Sources and Movements of Water

An Interim Report
October 1973

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SOURCES AND MOVEMENT OF WATER
An Interim Report

Long Island Sound Regional Study
New England River Basins Commission
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New Haven, Connecticut 06511

Prepared by the
U.S. Geological Survey, Water Resources Division
and the
National Oceanic and Atmospheric Administration

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FOREWORD

Long Island Sound is one of the nation's unique and irreplaceable natural resources. An almost fully enclosed arm of the ocean, it has over 1300 square miles of water surface and nearly a thousand miles of coastline. Spreading eastward along both shores from the great metropolitan center which lies at the Sound's western end, a growing concentration of increasingly affluent people make ever greater demands on this urban sea. At the same time, there is a growing feeling that the conflicting demands are destroying the Sound, and that the problems must be resolved if the Sound is to be preserved.

The Long Island Sound Regional Study is a comprehensive planning effort by the federal government and New York and Connecticut, led by the New England River Basins Commission. Assisting the Commission are professionals from many disciplines representing the federal, state and regional agencies listed on the back cover, a Citizen Advisory Committee, and a Research/Planning Advisory Committee composed of members of the region's scientific community.

THE GOAL OF THE STUDY IS TO PRODUCE A PLAN OF ACTION BY JANUARY, 1975, WHICH BALANCES THE NEEDS TO PROTECT, CONSERVE AND WISELY DEVELOP THE SOUND AND ITS RELATED SHORELANDS AS A MAJOR ECONOMIC AND LIFE-ENRICHING RESOURCE FOR THE 12 MILLION PEOPLE WHO LIVE NEAR IT.

This interim report is one of a series which outline demands placed on the Sound, its capacity to supply these demands, and the present or expected deficiencies to be overcome if it is determined that supply should meet demand. The reports provide a base for developing single purpose management plans which will evaluate the environmental and socio-economic impacts of suggested alternative solutions and propose courses of action. These management plans will be integrated into a comprehensive multi-purpose plan of conservation and development, reflecting relationships between types of demands and setting forth goals and recommendations, the means for achieving them, and a schedule of priorities. Interim reports in the series include:

Sources and Movements of Water
Water Quality
Scenic and Cultural Resources
Mineral Resources and Mining
Soils
Erosion and Sedimentation
Ecological Studies

Water Supply
Recreation
Land Use and Ownership
Flood Plains
Electric Power Generation
Transportation

SUMMARY

PURPOSE OF THIS REPORT. To summarize present knowledge about the sources, distribution and movement of water in the Long Island Sound Region. Climatological factors such as temperature, wind and cloud cover that affect elements of the hydrologic system are also discussed.

HOW DOES WATER ENTER AND LEAVE THE SOUND?

Long Island Sound holds about 16,800 billion gallons of water---but much more than this amount moves in and out each year---estimated average quantities in billions of gallons a year (bgy) are:

	<u>IN</u>	<u>OUT</u>
Exchange with the ocean (east end)	64,000	79,800
Net Exchange through the East River (west end)	9,200	
Runoff from streams	6,200	
Precipitation on the Sound	800	
Evaporation from the Sound		630
Diversions into the region	130	
Ground-water outflow (Long Island)	100	

Many of these estimates rest on incomplete or poor data---more accurate quantification is needed for planning and management.

WHAT ARE THE PRINCIPAL CLIMATIC FEATURES?

The climate of the Long Island Sound Region is characterized by: four distinct seasons, little monthly variation in normal precipitation, marked temperature contrasts over short distances, and the maritime influence which modifies air masses entering the region---the climate may vary appreciably from one location to another and from one year to another---distinctive climate events such as hurricanes, tornadoes, droughts and blizzards occur in the region, resulting in floods, wind damage, crop failure, and even loss of life.

WHAT IS THE HYDROLOGIC SYSTEM IN THE REGION?

The Region has an abundant supply of fresh water derived from precipitation and from inflowing streams.---of the total precipitation falling on the land each year, about half returns to the atmosphere by evapotranspiration---the remainder ultimately discharges to streams and the Sound, either directly by overland flow or indirectly by downward percolation to the water table---some 75 streams drain into Long Island Sound---they are hydraulically connected to adjacent ground-water reservoirs and are tidal in their lower reaches--the Connecticut, Thames and Housatonic Rivers account for over 80 percent of total streamflow into the Sound---about 16,500 square miles of land drains into the Sound, only 12 percent of this area is within the study region---inflow is highest in the spring, lowest in the summer.

Long Island is underlain by a large ground-water reservoir of generally good quality---it meets almost all the Island's fresh water needs---the fresh and salty water systems are hydraulically connected on the surface and below it---the yield of the fresh ground-water reservoir is not a single fixed quantity; it will vary depending on hydrogeologic conditions, the management scheme, and the extent to which undesirable effects of development will be tolerated---the mainland on the north shore of the Sound is underlain by deposits of sand, gravel, silt and clay (stratified drift and till) and bedrock---the area contains many hydrologically separate ground-water reservoirs of generally good quality---large quantities of ground water may be pumped from wells tapping stratified-drift deposits whereas most individual domestic wells obtain adequate water from bedrock.

HOW DOES SALT WATER CIRCULATE WITHIN LONG ISLAND SOUND?

Long Island Sound is a 1,300 square mile water body with estuarine characteristics in its western and central parts and embayment characteristics in its eastern third---the minimum tidal range and maximum tidal currents occur at the eastern end and the maximum tidal range and minimum tidal currents at the western end---circulation is controlled principally by tidal currents modified by fresh-water inflow, weather conditions and topography---the circulation pattern of surface and near surface waters is fairly well defined, but relatively little is known about deep current circulation---surface tidal current patterns in the central and eastern Sound are elliptical and counter-clockwise in direction---at the eastern end, surface water flows into Block Island Sound, while more dense and saline bottom waters flow into Long Island Sound---at the western end, surface water from the East River flows into the Sound and bottom waters move into the East River---movement of water within major estuaries is complex because of the effects of tides and fresh-water inflow conditions---understanding this movement is important for water management.

WHAT WILL THE STUDY DO NEXT?

It will work on solutions in all management areas---information from this report and its supporting studies should be reflected in the solutions, especially for water quality, water supply and flooding---proposals will be made to resolve major knowledge gaps such as the quantification of the dynamic circulation system within the Sound and its major estuaries.

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1.0 INTRODUCTION

The purpose of this report is to summarize present knowledge about the sources, distribution and movement of water in the Long Island Sound Regional Study Area. Climatological factors such as temperature, wind and cloud cover that affect elements of the hydrologic system and in turn development patterns are also discussed.

Water sources, the quantity stored at any time above or below the ground, the pattern of water movement and water quality are of direct concern to a variety of interests within the region. Flood control, water supply, waste disposal, recreation, agriculture, transportation and power generation are some examples of activities that are water dependent or water related. Man-made changes in land use, such as urbanization, alter the natural hydrologic system and coordinated water and land use planning is therefore essential. Conversely, too little or too much water can limit development or require large costs to support growth.

The information in this report together with supporting studies and data listed in appendices A and C will be used in the plan formulation phase of this study. The scope of subsequent planning must take into consideration (1) the existing requirements, interrelationships and often conflicts between various groups of water users and how they will change with time and (2) the effect on the hydrologic system of alternative water and land use practices.

2.0 HYDROLOGIC FRAMEWORK OF THE LONG ISLAND SOUND REGION

Within the framework of the hydrologic cycle, water continually moves between and is temporarily stored in the atmosphere, on and below the land, and in the ocean. Water enters the Long Island Sound Region from (1) precipitation directly on the land or water within the region (2) as runoff from adjacent land areas that drain into the Sound (3) from Block Island Sound to the east and the East River to the west and (4) from sewage treatment plants that process water from outside of the Long Island Sound drainage area. Water leaves the region by (1) evaporation and transpiration into the atmosphere or (2) by outflow into Block Island Sound and perhaps into New York Harbor. This general pattern of circulation and the average quantities of water involved are shown on Figure 1.

The hydrologic conditions are largely governed by the climate within and adjacent to the region. Located between the source regions of warm moist air and of cold dry air places the study area near the principal west to east storm tracks. Furthermore, coastal storms originating in the ocean off the southeastern United States frequently travel on courses that bring them nearby.

* NET INFLOW FROM EAST RIVER OF 9,200 bgg may be significantly in error.

Figure 1. General pattern of water circulation and estimated average quantities of water involved in billions of gallons per year (bgg). Blocks drawn to scale. The water volume in the Sound itself is approximately 16,800 billion gallons.

Passing storms bring clouds, wind, rain and snow. Average annual precipitation in the Long Island Sound Region ranges from approximately 36 to 51 inches (1.7 to 2.4 million gallons per day per square mile) and has fairly equal monthly distribution. The minimum average annual precipitation over the land, 38 to 44 inches, occurs along the north shore of Long Island and the south shore of Connecticut between Norwalk and Guilford. The maximum over Long Island, 44 to 48 inches, occurs along an east-west axis centered near Lake Ronkonkoma, and in Connecticut, 46 to 51 inches, over

northern parts of the study area. Assuming the average annual precipitation is approximately 45 inches on the 1940 square miles of land and 36 inches on the Sound the Long Island Sound Region receives approximately 2,300 billion gallons of water each year in the form of rain and snow.

The precipitation that falls on the land under natural conditions is either returned to the atmosphere by evaporation and transpiration (evapotranspiration) or flows across the land and through subsurface materials to stream channels, estuaries and the Sound. The average annual evapotranspiration is approximately one half of the average annual precipitation. Almost all evapotranspiration occurs in the growing season (April through October) when plants use a large amount of water, temperatures are above freezing and hours of daylight are longest.

The water that is not evapotranspired either flows over the land surface, to streams (direct runoff) or infiltrates downward through the various earth materials eventually reaching the saturated zone. Most of the subsurface water in the saturated zone, termed ground water, moves toward and discharges into stream channels, estuaries and the ocean. The total fresh water runoff into Long Island Sound is the sum of the direct runoff and ground-water discharge from the entire Long Island Sound land drainage area of approximately 16,500 square miles. The average annual total runoff is approximately 6,200 billion gallons per year (bgp) or 5.5 cubic miles of water as computed by the U.S. Geological Survey.

The average annual runoff into Long Island Sound is almost three times as large as the average annual precipitation within the study region. Water quality, flood control and sedimentation are therefore significantly affected by natural events and man's activities in the large 14,500 square mile drainage area north of the region boundary.

Long Island contrasts sharply with the land on the north shore of the Sound in respect to the pattern of water circulation. Long Island is underlain by a wedge-shaped mass of unconsolidated sediments that rests on a gently southeast-sloping surface of relatively impermeable bedrock. The saturated zone beneath Long Island constitutes a large ground-water reservoir containing in excess of 60 trillion gallons of fresh ground water (5).¹ The fresh and salty ground water and fresh and salty surface water are hydraulically connected and Long Island both within and out of the study region is an integrated hydrologic system.

Because Long Island is relatively flat and the surface materials are permeable almost all the precipitation not consumed by evapotranspiration percolates down to the saturated zone. Only 5 to 10 percent of the streamflow consists of direct runoff and the ground water and surface drainage divides are not coincident. The ground water beneath Long Island is constantly moving vertically downward and horizontally toward the shores

¹ - Underlined numerals in parentheses are references in Appendix A.

from the ground-water drainage divide near the center of the island. About half of the ground-water discharge is subsurface outflow into Long Island Sound and the Atlantic Ocean, the rest is discharged to streams and springs or evapotranspired from the upper part of the saturated zone. Figure 2 shows the pattern of water circulation on Long Island under natural conditions.

Figure 2. Block diagram illustrating ground-water movement and discharge on Long Island, New York under natural conditions. After Cohen and others (1968 pl. 4F).

The land on the north shore of Long Island Sound is underlain by bedrock at relatively shallow depth. The surface is discontinuously covered by unconsolidated deposits composed of sand, gravel, silt and clay. Major surface-water and ground-water drainage divides are coincident and the area hydrologically consists of a number of separate ground-water reservoirs each drained by a perennial stream and extending from one drainage divide to another. The amount of water stored in and moving through the saturated zone varies in each basin because of differences in size and type and distribution of subsurface materials.

Direct runoff constitutes a high proportion of streamflow, principally because of the topography and relatively low permeability of much of the surface materials. Ground-water circulation is generally confined within delineated drainage basins and the direction of ground-water movement is away from the drainage divides and toward major streams and estuaries. Most ground-water discharge is to streams and where computed (4) ranges from 28 to 62 percent of the total annual runoff. A small amount of ground-water discharge in coastal areas is subsurface outflow into Long Island Sound. Figure 3 shows the general pattern of water circulation in a major drainage basin on the north shore of the Sound.

Figure 3. Idealized section illustrating ground-water movement and discharge on the north shore of Long Island Sound. After Cervione and others (1968, Fig. 33).

The direction of ground-water movement is shown by flow lines. Ground-water discharge consists of (1) seepage to streams and (2) ground-water evapotranspiration.

Long Island Sound is an approximately 1300 square mile embayment bounded on the south by Long Island and on the north by the New York and Connecticut shorelines. The eastern third may be thought of as an extension of the continental shelf, whereas the central and western parts are more analogous to an estuary. The eastern end of the Sound is generally considered to

extend from Watch Hill Point in Rhode Island to Orient Point on Long Island while the western boundary extends from Throgs Neck to Willets Point. Using a slightly different eastern boundary (extending from Orient Point, Long Island through Plum Island, to Race Point on Fishers Island and thence to Groton Long Point) the National Ocean Survey computed the volume of water in the Sound to be approximately 16,800 billion gallons or 15.4 cubic miles.

