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WATER TABLE FLUCTUATIONS IN PERIODICALLY WET SOILS OF CENTRAL NEW ENGLAND

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ABSTRACT

Depths to water tables in periodically wet forested soils in central New England show a definite pattern during the course of the year. Water tables are highest during the late fall, winter, and early spring, gradually lower in late spring and early summer, and rise again in the fall. Water table fluctuation is related to natural soil drainage class, and for this reason soil morphology provides a basis for predicting the height of the water table at any time of year and is particularly accurate for predicting the maximum stable water level.

Soil development in periodically wet soils in any one year may take place continuously, intermittently, or perhaps not at all. Changes in the magnitude of the downward, upward, and outward movement of water in these soils are dependent principally on local changes in climate or vegetation. Conceivably, if the local vegetation or climate is suddenly changed by fire, blowdown, decay, insect injury, cutting or other disturbances, then, some kinds of soil development may take place in periods of only a few years at a time, but with the periods separated by long intervals (perhaps 100-200 years).

INTRODUCTION

Some soils are waterlogged within the upper two or three feet of the surface for rather long intervals during the course of the year. The height to which the soils are waterlogged and the length of time involved have a bearing on the vegetation that grows on these soils, the manner in which they can be used or managed, and their morphology and genesis.

This paper is concerned with water table fluctuations in periodically wet forested soils and is based on measurements in two places in central New England for periods ranging from four to six years. The principal purpose of the study was to provide information about the role of ground water in the development of periodically wet soils, and hopefully, to obtain clues about the rate of soil development and the time of year when soil development takes place.

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REVIEW OF LITERATURE

A great many water table-soil relation studies have been made. Holstener-Jørgensen (1961) has made an extensive review of the recent world literature that deals especially with ground water in forested soils.

Within the United States some important studies in periodically wet forested soils have been those of Spaeth and Diebold (1938) in New York, Wilde et. al. (1953) in Wisconsin, Trousdell and Hoover (1955) in North Carolina, and Evans (1963) in Ohio.

Within New England, Midgley (1957) reported on water table fluctuations in cultivated soils of the Hadley and Suffield catenas in Vermont, Gile (1958) made a short study of the water tables in soils with fragipans in southeastern New Hampshire, Husch (1958, 1959) studied fluctuations of the water tables at Fremont, in southeastern New Hampshire over a period of three years in three different soils, Hatheway (1954) and Patric (1956) conducted short time studies at the Harvard Forest in central Massachusetts.

In Ontario, Fraser (1957, 1962) made water table studies that are especially useful for comparison with the data presented in this paper. Some of the soils he worked with are similar, if not identical, with some of the soils at Fremont, N.H. and the Harvard Forest. Fraser's curves for the water tables of the same three periodically wet soils covered a period of 10 years and for two of these soils covered a total of 11 years.

PROCEDURE

Depths to water tables in open wells were measured over 4 to 6 year periods in two places in central New England. At Fremont, Rockingham County, New Hampshire, measurements were made on the Husch and Lyford tracts separated about one-half mile from each other. The Husch tract is where a growth study of a young stand of old-field white pine (Pinus Strobus) was made by Husch (1958, 1959) during the period 1955-1957. Measurement of water tables in the four wells he established were continued by the writer until 1960 thereby giving a coverage of 6 years at this site. Measurements on the Lyford tract covered the four year period 1957-1960. This tract was chosen because of the wide range of natural soil drainage and complexity of soil pattern, and also because daily observations were possible. Wells were spaced at the corners of a 50-foot grid, and some were only 10 feet apart.

At the Harvard Forest, Petersham, Worcester County, Massachusetts, measurements were made for the four year period 1960-1963 in Compartments I and II of the Tom Swamp tract. Wells were spaced at 50 foot intervals down a long 5-15 percent slope in Compartment I, and Patric's original wells were also used. A single well in Compartment II was used.

Measurement of water table depth was made to the nearest inch. Most wells were dug with a post hole digger and were 4 to 6 inches in diameter. They ranged in depth from 2 to 5 feet in the wetter soils to 5 to 8 feet in some of the drier soils. Four inch diameter perforated asphalt tile was placed upright in some of the sandy wet soils to prevent filling of the lower part by slumping. Most of the measurements were made at weekly intervals. The cistern effect was avoided by terminating wells above or below slowly permeable layers.

Official U.S. weather data are available at the Harvard Forest. Precipitation data were collected at the tract locations at Fremont, N.H. while the water table measurements were in progress.

