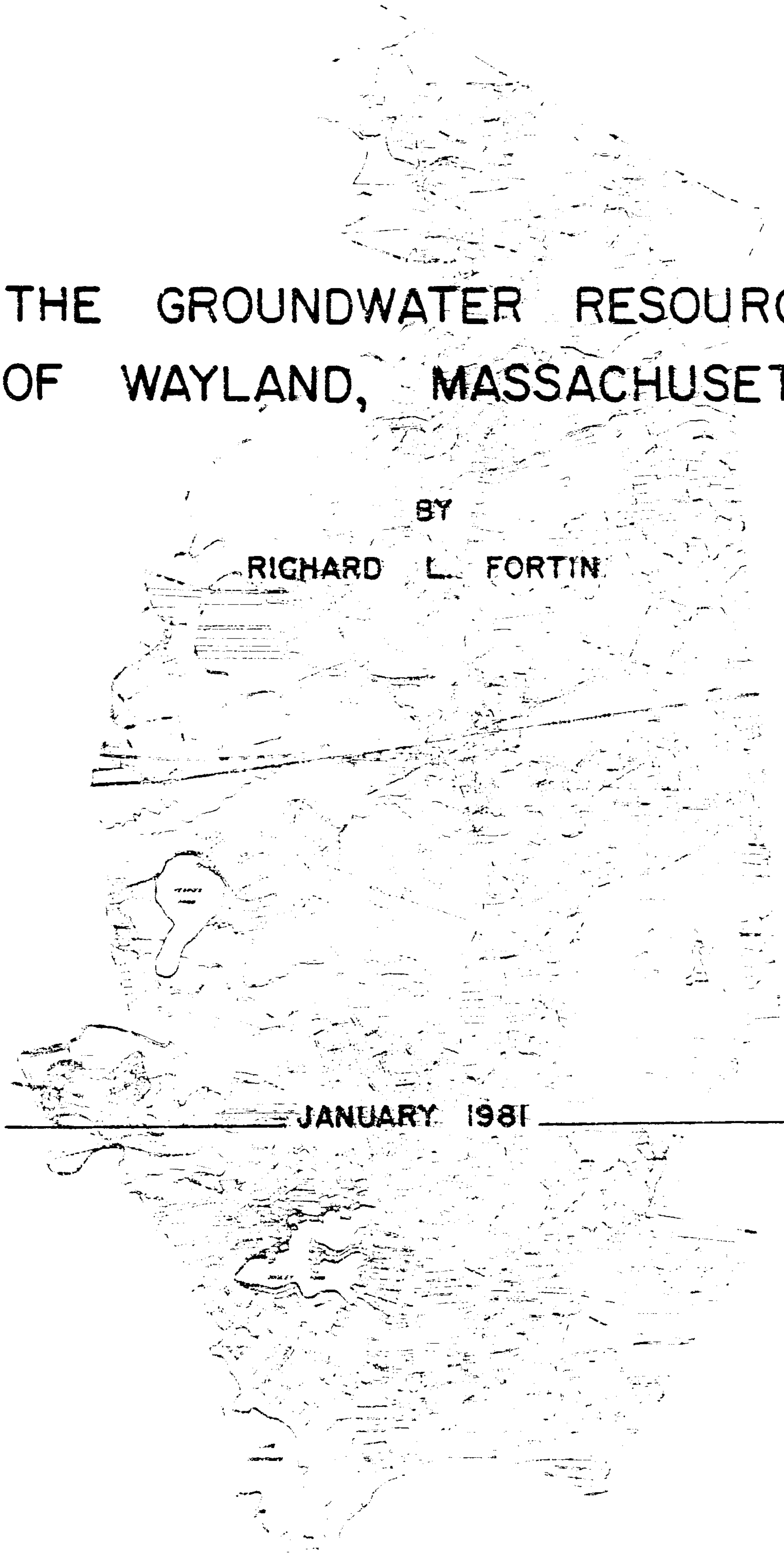
THE GROUNDWATER RESOURCES OF WAYLAND, MASSACHUSETTS

BY

RICHARD L. FORTIN

JANUARY 1981



THE GROUNDWATER RESOURCES OF WAYLAND, MASSACHUSETTS

by

Richard L. Fortin
MUA, Hydrogeology
Boston University

January 1981

To [illegible] Bowker
From Richard Fortin

ACKNOWLEDGMENTS

I would like to express my deep appreciation to the following people for having been extremely helpful to me during the course of this study.

<u>For Technical Information</u>:

Mr. John Roche, Superintendent
Wayland Water Department

Mr. Bruce Hansen
U.S. Geological Survey, Boston

D. L. Maher Company
North Reading, MA

State and Municipal Governments
Referenced in this report.

<u>For Review of Text and Maps</u>:

Dabney W. Caldwell, Ph.D.
Geology Department
Boston University

Mrs. Sarah R. Newbury
Wayland Conservation Commission

Mr. Lewis L. Bowker, Jr.
Wayland Engineering Department

CONTENTS

Page

CONTENTS

INTRODUCTION

A. Purpose and Scope

In the late 1800's Wayland developed a reservoir for water supply to the Cochituate area. The reservoir was created by constructing an earth and stone dam in the upper reaches of the Snake Brook watershed. On the lower side of the dam a gatehouse was built to control the main water line leading south. By the 1920's the reservoir could no longer serve as the Town's water supply. The gravel infiltration beds had become clogged and runoff from upland swamps carried dissolved iron and organics into the reservoir resulting in poorer water quality. Consequently, the Town began to look for other sources of water and initiated an aggressive testing program to find productive well sites.

The results of this program are evident today. The Water Department has seven wells in operation and another site confirmed for future use. In the past some of the wells were threatened by contaminants from various sources, but fortunately these problems have been corrected. Other communities have been less fortunate. A report by the Massachusetts Division of Water Resources (1976) lists numerous well sites abandoned because of pollution. For example, in the 1960's and 1970's water supplies were contaminated by road salt, landfill leachate, sewage disposal and pesticides. Within the last two years, hazardous waste disposal has been recognized as a very serious threat to groundwater resources in New England and throughout the United States.

Pollution of water supplies has increased in developed areas where land use controls are lacking. Therefore, it has become very important for communities to understand the occurrence and movement of groundwater so that effective protection and management strategies can be adopted. This study was initiated in order to assist Wayland in this regard. The purpose and scope of this report are:

1. To provide an understanding of where, when and how groundwater occurs within the Town, including a delineation of physical conditions and an evaluation of hydrogeologic relationships.

2. To review records of past and present use of water in the Town in order to determine important trends and suggest useful water management strategies.

3. To analyze the hydraulic characteristics and spatial relationships of certain municipal wells currently in use.

4. To recommend techniques for controlling and improving land use practices for the protection of surface and groundwater resources.

5. To recommend additional studies and site investigations for developing a better understanding of the hydrogeology in areas where current information is inadequate.

B. Description of Study Area

1. Natural Environment

The Town of Wayland occupies 15.9 square miles of the inland coastal plain in eastern Massachusetts. Located approximately 20 miles west of Boston, Wayland borders Sudbury on the west, Lincoln on the north, Weston on the east and Natick and Framingham on the south (see Figure 1).

Wayland experiences four seasonal variations in climate due to the influence of the earth's rotation, orientation and the prevailing westerly air currents. Cold fronts move into this region from the northwest, whereas moist weather patterns originate from the south. The ocean often influences these weather patterns by moderating both summer and winter temperatures.