The average annual fresh water inflow as previously stated is approximately 6,200 billion gallons, equal to 37 percent of the total volume. Most of the fresh water inflow (80 percent or more) is into the eastern end of the Sound from the Connecticut and Thames Rivers. Assuming that the average annual precipitation is 36 inches, an additional 800 billion gallons a year of fresh water falls directly on the Sound.

Riley (29), Swanson (33), LeLacheur and Sammons (50) and others have described the general pattern of circulation. The dominant horizontal motions are the semidiurnal tidal currents; reversing currents occur along the coast while in central Long Island Sound the currents are elliptical. The mass transport pattern is the eastward movement of waters in the surface layer out of Long Island Sound and the westward movement of bottom waters into Long Island Sound from Block Island Sound (29). The volume of fresh water drainage controls the exchange and the annual total inflow of saline water along the bottom is equal to 3.8 times the volume of water in the Sound (29). Although the tidal circulation pattern of surface and near surface waters is known, relatively little information on deep current circulation is available.

Limited exchange of water is believed to occur between the western end of Long Island Sound and New York harbor. The net inflow from the East River into western Long Island Sound has been estimated to be as high as 1,100 cubic meters per second (9,200 billion gallons per year), but recent studies (11) indicate that this estimate may be too high by an order of magnitude. The only other outflow is evaporation from the Sound to the atmosphere estimated to be 630 billion gallons per year, slightly less than the precipitation on the Sound.

3.0 CLIMATOLOGY

The unique features of the climate of the area surrounding Long Island Sound are: four distinct seasons; a variety of precipitation types but with little monthly variation in normal precipitation amounts; marked temperature contrasts over short distances; and the maritime influence which modifies the air masses that affect the area. The climate varies from one location to another and from one year to another. There has been, for example, a winter season with only 10 inches of snow in the northern part of the region and another winter season with over 80 inches of snow in coastal Connecticut; a record daily maximum temperature at a northern location of 104°F and a record February minimum near the coast of -24°F; Octobers with almost no rainfall and a single October day in which nearly 10.5 inches of rain fell at one location.

3.1 Weather systems

In winter, polar-continental air dominates the region resulting in many clear, dry and bright days. Daily mean temperatures are generally below freezing from mid-December through early March except for a shorter period along the shore. Pacific air masses frequently reach the area during the winter resulting in somewhat higher temperatures and humidities. Occasionally tropical air reaches the Sound area in the winter. Because of its lower density the tropical air usually overrides the colder air from the north but at times it reaches the surface causing the well known "January thaw."

In summer, air from the Gulf of Mexico and the tropical Atlantic brings high temperature and humidity. In crossing the Sound from the southwest, this air mass may be cooled from below creating pollution-trapping inversions along the Connecticut shore. The hazy skies may clear up after midday if the inversion is destroyed, but when the sea breeze prevails or if the flow is more southerly stable conditions may remain into the evening and longer. Air of Pacific origin traveling eastward from the Canadian northwest brings bright skies and relief from haze and pollution associated with the tropical air.

North Atlantic source region air also reaches the area in the summer resulting in cooler temperatures and frequently steady light precipitation. Polar continental air, modified by intense solar heating, occasionally moves into the area in summer while hot dry continental air from Arizona and New Mexico infrequently reaches the area during this season. Spring and autumn are periods of transition characterized by rapid alternation of air masses and fast changes in weather patterns.

Winter storms frequently move into the region from the area near Cape Hatteras, N.C. During the remainder of the year storms develop further east and north over the Atlantic Ocean and further north over the Great Lakes. The period August through November is characterized by occasional tropical disturbances.

Air masses undergo temperature and humidity changes when they move over the Ocean and Sound, travel over snow covered ground or are lifted over hilly terrain. The presence of the Sound provides one of the major climatic controls for the area in that it acts as a vast reservoir for the storage and subsequent exchange of heat energy with the atmosphere.

3.2 Availability of climatological records

Reliable records date back to 1778 at New Haven, Connecticut and for shorter periods elsewhere in the Long Island Sound Regional Study Area. Comprehensive analysis of climatological data for selected time periods are available in: The Climate of Connecticut (3); The Precipitation Regime of Long Island, N.Y. (17); The Climatic Guide for New York City, N.Y. and Near-by Areas (46); and Climates of the States, New York (47).

Climatological records for existing stations in and near the study area are published each month by the National Weather Service (18). Short and long-period weather forecasts for the area are regularly furnished by offices of the National Weather Service in New York City, N.Y., Windsor Locks, Conn. and Bridgeport, Conn.

As part of the Long Island Sound Regional Study, the climatological data for the period 1951-1970 together with selected long-period information was inventoried and analyzed by the National Weather Service. Most data was obtained from the archives of the National Climatic Center, Asheville, North Carolina. The existing records are of good quality and areal distribution, except for the area directly over Long Island Sound. Records from all stations in New England and parts of eastern New York were used to evaluate monthly and water year¹ precipitation, whereas the balance of the climatological analyses are based on data from 15 stations supplemented where necessary by additional stations. The locations of the principal and supplementary stations are shown in Appendix D.

Approximately 100 tables, graphs and maps prepared for the Long Island Sound Regional Study are listed in Appendix C of this report. They depict averages, extremes, ranges and variability in time and space of climatic events or contain statistics on frequency, variability and probability. Because of the scope of available information only brief descriptions of specific climatic phenomena are contained in this report. Therefore, in the sections that follow the objective is to apprise the report user of what information is available on specific topics such as temperature and precipitation.

3.3 Temperature

The mean annual temperatures generally decrease eastward from New York City, inland from the Connecticut shoreline and from the interior toward the shore on Long Island. Mean annual temperatures for the region range from 49 to 55°F, are lowest in eastern Connecticut, northern portions of southwestern Connecticut and in eastern Long Island and are highest in western and central Long Island. Maps showing the geographic distribution of mean annual temperature and mean annual temperature range are listed in Appendix C. Mean annual temperature has little significance in an area where daily ranges vary from 10 to 25°F and annual ranges vary from 14 to 23°F.

Monthly mean-maximum, mean-minimum and mean temperatures have been tabulated for the region (see Appendix C) and provide a basis for predicting future temperatures. Monthly mean-maximum, mean-minimum and mean temperatures all trend in a latitudinal direction except where topography and the influence of the Sound predominate. The moderating influence of Long Island Sound is best defined in late spring and summer when water temperatures are cooler than air temperatures and in late autumn and winter when water temperatures are generally warmer than air temperatures.

¹ - A water year is the continuous 12-month period, October 1 through September 30. It is designated by the calendar year in which it ends.

In certain economic undertakings a knowledge of the frequency of climatic events is required before decisions involving risks are implemented. Tables, listed in Appendix C present the monthly and annual greatest, least and mean numbers of days of occurrence of maximum temperatures equal to or below 32 and 45°F and equal to or above 80 and 90°F and minima equal to or below 45, 36, 32, 24, 16 and 0°F.

The observed variations clearly demonstrate the difference in climate between northern Long Island and southern Connecticut; between interior sections and coastal areas; and between western and eastern parts of the region. In summer, temperatures of 90°F or higher occur most frequently over inland areas of southern Connecticut and in western portions of the region and least frequently along the eastern perimeter of Long Island Sound. These temperatures also occur less frequently along the coastal section and more often on northern Long Island than in southern Connecticut. In winter temperatures below 16°F are 2 to 3 times more likely in southern Connecticut than northern Long Island and occur frequently at short distances from the coast in Connecticut. For example, the average annual frequency of days with maximum temperatures of 90°F or higher is 9 at Riverhead, Long Island, 16 at LaGuardia Field, New York, but at New Haven, Connecticut, it is 3 and at Scarsdale, New York, 22. Days with minimum temperatures of 16°F or lower usually occur 15 times a year at Riverhead, 11 at LaGuardia, 22 at New Haven, 24 at Scarsdale and 30 to 36 in the interior of southern Connecticut.

Design data for heating and air conditioning were tabulated for four stations. The data included: the dry and wet bulb temperatures that are exceeded 10, 5, $2\frac{1}{2}$ and 1 percent of the time, the number of hours that dry bulb temperatures of 93, 80, 73 and 67°F and wet bulb and dew point temperatures of 80, 73 and 67°F are equaled or exceeded through the warm season; and the temperatures which are reached or surpassed 97.5 and 99 percent of the time during the cold season. Monthly and seasonal cooling and heating degree-day data for 14 stations are also contained in tables listed in Appendix C.

Freeze statistics are employed in agriculture to choose areas suitable for special cropping, to design planting schedules and to make long-range management decisions. The longest average annual freeze-free season, 190-205 days, along the shore areas of Connecticut and Long Island is similar to the freeze-free period in northern Alabama and Georgia. A sharp gradient--40 days within 10 miles--generally exists between coastal and interior valley stations in Connecticut. Tables giving the 95, 90, 75, 50, 25, 10 and 5 percent probability dates for the last occurrence of 32, 24 and 16°F or lower temperatures in spring and the first occurrence date of the same temperatures in the fall have been prepared for this study.

The Sound produces a longer growing season along its shores even though the cooler ocean waters in early spring retard the start of the growing season. As the Sound begins to act as a heat source in fall, the length of the season is significantly extended along the shores of both Long Island and western Connecticut. The largest reduction in heat available for growing occurs in eastern coastal areas of Connecticut where cold water lowers the daily mean temperatures during most of the growing season.

3.4 Precipitation

Precipitation near and within the Long Island Sound Region results from a variety of causes including tropical storms, air mass thunderstorms and extra-tropical low pressure areas. The amount and areal distribution of precipitation for water years 1941-70 has been compiled for the entire Long Island Sound drainage area by the National Weather Service. Over the study region itself the average annual precipitation ranges from 36 to 51 inches. About 5 to 20 percent of the annual total precipitation is snowfall with maximum amounts in northern sections. The average annual precipitation is greatest near the slightly elevated part of Long Island and away from the immediate shore in Connecticut. Two factors affect the geographic distribution of precipitation: distance from the stabilizing influence of water bodies and differences in altitude.

Besides the amount and areal distribution of precipitation, information on the intensity and duration of precipitation is required for many purposes. For example, the extreme 24-hour precipitation event at New Haven was 8.73 inches on August 8-9, 1874. This knowledge is useful, but short-period excessive rainfalls are sometime even more important. Rainfalls of 1.38 inches in 10 minutes and 2.34 inches in 30 minutes at New Haven on July 24, 1928 are examples of precipitation events which caused serious stresses on engineering works. Listed in Appendix C are (1) a table based on Hershfield (13) which gives maximum point-precipitation amounts for selected durations from 5 minutes to 24 hours and return periods from 2 to 100 years and (2) a table listing the monthly extreme 24-hour precipitation and snowfall together with their years of occurrence and (3) a listing of the mean monthly 24-hour extremes of the data and their standard deviations.

Long-term precipitation records for New Haven, Connecticut, New London, Connecticut, and Setauket, Long Island are shown in 6 graphs (see Appendix C). Three of the graphs permit calculation of the frequency with which a given amount of precipitation can be expected at each location. For example, the chances are that 80 percent of the time water-year precipitation at Setauket will be equal to or greater than 39 inches but only 1 in 100 that it will be as little as 32 inches.

Tables which give the least and greatest recorded monthly and annual precipitation amounts, together with their years of occurrence, are listed in Appendix C. These tables show, for example, that annual calendar year precipitation has varied locally from 25.35 inches at New London, Connecticut, in 1863 to 78.37 inches at Lake Konomoc near Waterford, Connecticut in 1972. Three additional tables list the mean, greatest and least monthly and annual number of days with precipitation equal to or greater than 0.01, 0.10, 0.50 and 1.00 inches.

Mean and greatest monthly and mean seasonal snowfall for the 1951-70 period are listed in a table (see Appendix C). Average seasonal snowfall on the north shore of Long Island ranges from about 23 to 28 inches. Along the mainland coast, the amounts vary from 26 to 33 inches with the larger totals between New Haven, Connecticut and Westbrook, Connecticut. Snowfall increases rapidly away from the coast and in the more hilly portions of

the mainland interior the averages range from 39 to 49 inches. The geographic distribution of snowfall based on the tabular data is shown on the figure below. Large variations may occur within short distances in the hilly sections, so that for these areas the map should only be used as a guide.

Figure 4. Mean annual snowfall in inches over the Long Island Sound Region, January 1951 to December 1970.

Four of the tables listed in Appendix C give the mean and greatest monthly and annual number of days with snowfall equal to or greater than 1, 2, 4 and 8 inches. Since there are many years without snowfalls of 4 inches or more in the region, only two tables for the least number of snowfalls equal to or greater than 1 and 2 inches were prepared.

Snow cover data from 13 stations in and north of the study area, presented in maps and tables give (1) the mean, maximum and least number of periods per season of 3 days or longer with snow depth equal to or greater than 1 and 6 inches; (2) the mean, median, maximum and minimum number of days involved and (3) the mean, median, greatest and least days per period. The tables also provide information of the first day-first period and last day-last period dates for various probability levels.

3.5 Tropical storms and hurricanes

Tropical storms (maximum winds of 39 to 73 miles per hour) and hurricanes (maximum winds of 74 miles per hour or more), exist as part of the general atmospheric circulation. In well developed hurricanes, the speed of the maximum winds near the center of the storm can reach 200 miles per hour (mph) or more in the tropics, but in the Long Island Sound Region surface winds probably have never exceeded 150 mph. Tides along the perimeter of the Sound may reach 10 feet above normal in intense hurricanes. The accompanying precipitation is both beneficial and harmful, supplying needed moisture for crop development if amounts are moderate, but causing damaging floods if precipitation amounts are excessive. Torrential rainfall over a considerable area is a common feature of tropical cyclones of all intensities including tropical depressions (winds less than 39 mph). In fact, some of the less violent storms are the greatest flood producers because they sometimes linger over the region for days.

