Article 168

SEASONAL TEMPERATURE FLUCTUATIONS IN SURFICIAL SAND NEAR ALBANY, NEW YORK

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Work done in cooperation with the
New York Water Resources Commission

Abstract.—Subsurface temperature fluctuations are due to thermal waves that originate at the land surface in response to changes in air temperature. The annual average temperature of the zone of saturation, 6 to 18 feet below land surface, is about 3°F higher than the annual average air temperature.

The temperature of ground water at the top of the zone of saturation in most places corresponds closely to the mean annual air temperature. Collins (1925) pointed out that the temperature of ground water between depths of 30 and 60 feet is generally 2°F to 3°F above the mean annual air temperature. The temperature of shallow ground water under natural conditions is affected by (1) air temperature, (2) character of the land surface and ground cover (Pluhowski and Kantrowitz, 1963), (3) thermal conductivity of the zone of aeration, (4) temperature of recharge reaching the zone of saturation, and (5) heat from the earth's interior. Of these, the first three are the most important. The temperature of recharge generally has a significant effect only where the water table is relatively close to the land surface or where the zone of aeration is composed of highly permeable material. Heat from the earth's interior increases the temperature of ground water approximately 1°F for each 65 feet of increase in depth in northern New York. The effect of the earth's heat on the temperature of shallow ground water cannot be determined until the direct and indirect effects of the other factors are better known.

A study of the seasonal fluctuation of soil and ground-water temperatures was started in July 1959 in a residential area in the unincorporated village of McKownville, N.Y., a suburb just west of Albany. The land surface is a gently rolling plain covered principally by grass and scattered trees. The surficial deposit, about 20 feet thick, consists of fine to medium sand and mantles a series of interbedded silts and clays approximately 100 feet thick. The sand layer contains water under unconfined conditions. Because the sand is stratified, its horizontal permeability is substantially greater than its vertical permeability.

Temperatures were measured at 5 levels within the surficial sand: 2 in the zone of aeration, and 3 in the zone of saturation. Temperature measurements were made in the zone of aeration with indoor-outdoor thermometers having steel-encased fluid reservoirs buried at 1.5 and 3 feet. The temperature within the zone of saturation was measured at depths of 6.4, 11.1, and 17.7 feet below land surface in 3 wells driven to depths of 8, 13, and 20 feet, respectively. The bulbs of the thermometers were imbedded in sand in the lower part of small open glass bottles that were left submerged between temperature readings.

Two homes are located about 50 feet downgradient from the temperature-measurement site, and several others are within a few hundred feet downgradient. Other homes are located 100 to 200 feet upgradient. All domestic wastes from these homes, except those originating in the bathrooms, are disposed of through sewers. Bathroom wastes are disposed of through septic tanks, the nearest of which is 32 feet downgradient from the site.

The data collected during 1960 at the temperature-measurement site are summarized in the accompanying table. Also summarized in the table are the air temperatures measured by the U.S. Weather Bureau station at the Albany, N.Y., airport, 5 miles to the northeast. As the snow cover during the winter of 1959–60 was

ART. 168 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–D, PAGES D204–D208. 1964.

Summary of monthly air and subsurface temperatures, 1960, in degrees Fahrenheit

Measuring point	Monthly average maximum temperature		Monthly average minimum temperature		Range in monthly average temperatures	Annual average temperature
	Month	Temperature	Month	Temperature		
Air, at a height of 5 feet.	July	[1] 80.6	January	[1] 14.9	46.8	48.6
Subsurface, at indicated depth (feet):						
1.5	August	[2] 70	do	27	43	48
3.0	do	[2] 69	March	35	34	52
6.4	September	59.5	do	43.2	16.3	51.5
11.1	October	55.9	April	46.4	[3] 9.5	[3] 51.3
17.7	November	53.1	May	49.5	3.6	51.3

[1] U.S. Weather Bureau station at Albany, N.Y., airport.
[2] Record incomplete.
[3] November 1959 to October 1960.

thin, and so did not have a detectable effect on subsurface temperatures, no data on it are included in the table.

Each measurement of subsurface temperature made during the period July 1, 1959, to December 31, 1960, is plotted in the upper graph on figure 168.1. Also plotted in the upper graph are the monthly average maximum air temperatures and the monthly average minimum air temperatures. Measurements of the depth to water in the well used for making temperature measurements at a depth of 11.1 feet are plotted in the lower graph in figure 168.1.

