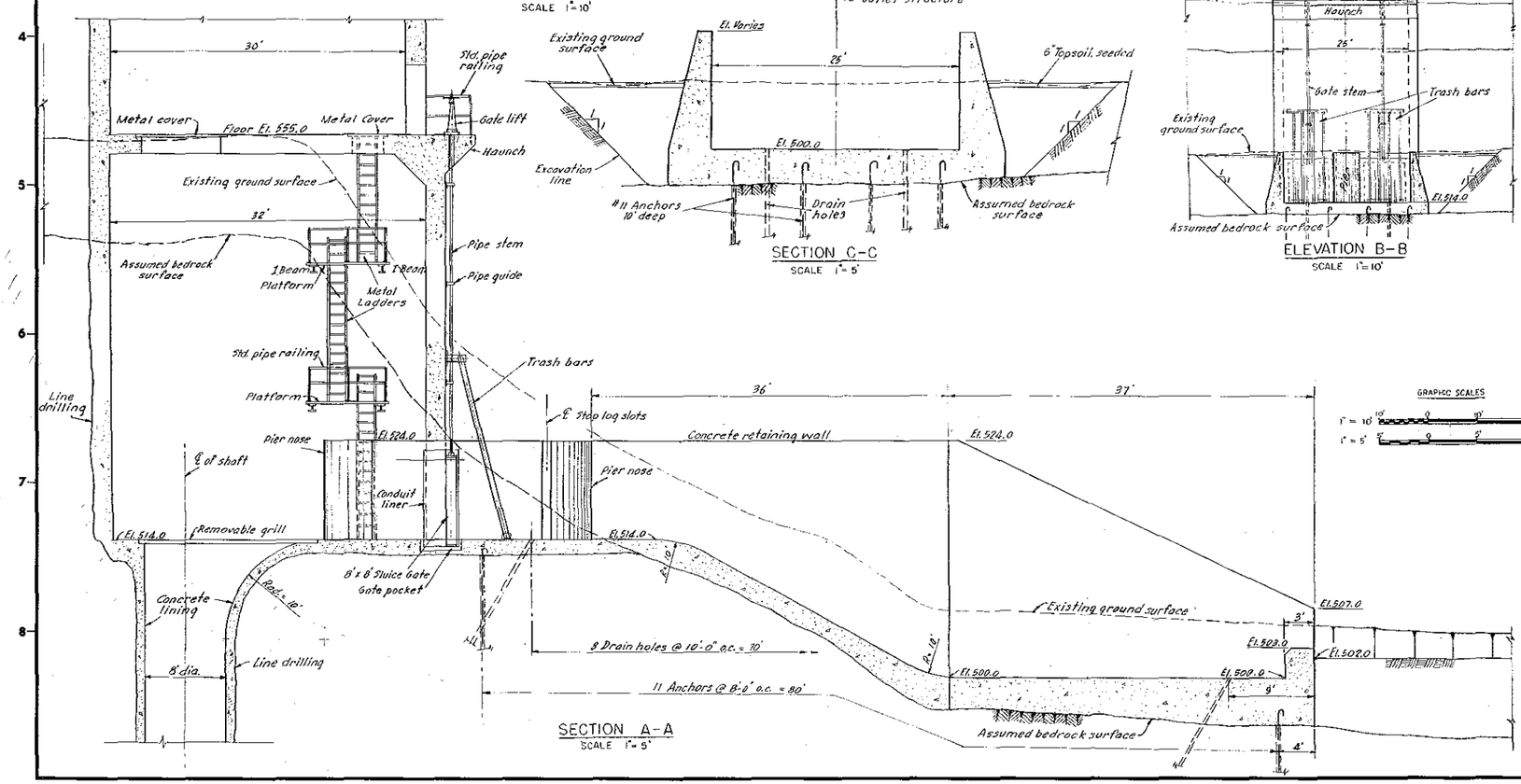


PLAN
SCALE 1"=10'

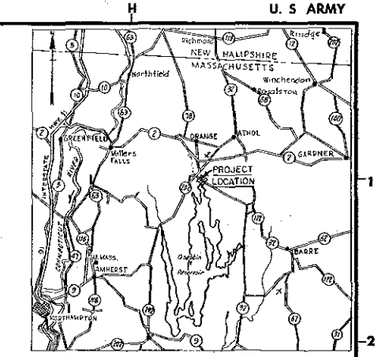
SECTION C-C
SCALE 1"=5'



ELEVATION B-B
SCALE 1"=10'



SECTION A-A
SCALE 1"=5'



LOCATION MAP

NOTES

GRAPHIC SCALES
1" = 10'
1" = 5'

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

QUABBIN RESERVOIR
TUNNEL OUTLET STRUCTURE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

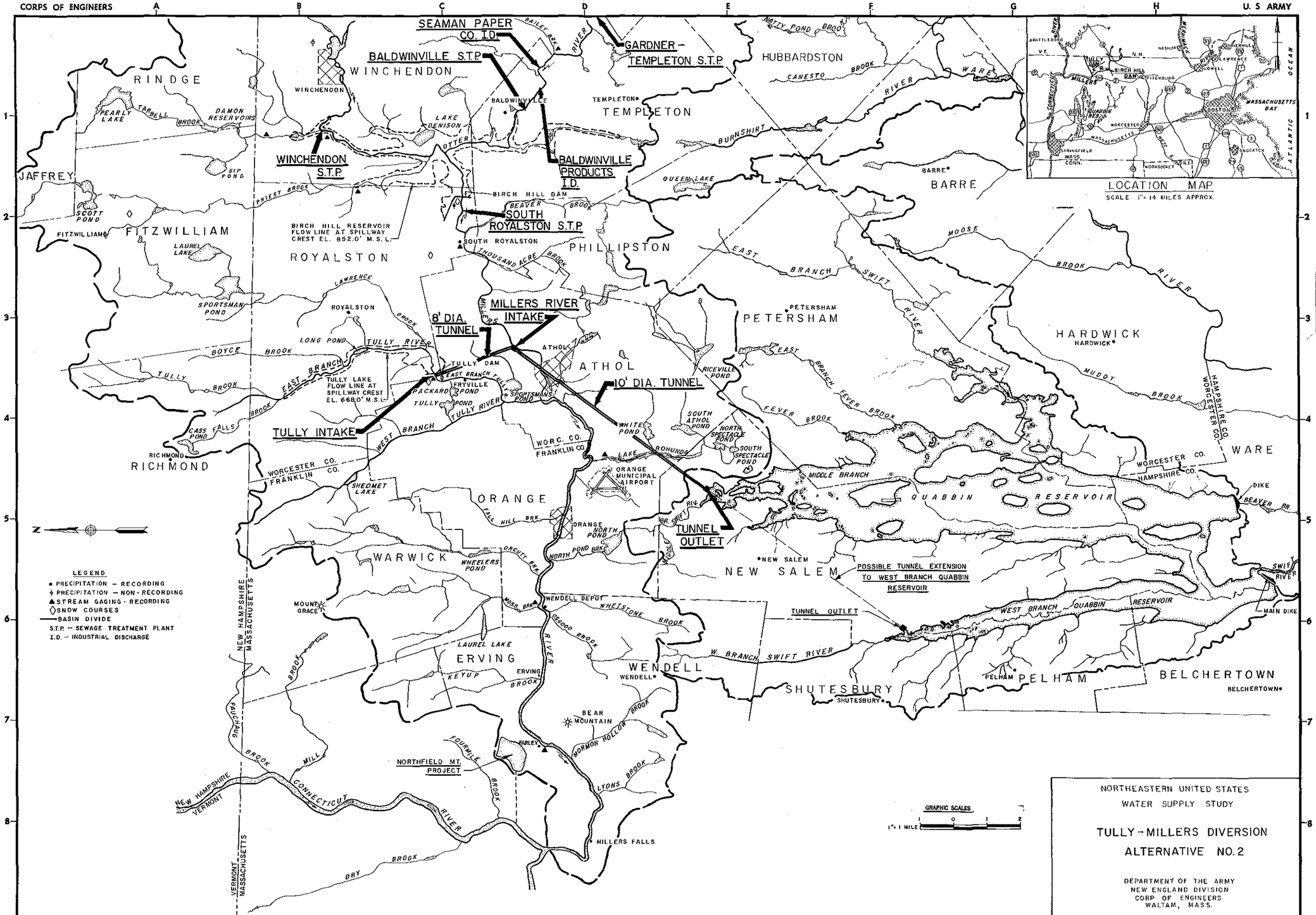
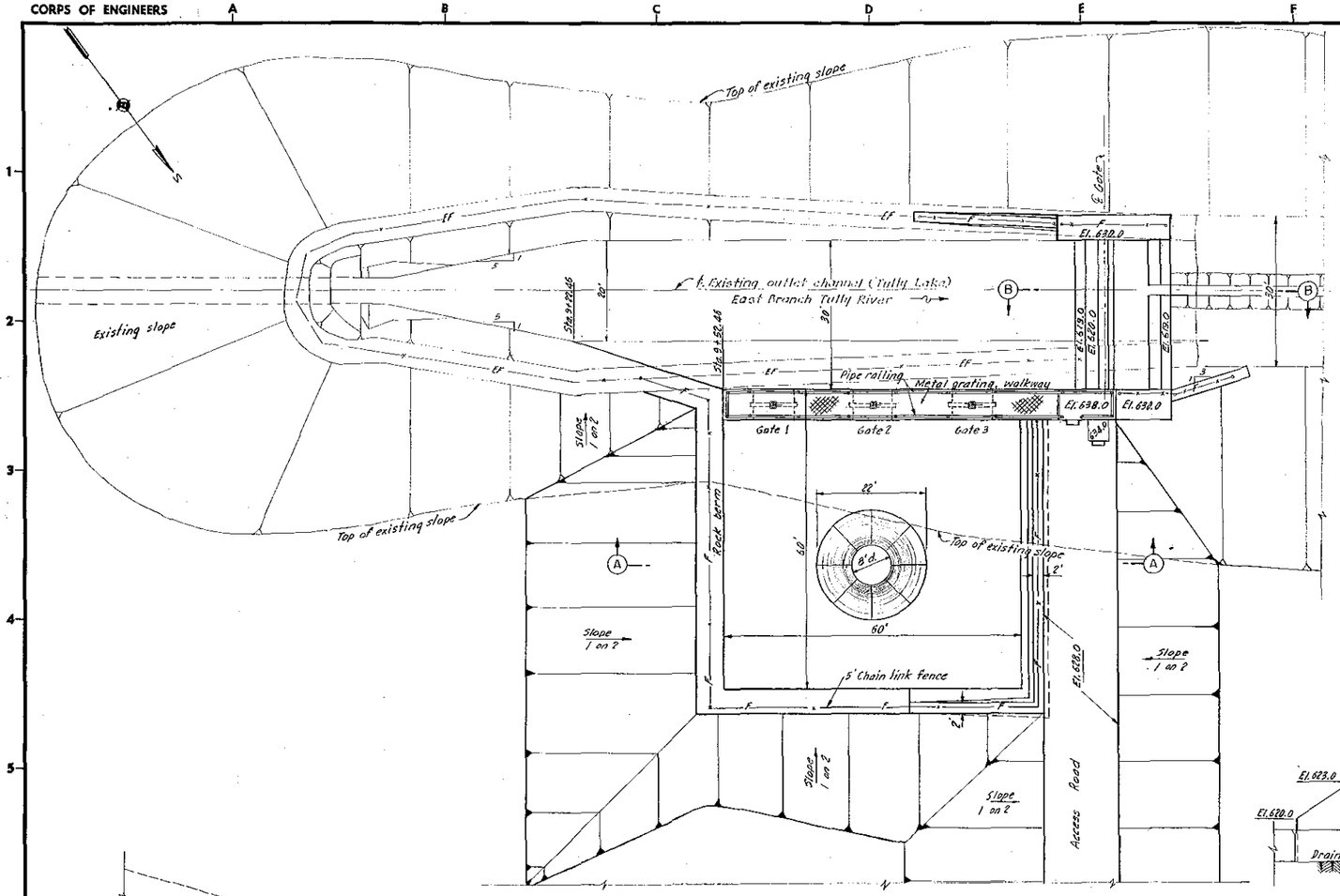
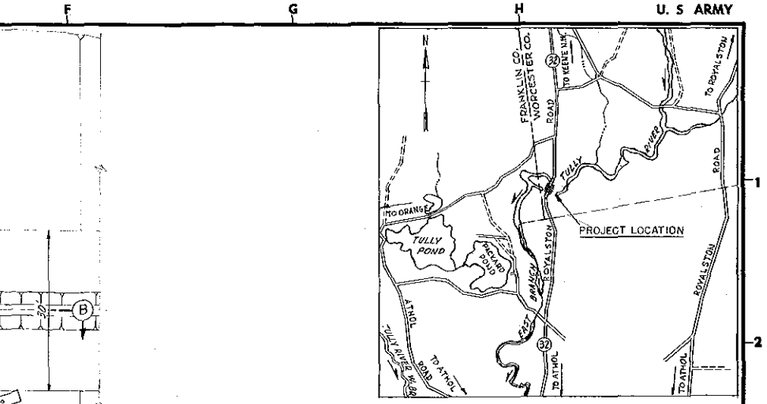

CORPS OF ENGINEERS
U. S ARMY
SEAMAN PAPER CO. I.D.
BALDWINVILLE S.T.P.
GARDNER-TEMPLETON S.T.P.
WINCHENDON S.T.P.
BALDWINVILLE PRODUCTS I.D.
SOUTH ROYALSTON S.T.P.
MILLERS RIVER INTAKE
8' DIA. TUNNEL
10' DIA. TUNNEL
TULLY INTAKE
TUNNEL OUTLET
POSSIBLE TUNNEL EXTENSION TO WEST BRANCH QUABBIN RESERVOIR
NORTHFIELD MT. PROJECT
RINDGE
WINCHENDON
HUBBARDSTON
TEMPLETON
JAFFREY
FITZWILLIAM
ROYALSTON
PHILLIPSTON
BARRE
PETERSHAM
HARDWICK
ATHOL
RICHMOND
ORANGE
WARE
WARWICK
NEW SALEM
ERVING
WENDELL
SHUTESBURY
PELHAM
BELCHERTOWN
QUABBIN RESERVOIR
LOCATION MAP
SCALE 1" = 14 MILES APPROX.
LEGEND
• PRECIPITATION - RECORDING
PRECIPITATION - NON-RECORDING
STREAM GAGING - RECORDING
SNOW COURSES
BASIN DIVIDE
S.T.P. - SEWAGE TREATMENT PLANT
I.D. - INDUSTRIAL DISCHARGE
GRAPHIC SCALES
1" = 1 MILE
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
TULLY-MILLERS DIVERSION
ALTERNATIVE NO. 2
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORP OF ENGINEERS
WALTAM, MASS.

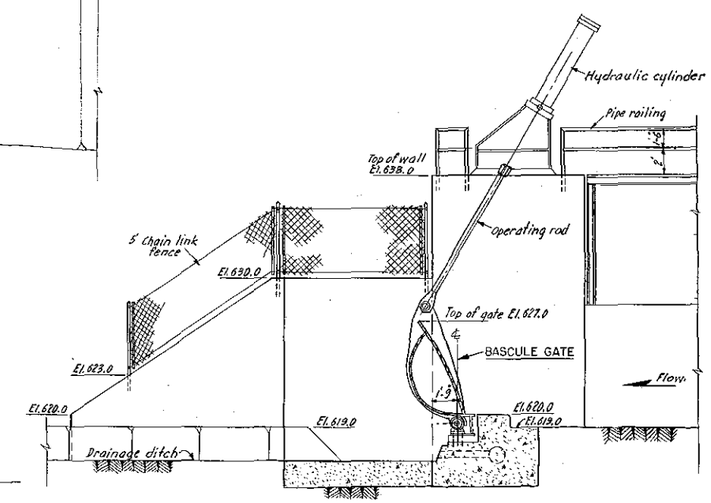
PLATE D-6



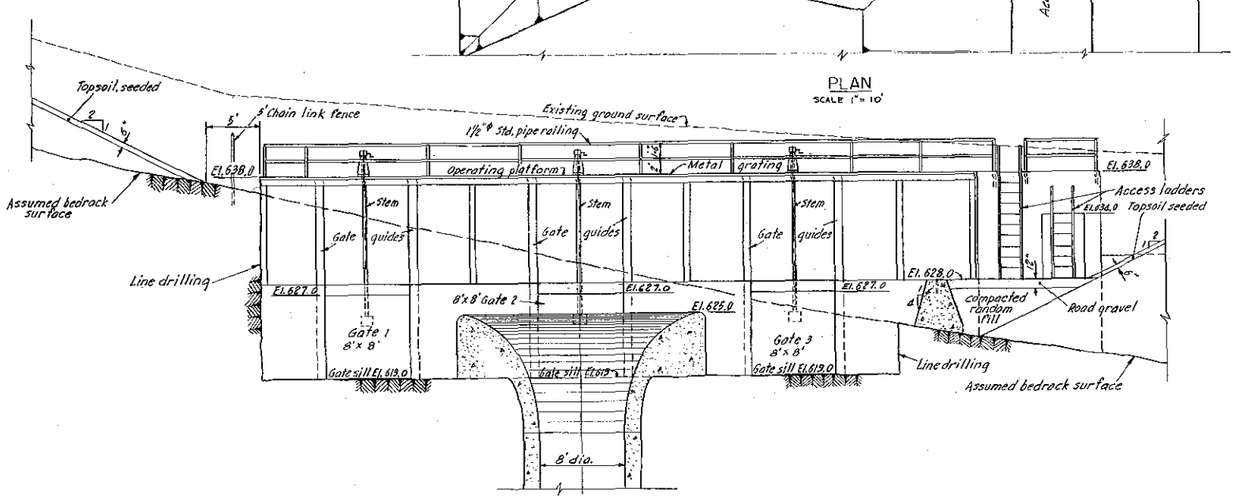
PLAN
SCALE 1" = 10'



LOCATION MAP
2000' 0 2000' 4000 Ft.



SECTION B-B
SCALE 1/4" = 1'-0"



SECTION A-A
SCALE 1" = 5'

NOTES

Elevations refer to Mean Sea Level Datum.

GRAPHIC SCALES
1" = 10' 10' 0 10' 20'
1" = 5' 5' 0 5' 10'
1/4" = 1'-0" 1' 0 1' 2'

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

EAST BRANCH TULLY RIVER
TUNNEL INLET STRUCTURE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

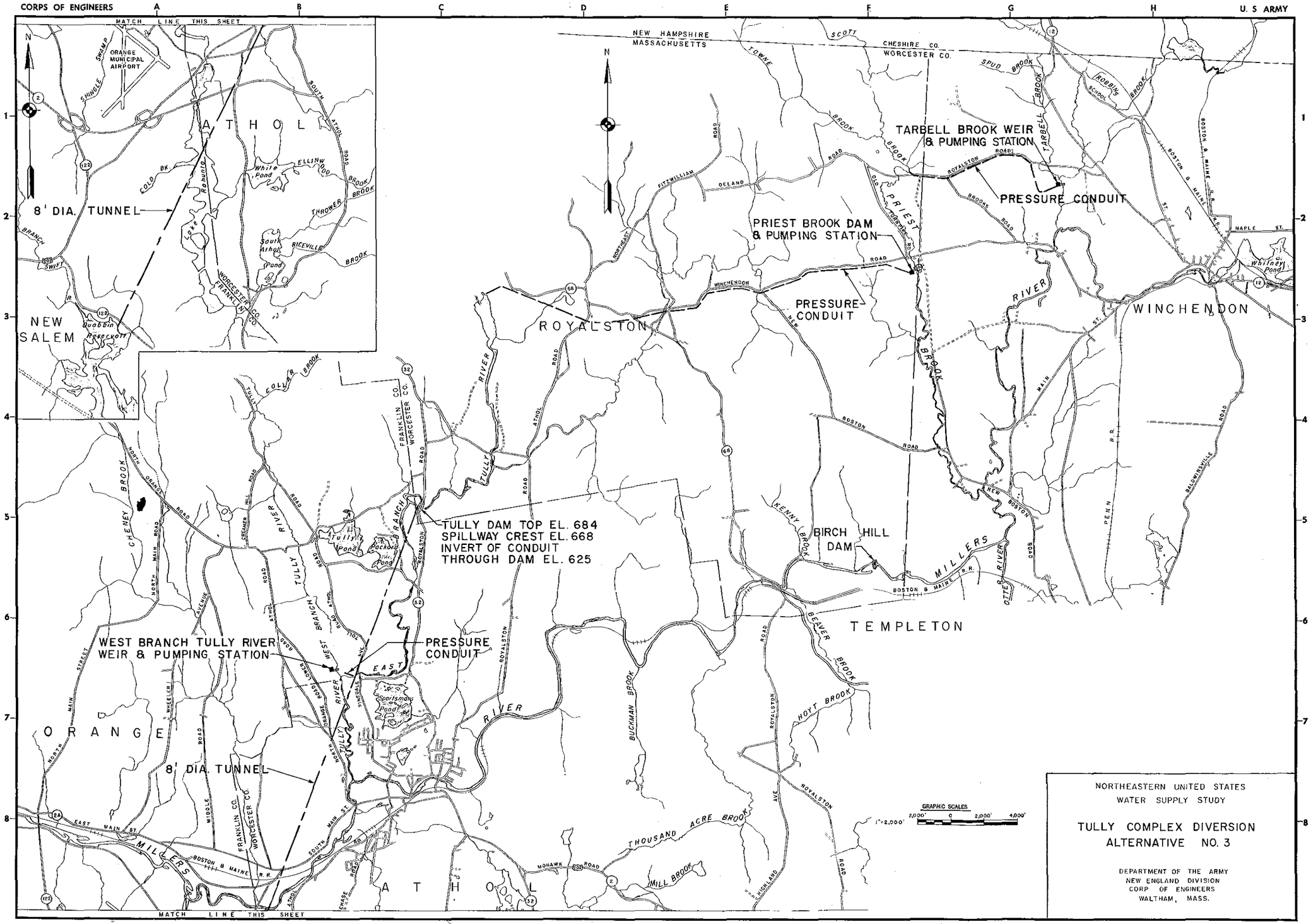
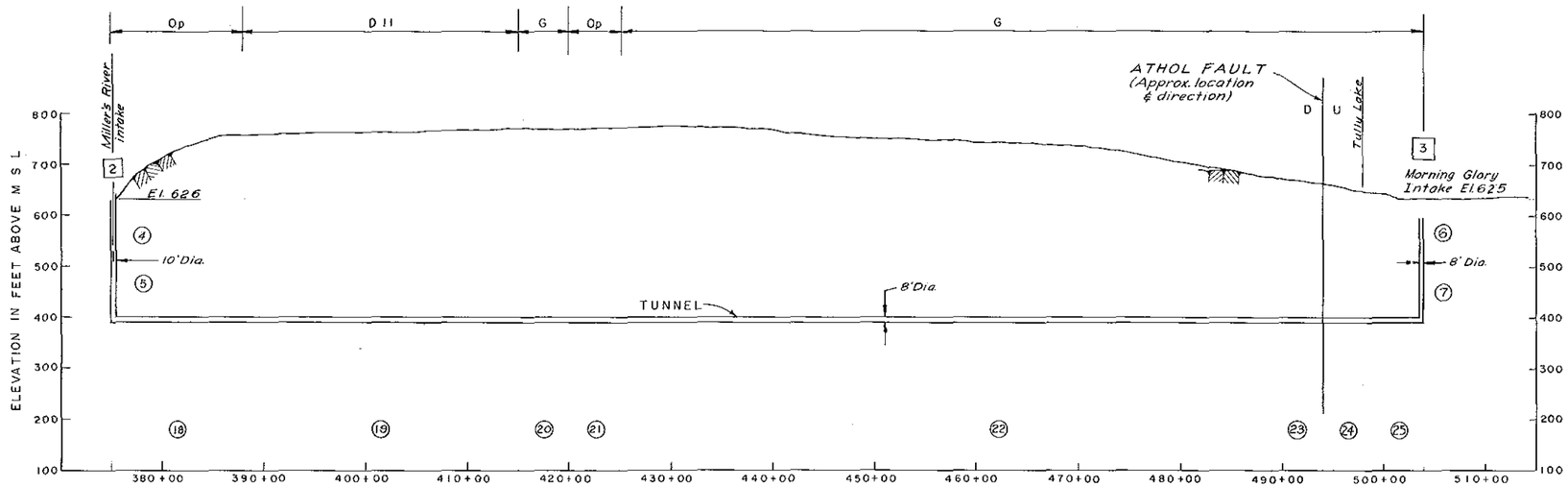
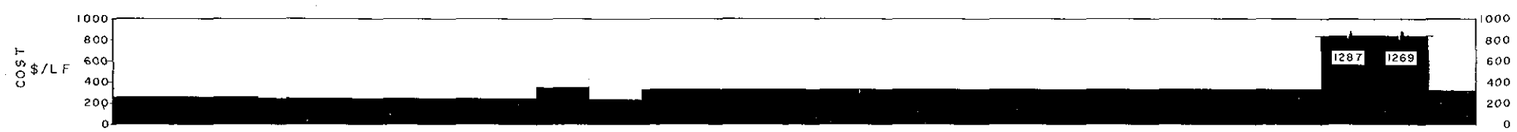
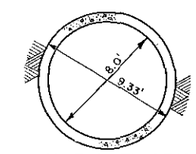

CORPS OF ENGINEERS
U. S ARMY
MATCH LINE THIS SHEET
NEW HAMPSHIRE
MASSACHUSETTS
CHESHIRE CO.
WORCESTER CO.
ORANGE MUNICIPAL AIRPORT
ATHOL
8' DIA. TUNNEL
NEW SALEM
ROYALSTON
TARBELL BROOK WEIR & PUMPING STATION
PRESSURE CONDUIT
PRIEST BROOK DAM & PUMPING STATION
PRESSURE CONDUIT
WINCHENDON
TULLY DAM TOP EL. 684
SPILLWAY CREST EL. 668
INVERT OF CONDUIT
THROUGH DAM EL. 625
BIRCH HILL DAM
TEMPLETON
WEST BRANCH TULLY RIVER
WEIR & PUMPING STATION
PRESSURE CONDUIT
ORANGE
8' DIA. TUNNEL
ATHOL
GRAPHIC SCALES
1"=2,000'
2,000' 0 2,000' 4,000'
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
TULLY COMPLEX DIVERSION
ALTERNATIVE NO. 3
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORP OF ENGINEERS
WALTHAM, MASS.

PLATE D-9







TYPICAL TUNNEL SECTION
SEGMENT NO. 22
NOT TO SCALE

NOTE:
See Plate D-3 for pertinent notes.

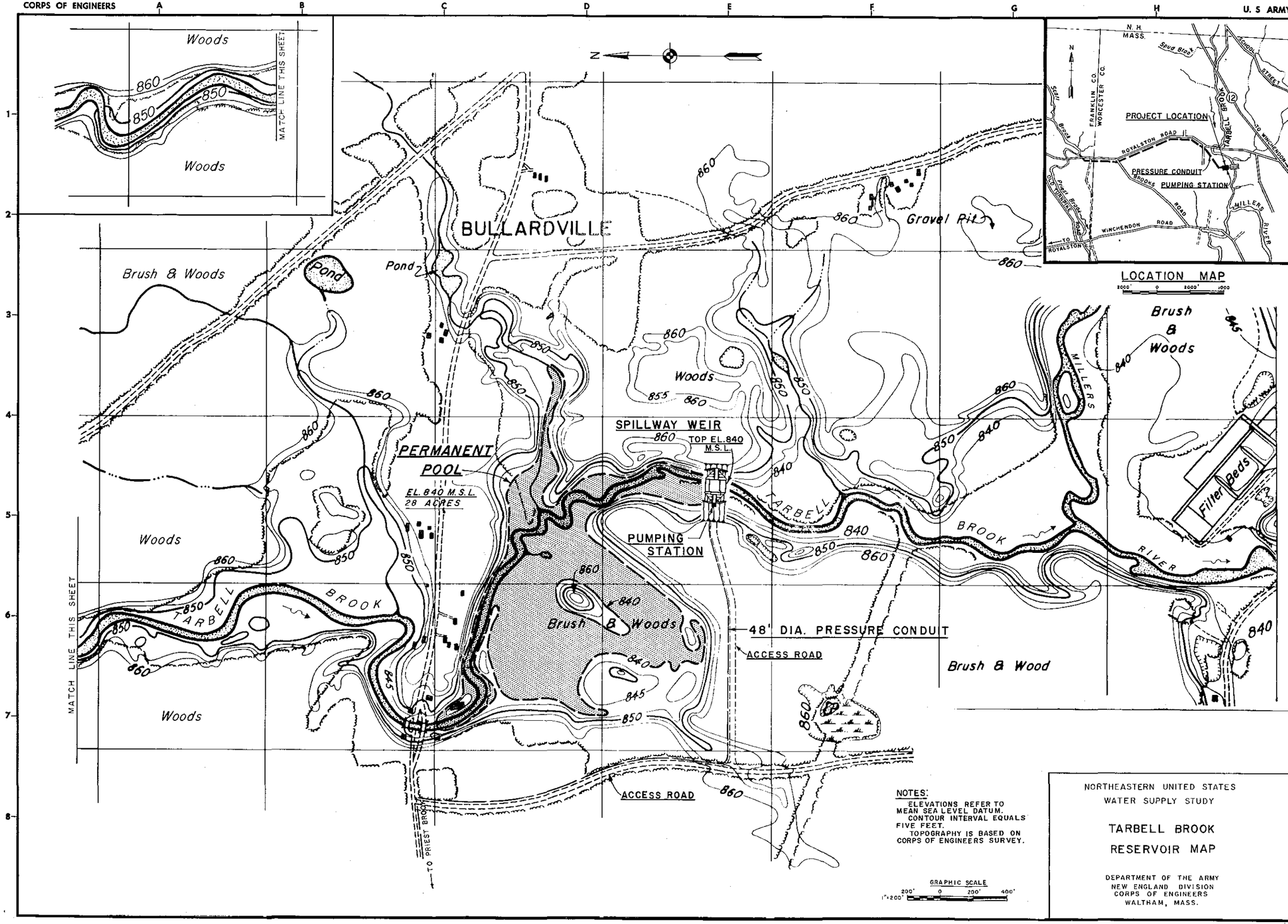
GRAPHIC SCALES

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO MILLERS RIVER
TUNNEL ALINEMENT NO. 14

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

CORPS OF ENGINEERS U. S ARMY



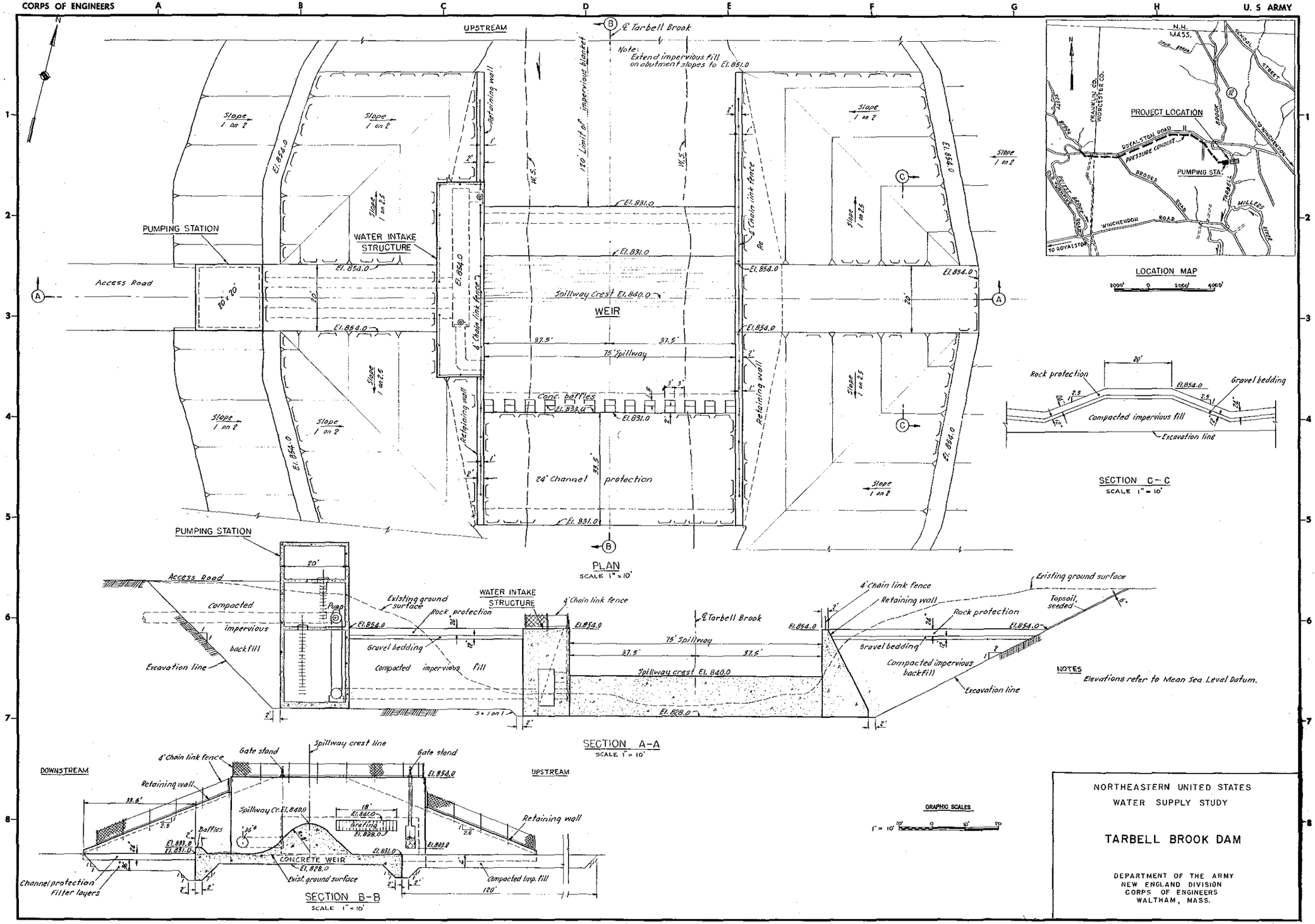
NOTES:
ELEVATIONS REFER TO MEAN SEA LEVEL DATUM.
CONTOUR INTERVAL EQUALS FIVE FEET.
TOPOGRAPHY IS BASED ON CORPS OF ENGINEERS SURVEY.