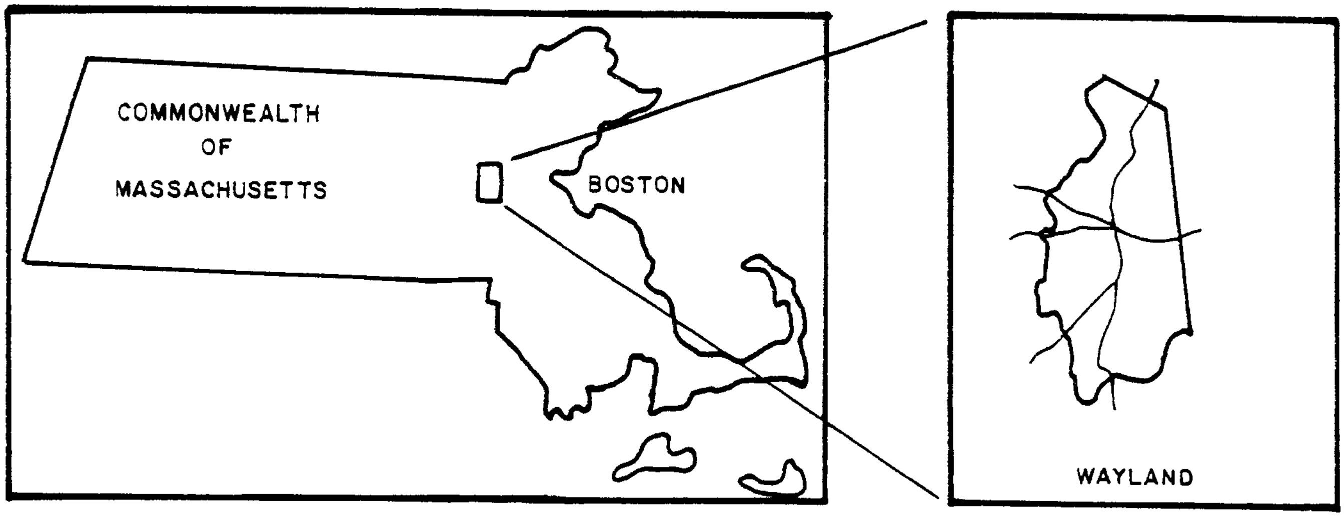


Figure 1: Locus map of Wayland, Massachusetts.

The mean annual temperature is about 50°F. Wide variations occur during warm, humid summers and cold, wind-chilled winters. Dramatic fluctuations are common even within the short span of a week or a day.

Average annual precipitation is about 42 inches. Records of rainfall since 1960 published by the USGS (1978) indicate "wet" years in 1972, 1975, 1978 and 1969; "dry" years in 1965, 1966 and 1963, listed in decreasing order of severity.

The average monthly distribution for the years 1961 to 1978 is shown in Figure 2. If records for a longer period were used, the distribution of rainfall would be nearly the same for each month.

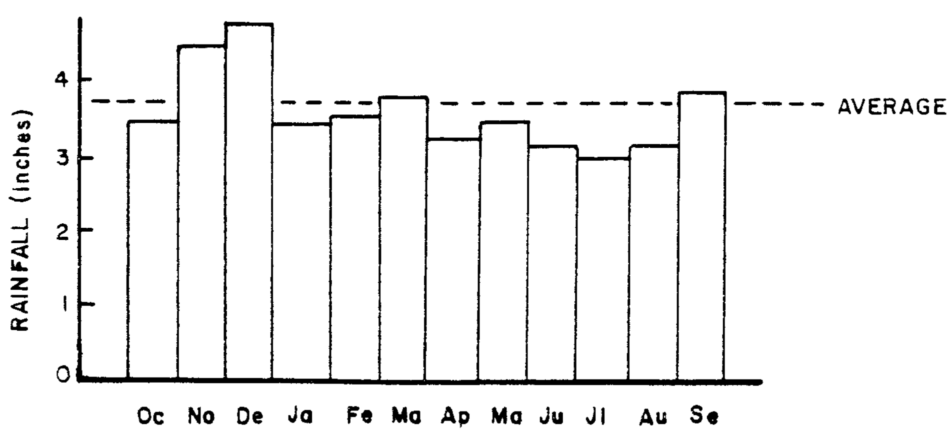


Figure 2: Average monthly distribution of rainfall recorded at a station in Framingham, MA during the years 1961-1978, (USGS, 1978).

Seasonal changes in precipitation affect the amount of water drainage from each watershed in the study area. Fluctuations in monthly streamflow can be shown by a typical annual hydrograph, Figure 3a. Similarly, groundwater levels respond to the annual distribution of precipitation as shown in Figure 3b. Surface and groundwater levels decrease through the summer to a low in the fall. In the winter and spring the trend is reversed.

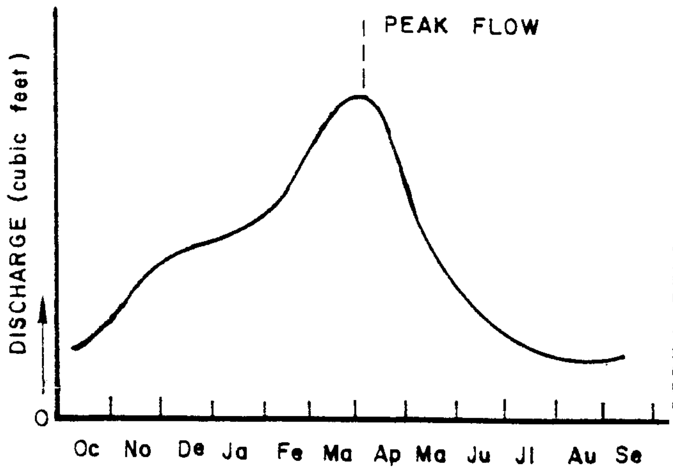


Figure 3a: Typical annual hydrograph of monthly runoff.

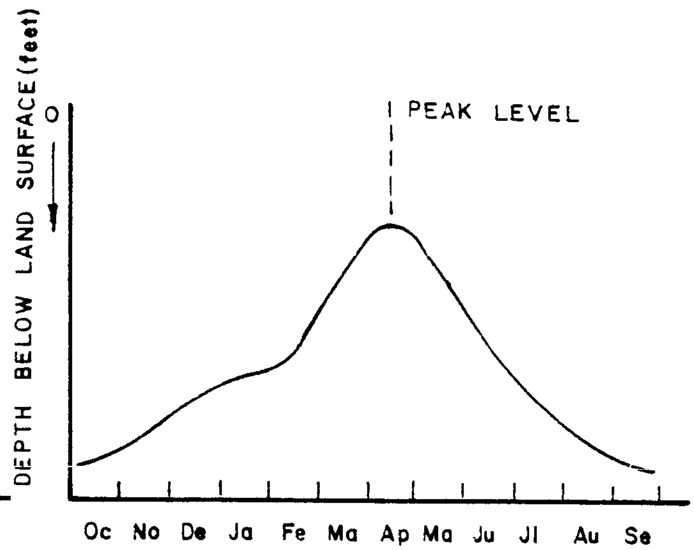


Figure 3b: Typical annual hydrograph of groundwater fluctuations.

These hydrographs are nearly the same shape except that the peaks are out of phase in the spring. Peak flow conditions occur in streams during March and April whereas maximum groundwater levels occur later in April and May.

The physiography of Wayland consists of upland hills to the east and the Sudbury River to the west. The river flows south to north until it joins with the Assabet River to form the Concord River. The river surface drops only about two feet from Stonebridge Road to Sherman's Bridge Road. Because of the broad, flat meadows and adjacent swamps comprising 24 percent of Wayland's total area (determined by the 124 msl contour), the flood plain provides a vast area for storage of storm runoff.

To the south Reeves Hill (406 msl) and Turkey Hill (382 msl) are the highest points in Town. Ridges formed by these and other lower hills define the watershed limits and drainage patterns. A general east-west topographic profile directs runoff towards the Sudbury River via the following brooks: Trout, Hazel, Mill, Hayward, Pine and Snake Brooks and numerous unnamed tributaries. The watershed areas are shown on Plate I and their acreage is given in Table I in the Appendix. Note that some of these watersheds extend into adjacent towns.