Table I

KEY TO SOIL SERIES IN WHICH WATER TABLES WERE MEASURED

General Characteristics.	Excessive, somewhat ex. or well drained	Mod. well or somewhat poorly drained	Poorly drained	V. poorly drained
Soils on stratified glacial drift.				
Gravelly throughout or within 24 inches of the surface.				
Brown Podzolic, Low Humic Gley, or Humic Gley soils.	Hinckley	Sudbury	Walpole	Scarboro
Ground Water Podzols.				
With cemented B horizons		Saugatuck	Saugatuck	
Lacking cemented B horizons		AuGres	AuGres	
Sandy throughout.	Windsor	Ninigret		
Sandy but with a 6-8 inch strata of varved silt or clay at a depth of about 20-30 inches	Melrose	Elmwood	Swanton	Whately
Soils on unstratified glacial drift.				
Stony, gravelly, sandy glacial till. Soils lack fragipans	Gloucester	Acton	Leicester	
Stony, gravelly, sandy loam glacial till. Soils have fragipans	Paxton	Woodbridge	Ridgebury	Whitman

Relationships of the soils in which water table measurements were made, both in New Hampshire and Massachusetts, are shown in Table 1. In brief the well, moderately well, and somewhat poorly drained soils are members of the Brown Podzolic great soil group. The poorly and very poorly drained soils are Low Humic Gley and Humic Gley soils respectively. Exceptions are the AuGres and Saugatuck soils on coarse sandy deposits. These two are Ground Water Podzols and cover the somewhat poor and poor drainage classes. An overall resume of the soils of New England is given by the Northeast Soil Research Committee (1954). Detailed description of the soils used in both the New Hampshire and Massachusetts study areas are given in the recently published soil survey report for Rockingham County, N.H. (Van der Voet, 1959). Physical and chemical data for several of the soils used in this study are given by Prince and Raney (1961). Soils of Compartment I of the Tom Swamp tract, Harvard Forest, are described by Lyford, Goodlett and Coates (1963).

Tree vegetation on the Husch tract at the time of water table measurement was a 12-20-year-old stand of white pine. On the Lyford tract white pine about 50 years of age was growing on the well drained soils with progressively more red maple (*Acer rubrum*) as the soils became wetter until in the wettest portion red maple was the only tree. At the Harvard Forest the tree vegetation consists of a 40-50-year-old stand of hardwoods in which red oak (*Quercus rubra*), red maple, sugar maple (*Acer sacharum*), white ash (*Fraxinus americana*), black birch (*Betula lenta*), and paper birch (*Betula papyrifera*) are the most numerous species.

RESULTS

Although measurements of depths to water tables were made at about 130 different wells the results are presented for only a few selected ones. These few were chosen as representative of the several classes of natural soil drainage by repeated comparison with all wells during the course of measurement.

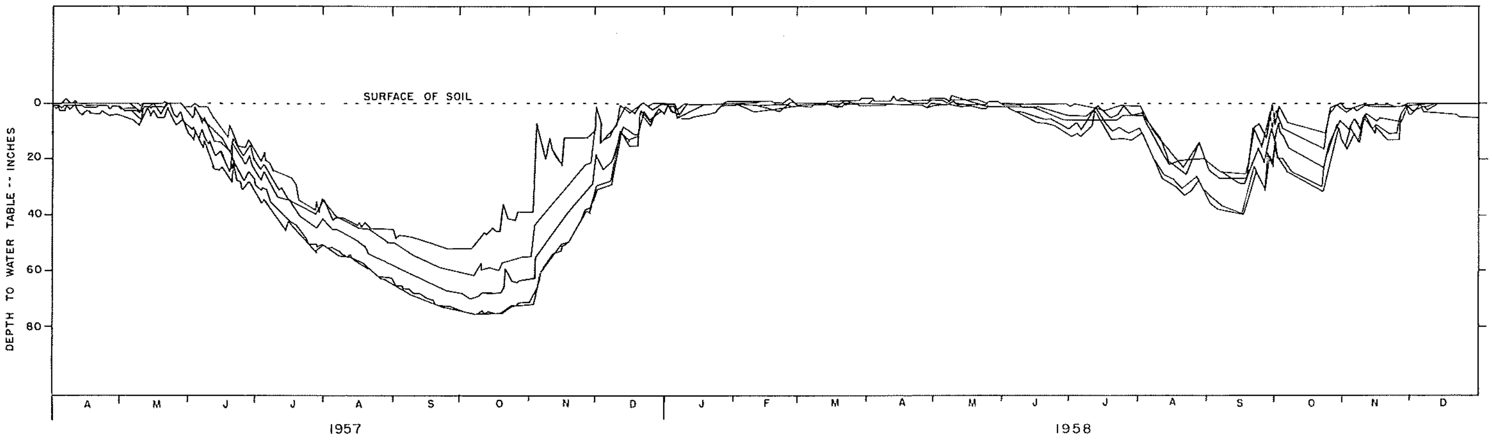

Figure 1. Depths to water tables in five wells in the same small area of very poorly drained Whately loam at Fremont, N.H.

March of the water table in the very poorly drained Whately soil at Fremont, N.H., for a two year period is shown in Figure 1. During the growing season of the first year there was a deficiency of rainfall and the soils were unusually dry. In the second year the soil was moister than common. The water table is closest to the surface of the soil in the spring, gradually becomes deeper beginning about May or June, and tends to be at the greatest depth in September or October. This yearly march, documented by most of those cited in the literature review is particularly noticeable in any continuous study involving poorly or very poorly drained soils. In these wet soils the water table is so close to the surface in the winter months that its presence can not be overlooked.