Figure 5. Tracks of hurricanes with first landfall on the Long Island Sound Region.

At low latitudes, tropical disturbances usually move with the flow around the large permanent subtropical anticyclones. Existing circulation patterns associated with transient mid-latitude weather systems increasingly influence the motion of tropical cyclones when they migrate toward higher latitudes. Here tropical cyclones may be modified by interaction with nontropical air although winds may remain above hurricane force in some cases.

During the period 1871-1972 a total of 63 disturbances of tropical origin passed within about 150 miles of the Long Island Sound Region. Sixteen of these storms passed directly over the area and four hit Long Island and Connecticut from the ocean without prior landfall. The endless variety of tracks is a reflection of the continual changes in pattern of the general circulation during the period when tropical cyclones are in existence. Figure 5 charts the paths of the four hurricanes which hit the region directly from the sea.

The time-frequency distribution of tropical storms and hurricanes in the study region is such that no climatological summary can be considered a stable assessment of the risk of recurrence of these storms in any locality. Nevertheless, it is important that the best possible information be available for planning purposes. A table, listed in Appendix C and modeled after Crutcher and Quinlan (15) indicates the percent probabilities with which the center of an existing tropical cyclone at a specified latitude and longitude can be expected to be within the Long Island Sound Region after 72, 48 and 24 hours. The greatest probability of occurrence in the region after 24 hours is about 1 in 5 during August for a tropical cyclone located at 35.5°N and 77.5°W. If the current position of the storm were at the same longitude but 5° farther south the probability that the storm center would be within the Long Island Sound Region after 24 hours reduces to 1 in 50 but for occurrence in the region after 48 hours the chances again increase to 1 in 13.

Although the chance that an individual tropical cyclone will directly hit the region is relatively low, the percentage "strike probability" in any one year is considerably higher--nearly 16 percent for a direct hit and about 60 percent for an occurrence within 150 miles of the area. The region was rarely subject to hurricanes between 1901 and the massive hurricane of 1938 but was severely affected several times since, notably in 1944, 1954, 1955 and 1960. The planner should be aware of the effects of intense winds, torrential rainfall and high storm surges produced by these severe hurricanes on a highly developed area not geared to such disasters.

3.6 Thunderstorms

Thunderstorms commonly result in damage to crops and property. In the region the number of days with thunderstorms varies markedly throughout the year from a low of less than one day per month in winter to 5 to 8 days per month in summer. The greatest annual total, 20 to 25, occurs in southwest Connecticut, central Long Island and around heavily populated urban areas. The smallest number, approximately 14, is recorded in eastern Long Island and southeastern Connecticut. The frequency of thunderstorm occurrence is related to distance from water, altitude and perhaps air pollution in industrial areas.

Two maps have been prepared (see Appendix C) that show the mean and maximum annual number of thunderstorms in the region. Generally the mean number of thunderstorms increases from east to west and inland from the shore, with the smallest number occurring in eastern Connecticut and eastern Long Island.

3.7 Tornadoes

Tornadoes occasionally develop in air mass or pre-frontal thunderstorm areas during the afternoon or evening. Most tornadoes in the region have occurred in southwestern Connecticut and the risk of their occurrence decreases eastward because of the stabilizing effect of the Sound. A table is furnished (see Appendix C) that chronologically lists all known tornadoes in the region since 1682.

3.8 Cloudiness

Cloud cover averages computed over the full day for the period 1951-70 are available from LaGuardia Field, New York and for the period 1951-69 from Westhampton Beach, New York. The annual march of mean cloudiness in tenths for these two stations is shown on a graph prepared for this study (see Appendix C). Mean monthly cloudiness for the sunrise to sunset period for Bridgeport, Connecticut and for 4 stations near the study area--Block Island and Providence, Rhode Island; LaGuardia Field, New York and Hartford, Connecticut are shown on a separate graph.

Annual mean sky cover averages about 60 percent over the study region, but there is considerable variation both in time and space. Cloud amounts over mainland interior areas are generally greater than over coastal sections except from June through September. Western mainland interior areas have greater cloud amounts than eastern areas whereas along the coasts cloudiness is generally greater in the east than in the west. The greatest number of clear days throughout the region occur in September and October.

Comparisons among stations point out the influence of season and the proximity to the Sound and Ocean on sky cover. Graphs have been prepared for four stations to illustrate the controls operating on sky cover. The graphs show the annual march of mean cloudiness and the percentage frequencies for two classes of sky cover for the hours from 6 a.m. to 8 p.m. (See Appendix C.)

3.9 Wind

The frequency distribution of the occurrence of wind direction and speed reflects the passage of weather systems, the distribution of land and water and the local exposure. Wind data in the Long Island Sound Region are available for LaGuardia Field, New York and Bridgeport and New Haven, Connecticut. Data for Newburgh and Westhampton Beach, New York have also been used for this study. All weather wind-rose diagrams for each of the four seasons at these five stations are listed in Appendix C.

Around the Sound, west-northwesterly winds prevail in winter with the wind blowing from west to north 52 percent of the time, the most persistent wind of any season. Mean speeds averaged over all directions range from 8 to 12 knots (9.2 to 13.8 mph), but the strongest winds are northwesterly, averaging between 11 and 16 knots (12.7 to 18.4 mph) over the entire season.

Spring is a time of variable wind with frequent changes in weather control. Northwestern winds prevail in western portions of the region, but southwesterlies begin to assert themselves gradually in more easterly sections. The mean wind speed for the season ranges from 9 to 11 knots (10.3 to 12.7 mph) but strongest winds range from 11 to 14 knots (12.7 to 16.1 mph) and are from the northwest.

Southwesterly winds prevail in the summer as the flow is most frequently dominated by the high pressure area which extends into the southeastern United States from the Atlantic Ocean. Southwesterly winds occur from 14 to 20 percent of the time although there is considerable alternation from south to west-southwest and sometimes east. Mean wind speeds over all directions range from 7 to 9 knots (8.1 to 10.3 mph).

Winds in the autumn reflect the transition from summer to winter in both speed and direction. Cyclonic activity begins to increase and prevailing winds gradually shift from southwesterly to northerly directions, ranging between northwest and northeast except in extreme easterly sections where the southwesterly winds continue longer into the season. Mean speeds averaged over all directions range from 7 to 10 knots (8.1 to 11.5 mph) and show a gradual increase through the season.

In general the Sound and Atlantic Ocean have a dampening effect on hot summer winds and the Sound has an accelerating effect on cold winds from the mainland in winter. When anticyclonic conditions prevail on the mainland in winter, the wind frequently reaches the northern shore of Long Island with much higher velocities than occur over Connecticut. Since the Long Island Sound Region lies well south of the northern storm track and north of the path usually followed by the southern storms, wind movement is not as great as it is in these areas. Winds of gale force are seldom experienced. Many times when areas east of the region are lashed by violent coastal storms, only moderately high winds are experienced. Occasionally, however, when a storm or hurricane moves up the coast or when a storm from the Great Lakes moves southeastward, destructive winds occur throughout the Long Island Sound Region.

In designing large structures, it is necessary to take wind pressure into account. Estimates of the distribution of extreme wind speeds likely to be experienced once in 50 years and once in 100 years have been prepared for the entire United States by H. C. S. Thom (35). These estimates are based on winds 30 feet above the ground, but can readily be adjusted to other elevations. For the 50-year return period, values of 65 to 80 mph are estimated for Connecticut, increasing from the northwest toward the southeastern coast. The extreme wind speed to be expected once in 100 years ranges from 80 to 90 mph in the interior and along the southwestern coast to close to 100 mph in the extreme southeast.

3.10 Drought

Drought has many different meanings and definitions vary widely. For example, it may be termed an agricultural drought when precipitation is inadequate to maintain the moisture content of the soil at optimum levels thereby affecting agricultural production. To others, droughts are characterized by more severe precipitation deficits that persist to the degree that streamflow and ground water and thereby man's water supply are affected. A satisfactory definition for the Long Island Sound Region is that of Thomas (38) "drought is a meteorologic phenomenon that occurs during a period when precipitation is less than the long-term average and when this deficiency is great enough and continues long enough to hurt mankind."

The area may be affected by deficient precipitation for short periods in any year or season. A table prepared for the region gives the distribution of the total number of occurrences of consecutive days with less than 0.1 inch of precipitation for durations of from 1 to 19 days and 20 or more days. The total number of occurrences of 5 or more consecutive dry days (less than 0.1 inch of precipitation) is uniform throughout the area. The number of occurrences of 20 or more consecutive dry days however shows considerable areal variation, ranging from 20 to 30 along the perimeter of the Sound to 14 to 26 in interior parts of southern Connecticut. The chance of an extended dry spell appears to be 15 to 50 percent greater along the coast than in the hilly interior areas.

A widely used measure of drought severity and duration is the Palmer Drought Index (24). This index is based on the accumulated weighted difference between actual precipitation and that required for the particular time and place. Figure 6 is a plot of the monthly Palmer Drought Index for the period 1929-72 and can be used to determine the length and severity of both wet and dry periods in the region.

Figure 6 shows a total of 21 periods of drought lasting 3 or more months. Droughts of severe or extreme intensity lasting a month or more occurred 7 times encompassing a period of 53 months. The first prolonged drought in the period of record began in July 1929 and continued through August 1932; the most extreme conditions were reached in September and October of 1930. The longest and severest drought affecting the entire northeastern United States, began in March 1962 and continued through 1967. This drought is classed as severe or worse from August 1964 through February 1967.

In addition to affecting plant life these lengthy droughts resulted in reduced streamflow and lowered ground-water levels. The greatest impact was felt during the growing season when both agriculture and water supply must be satisfied by precipitation plus the water stored in reservoirs and the ground. The effect of the 1960's drought on streamflow and ground-water levels has been summarized by Barksdale and others (1) and Cohen and others (6). Figure 7 depicts the streamflow and antecedent ground-water conditions in 1965 when the hydrologic effects of the drought were most severe.

Figure 6. Hydrologic conditions in coastal Connecticut as indicated by the Palmer Drought Index

Figure 7. Effect of drought on streamflow and ground-water levels. After Barksdale and others (1966).

Drought conditions can end rapidly as illustrated by the events of August 1955 in coastal Connecticut. This area had been experiencing a moderate drought during July of 1955 but two August hurricanes resulted in 2.5 times the normal monthly precipitation. As a result the Palmer Drought Index went from moderate drought to extreme wet spell values in a one month interval.

4.0 FRESH SURFACE-WATER BODIES

Fresh surface-water bodies include approximately 75 streams of various size that drain into Long Island Sound and numerous lakes and ponds. All of the streams located on both shores of the Sound are tidal in their lower reaches and are hydraulically connected to adjacent ground-water reservoirs. Streamflow is derived from direct runoff of precipitation and ground-water discharge both within and out of the Long Island Sound Region. Flow characteristics of the streams vary depending on precipitation, on drainage area, on basin characteristics such as geology, slope and the degree of urbanization, and on effects of man-made diversions.

4.1 Availability of data

Measurements of streamflow have been made on many streams within or adjacent to the Long Island Sound Region since the early 1900's. These records have been published in U.S. Geological Survey Water-Supply Papers and in the annual series entitled Water Resources Data for Connecticut, Part 1 (41), and Water Resources Data for New York, Part 1 (42). Flow records of selected streams are published on a monthly basis in Water Resources Conditions in Connecticut (43) and Water Resources Summary, Long Island (44). Short-term forecasts of streamflow are published monthly by the National Weather Service in Water Supply Outlook for the northeastern United States (19).

Twelve continuous-record stream gaging stations in Connecticut and one in New York having periods of record in water years 1941-70 were used as the primary surface-water data for the mainland part of the study area. Four of these stations, located outside the region boundary, measure inflow to the area. Ten continuous-record stations within the region have periods of record for water years 1961-70. The records of five of these stations were adjusted to the reference period 1941-70, while the other five stations were used for low-flow values only.

Forty-two low-flow partial-record sites, in and near the mainland part of the region, at which discharge measurements were made in water years 1961-70 were selected to study the range and variability of low flows. The values of the 7-day, 10-year recurrence interval low flow for these sites were estimated through relation curves of discharge, with the long-term records. Drainage areas of the low-flow partial-record sites range from 1 to 29 square miles but are generally between 4 and 15 square miles.

The primary surface-water data for Long Island consists of 19 continuous-record stream gaging stations having periods of record in water years 1940-65. Four of these stations are on streams that discharge into Long Island Sound whereas the others drain south into the Atlantic Ocean or into Great Peconic Bay. Surface drainage areas of these streams range from 4 to 75 square miles.

The information on average annual, and average monthly runoff and the 7-day, 10-year low flows has been prepared in map format (see Appendix C). The streamflow information for the continuous record gaging stations on the mainland is summarized in Appendix E.

4.2 Fresh water inflow to the Sound

The three principal streams flowing into Long Island Sound--the Thames, Connecticut, and Housatonic Rivers--have a combined drainage area of 14,700 square miles, 91 percent of the 16,200 square mile mainland drainage area. Annual runoff to the Sound averages 26,200 cubic feet per second (cfs)¹

¹ - One cubic foot per second (cfs) is equivalent to 646,317 gallons per day to approximately 0.65 million gallons per day (mgd), and to 0.24 billion gallons a year (bgd).

equivalent to 1.62 cfs per square mile or 6,200 billion gallons per year and varies from 14,000 to 37,000 cfs as shown on Figure 8.

Figure 8. Estimated annual inflow to Long Island Sound 1929-70. The graph indicates that one calendar year can bring almost three times as much fresh water inflow as another.