Both the soils and vegetation in Wayland have been inventoried and reports are available in the Town Office Building. The soil survey report (USDA Soil Conservation Service (SCS), 1965), includes a description of the soil conditions and interpretations for specific land uses. The different types of soils are grouped into four associations: Marsh-muck (organic) 13%, Narragansett-Hollis-Paxton (stoney, bouldery on glacial till) 25%, Enfield-Windsor-Hinckley (sandy, gravelly) 56%, and Windsor-Hinckley (sandy, gravelly) 56%, and Hinckley-Merrimac (sandy, gravelly on steep slopes) 6%. The percent is based on the total area of the Town. The soils included in the SCS report comprise the upper 3 to 5 feet of the land surface and are derived from the "parent material", otherwise known as glacial drift.

Soils with good infiltration characteristics are important for groundwater recharge and attenuation of storm runoff. Recharge is enhanced where the soils overlay parent material consisting of permeable sands and gravels. This is significant for Wayland since over half the soils are underlain by well drained glacial drift, i.e., the Enfield-Windsor-Hinckley and Hinckley-Merrimac Soil Associations.

Vegetation affects infiltration and runoff by interception, evaporation and transpiration of moisture. A comparison of the 1951 and 1971 inventories of vegetation type and land use (MacConnell and Cobb, 1974) is given in Table II in the Appendix. The report shows a 13% decrease in forested areas, a 17% drop in agricultural land, and a 17% increase in urban land use (light residential). The trend from low to high runoff coefficients (woodland and farmland to urban areas) results in a larger portion of the total annual precipitation flowing from upland areas into the Sudbury River. The degree of change in runoff rates and volumes varies within each watershed depending on many factors relating to both natural and artificial drainage conditions.

2. Man-made Environment

In 1979 the population of Wayland was recorded at 12,542 persons. This represents a decrease from 1972 when the population peaked at 13,800. In the last few years, the population has remained at a fairly constant level even though movement in and out of Town has been quite prevalent.

Ninety-eight percent of the Town's land area is zoned for residential use (Table III in the Appendix). The number of homes now exceeds 3,800. Growth was slow during the past 10 years following a period of rapid development in the 1950's and early 1960's. The average density today is about 1.2 persons per acre or 1.0 house per 2.7 acres. In the southern part of Town, the density is considerably greater. By comparison, more thickly settled areas pose a greater potential threat to water resources because of waste disposal, water consumption and urban runoff problems.

On-site sewage disposal systems are used throughout the Town. When properly located and constructed three important advantages are provided: 1) recharge of water back into the ground within the local watershed, 2) dispersion of nutrients over a large portion of the soil environment, and 3) controlled development within the assimilative capacity of the land. The degree of natural treatment provided by soils and plants varies depending on their physical, chemical and biological characteristics and the effluent load placed on them.

Approximately two percent of Wayland is zoned for business, commercial and industrial uses. Land designated for such use is located primarily in Wayland Center, Cochituate Center, and along Route 20 east and Route 30 east. Wayland Center is a sensitive area because of its location in the flood plain. Land use in Cochituate Center is a significant concern because of the potential influence of urbanization on the quality of water in Snake Brook and Lake Cochituate.

Wayland has approximately 47 miles of paved roads within its corporate limits. The major traveled roads, both local and commuter traffic, are Route 126, Route 27, Route 30 (all two lanes) and the Massachusetts Turnpike (a four lane toll road). This road network affects surface and groundwater resources in several respects: 1) water quality is impacted by the discharge of sand, salt, grease, oils and other impurities from storm drainage systems and paved surfaces; 2) groundwater recharge is reduced because of the increased amount of impervious cover on upland soils; and, 3) storm runoff in streams and rivers is altered where road crossings restrict channel capacity. The effects on flow rate, volume and local flood levels vary depending on the watershed characteristics and hydraulic structures along the watercourse.

C. Data Collection and Evaluation

Most of the data used in this study was provided by the Wayland Water Department. The information included well logs, aquifer tests, drawdown measurements, water quality, well design and yield. Well logs were also acquired from adjacent towns and from the United States Geological Survey (USGS), Boston Office. Data was sought on private wells through a survey questionnaire mailed to owners believed to have a well and by direct contact with well drillers, particularly the D. L. Maher Company of North Reading. Other useful depth profiles and boring logs were received from the Metropolitan District Commission (MDC), Massachusetts Department of Public Works, Massachusetts Turnpike Authority, Boston Edison Company and Raytheon Company. Seismic profiles and boring logs were retrieved from studies of the old and new landfill sites. A Data Supplement Section consisting of a catalog of this information has been compiled as a separate report for reference. More than 300 data points were used for interpreting subsurface conditions. Plate II gives the location of these points and shows the location of Subsurface Profiles I - V, included in the Appendix. Shallow subsurface soil characteristics and water table measurements were obtained through an examination of sewage disposal system plans on file in the Wayland Board of Health Office. Over 400 of these points, water table readings from well logs and boring logs were considered in determining average maximum groundwater elevations throughout the study area.

The surficial geology has been mapped by Koteff (1964) and Nelson (1974). Nelson also mapped the bedrock geology in the Natick Quadrangle (1975). The work of both authors was combined into a composite surficial map labeled Plate III and a description of the geologic units is given in Table IV in the Appendix. A small portion of Wayland located in the Maynard Quadrangle was mapped by Hansen (1956). The 1965 and 1970 USGS 7.5 minute series topographic maps (1:24,000) were used as a base map and for general reference.

Aquifer drawdown tests were used to determine the hydraulic properties, i.e., permeability, transmissibility and storage of the well sites. Methods for evaluating steady and non-steady flow were developed by Theim (1906), Theis (1935), Jacob and Cooper (1940). All of these works draw on the observations of Darcey (1856) which were concerned with groundwater flow. Formulas for these methods are given in Table V in the Appendix. Also included are the assumptions applicable to each one.

D. Geologic Studies and Related Hydrologic Investigations

Geology and hydrology reports for the Hudson and Maynard Quadrangles (Hansen, 1956), the Town of Sudbury (Motts, 1977) and the Town of Concord (I.E.P., 1979) were correlated with this study. Additional hydrogeologic information has been developed by several studies related to the Town's landfills. Test wells were installed at the old site by Reed (1978) to determine the presence of surface and/or groundwater contamination. The new landfill was investigated by Weston Geophysical Engineers, Inc. (1970), Haley and Aldrich, Inc. (1972) and Linenthal, Eisenberg, Anderson, Inc. (1979) to assess its suitability for waste disposal purposes.

1. Ongoing Research

The USGS is currently working on a groundwater favorability study in the Sudbury River watershed. This work will encompass most of Wayland except for the small area located in the Charles River watershed. A similar study has already been completed for the Assabet River valley (Pollock et.al., 1969). In addition, the USGS has been evaluating surface and groundwater conditions in the Cochituate Lake area.

Through the Water Department, a consultant will study surface and groundwater data in order to determine the hydraulic relationship between the well fields and the Sudbury River. Because of the proximity of the wells to the river, it is believed that aquifer recharge may occur during spring high water (or floods), or that surface water may be induced into the aquifer as groundwater is pumped out of the wells. This study will become an important part of the Town's overall understanding of its groundwater supply.

The Metropolitan District Commission has projected the need for more water in order to meet the present and future demand of the cites and towns in Massachusetts served by its water supply system. The Metropolitan District Commission is now considering a plan to divert an average of 22 million gallons per day from an upstream reservoir in the Sudbury River watershed. A detailed environmental impact report is necessary in order to determine the effects of withdrawing water from the river system. This study is expected to begin in the near future.