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TARBELL BROOK
RESERVOIR MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

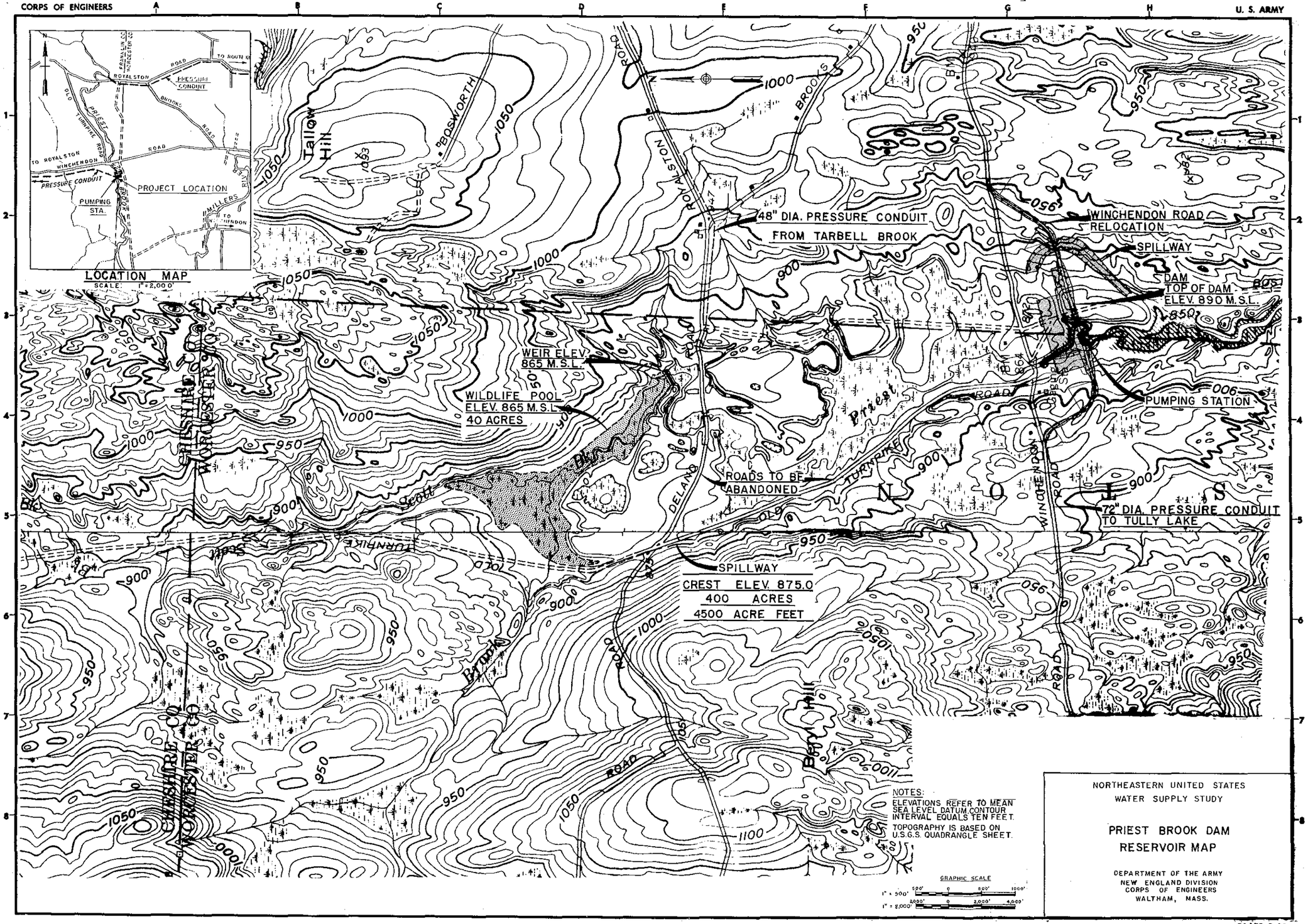
PLATE D-10



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TARBELL BROOK DAM

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

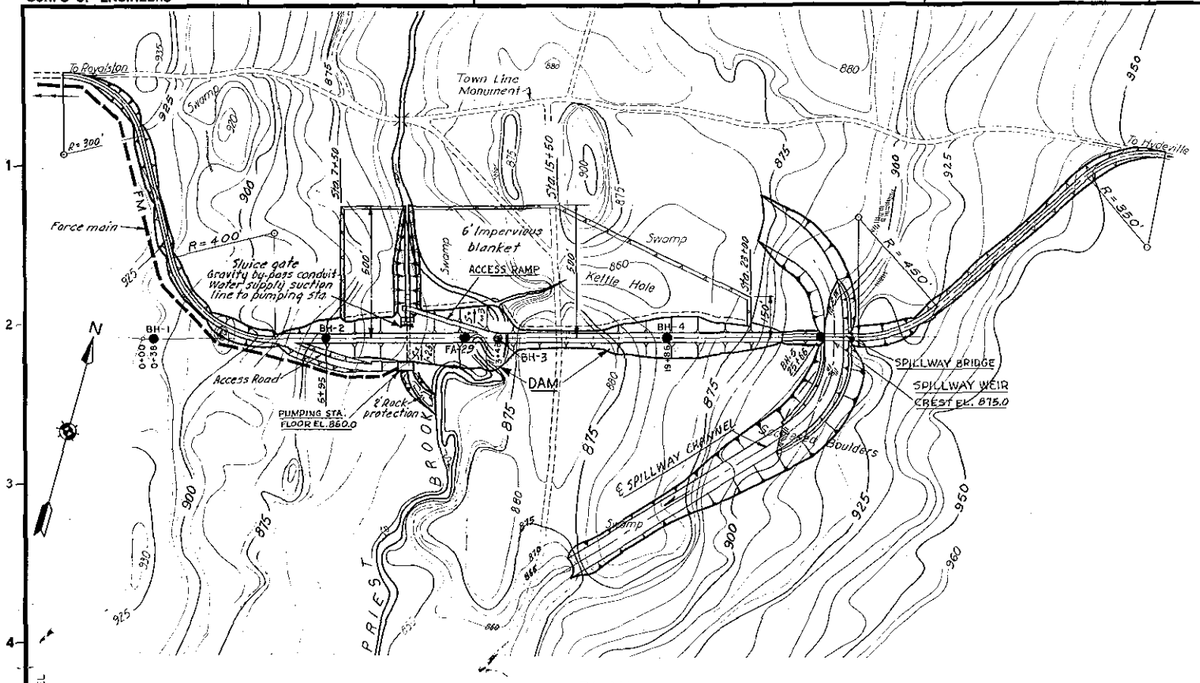


NOTES:
ELEVATIONS REFER TO MEAN SEA LEVEL DATUM. CONTOUR INTERVAL EQUALS TEN FEET.
TOPOGRAPHY IS BASED ON U.S.G.S. QUADRANGLE SHEET.

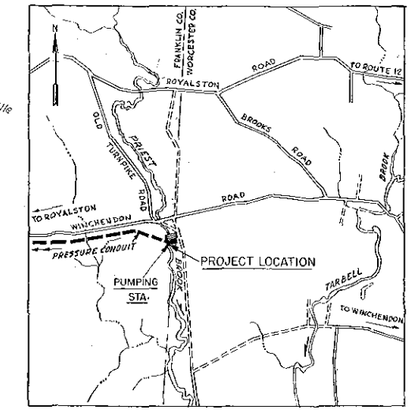
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

PRIEST BROOK DAM
RESERVOIR MAP

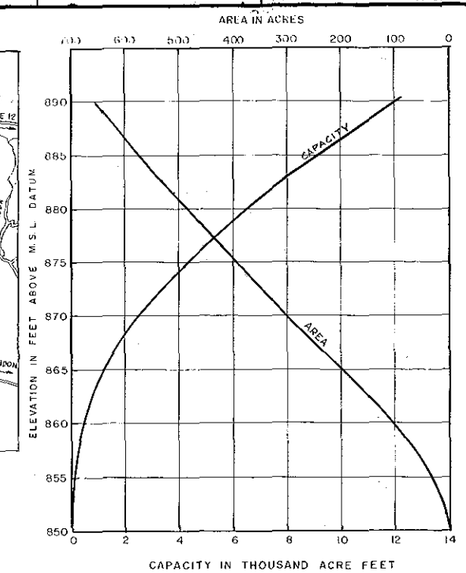
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.



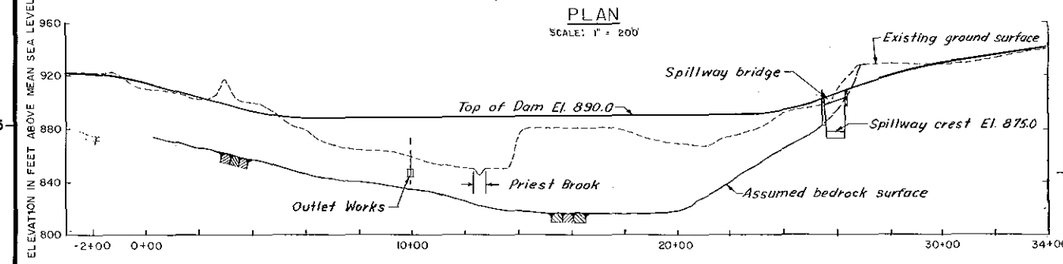
PLAN
SCALE: 1" = 200'



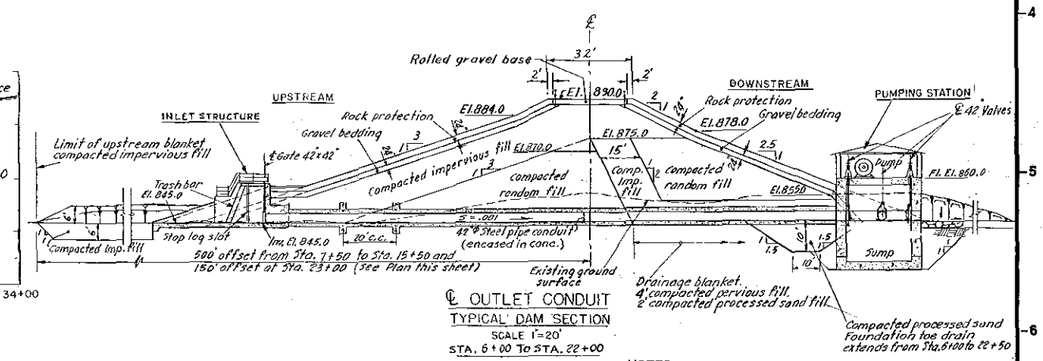
LOCATION MAP



AREA-CAPACITY CURVE

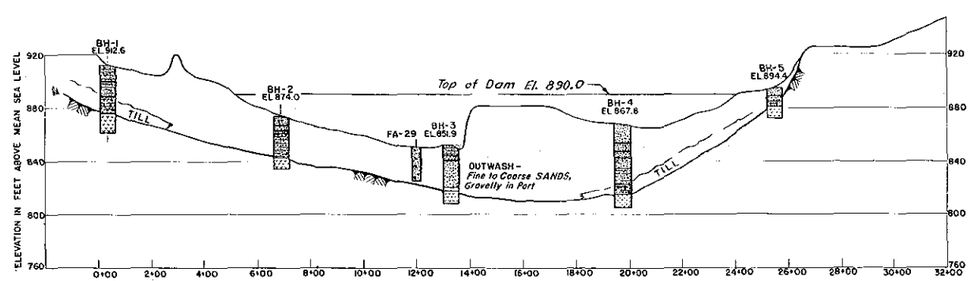


℄ PROFILE
SCALE HOR 1" = 200' VERT 1" = 40'



℄ OUTLET CONDUIT
TYPICAL DAM SECTION
SCALE 1" = 20'
STA. 6+00 TO STA. 22+00

NOTES
Elevations refer to Mean Sea Level Datum.



GEOLOGIC PROFILE ON ℄ OF DAM
SCALE HOR 1" = 200' VERT 1" = 40'

GRAPHIC LEGEND

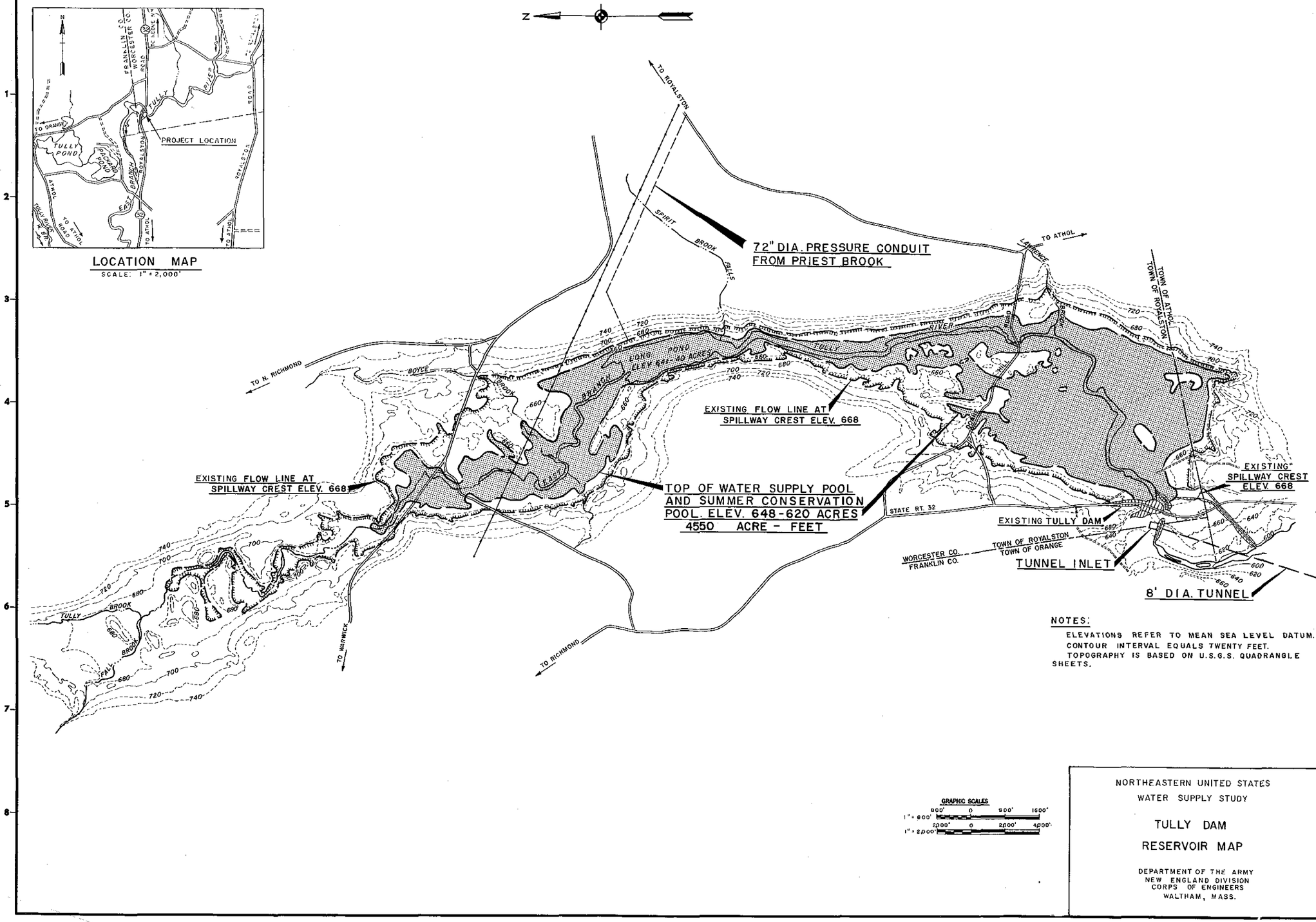
SAND
SILT OR ROCK FLOUR
CLAY
GRAVEL
GRANITE
WEATHERED OR FRACTURED ROCK
ROCK EXPOSURE
ASSUMED ROCK SURFACE
BH = TEST BORING-1936
FA = AUGER BORING-1931

GRAPHIC SCALES
1" = 20' 20' 0 20' 40'
1" = 40' 40' 0 40' 80'
1" = 200' 200' 0 200' 400'

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

PRIEST BROOK DAM

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.



NOTES:

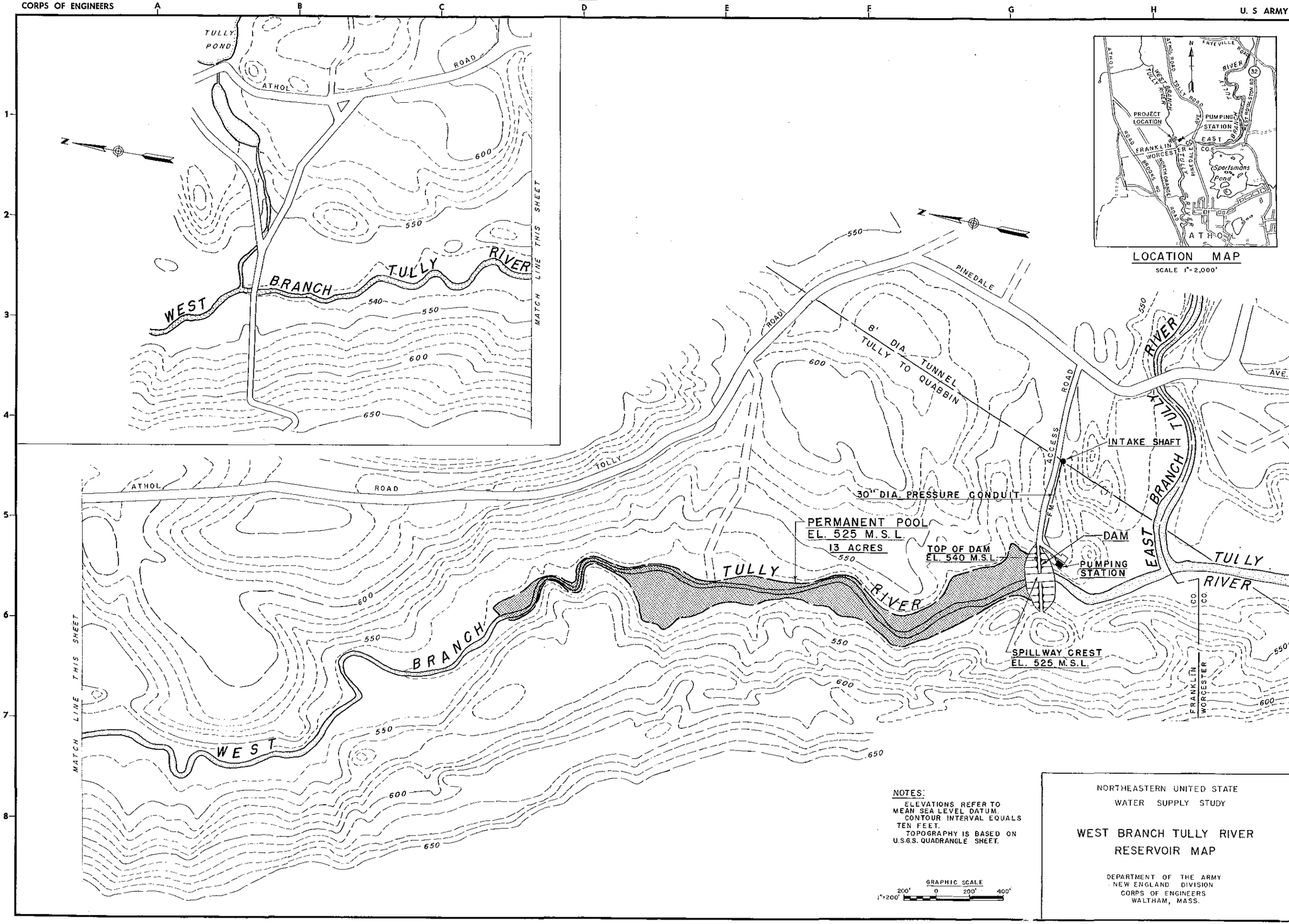
ELEVATIONS REFER TO MEAN SEA LEVEL DATUM.
CONTOUR INTERVAL EQUALS TWENTY FEET.
TOPOGRAPHY IS BASED ON U.S.G.S. QUADRANGLE SHEETS.

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY DAM
RESERVOIR MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

CORPS OF ENGINEERS U. S ARMY



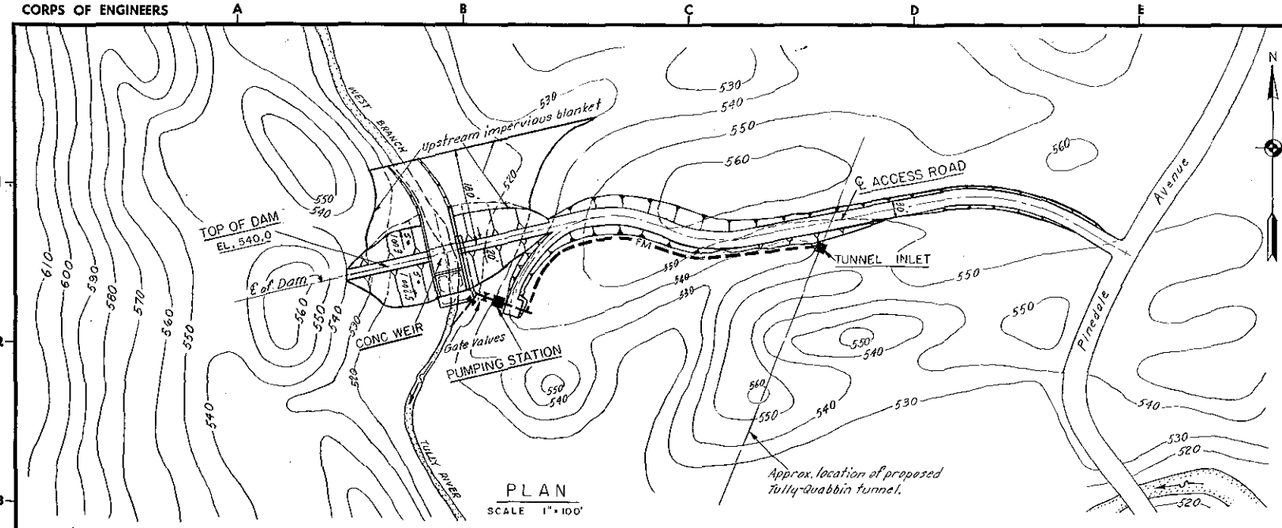
NOTES:
ELEVATIONS REFER TO MEAN SEA LEVEL DATUM.
CONTOUR INTERVAL EQUALS TEN FEET.
TOPOGRAPHY IS BASED ON U.S.G.S. QUADRANGLE SHEET.

NORTHEASTERN UNITED STATE
WATER SUPPLY STUDY

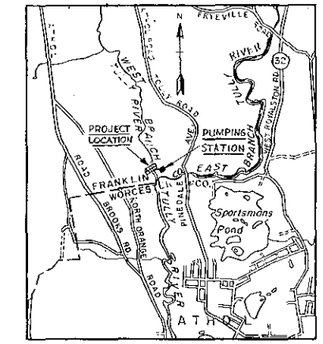
WEST BRANCH TULLY RIVER
RESERVOIR MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

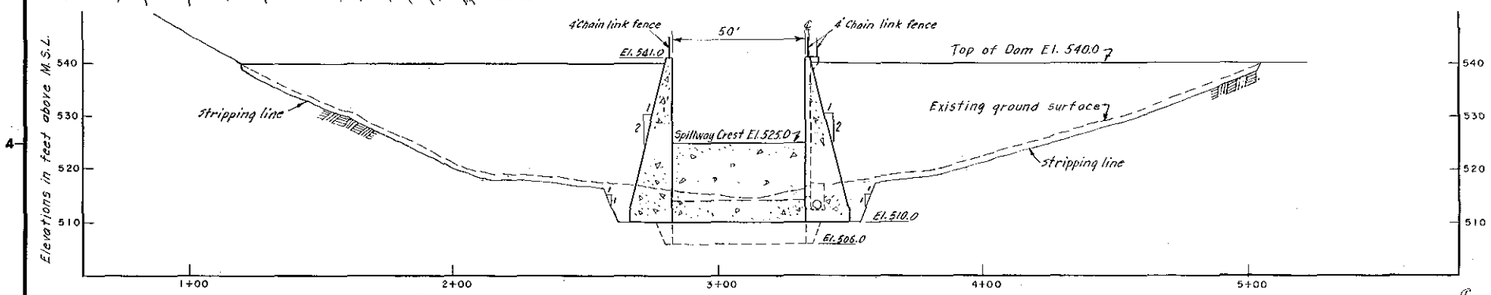
PLATE D-15



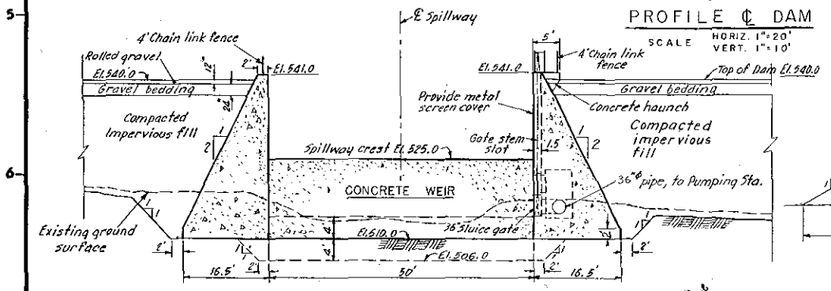
PLAN
SCALE 1" = 100'



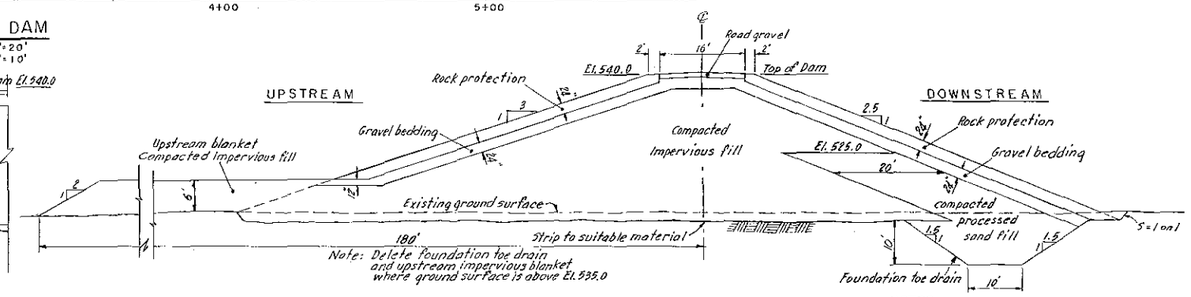
LOCATION MAP
SCALE 1" = 2,000'



PROFILE ℄ DAM
SCALE HORIZ. 1" = 20' VERT. 1" = 10'

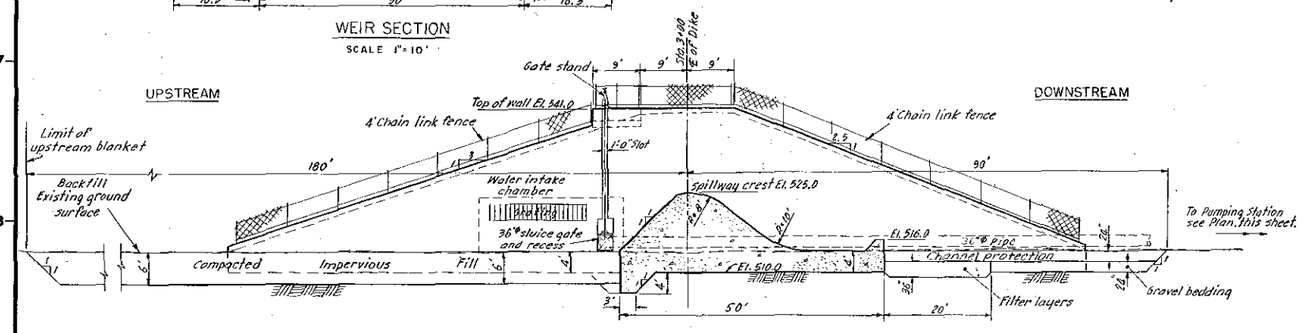


WEIR SECTION
SCALE 1" = 10'



TYPICAL DAM SECTION
SCALE 1" = 10'

NOTES
Elevations refer to Mean Sea Level Datum.



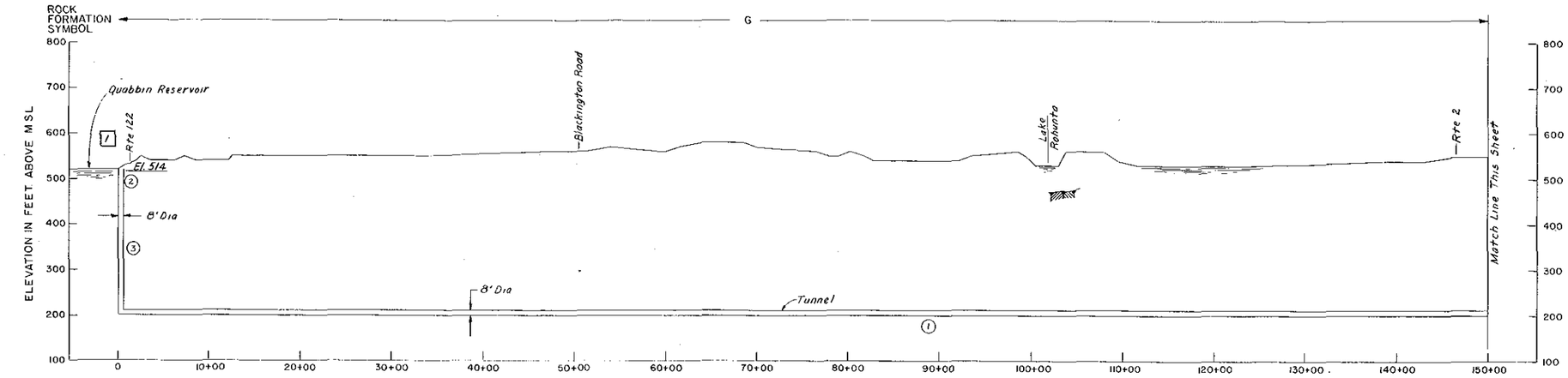
SECTIONAL ELEVATION
SCALE 1" = 10'

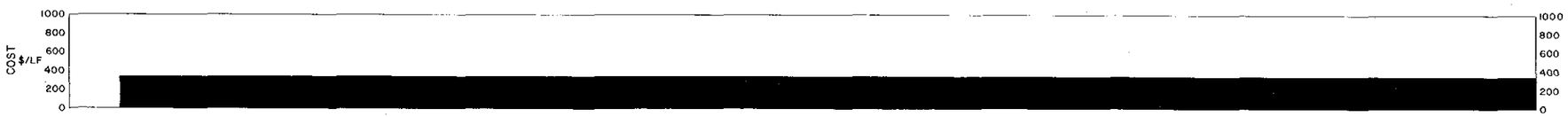
GRAPHIC SCALES
1" = 10' 10' 0 10' 20'
1" = 20' 20' 0 20' 40'
1" = 100' 100' 0 100' 200'
1" = 2,000' 2,000' 0 2,000' 4,000'

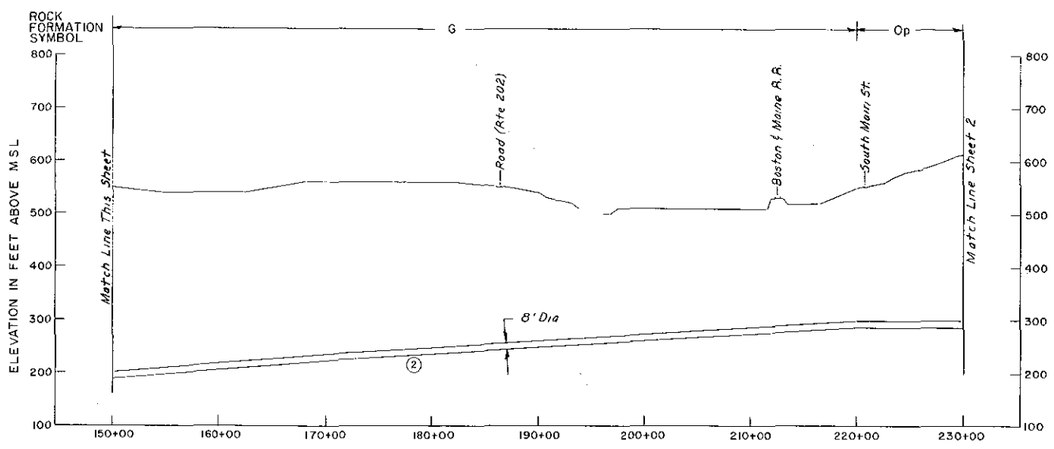
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

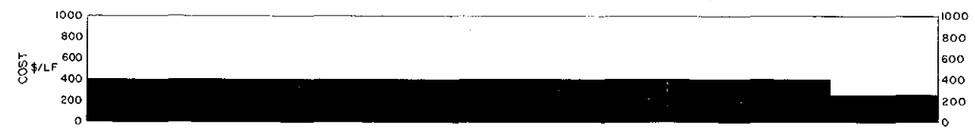
WEST BRANCH TULLY DAM

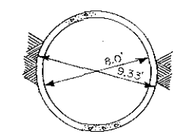
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.





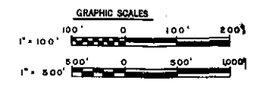






TYPICAL TUNNEL SECTION
SEGMENT 1
NOT TO SCALE

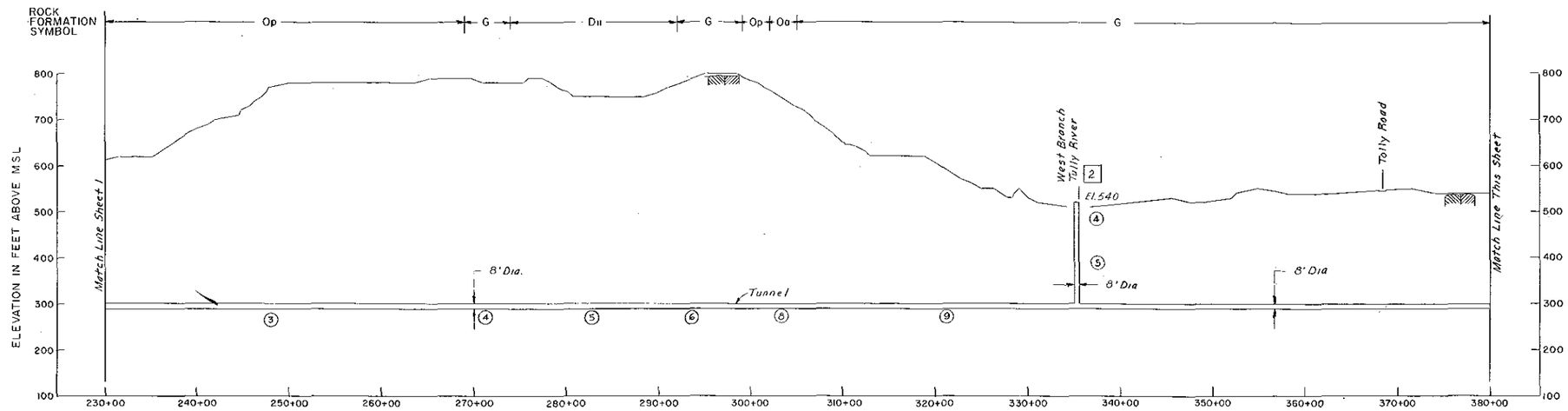
NOTES:
1. For Alinement Location & Legend See Plate E-1
2. For Rock Formation Data See Table E-1
3. Cost Chart $/LF For Machine Tunnel (MOLE) Excavation, Not Including Shaft Costs.
4. Segment Numbers (6) Refer To Computerized Cost Program.

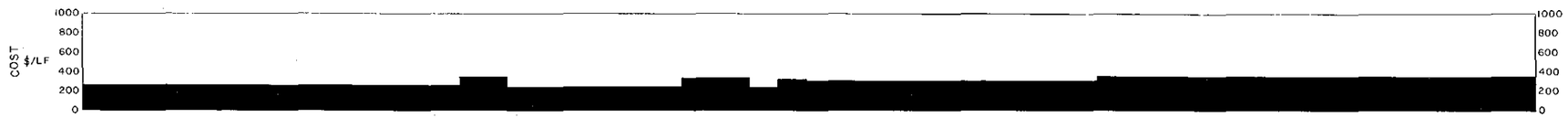


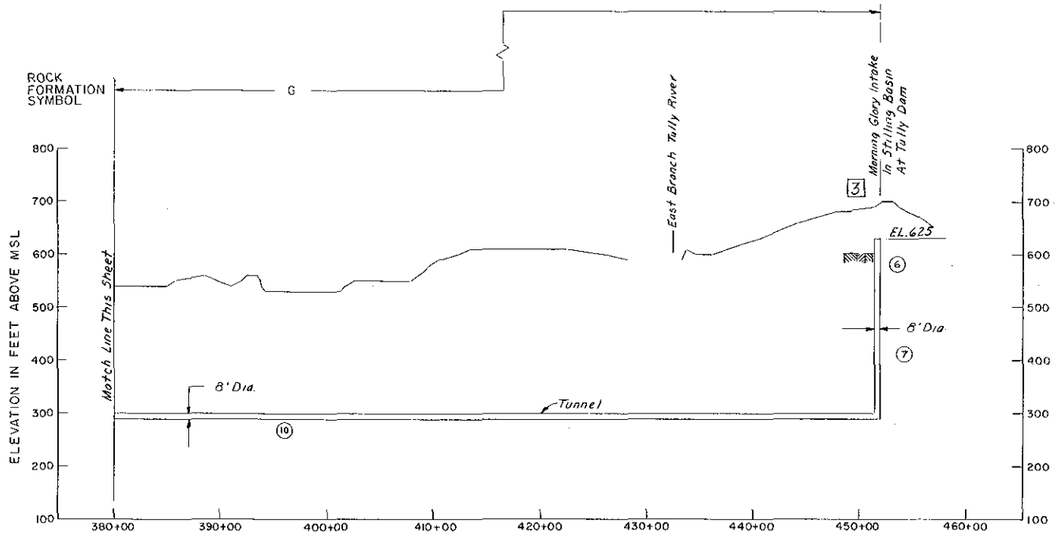
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

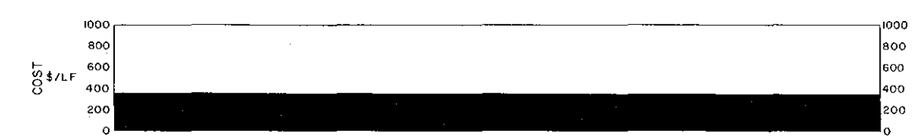
TULLY LAKE TO QUABBIN RESERVOIR
TUNNEL ALINEMENT NO. 13

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.









NOTE:
See Sheet 1 For Pertinent Notes.

GRAPHIC SCALES

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO QUABBIN RESERVOIR
TUNNEL ALINEMENT NO. 13

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

APPENDIX E

GEOLOGY, FOUNDATIONS AND EMBANKMENTS

This appendix develops the rationale used to determine the major cost of the various alternatives -- the tunnels. A computerized program was prepared which estimated tunnel construction costs. Input to the program included assumed geologic conditions with recent labor, equipment, and material rates. Geologic information was obtained from previous work in the area consisting primarily of mapping.