Average annual runoff from the Thames River basin is 1.64 cfs per square mile. This is slightly greater than the rate of runoff from the Connecticut and Housatonic River basins (1.62 and 1.61 cfs per square mile, respectively). The distribution of average annual runoff in the mainland part of the region is shown on Figure 9.

Average monthly runoff to the Sound varies from 4.0 cfs per square mile in April (65,100 cfs, or 1,250 billion gallons) to 0.6 cfs per square mile in September (9,800 cfs, or 190 billion gallons); monthly inflow to the Sound has been as high as 139,000 cfs and as low as 4,300 cfs, in the period of record beginning in 1928. The average monthly runoff for the calendar year period 1941-70 is shown on Figure 10.

Figure 9. Average annual runoff on the north shore of Long Island Sound in cubic feet per second per square mile, 1941-70 water years.

Figure 10. Estimated average monthly inflow to Long Island Sound 1941-70.

The average inflow to the Sound in 7 consecutive days of a dry weather period may be expected to go below 3,000 cfs (0.18 cfs per square mile) once in ten years. Regulation of the three principal streams entering the Sound holds the dry-weather inflow at a higher level than would occur without regulation. The 7-day, 10-year annual minimum runoff from unregulated tributaries in the mainland part of study area ranges from 0.01 to 0.05 cfs per square mile.

4.3 Coastal streams

The 66 mainland coastal streams flowing directly into the Sound, other than the Thames, Connecticut and Housatonic Rivers, have a combined drainage area of 1,467 square miles. The three largest are the Pawcatuck River (304 square miles), the Quinnipiac River (166 square miles), and the Saugatuck River (93.2 square miles). Drainage areas of the other coastal streams vary from about 1 to 64 square miles, with most ranging from 3 to 30 square miles.

The average annual runoff from a sample of mainland coastal streams (mean drainage area less than 10 square miles) is 1.8 cfs per square mile; the average monthly runoff varying from a high of 3.9 cfs per square mile in March to a low of 0.5 cfs per square mile in August. The 7-day, 10-year annual minimum runoff is estimated to be about 0.01 cfs per square mile, which is probably close to the lowest 10-year runoff to be expected from the mainland coastal streams.

An estimated 77 cfs (50 mgd) is discharged into the Sound from coastal streams on Long Island. The four continuously gaged streams that flow into the Sound (Glen Cove Creek, Mill Neck Creek, Cold Spring Brook and the Nissequogue River) have surface drainage areas of 7 to 27 square miles and average annual runoff of 4.6 to 42.1 cfs. In comparison with mainland streams, the variation in annual and average monthly runoff is small. For example, the average monthly flow of the Nissequogue River during the highest average month (March) is 45.6 cfs, only 1.2 times greater than the lowest average month (October).

Under natural conditions 90 to 95 percent of Long Island stream-flow consists of ground-water discharge and as a result the correlation between surface drainage areas and average flows is poor. In areas of urban development, however, direct runoff constitutes a much higher percentage of total discharge.

4.4 Annual maximum streamflows

The mean of the annual maximum discharges (the "mean annual flood") for the continuous-record stations in and near the mainland part of study area ranges from 10 cfs per square mile for a drainage area of 10,000 square miles to about 50 cfs per square mile for a drainage area of 10 square miles. The maximum discharge of the Connecticut River near Middletown (10,900 square mile basin) was 267,000 cfs on March 12, 1936, while combined maximum discharge for the seven largest rivers flowing to the Sound (gaged drainage area of 13,900 square miles) was more than 400,000 cfs in March 1936 and in August 1955.

TABLE 1. PRINCIPAL LAKES, PONDS AND RESERVOIRS

Sub-region	Name and location	Surface area (acres)	Maximum depth (ft)	Total storage (million gallons)	Usable storage (million gallons)	Type of use
1	Ashland Pond at Jewett City	102	17	200	200	Not used
1	Amos Lake at Preston	105	48	655	65	Recreation
1	Aspinook Pond at Jewett City	333	27	942	800	Not used
1	Avery Pond near Preston	146.1	14	101	14	Recreation
1	Babcock Pond near Westchester	147	8	134	134	Do.
1	Barnes Reservoir near Chesterfield	46.5	25	170	170	Public water supply
1	Beach Pond near Voluntown	394	65	2,633	1,290	Recreation
1	Beachdale Pond at Voluntown	45.9	10	42.2	35.9	Do.
1	Billings Lake near Glasgo	105	33	469	205	Do.
1	Bogue Brook Reservoir near Chesterfield	72	25	212	212	Public water supply
1	Buddington Pond near Groton	15	--	20	20	Do.
1	Deep River Reservoir near Gilman	119	35	384	384	Do.
1	Dodge Pond at Niantic	33.8	51	227	None	Scientific investigations
1	Fairview Reservoir near Norwichtown	68	30	450	450	Public water supply
1	Fairy Lake near Chesterfield	84	60	235	235	Do.
1	Fitchville Pond at Fitchville	69.2	20	140	140	Recreation
1	Gardner Lake near Fitchville	487	43	2,177	1,055	Do.
1	Glasgo Pond at Glasgo	184	26	395	350	Do.
1	Groton Reservoir near Groton	115	12	256	256	Public water supply
1	Hog Pond near Hamburg	69	--	502	502	Recreation
1	Hopeville Pond at Hopeville	149	16	225	225	Do.
1	Lake Konomoc near Chesterfield	225	60	672	672	Public water supply
1	Lake of Isles near Shewville	87.1	10	172	100	Recreation
1	Lantern Hill Pond near Shewville	15.1	32	72	None	Do.
1	Ledyard Reservoir near Groton	95	24	476	476	Public water supply
1	Long Pond near North Stonington	98.6	72	488	245	Recreation
1	Mystic (Dean) Reservoir near Mystic	12.5	10	35	35	Public water supply
1	Mystic (Palmer) Reservoir near Mystic	23.9	12	80	80	Do.
1	Norwich Pond near Hamburg	27.5	38	206	206	Recreation
1	Oxbow Lake near Montville	164	37	1,077	613	Industrial
1	Pachaug Pond at Pachaug	831	18	1,640	1,640	Recreation
1	Paper Mill Pond at Versailles Station	61	20	126	114	Industrial
1	Pataganset Lake at East Lyme	123	34	497	105	Recreation
1	Pickrel Pond near Moodus	88.6	10	175	175	Do.
1	Pohegnut Reservoir near Groton	80	9	223	223	Public water supply
1	Powers Lake near East Lyme	153	14	442	442	Recreation
1	Rogers Lake at Laysville	265	--	1,740	1,740	Do.
1	Smith Lake near Groton	42	67	436	436	Public water supply
1	Stony Brook Reservoir near Oakdale	73	30	500	500	Do.
1	Taftville Pond at Taftville	120	21	331	331	Industrial
1	Taftville Reservoir at Taftville	22	20	88	88	Public water supply
1	Wabog Pond near Glasgo	105	33	469	205	Recreation
2	Cedar Lake near Chester	68	45	428	428	Recreation
2	Deep Hollow Reservoir	249	--	65	65	Public water supply
2	Deuces Pond near Chester	3.4	--	6	6	Do.
2	Hammonasset Reservoir near North Madison	377	--	1,460	1,080	Do.
2	Kelseytown Reservoir near Killingworth	15.4	--	221	18.9	Do.
2	Killingworth Reservoir near Killingworth	80	--	221	221	Do.
2	Pataconk Reservoir near Chester	55.5	--	187	187	Recreation
2	Turkey Hill Reservoir near West Haddam	80.4	10	149	149	Public water supply
2	Upper Pond near Tylerville	6.2	--	12	9	Do.
2	Waterhouse Pond near Chester	47.1	--	190	120	Do.
3	Bradley and Hubbard Reservoir	50	--	168	--	Public water supply
3	Branford Supply Ponds near Branford	26	--	--	--	Recreation
3	Cedar Pond near North Branford	23	17	82	--	Do.
3	Clarks Pond at Mt. Carmel	10	--	--	--	Do.
3	Clear Lake near North Branford	19	--	--	--	Do.
3	Community Lake at Wallingford	90	--	--	--	Industrial
3	Foster Lake near Meriden	25	--	--	--	Recreation
3	Glen Dam Reservoir near Woodbridge	30	--	197	193	Public water supply
3	Hanover Pond at Meriden	72	--	--	--	Recreation
3	Indian Lake at Orange	36	--	--	--	Do.
3	Konolds Pond near Woodbridge	83	--	--	--	Do.
3	Lake Bethany near Bethany	100	--	650	603	Public water supply
3	Lake Chamberlain near Bethany	100	--	--	894	Do.
3	Lake Dawson near Woodbridge	70	--	--	209	Do.
3	Lake Gaillard near Branford	1,010	100	--	5,405	Do.
3	Lake Quonnapaug at North Guilford	112	48	494	494	Recreation
3	Lake Saltonstall at East Haven	390	108	--	1,500	Public water supply
3	Lake Watrous near Bethany	106	--	725	709	Do.
3	Lake Whitney at New Haven	200	--	--	258	Do.
3	Lake Wintergreen at Woodbridge	42	--	100	100	Do.
3	Lane Pond Reservoir near North Branford	13	15	50	50	Do.
3	Lidyhites Pond near North Branford	13	--	--	--	Recreation
3	Linsley Pond near North Branford	23	44	153	--	Do.
3	Maltby Lakes near West Haven	70	--	--	260	Public water supply
3	Memuncatuck Reservoir at North Guilford	39.5	--	203	197	Do.
3	Merlme Reservoir near Meriden	44	--	351	--	Do.
3	New Naugatuck Reservoir near Stratsville	86.3	--	506	--	Do.
3	North Farms Reservoir near Wallingford	62	5	63	--	Recreation
3	Phipps Lake Reservoir at West Haven	25	--	--	--	Do.
3	Pine River (McKenzie) Reservoir near Wallingford	70	25	225	225	Public water supply
3	Pistapaug Pond near Durham	140	50	1,200	650	Do.
3	Silver Lake near Meriden	151	--	222	222	Recreation
3	Spring Brook Reservoir near East Wallingford	129	25	900	900	Public water supply
3	West Lake near North Branford	50	--	--	--	Recreation
4	Aspetuck Reservoir near Easton	61	12	66	66	Public water supply
4	Beaver Dam Lake near Nichols	58.4	44	415	415	Recreation
4	Bunnells Pond near Bridgeport	42	22	147	147	Do.
4	Easton Reservoir near Easton	488	130	5,848	5,848	Public water supply
4	Hemlock Reservoir near Plattsville	437	90	3,801	3,801	Do.
4	Lake Forest near Bridgeport	72	22	342	342	Do.
4	Peat Swamp Reservoir near Ansonia	82.6	--	537	--	Do.
4	Samp Mortar Reservoir near Fairfield	50	26	177	177	Recreation
4	Trap Falls Reservoir near Huntington	344	--	2,464	2,464	Public water supply
5	Grupes Reservoir near New Canaan	22	22	56	56	Public water supply
5	John D. Milne Lake near New Canaan	71	71	610	610	Do.
5	Laurel Reservoir at High Ridge	265	45	2,253	2,253	Do.
5	Mianus (Bargh) Reservoir near Stamford	120	64	2,450	2,250	Do.
5	New Canaan Reservoir near New Canaan	22	42	132	116	Do.
5	North Stamford Reservoir at North Stamford	114	21	512	512	Do.
5	Putnam Lake near Round Hill	96	19	572	572	Do.
5	Rockwood Lake near Round Hill	96	23	500	468	Do.
5	Saugatuck Reservoir near Lyons Plain	868	123	11,924	11,924	Do.
5	Streets (Popes) Pond at North Wilton	75	18	240	240	Do.

4.5 Lakes and ponds

There are hundreds of lakes and ponds of various size mostly located in the Connecticut part of the Long Island Sound Region. The larger lakes are generally man made and are used for water supply, flood control and recreation. Table 1 lists pertinent data on the major lakes and ponds in Connecticut.

5.0 GROUND WATER

5.1 Availability of hydrogeologic data

Hydrogeologic information for the Long Island Sound Region is contained in numerous basic data and interpretive reports. Most interpretive studies published prior to 1960 are qualitative and cover relatively small parts of the region. Recent comprehensive reports include the series of Water Resources Bulletins prepared by the U.S. Geological Survey in cooperation with the State of Connecticut (27, 36, 37, 31); New York Water Resources Commission Bulletins (5, 8) and several U.S. Geological Survey Water-Supply and Professional Papers prepared in cooperation with New York State and county agencies (6, 10, 25, 26, 34).

Water-level and ground-water quality data from wells within the study region are published each year in Water Resources Data for Connecticut, Parts 2 and 3 (41); and Water Resources Data for New York, Part 2 (42). Water levels are also published on a monthly basis in Water Resources Conditions in Connecticut (43) and Water Resources Summary, Long Island (44).

The existing information on ground-water availability and quality necessary for planning has been updated and presented in map format for this study (see Appendix C). In some aspects of plan formulation it may be necessary to refer to information contained in the selected references listed in Appendix A.

5.2 The hydrogeologic system of Long Island

Two recent reports (5, 10) have summarized the pertinent existing information on Long Island's hydrologic system and are the basis of this section. Although Long Island is generally considered as a single hydrologic unit it can be divided into subareas for purposes of analysis. Subareas referred to in the text and on tables are shown on Figure 11.

The most important hydrologic feature of Long Island is the fresh ground-water reservoir beneath its surface. The boundaries of this reservoir are (1) the water table (2) the fresh-salt water interfaces (3) the bedrock surface and (4) the streams. The geologic framework of the ground-water reservoir consists of a thick wedge-shaped mass of saturated sand, gravel, silt and clay as shown on Figure 12.

Figure 11. Hydrologic areas and subareas on Long Island. After Franke and McClymonds (1972, Fig. 2).