II. Groundwater Hydrogeology

GROUNDWATER HYDROGEOLOGY

A. Pre-Glacial Setting

Geologists believe that prior to the advance of glaciers, the New England coastal plain sloped toward the southeast and most streams flowed in that direction. Runoff flowed overland conforming to fractures, foliation planes and weathered surfaces where erosion channels could easily develop. Clapp (1901), Crosby (1939) and Hansen (1953) believe that present day rivers, the Sudbury, Assabet, Concord and Charles, follow channels which in some areas are quite different than streambeds of former valleys. The system of buried valleys is believed to consist of 1) the pre-glacial Assabet transecting from the northwest via Boon's Pond in Stow and Hop Brook or Pantry Brook in Sudbury towards Heard Pond; 2) the pre-glacial Sudbury oriented west to east from Westboro to the pre-glacial Assabet near the north end of Lake Cochituate; and, 3) a major tributary valley aligned north-south from West Concord, through White Pond and Pantry Book to the pre-glacial Sudbury. Beyond the confluence of these buried valleys, a broad deep valley called the pre-glacial Sudbury-Charles turns north through Wellesley and then follows an easterly course to the Boston Bay. An approximate location of the pre-glacial system is shown in Figure 4.

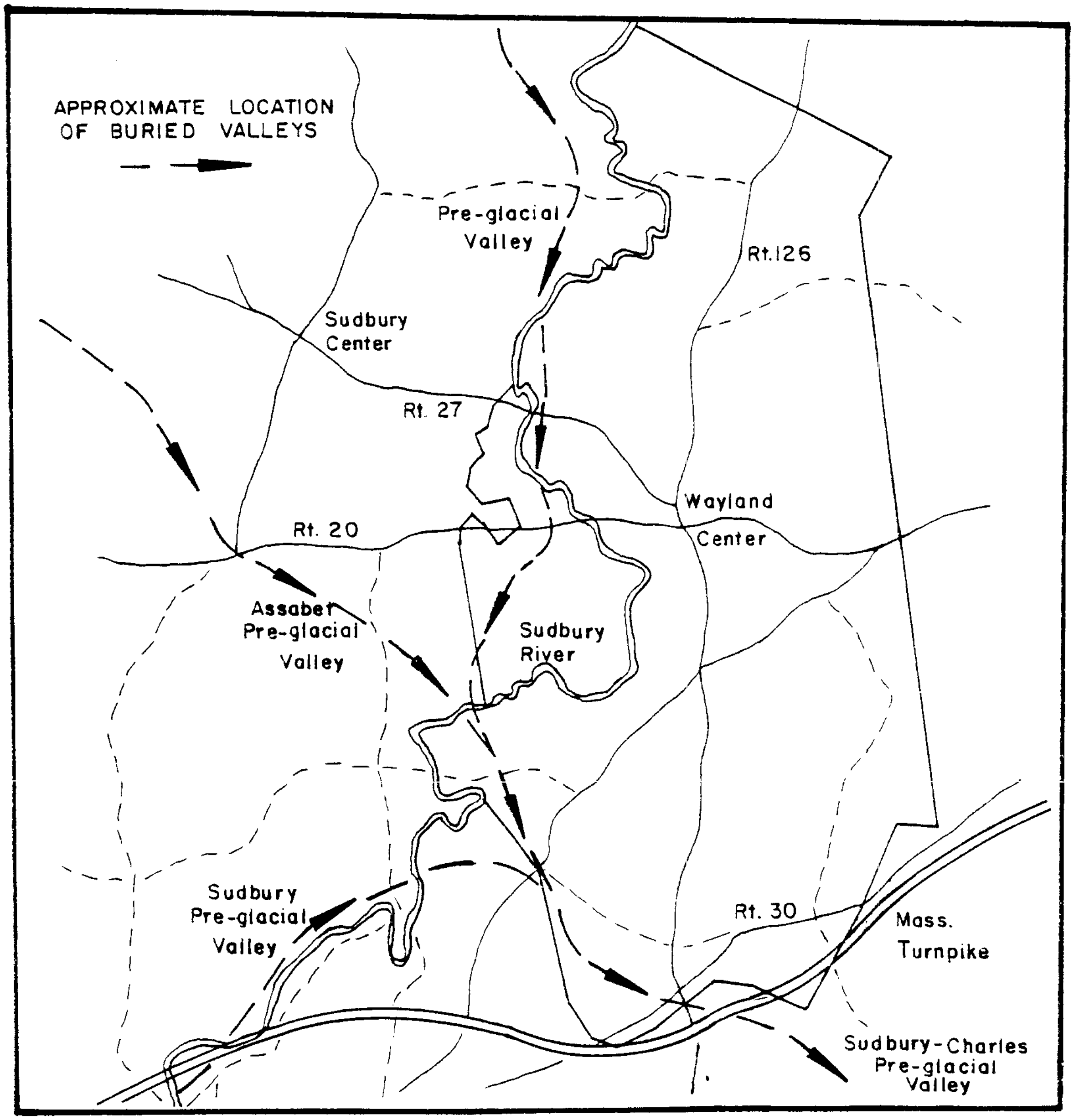


Figure 4: Approximate location of the pre-glacial buried valley system as reported by Clapp (1901), Crosby (1939) and Hansen (1953).

B. Glacial Deposits

With the advance of the last glaciers (Late Wisconsin Ice Advance about 22,000± B.P.), bedrock surfaces and pre-glacial sediments were shaped into new topographic features by the deposition of glacial drift (soil and rock picked up and transported by ice). Glacial drift is separated into two types because of the way it was formed and because of its physical characteristics. Drift deposited by active ice is called till, while stratified drift refers to glacial material laid down by meltwater flowing from or within an ice mass. In Wayland, two types of till are present. Glacial debris deposited under the ice became compacted into a hard, lower till consisting of finer sediments. Above this layer an upper till is present comprised of loose, sandy, bouldery drift formed during deglaciation, also called ablation or melt-out till.

The upper till is exposed at the surface in many places throughout the eastern half of the study area. In a few locations till was formed as drumlins and may be several hundred feet thick. In buried valleys, well logs show till less than 20 feet in depth. Till underlies swamps and bogs where the water table intersects the land surface and supports wetland growth.

During deglaciation, meltwater streams flowed from the ice sheets and deposited stratified drift on the sides, in front of and in crevasses within the glaciers. Soil and rock were graded over the land surface and into lakes formed when meltwater was temporarily dammed by glacial drift or large blocks of stagnant ice. Streams flowing into glacial Lakes Charles, Sudbury and Concord formed large deltas, several of which are found in Wayland. Fine silt and sand was redistributed as a thin blanket (eolian) throughout most of the study area. Within the last 10,000 years, younger deposits of organic matter accumulated in wetland environments and alluvium settled along streams and rivers.

The morphological sequence concept was derived by Jahns (1941) to describe the progression of glacial landforms deposited from a retreating ice margin with each feature having distinct characteristics depending on how it was made. Deposition was controlled by the current velocity and sediment load of the meltwater streams and by the presence of glacial lakes. The landforms consist of stratified sand, silt, gravel and clay laid down in fluvial (stream), lacustrine (lake) or marine environments. In general, particle size decreases further downstream from the source and sorting increases. This concept is helpful in identifying the distribution and progression of coarse, medium and fine sediments. Frequently, ice marginal positions, located by a steep ice-contact slope facing to the north, mark the beginning of a morphological sequence.

Glacial fluvial deposits are most easily seen in the southern portion of Wayland adjacent to upland areas covered by till. The fluvial deposits store large volumes of groundwater which are important for maintaining the base flow of Pine Brook and Snake Brook. Exposures in these deposits show coarse, gravelly textures, although the degree of sorting is poor. The best example of a well-graded fluvial landform can be viewed off Rice Road north of the old reservoir. I.E.P. (1978) described the surficial geology of this area in considerable detail.