Also, geologic reconnaissance of the intake structure sites was made to determine the foundation conditions. On Priest Brook, this was augmented by borings taken in the 1930's by the Providence District, Corps of Engineers. Information was then used to aid in the design of the various intake structures.

The estimated tunnel construction costs derived here were then added to the intake and outlet works costs and other project costs allocated to the water supply function, resulting in the total project cost shown in the main report.

APPENDIX E

GEOLOGY, FOUNDATIONS AND EMBANKMENTS

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APPENDIX E

GEOLOGY, FOUNDATIONS AND EMBANKMENTS

1. Tunnel Geology

A. Introduction

The purpose of this appendix is to present an estimate of the cost of constructing a series of water supply tunnels from the Millers River Basin to Quabbin Reservoir. Studies were confined to various routes which had been selected on a straight line basis with intakes and discharges at locations of surface water supplies.

A computerized program 1/ was used for the tunnel estimates allowing flexibility in costing varying alignments and diameters to obtain the maximum benefits. All structural design considerations are based on those programmed in the computer to allow for the geologic input conditions. No allowances are made for headworks and intake structures above the shaft level.

Based on the above studies, a series of conclusions and recommendations are made relative to geologic effects which could have a cost effect on the project structures.

B. Available Subsurface Data

Geologic data was primarily derived from existing literature and mapping with a brief surface reconnaissance of the approximate alignments. No borings or engineering tests were conducted on the project features. Depth of overburden was obtained from water well data where adjacent to the alignment and bedrock formations were determined primarily from geologic mapping of the Orange Area. 2/ (See Plate No. E-1.) Assignment of engineering values to the rock formations was by experience with engineering properties of similar rock formations. (See Table E-1.) Permeability of the rock formations was by correlation with available water well test data with geologic features such as faults, buried

1/ A computer program for estimating costs of hard rock tunneling (COHART) prepared by Harza Engineering Co., 400 West Madison Street, Chicago, Illinois - May 1970 for the Office of High Speed Ground Transportation. Urban Mass Transportation Administration, Department of Transportation, Washington, D. C. 20591. (Modified by NED.)

2/ Gneiss Domes and Recumbent Folds of the Orange Area, West Central Massachusetts by Peter Robinson. Field Trips of the Connecticut Valley 1967.

valleys and rock conditions at depth being those described and inferred by literature review. Geologic formations crossed by the tunnel alignment are shown in plan on Plate No. E-1 and in profile on Plates No. E-2 through E-10. The approximate physical properties and formation descriptions of the rocks intersected by the tunnel alignments are shown on Table No. E-1.

C. Alignments

The proposed alignments shown on Plate No. E-1 represent the layouts which were selected for cost evaluation. These alignments were made on a minimum distance basis with an approximate hydrostatic head evaluation for shaft location. Diameters of tunnels and shafts were compatible except where the intake diameter was modified to meet the hydraulic criteria at Shaft 2 of the Millers River Intake. All tunnels (Mechanical and Conventional Rock Tunneling) were costed at a minimal lining thickness consistent with the estimated magnitude of structural support. All alignments except No. 13 and No. 14, 10' diameter terminated in reservoirs with intake elevations as selected by hydraulic criteria and reservoir control. Alignments No. 13 and No. 14 were advance studies which begin at a morning glory intake downstream of the Tully Dam outlet works. Alternate alignment 2A as shown on the plan (Plate No. E-1) is a suggested longer alignment which, based on more favorable geologic conditions results in no additional cost, but allows greater flexibility in the approach to Quabbin Reservoir. (See Table No. E-2). Minor adjustments were made in the tunnel depth profiles to maintain stable tunneling conditions.

D. Cost Estimate

Costs were estimated by computer based on the proposed scheme and the approximate geologic conditions anticipated along the proposed alignment. (See Table No. E-3 for typical computer output). All costs were made without profit or overhead based on current labor, equipment and materials rates for February 1971, except for advance studies on alignments 13, 14 and 15. Their costs include profit and overhead and were based either on October 1971 or on July 1973 rates. All structural design was based on the assumed geologic conditions with costs based on labor and materials required for the project work. A bar graph on the tunnel profile plates (Plates No. E-2 through No. E-5) represents the cost, $/LF, for conventionally excavated fully lined tunnels with costs varying for each segment based on the geologic or alignment conditions.

Plates No. E-6 Through No. E-10 represent the cost, $/LF, for mole excavated fully lined tunnels. Noticeable increases will occur where assumed fault lines are crossed due to a probable poor rock condition and a high hydrostatic head. (Note segments 11, 12, 23, and 24 on Alignments 2 and 7.) Disposal costs were computed on an area basis at a circumferential distance from the most appropriate shaft. Land costs represent a real estate estimate of the approximate value of land for the section involved. All shaft disposal cost and configuration of rock removal cost have been programmed to reduce construction activities within the reservoir areas. Shaft locations are based on required intake locations for input from surface structures. All alignments have been costed by computer on the basis of both mole and conventional excavation methods; however, selected excavation methods have been shown in graphical presentation on the profile plates. A summary of mole versus conventional costs is shown on Table No. E-2 and a typical computer run for a conventionally excavated tunnel input and calculated data is shown on Table No. E-3.

Costing of the mole method of operation includes the following variations from the conventional method:

a. All cost of re-setups after the initial set up, i. e., when conventional excavation must be used in a fault zone, is computed at one-fourth of the initial setup.

b. Equipment cost includes the cost of depreciation of the mining machine during its setup and takedown and the cost of all assisting equipment.

c. Loading of tunnel muck is not carried as a cost item as it is automatic to the operations of the mole.

E. Conclusions and Recommendations

Computerized cost studies indicate that the mole (Mechanical Rock Tunneling) has an economic advantage on most tunnel alignments in the Tully to Quabbin Reservoir area. The efficiency of the mole is directly related to rock strengths with most efficiency in the range of 8,000 to 16,000 psi unconfined compression strengths which are indicated to occur in a high proportion in this area. (See Plate No. E-1.) A summary of all costs and construction time for all alignments are shown on Table No. E-2 and indicate the degree of savings which may be realized from use of the mole.

The mole method is restricted to circular tunnel shapes. It does have secondary advantages which are not reflected in the cost summaries such

as (1) a potential for reduction of lining thickness by use of shotcrete at an estimated additional possible savings of as much as 20 percent of the total cost and (2) reduced vibratory effects in urban areas.

Alignments may be modified to provide improved tunnel conditions over a longer alignment at reduced cost. Note time and cost for Alignment 2A versus 2 on Table No. E-2 and alignments shown on Plate No. E-1.

Design of shafts outside of Quabbin Reservoir would improve muck removal and reduce contamination of the reservoir. Present costs are increased due to restricted use of Shaft 1.

Consideration should be given to unlined mole tunnels. Considerable monies could be saved with reduction of lining but the effect upon the subsurface water regimen and contamination from surface water infiltration should be evaluated.

Maximum importance should be placed on hydraulic criteria in fixing tunnel diameter. A one-foot change of diameter on a single alignment may alter the construction cost by 1/2 to $1 million.

Any further refinement of costs requires subsurface explorations and detailed field geologic studies to obtain reliable strength parameters of the rock formations.

2. Site Geology and Foundations Conditions for Structures

A. General Topography and Geology

The drainage of the Millers and Tully Rivers and their tributaries lies within the upland region of New England in Worcester County, North-Central Massachusetts and Cheshire County, Southwestern New Hampshire. Relief is moderate with elevations in the hill areas generally attaining 1,100 to 1,400 feet and 800 to 900 feet in the valleys. The topography of the region is largely controlled by the structure of the underlying igneous and metamorphic bedrock of the paleozoic era which has produced a general north-south trend of the valleys and ridges.

Glaciation has modified a preglacial bedrock topography by scour and moreso from glacial debris deposited by the ice and by melt-water streams. Glacial deposition has locally disarranged preglacial courses of drainage. Much of the region is covered by glacial till deposited directly by the ice mantling the bedrock on the crests and upper slopes

of the hills and thickest on the lower slopes and in the valleys. Overlying the till in the valleys are extensive glacial outwash deposits of sands and gravels in the form of kames, kame terraces, kame plains, and ice-channel fillings.

B. Mineral Resources

The proposed reservoirs will majorly inundate glacio-Fluvial deposits of sands and gravels of possible commercial value, however, untapped deposits of this nature occur in abundance in the region.

C. Explorations

Reconnaissances have been made of all sites and their vicinities. Subsurface explorations were not made for the very low structures proposed on Tarbell Brook and the West Branch of the Tully River and on the Millers River. The site on Priest Brook was explored in the period 1931-1936 by the Providence District, Corps of Engineers. Five test borings and a deep auger boring applicable to the proposed alignment are shown in plan and profile on Plate No. E-11. No field and laboratory records are available from these explorations. Borings made in this period are known to have been intermittently sampled in overburden, using an 18-inch split sample spool of 2-inch nominal diameter driven by a 375 pound drop weight falling about eight inches. Bedrock was core-drilled in 1-5/8 inch diameter, a minimum penetration of 10 feet. The graphic presentation of materials encountered as shown on this Plate are taken from a drawing prepared by the Providence District in 1937. The topography shown has been determined as fairly reliable from a recent profile check by field survey

D. Site Geology

1) West Branch Tully River - The site is located on the Athol, Massachusetts Quadrangle, 1:24,000, about 800 feet upstream of the confluence of the West Branch with the East Branch. Except for a mantle of swamp deposits in the river section, very pervious glacial outwash sediments dominate the siting and vicinity. The ridge forming the right bank is an esker or crevasse-filling composed of sands and gravels. The left bank area is a kame terrace composed of coarse sands and some gravel. Well records in the general vicinity indicate thicknesses of these water-laid deposits up to 80 feet. The water table is relatively level in these deposits and is exposed in the kettle-holes occupied by Sportsman Pond and Silver Lake at about elevation 530.

2) Tarbell Brook - The site is located on the Winchendeon, Massachusetts-New Hampshire Quadrangle 1:24,000, about one-half mile upstream of the confluence of the brook with the Millers River. The site and wide surrounding areas are characterized by thick glacio-fluvial deposits pitted with ice-block holes. The water table is free and relatively level at about elevation 835 or near brook levels.

3) Priest Brook - The site is located on the Winchendon, Massachusetts-New Hampshire Quadrangle, 1:24,000, about 2-3/4 miles upstream of the confluence of the brook with the Millers River. The valley of Priest Brook is deeply filled with glacial outwash sediments, principally sands and gravelly sands. The abutments above about elevation 900 have an overburden of glacial till. Bedrock, a coarse granite, is exposed above elevation 900 on the left abutment as shown on Plate No. E-11. Maximum indicated depth to bedrock in the valley section is 80 feet and is overlain, in part, by a thin mantle of glacial till, in burn overlain by pervious glacial outwash. Cutoff to till or bedrock under the embankment is not economically feasible and control of under-seepage will be accomplished by an upstream impervious fill section in the embankment tied to an impervious blanket. The spillway weir will be founded on bedrock in the left abutment. Surficial geology coupled with the depth to bedrock (15 feet) in test boring BH-5 indicate that the bedrock surface falls off rapidly down slope from the exposures shown in plan. Therefore, little rock will be encountered in the approach excavation to the weir and the availability of rock for channelization of spillway discharges will be lost at about elevation 900. The outlet conduit will be founded in glacial overburden in the stream section.

4) Millers River - The site of the structure is located on the Millers River approximately one mile east of the city limits of Athol, Massachusetts. Bedrock outcrops of gneisses and schists project through a thin overburden on the steep northerly cut bank of the stream. The central portion of the valley is buried beneath alluvial deposits of sands and gravels with large surface boulders in the stream channel. The left abutment is comprised of railroad fill of the Boston and Maine Railroad.

E. Construction Materials

1) West Branch Tully River - Bank-run sands and gravels are abundant in the river valley from esker and kame terrace deposits in which several openings have been made. Gravel bedding materials should be obtainable with selection from these deposits at a haul distance of about one-half to two miles. Sources of processed sand and

also concrete aggregates and transit mix concrete are Templeton, Massachusetts (14 miles), Greenfield, Massachusetts (25 miles), Keene, New-Hampshire (22 miles) and Northfield, Massachusetts (20 miles). Impervious materials would have to be contractor-furnished from an off-site source with potentials at about a 2-mile haul distance. Since there are no required rock excavations and requirements would be small, any rock needed for slope protection or other purposes would be furnished from a commercial quarry. Operating quarries are located at East Deerfield, Massachusetts (25 miles), Lunenburg, Massachusetts (35 miles) and Sterling, Massachusetts (35 miles). Consideration might be given to contractor quarrying in exposed rock faces adjacent to the area of spillway at Tully Dam, a haul distance of about 2 miles. A long abandoned quarry in gneissic granite occurs in Warwick, Massachusetts at a haul distance of about 15 miles.

2) Tarbell Brook - Gravel bedding materials from selective excavations should be available from the extensive glacial outwash deposits in the Millers River valley in the Birch Hill Reservoir area. A sand and gravel pit does exist just south of Harrisville, New Hampshire at a haul distance of about one mile. Haul for these materials should be estimated at 1-1/2 miles. A commercial sand and gravel plant, not processing for concrete aggregates, is located in Winchendon, Massachusetts, about 1-1/2 miles south of site. Impervious materials would be found on the valley walls above the right bank of the river at about elevation 900. Maximum haul for these materials would be about one mile. Processed and concrete aggregates and transit mix concrete are nearest available at Templeton, Massachusetts at a haul of about 10 miles. Other sources are located at Barre, Massachusetts and Leominster, Massachusetts at approximate haul of about 21 and 25 miles respectively. Rock, if needed, for slope protection or other purposes might be provided by contractor quarrying in the rock knolls in the vicinity of the spillway area at Birch Hill Dam. Operating quarries are located at Lunenburg and Sterling, Massachusetts at comparable haul distances of about 30 miles.

3) Priest Brook - Gravel bedding materials should be available from terrace, kame and other deposits within the limits of the proposed reservoir or within the limits of Birch Hill Reservoir downstream of Priest Brook Dam at a haul of about one mile. A commercial sand and gravel plant, not processing for concrete aggregates is located in Winchendon about three miles haul west of the site. Random and impervious materials should be available on the right abutment area above elevation 900. Sandy till is exposed on Winchendon Road. Haul of one mile should be used for estimating. Processed sand and concrete aggregates and transit mix concrete are nearest available at Templeton, Massachusetts at a

haul of about 10 miles. Other sources are located at Barre, Massachusett and Leominster, Massachusetts at approximate hauls of about 21 and 25 miles, respectively. The granitic rock from spillway excavations is suitable for use as rock protection materials.

4) Millers River - The only materials needed at this site would be processed sand and concrete aggregates and transit mix concrete. The nearest source is located at Templeton, Massachusetts at a haul distance of about 10 miles. Other sources are located at Barre, Massachusetts and Leominster, Massachusetts at hauls of about 21 and 25 miles, respectively.

F. Reservoir Leakage

1) Priest Brook - There are no pervious divides on the reservoir rim and at elevations of about 900 impervious glacial till mantles a shallow bedrock surface. Provisions for reduction of through seepage and under seepage are included in the embankment design.

2) West Branch Tully River and Tarbell Brook - These low structures are underlain and abutted by thick and extensive deposits of pervious materials in which the water table is a free one with continuity and low gradient over wide areas with discharge to the river. The impoundments will assist in raising the water table during periods of heavy precipitation which would normally be the time for diversion by pumping. To further assist in maintaining a high water table, consideration should be given to impervious blanketing of natural ground features contiguous with the abutments.

G. Foundations and Embankment Design

1) Priest Brook

a. General. Design and engineering studies have been made to the extent considered necessary for this report relative to the foundation, embankment, and earthwork. Investigations consisting of the utilization of records of subsurface explorations made in the 1930's and field reconnaissance were conducted to determine: (1) the characteristics of the foundation soils for the proposed structures; (2) the characteristics and extent of the materials to be excavated; and (3) the characteristics and availability of potential borrow materials. The location of the explorations are shown on Plate No. E-11. The site geology and availability of materials are described in previous paragraphs.

b. Characteristics of Foundation Soils. The foundation soils consist mainly of pervious glacial outwash deposits of sands and gravelly sands extending to depths of from 25 to 40 feet on the abutments to over 80 feet in the valley. The sands and gravelly sands thin out above about elevation 900. The bedrock surface in the valley and abutments is overlain in part by a thin mantle of glacial till.

c. Characteristics of Earthen Embankment Materials.

(1) Overburden materials from the required excavations for this project will include materials from both the outwash and glacial till. All suitable material from these excavations will be utilized to the extent practicable in the permanent work.

It is anticipated that the small quantities of embankment drainage materials required in the embankment can be obtained from the required excavations with only a minor degree of selection and separation. The remainder of the material from the required excavations will be utilized in the random fill zones of the dam and highway embankments, and in covering the organic deposits in the reservoir below elevation 860.

(2) Rock. The required rock excavation from the spillway channel is suitable for rock protection. In the event that more rock protection material is needed, additional material can be furnished from commercial quarries or by contractor quarrying in the exposed rock faces adjacent to the spillway area.

(3) Borrow Materials. Impervious embankment material may be obtained from glacial till deposits on the right abutment area above elevation 900. Gravel bedding and processed sand material are available from commercial sources.

d. Embankment Design.

(1) The embankment as selected for this report is shown on Plate No. E-11. The zonation of the embankment is based on providing room for maximum utilization of materials from the required excavations and the minimum economical use of impervious, gravel bedding and processed sand fills consistent with adequate seepage control. Internal seepage control will be provided by the pervious fill wick drain and horizontal drainage blanket. A foundation cutoff to impervious foundation soils does not appear to be feasible. An upstream impervious blanket therefore, is provided to control foundation seepage in

conjunction with a downstream drain. The average gradient for seepage through the dam foundation will be in the order of 5 percent at maximum water supply pool (elevation 875). The maximum height of the embankment is about 40 feet. The side slopes of the embankment have been selected on the basis of experience with the design and construction of dam embankments of similar height, embankment materials, and foundation conditions.

e. Foundation Design for Concrete Structures. The foundation for the spillway weir and the bridge over the spillway will be founded on bedrock. The outlet works and pumping station will be founded on pervious granular materials. No significant settlements are expected to occur in the foundation of concrete structures founded on these materials. The major portion of the discharge channel will be excavated in overburden. As the spillway will discharge frequently, a 2-foot layer of rock protection is provided to minimize erosion.

2) West Branch Tully River

a. General. Design and engineering studies have been made to the extent considered necessary for this report relative to the foundation embankment and earthwork. No subsurface explorations were made at this site. Investigations consisted of field reconnaissance. The site geology and availability of materials is described in paragraphs D and E of this appendix.

b. Characteristics of Foundation Soils. Based upon visual observations and geology, the foundation and abutment soils consist of very pervious glacial outwash sediments of substantial thickness.

c. Characteristics of Earthen Embankment Materials.

(1) Overburden. Suitable materials from the required earth excavations will consist of glacial outwash sediments and will be utilized as random fill material in the dam embankment and access road.

(2) Rock. Since there are no required rock excavations and requirements will be small, rock needed for rock protection and channel protection will be furnished from commercial quarries.

(3) Borrow Materials. Impervious embankment material and gravel bedding material may be borrowed from deposits within two miles of the site. Processed sand material and concrete aggregates for use as filter and drainage materials are available from commercial sources.

d. Embankment Design. Typical embankment and concrete spillway structure sections are shown on Plate No. E-12. The selected embankment section has been designed to adequately control seepage. Internal seepage will be provided by the downstream processed sand fill zone. Based upon the available information, a foundation cutoff is not feasible; therefore, an upstream impervious fill blanket is provided to control foundation seepage in conjunction with a downstream toe drain. The maximum height of embankment is about 25 feet. Side slopes of 1 vertical on 3 horizontal upstream and 1 vertical on 2.5 horizontal have been adopted. The outer slopes of the embankment will be protected by layers of rock protection and gravel bedding.

e. Foundation Design for Concrete Structure Spillway. The foundation for the concrete spillway structure and pump house will be glacial outwash sediments. Seepage through the foundation will be controlled by an upstream compacted impervious fill blanket and downstream toe drain. The average gradient for seepage through the weir foundation will be in the order of 5 percent at maximum water supply pool (elevation 525). The quantities of seepage through the abutments and foundations could be sufficient to render it impossible to maintain a permanent pool during periods of low flow or drought. Based upon the available information, no significant settlements are expected to occur in the foundation of the concrete spillway structure.

3) Tarbell Brook

a. General. Design and engineering studies have been made to the extent considered necessary for this report relative to the foundation, embankment, and earthwork. No subsurface explorations were made at this site. Investigations consisted of field reconnaissance. The site geology and availability of materials are described in paragraphs D and E of this appendix.

b. Characteristics of Foundation Soils. The foundation and abutment soils are very pervious glacio-fluvial deposits of substantial thickness.

c. Characteristics of Earthen Embankment Materials.

(1) Overburden. Suitable materials from the required earth excavations will consist of glacial outwash deposits and will be utilized as random fill material in the access road.

(2) Rock. Since there are no required rock excavations and requirements will be small, rock needed for rock protection and channel protection will be furnished from operating quarries.

(3) Borrow. Impervious embankment material may be borrowed from the valley walls above the right bank of the river at about elevation 900. Concrete aggregates for use as filter and drainage materials are available from commercial sources. Gravel bedding materials are available within a mile haul distance of the site.

d. Foundation Design for Concrete Spillway Structures. Based upon the available information, a foundation cutoff is not feasible; therefore, an upstream impervious fill blanket is provided to control seepage through the foundation and abutments in conjunction with a downstream toe drain. The average gradient for seepage through the weir foundation will be in the order of 5 percent at maximum water supply pool (elevation 840). The quantities of seepage through the abutments and foundations could be significant to render it impossible to maintain a permanent pool during periods of low flow or drought. Based upon the available information, no significant settlements are expected to occur in the foundation of the concrete spillway structure.

4) Millers River

No subsurface exploration or surveys were made at the site. Preliminary examination indicates that the tunnel intake will be in rock on the right abutment. The low weir will be a concrete structure imbedded in the river alluvium with a suitable wraparound and seepage control to protect the gate and right abutment section. It is assumed for the purpose of preliminary design that foundation bearings are adequate for the proposed structures. Finished rock cuts are designed as 4 on 1 with earth cuts above 1 on 1.5. Where slopes have been designed adjacent to existing railroad fills, a slope of 1 on 2.5 would be used. All construction cuts in earth would be 1 on 1.

TABLE E-1

ROCK FORMATIONS AND ENGINEERING PROPERTIES

FORMATION NAME	ROCK FORMATION SYMBOL	U.C. STRENGTH (psi)		R. Q. D.		INFLOW GPM		REMARKS
		0-100' Depth	100'+ Depth	0-100' Depth	100'+ Depth	0-100' Depth	100'+ Depth	
Ammonoosoc Volcanics	O_a	8,000	16,000	60	80	60	30	Feldspar quartz gneiss and amphibolite. Contains amphibolite with phyllite and gneisses w/kyanite and sillimanite
Monson Gneiss	G	8,000	16,000	60	80	60	30	Bedded, feldspar quartz gneiss and amphibolite with massive gneisses
Littleton	Dll	-	8,000	-	90	-	60	Mica schist with minor quartzite generally garnetiferous
Partridge	O_p	-	8,000	-	90	-	50	Mica schist and gneisses with layers of amphibolite.
Fault	Fault Line Noted	-	2,000	-	10	-	500	Broken and fractured rock zone w/tunnel supports
Prescott Intrusive	ddg	16,000	32,000	70	80	40	20	Hornblende Gabbro, surrounded by strongly lineated biotite, quartz, diorite, granodiorite and quartz monzonite.

TABLE E-2

TUNNEL COST & CONSTRUCTION TIME

Alinement	Aline. No.	Finished Tunnel Diameter	Length	Conventional Cost ($1000) Labor	Conventional Cost ($1000) Equip.	Conventional Cost ($1000) Matls	Conventional Cost ($1000) Total	Conventional Constr Time (days)* Max.	Conventional Constr Time (days)* Min.	Mole Cost ($1000) Labor	Mole Cost ($1000) Equip.	Mole Cost ($1000) Matls	Mole Cost ($1000) Total	Mole Constr Time (days)* Max.	Mole Constr Time (days)* Min.	Disposal Area Acres 30' deep	Disposal Area Shaft Shaft No.
Tully to Middle Br	1	8'	38,520	7,313	2,164	1,084	10,561	1,096	675	-	-	-	-	-	-	2	1 & 2
"	1	10'	38,520	8,012	2,318	1,524	11,854	1,096	675	7,535	1,899	1,491	10,925	1,088	598	2	1 & 2
Tully to Millers Rvr	7	10'	13,650	3,524	1,103	606	5,233	497	456	2,737	737	544	4,018	411	368	2	2
Tully to Millers Rvr to Quabbin Res.	2&7	10' & 10'	49,450	11,360	3,387	2,113	16,860	**	**	-	-	-	-	-	-	5	1 & 2
"	2&7	11 & 10	49,450	11,715	3,476	2,259	17,450	1,406	565	9,507	2,352	2,132	13,991	1,327	526	6	1 & 2
"	2&7	12 & 10	49,450	12,053	3,631	2,477	18,161	**	**	-	-	-	-	-	-	7	1 & 2
"	2&7	14 & 10	49,450	12,789	3,897	2,897	19,535	**	**	-	-	-	-	-	-	9	1 & 2
"	2&7	11 & 10	53,300	11,373	3,243	2,176	16,687	1,436	576	9,251	2,368	2,084	13,703	1,255	410	6	1 & 2
Tully to Quabbin Res.	13	8'	45,200	8,806	2,412	1,383	12,601	1,254	711	8,178	1,935	1,343	11,451	1,242	621	3	1 & 2
"	13***	8'	45,200	12,423	3,221	2,194	17,838	1,254	711	11,568	2,528	2,219	16,369	1,209	621	2	1 & 2
"	13	10'	45,200	9,919	2,811	1,801	14,531	1,305	740	8,642	2,070	1,742	12,454	1,262	631	4	1,2&3
Tully-Millers Quabbin	13****	8'	45,200	-	-	-	-	-	-	12,999	2,639	2,661	18,299	1,229	621	2	1 & 2
"	14***	10 & 8	50,400	15,370	4,400	3,181	23,311	1,523	602	14,489	3,562	3,093	21,144	1,472	551	5	1,2&3
Gays Hill to W. Br. Quabbin Res.	14a***	10'	37,500	11,846	2,224	2,522	16,592	1,087	602	10,854	2,570	2,430	15,744	1,064	551	4	1 & 2
	14****	10 & 8	50,400	-	-	-	-	-	-	16,338	3,676	3,834	23,848	1,472	551	5	1,2,&3
	15***	10'	40,000	13,891	3,891	2,829	20,259	1,325	658	15,958	3,845	3,090	22,893	1,713	675	3	1,2&3

All costs w/o overhead or profit are based on February 1971 labor, equipment and material costs.

* Construction time variable depends on number of shafts which are worked simultaneously.

** Time will increase slightly with increased diameter but was not completed during this study.

*** All costs with 25% overhead and 5% profit are based on October 1971 labor, equipment and material costs.

**** Costs with 25% overhead and 5% profit margin are based on July 1973 labor, equipment and material costs.

TABLE E-3

COMPUTER PRINTOUT OF TYPICAL TUNNEL PROGRAMS

```
*****************************************************************************
*                                                                           *
*          TULLY DAM TO MILLERS RIVER AND QUABBIN RESERVOIR                 *
*                    ALIGNMENTS NO. 2 AND NO. 7                             *
*                     CONVENTIONAL EXCAVATION                               *
*                                                                           *
*****************************************************************************

*********************************
*                               *
*  PROFIT MARGIN.............0.00 *
*  OVERHEAD MARGIN...........0.00 *
*                               *
*********************************
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**** WARNING ****   RQD IN SEGMENT   11 IN REACH   2 IS IN THE RANGE OF ZERO TO 25   ************************
**** WARNING ****   RQD IN SEGMENT   12 IN REACH   2 IS IN THE RANGE OF ZERO TO 25   ************************
**** WARNING ****   RQD IN SEGMENT   23 IN REACH   3 IS IN THE RANGE OF ZERO TO 25   ************************
**** WARNING ****   RQD IN SEGMENT   24 IN REACH   3 IS IN THE RANGE OF ZERO TO 25   ************************
```

NODAL POINT	ELEVATION
1	524.
2	440.
3	190.
4	190.
5	390.
6	390.
7	390.
8	390.
9	390.
10	390.
11	390.
12	390.
13	390.
14	390.
15	390.
16	390.
17	390.
18	390.
19	390.
20	605.
21	500.
22	390.
23	390.
24	390.
25	390.
26	390.
27	390.
28	390.
29	390.
30	635.
31	545.
32	390.

********** TUNNEL INPUT DATA **********

REACH	SEG	NP BOUNDRY LEFT	NP BOUNDRY RIGHT	EXIT SHAFT	HORIZ LGTH	TUNNEL SHAPE	TUNNEL SIZE (FT)	MUCK REMOVAL METHOD	EXCAVA-TION METHOD	ADVANCE RATE (FT/DAY)	***ROCK PROPERTIES*** STRENGTH (PSI)	RQD	TEMP (F)	INFLOW (GDM)	**LINING*** TYPE	THICK (IN)
1	1	3	4	1	6950	CIRCLE	11.00	TRAIN	CONVNT	55.0	16000	70	55	50	CONC	
	2	4	5		4000				CONVNT	55.0	16000	80	55	50	CONC	
	3	5	6		7000				CONVNT	55.0	16000	80	55	30	CONC	
2	4	6	7	2	1850	CIRCLE	11.00	TRAIN	CONVNT	60.0	8000	90	55	50	CONC	
	5	7	8		600				CONVNT	55.0	16000	80	55	30	CONC	
	6	8	9		1900				CONVNT	60.0	8000	90	55	60	CONC	
	7	9	10		250				CONVNT	60.0	8000	90	55	50	CONC	
	8	10	11		750				CONVNT	55.0	16000	80	55	30	CONC	
	9	11	12		250				CONVNT	60.0	8000	90	55	50	CONC	
	10	12	13		3350				CONVNT	55.0	16000	70	55	50	CONC	
	11	13	14		500				CONVNT	10.0	2000	10	55	500	CONC	
	12	14	15		500				CONVNT	10.0	2000	10	55	500	CONC	
	13	15	16		3800				CONVNT	55.0	16000	70	55	50	CONC	
	14	16	17		1200				CONVNT	60.0	8000	90	55	50	CONC	
	15	17	18		900				CONVNT	55.0	16000	80	55	30	CONC	
	16	18	19		1200				CONVNT	60.0	8000	90	55	60	CONC	
	17	19	22		900				CONVNT	60.0	8000	90	55	50	CONC	
3	18	22	23	2	600	CIRCLE	10.00	TRAIN	CONVNT	60.0	8000	90	55	50	CONC	
	19	23	24		600				CONVNT	60.0	8000	90	55	60	CONC	
	20	24	25		600				CONVNT	55.0	16000	80	55	30	CONC	
	21	25	26		600				CONVNT	60.0	8000	90	55	50	CONC	
	22	26	27		9650				CONVNT	55.0	16000	80	55	30	CONC	
	23	27	28		500				CONVNT	10.0	2000	10	55	500	CONC	
	24	28	29		500				CONVNT	10.0	2000	10	55	500	CONC	
	25	29	32		500				CONVNT	55.0	16000	80	55	30	CONC	

********** SHAFT INPUT DATA **********

SHAFT NUM	SEG NUM	FINISHED DIAMETER (FT)	NODAL POINT BOUNDRY UPPER	NODAL POINT BOUNDRY LOWER	ROCK STRENGTH (PSI)	R.Q.D.	EXCAVA-TION METHOD	ADVANCE RATE	INFLOW	LINING TYPE	LINING THICK (IN)	DISPOSAL DISTANCE (MILES)	DISPOSAL COST ($/ACRE)	ABOVE GROUND TEMP.
1	2	11.00	1	2	8000	60	CONVNT	4.0	WET	CONC		6.00	150	80
	3		2	3	16000	80	CONVNT	9.0	DRY	CONC				
2	4	12.00	20	21	4000	60	CONVNT	4.0	WET	CONC		2.00	150	80
	5		21	22	8000	90	CONVNT	9.5	DRY	CONC				
3	6	10.00	30	31	8000	60	CONVNT	4.0	WET	CONC		4.00	150	75
	7		31	32	16000	90	CONVNT	9.5	DRY	CONC				

********** CALCULATED TUNNEL DATA **********

REACH	SEG	STATION AT LEFT OF SEG	SLOPE LENGTH (FT)	MUCK HAUL DIST (FT)	MUCK HAUL SLOPE	*TUNNEL FINISH (FT)	DIMENSIONS* EXCAV (FT)	EXCAV WITH O.B.	ADVANCE RATE (FT/DAY)	LINING THICKNESS (IN)	EXCAV VOL (CY/FT)	PUMP FLOW RATE (GPM)	PUMP HEIGHT (FT)	CONSTR TIME (DAYS) REACH	SEG	RML-MAX (CY/FT)
1	1	0-00	6950	3475	0.000	11.00	12.33	13.18	55.0	8.00	5	223	334	444	172	25
	2	69-50	4004	8952	-.011		12.33	12.98	55.0	8.00	4	497	334		99	
	3	109-50	7000	14454	-.014		12.33	12.98	55.0	8.00	4	682	334		173	
2	4	179-50	1850	17025	0.000	11.00	12.33	12.77	60.0	8.00	4	937	215	511	43	30
	5	198-00	600	15800	0.000		12.33	12.98	55.0	8.00	4	861	215		14	
	6	204-00	1900	14550	0.000		12.33	12.77	60.0	8.00	4	825	215		44	
	7	223-00	250	13475	0.000		12.33	12.77	60.0	8.00	4	752	215		5	
	8	225-50	750	12975	0.000		12.33	12.98	55.0	8.00	4	715	215		18	
	9	233-00	250	12475	0.000		12.33	12.77	60.0	8.00	4	717	215		5	
	10	235-50	3350	10675	0.000		12.33	13.18	55.0	8.00	5	627	215		83	
	11	269-00	500	8750	0.000		12.33	14.42	10.0	8.00	6	568	215		53	
	12	274-00	500	8250	0.000		12.33	14.42	10.0	8.00	6	518	215		53	
	13	279-00	3800	6100	0.000		12.33	13.18	55.0	8.00	5	348	215		94	
	14	317-00	1200	3600	0.000		12.33	12.77	60.0	8.00	4	223	215		28	
	15	329-00	900	2550	0.000		12.33	12.98	55.0	8.00	4	160	215		22	
	16	338-00	1200	1500	0.000		12.33	12.77	60.0	8.00	4	140	215		28	
	17	350-00	900	450	0.000		12.33	12.77	60.0	8.00	4	72	215		21	
3	18	359-00	600	300	0.000	10.00	11.33	11.73	60.0	8.00	4	64	215	413	14	25
	19	365-00	600	900	0.000		11.33	11.73	60.0	8.00	4	107	215		14	
	20	371-00	600	1500	0.000		11.33	11.92	55.0	8.00	4	104	215		14	
	21	377-00	600	2100	0.000		11.33	11.73	60.0	8.00	4	148	215		14	
	22	383-00	9650	7225	0.000		11.33	11.92	55.0	8.00	4	288	215		239	
	23	479-50	500	12300	0.000		11.33	13.25	10.0	8.00	5	528	215		53	
	24	484-50	500	12800	0.000		11.33	13.25	10.0	8.00	5	578	215		53	
	25	489-50	500	13300	0.000		11.33	11.92	55.0	8.00	4	540	215		12	

********** CALCULATED SHAFT DATA **********

SHAFT	SEG	STATION ALONG TUNNEL ALIGN.	ELEVATION AT BOTTOM OF SEG	LENGTH (FT)	HOIST HGT (FT)	*SHAFT FINISH (FT)	DIMENSIONS* EXCAV (FT)	EXCAV WITH O.B.	ADVANCE RATE (FT/DAY)	LINING THICK. (IN)	EXCAV VOL (CY/FT)	SIZE OF DISPOSAL AREA (ACRES)	CONSTRUCTION TIME (DAYS) SHAFT	SEGMENT	RML-MAX (CY/HR)
1	2	0-00	440	84	42	11.00	12.33	13.39	4.0	8.00	5	2	54	22	4
	3		190	250	209		12.33	12.98	9.0	8.00	4			32	
2	4	359-00	500	105	52	12.00	13.33	14.47	4.0	8.00	6	4	41	28	5
	5		390	110	160		13.33	13.80	9.5	8.00	5			13	
3	6	494-50	545	90	45	10.00	11.33	12.30	4.0	8.00	4	0	43	24	3
	7		390	155	167		11.33	11.73	9.5	8.00	4			19	

