CONNECTICUT OBSERVATION WELLS -

GUIDELINES FOR NETWORK MODIFICATION

By Robert L. Melvin

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ABBREVATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to metric units and abbreviation of units

Multiply Inch-Pound Unit	By	To Obtain Metric Unit
inch (in)	25.4	millimeter (mm)
feet (ft)	0.3048	meter (m)
square mile (mi^2)	2.59	square kilometer (km^2)

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ABSTRACT

The U.S. Geological Survey and Connecticut Department of Environmental Protection are developing a baseline observation well network to (1) assess the present status of ground-water storage and relate it to long-term conditions, and (2) describe and characterize natural changes in ground-water storage and the magnitude of resulting water-table fluctuations in relation to climate variations, topography, and hydrogeologic setting. The present network of 31 observation wells was evaluated to determine if modifications are needed. Examination of the records of 25 wells indicates that most water-level changes are due to natural climatic factors, particularly precipitation. Several wells are providing equivalent information and six wells can be discontinued.

The distribution of the established network wells is not representative of the climatic areas of the State or of the major hydrogeologic units. Thirty-five percent of the network wells are in one climatic zone and more than 75 percent of the wells tap unconsolidated stratified drift. To remedy these deficiencies and develop a network that meets the objectives will require 50 to 60 new observation wells. Fourteen wells with long-term records that are part of the present network should be retained as a basis for historical comparisons.

The most effective way to obtain needed information on changes in ground-water storage and on the controlling hydrologic processes is by installing four or five new wells in a single drainage basin in each climatically similar part of the State. These subnetworks should include wells in different parts of the ground-water flow system that tap major hydrogeologic units in the basin. Approximately 10 additional new wells in atypical hydrogeologic settings are needed to fully characterize storage and water-level changes and relation to factors such as variations in climate, lithology, and thickness of the unsaturated zone.

INTRODUCTION

Since the early 1930's, the U.S. Geological Survey, in cooperation with the State of Connecticut, has operated a network of observation wells in which water levels are periodically measured. This network has changed over the years in respect to the number of wells, the frequency of measurement, and uses of the water-level data. In 1983, the network included the 31 wells listed in table 1 and shown in figure 1.

Because the objectives of the network were not clearly developed at the start and funding was limited, wells were added to the network mainly to attain uniform geographic distribution. Most were wells originally used in short-term hydrologic investigations conducted for ground-water

Table 1.--Observation wells in Connecticut, 1983 water year.
(Wells are grouped by climatic zone.)

Well number (see fig.1)	Site identification number	Town	Topographic quadrangle (7.5 minute, 1:24,000 scale)	Altitude land surface (feet above NGVD of 1929)	Well owner	Date record began	Climatic zone	Topographic setting	Aquifer	Type of well	Depth of well (feet below land surface)	Casing (from-to, in feet)	Open to aquifer (from-to, in feet)	Frequency of measurement
FF 23	411256073153101	Fairfield	Westport	130	Conn. Dept. of Trans.	Sept 1966	Coastal - West	Valley Terrace	1/SD	Bored	42	0-39	39- 42	Monthly
GT 19	412013072030601	Groton	New London	22	John E. Ackley, Jr.	June 1958	Coastal - East	Coastal Flat	SD	Dug	18	0-18	to 18	Weekly
SN 164	412311071522301	Stonington	Ashaway	48	Pawcatuck Little League	Oct 1976	Coastal - East	Valley Flat	SD	Bored	19.6	0-14.6	14.6-19.6	Weekly
MA 314	411723072344701	Madison	Clinton	45	Conn. Dept. of Trans.	March 1982	Coastal - Central	Valley Terrace	SD	Bored	26.7	0-24.7	24.7-26.7	Monthly
BD 8	413007073250601	Brookfield	New Milford	256	Conn. Dept. of Trans.	Dec 1966	Southwest Hills	Valley Terrace	SD	Bored	52.8	0-49.7	49.7-52.8	Monthly
NT 15	412429073165101	Newtown	Newtown	265	U.S. Geological Survey	Dec 1966	Southwest Hills	Valley Flat	SD	Bored	33.3	0-31.3	31.3-33.3	Monthly
NT 54	412424073154701	Newtown	Newtown	320	S. Curtis, Inc.	Aug 1976	Southwest Hills	Valley Terrace	SD	Bored	62	0-57	57- 62	Monthly
WB 93	413134073021701	Waterbury	Waterbury	320	Mrs. Simeon W. Nichols	Feb 1944	Southwest Hills	Valley Terrace - Hillside	SD	Dug	32.6	0-32.6	to 32.6	Monthly
WB 198	413245072584201	Waterbury	Southington	540	A. A. Baker	Feb 1944	Southwest Hills	Hillside	Till	Dug	30.9	0-30.9	to 30.9	Monthly
WY 1	413202073122401	Woodbury	Woodbury	270	Irene Boultbee	April 1944 (also Oct 1913 to Dec 1916)	Southwest Hills	Valley Terrace	SD	Dug	30.5	0-30.5	to 30.5	Monthly
BU 2	414615072581601	Burlington	Collinsville	880	Snow Realty	April 1946	Northwest Hills - East	Valley Terrace	SD	Dug	37	0-37	to 37	Monthly
NOC 7	420125073193001	North Canaan	Ashley Falls	675	James Lyle	Aug 1958	Northwest Hills - East	Valley Terrace	SD	Dug	12	0-12	to 12	Weekly
T 2	414910073072301	Torrington	Torrington	650	Warrenton Woolen Co.	Aug 1958	Northwest Hills - East	Valley Flat	Bedrock	Drilled	381	0-34	34-381	Weekly
F 283	414315072511401	Farmington	New Britain	164	Town of Farmington	Oct 1976	Central Valley - West	Valley Flat	SD	Bored	23	0-18	18- 23	Monthly
F 294	414517072503301	Farmington	Avon	232	Pennington Corp.	Sept 1976	Central Valley - West	Valley Terrace	SD	Bored	28.4	0-23.4	23.4-28.4	Monthly
GR 328	415649072494801	Granby	Tariffville	440	Univ. of Connecticut	June 1981	Central Valley - West	Hilltop	Till	Bored	22	0-20	20- 22	Weekly
GR 329	415647072495901	Granby	Tariffville	400	Univ. of Connecticut	May 1982	Central Valley - West	Hillside	Till	Bored	22	0-20	20- 22	Weekly
GR 330	415643072502201	Granby	Tariffville	309	Univ. of Connecticut	May 1982	Central Valley - West	Valley Flat	SD	Bored	22	0-20	20- 22	Weekly
GR 331	415652072501701	Granby	Tariffville	329	Univ. of Connecticut	1983	Central Valley - West	Valley Terrace	SD	Bored	31.5	0-29.5	29.5-31.5	Weekly
NHV 201	412307072515201	North Haven	Wallingford	260	Town of North Haven	Oct 1975	Central Valley - West	Valley Terrace	SD	Bored	32	0-27	27- 32	Monthly
NHV 202	412550072510701	North Haven	Wallingford	35	Conn. Dept. of Trans.	Oct 1975	Central Valley - West	Valley Terrace	SD	Bored	65	0-60	60- 65	Monthly
S 375	413724072551101	Southington	Southington	55	Forestville Fish and Game	Oct 1975	Central Valley - West	Valley Terrace	SD	Bored	28	0-23	23- 28	Monthly
S 377	413608072523801	Southington	Southington	200	Town of Southington	Oct 1975	Central Valley - West	Valley Terrace	SD	Bored	32	0-27	27- 32	Monthly
MF 1	413033072432001	Middlefield	Middletown	150	The Leisure Group, Inc.	July 1946	Central Valley - West	Hillside	Till	Dug	22	0-22	to 22	Monthly
SW 64	414910072372101	South Windsor	Manchester	40	Frank Pierce, Jr.	Oct 1948 (also Nov 1934 to Sept 1939)	Central Valley - East	Valley Terrace	SD	Dug	18	0-18	to 18	Monthly
PL 1	414054071552001	Plainfield	Plainfield	180	Clifford Starkweather	Oct 1942	Southeast Hills	Valley Terrace	SD	Dug	34	0-34	to 34	Monthly
MT 261	413254072335601	Middletown	Middle Haddam	145	United Technologies Corp.	March 1956	Southeast Hills	Valley Terrace	SD	Dug	27.6	0-27.6	to 27.6	Monthly
SM 7	412824072173301	Salem	Hamburg	238	Conn. Dept. of Trans.	March 1979	Southeast Hills	Valley Terrace	SD	Bored	17	0-12	12- 17	Monthly
BK 41	414911071562001	Brooklyn	Danielson	330	Richard Broullard	March 1957	Northeast Hills	Hillside	Bedrock	Drilled	107	0- 9	9-107	Monthly
MS 19	415448072114501	Mansfield	Spring Hill	260	C. T. De Boer	May 1958	Northeast Hills	Valley Terrace	SD	Dug	21	0-21	to 21	Monthly
MS 44	414741072134501	Mansfield	Spring Hill	654	Univ. of Connecticut	June 1982	Northeast Hills	Hilltop	Till	Bored	22	0-20	20- 22	Monthly

1/ Stratified-drift aquifer is abbreviated SD.