Glacial lacustrine deposits exist throughout Wayland. They consist of stratified sand, gravel, silt and clay carried into a lake by a glacial stream. Extensive deltas were formed varying in depth from a few feet to more than 100 feet. The deltas characteristically have coarse to fine topset and foreset beds and fine bottomset beds. The topset beds are graded above the lake level; bottomset beds formed as particles settled in the lake. Both have relatively flat topographic expressions. Foreset beds formed below the lake level as the sloping face in front of the delta. The horizontal line formed by the intersection of the topset beds over the foreset beds represents the level of the glacial lake at the time the delta was formed. A good example of a delta is located in the Bow Road area. Lake bottom sediments occupy a large part of the flood plain area north of Heard Pond. Wetland deposits have accumulated over most of these sediments, except for an area north of Route 27, which is overlain by an extensive blanket of sand and gravel outwash. South of Heard Pond the stratigraphy of glacial sediments is more complex. Throughout most of the flood plain area, sand and gravel is frequently interbedded with silt and clay. The existence of one or more former glacial lakes during deglaciation is probably responsible for such wide variability in the horizontal stratification in this area.

South of Dudley Pond several well logs provide some information about the subsurface conditions. On the northwest side of Lake Cochituate, stratified medium to coarse sand and gravel occupies most of the geologic column for a depth of about 190 feet. Directly east of the lake and Old Connecticut

Path the vertical profile changes considerably. The upper strata consist of coarse, well-graded materials to an approximate depth of 50 feet, elevation 100 feet msl. Below elevation 100 feet msl the sediments are much finer for at least another 50 feet. Near West Plain Street and Bent Avenue the well-graded layer occurs down to elevation 160 feet msl before clay sediments are encountered. At Cochituate Center the clay layer is closer to the surface and finally becomes exposed in the area of Snake Brook Road. Along Snake Brook the fine sand and clay averages about 30 feet deep. This information indicates that glacial sediments were deposited from an ice-contact slope near Old Connecticut Path towards the lower course of Snake Brook. At first only a shallow glacial lake existed in front of the ice. Later the lake level rose to about elevation 100 feel msl. As sediments washed into the lake the level continued to rise and the depth of the bottomset beds increased further from the ice-contact slope. The boring near Bent Avenue shows the level (160 feet msl) reached at this location. Eventually the lake drained or became almost completely filled and the topset beds graded across the clay strata becoming thinner towards Snake Brook. Data west of Lake Cochituate show a similar clay formation at 160 feet msl and below, Figure 5. While these sediments were deposited, Lake Cochituate was occupied by ice which eventually melted to form the lake as seen today.

Because of the presence of a clay area south of Dudley Pond, groundwater movement towards Lake Cochituate is severely limited. Observation wells at the west end of Dudley Pond indicate that groundwater is moving towards Pod Meadow. The confining influence of the clay materials south of Dudley Pond probably contribute to the maintenance of a higher water level in the pond as compared to the level in Lake Cochituate. The difference is approximately ten feet.

C. Aquifer Characteristics

An aquifer is generally considered to be a porous formation of soil and/or rock bearing water in a fully saturated condition. For water supply purposes, an aquifer may be visualized as only the highly permeable portions of a porous formation even though saturated conditions extend well beyond

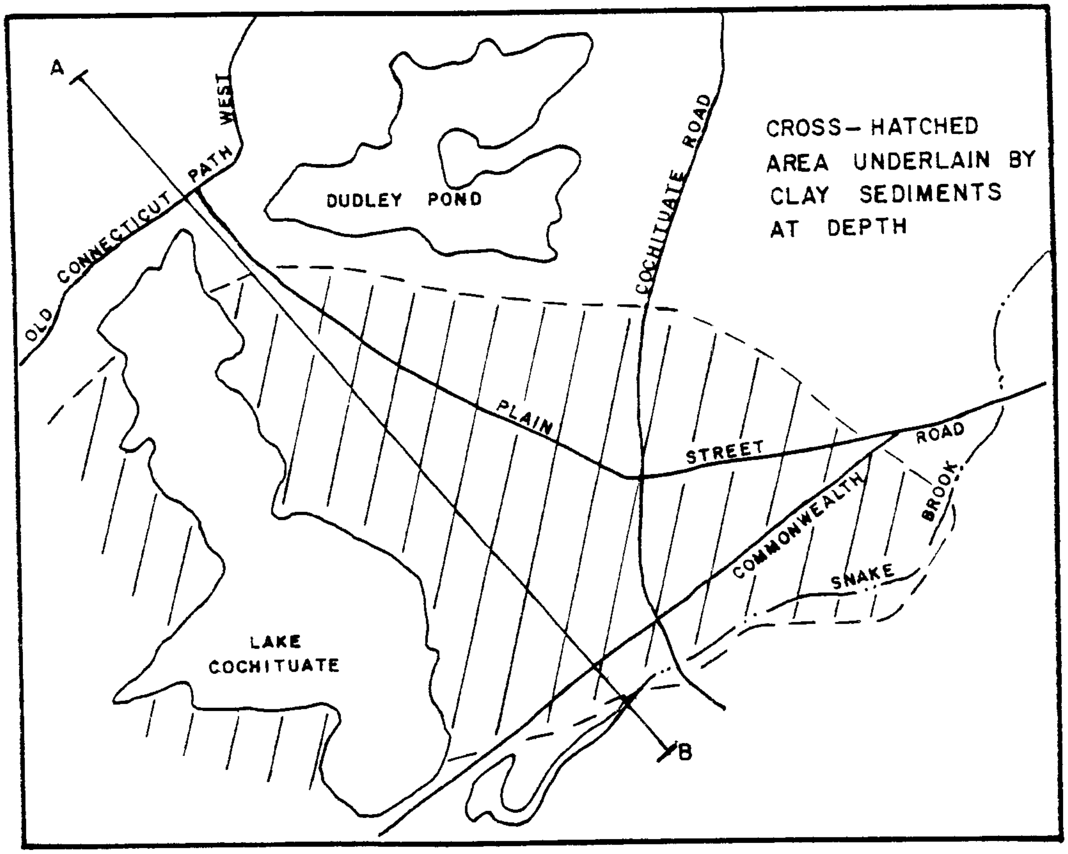
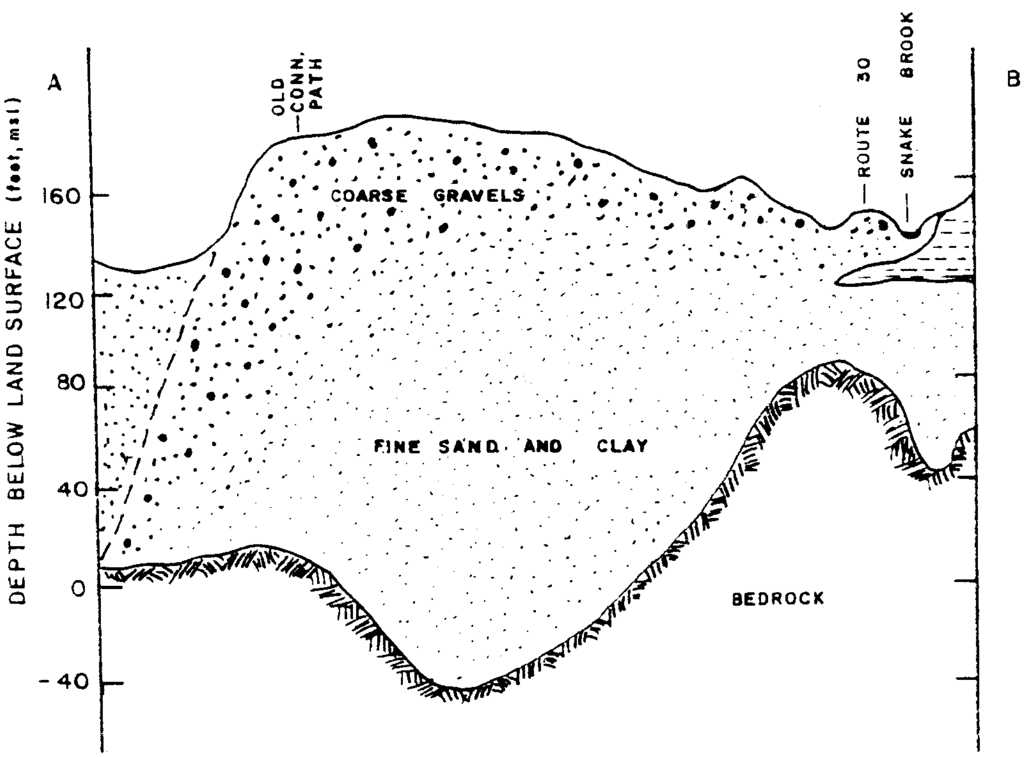