********** TUNNEL COSTS **********

REACH NO	SEG NO		COST IN DOLLARS PER FOOT OF TUNNEL: EXC SETUP	EXC	MUCK LOAD	MUCK TRAN	MUCK HOIST	MUCK DISP	SUP-PORTS	LIN-ING	LIN FRM	GROUT	PUMP-ING	AIR-COND	SEG COST ($/FT)	SEGMENT LENGTH (FEET)	SEGMENT COST ($1000)
1	1	L	0	58	6	22	26	14	13	25	23	0	4	1	192		1334
		E	0	19	2	6	6	7	1	6	8	0	0	1	56		389
		M	0	9	0	0	0	2	10	22	2	0	0	4	49		340
		T	0	86	8	28	32	23	24	53	33	0	4	6	297	6950	2063
1	2	L	0	60	6	34	26	13	8	29	24	0	4	3	207		829
		E	0	19	2	7	6	7	1	6	8	0	0	1	57		228
		M	0	9	0	0	0	2	6	20	2	0	0	4	43		172
		T	0	88	8	41	32	22	15	55	34	0	4	8	307	4004	1229
1	3	L	0	62	6	46	26	13	8	34	25	0	4	5	229		1603
		E	0	19	2	9	6	7	1	7	8	0	0	1	60		420
		M	0	9	0	0	0	2	6	20	2	0	1	5	45		315
		T	0	90	8	55	32	22	15	61	35	0	5	11	334	7000	2338

REGIONAL COST FACTOR 1.20

COST INDEX

LABOR	1.17
EQUIPMENT	1.07
MATERIALS	0.93

TOTAL REACH LABOR COST.....	3766
TOTAL REACH EQUIPMENT COST.....	1037
TOTAL REACH MATERIALS COST.....	827
TOTAL REACH COST.....	5630

TUNNEL COSTS

REACH NO	SEG NO		COST IN DOLLARS PER FOOT OF TUNNEL: EXC SETUP	EXC	MUCK LOAD	MUCK TRAN	MUCK HOIST	MUCK DISP	SUP-PORTS	LIN-ING	LIN FRM	GROUT	PUMP-ING	AIR-COND	SEG COST ($/FT)	SEGMENT LENGTH (FEET)	SEGMENT COST ($1000)
2	17	L	0	52	5	13	24	10	3	21	22	0	3	1	154		138
		E	0	18	2	5	6	6	1	5	8	0	0	1	52		46
		M	0	7	0	0	0	1	2	18	2	0	0	4	34		30
		T	0	77	7	18	30	17	6	44	32	0	3	6	240	900	214
2	16	L	0	52	5	16	24	10	3	22	22	0	3	0	157		188
		E	0	18	2	5	6	6	1	5	8	0	0	1	52		62
		M	0	7	0	0	0	1	2	18	2	0	0	4	34		40
		T	0	77	7	21	30	17	6	45	32	0	3	5	243	1200	290
2	15	L	0	57	6	19	26	10	8	23	23	0	4	1	177		159
		E	0	19	2	6	6	6	1	6	8	0	0	1	55		49
		M	0	9	0	0	0	1	6	20	2	0	0	4	42		37
		T	0	85	8	25	32	17	15	49	33	0	4	6	274	900	245
2	14	L	0	53	5	20	24	10	3	24	23	0	3	1	166		199
		E	0	18	2	6	6	6	1	6	8	0	0	1	54		64
		M	0	7	0	0	0	1	2	18	2	0	0	4	34		40
		T	0	78	7	26	30	17	6	48	33	0	3	6	254	1200	303
2	13	L	0	59	6	28	26	10	14	27	23	0	4	2	199		756
		E	0	19	2	7	6	6	1	6	8	0	0	1	56		212
		M	0	9	0	0	0	1	10	22	2	0	0	4	48		182
		T	0	87	8	35	32	17	25	55	33	0	4	7	303	3800	1150
2	12	L	0	327	33	164	126	39	28	30	24	0	20	16	807		403
		E	0	106	11	43	34	22	22	7	8	49	1	1	304		152
		M	0	6	0	0	0	1	44	37	2	7	1	6	104		52
		T	0	439	44	207	160	62	94	74	34	56	22	23	1215	500	607
2	11	L	0	328	33	170	126	39	28	30	24	0	20	17	815		407
		E	0	106	11	44	34	22	22	7	8	49	1	1	305		152
		M	0	6	0	0	0	1	44	37	2	7	2	6	105		52
		T	0	440	44	214	160	62	94	74	34	56	23	24	1225	500	611
2	10	L	0	60	6	38	26	10	14	31	24	0	4	4	217		726
		E	0	19	2	8	6	6	1	6	8	0	0	1	57		190
		M	0	9	0	0	0	1	10	22	2	0	0	4	48		160
		T	0	88	8	46	32	17	25	59	34	0	4	9	322	3350	1076
2	9	L	0	56	6	38	24	10	3	32	24	0	3	4	200		50
		E	0	18	2	8	6	6	1	6	8	0	0	1	56		14
		M	0	7	0	0	0	1	2	18	2	0	0	4	34		8
		T	0	81	8	46	30	17	6	56	34	0	3	9	290	250	72

TUNNEL COSTS

REACH NO	SEG NO	COST IN DOLLARS PER FOOT OF TUNNEL: EXC SETUP	EXC	MUCK LOAD	MUCK TRAN	MUCK HOIST	MUCK DISP	SUP-PORTS	LIN-ING	LIN FRM	GROUT	PUMP-ING	AIR-COND	SEG COST ($/FT)	SEGMENT LENGTH (FEET)	SEGMENT COST ($1000)
2	8 L	0	61	6	42	26	10	8	33	24	0	4	5	219		164
	E	0	19	2	9	6	6	1	6	8	0	0	1	58		43
	M	0	9	0	0	0	1	6	20	2	0	0	4	42		31
	T	0	89	8	51	32	17	15	59	34	0	4	10	319	750	238
2	7 L	0	56	6	40	24	10	3	33	24	0	3	5	204		51
	E	0	18	2	8	6	6	1	6	8	0	0	1	56		14
	M	0	7	0	0	0	1	2	18	2	0	0	4	34		8
	T	0	81	8	48	30	17	6	57	34	0	3	10	294	250	73
2	6 L	0	57	6	42	24	10	3	34	25	0	3	5	209		397
	E	0	18	2	8	6	6	1	6	8	0	0	1	56		106
	M	0	7	0	0	0	1	2	18	2	0	0	4	34		64
	T	0	82	8	50	30	17	6	58	35	0	3	10	299	1900	567
2	5 L	0	62	6	48	26	10	8	35	25	0	4	6	230		138
	E	0	19	2	9	6	6	1	7	8	0	0	1	59		35
	M	0	9	0	0	0	1	6	20	2	0	0	5	43		25
	T	0	90	8	57	32	17	15	62	35	0	4	12	332	600	198
2	4 L	0	58	6	47	24	10	3	36	25	0	3	6	218		403
	E	0	18	2	9	6	6	1	7	8	0	0	1	58		107
	M	0	7	0	1	0	1	2	18	2	0	0	5	36		66
	T	0	83	8	57	30	17	6	61	35	0	3	12	312	1850	576

REGIONAL COST FACTOR 1.20

COST INDEX — LABOR 1.17
EQUIPMENT 1.07
MATERIALS 0.93

TOTAL REACH LABOR COST..... 4179
TOTAL REACH EQUIPMENT COST..... 1246
TOTAL REACH MATERIALS COST..... 795
TOTAL REACH COST..... 6220

TUNNEL COSTS

REACH NO	SEG NO		COST IN DOLLARS PER FOOT OF TUNNEL: EXC SETUP	EXC	MUCK LOAD	MUCK TRAN	MUCK HOIST	MUCK DISP	SUP-PORTS	LIN-ING	LIN FRM	GROUT	PUMP-ING	AIR-COND	SEG COST ($/FT)	SEGMENT LENGTH (FEET)	SEGMENT COST ($1000)
3	18	L	0	48	5	12	26	9	2	21	20	0	3	2	148		88
		E	0	16	2	4	6	5	1	5	8	0	0	1	48		28
		M	0	5	0	0	0	1	2	16	2	0	0	4	30		18
		T	0	69	7	16	32	15	5	42	30	0	3	7	226	600	134
3	19	L	0	48	5	14	26	9	2	22	20	0	3	0	149		89
		E	0	16	2	5	6	5	1	5	8	0	0	1	49		29
		M	0	5	0	0	0	1	2	16	2	0	0	4	30		18
		T	0	69	7	19	32	15	5	43	30	0	3	5	228	600	136
3	20	L	0	52	6	17	27	10	7	22	20	0	4	1	166		99
		E	0	18	2	5	6	5	1	5	8	0	0	1	51		30
		M	0	8	0	0	0	1	6	18	2	0	0	4	39		23
		T	0	78	8	22	33	16	14	45	30	0	4	6	256	600	152
3	21	L	0	48	5	17	26	9	2	23	21	0	3	1	155		93
		E	0	16	2	5	6	5	1	5	8	0	0	1	49		29
		M	0	5	0	0	0	1	2	16	2	0	0	4	30		18
		T	0	69	7	22	32	15	5	44	31	0	3	6	234	600	140
3	22	L	0	54	6	30	27	10	7	27	21	0	4	3	189		1823
		E	0	18	2	7	6	5	1	6	8	0	0	1	54		521
		M	0	8	0	0	0	1	6	18	2	0	0	4	39		376
		T	0	80	8	37	33	16	14	51	31	0	4	8	282	9650	2720
3	23	L	0	309	34	212	127	38	25	33	22	0	20	25	845		422
		E	0	98	11	45	33	21	21	7	8	46	1	1	292		146
		M	0	5	0	0	0	1	38	32	2	7	2	6	93		46
		T	0	412	45	257	160	60	84	72	32	53	23	32	1230	500	614
3	24	L	0	310	34	218	127	38	25	33	22	0	20	26	853		426
		E	0	98	11	46	33	21	21	7	8	46	1	1	293		146
		M	0	5	0	0	0	1	38	32	2	7	2	6	93		46
		T	0	413	45	264	160	60	84	72	32	53	23	33	1239	500	618
3	25	L	0	57	6	43	27	10	7	33	22	0	4	5	214		107
		E	0	18	2	8	6	5	1	6	8	0	0	1	55		27
		M	0	8	0	0	0	1	6	18	2	0	0	4	39		19
		T	0	83	8	51	33	16	14	57	32	0	4	10	308	500	153

REGIONAL COST FACTOR 1.20

COST INDEX — LABOR 1.17
EQUIPMENT 1.07
MATERIALS 0.93

TOTAL REACH LABOR COST..... 3147
TOTAL REACH EQUIPMENT COST..... 956
TOTAL REACH MATERIALS COST..... 564
TOTAL REACH COST..... 4667

********** SHAFT COST **********

SHAFT NO	SEG NO	COST IN DOLLARS PER FOOT OF SHAFT: EXC SETUP	EXC	MUCK LOAD	MUCK HOIST	MUCK DISP	SUP-PORTS	LIN-ING	LIN FORM	GROUT	SEG COST ($/FT)	SEGMENT LENGTH (FEET)	SEGMENT COST ($1000)
1	2 L	0	694	78	245	92	0	40	47	0	1196		100
	E	0	271	27	24	50	0	7	16	123	518		43
	M	0	33	9	0	2	25	25	9	14	117		9
	T	0	998	114	269	144	25	72	72	137	1831	84	152
1	3 L	0	309	35	110	45	0	40	47	0	586		146
	E	0	120	12	11	24	0	7	16	0	190		47
	M	0	30	8	0	2	21	20	9	0	90		22
	T	0	459	55	121	71	21	67	72	0	866	250	215

REGIONAL COST FACTOR 1.20

COST INDEX — LABOR 1.17
EQUIPMENT 1.07
MATERIALS 0.93

SHAFT LABOR COST..... 246
SHAFT EQUIPMENT COST..... 90
SHAFT MATERIALS COST..... 31
SHAFT COST..... 367

********** SHAFT COST **********

SHAFT NO	SEG NO	COST IN DOLLARS PER FOOT OF SHAFT: EXC SETUP	EXC	MUCK LOAD	MUCK HOIST	MUCK DISP	SUP-PORTS	LIN-ING	LIN FORM	GROUT	SEG COST ($/FT)	SEGMENT LENGTH (FEET)	SEGMENT COST ($1000)
2	4 L	0	730	78	245	89	0	40	49	0	1231		129
	E	0	288	27	25	49	0	7	17	131	544		57
	M	0	34	10	0	1	27	28	9	15	124		13
	T	0	1052	115	270	139	27	75	75	146	1899	105	199
2	5 L	0	307	33	104	40	0	39	49	0	572		62
	E	0	121	11	10	22	0	7	17	0	188		20
	M	0	29	9	0	1	20	20	9	0	88		9
	T	0	457	53	114	63	20	66	75	0	848	110	91

REGIONAL COST FACTOR 1.20

COST INDEX — LABOR 1.17
EQUIPMENT 1.07
MATERIALS 0.93

SHAFT LABOR COST..... 191
SHAFT EQUIPMENT COST..... 77
SHAFT MATERIALS COST..... 22
SHAFT COST..... 290

********** SHAFT COST **********

SHAFT NO	SEG NO	COST IN DOLLARS PER FOOT OF SHAFT: EXC SETUP	EXC	MUCK LOAD	MUCK HOIST	MUCK DISP	SUP-PORTS	LIN-ING	LIN FORM	GROUT	SEG COST ($/FT)	SEGMENT LENGTH (FEET)	SEGMENT COST ($1000)
3	6 L	0	658	78	245	89	0	40	44	0	1154		103
	E	0	254	27	24	49	0	7	15	115	491		44
	M	0	31	7	0	1	23	22	8	13	105		9
	T	0	943	112	269	139	23	69	67	128	1750	90	156
3	7 L	0	277	33	104	40	0	39	44	0	537		83
	E	0	107	11	10	22	0	7	15	0	172		26
	M	0	28	7	0	1	17	16	8	0	77		11
	T	0	412	51	114	63	17	62	67	0	786	155	120

REGIONAL COST FACTOR 1.20

COST INDEX — LABOR 1.17
EQUIPMENT 1.07
MATERIALS 0.93

SHAFT LABOR COST..... 186
SHAFT EQUIPMENT COST..... 70
SHAFT MATERIALS COST..... 20
SHAFT COST..... 276

TUNNEL REACH COST SUMMARY

REACH	EXIT SHAFT	REGIONAL COST FACTOR	COST INDEXES LABOR	COST INDEXES EQUIP	COST INDEXES MATL	COSTS ($1000) LABOR	COSTS ($1000) EQUIPMENT	COSTS ($1000) MATERIAL	COSTS ($1000) TOTAL
1	1	1.20	1.17	1.07	0.93	3766	1037	827	5630
2	2	1.20	1.17	1.07	0.93	4179	1246	795	6220
3	2	1.20	1.17	1.07	0.93	3147	956	564	4667

********** SHAFT COST SUMMARY **********

SHAFT	REGIONAL COST FACTOR	******* COST INDEXES ******** LABOR	EQUIP	MATL	********** COSTS ($1000) ********** LABOR	EQUIPMENT	MATERIAL	TOTAL
1	1.20	1.17	1.07	0.93	246	90	31	367
2	1.20	1.17	1.07	0.93	191	77	22	290
3	1.20	1.17	1.07	0.93	186	70	20	276

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*****************************************************
*                                                   *
*   TULLY DAM TO MILLERS RIVER AND QUABBIN RESERVOIR *
*          ALIGNMENTS NO. 2 AND NO. 7               *
*           CONVENTIONAL EXCAVATION                 *
*                                                   *
*****************************************************
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PROFIT MARGIN	0.00	TOTAL TUNNEL LABOR COST.....($1000)	11092
OVERHEAD MARGIN	0.00	TOTAL TUNNEL EQUIPMENT COST.....	3239
		TOTAL TUNNEL MATERIAL COST.....	2186
		TOTAL TUNNEL COST.....	16517
		TOTAL SHAFT LABOR COST.....	623
		TOTAL SHAFT EQUIPMENT COST.....	237
		TOTAL SHAFT MATERIAL COST.....	73
		TOTAL SHAFT COST.....	933
		TOTAL PROJECT LABOR COST.....	11715
		TOTAL PROJECT EQUIPMENT COST.....	3476
		TOTAL PROJECT MATERIAL COST.....	2259
		TOTAL PROJECT COST.....	17450

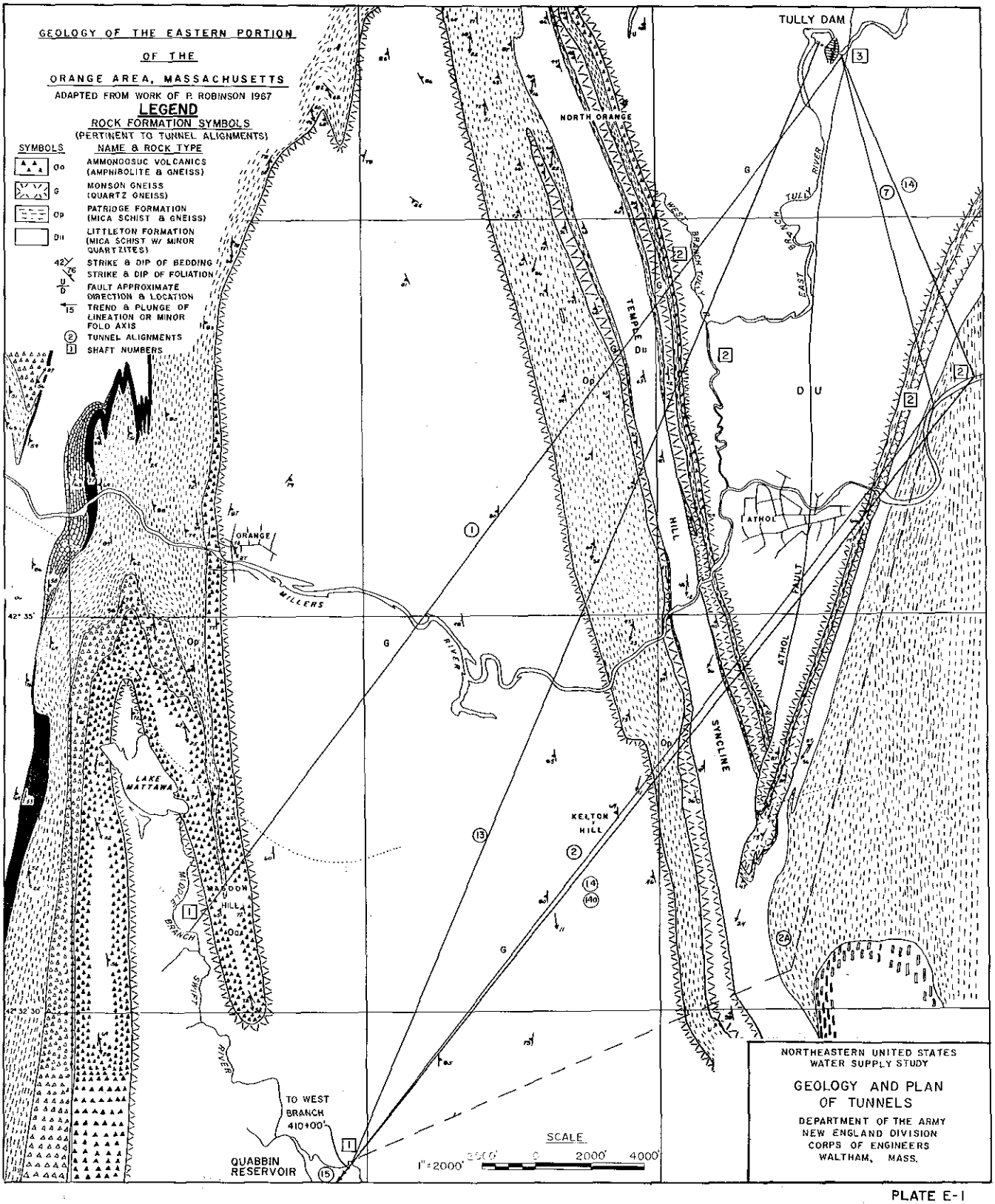
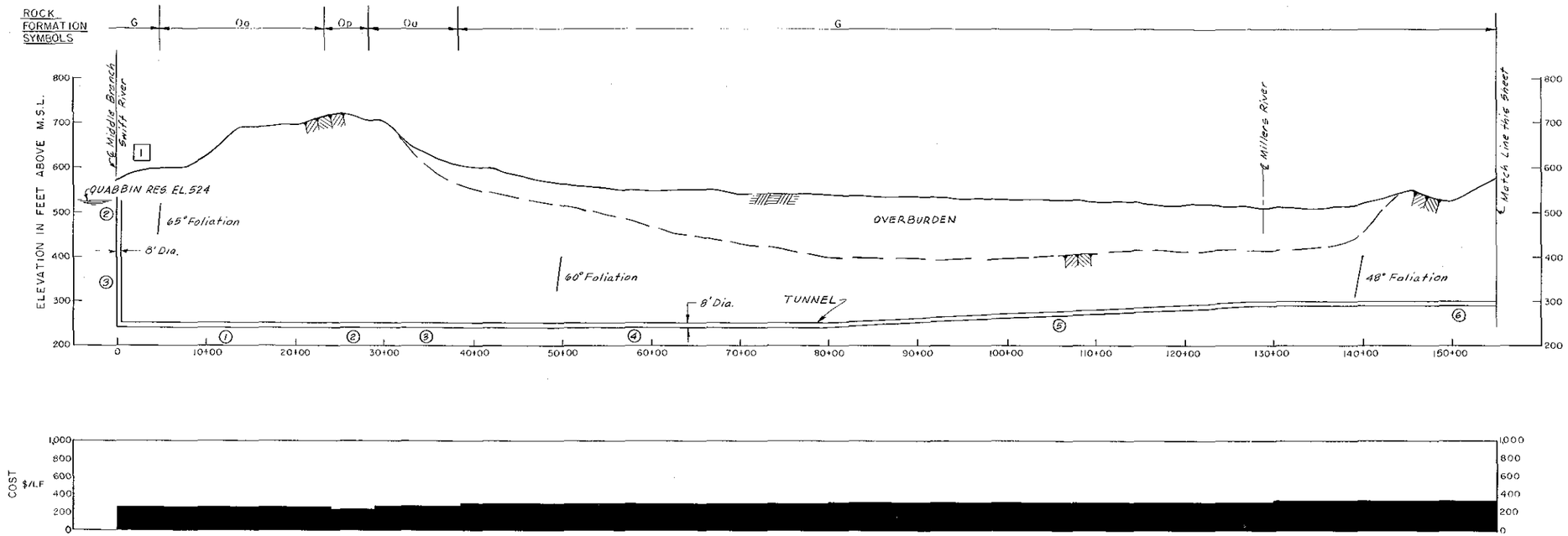
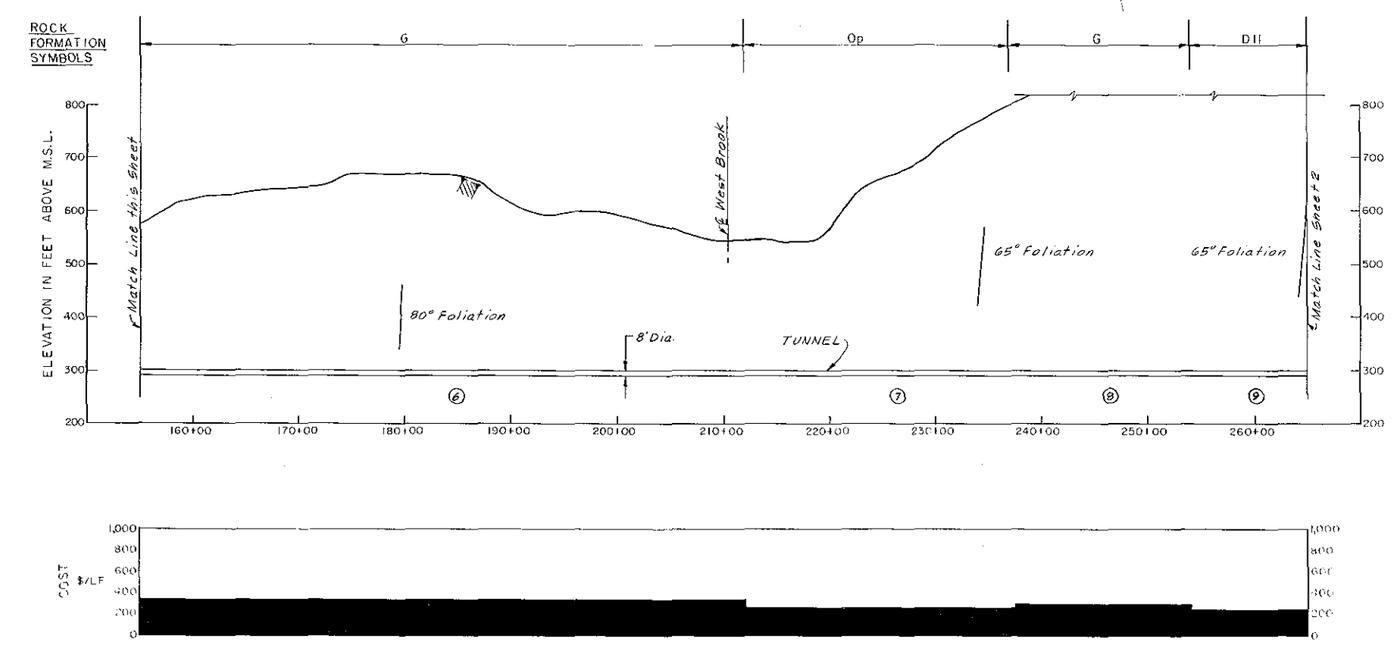
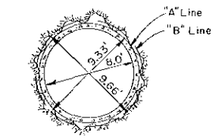

GEOLOGY OF THE EASTERN PORTION
OF THE
ORANGE AREA, MASSACHUSETTS
ADAPTED FROM WORK OF P. ROBINSON 1967
LEGEND
ROCK FORMATION SYMBOLS
(PERTINENT TO TUNNEL ALIGNMENTS)
SYMBOLS
NAME & ROCK TYPE
Oa AMMONOOSUC VOLCANICS (AMPHIBOLITE & GNEISS)
G MONSON GNEISS (QUARTZ GNEISS)
Op PATRIDGE FORMATION (MICA SCHIST & GNEISS)
Du LITTLETON FORMATION (MICA SCHIST W/ MINOR QUARTZITES)
42 76 STRIKE & DIP OF BEDDING
STRIKE & DIP OF FOLIATION
U D FAULT APPROXIMATE DIRECTION & LOCATION
15 TREND & PLUNGE OF LINEATION OR MINOR FOLD AXIS
2 TUNNEL ALIGNMENTS
1 SHAFT NUMBERS
TULLY DAM
NORTH ORANGE
WEST BRANCH TULLY R.
EAST BRANCH TULLY RIVER
TEMPLE HILL SYNCLINE
ATHOL
ATHOL FAULT
ORANGE
MILLERS RIVER
LAKE MATTAWA
MASDON HILL
MIDDLE BRANCH SWIFT RIVER
KELTON HILL
42° 35'
42° 32' 30"
TO WEST BRANCH 410+00'
QUABBIN RESERVOIR
SCALE
1"=2000'
2000' 0 2000' 4000'
NORTHEASTERN UNITED STATES WATER SUPPLY STUDY
GEOLOGY AND PLAN OF TUNNELS
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE E-1







TYPICAL TUNNEL SECTION

SEGMENT NO. 7

NOT TO SCALE

NOTES:

1. For Alignment Location & Legend See Plate E-1.
2. For Rock Formation Data See Table E-1.
3. Cost Chart $/LF For Conventional Tunnel Excavation, Not Including Shaft Costs.
4. Segment Numbers (6) Refer To Computerized Cost Program.

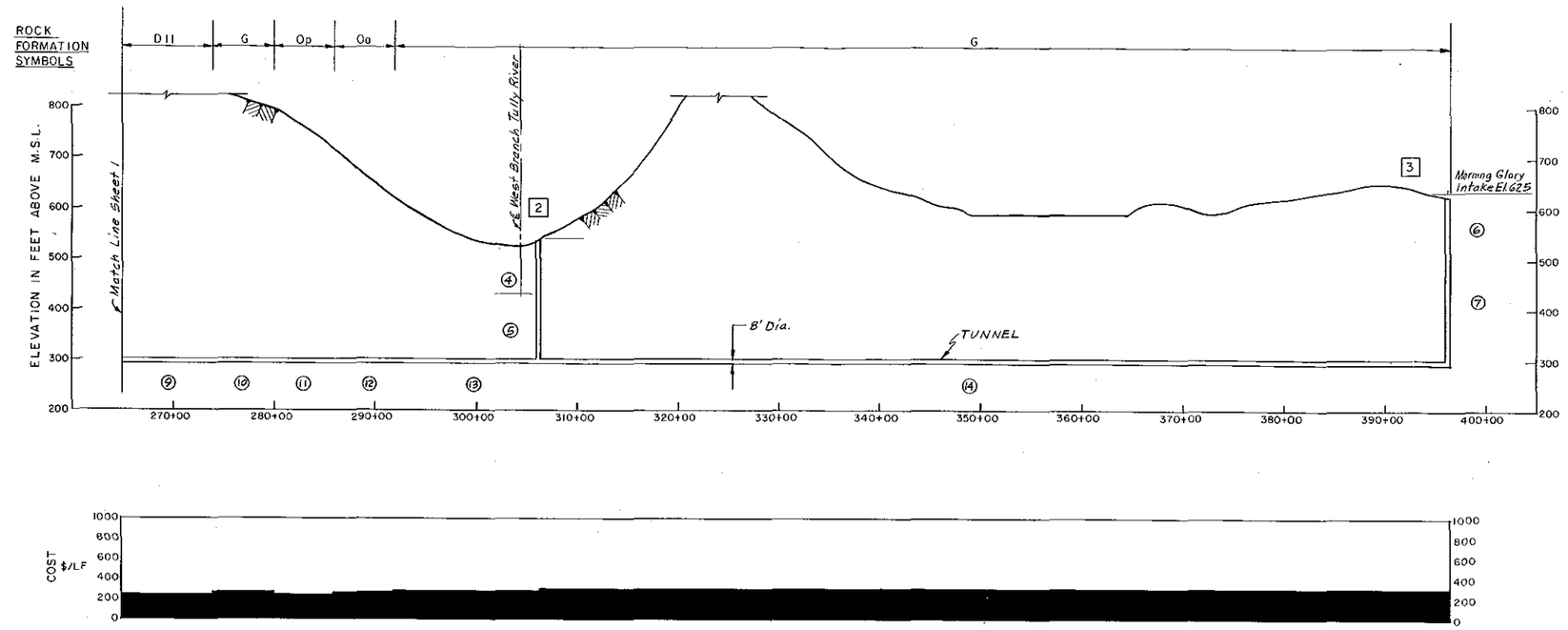
GRAPHIC SCALES

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO
MIDDLE BRANCH SWIFT RIVER
TUNNEL ALINEMENT NO. 1

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

CORPS OF ENGINEERS U. S ARMY



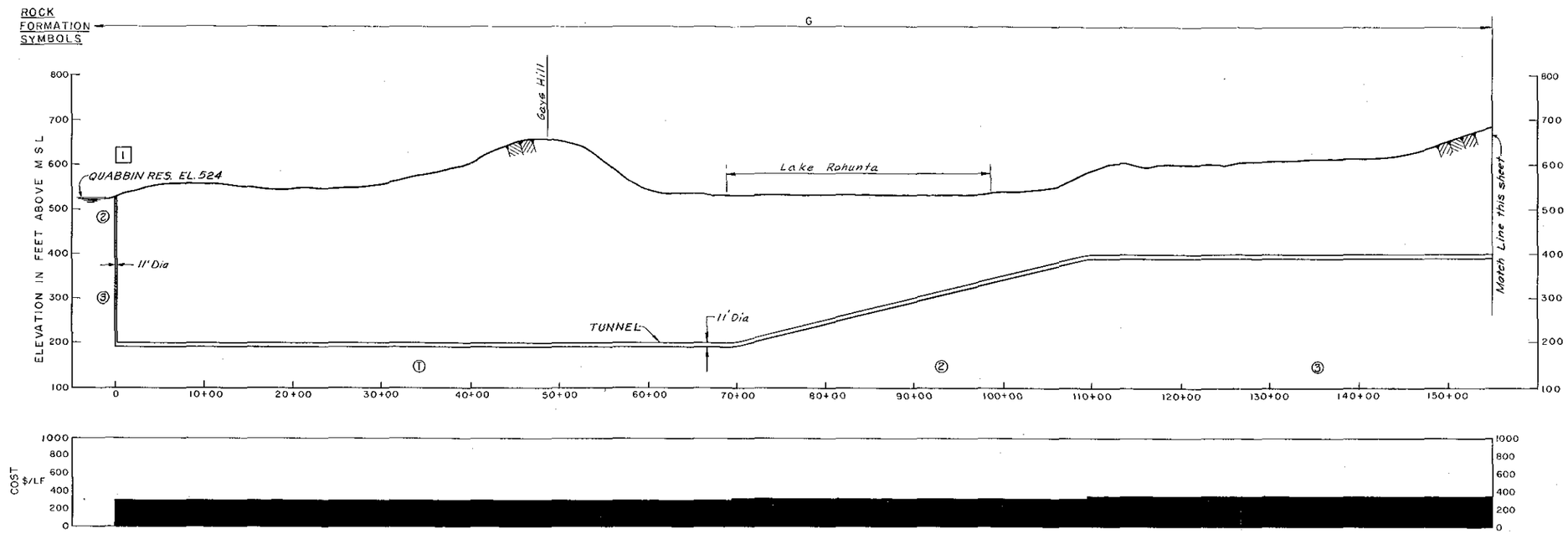
Notes:
See Sheet E-2 For Pertinent Notes

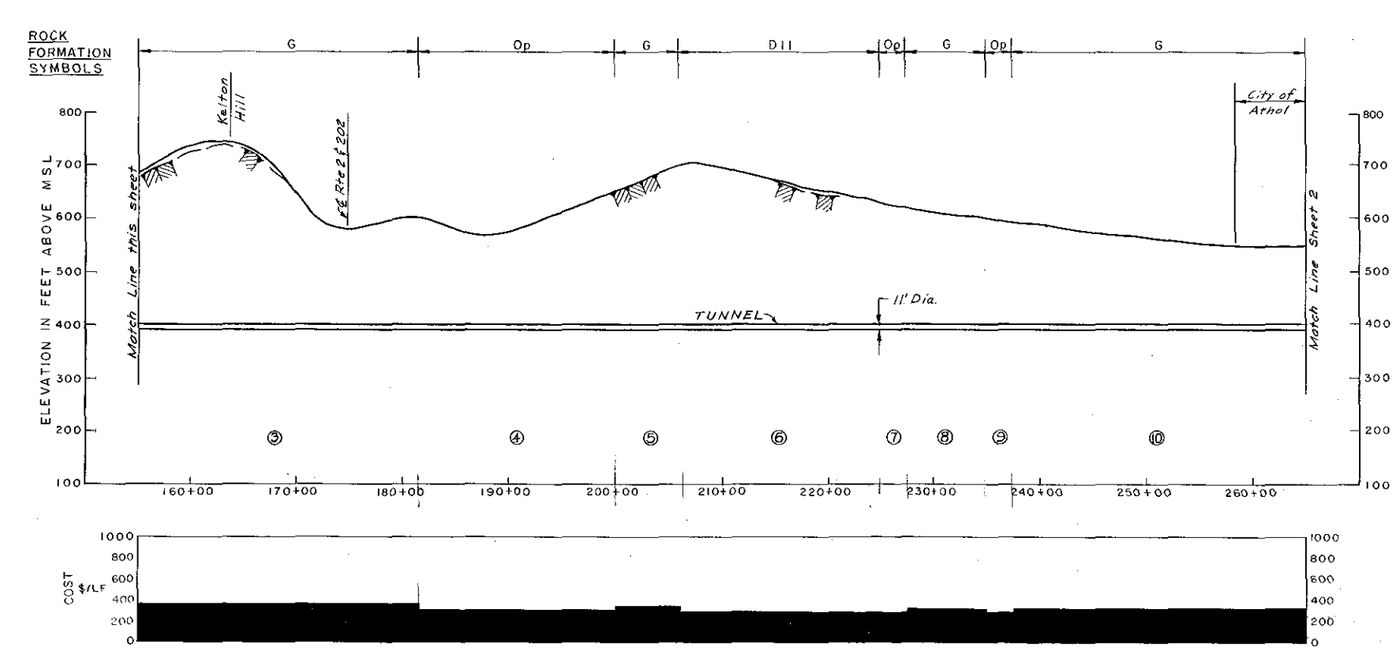
GRAPHIC SCALES

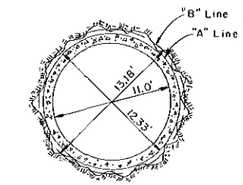
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO
MIDDLE BRANCH SWIFT RIVER
TUNNEL ALINEMENT NO. 1

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.