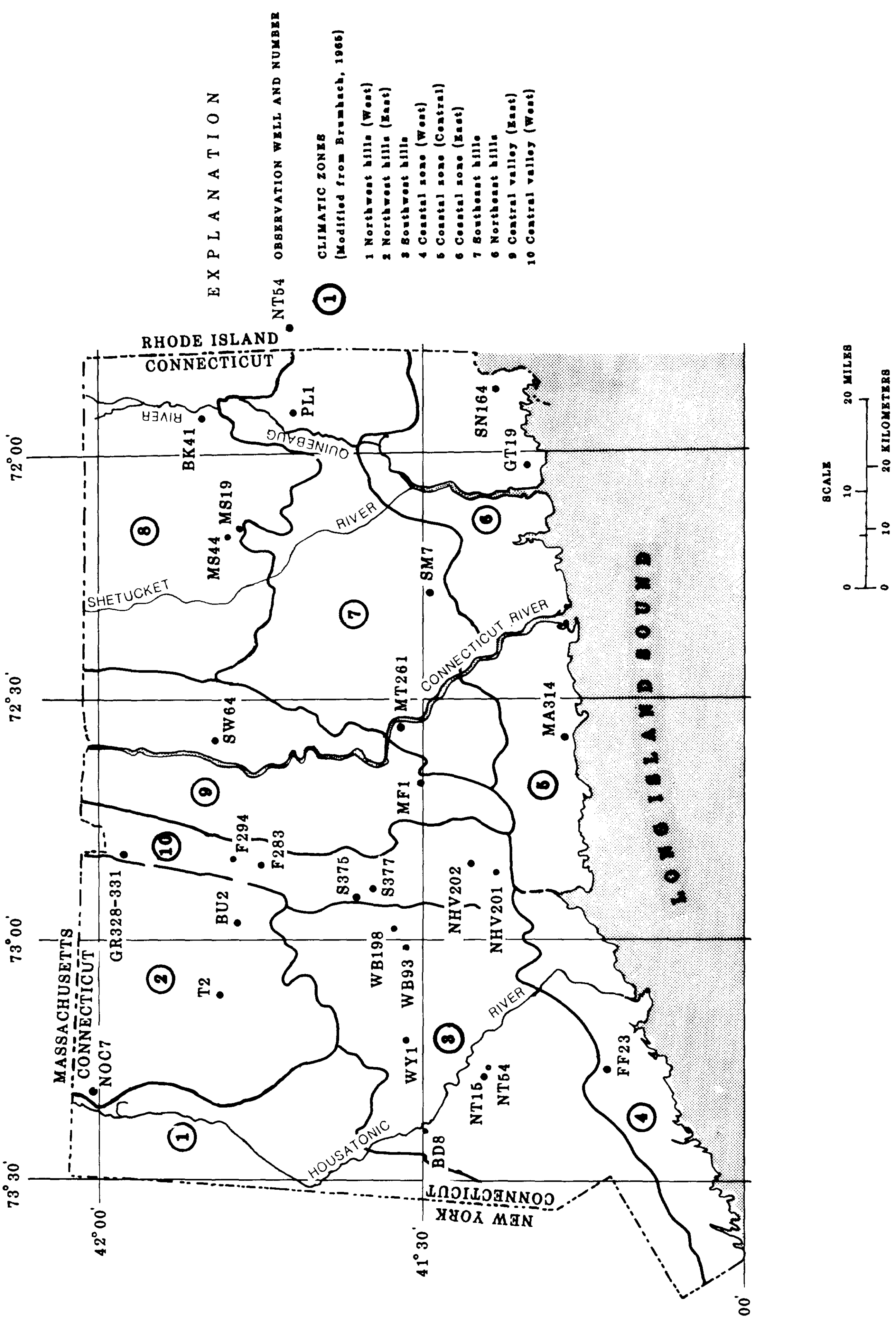


Figure 1.--Observation wells in Connecticut during 1983 water year and climatic zones.

appraisals. Although the objectives were not thoroughly developed, the network wells were intended to measure water-level changes caused by natural phenomena throughout the State and included wells that tapped the major hydrogeologic units--stratified drift, till, and bedrock. Recently, the U.S. Geological Survey and Connecticut Department of Environmental Protection reviewed their needs for information on ground-water levels. The first priority is development of a "baseline" network (Heath, 1976) that would meet the objectives outlined in the following section of this report.

This report describes the results of a study to (1) determine if elements of the present network are providing reliable, useful, and non-redundant data relative to network objectives, and (2) determine changes, including the addition of new wells, that would be required to meet the objectives.

This study includes a description of the network objectives, an evaluation of the data that has been obtained from present network wells in relation to these objectives, an identification of data deficiencies and redundancies, and a program to develop a network that will meet the objectives.

NETWORK OBJECTIVES

The principal objectives of a baseline observation-well network for Connecticut are:

1) To assess the present status of ground-water storage and relate it to long-term conditions.

2) To describe and characterize natural changes in ground-water storage and water-levels in relation to short- and long-term variations in climatic factors, topography, and hydrogeologic setting (water-bearing unit and location within flow system).

Data from the present network are used principally by the U.S. Geological Survey and Connecticut Department of Environmental Protection to assess the monthly status of ground-water storage by statistically comparing water levels to long-term observations for the same month or season or to the entire period of record. This assessment is reported monthly in the informal series of publications of the Connecticut office of the U.S. Geological Survey entitled "Water Resources Conditions for Connecticut". The water-level data for each observation well are published annually in the series of U.S. Geological Survey publications entitled "Water Resources Data for Connecticut". Data from a baseline network can also be used to:

1) Serve as a base against which present water-supply conditions can be compared to historical conditions and as an index of future, conditions using qualified assumptions about subsequent rainfall, recharge, and direct runoff.

2) Evaluate the relation of long-term trends in storage to natural factors that control recharge, such as reduced storage due to a long-term decrease in precipitation or to man-made factors.

3) Provide benchmark data for evaluating if observed changes in water levels elsewhere in Connecticut are related to natural or manmade events.

4) Evaluate the response of aquifers to climatic changes of days to several years in duration, including abnormally high precipitation and droughts.

5) Evaluate if water-level measurements made elsewhere in the State, but in similar climatic zones and hydrogeologic settings, represent average, above-average, or below-average conditions, and if significantly higher or lower levels may be expected in the future.

6) Provide a basis for preparing hydrologic budgets for water-resources assessments and for calibrating of ground-water flow models.

Data from the present network are of limited use in respect to some of the applications listed above because of deficiencies in the number, location and sampling frequency of observation wells. It should also be noted that the network is not sufficiently diverse or large enough to evaluate the effects of topography and hydrogeologic setting on water-level changes--one of the two principal objectives.

HYDROGEOLOGIC SETTING

Description of Hydrogeologic Units

Connecticut is underlain by three major hydrogeologic units--bedrock, stratified drift, and till as shown in figure 2. Bedrock aquifers underlie the entire State and are the principal sources of water for self-supplied domestic and commercial use. In eastern and western Connecticut, the bedrock is composed mainly of metamorphic rocks, whereas in the central part of the State the bedrock is a thick sequence of sedimentary rocks (sandstone, shale, and conglomerate) interbedded with three extensive igneous lava flows (basalt). Ground water in these bedrock aquifers is primarily contained in and transmitted through networks of interconnected fractures that are generally more prevalent at shallow depths (less than 300 feet below the bedrock surface). In the sedimentary bedrock of central Connecticut, some ground water is also stored in and transmitted through intergranular pore spaces. Ground water in the upper part of the bedrock aquifers is generally unconfined, although artesian conditions are locally present. At depths of more than 300 feet, artesian conditions are likely in many parts of central Connecticut that are underlain by interbedded sedimentary and igneous rocks.