Figure 12. Section illustrating the geologic features of the ground-water reservoirs beneath Long Island. After Franke and McClymonds (1972, Fig. 8).

TABLE 2. ESTIMATED VOLUME OF FRESH GROUND WATER BENEATH PARTS OF LONG ISLAND

Volume designation		Volume of deposits satu- rated with fresh ground water (cubic miles)	Total volume of fresh ground water (trillions of gallons)	Range in estimated storage capacity
Item	(1)	(2)	(3)	(4)
(a) Above sea level in water-budget area---		5	1.6	0.28- 0.56
(b) Beneath entire water- budget area-----		180	59	10 -20
(c) Beneath area adja- cent to water- budget area'-----		100	33	5.5 -11
(d) Sums of Items b and c (rounded)-----		280	92	15 -31
(e) Beneath mainland Kings and Queens Counties -----		10	3.3	.55- 1.1
(f) Sums of items d and e (rounded)-----		290	95	16 -32

1 Includes volume beneath the nearshore areas and the adjacent bays.

Adapted from Franke and McClymonds (1972)

Fresh ground water occurs from the bedrock surface to the water table except in the Forks and islands of eastern Long Island. The estimated quantities of fresh water stored beneath various parts of Long Island are listed on Table 2. Only a part of the fresh water beneath Long Island is available for use by man and the amount that can be recovered depends upon the water management scheme.

The water table and fresh-salt water interfaces are not stationary boundaries and their position depends on the balance between inflow (recharge) to and outflow (discharge) from the ground-water reservoir. A map prepared for this study (see Appendix C) shows the position of the upper boundary, the water table, as of March 1971. The position of the fresh-salt water interface generally lies seaward of the shore but has been accurately determined only in southwestern Nassau and Southeastern Queens Counties.

Recharge to the ground-water reservoir under natural conditions is derived solely from precipitation. In the 760 square mile "water budget area" it is estimated that the average annual recharge from precipitation is approximately 820 million gallons per day (5). Most recharge takes place during the period October to March when vegetation is generally dormant.

The ground-water reservoir contains six major hydrogeologic units whose properties affect the storage and movement of water. Maps showing the known extent, thickness, depth to and hydraulic properties of these units were prepared or modified for this study by the U.S. Geological Survey (see Appendix C). Such maps in conjunction with continuing programs will enable

predictions of the quantity of water that can be withdrawn from the ground-water reservoir at a given site and the hydrologic response to man-made or natural changes. A summary of information on the major hydrogeologic units is shown on Table 3.

There are two general systems of circulation within the ground-water reservoir. A shallow circulating subsystem, generally under water-table conditions, that discharges principally into streams and a deep circulation subsystem, generally under artesian conditions, that discharges into the bays, the Atlantic Ocean and Long Island Sound. Seepage to springs and ground-water evapotranspiration are the other principal means of natural discharge from the ground-water reservoir. The pattern of ground-water circulation under natural conditions is shown on Figure 2.

A water budget analysis quantitatively expresses the inflow to, outflow from and changes in storage within a hydrologic system. Table 4 is a water budget for approximately half of Long Island (refer to Fig. 11) prepared by Franke and McClymonds (10). This table is an approximate summary of relations between the components of the hydrologic system under natural conditions.

Fresh ground water on Long Island, under natural conditions, has a dissolved solids content of less than 50 mg/l (milligrams per liter) and is of excellent chemical quality for most uses. The low dissolved solids concentration is due to the generally low solubility of materials in the saturated zone. The pH is generally low (commonly less than 6) which makes the water corrosive to metals and in places the iron content is considerably above the 0.3 mg/l limit recommended for public supply use (45).

The ground-water quality in the upper glacial, Magothy and Lloyd hydrogeologic units has been summarized on maps by the U.S. Geological Survey (see Appendix C). The chemical and physical quality of water at any point within the ground-water reservoir results from the natural geochemical conditions and the effects of man's activities.

The average natural ground-water temperature varies from about 50° to 70°F (10-21°C) depending on depth below land surface. The average temperature to a depth of about 400 feet is relatively constant and thereafter increases at a rate of about 1°F per hundred feet of depth (5). Seasonal variation in ground-water temperatures in the upper part of the saturated zone ranges from 2° to 20°F. The range in seasonal variation decreases with depth.

Man's activities have to various degrees affected the natural hydrologic system by depleting the ground-water reservoir, artificially recharging the ground-water reservoir and changing the ground-water quality. The ground-water reservoir is depleted by (1) irrigation (2) increased direct runoff to streams from urbanized areas (3) disposal of sewage effluent to the ocean and (4) export of water to New York City. The total loss is estimated at 125 mgd in 1965, 60 percent of which (75 mgd) is discharge of sewage effluent to the ocean (10).

TABLE 3. MAJOR HYDROGEOLOGIC UNITS OF THE GROUND-WATER RESERVOIR
ON LONG ISLAND, NEW YORK

Geologic unit	Hydrogeologic unit	Approximate maximum thickness (feet)	Depth from land surface to top (feet)
Upper Pleistocene deposits	Upper glacial aquifer	600	0-50
Gardiners Clay	Gardiners Clay	300	50-400
Jameco Gravel	Jameco aquifer	300	100-550
Matawan-Group			
Magothy Formation undifferentiated	Magothy aquifer	1,100	0-600
Raritan Formation			
Clay Member	Raritan clay	300	0-1,500
Lloyd Sand Member	Lloyd aquifer	500	200-1,800
Bedrock	Bedrock	--	0-2,700

Adapted from Franke and McClymonds (1972) and Jensen and Soren (in press)

1/ Hydraulic conductivity denotes how readily water can move through porous material.

TABLE 3. MAJOR HYDROGEOLOGIC UNITS OF THE GROUND-WATER RESERVOIR
ON LONG ISLAND, NEW YORK--Continued

Physical characteristics of deposits	Water-bearing properties
Till (mostly along north shore and in moraines) composed of clay, sand, gravel, and boulders. Outwash deposits (mostly between and south of terminal moraines, but also interlayered with till) consist of sand, fine to very coarse, and gravel. Glaciolacustrine deposits (mostly in central and eastern Long Island) and marine clay (locally along south shore) consist of silt, clay, and some sand and gravel layers; includes "20-foot clay" in southern Nassau County and Queens County.	Till has low hydraulic conductivity; ¹ /commonly causes perched-water bodies and impedes downward percolation of water to underlying beds. Outwash deposits have moderate to high hydraulic conductivity; specific capacities of wells tapping them range from about 10 to more than 200 gpm per foot of drawdown. Good to excellent infiltration characteristics. Glaciolacustrine and marine clay deposits have mostly poor hydraulic conductivities, but locally have thin layers of sand and gravel with moderate hydraulic conductivities; generally retard downward percolation of ground water. Contains fresh water, except near shorelines. Till and marine deposits locally retard salt-water encroachment.
Clay, silt, and few layers of sand and gravel. Altitude of top generally is 50-80 ft below mean sea level. Occurs in Kings and Queens Counties, southern Nassau County, and Suffolk County; similar clay occurs in buried valleys near north shore.	Poor hydraulic conductivity; constitutes confining layer for underlying Jameco aquifer. Locally, sand layers yield small quantities of water.
Sand, fine to very coarse, and gravel; few layers of clay and silt. Occurs in Kings and Queens Counties, and southern Nassau County; similar deposits occur in buried valleys near north shore.	Moderate to high hydraulic conductivity; contains mostly fresh water, but brackish water and water with high iron content locally in southeastern Nassau County and southern Queens County. Specific capacities of wells in the Jameco range from about 20 to 150 gpm per foot of drawdown.
Sand, fine to medium, clayey in part; interbedded with lenses and layers of coarse sand and sandy and solid clay. Gravel is common in basal 50-200 ft.	Most layers have poor to moderate hydraulic conductivity; some have high hydraulic conductivity locally. Specific capacities of wells in the Magothy generally range from 1 to about 30 gpm per foot of drawdown, rarely are as much as 80 gpm per ft. Water is unconfined in uppermost parts, elsewhere is confined. Water is generally of excellent quality but has high iron content locally along north and south shores. Constitutes principal aquifer for public-supply wells in western Long Island, except Kings County where it is mostly absent. Has been invaded by salty ground water locally in southwestern Nassau County and southern Queens County, and in small areas along north shore.
Clay, solid and silty; few lenses and layers of sand; little gravel.	Poor to very poor hydraulic conductivity; constitutes confining layer for underlying Lloyd aquifer. Very few wells produce appreciable water from these deposits.
Sand, fine to coarse, and gravel, commonly with clayey matrix; some lenses and layers of solid and silty clay.	Poor to moderate hydraulic conductivity. Specific capacities of wells in the Lloyd generally range from 1 to about 25 gpm per foot of drawdown, rarely are as much as 50 gpm per ft. Water is confined under artesian pressure by overlying Raritan clay; generally of excellent quality but has high iron content locally. Has been invaded by salty ground water locally in necks near north shore, where aquifer is mostly shallow and overlying clay discontinuous. Called deep confined aquifer in some earlier reports.
Crystalline metamorphic and igneous rocks. A soft clayey zone of weathered bedrock locally is more than 100 ft thick.	Hydraulic conductivity poor to virtually zero; constitutes virtually the lower boundary of ground-water reservoir. Some hard, fresh water is contained in joints and fractures, but is impracticable to develop at most places; however, a few wells near the western edge of Queens and Kings Counties obtain water from the bedrock.

TABLE 4. WATER BUDGETS OF THE NORTHERN AND SOUTHERN PARTS OF THE
"WATER BUDGET AREA" OF LONG ISLAND, WATER YEARS 1940-65

[In millions of gallons per day]

Type of water- budget element	No.	Water-budget element	Water-budget area		
			Northern part	Southern part	Entire part
Inflow.....	1	Precipitation.....	650	950	1,600
Internal dis- tribution.	2	Direct runoff.....	5	15	20
	3	Ground-water recharge ² ..	320	465	785
	4	Ground-water discharge to streams. ³	45	275	320
Outflow.....	5	Evapotranspiration of precipitation. ⁴	325	470	795
	6	Subsurface outflow of ground water.	270	180	450
	7	Streamflow discharging to salt water.	50	290	340
	8	Evapotranspiration of ground water. ⁵	5	10	15

¹ The quantities in this table were derived with the assumption that no significant change in ground-water storage occurred in the water-budget area during the period, water years 1940-65. Independent quantitative estimates were made for all components in the table unless otherwise noted. None of the values in this table are accurate to more than 2 significant figures, and many values are accurate to less.

Where more than 2 significant figures are shown, the entry was derived from other entries in the table, and an additional significant figure was retained to balance inflow and outflow. (See footnotes below.)

² The estimate of ground-water recharge was obtained by adding components 4, 6, and 8.

³ The estimate of ground-water discharge to streams was obtained by subtracting component 2 from component 7.

⁴ The estimate of evapotranspiration of precipitation was obtained by adding components 6, 7, and 8 and subtracting the total from component 1. Therefore, the subtotal of components 5, 6, 7, and 8 (total outflow) equals component 1 (total inflow).

⁵ These values may be in error by as much as 100 percent or more. Values are included mainly to indicate order of magnitude.

After Franke and McClymonds (1972)

Artificial recharge to the ground-water reservoir is from cesspools, septic tanks, recharge basins, injection wells and leaky water and sewer pipes. The total artificial recharge in Nassau and Suffolk Counties is estimated at 310 mgd in 1965; approximately 68 percent (210 mgd) of which is from cesspools, septic tanks and recharge basins (10).

The quality of ground water has been affected primarily by waste disposal practices that include disposal of sewage and industrial wastes into the ground through septic tanks, cesspools and recharge basins. Deterioration of quality has also resulted from the injection of heated water through recharge wells, the discharge of smoke and other particulate matter into the atmosphere, the leaching of fertilizers and salt-water encroachment in areas of overdevelopment.

Cohen and others (5) outlined the progressive pattern of ground-water development in Long Island in three stages:

Individually owned shallow wells used for water supply and cesspools used for domestic waste disposal.

Public supply wells that tap the deeper artesian hydrogeologic units and use of cesspools for domestic waste disposal.

Deep public supply wells and large scale communal sewage collection and disposal systems.

It is the third stage of development that has a significant impact. The effect of sewerage and subsequent discharge to the ocean disrupted the hydrologic balance resulting in large scale salt water encroachment and lowered water levels in areas of large-scale pumping (the status of water development in Long Island as of 1966 is shown on Fig. 13).

Figure 13. Status of water development in 1966. After Heath and others (1966, Fig. 8).

Recent hydrologic appraisals (5, 10) have emphasized that future water management must take into account the balance of the Long Island ground-water reservoir as expressed by the equation: $\text{Inflow} = \text{Outflow} \pm \text{changes in storage}$ and have outlined several management alternatives and their consequences. As of 1968, the total fresh-water outflow from the ground-water reservoir beneath the water budget area was greater than the inflow, and the amount of fresh ground water in storage was declining. If present management practices continue it is likely that within the water budget area (1) the hydrologic imbalance will increase, (2) ground-water levels will continue to decline, and (3) salty ground water will continue to move slowly inland. The yield of the Long Island ground-water system is not a single fixed number but will vary depending on hydrogeologic conditions, the management scheme, and the extent to which certain undesirable effects of development will be tolerated.

A continuous program of hydrologic investigations is essential to provide the information necessary for water management and planning. Present activities that provide a continuous record of the hydrologic system should be continued and further refined. More intensive study and monitoring of water quality are required in various parts of the island and continuing efforts should be made to define the shape and areal extent of the hydrogeologic units particularly in eastern Suffolk County.