TYPICAL TUNNEL SECTION
SEGMENT NO 10
NOT TO SCALE

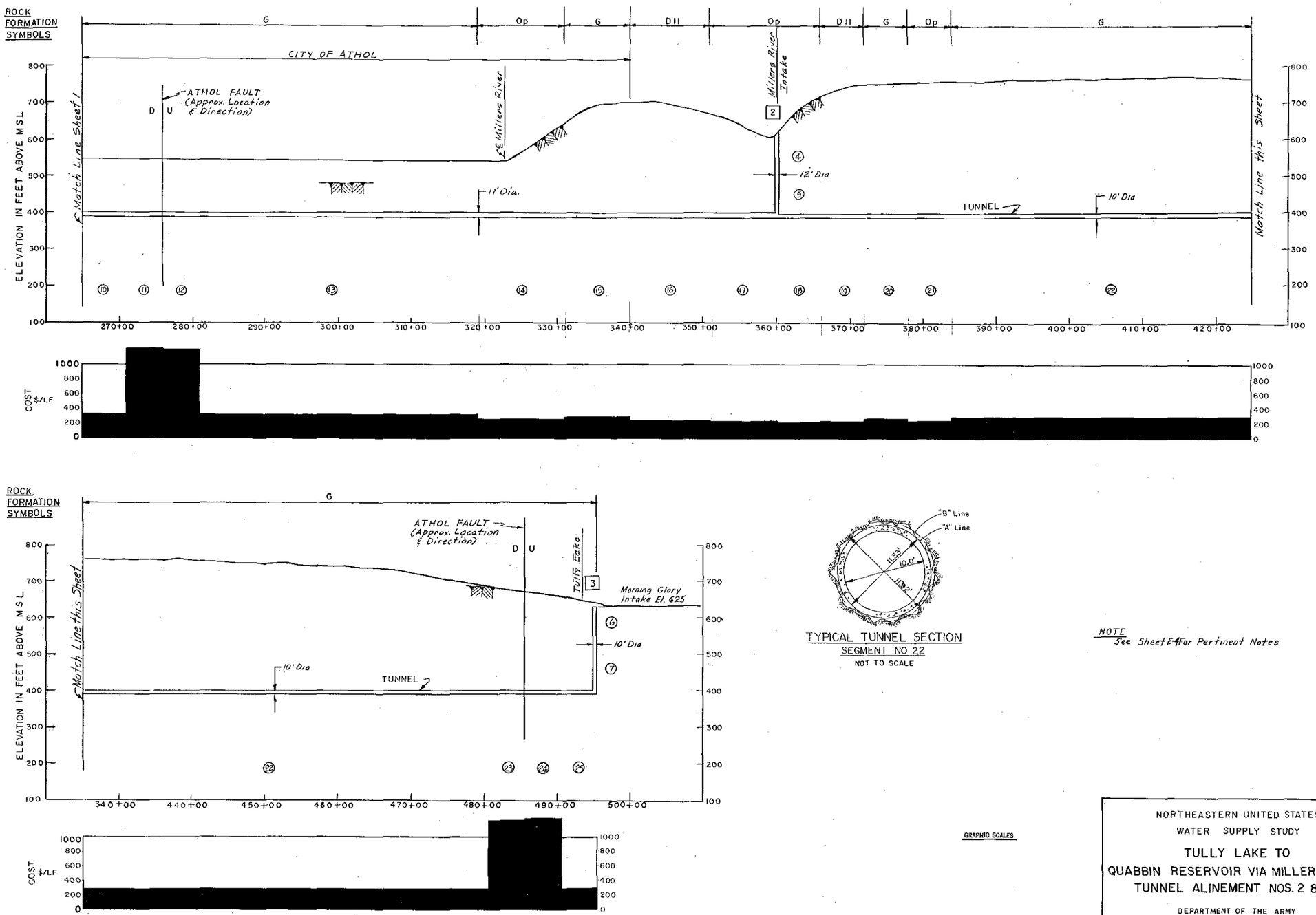
NOTES:
1. For Alignment Location & Legend See Plate E-1.
2. For Rock Formation Data See Table E-1.
3. Cost Chart $/LF Is For Conventional Tunnel Excavation Not Including Shaft Costs.
4. Segment Numbers (6) Refer to Computerized Cost Program.

GRAPHIC SCALES

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO
QUABBIN RESERVOIR VIA MILLERS RIVER
TUNNEL ALINEMENT NOS. 2 & 7

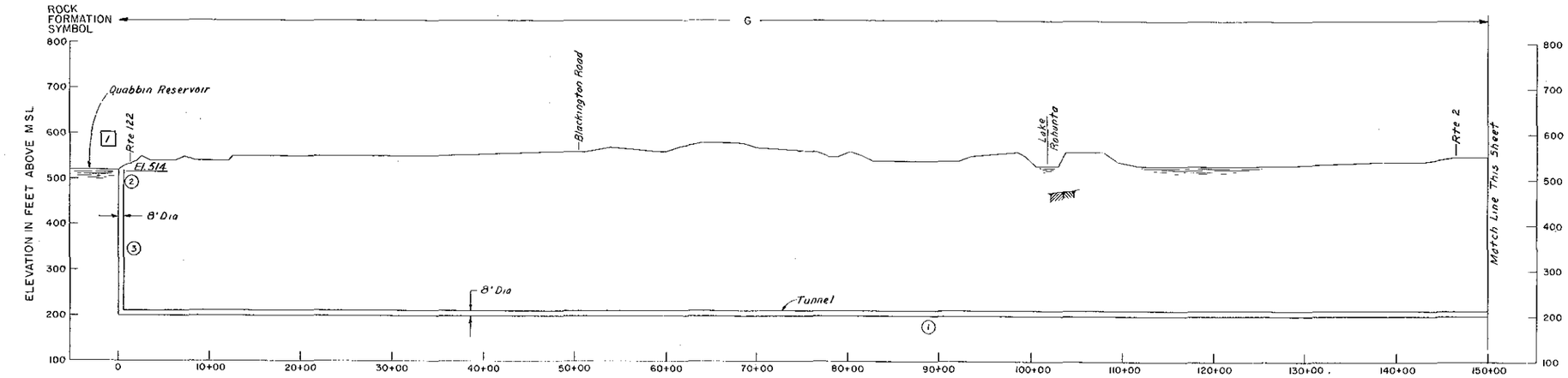
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

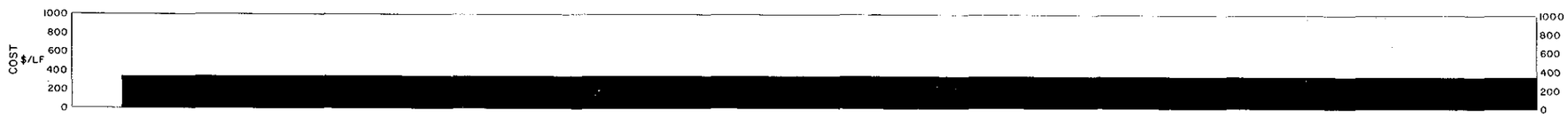


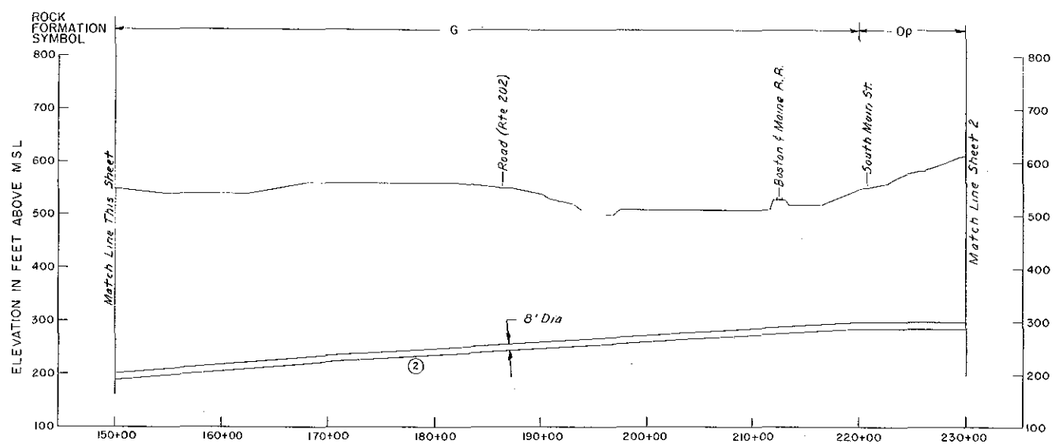
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

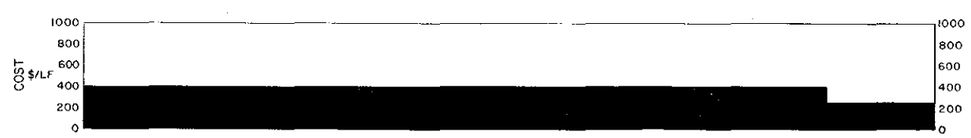
TULLY LAKE TO
QUABBIN RESERVOIR VIA MILLERS RIVER
TUNNEL ALINEMENT NOS. 2 & 7

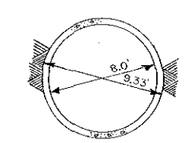
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.











TYPICAL TUNNEL SECTION
SEGMENT 1
NOT TO SCALE

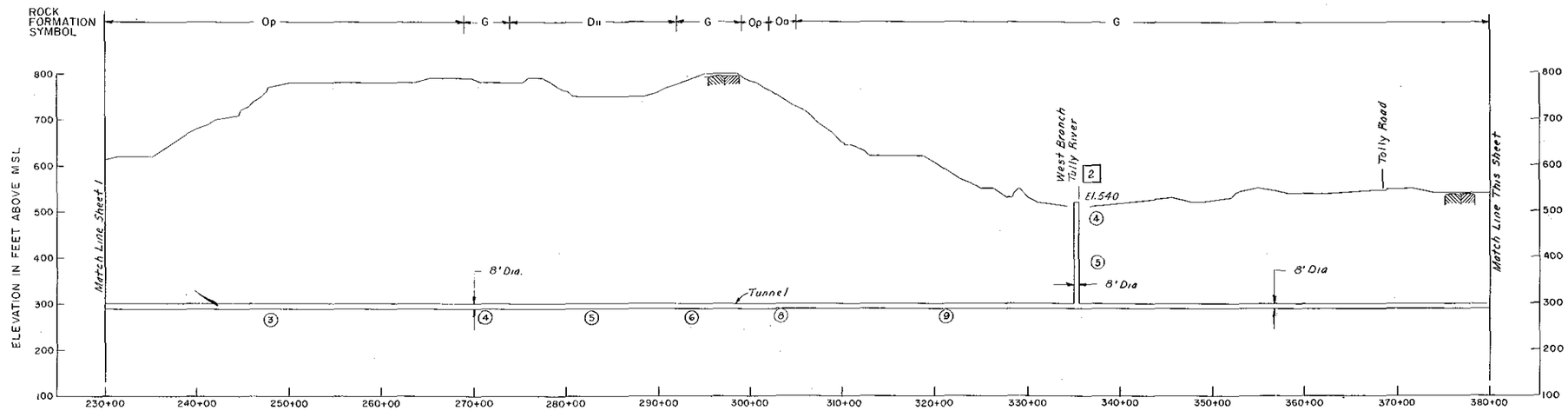
NOTES:
1. For Alinement Location & Legend See Plate E-1
2. For Rock Formation Data See Table E-1
3. Cost Chart $/LF For Machine Tunnel (MOLE) Excavation, Not Including Shaft Costs.
4. Segment Numbers (6) Refer To Computerized Cost Program.

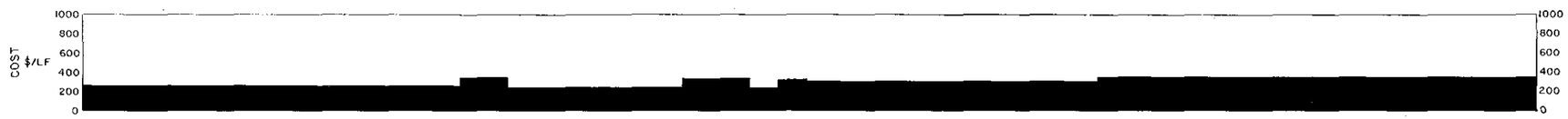
GRAPHIC SCALES
1" = 100' 100' 0 100' 200'
1" = 500' 500' 0 500' 1000'

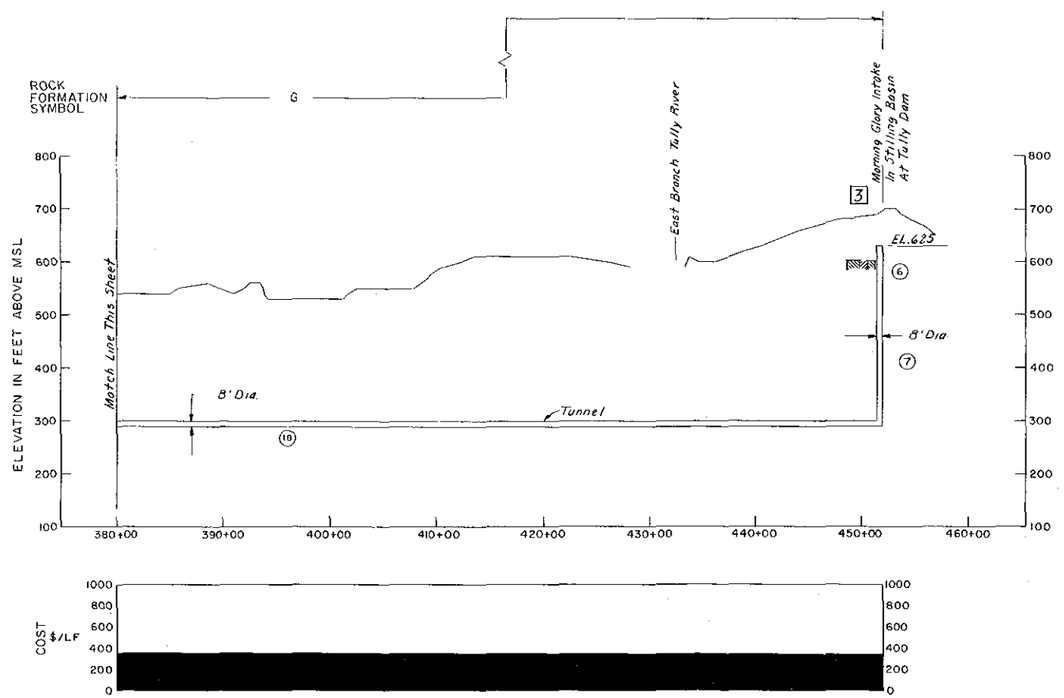
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO QUABBIN RESERVOIR
TUNNEL ALINEMENT NO. 13

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.







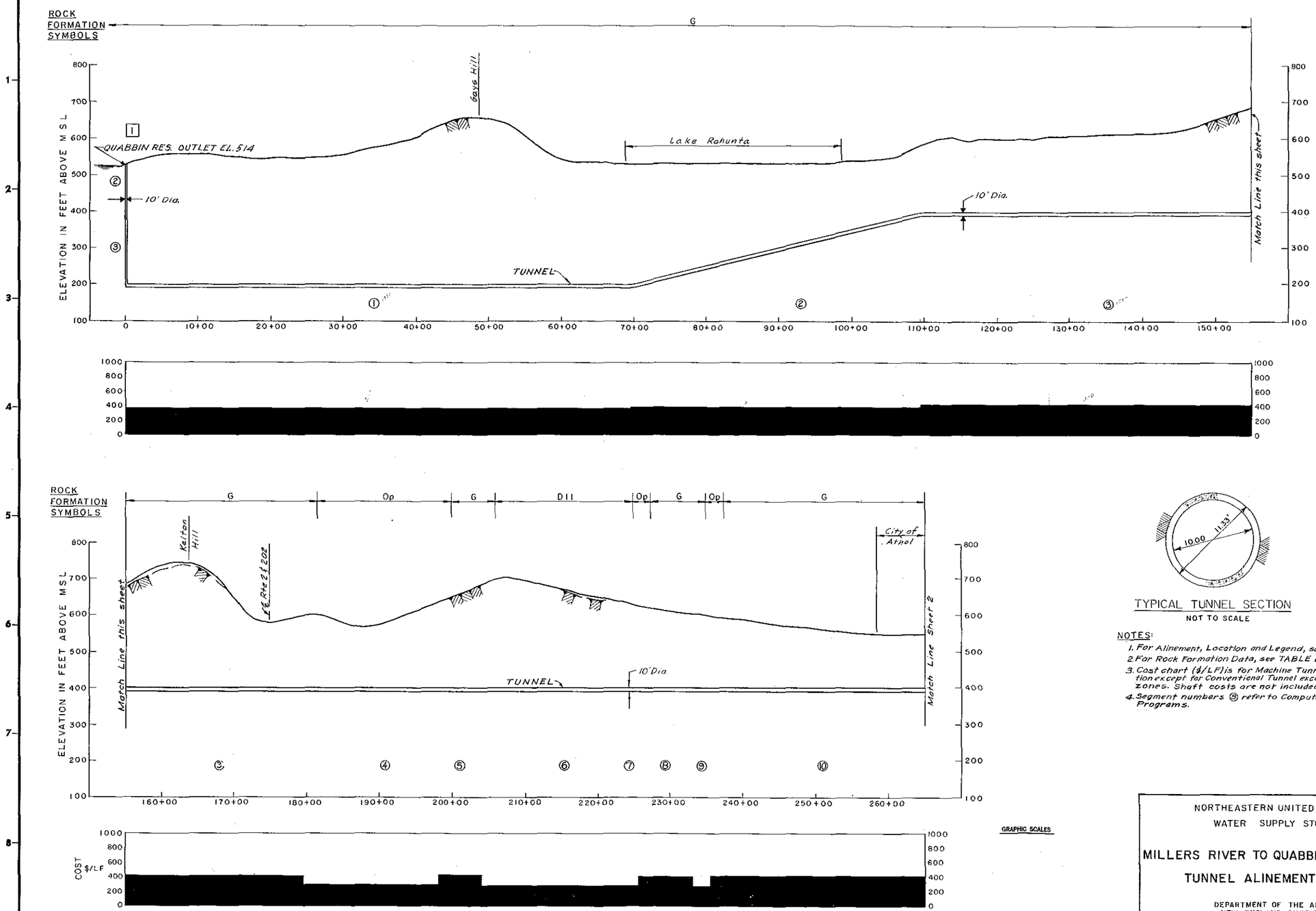
NOTE:
See Sheet 1 For Pertinent Notes.

GRAPHIC SCALES

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO QUABBIN RESERVOIR
TUNNEL ALINEMENT NO. 13

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.



TYPICAL TUNNEL SECTION

NOT TO SCALE

NOTES:

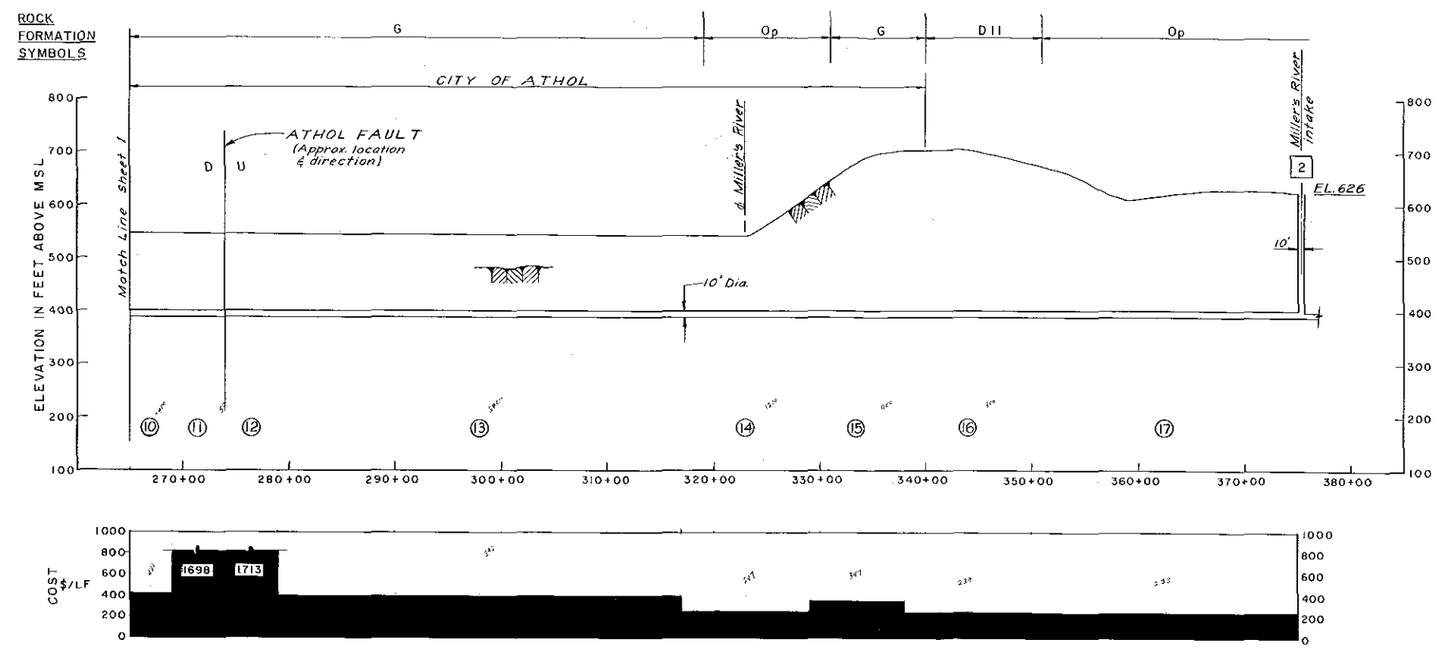
1. For Alinement, Location and Legend, see PLATE E-1
2. For Rock Formation Data, see TABLE E-1
3. Cost chart ($/LF) is for Machine Tunnel (Mole) Excavation except for Conventional Tunnel excavation in fault zones. Shaft costs are not included.
4. Segment numbers ③ refer to Computerized Cost Programs.

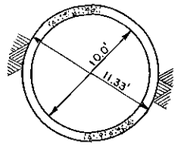
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

MILLERS RIVER TO QUABBIN RESERVOIR

TUNNEL ALINEMENT NO. 14

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.





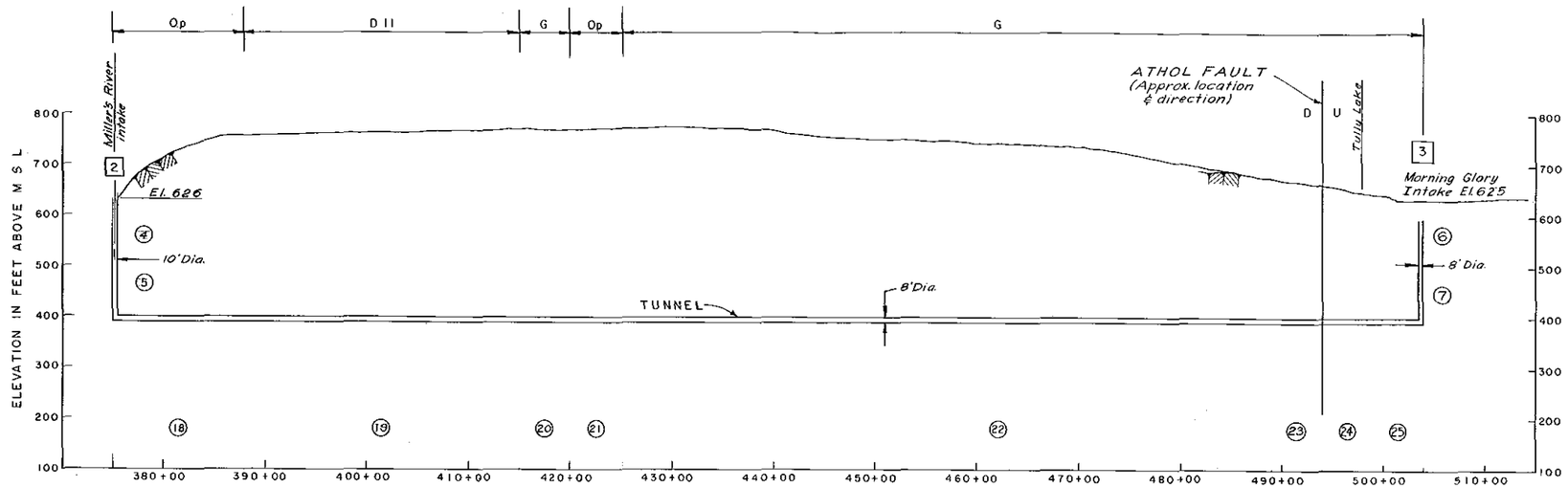
TYPICAL TUNNEL SECTION
SEGMENT NO. 13
NOT TO SCALE

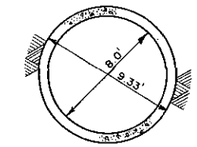
NOTE:
See Sheet 1 for pertinent notes.

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

MILLERS RIVER TO QUABBIN RESERVOIR
TUNNEL ALINEMENT NO. 14

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.





TYPICAL TUNNEL SECTION
SEGMENT NO. 22
NOT TO SCALE

NOTE.
See Plate D-3 for pertinent notes.

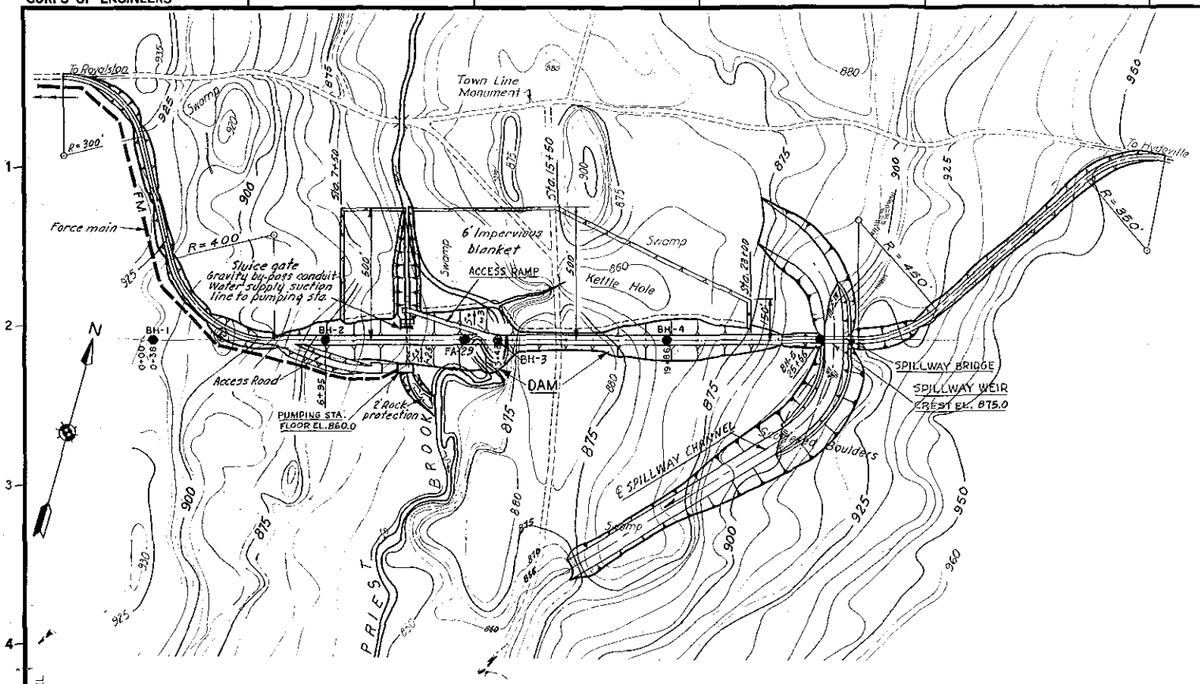
GRAPHIC SCALES

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY LAKE TO MILLERS RIVER
TUNNEL ALINEMENT NO. 14

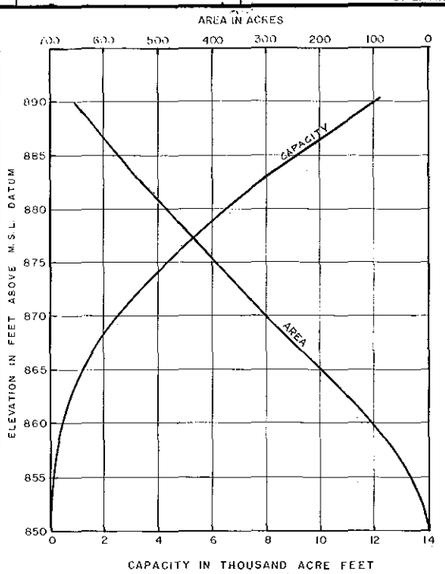
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

CORPS OF ENGINEERS U. S. ARMY

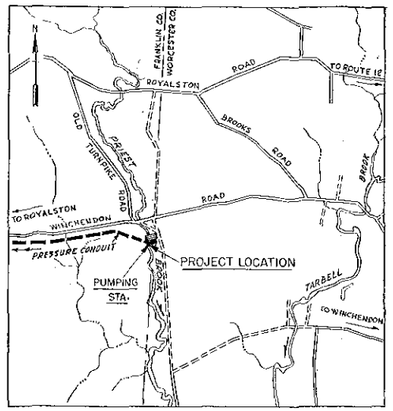


PLAN

SCALE: 1" = 200'

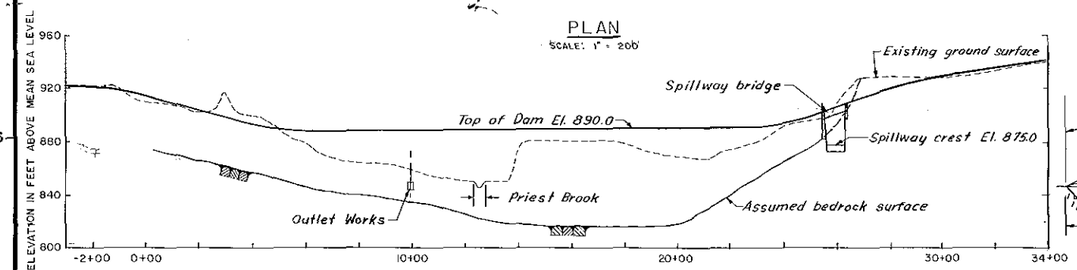


AREA-CAPACITY CURVE



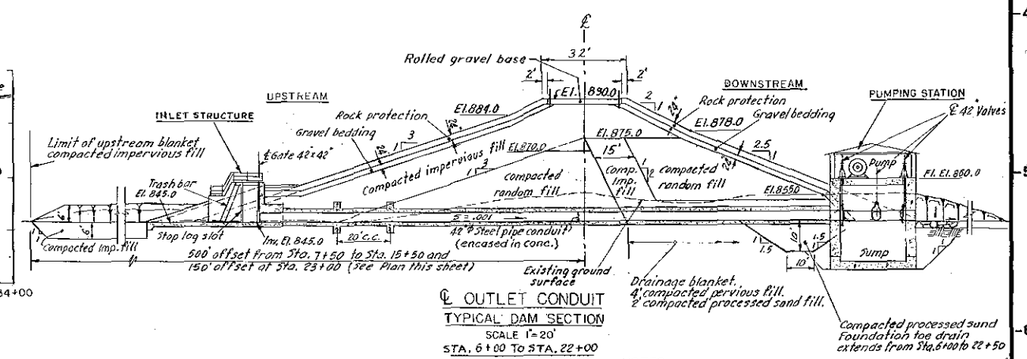
LOCATION MAP

2000' 0 2000' 4000 FT.



℄ PROFILE

SCALE HOR 1" = 200' VERT 1" = 40'



℄ OUTLET CONDUIT

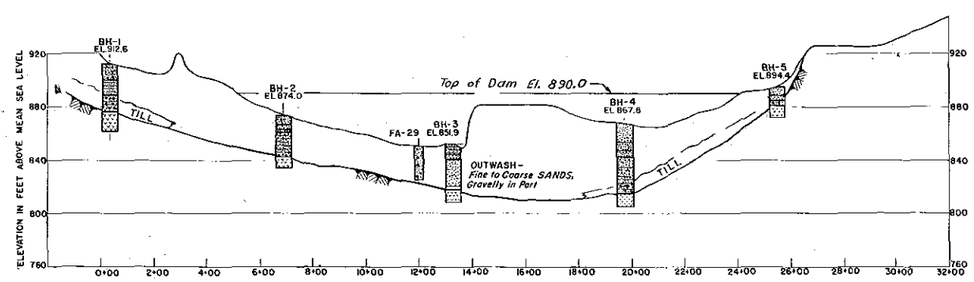
TYPICAL DAM SECTION

SCALE 1" = 20'

STA. 6+00 TO STA. 22+00

NOTES

Elevations refer to Mean Sea Level Datum.