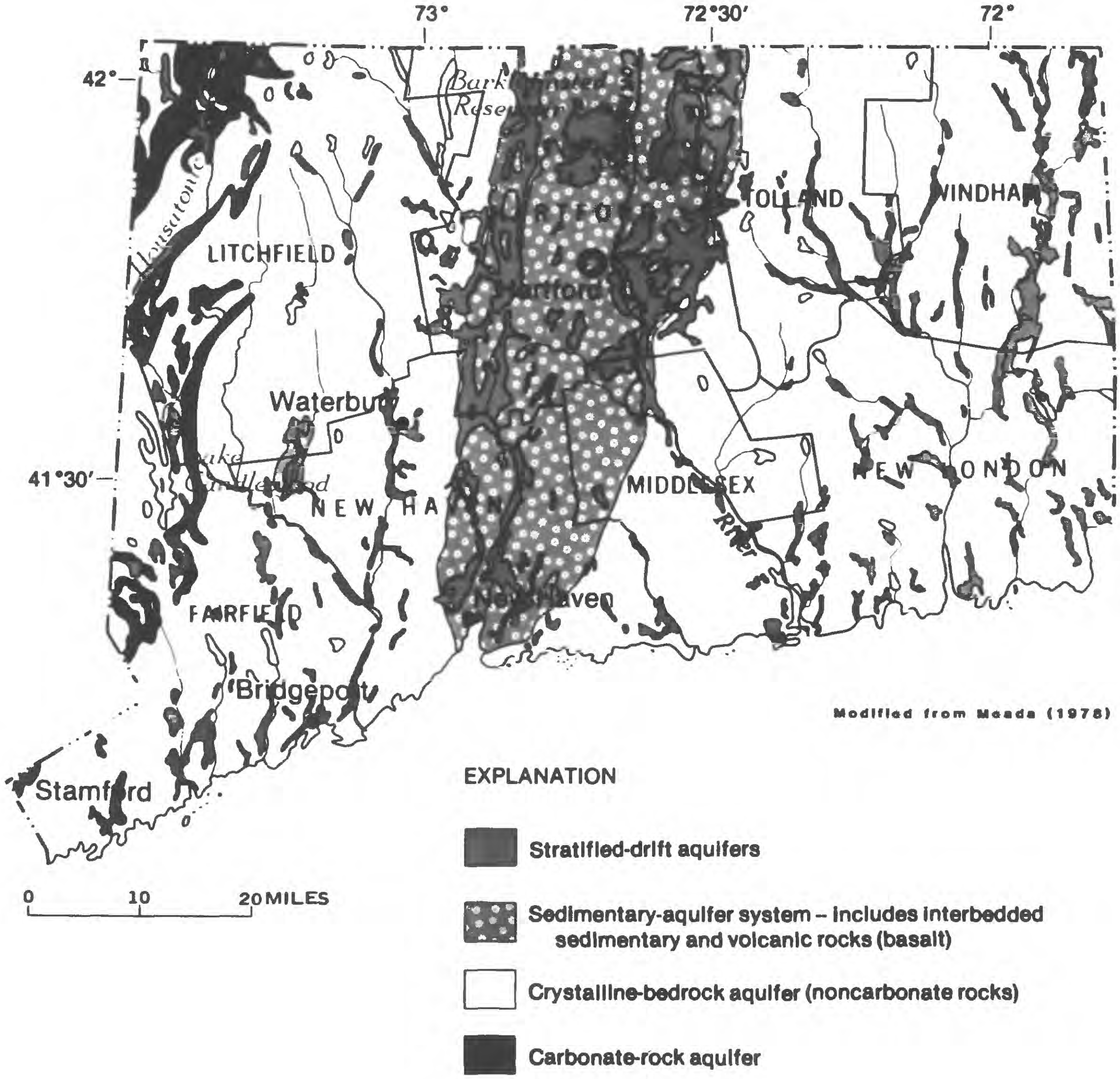


Figure 2.--Major hydrogeologic units in Connecticut.

Unconsolidated glacial deposits of stratified drift and till discontinuously mantle the bedrock aquifers. Stratified drift is mainly found in valleys that were drainage ways for glacial meltwaters or sites of temporary glacial lakes. These deposits are commonly less than 100 feet thick, but are 300 to 400 feet thick at a few locations. Saturated stratified-drift deposits composed of sand and gravel constitute the most productive aquifers in the State and are the principal sources of ground water for public supply.

Till is prevalent in most upland areas. Because it is commonly thin (less than 10 feet thick) and has relatively low hydraulic conductivity, till is only a minor aquifer that is tapped by few wells. Stratified drift and till aquifers are generally unconfined and water is stored in and transmitted through intergranular pore spaces. The distribution of major hydrogeologic units in Connecticut is shown in figure 2 and in more detail on the map compiled by Meade (1978). Spatial relationships between the units in a typical valley setting are shown in figure 3.

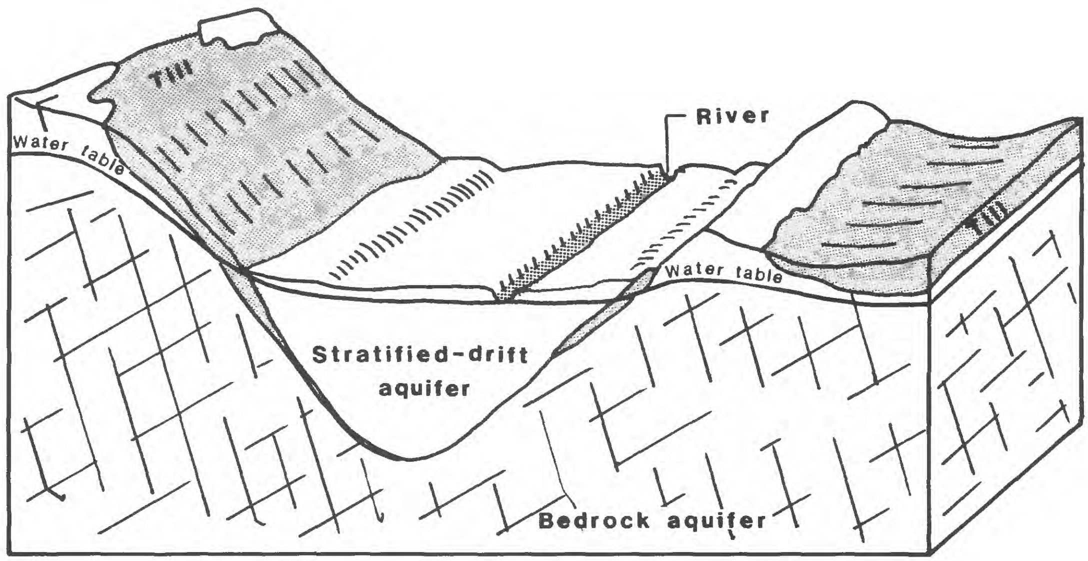


Figure 3.--Generalized block diagram showing spatial relationships between major hydrogeologic units.

Ground-water recharge and discharge

Ground-water recharge (inflow) is derived principally from precipitation that percolates downward from the land surface to the water table and surface water that is induced to infiltrate into an aquifer because of ground-water withdrawals that lower the water table. Within the saturated zone, ground water may flow from one hydrogeologic unit to another because of natural hydraulic gradients or gradients resulting from pumping.

Most ground water is ultimately discharged into streams, lakes, or estuaries, although some is evapotranspired or withdrawn by pumping wells. The pattern of ground-water circulation within the major hydrogeologic units can be described qualitatively, although detailed information is sparse. Most circulation is concentrated in the upper part of the saturated zone (within 300-400 feet of land surface), because of the limited thickness of the stratified drift and till and because the interconnected bedrock fractures are less prevalent at depth. The shallow nature of the flow system and the moderate topographic relief are believed to confine the circulation pattern in most areas laterally within boundaries defined by the surface-water drainage divides of basins drained by perennial streams.