5.3 The hydrogeologic system on the north shore of Long Island Sound

The hydrogeologic information in the subregions of the Long Island Sound Regional Study Area that lie north of the Sound varies in quantity and quality. The most complete information is presently available for Subregions 1, 4 and 5. On-going studies by the U.S. Geological Survey are in various stages of completion in Subregions 2 and 3 whereas the part of Subregion 6 in this area is deficient in data.

The principal hydrologic unit on the north shore of the Sound is the river basin drained by a perennial stream. The saturated zone beneath each of these basins constitutes a fresh ground-water reservoir, the boundaries of which are (1) the topographic drainage divides (2) the water table (3) the streams and (4) impermeable bedrock. For small areas that border the coast and are not drained by a stream the interface between fresh and salty ground water is a boundary. The geologic framework of the ground-water reservoirs on Figure 14 includes the upper fractured part of the bedrock and unconsolidated layered and unlayered deposits of sand, gravel, silt, clay (termed stratified drift and till respectively).

Recharge to each ground-water reservoir under natural conditions is derived solely from precipitation on the drainage basin. The amount and rate of recharge varies from basin to basin and with time. In areas where the surface materials are principally till and bedrock the estimated average annual recharge is approximately 0.3 mgd/mi^2 (million gallons per day per square mile) and in areas covered by stratified drift it is approximately 1 mgd/mi^2 . Most recharge occurs during the period October through March of each year when vegetation is generally dormant.

EXPLANATION

STRATIFIED DRIFT

SAND AND GRAVEL

SAND, SILT AND CLAY

SAND

TILL

HETEROGENEOUS COMPACT
MIXTURE OF SAND, GRAVEL,
SILT AND CLAY SIZED
MATERIAL

CRYSTALLINE BEDROCK

Figure 14. Block diagram illustrating the general geologic features of a ground-water reservoir on the north shore of Long Island Sound. Adapted from Cervione and others (1972, Fig. 32).

The ground-water reservoirs contain at least two and generally three major hydrogeologic units whose properties affect the storage and movement of water. Maps showing the known extent, thickness and hydraulic properties of the most important unit, stratified drift are available for parts of Subregions 1, 4 and 5 in the references cited in the introduction to this section. The important characteristics of all three hydrogeologic units is summarized on Table 5.

TABLE 5. MAJOR HYDROGEOLOGIC UNITS OF THE GROUND-WATER RESERVOIRS ON THE NORTH SHORE OF LONG ISLAND SOUND

Geologic unit	Hydrogeologic unit	Physical characteristics of deposits	Water-bearing properties
Pleistocene deposits	Stratified-drift aquifer	Unconsolidated sediments composed of interbedded layers of gravel, sand, silt and clay. Sites of former glacial lakes contain predominantly very fine sand, silt and clay. Deposits occur principally in valley areas. Maximum known thickness is approximately 300 ft.	Most saturated stratified drift has moderate to high hydraulic conductivities. ^{1/} Lacustrine deposits of very fine sand, silt and clay, however, have low hydraulic conductivity. Major water-bearing unit in the area capable of yielding from 50 to over 2000 gpm (gallons per minute) to properly constructed individual wells. Estimated long-term yields of selected stratified-drift aquifers in Subregions 1, 4 and 5 range from less than 0.5 to over 15 million gallons per day.
	Till	Unconsolidated nonstratified sediment composed of various proportions of sand, gravel, silt and clay. Discontinuously mantles bedrock and is overlain in valley areas by stratified drift. Generally less than 10 ft thick but maximum known thickness exceeds 150 ft.	Till has low hydraulic conductivity and is generally thin. Shallow wells tapping till formerly used for domestic supply but most proved inadequate for modern demands and were replaced by drilled wells tapping bedrock.
Triassic sedimentary bedrock	Sedimentary-bedrock aquifer	Consolidated sandstones, shales and conglomerates interbedded with basalt (traprock). Underlies part of Subregion 3.	Hydraulic conductivity unknown. Contains water-bearing fractures and pores in at least the upper several hundred feet. Water quality locally poor. Yields of wells tapping this aquifer range from less than 1 to 305 gpm. The median yield is approximately 11 gpm and the median specific capacity is approximately 1.3 gpm per foot of drawdown.
Crystalline bedrock	Crystalline-bedrock aquifer	Consolidated crystalline metamorphic and igneous rocks. A soft zone of weathered bedrock locally is more than 100 ft thick.	Hydraulic conductivity unknown. Contains water-bearing fractures in at least the upper 300 ft. Yields of wells range from less than 1 to 200 gpm but yields greater than 20 gpm are rare. The median yield is approximately 7 gpm.

^{1/} Hydraulic conductivity denotes how readily water can move through porous material.

In order to assess ground-water availability at any given location the major hydrogeologic units have been subdivided or combined according to their ability to yield similar amounts of water to wells. Maps prepared by the U.S. Geological Survey for Subregions 1 through 5 delineate the areas capable of yielding selected amounts of water to individual wells (see Appendix C).

Circulation within each ground-water reservoir is relatively shallow. Most ground water moves through the upper 300 feet of the saturated zone and discharges principally to streams. A deep circulation subsystem may be present in the part of Subregion 3 containing saturated sedimentary rocks. Ground-water evapotranspiration and subsurface outflow to Long Island Sound are the other means of natural discharge from the ground-water reservoirs. The amount of subsurface outflow has been estimated to be 100 mgy (million gallons per year) per mile of coastline in Subregion 1 (37). The general pattern of ground-water circulation under natural conditions is shown on Figure 3.

Fresh ground water under natural conditions is generally of excellent chemical quality for most uses. Dissolved solids are less than 500 mg/l with the exception of some ground water in the sedimentary rocks of

Subregion 3. Iron and manganese concentrations commonly exceed the recommended limit for public supply use of 0.3 mg/l and 0.05 mg/l respectively (45). Approximately 40 percent of the wells tapping stratified drift and crystalline bedrock, sampled by the U.S. Geological Survey, had excessive concentrations of iron and/or manganese. Hard to very hard ground water (hardness as CaCO_3 , greater than 120 mg/l) is common in the sedimentary rocks of Subregion 3 and in parts of Subregions 5 and 6 underlain by bedrock or unconsolidated materials composed of calcium and magnesium carbonate. The distribution of dissolved solids, iron and manganese and hardness of ground water and of streams under conditions of low flow have been summarized on maps for this part of the study region (see Appendix C).

Other natural chemical constituents that are locally present in concentrations exceeding U.S. Public Health Service (45) or Connecticut State Department of Health (7) recommended limits for drinking water include sodium, fluoride, chloride and sulfate. Most of the reported excess concentrations of these constituents are from wells tapping the sedimentary bedrock in Subregion 3.

In the Connecticut part of the study region, ground water pH is generally between 6 and 8 although values as low as 4.4 and as high as 9.4 have been measured. The average ground-water temperature is approximately 50°F and at depths greater than 30 feet fluctuates slightly. Ground water at depths of less than 30 feet however may seasonally vary in temperature by as much as 20°F (27).

The effect of man's activities on the hydrologic system, while qualitatively similar to Long Island, are quantitatively different. Hydrologic imbalances resulting from overpumping or impairment of ground-water quality are confined to within the area of a drainage basin. In addition, only a small part of the total water used on the north shore of Long Island Sound is derived from the ground-water reservoirs. For example, in the lower Thames River basin and in southwestern Connecticut approximately 5 to 10 percent of the water used in the mid-1960's was from wells (37, 31).

The two principal activities that result in losses of water from the ground-water reservoirs are (1) disposal of waste water originally derived from wells to streams or the ocean and (2) increased direct runoff to streams in urbanized areas. This loss is greatest in the urbanized coastal areas, but no quantitative estimate of its magnitude has been made.

Artificial recharge to the ground-water reservoirs is from septic tanks, leaky water and sewer pipes and from streams and lakes adjacent to centers of ground-water development. Artificial recharge from streams and lakes is a very important factor in sustaining well yields. Most large public and industrial supply wells tap stratified drift that is hydraulically connected to an adjacent stream. The effects of pumping induce the surface water to move through the streambed materials and into the ground-water reservoir.

The quality of ground water has been locally altered by (1) disposal to the ground of sewage and industrial effluent and landfill disposal of solid wastes, (2) leaching of fertilizers and deicing compounds, and (3) induced recharge of water from streams and salt-water encroachment in areas of ground-water development. Most cases of pollution are apparently local, but there is no continuing program of monitoring ground-water quality to evaluate long-term changes.

The existing pattern of development on the north shore of Long Island Sound consists of:

(1) Surface-water reservoirs and well fields tapping stratified-drift deposits that provide water for urbanized areas. Waste disposal is principally by sewage treatment plants that discharge to streams, estuaries and the ocean.

(2) Individual wells principally tapping bedrock provide water for rural and many suburban parts of the area. Waste disposal is to septic tanks and cesspools.

Both of the above patterns of development may produce hydrologic problems. Large scale ground-water development reduces streamflow in adjacent streams and by lowering the water table can affect lake levels and swamps. During periods of low streamflow, the pumping may even dry up a reach of stream. In the coastal urban centers of New Haven and Bridgeport, Connecticut pumping over a long period resulted in widespread salt-water encroachment of the stratified-drift aquifers and subsequent abandonment of many wells. In the less developed areas, septic tank disposal may be inadequate and require sewer-ing or the effluent may deteriorate the ground-water quality.

The development and management of ground-water resources must take into account the hydrologic balance between inflow and outflow within each ground-water reservoir. Only small local imbalances exist at the present, primarily because of the small amount of development.

Future large scale ground-water development will occur principally in valleys containing thick permeable deposits of stratified drift. In most areas, these deposits are hydraulically connected to adjacent streams and may be termed stream-aquifer systems. The sustained yield of these stream-aquifer systems may vary considerably depending on the scheme of management. For example, estimated yields of several stream-aquifer systems in Subregions 1, 4 and 5 shown on maps prepared for this study (see Appendix C) range from less than 0.5 to over 15 million gallons per day. These yields were predicted on a management scheme, the essential elements of which are (1) the water pumped is not returned to the ground-water reservoir or stream near the site of withdrawal, (2) minimal effect on streamflow, and (3) fairly constant rate of pumping. Several alternative management schemes would significantly alter the estimated long-term yields.

A continuous program of hydrogeologic investigations is necessary for planning the optimal development and management of both ground- and surface-water resources on the north shore of Long Island Sound. Such a program should

include (1) expanded data collection activities particularly in areas of potential development and existing centers of ground-water pumpage, (2) monitoring of ground-water quality to evaluate long-term changes due to man's activities, (3) determination of the hydraulic properties of stratified drift and sedimentary bedrock aquifers, (4) definition of the geometry and pattern of ground-water circulation in the sedimentary bedrock of Subregion 3.

6.0 BRACKISH AND SALT WATER BODIES

Salty and brackish waters occupy Long Island Sound, the lower reaches of the streams that drain into the Sound and the coastal and offshore parts of the ground-water reservoirs. This section is concerned with the Sound and saline parts of the estuaries because little is known about the movement of salty ground water in the region. Some geographic features of the Sound such as area and volume have already been noted on pages 5 and 6, and detailed information on the configuration and depth is shown on hydrographic charts and bathymetric maps (21, 40) published by the National Ocean Survey. Figure 15 shows several geographic features of the Sound and the principal estuaries referred to in this report.

Figure 15. Geographic features of Long Island Sound.

6.1 Availability of Data

Measurements of tides and tidal currents have been made in various parts of Long Island Sound and adjacent estuaries for at least 136 years (33). The National Ocean Survey (formerly the U.S. Coast and Geodetic Survey) publishes tide tables of daily tide predictions and tidal current tables on an annual basis (22, 23). This agency also periodically publishes hydrographic charts and bathymetric contour maps of Long Island Sound (21, 40). Information on water movement as well as other aspects of physical oceanography in the Sound and estuaries is contained in numerous publications of Oceanographic institutions and scientific journals, many of which are cited in the list of references.

6.2 Circulation and movement

The circulation or movement of water within Long Island Sound and the adjacent estuarine streams is controlled by tides, fresh-water inflow, winds and other weather conditions, bottom topography and salinity or temperature gradients. The circulation pattern in turn affects the chemical composition of water and sediment distribution within the Sound and estuaries.

Figure 16. Tidal currents at the eastern end of Long Island Sound two hours after "slack water" at The Race. Speed of currents in knots at time of spring tides.

Long Island Sound is technically described as a co-oscillating tidal basin (33) characterized by minimum tidal range and maximum tidal current at its mouth and maximum tidal range and minimal tidal currents at the almost closed western end. At the eastern passage known as The Race the tidal range is 2.5 feet and the maximum currents are over 5 knots (5.8 mph). The tide range increases to the west, whereas the current velocities decrease.

The dominant horizontal motion of the waters of the Sound are the semidiurnal tidal currents. The direction and speed of tidal currents in the upper waters at the time of full moon and under normal weather conditions are shown on tidal current charts prepared by the National Ocean Survey (22). An example of tidal surface currents at the eastern end of the Sound is shown on Figure 16. While the tidal circulation pattern of the surface and near surface waters is well defined relatively little is known about the deep current circulation.

Tidal currents shown on such charts are subject to modification by nontidal currents due to winds and fresh water inflow from rivers. For example offshore and onshore winds modify the currents along the coast and during periods of very high runoff the fresh water inflow from the Connecticut River creates a distinct plume of lighter and fresher water that moves generally eastward toward Block Island Sound (29, 51, 52).

Figure 17. Observations of tidal current speed at various depths. Measurements made at an anchor station in east-central Long Island Sound (Lat 41°11.9'N, Long. 72°29.4'W) in 1953. After Riley (1956, Fig. 7).