GEOLOGIC PROFILE ON ℄ OF DAM

SCALE HOR 1" = 200' VERT 1" = 40'

GRAPHIC LEGEND

SAND
SILT OR ROCK FLOUR
CLAY
GRAVEL
GRANITE
WEATHERED OR FRACTURED ROCK
ROCK EXPOSURE
ASSUMED ROCK SURFACE
BH = TEST BORING-1936
FA = AUGER BORING-1931

GRAPHIC SCALES

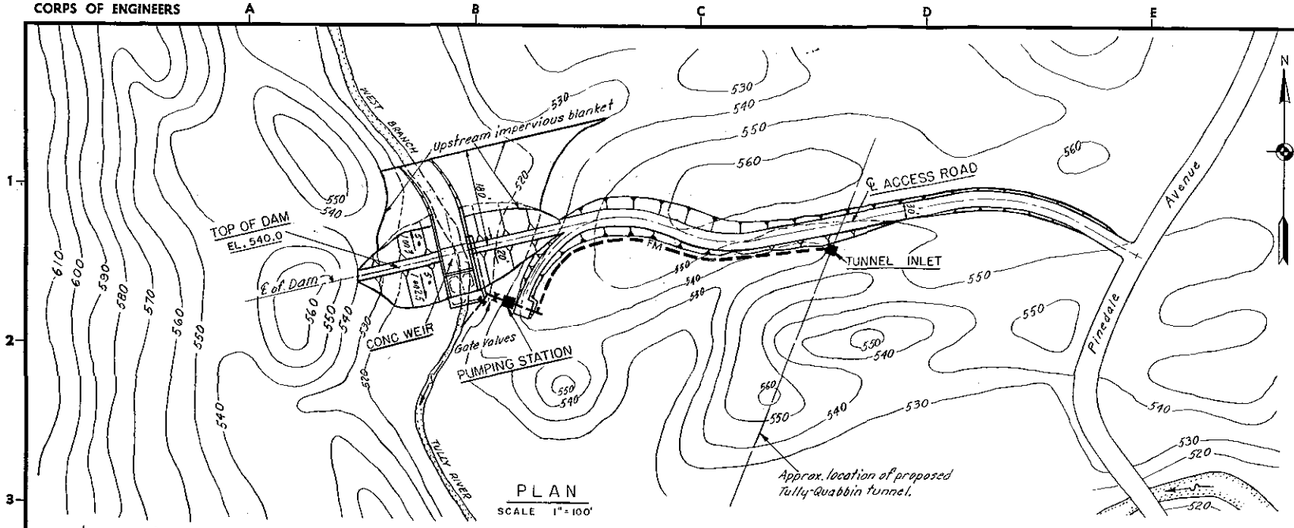
1" = 20' 20' 0 20' 40'
1" = 40' 40' 0 40' 8
1" = 200' 200' 0 200' 400'

NORTHEASTERN UNITED STATES WATER SUPPLY STUDY

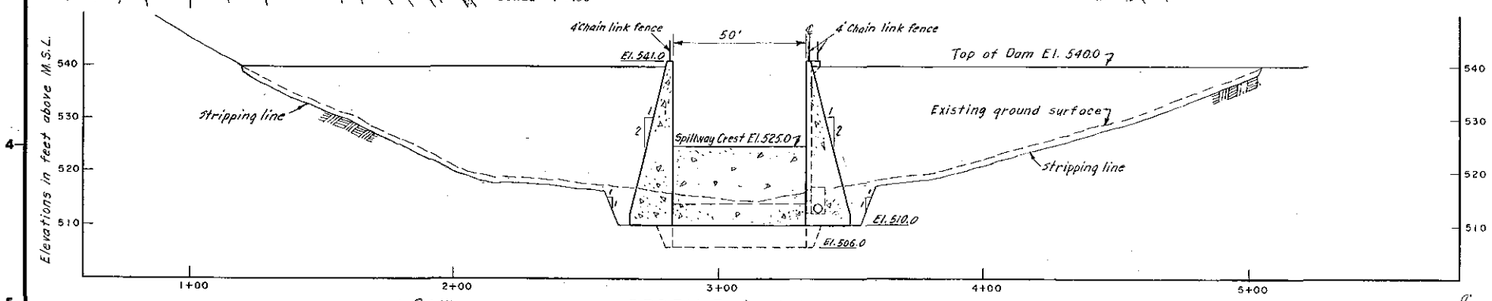
PRIEST BROOK DAM

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

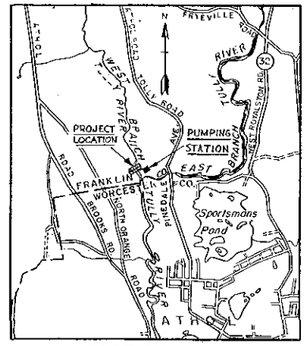
PLATE E-11



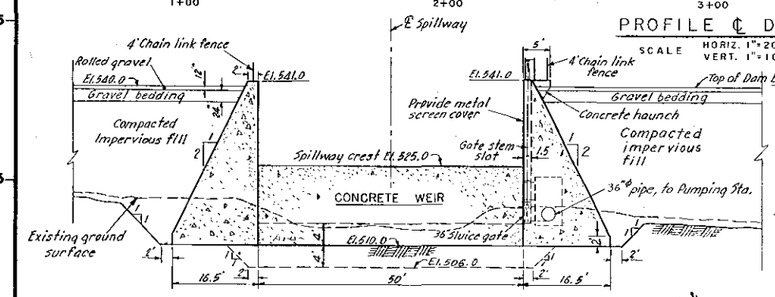
PLAN
SCALE 1" = 100'



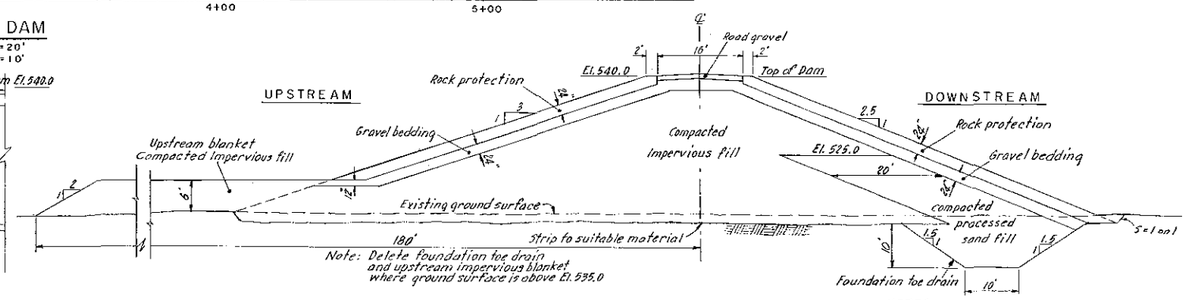
PROFILE ℄ DAM
SCALE HORIZ. 1" = 20'
VERT. 1" = 10'



LOCATION MAP
SCALE 1" = 2,000'

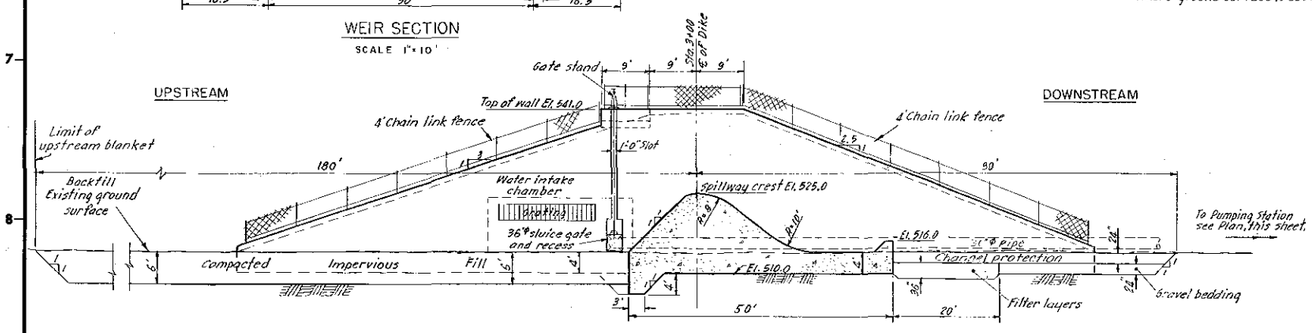


WEIR SECTION
SCALE 1" = 10'



TYPICAL DAM SECTION
SCALE 1" = 10'

NOTES
Elevations refer to Mean Sea Level Datum.



SECTIONAL ELEVATION
SCALE 1" = 10'

GRAPHIC SCALES
1" = 10' 10' 0 10' 20'
1" = 20' 20' 0 20' 40'
1" = 100' 100' 0 100' 200'
1" = 2,000' 2,000' 0 2,000' 4,000'

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

WEST BRANCH TULLY DAM

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

APPENDIX F

REAL ESTATE STUDIES

This appendix details how the real estate costs for each site were determined. Also, the present and potential use of the land is presented. Real estate costs not only include the value of the property, but also the costs incurred in acquiring the land. In the instances of tunnels and pipelines, the real estate cost is simply the amount required to obtain an easement across the property.

These costs were then added to the construction costs for each alternative to develop the total project cost shown in the main report.

APPENDIX F

REAL ESTATE STUDIES

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APPENDIX F

REAL ESTATE STUDIES

1. Preliminary Estimate of Real Estate Costs for Potential Water Storage Areas

A. Locations

The proposed locations which have been considered in this report are located in the towns of Windhendon, Royalston, Orange, and Athol, Massachusetts. The specific locations of each site are further delineated under "General Description" of each site.

B. General Information

In the preparation of this appendix, a physical inspection was made of each site to determine the types of properties involved, the present uses, and the permitted uses under zoning regulations, if any.

An attempt was also made to estimate the approximate number of private ownerships within the ponding area, and the ownerships of lands in which easements will be required to use in estimating the administrative costs for acquisition and the severance damages which might be anticipated. It is further noted that the proposed takings for the reservoir areas and for the drainage inlets will require partial takings which may cause damages to the remaining property in addition to the land taken in fee.

C. Potential Water Storage Impoundment Areas

1) Tarbell Brook and Weir Site, Winchendon, Massachusetts

a. General Description. The proposed site is situated on Government owned land located in the Birch Hill Dam Project and on private ownership lands. The project is located in the northwestern section of Winchendon about 500 feet southwest of the intersection of Royalston Road and Brown Street. The subject area is largely wooded and brush covered, has irregular terrain and is sparsely developed as a residential area. It is proposed to create a water storage area which will inundate about 37 acres of wood and brush covered land. The guide taking line for the reservoir has been established at elevation 845 feet mean sea level (msl).

Easement interests will be required over privately owned land to construct an access roadway leading from Brown Road to the proposed weir site.

The easement location will commence on Brown Road about 800 feet south of the intersection of Brown and Royalston Roads. The access road easement will be 1,300 feet in length by 50 feet in width leading to the proposed 5-foot weir. About 2 acres are required for this easement.

It is further proposed to install a pipeline under land privately owned, leading from the weir site in a northerly direction to Royalston Road about 500 feet east of the intersection of Royalston and Brooks Roads. The length of the proposed easement is 4,000 feet and having a width of 50 feet. The easement will encompass 5 acres of land.

From the point at which the pipeline easement bisects Royalston Road, the pipeline will follow along and under Royalston Road in a westerly direction for a distance of about 8,600 feet to the Priest Brook impoundment water storage area. A permit issued by the town of Winchendon is required by the Government to allow the pipeline to traverse under Royalston Road.

b. Highest and Best Use. Rural and rural residential with possible development of homesites fronting on Royalston Road.

c. Mineral Rights. None.

d. Utilities. Telephone and electrical services are available along Brown Road and Royalston Road.

e. Relocations. None

f. Resettlement. Public Law 91-646, Uniform Relocation Assistance and Real Property Act of 1970, which provides for a uniform and equitable treatment of persons displaced from their homes, businesses, and farms by Federal and Federally assisted programs in accordance with this law, an estimate of $1,400 is included in this report to cover payments of expense incidental to the transfer of real property.

g. Severance Damages. Some acquisitions required for this project will consist of partial takings, which in some cases will cause severance damages to the remaining property in addition to the lands taken in fee. For purposes of clarification, severance damage is the damage to the part not taken which arises by reason of the taking and or construction of the improvement.

h. Administrative Costs. Experience of this office in other similar civil works projects in the area indicate that acquisition costs will

average about $1,200 per owner. The costs include mapping, surveying, legal descriptions, title work, appraisals, negotiations, closing and administrative costs for condemnation. The number of tracts within the project have been estimated without benefit of detailed ownership data. There are no property or assessors' maps available. The number of tracts affected by this project were estimated at 7.

i. Scope, Field Work, and Basis for Evaluation. The value estimates of the land were developed through conferences with local officials, through investigation and analysis of recent sales. The latter involves making a comparison between former sales and the subject property. Search was made of the general area to locate the comparative sales.

j. Contingencies. A contingency allowance of $6,100 is included to cover actual, practical and realistic negotiations pursuant to Section 301, Public Law 86-645 approved 14 July 1900, in accordance with EM 405-1-620 dated 25 October 1961.

Based upon the market data obtained from discussions with knowledgeable real estate persons, it is the opinion of the Corps of Engineers that the market value of the subject land is $150 per acre.

It is assumed that the weir and retention basin, consisting of 37 acres, will be all located on lands currently owned by the Government, and therefore, their value is not included in this report.

The access road easement, containing approximately 2 acres of privately owned land is based on the fee value of the land. An easement interest is recommended in lieu of a fee interest, to reduce severance damages which may be created by distortion of plottage, landlocking of difficult access to remaining ownerships. Therefore, the market value of the road easement is as follows:

2 Acres @ $150 P/A = $300

The underground pipeline easement contains approximately 5 acres of land. It is the appraiser's opinion that there will be a residual value remaining to the owner after the imposition of easement. The use of the land will be restricted, however, it will allow owners to cross and recross to remaining ownerships, and in most cases will serve to allow easier access. The market value of this easement is estimated as follows:

5 Acres @ $150 P/A = $750 x 80% = $600

SUMMARY

37 Acres Government Land	$-0-
2 Acres Access Road Easement	300
5 Acres Underground Pipeline Easement	600
TOTAL	$900

k. Recapitulation

Improvements	$ -0-
Lands	900
Severance Damages	1,000
Contingencies	6,100
Resettlement	1,400
Acquisition Costs	8,400
TOTAL	$17,800
Rounded to	$18,000

2) Priest Brook

a) General Description. The proposed site is situated at the uppermost northwest section of Winchendon, Massachusetts, near the intersection of Royalston Road and Brooks Road, Winchendon, and further extending in a westerly direction into Royalston, Massachusetts. The Winchendon-Royalston town line lies within the confines of this project.

It is proposed to create a water storage area across Priest Brook at a point about 800 feet south of its intersection with Winchendon Road. The minimum guide taking line has been established at a distance of 300 feet holizontally from the full static pool elevation of 875 feet msl.

The land takings will encompass an area of about 1,060 acres, including areas for storage, work area, borrow area, installation of pipelines, and the relocation of Winchendon Road. Also included within the taking area are Deland Road and Old Turnpike Road. These roads will not be relocated. Deland Road, which runs in a westerly direction from the intersection of Royalston Road and Brooks Road, across the proposed reservoir to Stone Road, Royalston, will be dead ended at about 1,000 feet west of its intersection in Winchendon. Following Deland Road in an easterly direction from the Stone Road intersection, Deland Road will be dead ended at about 2,500 feet east of a point where Taft Road bisects Deland Road.

The reservoir supply will be provided by its present natural drainage in addition to water supplied by gravity pumping through the proposed pipeline leading from the Tarbell project.

Most of the project area is wooded and brush covered, has irregular terrain, and is sparsely developed.

The present Old Turnpike Road, Royalston, Massachusetts, which extends from Winchendon Road in a northerly direction into the State of New Hampshire, will be completely inundated and abandoned within the project area. Privately owned properties on both sides of Old Turnpike Road will be acquired.

Based upon a field inspection of the area, indications are that the only improved properties in the taking area are sporting clubs, summer cottages, and year-round residences which are described below.

Located on the northerly side of Winchendon Road at the Winchendon-Royalston town line is the Winchendon Rod and Gun Club, Inc. This ownership is improved by a 1-1/2 story, wooden framed, year-round clubhouse, having an open soda stand, a fishing pond, and related sporting facilities. A dirt roadway leading from the parking lot which is located along the Winchendon Road and extending back to the clubhouse, extends through cleared lands which are used as picnic grounds and shooting ranges. The remaining lands are wooded and brush covered.

Located on the westerly side of Old Turnpike Road, about 800 feet from the point where Old Turnpike Road bisects Winchendon Road is an improved property containing an older type one story residence, a detached building containing a 2-car garage and workshop, and a well house. A small area of cleared land is used for trap shooting and a rifle range. The remaining lands are wooded and brush covered.

Located near the northeastern corner of Old Turnpike Road and Deland Road is a privately owned camping-sporting club. The area is improved by a seasonal concrete block and wood main building, having a metal roof, about 50 individual camp sites each having the usual amenities of platform and deck areas.

A network of dirt roads traverses throughout the cleared areas of this site, serving the individual camp sites, the fresh water ponds, and trap shooting area. Excepting for the above noted improvements, in addition, is another cleared area used for recreational, and the remaining lands are wooded and brush covered.

On the westerly side of Old Turnpike Road, near the Massachusetts-New Hampshire state line is a small low valued wooden framed seasonal residence. Excepting for roadway leading to the dwelling, the land area is wooded and brush covered. Located on Winchendon Road in Royalston, opposite Old Turnpike Road is a year-round wooden framed, fairly new ranch home.
The remaining lands located in the project area are brush and wood covered. There are some good stands of marketable timber interspersed throughout the subject area.

Telephone and electric power systems are located on the traveled ways and are the only utilities serving the area. Individual owners provide their own water and sewage systems.

A permit will be required to extend an underground pipeline from the westerly boundary line of the proposed dam site within the present right of way of Winchendon Road running in a westerly direction for a distance of about 15,000 feet to a point near the intersection of South Road and Winchendon Road.

At this point, easement interests for the installation of underground pipeline will be required over privately owned lands for a distance of approximately 1,500 feet in a southwesterly direction. It is estimated that about 2 acres of land are needed for this easement.

The pipeline from this point will follow an existing high powered transmission line overhead easement granted by the owners to a utility company. The pipeline easement will extend in a northwesterly direction for a distance of about 6,300 feet by 50 feet in width. Additional underground easements will be required from the fee owners.

From this point, at the crest of Jacob Hill, the pipeline will cross through private ownerships in a southerly direction for a distance of about 1,000 feet into Long Pond. Two acres are required.

b) Utilities. Telephone and electrical systems are available along all traveled ways.

c) Number of Ownerships. There are no assessors' maps available in the town of Royalston to use in determining property ownerships. Conversation with the town officials indicates that approximately 30 ownerships would be affected by the project.

d) Relocation. It is planned to relocate a section of Windhendon Road for a distance of about 9,000 feet. It is assumed that the electrical and telephone systems will also be included within the proposed right of way. Since this relocation is planned within the damsite area, no additional land is included for this purpose.

e) Mineral Deposits. Except for a few nearly depleted, small privately used sand and gravel areas, a field inspection revealed no commercial or mining operations.

f) Timber. Much of the lands within the project area are wooded or brush covered There are some stands of marketable species, however, for the purpose of this report, their values are reflected in the land value.

g) Resettlement. Public Law 91-646, Uniform Relocation Assistance and Real Property Policy Act of 1970, provides for a uniform and equitable treatment of persons displaced from their homes, businesses, or farms by Federal or Federally assisted programs. In accordance with this law, an estimate of $145,000 is included in this report to cover relocation expenses, payments of expenses incidental to the transfer of real property and possible litigation expenses.

h) Severance Damages. Some acquisitions required for this project will consist of partial takings, which in some cases, will cause severance damages to the remaining properties in addition to the property taken. For purposes of clarification, severance damage is the damage to the part not taken which arises by reason of the taking and or construction of an improvement.

i) Administrative Costs for Acquisition. Experience of this office in other similar civil works projects in the area indicate that acquisition costs will average around $1,200 per owner. These costs include mapping, survey, legal descriptions, title work, appraisal, negotiations, closings, and administrative costs for condemnation.

The number of tracts within the project have been estimated without benefit of detailed ownership data. There are no property maps or assessors' maps available. The number of tracts affected by this project were estimated, and also, through discussions with local officials.

j) Contingencies. A contingency allowance of 20 percent is considered reasonable to provide for possible adjustments or refinements of the taking lines or additional ownerships which may develop, for adverse condemnation awards, and to allow for actual, practical and realistic negotiations.

k) Evaluation. The value of the lands and improvements within the project have been estimated by the use of the market data approach. Based upon the comparable sales data obtained from discussions with knowledgeable real estate persons, the market value of the wooded and brush covered acreage averages about $150 per acre, and the market value of the sand and gravel areas averages approximately $300 per acre.

The value of pipeline easements containing about 4 acres of privately owned wooded land is based on the fee value of the land. An easement interest is recommended in lieu of a fee interest to reduce the severance damages. There will be a residual value remaining to the owner after the imposition of the easement. The use of the land will be restricted, however, it will allow owners to pass and repass to remaining ownerships. The market value of the easement is estimated as follows:

4 Acres @ $150 P/A = $600 x 80% = $480

The value of the residential units and the improvements located on the sportsmen clubs are based on experience and the market data obtained.

LANDS

Acres	Classification	Avg/Acre	Total
2	Homesite	$3,500	7,000
10	Sand & Gravel	300	3,000
35	Recreational	500	17,500
1,009	Woodland & Brush	150	151,350
			$178,850
4	Pipeline Easement		480
			$179,330

IMPROVEMENTS

2	Sportsmen Clubs	$ 81,000	
2	Residential Units	40,000	
1	Seasonal Camp	3,500	
			$124,500
	Total Value, Land and Improvements		$303,830

1) Recapitulation.

Improvement	$124,500
Lands	179,330
Severance Damages	40,000
Contingencies (20%)	68,766
Resettlement	125,000
Acquisition costs	19,200
Total	$556,796
Rounded to	$557,000

3) West Branch Tully River

a) General Description. The proposed reservoir site is situated in the southeastern section of Franklin County, Massachusetts in the town of Orange at the Worcester County-Franklin County line. The site is in an area encompassed by Tully Road, Orange, and Pinedale Road, Athol, Worcester County, Massachusetts, and the West Branch Tully River.

The purpose is to establish a reservoir and to construct a 5-foot weir at the southernmost end of the reservoir to direct water flowage into tunnels leading into either the Millers River or directly into the Quabbin Reservoir through pipelines of separate routings.

The lands within the reservoir area are mostly wooded and brush covered and sparsely developed. However, there is one improved property within the reservoir area.

The plan is to acquire in fee approximately 36 acres of land based on a guide taking line established at elevation 500 feet msl for water storage purposes, borrow and work area, and for shaft and pipeline construction.

The 5-foot weir will be constructed about 700 feet upstream of the confluence of the West and East Branches of the Tully River.

Extending from the weir in a southerly direction about 900 feet of underground pipeline installation is required by an easement 50 feet in width over private lands to an underground tunnel in which water will flow to the Quabbin Reservoir. Two acres are required for the easement.

Based upon a field inspection, the project will include the acquisition of one improved property. The remainder is privately owned brush and wooded land, and a small area of sand and gravel.

b) Estates to be Acquired. It is recommended that fee estates will be required over the reservoir area and easement interests for the underground pipelines.

c) Utility. Electrical and telephone facilities are available along adjacent roadways.

d) Mineral Deposits. A gravel excavation operation was conducted for several years on a knoll situated just west of Tully Road in the proposed impounding area. However, it is noted that this operation is only limited and probably used as a private source.

e) Number of Ownerships. There are about 12 ownerships within the project area.

f) Permits. Permits will be required to construct pipelines under public roadways.

g) Highest and Best Use. The highest and best use of lands are the present uses. No market data was obtained that would indicate any change in the foreseeable future.

h) Timber. Most of the land within the project area is wooded and brush covered. There are few stands of marketable timber, however, the quality and quantity are considered inadequate to require inclusion of any special allowance for marketable timber. The value of any timber is reflected in the land value.

i) Relocations. None.

j) Resettlement. Under Public Law 91-646, Uniform Relocation Assistance and Real Property Policy Act of 1970, provides for a uniform and equitable treatment of persons displaced from their homes, businesses, or farms by Federal or Federally assisted programs. In accordance with this law, an estimate of $4,100 is included in this report to cover relocation expenses, payment of expenses incidental to transfer of real property.

k) Severance Damages. Some acquisitions required for this project will consist of partial takings, which in some cases, will cause severance damages to the remaining property in addition to the lands taken in fee. For purposes of clarification, severance damage is the damage to the part not taken which arises by reason of the taking and or construction of an improvement.

l) Administrative Costs. Experience of this office in similar civil works projects in the area indicate that acquisition costs will average about $1,200 per owner. These costs include mapping, surveying, legal descriptions, title work, appraisal, negotiations, closings, and cost of condemnation.

The number of tracts within the project has been estimated without benefit of detailed ownership maps. There are no property or ownership maps available.

m) Contingencies. A contingency allowance of 20 percent is considered reasonable to provide for possible adjustments or refinements of the taking lines or additional ownerships which may develop, for adverse condemnation awards, and to allow for actual, practical and realistic negotiations.

n) Evaluation. The value of the lands and improvements within the project have been estimated by the market data approach. Based upon the market data obtained and from discussions with knowledgeable persons, the market value of the wooded and brush covered acreage is $150 per acre.

The road easements required for this project is based on the fee value of the land. An easement interest is recommended in lieu of a fee interest to reduce severance damages which may be created by distortion of plottage, land locking, or difficult access to remaining ownerships. There will be residual value remaining to the owner after the imposition of the easement. The use of the land will be restricted, however, it will allow owners to pass and repass to remaining ownerships. The market value of the easement is estimated as follows:

4 Acres @ $150 P/A = $600 x 80% = $480

The value of the summer residence, including the private entrance drive leading from Tully Road, the main building and the outer building is estimated at $10,000.

LANDS

32 Acres Wooded & Brush Land	@	$150 P/A	=	$4,800
3 Acres Sand & Gravel	@	300 P/A	=	900
1 Acre Camp Site				1,500
				$7,200

0) Recapitulation.

Lands	$ 7,200
Improvements	10,000
Severance Damages	1,800
Contingencies (20%)	3,800
Resettlement	4,100
Acquisition Costs	14,400
Total	$41,300
Rounded to	$41,000

4) Millers River

a) General Description. The proposed 40-acre site is an irregular shaped parcel located in the town of Athol, Massachusetts, along the southeasterly side of Royalston Road. It may be described as being similar in appearance to a pyramid with a handle on the northeast and southeast banks of the Millers at the base of the pyramid.

On Royalston Road, a frontage of about 40 feet will be acquired for an access road to the tract of land. At the curve on Royalston Road near the proposed frontage of subject some 30 feet inward are indications of a former logging tote road, long abandoned and now overgrown by heavy growth and bush. The proposed site is elevated about 5 feet above road grade. There is an old fieldstone wall along this frontage. The tote road winds through the wooded area along the base of the hill and circles around the property. The road does not reach the Millers River. It is reliably reported that about 50 years prior to this date, numerous pine and hardwoods were harvested and about one million feet of marketable timber were sold.

The area to be acquired rises gently from road elevation about 850 msl, to a depth of about 1,000 feet, then drops sharply to elevation about 630 msl, forming a gorge at the Millers River on the southerly boundary to a drop-off of about 70 feet. There are certain areas on the tract that are wet and overgrown with alder type brush growth. These areas are considered to be swampy. There is a Boston and Maine Railroad right-of-way which generally follows along the southerly bank of the Millers River. The proposed land to be acquired is bounded on the northerly side of this right-of-way. The proposed site is encumbered by a permanent New England Electric power line utility transmission easement which generally extends a distance of about 2,000 feet along the northwesterly boundary of the parcel containing five acres. This easement lessens the potential developability of this site.

The proposed frontage boundary begins about 4,500 feet northeast of the junction of Old Keene Road and Royalston Road, extending along that road about 40 feet; then turns and extends about 1,500 feet in a southwesterly direction to the referred handle shaped strip which strip encompasses the Millers River in a northeasterly direction for about 1,500 feet; then turns to follow westerly along the north and northwesterly boundary of the railroad right-of-way for a distance of about 3,000 feet; then extending in a northwesterly direction from the railroad right-of-way across the Millers River for a distance of about 500 feet; thence turning to follow along the northwesterly boundary of the utility easement about 2,000 feet to a point of beginning on Royalston Road.

b) Timber. Most of the land within the site area is classified as wooded, and there are a few small stands of marketable species. However, the quality and quantity are considered inadequate to require inclusion of any special allowances for marketable timber. The value of the timber within the proposed project area is reflected in the value of the land.

c) Ownerships. The entire subject site is in Athol, Worcester County, Massachusetts. The town of Athol has no real property maps. In the town center, there are sketches on some of the assessors's real estate records for property within the built-up area of the town center. For the most part, property lines and ownerships are difficult to define in the outlying rural areas. Ownership to the majority of the land of subject site is vested with:

Evelyn Merrifield
1777 Chestnut Hill Avenue
Royalston Road
Athol, Massachusetts

which includes all the land of the site north of the Millers River with certain exceptions. These exceptions are:

The Athol Conservation Commission owns the land on the southern side of the Millers River, known as the Bearsden Road Section. They purchased 700 acres in 1969 at $10.00 to $16.00 per acre, 100 acres of which were bought from Evelyn Merrifield at $25.00 an acre.

The Department of Fisheries and Game of the Commonwealth of Massachusetts bought land for $25.00 per acre in the same area leading to the river, from the Bragg Estate at Millers River along the southern side of the river.

On the eastern side of the river on its northern bank, Harian B. Davis of Athol, gratuitously bestowed three acres of unimproved land to the Athol Conservation Commission, which land is located near the northern river bank at the so-called "handle".

The subject site has 3 owners, Evelyn Merrifield, the town of Athol, and the Commonwealth of Massachusetts, Department of Fisheries and Game.

d) Zoning and Planning. The town of Athol does not have a building code but does have a planning board which exercises subdivision control powers. A master plan has been completed with use of Federal funds. Real estate maps are not available in Athol. Plot sketches are in the assessor's cards for some property in the town center only.

e) Taxes. Land and buildings in Athol are assessed at a reported rate of 33 percent of market value. The tax rate in 1971 was $148.00 per $1,000.

f) Population. The population in 1970, according to the U. S. Census, was 11,185; on that year the population density was 366 persons per square mile. The trend is considered to be static.

g) Utilities. Within the town center, the utilities are town water, electricity, telephone, and natural gas. Sanitary sewer facilities are also throughout this area which are being extended as funds permit. On the outskirts of the town property, the utilities consist of telephone and electric service. The water is from individual wells and the sanitary waste disposal is accomplished by private septic tanks or cesspools. Telephone and electric services are available to the subject site.

h) Topography. Athol terrain is a series of hills, ranging from 500 feet to 1,200 feet in elevation. The area at the site attains a height of about 850' msl on the north and slopes rapidly to about 630' msl at the Millers River elevation. The area is heavy with brush and trees, with swampy sections that make passing uncertain and hazardous.

i) Soils. The soil at the site is generally rough and stony along the east, but it is moist and of fair texture on the west and south.

j) Minerals. A field inspection revealed no commercial mining of gravel or other minerals being conducted within the project area.

k) Accessibility. As aforementioned, the site lies about 4,500 feet northeast of the junction of Old Keene Road and Royalston Road and is within close proximity to Route 32, a north route to New Hampshire and also to Routes 202 and 2A, southeast and east-west respectively. There is adequate bus transportation within the town limits.

l) Highest and Best Use. Generally, the present use of the undeveloped lands within this project area are considered to be their highest and best use. The subject unimproved lands within this proposed acquisition area are considered to be rural residentially developable.

m) Borrow Requirements. All borrow requirements for construction are expected to be obtained within the project area, therefore, no additional land is required for this purpose.

n) Comparable Sales. Considerable research to verify information gained from various sources has resulted in obtaining four recent land sales. Power line and other easements were checked but were not considered since they offered indistinct guides to the value of subject site. Since the town of Athol has no assessors' maps, it proved to be a deterrent in making positive identification regarding exact lot lines of the sales as well as the ownerships involved in area of the proposed site.

o) Severance Damages. Severance damages usually occur where partial takings are acquired and when the remaining portion may not be subject to full economic development. The severance damages are measured and estimated on the basis of "before and after" appraisal methods and will reflect actual value losses incurred by remainders as a result of partial acquisitions. The estimated severance damages for the entire project are $1,500.00.

p) Acquisition Costs. Experience in other similar civil works projects in the area indicate that acquisition costs will average about $2,700 per tract. These costs include mapping, surveying, legal descriptions, title work, appraisals, negotiations, closing, and administrative costs for condemnation. The number of tracts within the project have been estimated without benefit of detailed ownership data. Based on this ownership survey, the acquisition costs for this entire project are estimated to be:

3 ownerships @ $2,700 = $8,100
Total estimated acquisition costs = $8,100.00

q) Contingencies. A contingency allowance of 20 percent is considered reasonably adequate to provide for possible appreciation of property values from the time of this estimate to the acquisition date, for possible minor property line adjustments, or for additional hidden ownership which may be disclosed by refinements of taking lines, for adverse condemnation awards, and to allow for actual, practical and realistic negotiations pursuant to existing acquisition regulations.

r) Relocation Assistance. Public Law 91-646, Uniform Relocation Assistance and Real Property Act of 1970, now provides a uniform and equitable treatment of persons displaced from their homes, businesses, and farms by Federal and Federally assisted programs in accordance with

this law. An estimate of $.0 is included in this report to cover payments of expense incidental to the transfer of real property since the law is not applicable.

s) Evaluation and Analysis. A careful and thorough search was made in the area of the proposed site to secure sales data. In addition, several local officials, brokers, bankers, and knowledgeable persons were contacted to secure data and value estimates. A general knowledge of the real estate market was obtained from this survey and land sales indicative of market value. From these sales it was possible to establish a realistic valuation for the subject site after making adjustments for time, size, location, and topography. Based upon the market data obtained, the subject site, is valued at a fair and reasonable figure of $50.00 per acre.

t) Recapitulation. The costs involved are as follows:

40 acres - unimproved steep and low land @ $50.00 per acre	=	$ 2,000.00
Acquisition Costs		8,100.00
Severance Damages		1,500.00
Contingencies - 20% of $11,600 = $2,320. Rounded to $2,300		2,300.00
Relocation Assistance Costs		0
Total		$13,900.00
Rounded to		$14,000.00

2. Preliminary Estimate of Real Estate Costs for Potential Tunnel Routes

A. Purpose

An estimate was made of the real estate costs for a number of alternative tunnels from the Millers River Basin to Quabbin Reservoir to be used as a supplemental water supply source to Quabbin Reservoir.

B. Alternative No. 1 - Millers River Diversion

1) General Description

The proposed tunnel would be 10 feet in diameter, running from a point on the Millers River above Athol to Quabbin Reservoir. Some 2 miles of the 7 mile route passes beneath the center of Athol. The remainder of the route is largely wooded and brush covered land with some residential development. The depth of tunnel varies between 200 to 400 feet below the ground surface in rock.

2) Easement Costs

Easements will be required to construct this tunnel under privately owned land. An attempt was made to estimate the approximate number of private ownerships along the tunnel route. Since assessors or property maps of the area are not available and the easement costs are small compared with the construction cost of the tunnel, estimates of ownerships were made from USGS Quad sheets.

The number of tracts affected by the tunnel were estimated to be 160. This is without benefit of detailed ownership data. It is estimated that each ownership will require approximately $1000 to obtain the necessary easement. Ownerships instead of acres or linear feet of easement were used because of required easement procedures pursuant to Section 301, Public Law 86-645, approved 14 July 1960, in accordance with EM 405-1-620, dated 25 October 1961. Therefore, the estimated easement cost is as follows:

160 Tracts @ $1000/Tract = $160,000

A contingency allowance of 20 percent of the easement cost is included to cover actual negotiations necessary to obtain the tunnel easement.

3) Administrative Costs

These costs are those which are expected to occur as a result of the Real Estate Acquisition Program. They include costs for mapping and surveys, legal descriptions, title evidence, appraisals, negotiations and closings, and administrative costs for possible condemnations. The costs are based on this office's experience in similar civil works projects in this general area and are estimated at $1200 per ownership.

160 owners @ $1200/owner = $192,000

4) Recapitulation

EASEMENT COSTS	$160,000
CONTINGENCIES	32,000
ADMINISTRATIVE COSTS	192,000
TOTAL	$384,000

C. Alternative No. 2 - Tully-Millers Diversion

1) General Description

The proposed tunnel would be 8 feet in diameter from Tully Lake to a point on the Millers River above Athol, from there to Quabbin Reservoir it would be 10 feet in diameter. Some two miles of the 9.5 mile tunnel route passes beneath the center of Athol. The remainder of the route is largely wooded and brush covered land with some residential development. The depth of tunnel varies between 200 to 400 feet below the ground surface in rock.

2) Easement Costs

Easements will be required to construct this tunnel under privately owned land. An attempt was made to estimate the approximate number

of private ownerships along the tunnel route. Since assessors or property maps of the area are not available and the easement costs are small compared with the construction cost of the tunnel, estimates of ownerships were made from USGS Quad sheets.

The number of tracts affected by the tunnel were estimated to be 180. This is without benefit of detailed ownership data. It is estimated that each ownership will require approximately $1000 to obtain the necessary easement. Ownerships instead of acres or linear feet of easement were used because of required easement procedures pursuant to Section 301, Public Law 86-645, approved 14 July 1960, in accordance with EM 405-1-620, dated 25 October 1961. Therefore, the estimated easement cost is as follows:

180 Tracts @ $1000/Tract = $180,000

A contingency allowance of 20 percent of the easement cost is included to cover the actual negotiations necessary to obtain the tunnel easement.

3) Administrative Costs

These costs are those which are expected to occur as a result of the Real Estate Acquisition Program. They include costs for mapping and surveys, legal description, title evidence, appraisals, negotiations and closings, and administrative costs for possible condemnations. The costs are based on this office's experience in similar civil works projects in this general area and are estimated at $1200 per ownership.

180 owners @ $1200/owner = $216,000

4) Recapitulation

EASEMENT COSTS	$180,000
CONTINGENCIES	36,000
ADMINISTRATIVE COSTS	216,000
TOTAL	$432,000

D. Alternative No. 3 - Tully Complex Diversion

1) General Description

The proposed tunnel would be 8 feet in diameter running from Tully Lake to Quabbin Reservoir. The 8.5 mile route skirts the major residential areas going largely through wooded and brush covered land with some residential development. The sparsely developed area adjacent to the Millers River is the most populous area that the tunnel passes under. The depth of tunnel varies between 200 to 400 feet below the ground surface in rock.

2) Easement Costs

Easements will be required to construct this tunnel under privately owned land. An attempt was made to estimate the approximate number of private ownerships along the tunnel route. Since assessors or property maps of the area are not available and the easement costs are small compared with the construction cost of the tunnel, estimates of ownerships were made from USGS Quad sheets.

The number of tracts affected by the tunnel were estimated to be 100. This is without benefit of detailed ownership data. It is estimated that each ownership will require approximately $1000 to obtain the necessary easement. Ownerships instead of acres or linear feet of easement were used because of required easement procedures pursuant to Section 301, Public Law 86-645, approved 14 July 1960, in accordance with EM 405-1-620, dated 25 October 1961. Therefore, the estimated easement cost is as follows:

100 Tracts @ $1000/Tract = $100,000

A contingency allowance of 20 percent of the easement cost is included to cover the actual negotiations necessary to obtain the tunnel easement.

3) Administrative Costs

These costs are those which are expected to occur as a result of the Real Estate Acquisition Program. They include costs for mapping and surveys, legal description, title evidence, appraisals, negotiations and closings and administrative costs for possible condemnations.

The costs are based on this office's experience in similar civil works projects in this general area and are estimated at $1200 per ownership.

100 owners @ $1200 each = $120,000

4) Recapitulation

EASEMENT COSTS	$100,000
CONTINGENCIES	20,000
ADMINISTRATIVE COSTS	120,000
TOTAL	$240,000

APPENDIX G

ENVIRONMENTAL PROTECTION AGENCY REPORT ON WATER QUALITY STUDIES

A member of the Division of Air and Water Programs, Environmental Protection Agency, prepared this appendix in cooperation with the U. S. Army Corps of Engineers. The investigations included the mainstem Millers River and certain tributaries proposed for water supply development. Water quality data used included existing information from Federal and State Agencies and data collected by New England Research, Inc., under Corps of Engineers contract.