Within this geographic framework, ground water moves vertically downward near the drainage divides, thence laterally toward major sites of discharge (stream channels, lakes, and swamps). Beneath and immediately adjacent to discharge sites, ground water has a largely upward vertical component of flow. Local or minor circulation systems may also exist within a basin, particularly near small ponds and swamps and the natural pattern of circulation is altered by the effects of withdrawals from pumping wells. The general pattern of circulation in a typical drainage basin is illustrated by the hydrogeologic section in figure 4.

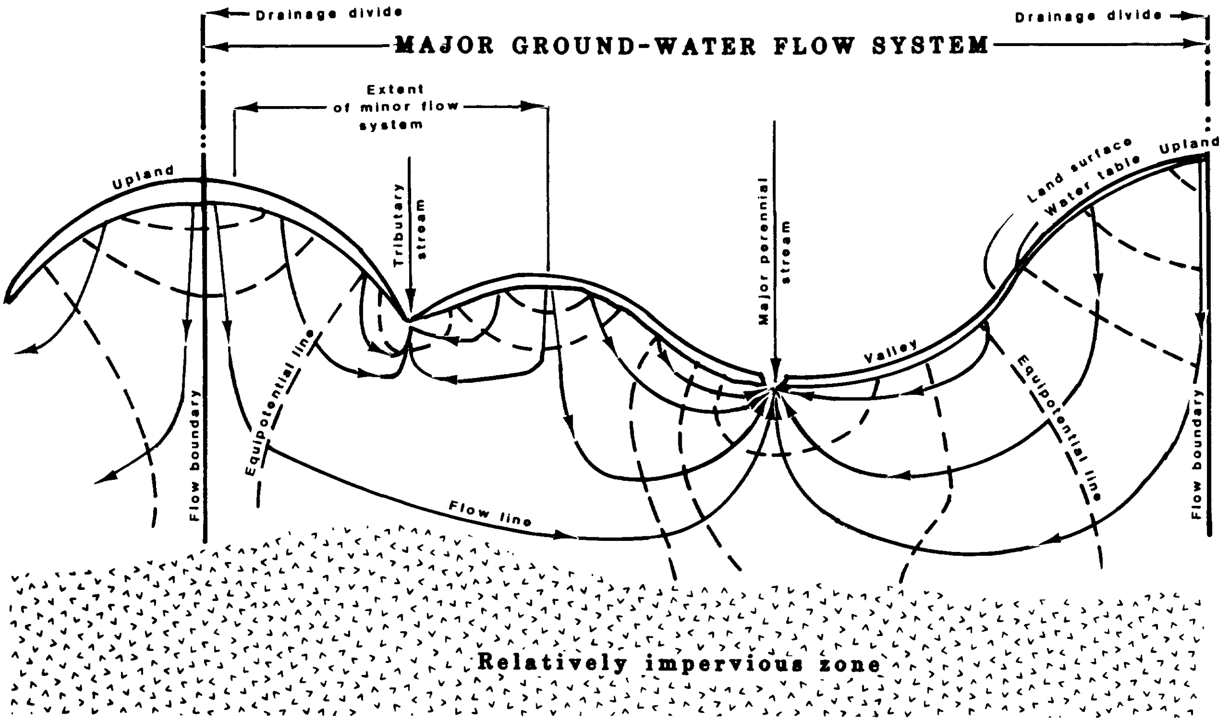
Natural Causes of Water-table Fluctuations

In almost all of Connecticut, the aquifers are unconfined and the water table that defines the top of the saturated zone is free to rise or fall in response to changes in recharge (inflow) and discharge (outflow). The extent that the water table rises or falls in response to a unit volume of recharge or discharge is generally proportional to the specific yield of the geologic materials in the zone within which the water table fluctuates. If recharge and discharge are exactly in balance throughout the flow system, changes in ground-water storage do not occur in the saturated zone, and the position of the water table remains constant. Recharge and discharge, however, vary with time and location, even though the system may be in long-term equilibrium. Consequently, the water table may rise in some areas and decline in others.

In Connecticut, recharge is generally greater than discharge during the non-growing season (essentially the period between the first killing frost in the fall and the last killing frost in the spring) and less than discharge during the growing season. This is because a large part of the infiltrating precipitation is withdrawn by plants during the growing season. The result is the typical annual pattern of water-table fluctuations shown by most of the hydrograph records in figures 5 and 6.

A number of complex and commonly related climatic, hydrogeologic, and topographic factors control the amount, rate, and timing of natural recharge and discharge and the magnitude of consequent water-level fluctuations[1/]. The amount, intensity, duration, frequency, and form (rain or snow) of precipitation, and temperature are the principal climatic factors. Soil-moisture content, the type of geologic materials at the land surface and in the unsaturated zone, depth to the water table, and the topography also have a major influence on the altitude of the water table at any time and at any specific location. The major factors that control water-table fluctuations help define the elements that should be part of Connecticut's hydrologic benchmark network. It is apparent, for example, that such a network should include observation wells within areas of differing climatic conditions, located in various parts of the ground-water flow system, in different hydrogeologic units, and in various topographic settings.

1/ This discussion excludes fluctuations that occur locally near surface-water bodies and are due to changes in stream or lake stage and tides.



Source: Cervione and others (1972)

Figure 4.--Generalized ground-water circulation in a typical Connecticut drainage basin.

The direction of ground-water flow and the distribution of hydraulic head are depicted by flow lines and equipotential lines. The actual configuration of these lines is more complex than shown because of differences in hydraulic conductivity of subsurface geologic units and other factors. Minor ground-water flow systems may be present only part of the year.

EVALUATION OF THE PRESENT NETWORK

Water-level records for 25 of the 31 wells in table 1 were examined to determine if observed water-level changes could be qualitatively related to major climatic factors such as amounts of precipitation, periods of low temperature that resulted in significant snow accumulation or were likely to have produced frozen-ground conditions, periods of extensive snow melt, and changes in evapotranspiration demands at the beginning and end of the growing season. The remaining six wells (GR 328-331, MA 314, and MS 44) were not examined because of their very short periods of record. This evaluation also considered the hydrogeologic setting of each well--specifically, depth to the water table and the geologic materials in the unsaturated zone--to assess the response of water levels to climatic factors.

Hydrographs prepared from computer plots of monthly water levels or plotted from weekly observations through 1980 were inspected visually, and several water years1/ of record were selected for evaluation. The years selected generally include at least 1 water year that had a typical seasonal pattern as well as years that showed atypical patterns, such as significant water-level rises during part of the growing season or significant declines during winter or early spring. Examples of atypical patterns are the periods July to October 1976 and December to February 1980 for well NT 15 in figure 6. In most cases, 5 years of record were examined but only 1 year was evaluated for a few wells with short periods of record. Climatological data were obtained from records of the nearest National Weather Service station that are contained in that agency's monthly series of publications titled "Climatological Data, New England".

Most water-level fluctuations on the individual hydrographs could be related to climatic factors--particularly, daily precipitation. There were, however, periods of from 1 to 3 months in almost all hydrographs where the water-level response was opposite to that anticipated from the climatic data and hydrogeologic setting. This anomalous behavior is most likely due to climatic data that did not accurately reflect local climatic conditions at the well site, and factors such as soil-moisture conditions that were not assessed.

A single example is sufficient to illustrate the relation between climatic factors--particularly, precipitation--and water levels that typifies most of the observation-well records. Figure 5 shows the hydrograph of well GT 19 and daily precipitation for the 1970 water year as measured at the National Weather Service station in Groton, Connecticut (U.S. Dept. of Commerce, 1969, 1970). Also shown are approximate dates of the first killing frost in the fall and last killing frost in the spring. The imbalances between recharge and discharge that are reflected in the water-table fluctuations shown in figure 5 can readily be related to precipitation, even in winter months. Well GT 19 is located near the coast where winter temperatures are relatively mild. Consequently, significant snow accumulation for long periods and extensive frozen-ground conditions do not

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1/ A water year includes the period from October 1 through September 30 of the following calendar year.

occur frequently. The water table in this well rises rapidly after rain because of the permeable material in the unsaturated zone (sand and gravel) as well as the moderately shallow depth to the water table. The hydrograph also shows that during the growing season daily precipitation, even exceeding 1 inch, had little effect on ground-water storage, probably because much of this water is evapotranspired or replenishes soil moisture deficiencies in the unsaturated zone.