Variation in depth to water table among wells in the same soil is also shown in Figure 1. Data for five wells spaced at 50-foot intervals along a 200-foot line in a single small area of the very poorly drained Whately soil are plotted as a family of curves. The five wells were selected purposely to cover the entire range of the moisture regime of this particular soil series rather than the central portion. The soil at the well showing the deepest water table level in summer is near the boundary of the slightly better drained Swanton soil. The soil at the well with the shallowest water table in summer grades toward shallow muck. In the spring when the water table is at its maximum height no appreciable differences are noted in the depths to water tables; the soil is waterlogged at all five wells and for short intervals the soil may be ponded and have up to three inches of water on the surface. During the summer months however, appreciable differences occur; there is a maximum spread in depths to the water table among the five wells of 23 inches in 1957 and 15 inches in 1958.

Depths to water tables at the same wells from year to year are shown in Figures 2 and 3. These curves show the fluctuation for four different soils. Depth to water table varies considerably from year to year in the same well and this variation is of considerably greater magnitude than the variation from well to well in the same soil shown in Figure 1.

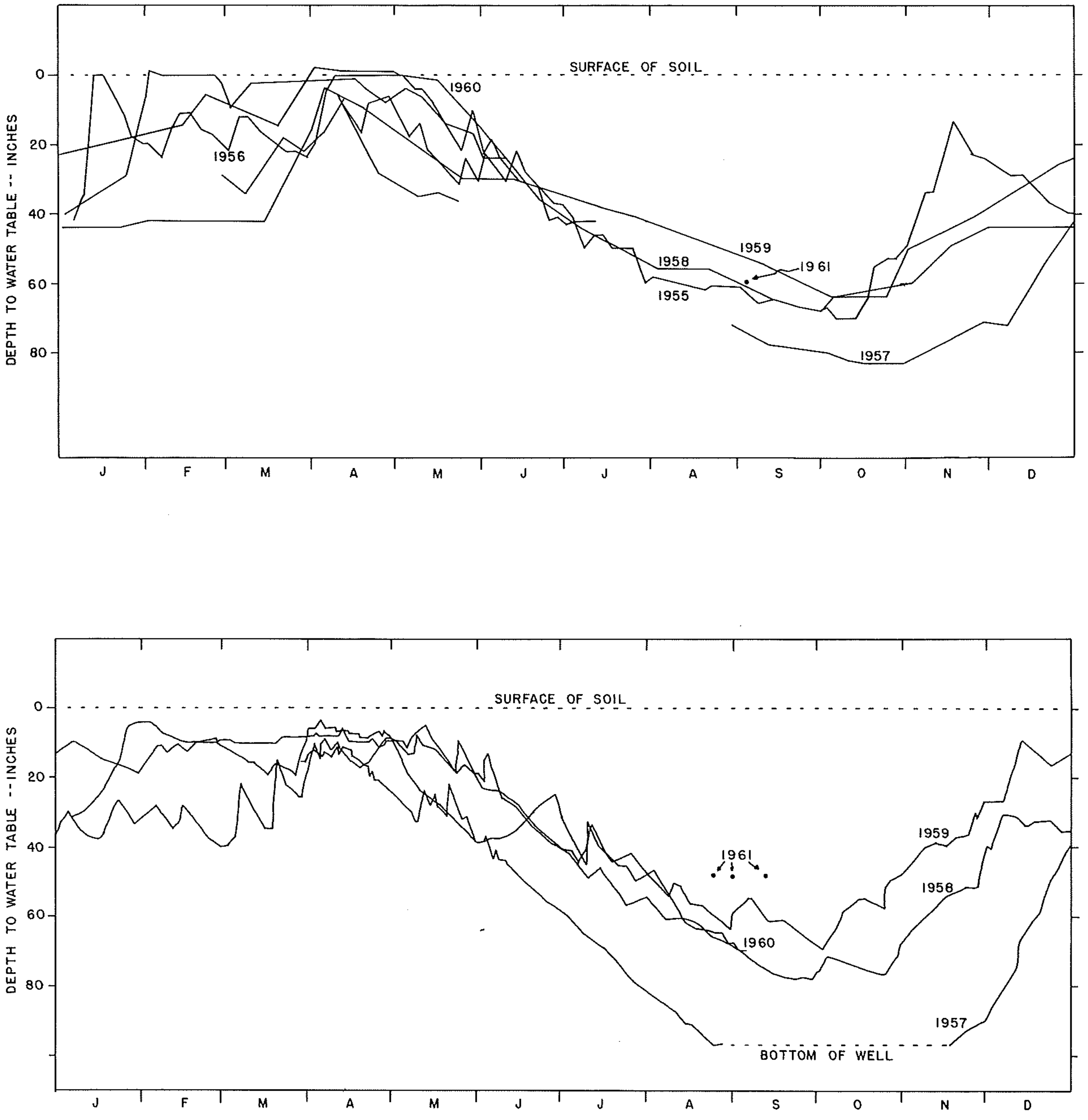

Figure 2. Depths to water tables in the same soil well at Fremont, N.H. over a period of years.

Upper figure - Somewhat poorly drained Sudbury loamy coarse sand, Husch tract, (Husch 1958, Plot D).