Measurements of both surface and bottom currents over many tidal cycles (33, 49) show that in the central part of the Sound the tidal current patterns are elliptical and counterclockwise in direction. Because of the effect of coastal topography, tidal currents along the coast are almost parallel to the shoreline. The significant vertical differences in tidal currents are that ebb tides are stronger at the surface than at depth and flood tides are weaker at the surface than at depth as shown on Figure 17. In the deep water of the central Sound tidal current speeds regularly exceed 30 centimeters per second (1 foot per second) near the bottom (written communication, Gordon and Pilbeam, 1973).

The eastern part of Long Island Sound contains a two-layered transport system where a less dense, less saline surface layer moves eastward into Block Island Sound at an average speed of 2.8 nautical miles per day. This water is replaced by more saline and dense bottom water that flows westward into Long Island Sound at an average speed of 0.6 nautical miles per day. Recent investigations on currents at the eastern end of the Sound (53) indicate (1) that there is a predominant inflow in the lower two thirds of the water column in deep portions of The Race over a tidal cycle, (2) there is a net outflow in the shallower remainder of the eastern passage between Orient Point and Fishers Island, and (3) the inflow and outflow pattern suggest there is a tidal-driven counterclockwise circulation in the eastern third of Long Island Sound. Detailed information on the duration and variability of the two-layered transport system at the eastern margin of the Sound is not yet available. The interchange although complex in detail is apparently controlled by the fresh-water inflow. The total annual inflow of water from Block Island Sound has been tentatively estimated at 3.8 times the total volume of Long Island Sound (29).

Moving westward into the central part of the Sound the circulation system becomes less dynamic. There is decreasing transport in the bottom layers principally because of upwelling and near shore mixing. According to Gordon and Pilbeam (written communication, 1973), the bottom water flows westward into the central Sound principally along the north side of Six Mile Reef near Clinton, becomes mixed with Connecticut River water and follows a west-southwest course along the Connecticut shore. Inshore of the 10-fathom (60 foot) curve the flow is toward the coast. The nontidal flow rate of near bottom waters is as high as 5 kilometers (3.1 miles) per tidal cycle in the deeper water and decreases toward either shore. Recent studies (14) indicate that upwelling of bottom waters occurs along the Connecticut shore between New Haven and Old Saybrook and in coastal Long Island between Mattituck Inlet and Orient Point. There is also an offshore movement of surface water away from the Connecticut coast. The net flow of near-surface waters is eastward from the central to the eastern part of the Sound. The general net flow pattern for eastern and east-central Long Island Sound is shown on Figure 18.

Hardy (11) characterized the waters of the central part of the Sound, west of the Mattituck Sill (see Fig. 15), as seasonally homogeneous probably because of vertical mixing due to tidal currents and wind. Mixing between the bottom and surface waters occurs along both shores and in the vicinity of Six Mile Reef (written communication, Gordon and Pilbeam, 1973). Salinity stratification, however exists at least part of the time in the central Sound.

Figure 18. Conceptualized view of the essential features of the net flow in eastern Long Island Sound and Block Island Sound. Black arrows depict net bottom flow and white arrows net surface flow. After Hollman and Sandberg (1972).

Water flows into western Long Island Sound from both directions. Bottom water enters from the east principally in the area south of Stratford Shoal (written communication, Gordon and Pilbeam, 1973) while relatively fresh water enters from the East River. The recently verified net transport of water from the East River into Long Island Sound (11) may be significantly less than the original estimate of 1100 cubic meters per second (29). The transport system at the western end of the Sound is two-layered with relatively fresh water flowing eastward into the Sound and then primarily along the north shore of Long Island while bottom water flows westward into the East River.

Western Long Island Sound waters are reported to be well mixed internally but poorly mixed with the water to the east. From Hempstead Sill (see Fig. 15) to the East River, however, the water exhibits vertical temperature, salinity and density stratification (11).

Riley (28, 29) and others have attempted to estimate the residual volume transport through various parts of the Sound or for one cross section for various periods of time. Because of incomplete data the calculations are very uncertain and continuous monitoring of currents are required to give reasonable estimates of transport.

The vertical movement of the water surface in the Sound results from the periodic tidal oscillations, from waves produced by wind and over long periods by changes in sea level. Factors influencing the heights of tides, abnormally high tides and storm generated waves are discussed in a separate report prepared for this study by the Dept. of the Army, Corps of Engineers (39).

Long-term changes in sea level over the last 10,000 to 15,000 years have produced extensive submergence of the coast (2). Tide gage records and tidal benchmark data indicate that sea level may still be rising at a rate of approximately 1 foot per century.

6.3 Estuaries

Estuaries are sometimes defined as the seaward ends of river valleys that contain salty water.¹ Ocean tides affect the streamflow and flow may be either upstream or downstream depending on location, tide and fresh water inflow conditions. The major estuaries in the region are the Connecticut, Thames, Housatonic and Quinnipiac. Studies (9, 16, 32) indicate that there is a two-layer transport system in the lower parts of these estuaries. Fresh water flows seaward near the surface while the tides move denser saline water upstream along the river bottom. Salinity generally increases downstream and top to bottom at any point in the brackish part of the estuary. The distribution of salinity changes with the tidal stage and the amount of fresh water inflow.

In the largest estuary, the Connecticut, saline water may reach 15 miles upstream from the mouth (16) and tidal effects may extend upstream approximately 60 miles. The upstream extent of salinity and tidal influence is generally controlled by the amount of fresh-water inflow. During periods of high fresh-water inflow (greater than 100,000 cfs), saline water is flushed to the mouth of the river and the tide-affected reach extends upstream only 30 miles. Figure 19 shows the effect of different river discharge conditions on chemical quality.

In the second largest estuary, the Thames, tidal effects and saline water extend upstream to Norwich. Information on the salinity distribution and its variability in this estuary is contained in a recent report by Soderberg and Bruno (32). The Housatonic and Quinnipiac estuaries extend upstream 12 and 10 miles respectively.

¹ - Another commonly used definition is: a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage.

Figure 19. Chlorinity at high slack water in the lower part of the Connecticut River during different river-discharge conditions. Chloride concentration in parts per thousand. Indicated discharge is for previous day at Thompsonville, Connecticut. After Meade (1966, Fig. 3).

Major estuaries and adjacent parts of the Sound receive a large proportion of the pollutants entering the region and are therefore areas of critical concern. The movement of water in estuaries is complex in that it is controlled to various degrees by tidal motion and fresh-water inflow. Flow information sufficient to permit predictions of the amount of pollutants and the rate of transport through an estuarine reach and into the Sound is generally not available. At present, continuous stage information in tide affected rivers is restricted to the 25-mile long reach of the Connecticut River between Hartford and Middle Haddam. This data collected by the U.S. Geological Survey can produce flow information such as stage, upstream and downstream discharge, water-surface profile and flushing time at any location in a reach and for any period of time. Limited flow data is available for a 45-mile reach between Wilson and Essex while flow is continuously computed for a 4-mile reach between Middletown and Middle Haddam.

7.0 WHAT THE STUDY WILL DO NEXT

The information on sources and movement of water gathered in the inventory phase of this study and summarized in this report will be used in developing management plans. The material should be especially useful for water quality, water supply and flooding. But it should also be useful for other plans such as land use, erosion and sedimentation, and ecological studies in assessing the impact of management on the existing natural system.

The work group on sources and movements of water will help the other work groups in four ways:

- (1) By providing this summary report to all work groups and by making the more detailed data upon which it rests available as needed.
- (2) In a passive way, by responding to work group requests for supplementary information or interpretations.
- (3) In an active way, by pointing out to the other work groups ways in which information on sources and movements on water might assist in solving their major problems. Some examples:

At the western end of the Sound, information on in-flow and outflow is very poor; the direction and velocity of flow varies in a poorly understood way according to tidal phase, depth, buoyancy and other factors. However, it is known that the net surface flow is towards the Sound and the net bottom flow is out of the Sound. Therefore, there is a potential capability, which needs further investigation, of directing the flow of sewage into or out of the Sound. This might be accomplished by considering the combined effects of currents, outfall locations and outfall elevations in New York City, and possibly by correlating sewage discharges there with favorable phases of the tidal cycle.

In the center of the Sound with its complex gyre patterns, the retention time of natural runoff and sewage is relatively long as compared with the eastern part of the Sound where they are swept much more rapidly out to sea through The Race. Recognition of these gross patterns might influence the priorities and degrees of waste treatment in Bridgeport, New Haven, New London, and cities along the Connecticut River. To the extent that thermal effects of proposed power plants are determined to be widespread and significant, the gross circulation patterns should be a significant consideration affecting site selection and outlet design.

The worst water quality in the Sound is probably in the metropolitan harbors where the direct pollution effects on people are the most intense. In addition to upgrading waste treatment systems, extending outfalls into the Sound is sometimes suggested. Our existing, generally poor knowledge of circulation patterns might still be able to tell us something about this approach, and more detailed localized knowledge should be collected.

(4) By articulating the highest priority research needs. Foremost among these are (a) the currently inadequate quantification of the dynamic circulation system within the Sound and major estuaries especially at the western end of the Sound, (b) the lack of climatologic data in the area over the Sound itself, (c) the need to continually monitor the hydrologic system of Long Island, and (d) the need for quantitative hydrogeologic data on the mainland part of the study region. The study team will evaluate the importance of the data deficiencies and make specific recommendations for programs to acquire necessary information. The proposed programs will consider ongoing studies and where possible be integrated with them.

APPENDIX A

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APPENDIX B

GLOSSARY

Air mass - A widespread body of air, the properties of which can be identified as having been established while that air was situated over a particular region of the earth's surface and having undergone specific modifications while in transit away from the source region.

Anticyclone - An atmospheric closed clockwise circulation. Because clockwise circulation and high atmospheric pressure usually coexist, the terms anticyclone and high are used interchangeably in common practice.

Artesian conditions - Ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.

Bathymetric - Relating to measurement of depths; usually applied to the ocean.

Bedrock - The solid rock, commonly called "ledge," that forms the earth's crust.

Chemical quality of water - The quantity and kinds of material in suspension or solution and the resulting water properties.

Chlorinity - The chloride content of sea water, measured by mass, or grams per kilogram of sea water, and including all the halides.

Climatic year - A continuous 12-month period, April 1 through March 31, during which a complete annual streamflow cycle takes place from high flow to low and back to high flow. It is designated by the calendar year in which it begins.

Continuous-record gaging station - A site on a stream at which continuous measurements of stream stage are made by automatic equipment or made manually at least once a day. These records are converted to daily flow after calibration by flow measurements.

Cubic foot per second (cfs) - A unit expressing rate of discharge. One cubic foot per second is equal to the discharge of a stream 1 foot wide 1 foot deep flowing at an average velocity of 1 foot per second.

Cyclogenesis - Any development or strengthening of cyclonic circulation in the atmosphere.

Cyclone - An atmospheric closed counterclockwise circulation.

Seven-day ten-year low flow - The mean daily stream flow for seven consecutive days occurring on an average once in ten years.

Degree day - Generally, a measure of the departure of the mean daily temperature from a given standard: one degree day for each °F of departure above or below the standard during one day. Degree days are accumulated over a "season" at any point during which the total can be used as an index of past temperature effect upon some quantity, such as plant growth, fuel consumption, power output, etc.

Dissolved solids - The residue from a clear sample of water after evaporation and drying for one hour at 180°C; consist primarily of dissolved mineral constituents, but may also contain organic matter and water of crystallization.

Drainage area of a stream at a specified location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

Estuary - A bay, as the mouth of a river, where the tide meets the river current.

Evapotranspiration - Discharge of water to the atmosphere by direct evaporation from the land and by transpiration from plants.

Extratropical cyclone - Any cyclonic-scale storm that is not a tropical cyclone.

Frequency - The rate of recurrence of an event in periodic motion: The number of times a specified event occurs in a given series of observations.

Ground water - Water in the saturated zone.

Ground-water discharge - The discharge of water from the saturated zone by 1) natural processes such as ground-water runoff and ground-water evapotranspiration and 2) discharge through wells and other man-made structures.

Ground-water divide - A line on a water table on each side of which the water table slopes downward in a direction away from the line. In the vertical dimension, a plane across which there is no ground-water flow.

Ground-water outflow - All natural ground-water discharge from a drainage area exclusive of ground-water evapotranspiration.

Hardness, of water - The property of water generally attributable to salts of the alkaline earths. Hardness has soap-consuming and encrusting properties and is expressed as the concentration of calcium carbonate (CaCO₃) that would be required to produce the observed effect.

Hydraulic conductivity - A measure of the ability of a porous medium to transmit a fluid.

Hydrogeology - The science that deals with subsurface waters and related geologic aspects of surface waters.

Impermeable - Having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Induced recharge - The amount of water entering an aquifer from an adjacent surface-water body by the process of induced infiltration.

Injection well - A well into which water is pumped.

Isotherm - A line of equal or constant temperature.

Isopleth - A line on a map connecting points at which a given variable has a specified constant value.

Knot - The unit of speed in the nautical system; one nautical mile per hour. It is equal to 1.1508 statute miles per hour or 0.5144 meters per second.

Milligrams per liter (mg/l) - A unit for expressing the concentration of chemical constituents in solution by weight per unit volume of water.

Palmer Drought Index - Provides a measure of drought severity as well as duration. It treats drought severity as a function of accumulated weighted differences between actual precipitation and the precipitation requirements, where the requirement depends on the carryover of previous rainfall as well as on the evapotranspiration, moisture recharge and runoff that would be climatically appropriate for the particular time and place being investigated.

Perennial stream - A stream that flows during all seasons of the year.

pH - The negative logarithm of the hydrogen-ion concentrations. Ordinarily a pH value of 7.0 indicates that the water is at its neutral point; values lower than 7.0 denote acidity, those above 7.0 denote alkalinity.