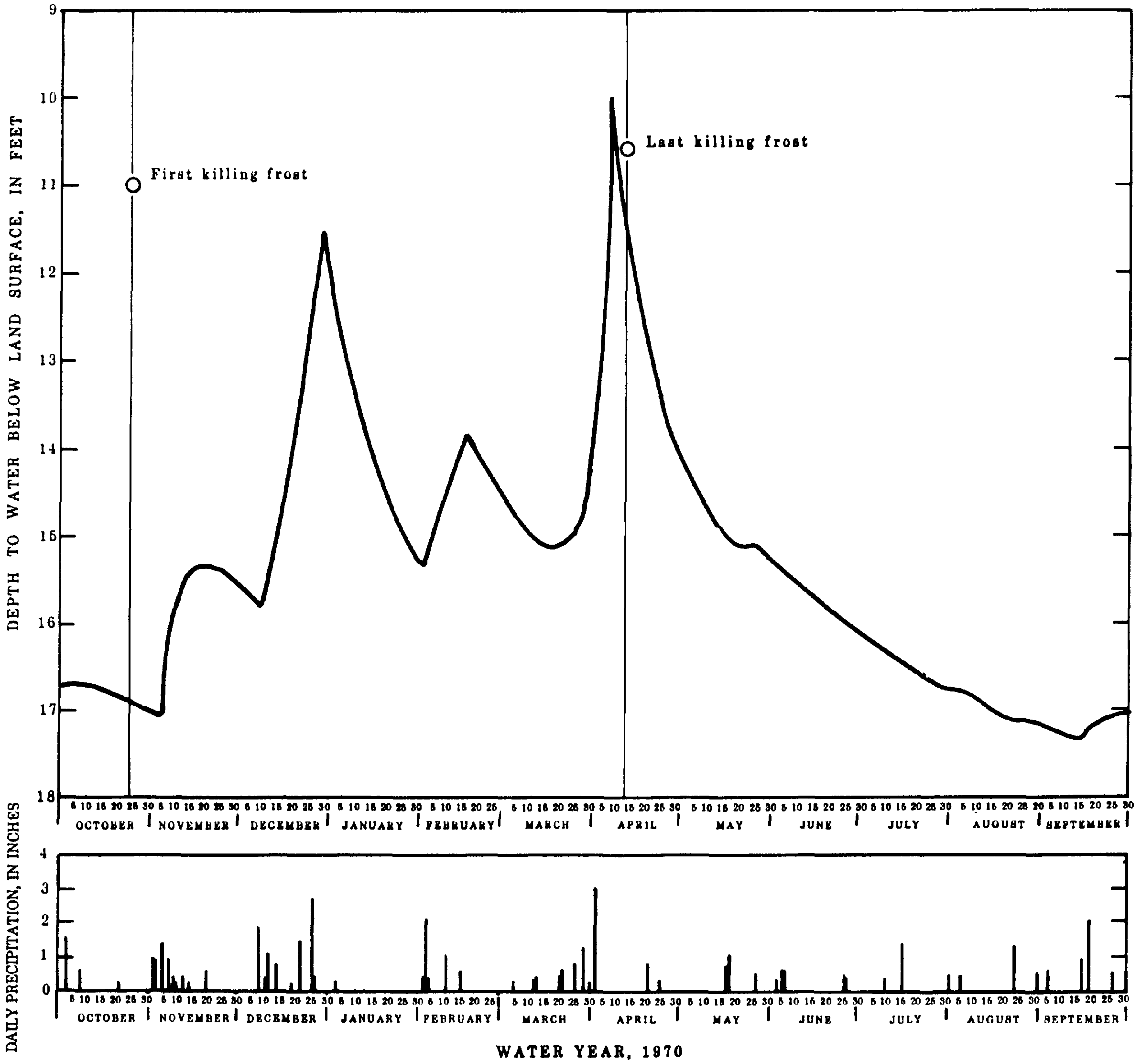

Figure 5.--Water levels in well GT 19 and daily precipitation at Groton, Connecticut, 1970 water year.

The water levels for March and April 1970 in well GT 19 illustrate why monthly measurements may not be adequate to assess changes in ground-water storage and to relate them to long-term conditions. The large amount of precipitation in late March and early April resulted in the highest observed water level for the period 1958-81 (9.98 feet below land surface). If the frequency of measurement had been monthly, rather than weekly and with measurements in the latter part of each month, only a small water-level change would have been observed from the end of March to the end of April and the highest water level would have appeared to be about 14 feet below land surface. The resulting difference of about 4 feet is more than half the total water-table fluctuation for the water year.

The next phase in evaluating the existing network consisted of comparing the hydrographs of all wells in similar hydrogeologic settings that are within an area where climatic conditions are approximately the same. The purpose of this comparison was to see if information on storage changes from relatively nearby wells was identical or similar. The comparisons also provided some insight into the variability of recharge and discharge within an area where climatic conditions are thought to be fairly uniform. Some hydrograph comparisons were also made between wells in different hydrogeologic settings but in the same climatic zone.

The State of Connecticut has been divided into five zones with generally similar climate on the basis of precipitation and temperature data and on physiographic features such as topographic relief and proximity to Long Island Sound (Brumbach, 1965). The boundaries of the climatic zones established by Brumbach (1965, p. 7) were modified and additional subdivisions made for this study (see fig. 1). The subdivision of Brumbach's coastal zone was done because of its large extent from the New York to the Rhode Island border, whereas other modifications were based on further consideration of topography and the distribution of average annual precipitation during the period 1931-80. The zones in this report are preliminary approximations that may be subject to revision.

A discussion of all the hydrograph comparisons is not warranted, but the following example illustrates the process. Figure 6 shows hydrographs of monthly water levels for wells BD 8, NT 15, and WY 1 over a 10-year period. BD 8 and WY 1 both tap stratified drift and are located on terraces where the water table is relatively deep and imbalances between recharge and discharge, reflected by monthly rise or fall of the water table, are qualitatively the same for almost the entire period of record. A few cases where water levels were rising in one well but falling in the other may simply reflect the fact that the wells were not measured contemporaneously.

It should be noted that the magnitudes of the fluctuations differ. The water level in WY 1 rises and falls about twice as much as in BD 8. The water levels in NT 15 also show the same general pattern of fluctation, although this well is located on a valley flat where the depth to the water table is much less. The range of fluctuation in NT 15 is less than in BD 8 and WY 1, and rises or declines are commonly one month out of phase with those in the other two wells. In summary, BD 8 and WY 1 provide equivalent information on monthly changes in ground-water storage within this climatic