Lower figure - Somewhat poorly drained Ninigret loamy sand, Lyford tract.

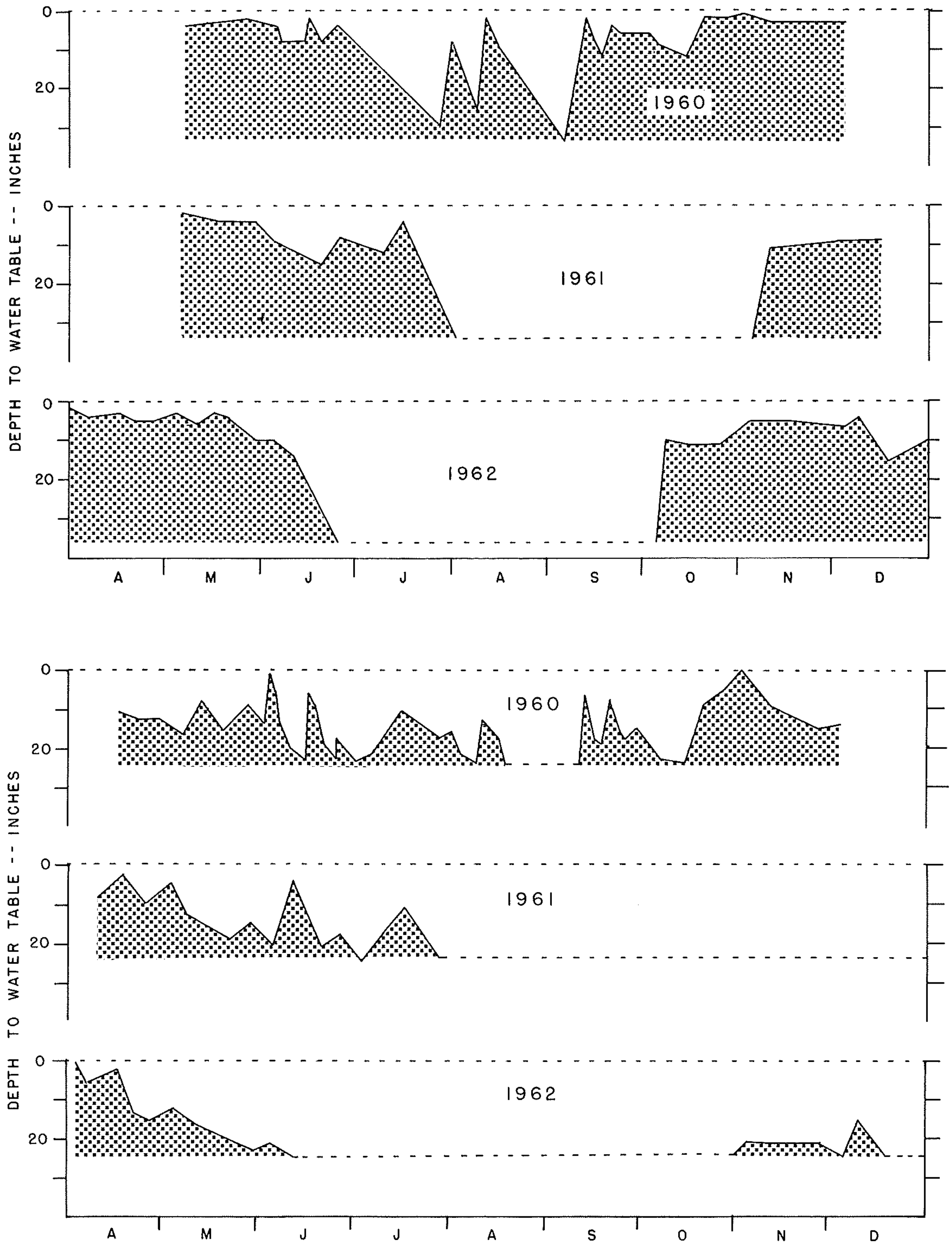

Figure 3. Depths to water tables over a three year period, Tom Swamp tract, Harvard Forest, Petersham, Mass.

Upper figure - Poorly drained Ridgebury fine sandy loam, Tom Swamp II.

Lower figure - Somewhat poorly drained Woodbridge fine sandy loam, Tom Swamp I.