The information was then used to determine the suitability of the various streams as water supply sources and to aid in the design of the treatment and conveyance facilities necessary for each alternative.

APPENDIX G

ENVIRONMENTAL PROTECTION AGENCY REPORT ON WATER QUALITY STUDIES

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APPENDIX G

ENVIRONMENTAL PROTECTION AGENCY REPORT ON WATER QUALITY STUDIES

1. General

The purpose of these studies is to investigate the existing water quality of all streams considered as alternatives in order to determine their suitability as water supply sources. In addition, the Millers River mainstem was examined for its water supply potential which could exist after pollution abatement.

The studies conducted were performed by a member of the Division of Air and Water Programs, Environmental Protection Agency, as input to this report. Water quality data utilized included information from both Federal and State Agencies as well as data collected under contract to the Corps of Engineers.[1]

Diversions being considered in this study include the use of Millers River and its tributaries. The following sections, therefore, describe water quality of the tributaries and the mainstem river.

2. Diversion from the Mainstem Millers River

A. Description of Proposed Diversion

As described in earlier sections of the report two alternatives considered would divert water from the mainstem Millers River to Quabbin Reservoir for storage and subsequent use as a water supply source. Estimated yield from the Millers River Basin Alternative No. 1 is about 68 mgd or about 24.8 billion gallons on an average annual basis. In Alternative No. 2, flow from a tributary of the Millers, the East Branch Tully River would be diverted together with flow from the Millers River itself. Estimated yield from Alternative No. 2 is about 76 mgd or about 27.7 billion gallons on an average annual basis. In both alternatives investigated, diversions would be achieved based on a control flow of 17,000 cfs at the U. S. Geological Survey gaging station at Montague City as well as control flows on the Millers River itself.

Because of the control flow constraints, diversion would be accomplished using a flood skimming technique about 70 days per year generally during spring runoff conditions.

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[1] See Appendix I

B. General Description of Basin

The Millers River Basin is situated principally in north-central Massachusetts with its northernmost portion located in southwestern New Hampshire. It lies wholly within the New England upland physiographic province. To the west is the Connecticut Valley lowland and to the east the seaboard lowland. In general, the terrain is quite hilly, rugged and dotted with a number of small ponds and lakes and swampy depressions. Many of the swampy areas are ponds in the spring when runoff and the water table are high but revert to swamps again when the water table drops in early summer. The area receives ample rainfall with an annual runoff of 22 $\pm$ inches.

The Millers River has a drainage area of 392 square miles. Of this, 78 percent is forest, 11 percent open land, 8 percent wetland and 3 percent urban area. Agricultural use of the land is very limited. There are a number of state forests and parks and two Federal flood control projects within the basin. Also, the "Mohawk Trail" runs through the basin making it a prime tourist area.

C. Present Water Quality

The Millers River from the confluence of the Otter River to the proposed location of diversion just east of Athol is unsatisfactory for water supply use. It receives the poorly treated municipal wastes from Winchendon and Gardner and it is also subject to untreated paper mill wastes from two paper plants and the untreated wastes from Templeton and South Royalston.

The results of chemical and physical analysis by the Metropolitan District Commission in 1965 showed B. O. D. 's as high as 156 mg/l at Baldwinsville, suspended solids 539 mg/l with 23,000 coliforms. At the Millers River near Athol, the B. O. D. was 3.0 mg/l with a suspended solids concentration of 135 mg/l.

Analysis of the Millers and Otter River conducted by the Massachusetts Department of Public Health and Massachusetts Water Resources Commission, Division of Water Pollution Control in the summer of 1965 showed that the average B. O. D. in the Otter River was 62.5 mg/l at the confluence with the Millers River.

The analysis of Millers River water and Otter River has been limited to the standard parameters and concentration of coliform bacteria. There is no evidence to date that detailed chemical and physical analysis has been made during the proposed time of diversion nor is there evidence of trace metal analysis being done during anytime of the year prior to 1970. As part of this study, water quality data was collected and analyzed during 1971 on the river.

In general Millers River water quality below Winchendon and above the confluence of the Otter River is similar to that of the relatively unpolluted tributary streams. The water quality deteriorates rapidly at the confluence of the Otter and remains of very low quality the remaining 29 ± miles to the Millers River confluence with the Connecticut River. This would indicate that the major sources of organic and inorganic pollutants are coming from sources below Winchendon.

The major point sources of pollution are all within the State of Massachusetts. They consist of two paper mills, one city and three towns. One paper mill, with maximum untreated discharge per day, amounts to 24,000 lbs. of B. O. D. /day, 73,000 lbs. of C. O. D. and 55,000 lbs. of suspended solids and 64,000 lbs. of volatile solids. A second paper mill proposes to discharge to the Otter River after secondary treatment 11 lbs. of B. O. D., 125 lbs. of C. O. D. and 118 lbs. of suspended solids. The point sources of municipal waste discharges are the city of Gardner, Town of Winchendon, Templeton and South Royalston, Massachusetts.

D. Proposed Abatement for Water Quality

On July 1, 1971, the City of Gardner, Massachusetts initiated bids for the modernization of their treatment plant. The plant is designed for 1988 with a 3.8 million gallons/day flow, with B. O. D. of 4,060 lbs. and suspended solids of 4,000 lbs. /day. The consulting engineers estimated a 95% B. O. D. and C. O. D. removal, thus the effluent B. O. D. would be 6.4 mg/l and a C. O. D. of 7.6 mg/l.

The Town of Winchendon as of July 1, 1971 has a proposed modernization plan for sewage treatment. The plan is to upgrade the plant by extended aeration, clarifier with final discharge to sand filters

and sludge drying beds. The design is to the year 1990 with a flow 500,000 gpd with 730 lbs. of B. O. D.

Waste from the Town of Templeton and the East Templeton section are to be treated at the Gardner Treatment Plant. Baldwinsville and Baldwinsville Products Paper Mill are presently planned as one combined plant located in Baldwinsville.

The proposed plant will have an effluent estimated at 80 mg/l of $B. O. D._5$ and 90 mg/l suspended solids. Thus, the daily release to the Otter River would be some 3,000 lbs. of $B. O. D._5$ and about 3400 lbs. of suspended solids. The maximum allowable loading on the Otter River would be 300 lbs. of $B. O. D._5$ using the $MA7CD_{10}$[1] flow rate. Thus, the loading from the plant would be 10 times the rated capacity of the river.

The community of South Royalston will also discharge to the river and will install an extended Aeration Plant based on a flow of 39,000 gallons/day.

E. Advanced Waste Treatment Required for Water Supply

The present[2] implementation schedule by the Massachusetts Water Resources Commission, Division of Water Pollution Control requires secondary treatment. This treatment will not remove the nitrogen or cadmium from the Millers River water nor will such treatment remove enough B. O. D., C. O. D. or suspended solids to be of suitable quality for diversion to Quabbin Reservoir.

The high concentration of nitrogen can only be removed by advanced waste treatment. The sources of heavy metals should be found within the individual plants and removal made at the point sources.

The water to be diverted to Quabbin must be class B at all times, and should meet the requirements of raw water quality standards required by the U. S. Environmental Protection Agency. The following is a description of the proposed tertiary treatment for the six major point sources of pollution to produce such a water.

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[1] 7 day low flow value to be expected once in ten years.

[2] Established prior to passage of the 1972 Water Quality Act.

(1) Baldwinsville Products, Inc. (Paper Mill)

The proposed planned secondary treatment with 80 mg/l of BOD_5 and 90 mg/l suspended solids remaining amounts to over 2300 pounds per day of BOD and over 2600 pounds of suspended solids. Based on an Otter River $MA7CD_{10}$ flow, the maximum estimated load assimulation of BOD would be 300 pounds.

In view of these requirements, the Balswinsville Plant could not meet the water supply stream standards with secondary treatment.

The very high suspended solids suggest that sand filtration would have to be used ahead of granular carbon absorption.

Preliminary cost estimates [1] for a 4.25 mgd plant would be:

a) Rapid Sand Filtration (Capital Costs)	$ 350,000.00
Annual Operating Costs & Maintenance	250.00
b) Granular Carbon Absorption (Capital Costs)	1,826,000.00
Annual Operating Costs & Maintenance	475.00/day

These figures are subject to many variables and may vary widely with secondary treatment efficiency and technology changes.

(2) Seaman Paper of Massachusetts, Inc.

The Seaman Company has recently installed waste-treatment facilities of a secondary nature. The waste load is approximately .580 mgd.

The discharge permit application estimates effluent discharges as follows:

	(lbs. per day)
Alkalinity	150
BOD_5	11
COD	125
Total Solids	182

[1] All cost estimates shown are based on data contained in The Merrimack: Designs for a Clean River, Alternatives for Managing Wastewater in the Merrimack River Basin, September 1971, North Atlantic Division, NEWS, updated to July 1973 price level.

	(lbs. per day)
Dissolved Solids	170
Suspended Solids	118
Volatile Solids	115
Ammonia (N)	312
Organic (N)	48
Nitrate	0.3
Phosphorous (P)	0.3

It is doubtful that these figures can be met under normal plant operation. Results of one analysis on the treatment plant effluent shows the following values:

1.	B. O. D.	38 lbs/day
2.	C. O. D.	1900 lbs/day
3.	Suspended Solids	85 lbs/day

The probable additional treatment for removal of C. O. D., TOC and VSS for a plant design of .580 mgd are:

Granular Carbon Absorption	
Capital Costs	$525,000.00
Operation & Maintenance	95.00/day

The use of a tertiary treatment process or processes is subject to many conditions, such as efficiency of the secondary process and the downstream requirements. Example, high suspended solids in the secondary effluent would require sand or multi-media filtration before absorption. The use of industrial waste water for water supply requires high contaminant removal.

Spray irrigation should be given consideration in March through June if there is an acceptable site.

(3) Gardner-Templeton Regional Plant

The present planned secondary treatment facilities will not provide for adequate B. O. D., C. O. D. or suspended solids removal nor will it provide for the adequate removal of nitrates and phosphates for water supply purposes.

The use of ion exchange treatment does not appear necessary; however, detailed metal analysis has not been performed to know the quality of the waste. The presence of cadmium in the Millers River

does indicate a source of this metal, probably from an industry within the city. This pollutant should be controlled at the source and not at the treatment plant.

The addition of advanced treatment would probably be based on a 4.0 mgd design with the removal of nitrogen, C.O.D., TOC, B.O.D. and suspended solids.

Estimated Costs are:

a) Nitrogen Removal

Capital Costs	$ 1,170,000.00
Operation & Maintenance	275.00/day

b) Carbon Absorption

Capital Costs	1,730,000.00
Operation & Maintenance	450.00/day

Here again the actual tertiary process will depend upon the analysis and the efficiency of the secondary effluent.

At the time of proposed engineering design, another review of the latest changes in advanced treatment design should be investigated. This field of technology is changing so rapidly that it is difficult to forecast the future design.

(4) Baldwinsville, Massachusetts

This section of the Town of Templeton is scheduled to be part of a Baldwinsville Products Company - Baldwinsville Treatment Plant to be operated by the Town. This arrangement may or may not come about. If they did not join together, the plant design would be based on a flow of about .250 mgd.

The addition of tertiary treatment would be nitrogen removal and Sand Filtration.

Probable Costs could be:

a) Nitrogen Removal

Capital Costs	$180,000.00
Operation & Maintenance	100.00/day

b) Sand Filtration

Capital Costs	$60,000.00
Operation & Maintenance	50.00/day

Should the final decision result in Baldwinsville going alone on treatment, then consideration should be given to spray irrigation during the time of any diversion. There are available large medium sand deposits in the area with very low ground water conditions. Such an irrigation system could operate throughout the spring and summer and early fall. This should be carefully considered should Baldwinsville choose to treat its own wastes separately.

(5) South Royalston

To protect the diversion water east of Athol from unnecessary added organic loads, the following additions to the Royalston extended aeration system secondary treatment facilities should be considered - Design flow .039 mgd.

(1) Stabilization Pond (100,000 gallons/min)

Capital Costs	$ 30,000.00
Operation and Maintenance	2.00/day

(2) Sand Filters (12,100 sq. ft.)

Capital Costs	70,000.00
Operation and Maintenance	5.00/day

(6) Winchendon

It appears that at this plant it will be necessary to install adequate filtration after secondary clarifiers. It is also likely that nitrate removal will be required by 1980.

Proposed Average Design Flow: .500 mgd
Cost of Proposed Advanced Waste Treatment
Nitrogen Removal

Capital Cost	320,000.00
Operation and Maintenance	175.00/day

The cost of rapid sand filter (.4 gallons per square foot per minute) should be included in the present design cost figure. The sand filter,

however, must be 4 feet above the elevation of the Millers River when the river flow is at 1200 cfs.

Sand Filtration

Capital Costs	$ 90,000.00
Operation & Maintenance	75.00/day

Also, raw sewage lagoons should be available to provide 48 hours of design storage in case of plant failure.

F. Future Water Quality Studies Required

Once the secondary plants are in operation, further testing will be required to design the advanced waste treatment facilities. Also, in order to determine what effect the existing sludge deposits will have on the water quality, additional sampling of the sludge banks should be accomplished. The depth of the sludges in the river must be approximated along with this analysis of oxygen demand and heavy metals present. The study to measure the depth and volume of sludge deposits in the Otter River from Seaman Paper Company to the confluence with the Millers, a distance of about four miles is estimated to cost $5,000.

After all treatment plants are in operation and the river has stabilized, only a permanent monitoring station would be required about a mile upstream of the diversion site. Measurements probably should be taken on turbidity, temperature and carbon chloroform extract which would provide a relative measure of the pollution load. Also, samples could be taken daily during the diversion period and weekly for the rest of the year on the Millers River, a half mile downstream of the confluence of the Otter River. Standard physical-chemical analysis, which includes turbidity, specific conduct, true color, NO_3, PO_4, alkalinity, hardness, iron Mn, NH_3, chlorides, BOD, COD, DO, TOC, sulfenants, suspended solids, phenols, sulfate, Al, tetanium and potassium probably would be performed on these samples. Also, pesticides, herbicides and bacteriological analysis should be performed. This program will provide a valuable index of the Millers River water quality and provide safeguards for use of the river as a supply source.

G. Water Requirements at Quabbin

The present water quality in Quabbin Reservoir is excellent. The pH is around 7.0, nitrates remain at about 0.20 mg/l, phosphates 0.16 mg/l, alkalinity 6 to 8 mg/l, hardness 10-15 mg/l, iron 0.05 mg/l, manganese 0.01 mg/l, chloride 5 mg/l, color about 6 units and turbidity is less than 1. This quality reflects the natural background chemical quality of the controlled watershed with some subsidence due to detention within Quabbin.

This natural "treatment plant" capacity will be used to improve the Millers River water quality as well as water diverted from the Connecticut River at the Northfield Mountain Pumped Storage Project.[1] However, care must be taken not to overtax this capacity. With existing information and the state of the act, the exact ecological balance within the reservoir is not known. If this balance is upset, the water quality could deteriorate especially if the hypolimnion zone loses its oxygen. Under these conditions, iron and mangananese would enter into solution. Also sulfates would be reduced to hydrogen sulfide gas causing odor and taste problems. However, it is felt that with this advance treatment of point sources the chances of any problems developing is very small. Once the reaction of the river to this advanced treatment is known, then a better prediction of the effects on Quabbin Reservoir can be made. In addition if for some reason problems develop, additional action could be undertaken. For example, further treatment of the water could be performed either at the pollution source or at the water supply intake or perhaps the tunnel could be extended to the West Branch of Quabbin Reservoir to provide better dilution.

H. Watershed Management

The use of the Millers River as a water supply source must be based on the sensible use of the watershed to maintain a quality of water that will not require treatment before entering Quabbin Reservoir. Also, measures should be taken to prevent accidents which could endanger public health. This would essentially take the form of not allowing discharge of untreated wastewaters into the river and controlling the discharge of unusual chemicals into the municipal sewer.

I. Discussion and Conclusions

The small number of polluting sources on the Millers River make it possible to establish a water pollution control program that will insure a good quality water for diversion to Quabbin Reservoir. The point sources of pollution are basically the city of Gardner, the

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[1] Subject of a companion report

towns of Templeton, Baldwinsville and Winchendon, and two papers. The largest contributors to the pollution load are the two paper mills. The river has large areas of sludge deposits along its course which during high flows are partially carried downstream.

Final approval of diversion of water from the Millers River is not possible until the treatment plants have been installed and are in full operation, and the results of the analysis are available. Once the river's chemical and organic load is minimized, the river through high flows and assimilation will greatly improve hopefully nearly reaching its background quality. It is assumed that 3-5 years after full treatment and safeguards are built into the waste treatment plants, that enough flushing will occur to wash away the large amounts of sludge in the Millers and Otter Rivers resulting in a relatively stable water quality.

It is essential to reduce the BOD, COD, TOC, suspended solids, turbidity and nitrates to a minimum before diversion to Quabbin. The O_2 demand must be kept to a minimum (estimated 10-15 mg/l) and the diverted water discharged in such a manner to provide good dilution, mixing and storage time.

The diversion of water from the Millers can occur when assurance of a good quality water is consistently available, which can be accomplished with the proposed plan, but it will take time. And time is something we may not have.

3. Diversions from Millers River Tributaries

A. Description of Proposed Diversions

The Tully[1] Complex Diversion, or Alternative No. 3, would divert water from four tributaries of the Millers River; namely, Tarbell and Priest Brooks and the East and West Branches of the Tully River, to Quabbin Reservoir as an additional water supply source. Estimated yield from this diversion is 48 mgd or some 17.5 billion gallons on an average annual basis. Diversions from this 114 square miles of drainage area would occur only during times of high flow (over 17,000 cfs flow at the Montague City U. S. G. S. gage and over the control flows at each diversion site).

B. General Watershed Description

The watershed consists of a general forested area made up of about 50% hardwoods and 50% softwoods. There are many areas of swamp on each individual watershed of the four streams. These swamps with their decaying organic matter add to the color observed in these waters.

The terrain is generally hilly. In the early to middle 1800's, farming was predominant. However, land on the watershed is not suitable for continued farming or expansion of farming. The growing season is basically 30 or more days shorter than in the Connecticut Valley. Therefore, the trend has been for farming to move towards the Connecticut River.

Records show an abundance of snow; and during the summer, ample rainfall with annual run-off of 22± inches.

Spring run-off is rapid due to the shallow soil zones. In the past, farms used considerable amounts of commercial fertilizers (N. P. K.) and manure. Presently, farming is on the decline, thus the amount of nitrates and phosphates lost from farm land during rapid run-off would not contribute significantly to the nutrient load in the streams.

The reduced farming and general population activity of the region lends itself to a minimum of erosion. The heavy forested area with ample

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[1] As described earlier, Alternative No. 2 would utilize flow from both the Millers and East Branch Tully Rivers. Water quality and necessary treatment facilities are described in the previous section. Water quality of the East Branch Tully River component of Alternative No. 2 is included in this section.

cover of humus and litter and underbrush all add to the reduction in water movement velocities. The region's characteristics account for the low turbidities in the four streams in the Tully Complex.

C. Water Quality Studies

The water quality studies conducted prior to 1971 were limited in scope. Studies involving the physical and chemical properties of the Tully Complex waters were limited basically to summer analysis from June through late September. Since the water to be diverted from the Tully Complex System would generally occur in high run-off periods generally in the spring, quality of this water was unknown during this period.

The Army Corps of Engineers in December 1970, initiated a contract[1] with New England Research, Worcester, Massachusetts. This study involves chemical, physical, bacteriological and zoological studies on these streams as well as analysis of stations on the Millers and Connecticut Rivers.

Additional studies were conducted on the Tully Complex streams from April through June 7, 1971. These studies were carried out by the Metropolitan District Commission, Water Division, with laboratory facilities at Belchertown, Massachusetts, Metropolitan District Commission, Construction Division, and the Environmental Protection Agency laboratory at Needham Heights, Massachusetts. The analysis involved turbidity, color, chlorides, alkalinity, hardness, pH, temperature, total and fixed residue, Fe, Mn and Specific Conductance. The purpose was to get some data of these streams at the time of diversion.

The results of a study by New Hampshire Water Pollution Commission in 1961 on the Millers Watershed including the East Branch Tully, Lawrence, Priest and Tarbell Rivers in the state of New Hampshire, found that a few individual homes were involved in pollution of some feeder streams of the Lawrence and Priest Brooks. There were a total of 24 homes involved in pollution of the streams. In each case, New Hampshire estimated (1961) that the cost of correction for 24 homes was $8,600.00. Based on 1971 construction costs would amount to about $20,000.00. These few individual domestic waste disposal systems that may be over-flowing into the river are a minor problem and can easily be corrected at the individual level. The watershed area in New Hampshire is used chiefly for recreation and residential development.

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[1] See Appendix I.

Analysis done during the freshet season indicates that the waters are low in pH (4.8 - 5.3) and high in color (35 -80). Also, C.O.D. ranges from 19.0 - 23.3 mg/l and ammonia concentration to about .70 mg/l.

These high concentrations are not the result of industrial or man-made pollution. It indicates that the cause is the upstream swamps where the drainage from these areas has undergone considerable decomposition and leaching. Thus, some of the products from decomposition of organics are in the form of carbon and ammonia.

The chemical analysis reflects the natural background of the water. The small upstream individual homes that are adding pollution to the watershed would not be reflected in the chemical analysis at the points of sampling because of the small volumes involved.

The waters of the Tarbell, Priest, Lawrence and East Branch Tully are, in general, relatively the same in chemical analysis. The soils in their watersheds are generally glacial tills. The depths of the saturated zones are limited and the base flows of these streams are low. Thus the water quality is lower in reference to color and organics.

The West Branch Tully River watershed comprises about 14 square miles. The soil consists of unconsolidated alluvial deposits. Although the slope of this stream is greater per mile than other streams in this complex, the water quality is excellent in reference to color, alkalinity, pH and C.O.D. Coliforms are generally lower in total numbers.

The Tully Complex System, consisting of Tarbell Brook, Priest Brook, Lawrence Brook, and East and West Branches of the Tully River, has a water quality similar to that of Quabbin Reservoir feeder streams. The watershed area is sparsely populated with little commercial or industrial activity and the analysis indicates the natural background chemical quality.

D. Water Quality at Storage Sites

On November 8, 1971, water samples were collected for color and pH at several points on the Priest Brook water course. The feeder streams to Priest, such as Towne Brook, have a color of 120 and pH of 4.7. Scott Brook at the northern end of the Priest Brook system has a color of 120 and a pH of 5.3.

The resultant water at the proposed dam site of Winchendon Road has a color of 120 and a pH of 5.3.

Also on November 8, 1971, water samples were collected on the East Branch Tully at Warwick Road. The color was 70 with a pH of 5.5. A sample taken at the outlet of Tully Lake on the East Branch Tully shows a color of 140 and a pH of 5.6.

It is estimated that the color of water entering Quabbin from the Tully Complex would be a maximum of 80.

The theoretical color at Shaft 12 based on complete mixing is estimated to be 15 ± units including the addition of the Northfield Mountain Water Supply Project with a color of 30 discharging to the Middle Branch.

Based only on Tully water, the estimate is about 15 - 20 at Shaft 12. All these estimates are based on complete mixing without short-circuiting. Therefore, the margin of maximum color acceptance in the finished water is too narrow to approve a single discharge for the Northfield Mountain Water Supply Project or the use of Tully Lake to store water from East Branch Tully River and Lawrence Brook, and the diverted waters from Priest and Tarbell Brooks without changes in the storage basins proposed in the various tributaries.

In the case of Tully Lake, the color increased at the outlet is as follows:

Date	Color Units	pH
05/10/71	47	6.0
05/17/71	60	5.8
05/24/71	80	5.9
06/07/71	90	6.2
11/08/71	140	5.6

Tully Lake is located in a swampy area of the East Branch Tully River. The area was flooded to an elevation that inundated large areas of vegetation. This dead vegetation and much of decaying debris remains in the Lake. The organic materials of the swamp and the added material from dead and decaying vegetation has resulted in the increase in color and may have caused a complete loss of oxygen in the stratified regions of the Lake and during the winter months.

The building of any Lake of the size of Priest Brook Lake which would flood the "Priest Brook Valley" would result in a rapid increase in color and decrease in oxygen.

The Tully Lake shows a build-up of color of 64% in five months. Considering an equal build-up of color of 15% per month in the Priest Lake, than in five months, the color of 120 units water could be about 200 units after storage. Assuming the storage time would be less and the leaching of organics greater in the Priest Lake, then the removal of all organic soils in the flooding zone is necessary.

The scheme of diversion to Tully Lake, therefore, will result in a lowering of the water quality unless the retention lakes - Tully and Priest - are cleaned of the organic material to the flow-line.

E. Water Requirements at Quabbin

The physical and chemical analysis of these waters determines that no treatment will be required prior to the entrance of this water into Quabbin Reservoir at any northern point in the reservoir, either the middle or west arms.

There will be no need to continue bacteriological and chemical analysis on these streams as long as the activity in the watershed does not change.

The analysis indicates a natural background chemical quality which can be expected to continue as long as the present activity on the watershed remains stable.

At the proposed time of diversion, a monitoring program should be started with weekly samples collected and analyzed during the times of diversion and throughout the flow period in the streams and Quabbin Reservoir.

F. Watershed Management Plan

The use of Tully Complex waters must be based on the sensible use of the watershed to maintain a quality of water that will not require treatment before Quabbin Reservoir. The installation of a treatment plant cannot be justified in cost and the short operational time. It is, therefore, necessary to maintain the high Quabbin quality with mixing and dilution which will result in the loss of identity of the river water in Quabbin Reservoir. The use of Quabbin as the polishing plant for the

water must be based on an incoming water of at least a Class B quality with low biological and chemical demands. The present quality of the Tully waters is well within this classification. Analysis to date indicates a Class A water. Problems would arise only without any watershed control.

G. Discussion and Conclusions

The Tully Complex watershed is a sparsely settled area involving about 114 square miles. The area is heavily forested, with soils, in general, consisting of glacial till. The brooks and river water course contain large areas of top soil washed in the valleys over the centuries. These areas have become marshy and swampy. The movement of water by seepage or direct run-off leaches much of the vegetative material and brings this material into solution. The results of this action cause highly colored water. The composition of the organic material increases the C.O.D. and nitrogen and ammonia. The low pH is probably caused by the uptake of CO_2 from the bacteriological activity within the heavy organic deposits, along these river courses.

The waters of this complex are similar to the waters of the middle branch feeder streams in Quabbin Reservoir, including the high color and low pH values.

The waters of the Tully system are acceptable for drinking purposes after their "treatment" within Quabbin Reservoir. The Tully Complex water quality shows a natural background quality very similar to that of the Ware and Quabbin feeder streams. As a single region diversion, the point of discharge from the Tully Complex can be accomplished at any point in the northern area of the middle branch of Quabbin.

In order to protect the water quality of the diverted water, the flooded areas behind Priest and Tully Dams would have to be stripped of all organic matter.

APPENDIX H

RECREATION

This appendix describes the recreation opportunities presented by each of the Millers River Basin alternatives. This includes the potential on the Millers River, such as full attainment of recreational activities and enhancement of the fish and wildlife habitat. Also, the pools that would be formed if Alternative No. 3 was implemented are discussed. Utilizing this data, the recreation benefits of each alternative were developed and presented in the Project Impact Analysis section of the main report.

APPENDIX H

RECREATION

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APPENDIX H

RECREATION

1. General

Recreation and other related opportunities were investigated for each of the Millers River Basin alternatives. The descriptions of the opportunities presented in the following paragraphs were derived based on discussions with the Massachusetts Department of Natural Resources, Fish and Game Division, and the U. S. Fish and Wildlife Service. Detailed investigations of any of the opportunities would be conducted following selection and authorization of the most advantageous alternative. The information contained in this Appendix, therefore, is not intended to provide design detail data, but rather to demonstrate various options which exist for the alternative projects.

2. Factors Influencing Recreation Development of the Millers River Basin

A. Features of Region Served

The basin is located in north-central Massachusetts and southwestern New Hampshire. Highway access to the watershed from all sections of New England and eastern New York State is excellent. Over five million people are within a two hour drive, including the populations of the metropolitan areas of Pittsfield, Springfield, Worcester, Lowell and Boston, Massachusetts; Providence, Rhode Island; and Hartford, Connecticut.

In contrast to the urban areas of eastern and southern Massachusetts, the western region of the State is relatively unspoiled. The area is scattered with small settlements typical of the early New England type, situated in the rolling foothills of the Wachusett Mountain range.

Tourism in the area is a year round industry with summer and fall being the most predominant seasons. In recent years, many significant ski areas have been developed by both State and private organizations. Tourism is the third ranking industry in Massachusetts, showing a $1,065,000,000 expenditure annually (1970's) with approximately 325 million dollars coming from out-of-state visitors.

B. Population

The population in the immediate vicinity is mostly rural and widely scattered. Within a 10-mile radius of the Tully Dam and Lake, there are only some 36,000 people and the population has remained about constant for the last 10 years. Within 50 miles of the project, the population has increased to over 1,000,000 people in 1970.

C. Existing Public Recreation Areas

Plate No. H-1 illustrates the number and location of public recreation areas within a 50-mile radius of the Tully Dam and Lake. A listing of the areas with the 1972 visitation and the facilities offered is contained on that plate.

D. Interest in Public Use

For a number of years, there has been much public interest in recreational development of the area. This interest has emanated from individuals, civic groups, Governmental bodies and political offices. The Massachusetts Department of Natural Resources has stated it feels that development of the Tully Reservoir will offer an excellent addition to the public recreation program in Massachusetts.

E. Anticipated Public Use

Developed recreation areas in Massachusetts and the Northeast have experienced ever-increasing use pressures in the past 20 years. All indications point to a continuation of this trend due basically to the population increase with 25% of the nation's population residing in the Northeast and a projected increase of 17% in the period 1960 to 1976 (ORRRC. Study Report 23). Other factors are the increases in availability, leisure time, and income. Adequate development of the Millers River Basin resources would provide a large degree of recreation opportunities to meet such future demands.

3. Millers and Otter Rivers

Presently, the Otter River and reaches of the Millers River are grossly polluted. Industrial and domestic waste discharges to the Otter River greatly exceed the assimilative capacity of the Otter River and degrade the Millers River as well. Existing stream classifications in the Millers River downstream from the confluence of the Otter River

include various large reaches of U (unsatisfactory) D and C water quality. Within the Otter River, the entire river with the exception of a small headwater reach is classified a U water quality.

At present then water quality in the Millers and Otter Rivers is unsuitable for most water-related uses and activities. Water quality studies conducted as part of this report plus reports prepared by State agencies and university students document the critical impact which the existing pollution loads have had on the river's eco-system.

The State Water Pollution Control Agency, in conjunction with the Environmental Protection Agency, has established an implementation schedule for pollution abatement in the basin. At present, this implementation schedule requires secondary treatment levels on all point sources of pollution in the basin by 1975. Installation and operation of these plants is expected to greatly enhance the river's water quality.

Following implementation of secondary treatment, water quality in much of the Millers River itself is expected to be Class B. These Class B river reaches are defined, among other uses, as suitable for bathing and recreational purposes including water contact sports, excellent fish and wildlife habitat and aesthetic value. A substantial portion of the river thus will be available for a wide range of water-related activities.

Even after the secondary treatment levels are in effect, however, some reaches of the Millers River mainstem are expected to be Class C. Class C water quality uses are partially defined as suitable for recreational boating, habitat for wildlife and common food and game fishes indigenous to the region and good aesthetic value. In addition, large reaches of the Otter River are expected to be Class C water. The majority of the Otter River, however, is classified as Class D water. Class D water is the lowest quality category in the adopted Massachusetts water quality standards and is not considered suitable for recreational pursuits nor fish and wildlife habitats.

Full attainment of recreational activities and enhancement of the fish and wildlife habitat thus will not be achieved under the present pollution abatement schedule. A measure of these lost opportunities is given in the statistic that about 14 river miles are categorized as Class C and D in the basin, even after present pollution abatement schedules are met.

Full measurement of all opportunity losses associated with the lower water classifications are, of course, difficult to quantify. For example, the environmental benefits from visual enjoyment of the river are

non-definable. On the other hand, potential recreation usage for these river reaches is given suitable water quality, estimated to total about 6,000[1] recreation days per season.

In anticipation of the presently planned pollution abatement, the Commonwealth of Massachusetts has purchased considerable land along the Millers River including additions to the Otter River State Forest and some 3-1/2 miles of the river bank along the Millers between South Royalston and Athol. This river bank land, shown on Plate No. H-2 is managed by the Division of Fisheries and Game providing public access to the river. Full use of this stream bank acquisition program and subsequent stocking and fishing activities are hindered by the C and D class water which will exist following planned pollution abatement programs.

Two of the three diversion proposals investigated in this report include provision of advanced waste treatment facilities on point sources of pollution. Based on data collected, it is felt that these advanced waste treatment facilities would be necessary to insure a good quality and safe water supply. Construction and operation of these plants which would be in addition to planned secondary level plants will enhance water quality throughout the entire Millers and Otter Rivers reaches. Information on the exact improvement in water quality parameters cannot be defined in this planning stage study. However, a definite enhancement of water quality would follow installation of the advanced treatment facilities. This environmental enhancement in the Millers River Basin would be a definite long-term benefit occasioned by adoption of either Alternative No. 1 or 2.

The recently enacted Water Quality Act of 1972 establishes as a national goal the elimination of pollutant discharge into navigable waters by 1985. Under this Act, the river reaches classified as C and D would be upgraded. It is anticipated, however, that attainment of these goals by the desired date may be difficult. Establishment of priorities and distribution of available monies will play a major role in the Millers River Basin water quality in the 1980's. The potential of using the river flow as a supply source for a major metropolitan area would undoubtedly contribute to the establishment of a higher priority for the Millers. Thus, although attainment of a high quality water in all of our nation's

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[1] Based on data extrapolated from Comprehensive Water and Related Land Resources Investigation, Connecticut River Basin, Connecticut River Basin Coordinating Committee, June 1970, Appendix H.

streams by 1985 is a national goal, the plans which would use the Millers for water supply should act as further assurance that the goals will be timely met.

4. Tributary Development

A. Tully Lake

The recreation opportunities at Tully Lake formed by the Tully Dam have long been recognized; and in 1965, a Master Plan for Reservoir Development was prepared. The 1965 Master Plan will be reviewed and updated by the New England Division and the Department of Natural Resources. Changes to the original plan will be made as necessary, particularly in respect to design features to protect the water quality of the reservoir. Also, further studies will be made to determine the ultimate level of the conservation pool for recreational use while still retaining the necessary flood control capabilities of the reservoir. Following is a discussion of the recreation characteristics and potential of the Tully Reservoir.

1) Project Resources

a) Suitability of Reservoir for Recreational Use. The principal recreation potential of the project arises from its comparatively undisturbed rustic setting close to major arteries of transportation. The addition of a 300 to 600 acre summer conservation pool will greatly enhance the existing natural resources of the project and its potential to accommodate outdoor recreation users.

The small crop and pasture land together with the larger woodland area had a limited number of residences or other developments prior to construction of the project. Long Pond, a shallow natural pond, 42 acres in extent, had four cottages on its shores prior to development of the Tully Dam. The immediate shore line of the pond is now in Federal ownership.

The land areas of the reservoir, particularly those adjacent to the conservation pool, are ideally suited for recreational development.

The diversity of terrain features within and adjacent to the project area add greatly to the overall attractiveness of the project area to a wide variety of outdoor recreation pursuits. Two natural waterfall areas on tributary streams abut the project lands. Doanes Falls on Lawrence Brook just south of Doane Hill Road lies immediately east of the project boundary.

The second natural waterfall is located on Spirit Brook which flows into Long Pond from the east. Protection of these natural assets is necessary to insure retention of the natural character of the area. The scenic falls enhance the diversity of use potential both on and adjacent to public land.

The project is traversed by two hard-surfaced roads, Doane Hill Road, about a mile above the dam, and Warwick Road, 3 miles above the dam. North - south State Route 32 has been constructed on top of the dam and provides excellent access to the project. Route 2, the principal northern highway between Boston and western Massachusetts, and Route 202, a northeast - southwest route from Maine to Connecticut pass through Athol, about 4 miles south of the dam.

b) Fish and Wildlife Resources. Fish and game activities have been prevalent throughout the project lands and surrounding area. The Tully River is stocked annually by state authorities with brook, brown and rainbow trout. Conservation authorities advise that the stream is classified as good trout water. In addition, a considerable hunting activity for birds and small animals as well as deer takes place in the area. The project lies 4-1/2 miles west of the Birch Hill Reservoir, where a fish and wildlife management program has been established by the Fish and Game Division, Department of Natural Resources, Commonwealth of Massachusetts, under a license from the Secretary of the Army. Extension of this program to portions of the Tully Reservoir is a possibility.