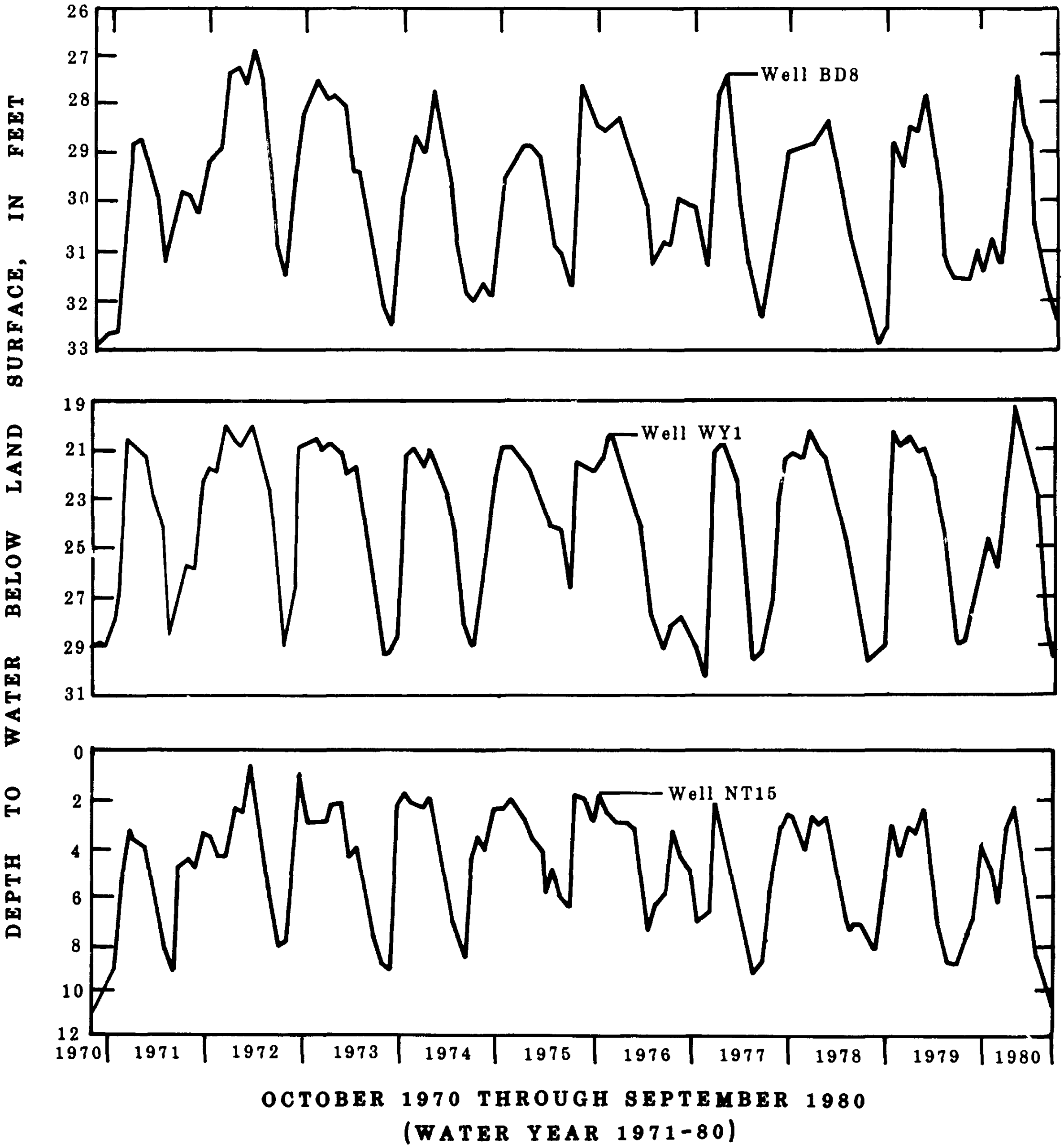

Figure 6.--Water levels in wells BD 8, NT 15, and WY 1, October 1970 through September 1980.

zone, and, if there are no other features of interest such as the magnitude of water-table fluctuations, measurement of one or the other could be discontinued. The fact that responses to climatic conditions are so similar also supports the contention that general climatic conditions are the same within the defined limits of this climatic zone.

The examination of individual hydrographs and the comparisons such as shown in figure 6 were the basis for recommending that some wells in the network be discontinued. These recommendations are contained in table 2. Other general recommendations resulting from this evaluation are:

1) Frequency of water-level measurement should be weekly, or at a minimum, bi-weekly, for all wells. If measurements cannot be made this frequently, then recorders or maximum water-level indicators should be used.

2) All wells should have recorders installed periodically to determine short-term response to climatic events or anomalous water-level changes that may be due to other natural causes or to pumping.

3) Field investigations should be made on an annual basis at each site to determine if there are any nearby wells or other manmade factors that may affect water levels. A report of each investigation should be filed with the observation-well records.

GUIDELINES FOR NETWORK DESIGN

Essential Components of Proposed Network

Consideration of network objectives and natural and manmade causes of changes in ground-water storage and water levels were used to develop guidelines for network design, listed below.

1. Areas of similar climatic conditions within the State provide a geographic framework for the distribution of observation wells.

2. Each climatic zone, should contain at least 3 observation wells that measure water-level changes in each of the major hydrogeologic units (stratified drift, till, and bedrock). Wells should also be located at points representative of major parts of the ground-water flow system as discussed in the next section of this report.

3. Present (1983) long-term observation wells (more than 20 years of record) that provide reliable, nonredundant information on natural changes in storage should be part of the network, as they provide the only basis for relating present and future observations to historical conditions.

Table 2.--Recommendations for retaining or deleting existing Connecticut observation wells.

WELL NUMBER	CHARACTERISTICS	RECOMMENDATION
BD 8	Stratified drift in intermediate part of the flow system. Southwest Hills climatic zone. Good response to precipitation events.	Delete after a subnetwork of new wells are installed in a basin within this climatic zone. Information on storage changes is the same as provided by WY 1, which is in the same climatic zone and hydrogeologic setting and has a substantially longer period of record.
BK 41	Bedrock in intermediate part of the flow system. Northeast Hills climatic zone. Generally good response to precipitation events.	Retain because it is the only long-term bedrock well in the climatic zone and only one of two such wells in the State.
BU 42	Stratified drift in intermediate or recharge dominated part of the flow system. Northwest Hills-East climatic zone. Generally good response to precipitation events.	Retain if water levels are not affected by pumping of bedrock well about 20 feet away. It is the only long-term well in this hydrogeologic setting within this climatic zone.
F 283	Stratified drift in intermediate or discharge dominated part of the flow system. Central Valley-West climatic zone. Generally good response to precipitation events.	Delete at end of 1984 water year. Equivalent information should be obtained from GR 330 or GR 331 that are part of a subnetwork being developed for this climatic zone. Before deletion, correlate concurrent records of these three wells.
F 294	Stratified drift in intermediate part of the flow system. Central Valley-West climatic zone. Fair response to precipitation events.	Do
FF 23	Stratified drift in intermediate part of the flow system. Coastal-West climatic zone. Generally good response to precipitation events.	Retain because it will be only well with relatively long record in this climatic zone.
GR 328	Till in recharge dominated part of the flow system. Central Valley-West climatic zone.	Retain as part of subnetwork of wells for basin in this climatic zone.
GR 329	Till in intermediate part of the flow system. Central Valley-West climatic zone.	Do
GR 330	Stratified drift in discharge dominated part of the flow system. Central Valley-West climatic zone.	Do
GR 331	Stratified drift in intermediate part of the flow system. Central Valley-West climatic zone.	Do
GT 19	Stratified drift in intermediate part of the flow system. Coastal-East climatic zone. Good response to precipitation events.	Retain because it is the only long-term observation well in this climatic zone.
MA 314	Stratified drift in intermediate part of the flow system. Coastal-Central climatic zone.	Delete after a subnetwork of new wells is installed in a basin within this climatic zone. Short period of record and will not be needed after a well in the same hydrogeologic setting is installed at another site.
MS 19	Stratified drift in intermediate part of the flow system. Northeast Hills climatic zone. Generally good response to precipitation events.	Retain because it is only long-term observation well in this hydrogeologic setting within this climatic zone.

Table 2.--(Continued)

WELL NUMBER	CHARACTERISTICS	RECOMMENDATION
MS 44	Till in recharge dominated part of the flow system. Northeast Hills climatic zone.	Delete after a subnetwork of new wells is installed in a basin within this climatic zone. Short period of record and will not be needed after a well in the same hydrogeologic setting is installed at another site.
MF 1	Till in intermediate part of the flow system. Central Valley-West climatic zone. Good response to precipitation events.	Retain because it is the only long-term observation well in this climatic zone.
MT 261	Stratified drift in intermediate or discharge dominated part of the flow system. Southeast Hills climatic zone.	Retain if unaffected by pumping. One of two long-term observation wells in this relatively large climatic zone. Other well (Pl 1) reportedly affected by pumping.
NT 15	Stratified drift in intermediate part of the flow system. Southwest Hills climatic zone. Generally good response to precipitation events.	Delete after a subnetwork of new wells is installed in a basin within this climatic zone. Other well in similar hydrogeologic setting (WY 1) with longer record available. Before deletion evaluate to see if additional record would be of use relative to model of Pootatuck aquifer (Haeni, 1978).
NT 54	Stratified drift in intermediate part of the flow system. Southwest Hills climatic zone. Response to precipitation events difficult to evaluate because of hydrogeologic setting (fine-grained sediments and thick unsaturated zone) and the short period of record.	No immediate recommendation. Warrants further evaluation to (1) see if well is open to aquifer and (2) assess if information on water-table fluctuations in this relatively atypical hydrogeologic setting will be useful.
NOC 7	Stratified drift in intermediate part of the flow system. Northwest Hills-East climatic zone. Good response to precipitation events.	Retain if unaffected by pumping. One of two long-term observation wells in this hydrogeologic setting within this climatic zone and only one in northwest corner of State.
NHV 201	Stratified drift in intermediate part of the flow system. Central Valley-West climatic zone. Generally good response to precipitation events.	Retain temporarily to assess if subnetwork may be required in southern part of this climatic zone. Assessment should be based on analysis of concurrent records for this well and GR 330-331, S 375 and 377 and F 283 and 294 through end of 1984 water year.
NHV 202	Stratified drift in intermediate part of the flow system. Central Valley-West climatic zone. Generally good response to precipitation events.	Delete at end of 1984 water year. Record similar to NHV 201 in same hydrogeologic setting. May be affected by stage changes in Quinnipiac River.
PL 1	Stratified drift in intermediate part of the flow system. Southeast Hills climatic zone. Generally good response to precipitation events.	Retain because it has the longest continuous record in the State and is the only long-term observation well in the eastern part of this large climatic zone.
SM 7	Stratified drift in intermediate part of the flow system. Southeast Hills climatic zone.	Delete after a subnetwork of new wells is installed within this climatic zone. Short period of record and will not be needed after a well in the same hydrogeologic setting is installed at another site.