Figure 5: Locus map of the fine sand and clay sediments underlying a surface gravel stratum which thins towards Snake Brook.



Profile A-B of the progression of gravel to fine sand clay sediments from west to east as shown on the locus map above.

these limits. To be more inclusive, the area of an aquifer is determined by boundaries formed by bedrock and/or impermeable glacial sediments. An aquifer may be freely connected to the atmosphere (unconfined) and receive direct precipitation, or it may be artesian (confined) more or less sealed from above by an overlying layer of semi-permeable material. It is not uncommon to find a water table aquifer located above an artesian aquifer with little or no hydraulic connection between them.

Precipitation falls on the land surface and water is introduced into ground throughout the year. This process is referred to as recharge and occurs at its maximum between October and April, although it is somewhat limited during January, February and March when the ground is likely to be frozen. Recharge can take place under several hydrologic conditions:

1. On upland areas where the water table is below the surface throughout the year. Flat stratified sand and gravel deposits provide the best opportunity to recharge. Recharge areas have been identified for Wayland and are shown on Plate V. An explanation of how the geology and topographic conditions were interpreted is given in the Appendix, Table VIII.

2. Along the banks of streams where temporary flood levels exceed the elevation of the water table and the ground is saturated by influent flow. It is possible that intermittent recharge of this type occurs along water-courses in Wayland, particularly where natural or artificial restrictions in the stream channel cause temporary backwaters (ponding). This relationship is believed to occur in areas along the Sudbury River, although no data has been collected to verify influent conditions. Flood levels in the River need to be compared with the adjacent groundwater levels to determine the hydraulic connection and direction of movement.

3. From wetland environments elevated temporarily or permanently above the groundwater table. The geology of an area may be such that a streambed is not intersected by the water table, which is at some depth below the land surface. Water in the stream will therefore saturate the ground over which it flows. This type of recharge occurs in the area north and south of Woodridge Road near the intersection with Cochituate Road. Influent recharge can also occur under lakes or ponds. For example, there is some evidence that Dudley Pond may have this type of hydrologic setting. Measurements taken near Mansion Road show the water table to be as much as 12 feet below the

level of the Pond. Although sufficient information is lacking, it appears that the groundwater table slopes east to west and Dudley Pond lies in whole or in part within the flow path depending on the extent of groundwater fluctuation during a given year. The map of ground watersheds shows the Pond located in the northeast corner of its groundwater province. Baker, et.al. (1964) reported on evidence which suggests that infrequent recharge can take place from swamps into the underlying glacial sediments. Seepage would be possible in the fall when the surface of the swamp is saturated by rainfall and runoff, yet, the groundwater table has not risen sufficiently enough to fully saturate the underlying material. Recharge could also occur during a major storm when flood waters rise above the water table in adjacent areas.

4. Drainage from an adjacent aquifer. Groundwater can leak from an unconfined aquifer through a semi-impervious layer into a confined aquifer. Under pressure of a hydraulic head, seepage may occur from fractured bedrock into unconsolidated deposits.

5. Recharge can be manipulated artificially through pumping water into or out of an aquifer. Water introduced into the ground through sewage disposal systems, storm drainage-leaching structures and leaks in underground water conduits are some examples.

The opposite function of recharge is discharge. Discharge is the release of groundwater at the point where the water table intersects the land surface. (Note that discharge can also take place into fractured bedrock from overlying saturated sediments.) Sites of groundwater discharge include streams, ponds, springs, swamps and other wetland features. Seepage may be continuous or intermittent during the year depending on available storage and elevation difference in the water between inflow and outflow areas. For instance, as the gradient in the water table between upland and lowland areas becomes less steep, head pressure is reduced and groundwater movement to surface wetlands is reduced. Discharge conditions prevail in the spring and diminish through the summer to low flows in the fall.

Groundwater discharge (base flow) can be approximated by measuring the flow in a stream throughout an average year of precipitation. This is done by plotting a flow hydrograph of discharge vs. time as shown in Figure 6.

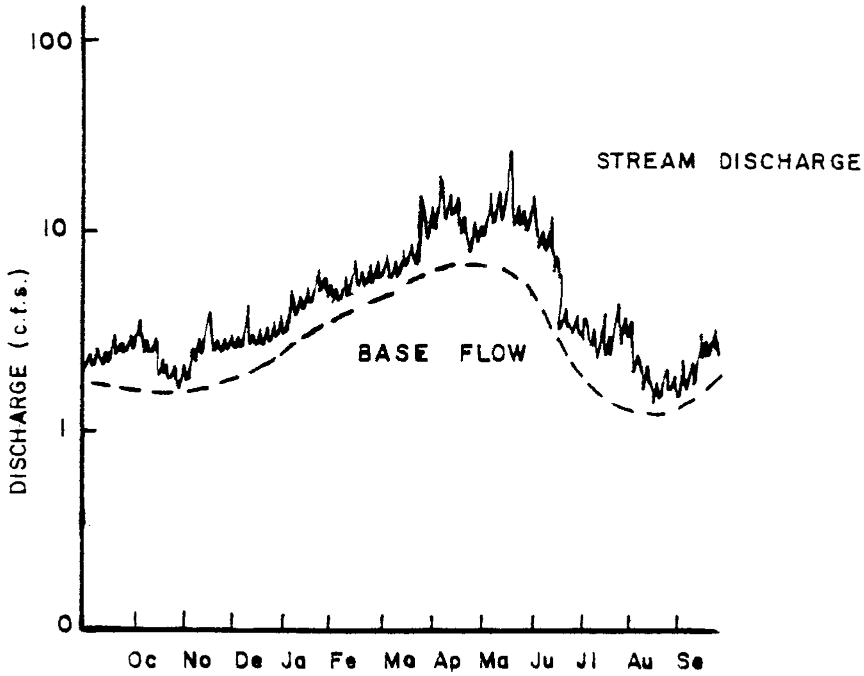


Figure 6: Typical hydrograph of stream flow showing the base flow component in an average "water year".

D. Defining Groundwater Parameters

In developing a groundwater supply, the aim is to locate an underground reservoir which is capable of yielding good quality water at a productive, sustained rate. To meet this objective all available geologic and hydrologic data can be assimilated into a series of maps which delineate specific groundwater characteristics. Each map portrays a component of the groundwater regime, i.e., bedrock surface, water table and saturated thickness, which in combination allow an interpretation of the spatial arrangement of subsurface conditions.