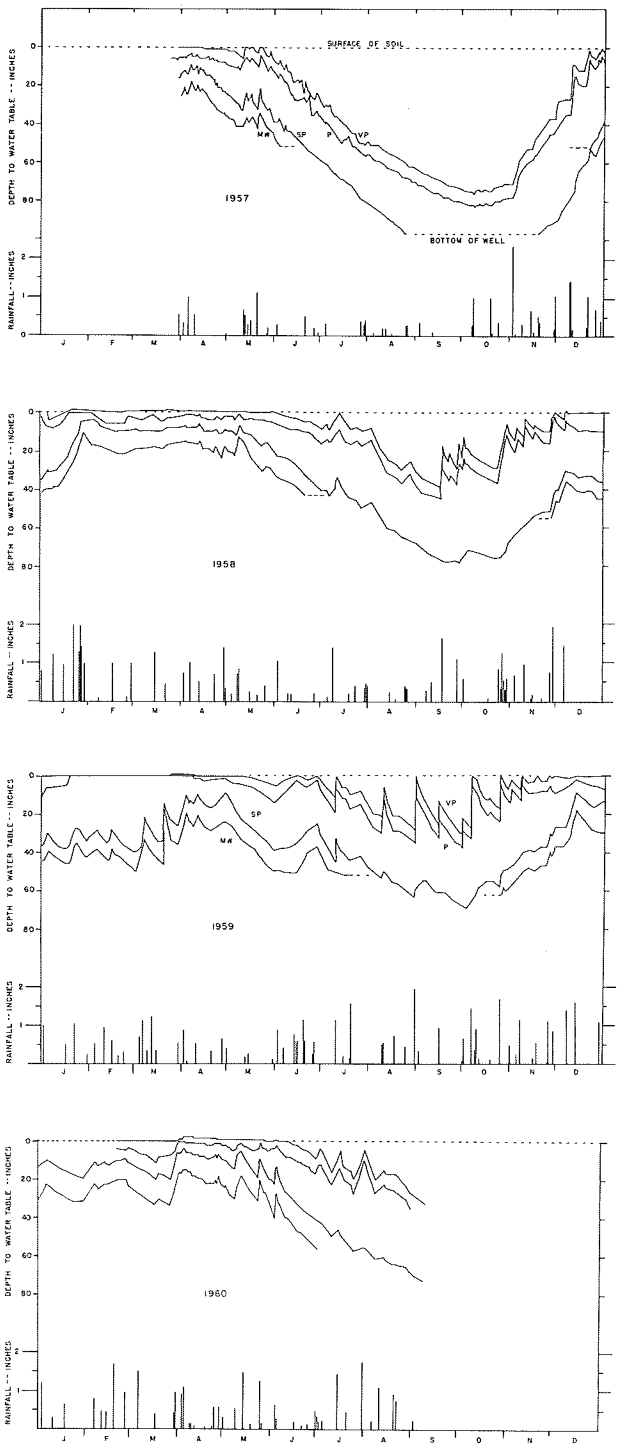

Figure 4. Depths to water tables in four soils with different degrees of natural drainage at Fremont, N.H.

MW - Moderately well drained Elmwood.
SP - Somewhat poorly drained Ninigret.
P - Poorly drained Swanton.
VP - Very poorly drained Whately.