Table 2.--(Continued)

WELL NUMBER	CHARACTERISTICS	RECOMMENDATION
S 375	Stratified drift in intermediate or discharge dominated part of the flow system. Central Valley-West climatic zone. Good response to precipitation events.	Delete at end of 1984 water year. Equivalent information should be obtained from NHV 201.
S 377	Stratified drift in intermediate part of the flow system. Central Valley-West climatic zone. Good response to precipitation events.	Do
SW 64	Stratified drift in intermediate part of the flow system. Central Valley-East climatic zone. Generally good response to precipitation events.	Retain because it is the only long-term observation well in this climatic zone.
SN 164	Stratified drift in intermediate or recharge dominated part of the flow system. Coastal-East climatic zone.	Delete at end of 1984 water year. Equivalent information is being obtained from nearby GT 19.
T 2	Bedrock in intermediate or recharge dominated part of the flow system. Northwest Hills-East climatic zone. Generally good response to precipitation events.	Retain because it is the only long-term bedrock well in this climatic zone and only one of two such wells in the State.
WB 93	Stratified drift in intermediate part of the flow system. Southwest Hills climatic zone. Good response to precipitation events.	Retain because of good long-term record.
WB 198	Till in intermediate part of the flow system. Southwest Hills climatic zone. Good response to precipitation events.	Retain because it is one of only two long-term observation wells in till within the State.
WY 1	Stratified drift in intermediate part of the flow system. Southwest Hills climatic zone.	Retain because of good long-term record. Also may be needed for ongoing investigative studies in the Pomperaug River basin.

4. All observation wells in this baseline network should be located at sites where water levels are unlikely to be affected by pumping, by changes in stream or lake stage, or by tides. They should also be reasonably accessible and at sites where continued operation over a long period of time (30 years) is feasible.

5. The frequency of water-level measurements in observation wells should be weekly or biweekly to assess monthly storage changes, permit comparisons with long-term conditions, and to determine the magnitude of fluctuations caused by average or extreme climatic events.

Proposed Modifications of Present Network

To develop a network that is consistent with the stated objectives, it is proposed that several new wells be placed in a single medium-size basin (about 5- to 25- mi^2 drainage area) within each of the climatic zones. The basins that are selected for additional wells should contain all three major hydrogeologic units (stratified drift, till, and bedrock) and preferably have climatologic and stream-gaging stations that are likely to continue in operation over the next 30 years. This strategy for network modification is based on the premise that climatic conditions are generally similar throughout each defined climatic zone. Therefore a number of carefully placed wells located in a single basin within a climatic zone should provide information on storage changes and water-table fluctuations representative of that entire zone. This information, together with data from present long-term observation wells should meet the principal objectives of a baseline observation-well network. The placement of wells within a selected number of individual basins also has operational advantages with respect to the cost of data collection. Where basins have long-term climatic and stream-gaging stations, the aggregate hydrologic data may provide an opportunity to develop a better understanding of relationships between climatic factors and other processes controlling recharge and discharge of ground water, and to compute hydrologic budgets that enable recharge and other elements of the hydrologic cycle to be quantified.

All the wells within this expanded network would be measured weekly or at a minimum biweekly. If this frequency of measurement is not feasible, then either continuous water-level recorders of maximum water-level indicators would be installed. Continuous water-level recorders would also be periodically installed on all network wells to define short-term response to climatic events and to detect anomalous water-table fluctuations that may be due to pumping.

Within a drainage basin, the new observation wells should be located in different parts of the ground-water flow system and also tap the major hydrogeologic units. Figure 4 is a generalized hydrogeologic section that qualitatively depicts the ground-water flow system in a typical basin where surface- and ground-water drainage divides coincide. In upland areas near the basin drainage divides, recharge is the dominant process and ground-water movement is toward the streams and swamps at lower altitudes. Flow has both horizontal and vertically downward components. In the areas intermediate between the drainage divides and major points of ground-water discharge, recharge also occurs although locally there is discharge to streams, ponds, and swamps from minor flow systems. Flow is mostly horizontal and toward major discharge areas. The streams and large swamps in the main valleys are the principl zones of ground-water discharge, and flow in the immediate vicinity of these discharge zones has both horizontal and vertically upward components.

The flow system as described and as shown in figure 4 is highly generalized. Recent studies by Winter (1983) show that the configuration of the water table and transient local flow sytems within a regional or basinwide framework can be complex even where the geologic conditions are relatively homogeneous. This is because variations in the thickness of the unsaturated zone result in nonuniform distribution of recharge. At times, recharge may be much greater in some parts of the flow system than in others. Likewise, recharge may exceed discharge in some parts of the system but may be less than discharge elsewhere.

Within the context of the generalized ground-water flow system that has been described, the locations for new wells in a basin include:

1) Uplands near basin drainage divides that represent the recharge dominant part of the system. These sites should not be located adjacent to surface-water bodies or topographic depressions where the water table is close to land surface.

2) Hillsides and terraces near margins of valleys that represent intermediate parts of the flow system. These sites should not be located adjacent to surface-water bodies or topographic depressions where the water table is very close to land surface.

3) Valley floors near discharge areas. These sites should not be located where they will be affected by changes in stage of adjacent surface-water bodies or in topographic depressions where the water table is very close to land surface.

Monitoring of water levels in these representative locations within the flow system and the major hydrogeologic units in an intermediate-size basin can be covered by a minimum of four wells. One would be located in the upland and tap either till or bedrock; the second would be located on a hillside and also tap till or bedrock; the third would be located on a terrace near the valley margin and tap stratified drift; and the fourth would be on the valley floor and tap stratified drift. In the upland and hillside locations, storage changes in bedrock and till would be similar, and therefore wells that tap each of these units would not be necessary. Data from these wells should provide the needed information on typical storage changes and water-table fluctuations in a basin.

If the premise that climatic conditions within each climatic zone are very similar, then the information on storage changes and water-table fluctuations obtained in a basin should be representative of changes in similar hydrogeologic settings throughout the climatic zone. Four wells recently installed in the West Branch Salmon Brook basin in Granby (wells GR 328-331 in table 1) can be considered as an example of this type of sub-