The water table topography map, Plate I, shows the elevation, slope and the overall direction of groundwater movement, i.e., perpendicular to the contour lines. Other minor flow systems are not shown because the map scale limits such fine detail. The contour lines represent the best approximation of average annual maximum water table elevations. The groundwater varies in depth below the land anywhere from a few inches to more than

40 feet in upland gravel formations. Unless specified, the water level data determined via deep hole tests assumes actual groundwater table and not perched conditions. In some locations perched conditions are suspected although they could not be confirmed with the available information.

The bedrock topography map, Plate IV, shows the location of pre-glacial buried valleys within the Town. A major channel winds from north to south under the present Sudbury River flood plain. In some cases the pre-glacial stream follows a much different course than the present-day river. Two other large tributary pre-glacial valleys trend from the east. One is found under the Lincoln Road area and the other is below the Town Center. In the Lake Cochituate area the major buried valley is very deep and wide, probably representing the confluence of more than one pre-glacial stream (Assabet and Sudbury), as described in an earlier section of this report. Beyond Lake Cochituate the pre-glacial valley follows a course southeast through Natick. The map does not specifically show where the pre-glacial Sudbury and Assabet valleys enter Wayland, although it appears (based on available data) that the former occurs southwest of Lake Cochituate below the toll road interchange and the latter appears from the west between Stonebridge Road and Pelham Island Road. Motts' (1977) bedrock map shows a pre-glacial valley under Wash Brook entering Wayland north of Pelham Island Road. The location of buried valleys at the north end of Wayland and Sudbury is unclear because the flood plain area above is very broad and subsurface data is scarce. It is possible that the pre-glacial valley under the Sudbury River is very wide or that several deep channels exist. This suggestion is based on the fact that Lincoln has a potential well site east of the Sudbury River in deep saturated sediments and Sudbury has an active well considerably west of the river, also in deep saturated deposits.

The difference in elevation between the water table and the bedrock surface determines the depth of the saturated zone. The saturated thickness map, Plate VI, shows where the deep glacial deposits are located as compared to the shallow upland areas. The range in saturated thickness varies from zero to over 100 feet. The extent of the saturated zone is restricted in some areas by subsurface bedrock ridges. These ridges are helpful in delineating the groundwater divides which are shown in Plate IV. In some cases the ground watersheds correspond to the surface watersheds.

A further step in evaluating groundwater occurrence is to classify surface areas in terms of their recharge and discharge function. Discharge areas are classified uniformly throughout the area, although outflow does vary in volume and rate depending on the particular hydrologic setting.

Recharge areas are divided into four classifications as described in Table VIII in the Appendix. Each class is established based on the topographic expression and grain size characteristics. The depth to the water table should be several (two or more) feet below land surface throughout the year, so that there is adequate void space for water recharge. The best recharge areas have medium to coarse fine sands and gravels, a flat topographic expression, low evapotranspiration potential and low runoff due to impervious surfaces. By comparison, till is generally less permeable and usually occurs on steep slopes. High recharge is common where runoff from upland till drains into an adjacent sand and gravel formation. The map of recharge areas does not account for the effects of vegetation or impervious surfaces.

Using the four maps previously described, an assessment of the groundwater availability or favorability can be made. The classification scheme presented in Table IX was applied to the study area in order to rank the aquifers in terms of favorability for groundwater development, illustrated in Plate VII. The most favorable aquifers consist of a large ground watershed, deep-saturated sediments, high transmissibility, hydraulic connection with a primary recharge area and proximity to a discharge area, i.e., stream or pond. Several areas along the Sudbury River exhibit these characteristics and are currently being used as productive well sites.

E. Hydrologic Properties of Glacial Sediments

Earlier discussion has focused on how topography, soils, vegetation cover and land use can affect the balance between infiltration and surface runoff. After precipitation enters the ground, its disposition is influenced primarily by the physical characteristics of the geologic materials.

In a typical vertical profile, water percolates down through sediments by means of the openings between individual grains of rock. These void spaces may remain dry or become partially wetted for a certain depth below the land surface. This area is commonly referred to as the zone of aeration. With increasing depth the openings become completely filled by groundwater. This section is called the zone of saturation. The water table surface is the boundary between these two zones which fluctuates depending on the climatic, geologic and hydrologic conditions.

Once precipitation has reached the saturated zone, the hydrologic properties of the sediments determine the storage and movement of groundwater. The water bearing capacity of glacial drift or fragmented rock is dependent on the void spaces or porosity. Porosity is determined by the number, size, shape and arrangement of these openings. Porosity is higher in sediments which are well sorted and more uniform in shape, i.e., similar to uniform spheres packed end to end in three dimensions. Sorting represents the range of grain sizes. Glacial deposits are well sorted if they have a narrow distribution of grain sizes; poorly sorted if they have a wide range of grain sizes. An example of the grain size distribution for various materials sampled in Wilmington, Massachusetts (Baker, et.al., 1964) is shown in Figure 7.

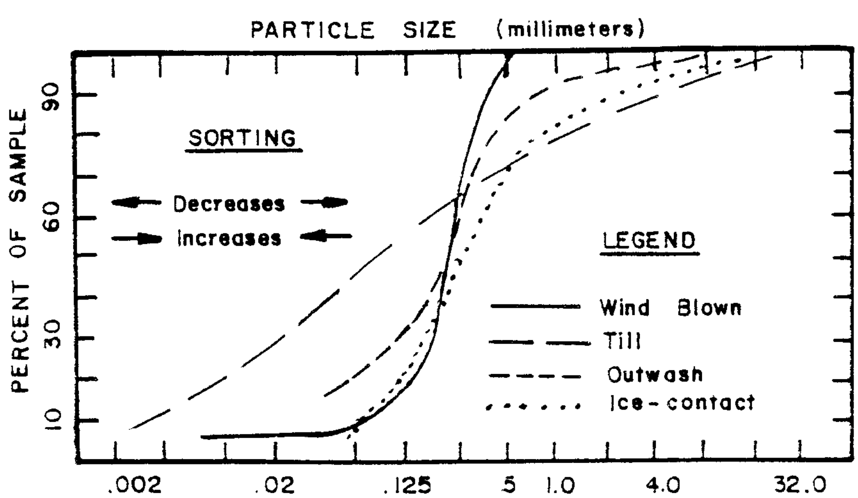


Figure 7: Particle size distribution curves, Wilmington, Mass. (Baker, et.al., 1964)

Water drains from the saturated zone by gravity or artificial pumping. Under the force of gravity only a portion of the total volume of water is actually released. This amount is known as the specific yield. The water remaining and held tightly to the sediments is the specific retention. Values for both specific yield and specific retention vary depending on the size, packing and adhesion strength (capillary and osmotic forces) of the sediments as a collective unit. By comparison, a deposit with a clay or silty-clay content will hold water more tightly than a deposit consisting of sand and gravel. For this reason, the smallest (also called the effective diameter) ten percent of the total grain size distribution controls the rate at which water can flow through glacial deposits.

Groundwater flow is three dimensional. Vertical and horizontal movement occurs because of the difference in elevation along a sloping water table and because of a difference in equipotential forces, i.e., the water pressure increases with depth below the land surface. The typical flow path of groundwater is shown in Figure 8a.

Permeability is controlled by the soil properties which affect porosity and specific yield. The movement of water through the soil can be calculated by Darcey's Law (as explained in the Appendix) in connection with the coefficient of permeability. Coarse sediments with a high degree of interconnection and low resistance to flow will have a much higher permeability than finer, poorly sorted materials.

Horizontal permeability is often more rapid than vertical permeability because glacial deposits are stratified nearly parallel to the land surface, and pore spaces are aligned in the same direction. The rate of groundwater flow can vary from a few inches per year to several feet per day depending on the hydraulic conductivity of the sediments. Average values for different geologic materials are given in Table VII.