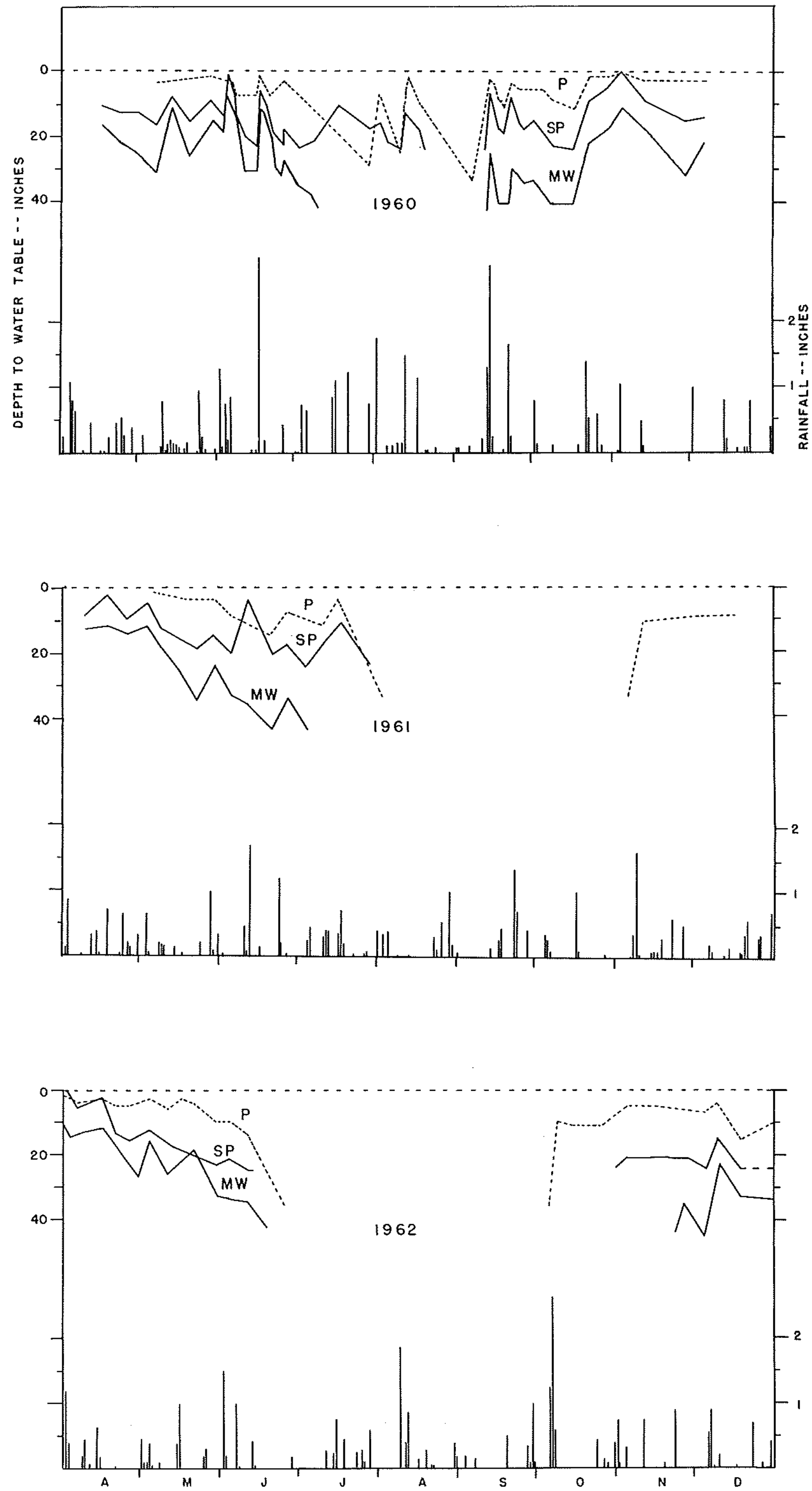

Figure 5. Depths to water tables in three soils with different degrees of natural drainage at the Harvard Forest.

MW - Moderately well drained Woodbridge.
SP - Somewhat poorly drained Woodbridge.
P - Poorly drained Ridgebury.

Variations among soils with different degrees of drainage are shown in Figures 4 and 5. These curves are for four soils at Fremont, N.H. and three at the Harvard Forest. The curves for the water tables in the soils of different degrees of drainage tend to parallel each other closely.

Comparison of water tables of somewhat poorly drained soil at Fremont with those of a U.S. Geological Survey well is shown in Figure 6. The Geological Survey well is at Auburn, N.H., about 20 miles due west of Fremont. Data from this well have been collected continuously since 1942 by the Water Supply Division in connection with a long-time study of water levels throughout the United States. The data are published periodically in a numbered series of Water Supply Papers. Those covering the Northeastern States are listed under "Literature Cited" in the present paper. The close correspondence of the curves from the two places is noteworthy. The fact that the water table in the well at Auburn is within 18-20 inches of the surface when at its maximum height in the spring suggests that the well is located in an area of somewhat poorly or moderately well drained soil. This suggests further that at least some of the published data of the Geological Survey would be useful to those who wish detailed information regarding the long-time trends of the water table either in well drained or periodically wet soils.

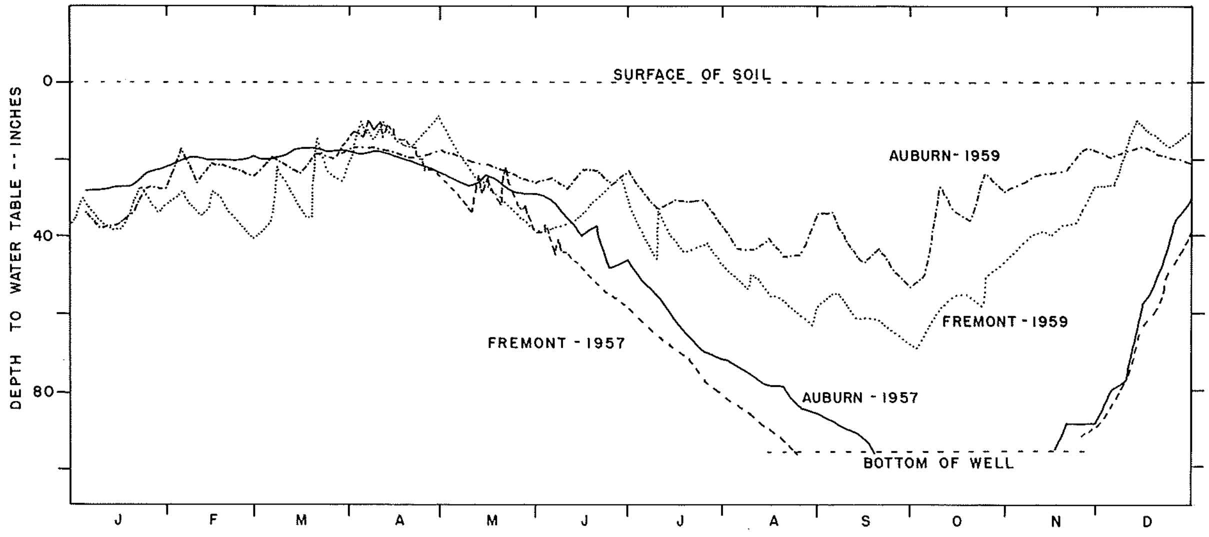

Figure 6. Depths to water tables in 1957 and 1959 in the somewhat poorly drained Ninigret soil at Fremont, N.H. and the USGS Auburn-8 well at Auburn, N.H. (1959 data for Auburn-8 well by courtesy of J.M. Weigle).