Recharge - The amount of water that is added to the saturated zone.

Recurrence interval - The average interval of time between extremes of streamflow, such as floods or droughts, that will at least equal in severity a particular extreme value over a period of many years. **Frequency**, a related term, refers to the average number of such extremes during the same period. The date of a drought or flood of a given magnitude cannot be predicted, but the probable number of such events during a reasonably long period of time may be estimated within reasonable limits of accuracy.

Runoff - That part of the precipitation that appears in streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Salinity - A measure of the quantity of total dissolved solids in water.

Salt-water encroachment - The phenomenon occurring when a body of salt water, because of its greater density, invades a body of fresh water.

Saturated thickness - Thickness of an aquifer below the water table.

Saturated zone - The subsurface zone in which all open spaces are filled with water. The water table is the upper limit of this zone and the water in it is under pressure greater than atmospheric.

Sedimentary rock - Rocks formed by the accumulation of sediment.

Specific capacity, of a well - The rate of discharge of water divided by the corresponding drawdown of the water level in the well (gpm/ft).

Stratified drift - A predominantly sorted sediment laid down by or in meltwater from a glacier; includes sand and gravel and minor amounts of silt and clay arranged in layers.

Till - A predominantly nonsorted, nonstratified sediment deposited directly by a glacier and composed of boulders, gravel, sand, silt, and clay mixed in various proportions.

Tropical cyclone - The general term for a cyclone that originates over the tropical oceans. Fully mature tropical cyclones range in size from 60 miles in diameter to well over 1,000 miles in diameter.

Water table - The upper surface of the saturated zone.

Water year - A continuous period October 1 through September 30 during which a complete streamflow cycle takes place from low to high flow and back to low flow. A water year is designated by the calendar year in which it ends.

Wind rose - Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period; it thus shows the prevailing wind direction.

APPENDIX C

HYDROLOGIC AND CLIMATOLOGIC MAPS, GRAPHS AND TABLES PREPARED FOR THE LONG ISLAND SOUND REGIONAL STUDY

Copies are on file at the offices of the New England River Basins Commission

- I. Flood Prone Area Maps for the following quadrangles in Subregions 1, 2, 3, 4 and 5. Scale 1:24,000.
Ansonia	Haddam	New Haven	Scotland
Clinton	Jewett City	Naugatuck	Southbury
Colchester	Long Hill	Norwalk North	Wallingford
Deep River	Meriden	Norwich	Westport
Essex	Middle Haddam	Old Lyme	Willimantic
Guilford	Moodus	Plainfield	
- II. Hydrologic maps for Subregions 6, 7, 8 and 9; all maps at 1:125,000 or 1:250,000 scale.
- Lines of equal thickness - Magothy aquifer
Contours on the surface of the upper glacial aquifer
Contours on the surface of the Magothy aquifer
Contours on the surface of the Raritan clay
Contours on the surface of the Lloyd aquifer
Contours on the surface of the bedrock
Elevation of water tables, March 1971
Piezometric surface of Lloyd aquifer, January 1972
Selected geohydrologic sections
Piezometric surface at the base of the Magothy aquifer, March, 1972
- Cross section of Long Island: Approximate time for ground water to travel along section c-c' from water table
 - The relation of heads of major aquifers
- Isopach of Raritan clay of the Raritan Formation
Isopach of Lloyd aquifer
Water quality of the Magothy aquifer
Isopach of saturated upper glacial aquifer
Mean-annual flow of all gaged streams
Mean-monthly flow of continuously gaged streams
Water quality of the Lloyd aquifer
Water quality of the upper glacial aquifer
Estimated average hydraulic conductivity of Magothy aquifer
Estimated average hydraulic conductivity of upper glacial aquifer
Patterns of ground-water development
Estimated average hydraulic conductivity of Lloyd aquifer
Transmissibility of Lloyd aquifer
Locations of stream gaging stations
Net change of ground-water levels as a result of the 1962-66 drought
Location of recharge basins in Naussau and Suffolk Counties, Long Island, N.Y.
- III. Hydrologic tables and maps for Subregions 1, 2, 3, 4 and 5.
- Ground-water availability; 1:62,500 scale.
Drainage areas; 1:24,000 scale.
Average yearly runoff; 1:62,500 scale.
Monthly average runoff, peak runoff (return periods of) 100, 50, 25, 2 years, 7 day-10 year runoff; 1:62,500 scale.
Time of travel - Quinnipiac River (table)
Time of travel - Connecticut River (table)
Distribution of dissolved solids in ground water and streams at low flow; 1:125,000 scale.
Distribution of iron and manganese in ground water and streams at low flow; 1:125,000 scale.
Distribution of hardness of ground water and streams at low flow; 1:125,000 scale.
- IV. Three maps showing locations of tidal bench marks for New York and Connecticut.
- V. Three lists of differences between Sea-Level Datum of 1929 (SLD) and mean low water (MLW) for each location where tidal bench marks and geodetic bench marks of the precise level net have been connected by spirit levels.
- VI. Thirty-one tidal bench mark sheets giving descriptions to aid in recovery of the marks and tide information. Mean high water (MHW) and mean tide level (MTL) are given as related to MLW. Mean range can be obtained as the difference between MHW and MLW.
- VII. Tide Tables, East Coast of North and South America showing time and differences in relation to reference stations as well as ranges. Nos. 1187-1263 and 1331-1407 are applicable to Long Island Sound.
- VIII. Tidal current charts
- Tidal current charts for:
Long Island Sound and Block Island Sound
Block Island Sound and Eastern Long Island Sound
Western Long Island Sound (will be available in January 1974)
 - Tidal current diagrams for 1973 to accompany the above charts
- IX. Volume of water in Long Island Sound
- X. Bathymetric data
- Bathymetric contour maps of Long Island Sound (C & GS 0808N-51, 53, and 55)
- B. Fourteen hydrographic survey sheets of surveys conducted within Long Island Sound since the compilation of the Bathymetric maps
H-8949 (1967)	H-8997 (1968)	H-9088 (1969)
H-8951 (1967)	H-9008 (1968)	H-9089 (1969)
H-8952 (1967)	H-9093 (1968)	H-9081 (1970)
H-8967 (1967)	H-9030 (1968)	H-9012 (1971)
H-8996 (1968)	H-9087 (1969)	
- These sheets are in the process of being verified.
- C. Nautical charts
C & GS 1212	Long Island Sound eastern part
C & GS 1211	Block Island Sound
C & GS 1213	Long Island Sound western part
- XI. Fresh water inflow into Long Island Sound
- XII. Map of New York State sewage treatment facilities discharging to Long Island Sound
- XIII. List of references
- Reference to bedrock, surficial deposits and ground-water resources of New York State in the Long Island Sound Study area.
 - List of Geological publications of the New York State museum
 - Resume of investigations of the marine geology of the environs of Long Island, New York
- XIV. Listing of the available historical precipitation data
- XV. Bedrock contour maps of major river estuaries; 1:24,000 scale.
- Bedrock contour map of the New London quadrangle
 - Bedrock contour map of the New Haven quadrangle
 - Bedrock contour map of the Milford quadrangle
 - Bedrock contour map of the Old Lyme quadrangle
- XVI. Climatological maps and graphs
- Mean annual temperature
Mean annual temperature range
Annual march of the standard deviation of mean temperatures for 5 stations
Long-term variations in precipitation at Setauket, N.Y., water years 1887-1971
Long-term variations in precipitation at New London, Conn., water years 1887-1967
Long-term variations in precipitation at New Haven, Conn., water years 1887-1967
Mean annual snowfall
Average length of the freeze free season (in days)
Observed frequency of tropical storm and hurricane occurrence in and near the Long Island Sound Study area
Maximum annual number of thunderstorms
Mean monthly radiation at Central Park, N.Y., Sayville, L.I. and Newport, R.I.
Annual march of mean cloudiness in tenths for 2 stations on Long Island
Wind roses for each of four seasons at 5 stations
- XVII. Climatological tables
- Monthly and annual mean maximum temperature
Monthly and annual mean minimum temperature
Monthly and annual mean temperature
Monthly and annual extreme maximum temperature statistics
Monthly and annual extreme minimum temperature statistics
Monthly and annual mean, greatest and least number of days with maximum temperature less than or equal to 32°, 45°, 80°, 90°F
Monthly and annual mean, greatest and least number of days with minimum temperatures less than or equal to 45°, 36°, 32°, 24°, 16°, 0°F
Air conditioning design data
Air conditioning criteria data
Heating design data
Mean monthly and seasonal heating degree-days (base 65°F)
Mean monthly and seasonal cooling degree-days (base 65°F)
Probability dates of last spring and first fall occurrence of 32°, 24°, and 16°F
Mean monthly and seasonal growing degree-days (base 50°F)
Mean monthly and seasonal growing degree-days (base 40°F)
Monthly and annual greatest, least and mean number of days with temperature moving through the 32°F threshold (freeze-thaw)
Expected recurrence intervals of maximum point rainfall amounts
Extreme 24-hour precipitation statistics
Extreme 24-hour snowfall statistics
Greatest monthly and annual precipitation for entire period of record
Least monthly and annual precipitation for entire period of record
Mean, greatest and least monthly and annual number of days with precipitation equal to or greater than .01, .10, .50 and 1.00 inches
Mean and greatest monthly and seasonal snowfall
Mean and greatest monthly and annual number of days with snowfall equal to or greater than 1, 2, 4 and 8 inches
Snow cover statistics and probabilities
Probability that an existing tropical cyclone centered at a specified latitude and longitude in the month shown will be within the Long Island Sound Study area after 72, 48 and 24 hours
Chronology of Long Island Sound Study area tornadoes
Humidity statistics for 4 stations for January, April, July and October
Frequency of occurrence of sky cover
Distribution of runs of dry days

APPENDIX D

LOCATION OF STATIONS USED IN LONG ISLAND SOUND REGION CLIMATOLOGICAL ANALYSIS.
STATIONS IN PRIMARY NETWORK INDICATED BY SOLID CIRCLES.

APPENDIX E

SUMMARY OF DISCHARGE RECORDS FOR MAINLAND STREAMS

Stream	Subregion <u>1/</u>	Drainage area	Mean annual flood (Discharge in cfs adjusted to base period 1941-70)	Mean annual discharge	Mean highest month	Mean lowest month 1941-70)	7-day, 10-year low flow
Pendleton Hill Brook near Clarks Falls	1	4.02	-	8.80	18.9	2.11	0.01
Great Brook at Poquonock Bridge	1	14.1	-	24.5	50.8	7.24	-
Shetucket River near Willimantic	(1)	402	6,060	648	1,340	219	38
Quinebaug River at Jewett City	1	715	9,060	1,190	2,410	447	86
Yantic River at Yantic	1	90.0	2,520	147	330	38.0	4.4
Connecticut River at Thompsonville	(2)	9,661	95,000	15,600	45,300	5,860	2,164
Coginchaug River at Rockfall	(2)	34.7	-	58.3	140	10.5	1.0
Salmon River near East Hampton	(2)	102	2,850	168	360	47.6	4.6
Hemlock Valley Brook at Madlyne	2	2.62	-	5.42	11.0	1.24	.2
East Br. Eightmile River near North Lyme	2	22.3	646	42.4	91.8	10.4	.29
Menunketesuck River near Clinton	2	11.2	481	21.0	45.7	4.31	.14
Neck River near Madison	3	6.55	-	12.0	25.8	2.31	.05
Quinnipiac River at Wallingford	3	110	1,890	192	373	90.7	32
Pomperaug River at Southbury	(4)	75.0	3,600	118	250	35.0	5.6
Copper Mill Brook near Monroe	4	2.45	-	4.03	9.55	.64	.05
Housatonic River at Stevenson	4	1,541	22,900	2,440	5,190	817	150
Naugatuck River at Beacon Falls	4	259	15,300 <u>2/</u>	486	982	185	64
Sasco Brook near Southport	4	7.27	-	-	-	-	.02
Saugatuck River near Redding	5	20.8	-	-	-	-	.2
Saugatuck River (coastal area)	5	26.3	-	-	-	-	1.4
Norwalk River at South Wilton	5	27.6	-	-	-	-	.9
East Br. Byram River at Riversville	5	7.54	-	-	-	-	.01
Blind Brook at Rye, N.Y.	6	9.20	631 <u>3/</u>	14.2 <u>3/</u>	28.5 <u>3/</u>	4.92 <u>3/</u>	.36
Beaver Swamp Brook at Mamaroneck, N.Y.	6	4.71	115 <u>4/</u>	6.01 <u>5/</u>	-	-	.09 <u>6/</u>
Mamaroneck River at Mamaroneck, N.Y.	6	23.4	1,240 <u>4/</u>	30.8 <u>5/</u>	-	-	.28 <u>7/</u>
Hutchinson River at Pelham, N.Y.	6	5.76	226 <u>4/</u>	6.43 <u>5/</u>	-	-	.08 <u>7/</u>
Bronx River at Bronxville, N.Y.	6	26.5	758 <u>4/</u>	38.9 <u>5/</u>	-	-	3.4 <u>7/</u>

1/ A subregion number in parentheses is for a stream tributary to the subregion. 2/ For period 1941-60; high flows regulated thereafter. 3/ For period 1944-67. 4/ For period 1943-72. 5/ For period 1946-67. 7/ For period 1945-66.

COORDINATING GROUP
LONG ISLAND SOUND REGIONAL STUDY
As of the date of this report

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Connecticut Office of State Planning	Horace Brown
State of New York	Edward A. Karath
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Tri-State Regional Planning Commission	Richard DeTurk
Atomic Energy Commission	Walter Belter
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Department of Housing and Urban Develop'nt	Nick M. Nibi
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