Permeability multiplied by the thickness of the aquifer gives a value for transmissibility. The transmissibility (T) is a measure of how well water can flow throughout the entire thickness of an aquifer. A high T value indicates that an aquifer can transmit a larger volume of groundwater. If T is large, the water table drawdown will be small, but the cone

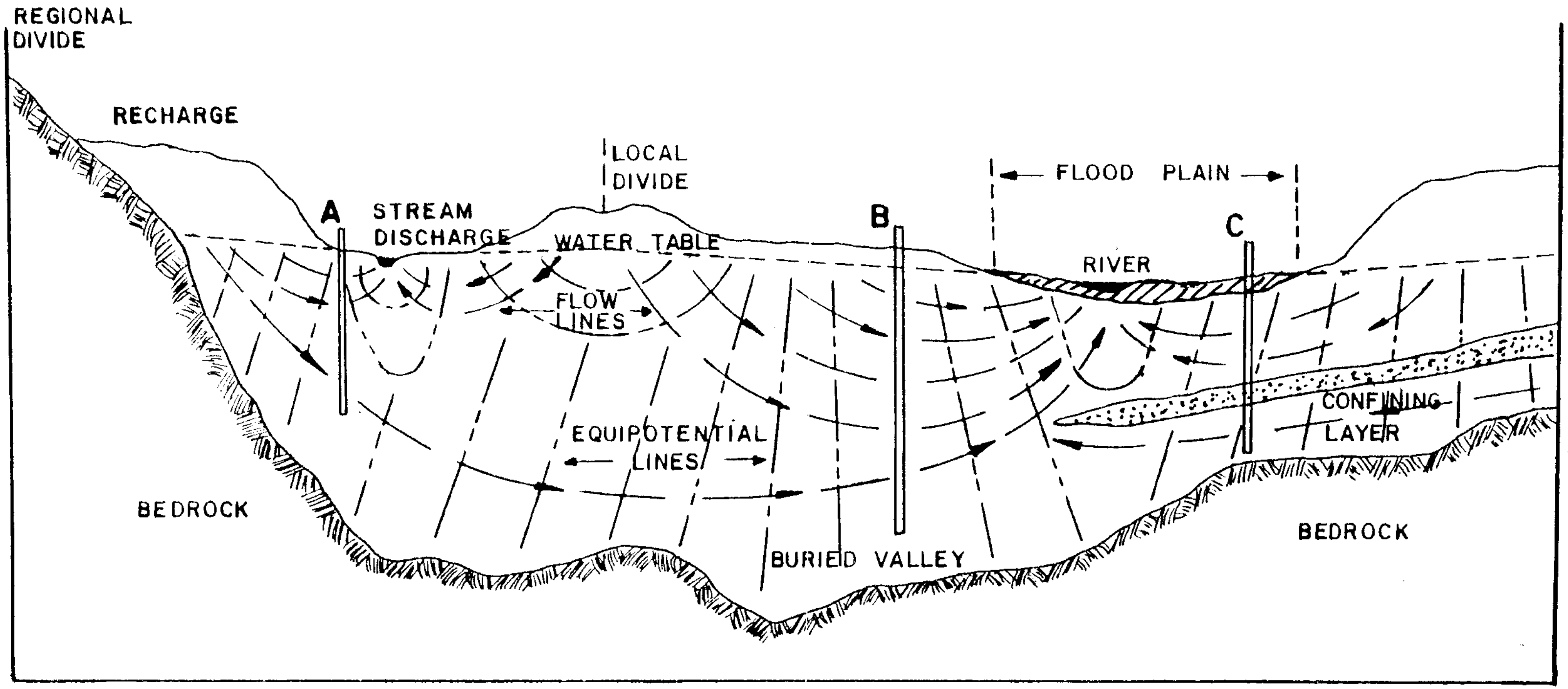


Figure 8a: Schematic profile showing groundwater movement in different hydrologic settings.

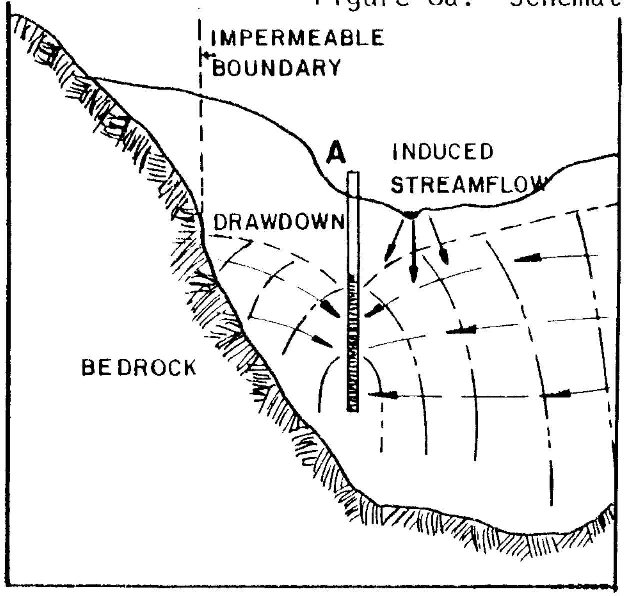


Figure 8b: Unconfined aquifer pumped with drawdown reaching impermeable boundary and extending beyond induced flow from stream.

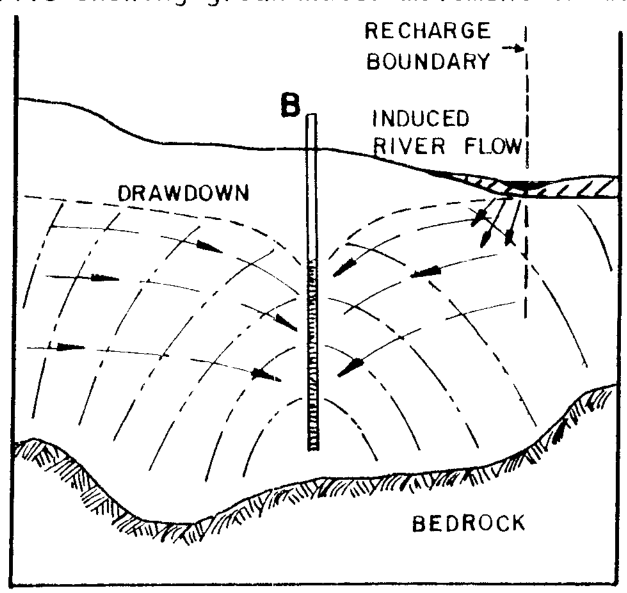


Figure 8c: Unconfined aquifer pumped and induced infiltration received from river acting as recharge boundary.

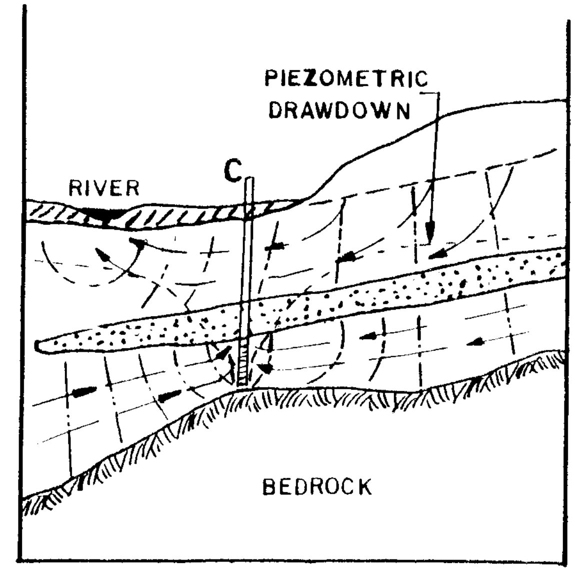


Figure 8d: Withdrawal of groundwater from confined aquifer, only.