DISCUSSION

WATER TABLE FLUCTUATIONS

Water tables in soils fluctuate in a more or less regular manner during the course of a year. Maximum heights in periodically wet soils can be expected about the first of April in central New England just after the snow melts and the frost comes out of the soil. Maximum depths can be expected in most years in late September or early October. Most of the fluctuation is dependent on the amount and spacing of rainfall but the consistently steady rate of water table lowering in the spring and early summer can be attributed to longer days, increasing temperatures, increasing evapotranspiration, and perhaps other factors that also show increases in magnitude during this time of year. Periods when leaves appear on the deciduous trees correspond well with periods when water table lowering becomes rapid. Fluctuation also depends on downslope movement of water and kind of soil. Bradley (1954), referring to water tables in New Hampshire stated that water levels in wells in glacial till commonly fluctuate through a range of 5 to 15 feet whereas in stratified sand and gravel they rarely fluctuate more than two or three feet.

Variation in depth of water table at any one time in an area where there is only one kind of soil is not large. This is illustrated in Figure 1. From a practical point of view this means that the determination of depth to the water table can be made at a single well within a tract and this figure can be applied to the tract as a whole with a high degree of certainty.

Year to year variation at any one well is dependent largely on the amount and spacing of rainfall and particularly the time of year when rainfall occurs. In the spring, for example, the soil is at its wettest and almost any precipitation causes immediate downward movement of moisture to the water table. Rains of only a half inch or so cause some raising of the water table. Even well drained soils are at field capacity just after the snow melts and much of the rainfall percolates through the soil to the water table. But in mid-summer, a fairly large rain may have little effect on the water table. All the moisture is used to replenish that previously removed from the root zone by transpiration and there is not enough moisture to bring the whole soil back to field capacity so that the water can move downward and raise the water table.

Parallelism of the water table curves for the soils of different degrees of natural drainage is striking. This is shown in Figures 4 and 5, and also by Evans (1963). Water tables in the drier soils are the first to fall in the spring, followed a week or two later by those in the wetter soils. When the water tables start falling in the wetter soils the rate of fall is about the same as in the drier soils and the curves from then on are essentially parallel. It is at this time that the water tables in all wells in a tract, irrespective of kind of soil, can be predicted with reasonable certainty after one measurement at a single well. Gile (1958) pointed this out in regard to the soils he studied. Lag in water table lowering of wet soils occurs because there is lateral seepage downslope from the well to the poorly drained soils. This lateral seepage can be traced when measurements are made at daily intervals by noting when the water in the various wells first starts to fall.

Soils are classified into natural drainage classes and soil series on the basis of features such as grayness, blackness, and depth to distinct or prominent mottling (Soil Survey Staff 1951). These same features apparently are closely related to the characteristics of the water tables in soils because the water table curves for soils with different degrees of natural drainage are parallel. Examination of the morphology of the soil, therefore, can be used to make a close estimate of the "maximum stable height" (Holstener-Jørgensen 1959), of the water table provided there has been no artificial drainage. This maximum height is attained each year about the first of April in central New England. Maximum depth to the water table can be predicted much less accurately than maximum height, because considerable variation in maximum depth occurs depending on the amount and spacing of the rainfall. This is illustrated by many of the curves in this paper and by Fraser and others.

When the water table is four feet or more below the surface, soil moisture is so depleted in the upper part by evapotranspiration that over an inch of rainfall is needed to bring the soil to field capacity so that excess moisture can move downward into the ground water and raise the water table. This is particularly noticeable in Figure 4. Apparently water table curves for most soils can be divided into three main sections corresponding to the ground water fluctuations during the year. One portion covers the time when the water level is at its maximum during late fall, winter, and early spring. Another is during the periods in late spring and fall when the water table is within about four feet of the surface and is either falling or rising at a more or less steady rate. The third covers that portion of the curve when the water table is below about four feet.

Curves for water tables in well drained soils have not been shown because there are only a few times during the year when the level is close enough to the surface to appear in shallow wells such as those used in this study. The records of the Geological Survey are useful in any study of the well drained soils because many of the measurements are made in deep wells. In general, water levels in soils like the Gloucester that are permeable to great depths seldom occur within the upper four or five feet. If however, these soils are on the lower portion of a slope or on a relatively smooth area with an altitude of no more than about 5-10 feet above a wet area there is a likelihood that the water levels will be within the upper two or three feet several times during the period when water tables in the surrounding wetter soils are at their maximum height. Husch (1958) for example, shows that the water level in one of his Gloucester soils (Plot C) was within 40 inches of the surface four times during the spring in the three years of his study but it did not come within 70 inches of the surface in the Gloucester soil (Plot D) that was up slope a short distance. Gloucester soil at the Lyford tract, located toward the lower part of a short slope and not far above a moderately drained soil had water within the upper 30 inches several times during the winter and spring of 1958. At Petersham water tables have occurred several times in the lower part of three different Gloucester soils. In none of these soils is there mottling within the upper 40 inches. Therefore it is probable that soil materials at this depth must be wet for rather long periods at this time of year before mottling is induced.