Numerous wood roads and trails remaining from past cutting activity provide foot access for hunters and fishermen.

c) Forestry Resources. The forestry resources of the reservoir have been evaluated by the Department of Natural Resources. These resources are of major importance to the high aesthetic and recreational qualities of the reservoir. The Department has instituted silvacultural practices to maintain and improve the forestry resources. These practices include type surveys, pruning, thinning and selective harvest cuttings.

d) Other Resources. There are no significant archeological, historical or mineral resources existing within the reservoir limits.

2) Recreation Activity Opportunities

a) General. With adequate development, the Tully Reservoir will offer a very diverse recreational resource with provisions for a number of outdoor recreation activities. The type of areas proposed for the reservoir range from high density park type development to primitive campsites accessible by boat and foot. The reservoir has valuable natural scenic qualities and these will be preserved by concentration of facilities at the high density development areas. The General Development Potentials, as shown in the July 1965 Master Plan, are indicated on Plates No. H-3 and H-4. These potentials will be reassessed in a supplemental master plan study as previously mentioned. Design and construction of recreation facilities at the reservoir will be a joint venture of this Division and the Department of Natural Resources.

b) Land Allocation. There are 1300 acres of land and water area in Federal ownership within the reservoir area. Of that area, there is approximately 368 acres of open water surface consisting of the presently maintained summer conservation pool, Long Pond and Tully River. There is another 170 acres of swamp land and 150 acres of land in the vicinity of the dam reserved for project operation.

Of the remaining 612 acres of land area, there are 225 acres of land south of Doane Road on the shore of the permanent pool. This land has been tentatively allocated for three purposes: "Day Use Park Type Development;" the "Doane Falls Scenic Area;" and the "Primitive Picnic and Hiking Area." North of Doane Hill Road, up to and including the shoreline of Long Pond, there are 230 acres of land which have potential for an Overnight Tent Camping Area and 70 acres as a flat water canoeing and hiking reserve.

There are approximately 300 acres of land above Long Pond which will be left untouched for recreational development. The area will be open for small game hunting and fishing along the East Branch of the Tully River.

c) Plan of Improvement. Development of recreational facilities will be a joint venture between this Division and the Massachusetts Department of Natural Resources. On-site layout of the development and design features will be done jointly by both agencies.

3) Changes in Master Plan Because of Water Supply Use

In some cases, recreation and water supply uses are not compatible within a water body; but in this case, since diversion for water supply occurs primarily during the spring and the recreation use is during the summer months, they are compatible. Also, Tully Lake is not a terminal reservoir. Water has to pass through at least Quabbin Reservoir before it reaches any consumers. Still, to insure against any public health dangers, no diversion would occur from Tully Lake during the recreation season (15 June to 15 September).

With either Alternative No. 1 - Millers River Diversion or Alternative No. 2 - Tully-Millers Diversion, Tully Lake would not be affected. For Alternative No. 3 - Tully Complex Diversion, the recreation plan would be revised to reflect a change in pool height from elevation 641 to elevation 648 msl. This change would increase the surface area of the lake to 600 acres and make the recreation and water supply pools the same height. The type of development could remain the same, but the actual facilities would be relocated to take advantage of the larger pool. Plate No. H-5 shows the pool at elevation 648 msl. Recreation development could include a day-use park area with swimming facilities, Doane Falls scenic area, an overnight camping area, a canoe and hiking reserve and a primitive picnic and hiking area around this new pool.

B. Priest Brook

The operating procedure in Alternative No. 3 for water supply calls for the pool at Priest Brook, shown on Plate No. H-6, to be kept at its lowest possible level at all times. Water would only be stored temporarily in Priest Brook Dam until it could be transferred to Tully Lake. Therefore, during the recreation season, usually there would not be a pool. Also, to maintain the quality of the water, the reservoir area below Deland Road would be cleared, stripped and grubbed. Therefore, other recreation sites in the area would be more appealing, such as Otter River State Forest, Tully Lake and the Lake Denison Complex at the Birch Hill Dam. Some people mostly from the local area might use the area for snowmobiling, cross country skiing, hiking and nature study. Upstream from Deland Road, a small pool will be held for waterfowl. During the summer and fall, the main pool probably would be empty, so this low waterfowl pool could be operated, providing a habitat for migratory birds. Benefits from this pool are, however, only minor. Essentially, these uses of Priest Brook would be incidental to the water supply use.

C. Tarbell Brook and West Branch Tully River

Small pools (less than 30 acres) would be created behind the Tarbell Brook and West Branch Tully diversion works in Alternative No. 3 -- Tully Complex Diversion. This shallow lake type environment created would have some value for waterfowl. Also, at West Branch Tully River, some trout fishing would be provided since the pool is long and narrow. Because the pools are small and have little access, they have negligible recreation potential. They do, however, provide suitable habitat for waterfowl.

5. Quabbin Reservoir

Quabbin Reservoir on the Swift River, a tributary of the Connecticut, was created by two large earth dams and controls some 186 square miles of drainage area. The reservoir has a surface area of 39 square miles and a shoreline of about 175 miles. At present, recreational activities on the reservoir are limited. Under sanitary rules and regulations established by the Massachusetts Department of Public Health, bathing in the Metropolitan District Commission's storage and distribution reservoirs is prohibited.

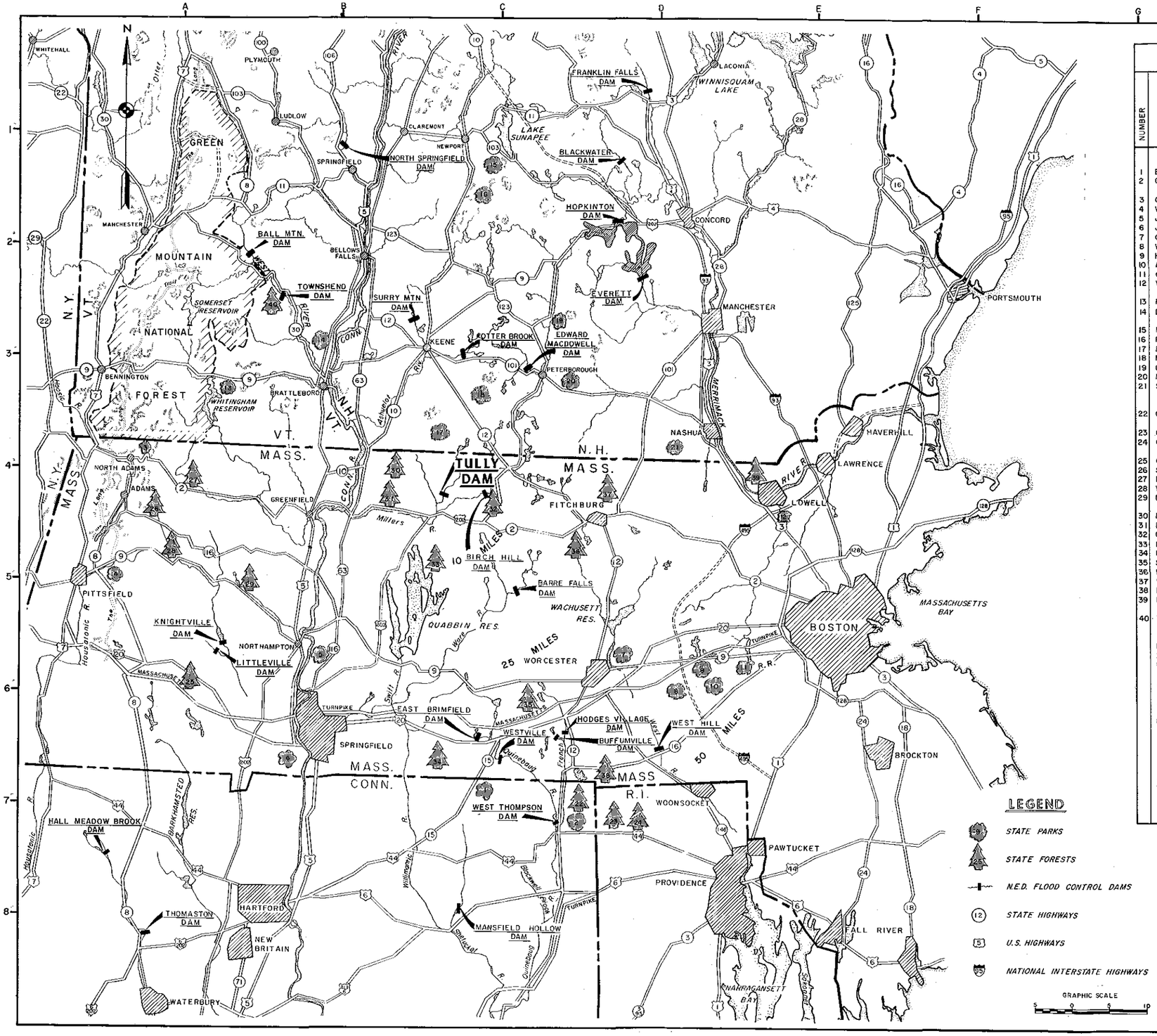
Recreation opportunities within the watershed include fishing, boating, hunting, and picnicking, all by permit only. For instance, in 1970, some 50,443 cars paid to park at Quabbin Reservoir.

Under special rules and regulations, the use of boats at Quabbin Reservoir for fishing purposes is permitted. Three boat mooring areas are maintained by the MDC on the reservoir, and outboard motor boats are rented during the fishing season. In addition, shore fishing is permitted on the reservoir from three locations. Although full attendance records at these controlled recreation locations are not maintained, the reservoir superintendent estimated that the facilities provided opportunities for 250,000 visitor days in 1971.

As the water supply demands increase on Quabbin, the long term trend will be for the pool level to drop. This drop in pool level is forecast to be accompanied by a decrease in water quality which would impair use of the reservoir for water supply as well as for the many existing recreational activities.

Recently, a number of fish and game clubs, watershed associations and other groups have requested that the reservoir and its watershed be opened further to recreational pursuits. In response to these requests, the MDC has stated that they are willing to consider specific proposals in conjunction with approval of the health authorities.

Any existing and future recreation opportunities, however, must depend on excellent water quality and wildlife habitat within the reservoir itself. As stated earlier, unless the reservoir's natural watershed is augmented, increasing water supply demands will diminish pool size and storage. This reservoir depletion, in turn, will lead to a degradation of the reservoir itself. Thus, the role which any of the three diversion alternatives would play in the recreational activities would be in their ability to prevent damage to the reservoir. This preventive action, in turn, will preclude loss of a major recreational center within western Massachusetts.



PUBLIC RECREATION AREAS
WITHIN 50 MILES OF TULLY RESERVOIR

NUMBER	TYPE OF AREA	INDEX	ATTENDANCE (1972)	FACILITIES PROVIDED: SWIMMING	BOATING	CAMPING	FISHING	HIKING	PICNICKING	SCENIC VIEWS	SKIING	HUNTING	ACREAGE
	STATE PARKS												
	CONNECTICUT												
1	BIGELOW HOLLOW	B-6	121,880		X		X		X				513
2	QUADDICK	B-7	123,375	X	X		X		X				118
	MASSACHUSETTS												
3	CLARKSBURG	A-3	28,368	X	X	X	X	X	X				366
4	WAHCONAH FALLS	A-4	650				X	X	X				47
5	J.A. SKINNER	A-6	59,015					X	X	X			375
6	J.C. ROBINSON	C-5	27,299	X			X	X	X	X			1086
7	QUINSIGAMOND	C-5	43,310	X		X	X	X	X	X			40
8	WHITEHALL	D-5	27,185		X		X	X		X			878
9	HOPKINTON	D-5	140,345		X		X	X		X			993
10	ASHLAND	D-5	41,035	X	X		X	X	X	X			593
11	COCHITUATE	D-5	159,182	X	X		X	X	X	X			1032
12	WARREN H. MANNING	D-4	6,603	X				X	X				N.A.
	VERMONT												
13	MOLLY STARK	A-3	15,779			X			X	X	X		158
14	DUTTON PINES	A-2	3,369						X				13
	NEW HAMPSHIRE												
15	MOUNT SUNAPEE	B-1	217,490	X			X	X	X	X	X		1784
16	PILLSBURY	B-1	5,481		X	X	X	X	X				3702
17	RHODODENDRON	B-3	4,323					X	X				294
18	MONADNOCK	B-3	70,772			X		X	X	X			699
19	GREENFIELD	C-2	115,672	X	X	X	X		X				85
20	MILLER	C-3	20,904					X	X	X			83
21	SILVER LAKE	D-3	65,000	X	X		X		X				82
	STATE FORESTS												
	CONNECTICUT												
22	QUADDICK	C-6	2,440	X	X		X	X	X				496
	RHODE ISLAND												
23	CASIMIR PULASKI MEM.	C-7	N.A.	X				X	X	X			100
24	GEORGE WASHINGTON MEM.	D-7	N.A.			X		X	X				244
	MASSACHUSETTS												
25	CHESTER BLANDFORD	A-5	3,384	X			X	X	X				2328
26	SAVOY MOUNTAIN	A-4	33,581	X	X	X	X	X	X				10705
27	MOHAWK TRAIL	A-4	72,597	X	/	X	X	X	X				6080
28	WINDSOR	A-4	10,728	X		X	X	X	X				1563
29	DAUGHTERS OF AMERICAN REVOLUTION	A-5	55,781	X	X	X	X	X	X				1280
30	MOUNT GRACE	B-4	19,899				X	X	X				1100
31	ERVING	B-4	99,692	X	X	X	X	X	X				5500
32	OTTER RIVER	C-4	41,697	X		X	X	X	X				714
33	MASS. FED. WOMENS CLUBS	B-4	9,491					X					1001
34	DEAN POND-BRIMFIELD	B-6	14,564	X			X	X	X	X		X	3079
35	SPENCER	C-6	32,350				X	X	X	X		X	776
36	LEOMINSTER	C-4	52,231	X			X	X	X	X		X	3518
37	WILLARD BROOK	C-4	81,352	X	/	X	X	X	X	X		X	2042
38	DOUGLAS	C-6	52,870	X	X		X	X	X	X			970
39	LOWELL-DRACUT	D-3	12,822					X					3879
	VERMONT												
40	TOWNSHEND	A-2	3,589			X		X	X				703
	N.E.D. RESERVOIRS												
	MASSACHUSETTS												
	BUFFUMVILLE	C-6	82,451	X	X		X	X	X			X	488
	KNIGHTVILLE	A-5	75,791				X	X	X	X		X	2430
	LITTLEVILLE	A-5	88,737		X		X	X	X	X		X	1612
	E. BRIMFIELD	B-6	231,862	X	X		X	X	X			X	2138
	WESTVILLE	C-6	104,082		X		X	X	X				578
	HODGES VILLAGE	C-6	53,578				X	X	X			X	873
	WEST HILL	D-6	123,799	X			X	X	X			X	614
	BARRE FALLS	C-5	64,474				X	X	X				557
	BIRCH HILL	C-4	204,673	X	X	X	X	X	X			X	4394
	VERMONT												
	BALL MOUNTAIN	A-2	54,788	X			X	X	X	X		X	965
	TOWNSHEND	A-2	88,474	X	X		X	X	X	X		X	1008
	NORTH SPRINGFIELD	B-1	39,891	X	X		X	X	X	X		X	1401
	NEW HAMPSHIRE												
	SURRY MOUNTAIN	B-2	148,916	X	X		X	X	X	X		X	1688
	OTTER BROOK	B-2	65,918	X	X		X	X	X	X		X	458
	EDWARD MACDOWELL	C-2	32,547		X		X	X	X			X	1194
	BLACKWATER	C-1	22,925				X	X	X			X	3604
	HOPKINTON-EVERETT	C-2	311,445	X	X		X	X	X	X		X	8083

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY RESERVOIR MASTER PLAN
PUBLIC RECREATION AREAS

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS

PLATE H-1

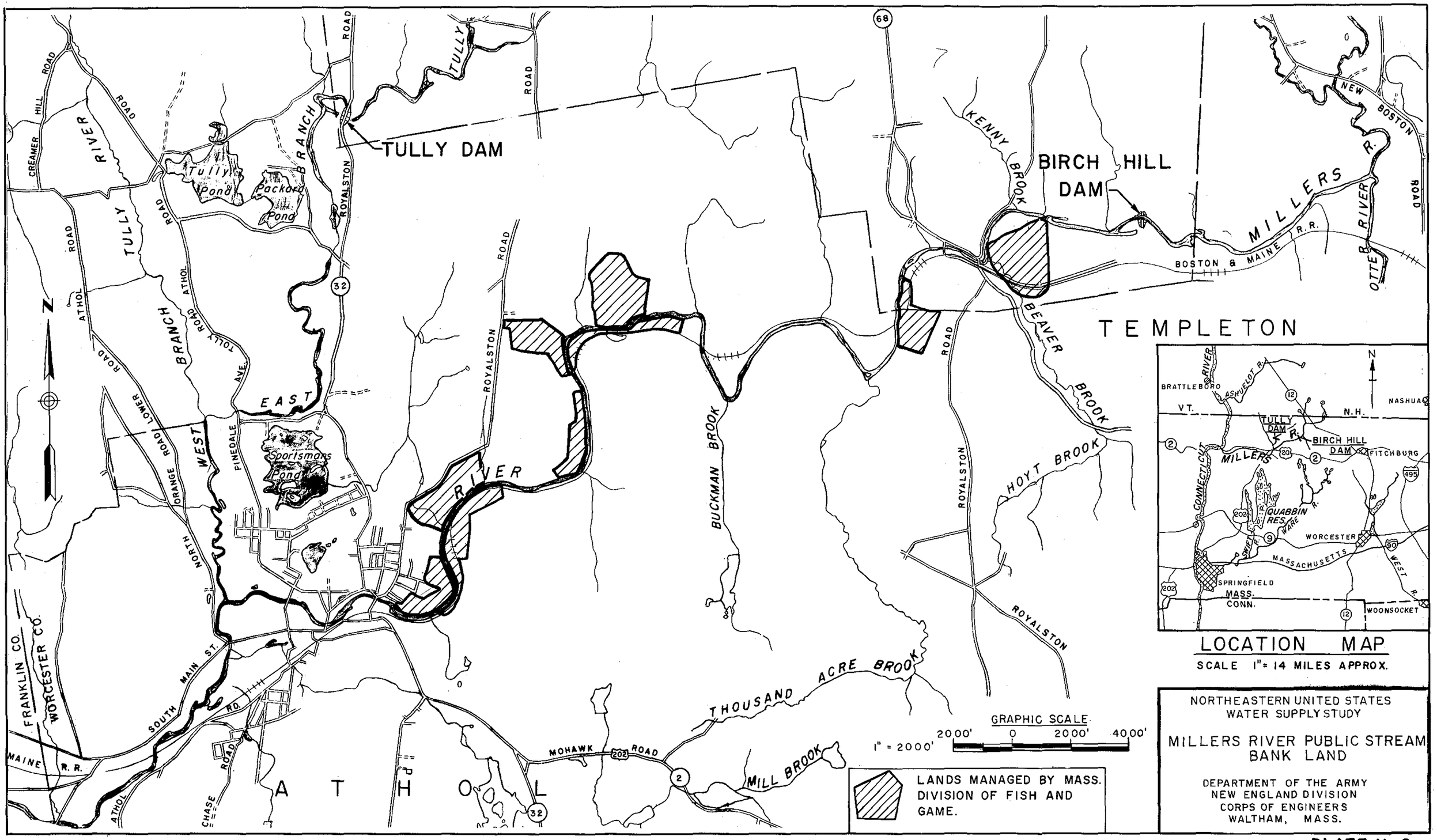
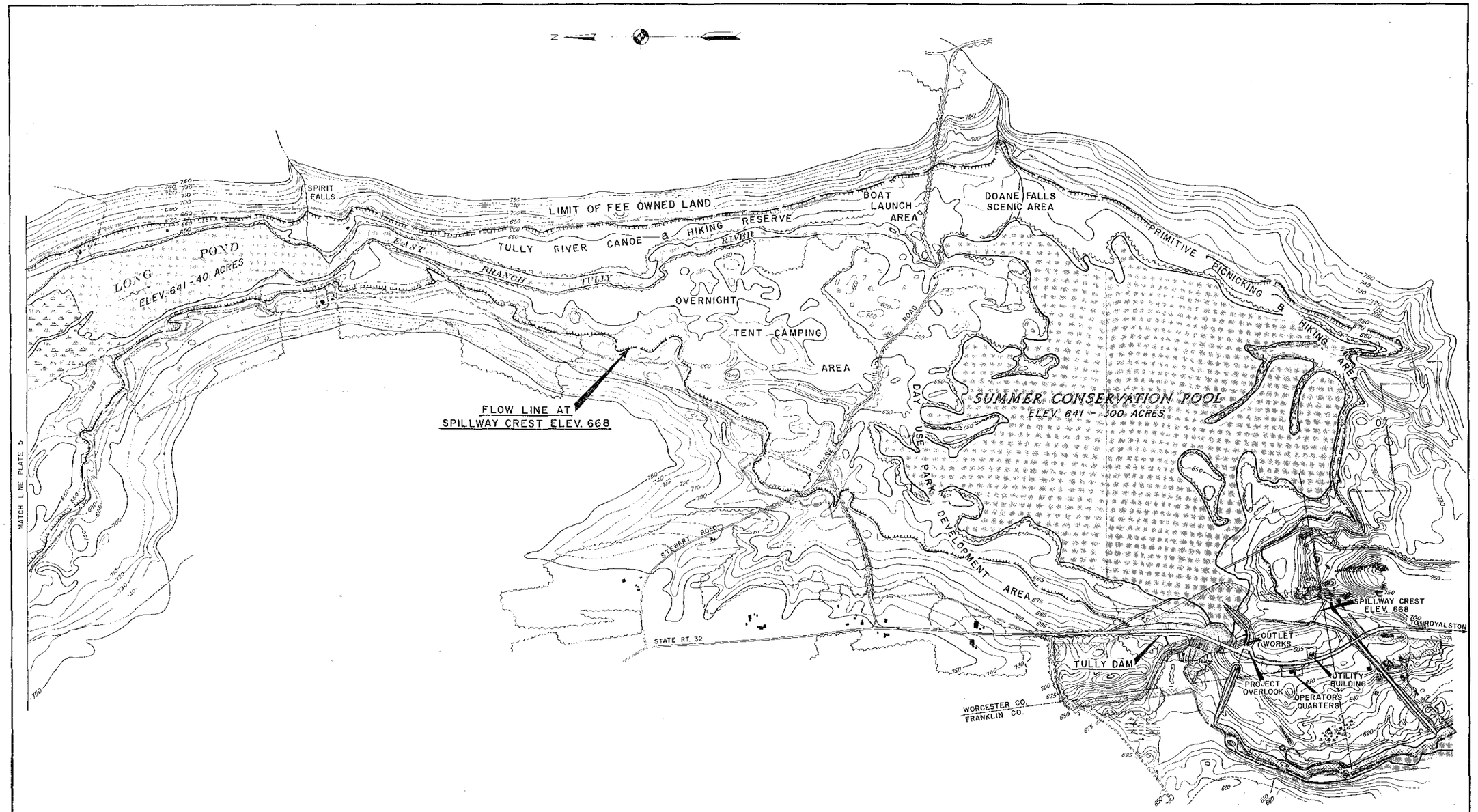

TULLY DAM
BIRCH HILL DAM
TEMPLETON
ATHOL
MILLERS RIVER
EAST BRANCH TULLY RIVER
WEST BRANCH TULLY RIVER
Tully Pond
Packard Pond
Sportsmans Pond
KENNY BROOK
BEAVER BROOK
BUCKMAN BROOK
HOYT BROOK
THOUSAND ACRE BROOK
MILL BROOK
OTTER RIVER
BOSTON & MAINE R.R.
NEW BOSTON ROAD
ROYALSTON ROAD
TULLY ROAD
CREAMER HILL ROAD
ATHOL ROAD
TOLLY ROAD
LOWER ROAD
ORANGE ROAD
PINEDALE AVE.
NORTH MAIN ST.
SOUTH MAIN ST.
CHASE ROAD
MOHAWK ROAD
FRANKLIN CO.
WORCESTER CO.
GRAPHIC SCALE
1" = 2000'
2000' 0 2000' 4000'
LANDS MANAGED BY MASS. DIVISION OF FISH AND GAME.
LOCATION MAP
SCALE 1" = 14 MILES APPROX.
BRATTLEBORO
VT.
N.H.
NASHUA
FITCHBURG
QUABBIN RES.
WORCESTER
MASSACHUSETTS
SPRINGFIELD
MASS.
CONN.
WOONSOCKET
CONNECTICUT RIVER
NORTHEASTERN UNITED STATES WATER SUPPLY STUDY
MILLERS RIVER PUBLIC STREAM BANK LAND
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE H-2



NOTE:

INDICATES AREA RESERVED FOR PROJECT OPERATIONS.

SCALE IN FEET

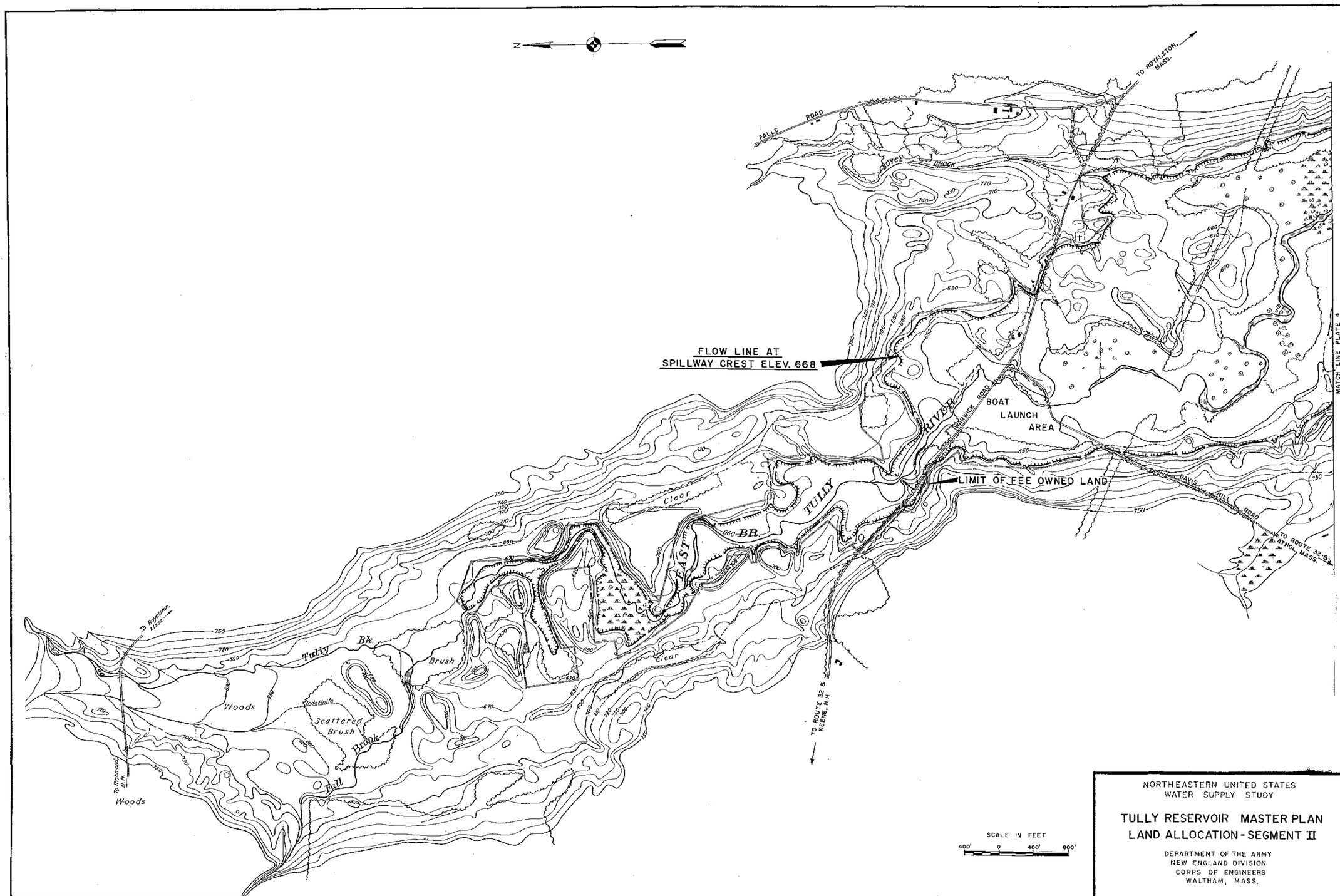
400' 0 400' 800'

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY RESERVOIR MASTER PLAN
LAND ALLOCATION - SEGMENT I

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE H-3



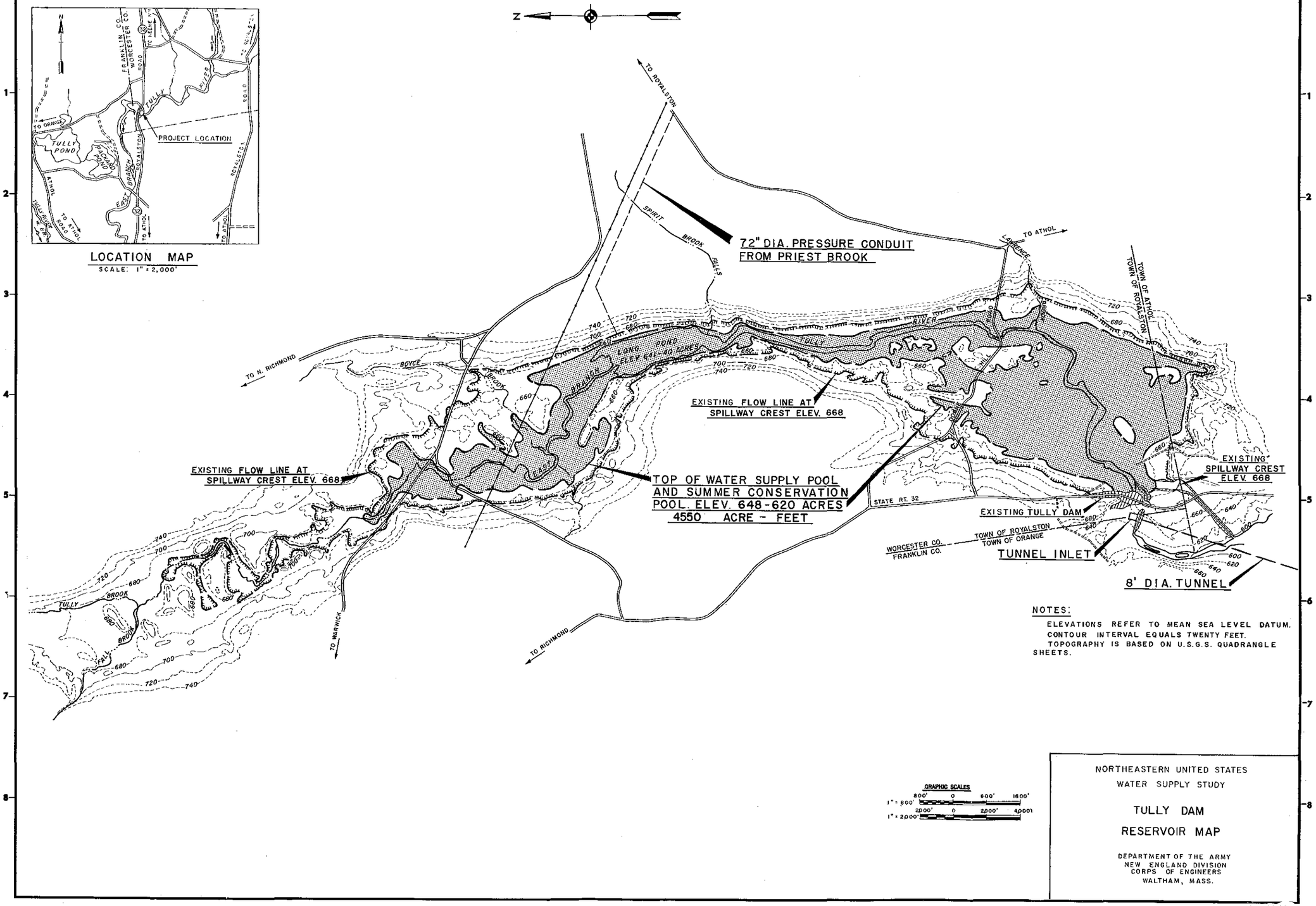
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY RESERVOIR MASTER PLAN
LAND ALLOCATION - SEGMENT II

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE H-4

CORPS OF ENGINEERS U. S ARMY



NOTES:

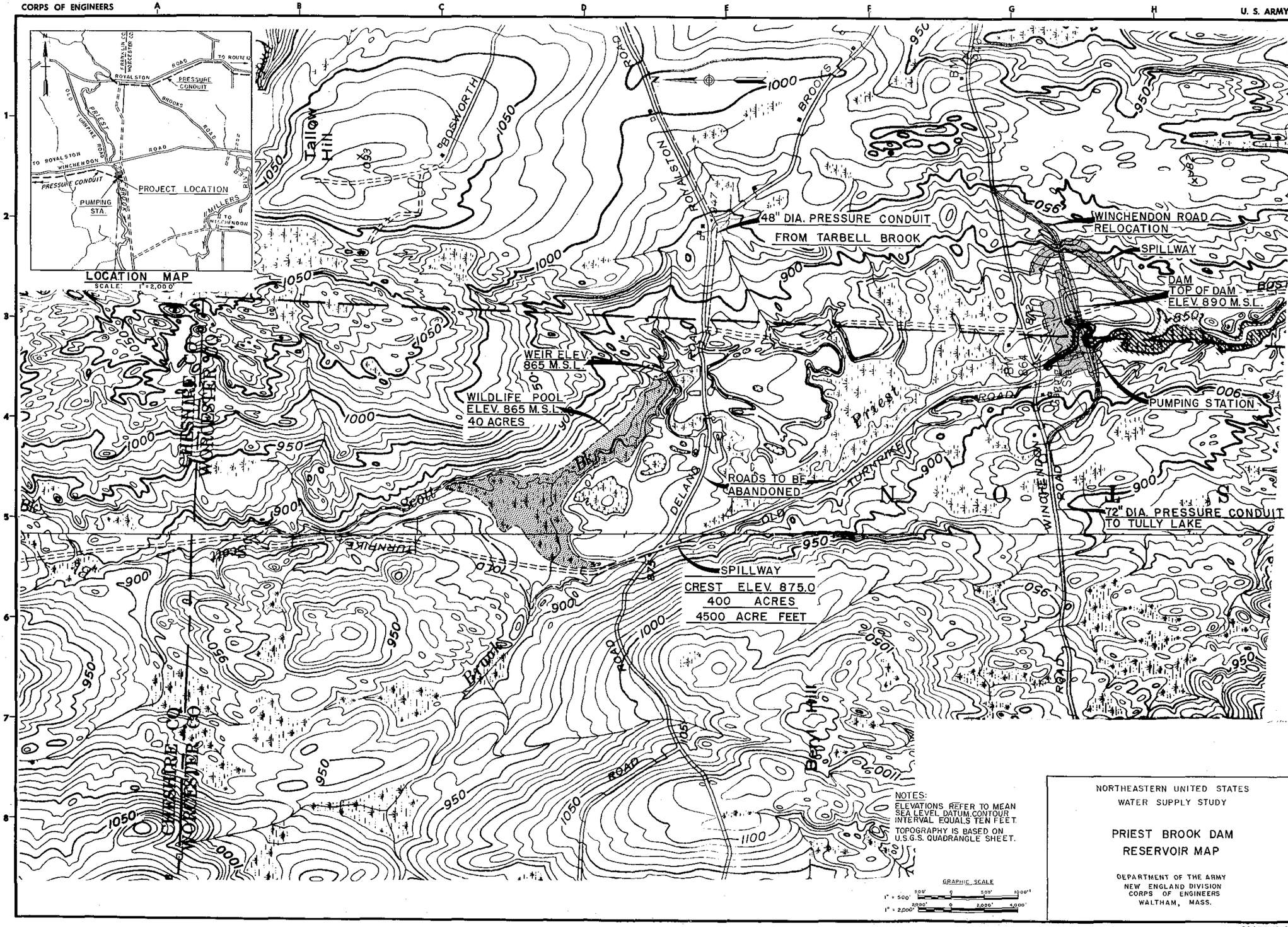
ELEVATIONS REFER TO MEAN SEA LEVEL DATUM.
CONTOUR INTERVAL EQUALS TWENTY FEET.
TOPOGRAPHY IS BASED ON U.S.G.S. QUADRANGLE SHEETS.

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

TULLY DAM
RESERVOIR MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

PLATE H-5



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY

PRIEST BROOK DAM
RESERVOIR MAP

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.