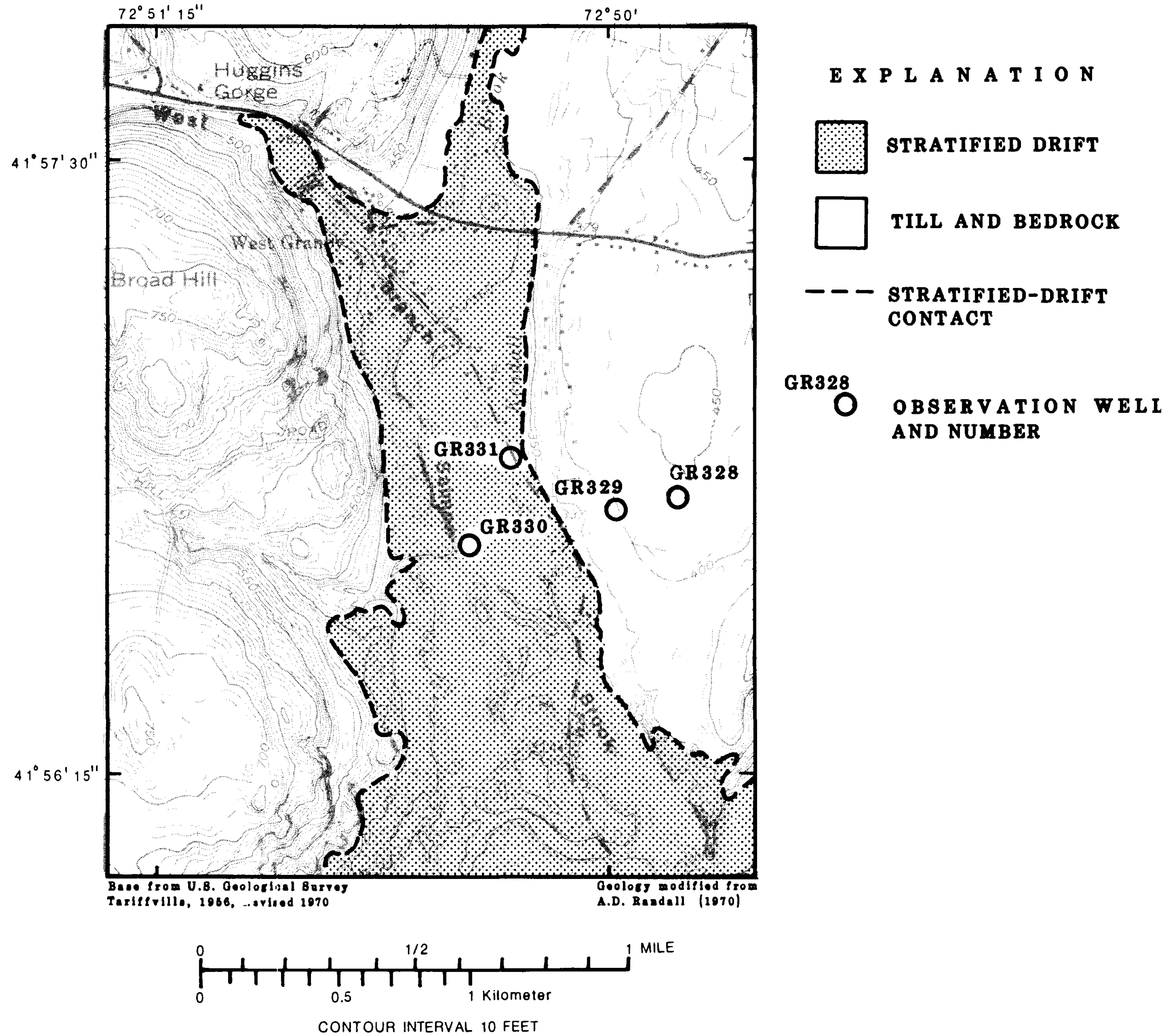

Figure 7.--Observation-well network in West Branch Salmon Brook basin, Granby, Connecticut.

network. The wells are located in a longitudinal segment of the basin extending from the drainage divide to the valley floor, as shown in figure 7.

A limited number of additional wells (estimated to total 10 or less) may be needed statewide to provide information on water-level changes in atypical settings. For example, a well located in a topographic depression on a terrace where the water table is relatively shallow, or in an area of fine-grained stratified drift or till where the water table is much deeper than usual, would aid assessment of the effects of variations in the thickness of the unsaturated zone on the distribution and amount of recharge over time.

Although almost any intermediate-size basin could be considered suitable for installing a subnet of observation wells, the most desirable are those where the effects of human activities on the hydrologic system are minimal, and where active climatologic and stream-gaging stations are present. A number of such basins that presently have climatologic and stream-gaging stations within or near the basin are listed in table 3. Although it is difficult to establish priorities, the Pomperaug basin in the Southwest Hills climatic zone, the Mt. Hope basin in the Northeast Hills climatic zone, and the Salmon River basin in the Southeast Hills climatic zone are areas for initial development of subnetworks of observation wells. All are used as index basins for long-term analysis of runoff conditions in Connecticut, and except for the Salmon River basin, have suitable nearby climatologic stations.

SUMMARY AND CONCLUSIONS

Most of the present observation wells in Connecticut are providing reliable and nonredundant information on changes in ground-water storage and water-level fluctuations caused by natural phenomena that is useful in meeting the objectives of a baseline network. All long-term observation wells should be retained to be able to compare present and future conditions with historical conditions. Six wells with less than 10 years of record can be discontinued at the end of the 1984 water year, and several others with short or intermediate periods of record can be discontinued later, if proposed network modifications are made.

The water-level data obtained from measurements in 31 observation wells that presently constitute Connecticut's baseline network do not provide all the information needed to meet the network objectives. The most serious deficiencies are the poor geographic distribution in relation to the State's climatic zones and the lack of diversity in respect to topography and hydrogeologic setting.

Modification of the present network that would provide the information essential to meet the objectives and also add to our basic knowledge about the hydrologic system include development of subnetworks of wells in 10 areas of the State where general climatic conditions are believed to be similar (see fig. 1). The individual subnetworks would consist of four to five wells located in major hydrogeologic settings within a single basin (total of 40 to 50 wells). The basins selected should preferably have long-term climatologic and stream-gaging stations. A small number of wells (tentative estimate of 10), located where topography and hydrogeologic conditions are atypical will be needed to fully describe and characterize storage changes and water-table fluctuations. All observation wells should be in sites where there is a high probability that long-term records can be collected and where water levels are not likely to be affected by pumping or changes in stage of surface-water bodies.

The frequency of water-level measurements should be bimonthly or weekly for all network wells in order to improve our understanding of relationships between changes in ground-water storage, local hydrogeologic setting, and variations in climatic conditions. Continuous water-level recorders or maximum water-level indicators may be required on some wells in order to meet this frequency of measurement. Water-level recorders also should be periodically installed on all wells to provide additional information on the causes of water-table fluctuations and to detect fluctuations due to man's activities such as pumping.

All water-level data should be evaluated annually as part of the preparation of the annual data report. The entire network should be evaluated periodically to determine if objectives are being met and to determine if modifications are needed. The evaluation in this report is preliminary and subsequent analysis should include correlations and other statistical methods. The premise that a limited number of wells in a single basin can adequately define storage changes throughout a climatic zone should be investigated further. This may require establishment of a more extensive network within a climatic zone for a short period of time.

Table 3.--Basins with suitable characteristics for observation-well subnetworks.

Basin Name	U.S. Geological Survey gaging station number	Drainage area (square miles)	Location of nearest climatologic station	Climatic zone	Remarks
Rooster River at Fairfield	01208873	10.9	Hemlock Res.	Coastal - West	
Sasco Brook near Southport	01208950	7.27	Hemlock Res.	Coastal - West	
Pendleton Hill Brook near Clarks Falls	01118300	4.02	Green Falls Res.	Coastal - East	Near boundary of Southeast Hills climatic zone.
Indian River near Clinton	01195100	5.64	Killingworth Res.	Coastal - Central	
Pomperaug River at Southbury	01204000	75.0	Woodbury	Southwest Hills	Slight regulation of Pomperaug River, well WY 1 in basin. Headwaters extend into Northwest Hills - East climatic zone
Saugatuck River near Redding	01208990	20.8	Saugatuck Res. or Danbury	Southwest Hills	
Burlington Brook near Burlington	01188000	4.13	Burlington	Northwest Hills - East	Occasional low-flow regulation of Burlington Brook.
Salmon Creek at Limerock	01199050	29.4	Falls Village	Northwest Hills - West	
Stony Brook near West Suffield	01184100	10.2	Bradley Field	Central Valley - West	
Broad Brook at Broad Brook	01184490	15.6	Bradley Field	Central Valley - East	
Coginchaug River at Middlefield	01192883	29.5	Mt Higby Res.or Cockaponset Res.	Central Valley - East Southeast Hills	Infrequent regulation of Coginchaug River. Observation well MT 1 in basin.
Salmon River near East Hampton	01193500	102	Mt Higby Res.	Southeast Hills	Slight regulation of Salmon River at low flow. No climatological station is within or close to this basin.
Yantic River at Yantic	01127500	90.0	Norwich Public Utility	Southeast Hills	Some low-flow regulation of Yantic River.
Little River near Hanover	01123000	30.4	Jewett City or Mansfield Hollow Dam	Northeast Hills	Near boundary of Southeast Hills climatic zone.
Mt Hope River near Warrenville	01121000	28.6	Storrs or Mansfield Hollow Dam	Northeast Hills	Surface-water index station.

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