No attempt was made to study the rates at which the water table lowers. Here again this can be done much more precisely by reference to studies such as those of the USGS where a continuous record is kept by recorder gages. A few general observations may be useful however. Maximum rate of water table lowering takes place just after a rain of sufficient magnitude to cause an appreciable rise of the water table. For two or three days the lowering may be as much as 6 to 8 inches per day. In general the rate of lowering is about one or two inches per day. For example, in the rather long dry period during the spring of 1957 the water table in the somewhat poorly drained Ninigret soil at Fremont (Fig. 4) fell 53 inches in 76 days, a rate of .7 inches per day. During the summer of 1961 the water table in the Tom Swamp II well at Petersham (Fig. 3) fell 30 inches in 17 days and in 1962, 22 inches in 14 days. These are rates of 1.8 and 1.6 inches per day respectively.

INFLUENCE OF CHANGES IN THE VEGETATION

If the vegetative cover on a soil remains approximately the same over a period of years variations in depths to water tables are dependent largely on rainfall. If however, there is a sudden and complete change of cover, as a result of fire, wind, disease, or even clear cutting, an immediate change in the yearly trend during the summer months may be expected. Cutting the forest, for example, apparently causes a sizeable reduction of water loss by transpiration and a greater amount of water in streams. (Trousdell and Hoover 1955, Reinhart et. al. 1963).

In the present study there is one bit of data that has an interesting, though not very conclusive, bearing on the changes that can occur in the water table as a result of cutting trees. At the Lyford tract in Fremont the merchantable white pine was cut during the winter of 1960-61 leaving about half as many trees as were present when the water table study was made during the 1957-60 period. In September, 1961, after a rather long droughty period the water tables were remeasured. The depths measured at this time on the Ninigret soil at the Lyford tract and the Sudbury soil at the Husch tract are shown in Figure 2. The water table at the Husch site where the vegetation was undisturbed is on the same portion of the curve where it also occurred at this same time in other years. The water table at the Lyford tract on the other hand was at a higher level than it had been at the same time of year, even during the unusually dry year of 1957. Removal of trees in the vicinity apparently had allowed the water table to be at a higher level at this particular time than it otherwise would have. This has some pedological significance for it emphasizes the problems involved in trying to relate characteristics of the soil, such as mottling, to short time measurements of the water table.

OUTWARD MOVING WATER

Evidence of outward moving water can be observed in winter from melted spots in the snow cover on the wet areas. This is shown in Figure 7. Presumably in these small areas the water is more plentiful or warmer and causes a more rapid melting of the

Figure 7. Small spots on the Lyford tract at Fremont, N.H. where snow was melted by outward moving water.

snow than over most of the area. Spaeth and Diebold (1938) called attention to this kind of snow melting but their photo suggested melting as a continuum in a stream bottom rather than in isolated spots. Continuous observation has shown that where the snow melts in these small spots there is usually a spring or long-continued wet place that is evident also at other times of the year.

Outward moving water can also be observed in below-zero weather on the surface of the ice in stream channels of narrow intermittent stream bottoms near the heads of watersheds. Water oozes out on the surface of the ice from the adjacent slopes as a result of downslope seepage. A rough rugose ice surface results from this seepage because the water freezes soon after it appears on the surface and before it has a chance to spread out. At times some of the outward moving water oozing over the surface of the ice is yellowish brown. When this freezes the resulting ice is also colored. Some of the colored ice was collected, the water evaporated, and the residue ignited. As the water evaporated the color of the solution changed from yellowish brown through brown to reddish brown, colors reminiscent of those in the B horizons of the Brown Podzolic soils and Ground Water Podzols nearby. Judging from loss of weight on ignition the residue had a fairly high organic matter content. These observations call attention to the fact that even though the water is very cold some soluble organic substances are carried in the water that moves outward from the mineral soils. This suggests that some soil forming processes, especially translocation, are active in cold periods.

SOIL DEVELOPMENT CONSIDERATIONS:

Time of year when soil development takes place doubtless is related in some manner to water movement in the soil. Certainly, in mid-summer when the water table is low moisture from light rains does not penetrate to the water table and under these circumstances there is no translocation of soluble substances to great depths in the soil. Possibly it is at this time that colored soluble substances in Brown Podzolic soils are moved and precipitated in such a manner that the characteristic distribution of strongest color in the upper part of the B horizon and its gradual decrease with depth takes place.

On the other hand the colored substances in ice show that even in winter there are substances present in the soil similar in color to those which coat mineral particles and give rise to the characteristic colors of the B horizons of Brown Podzolic soils and Ground Water Podzols. Conceivably Brown Podzolic soils develop during the growing season when the soil is at its driest or when the soil is drying rapidly, whereas the associated Ground Water Podzols receive their coloring substances in colder wetter periods.

Outward moving water, of course, is well known from its appearance in springs but is not generally recognized as occuring locally in soils so extensively as is pointed out here. Possibly small spots of outward moving water in fairly large areas of the wet Low Humic Gley and Humic Gley soils are localized in sandy places where Ground Water Podzols occur. This might account for the known complexity of soil in small sandy wet areas. At the time of the study this possibility was not considered and so no soil examinations were made specifically to test the hypothesis.

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