Subsurface temperatures respond principally to temperature waves originating at the land surface in response to changes in air temperature. There are at least three waves of different period and amplitude. The depth of penetration of the waves is proportional to their period, and the magnitude of the subsurface temperature fluctuations is proportional to both the amplitude and the period of the waves and to the thermal diffusivity of the subsurface materials. The shortest waves are generated by diurnal changes in air

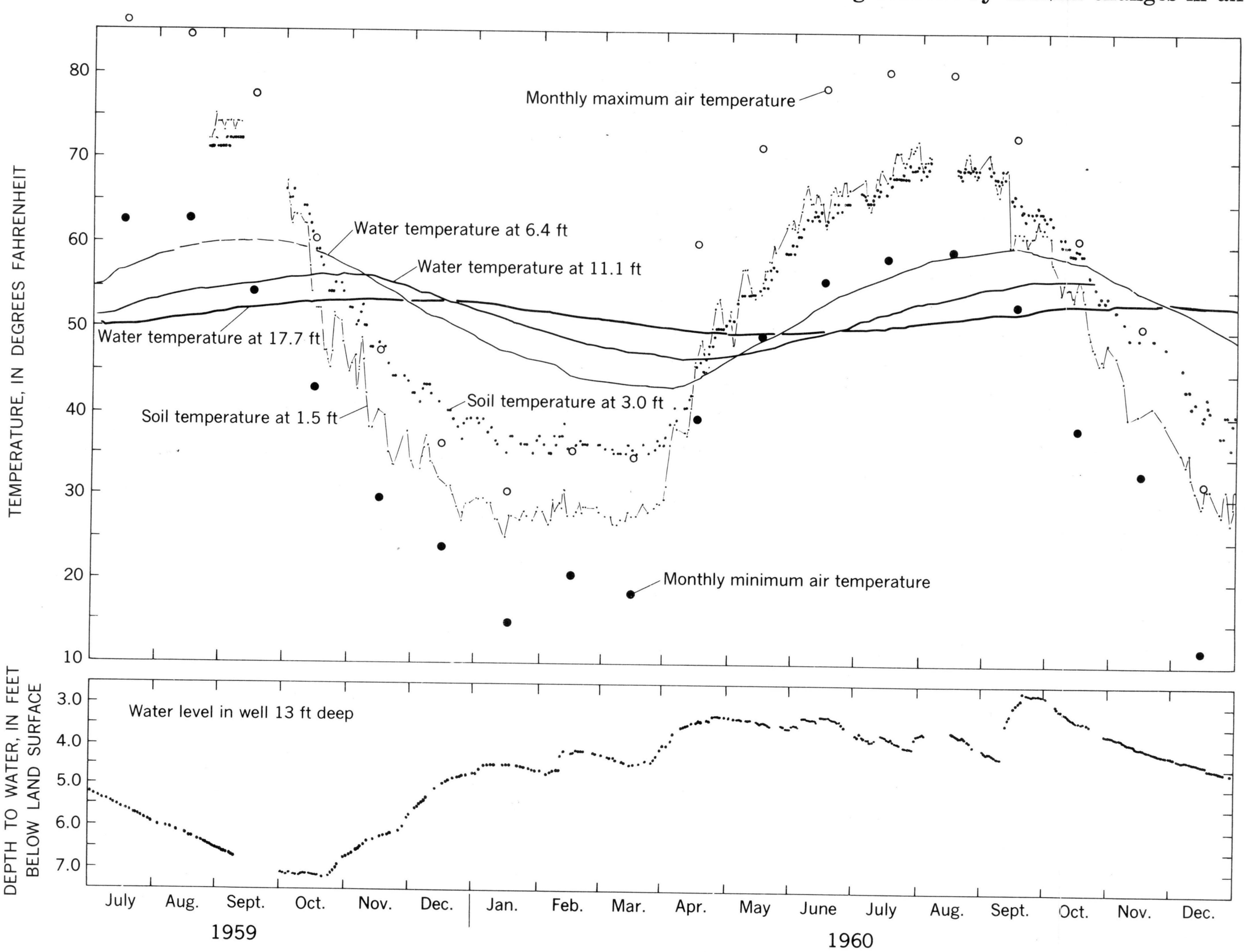

FIGURE 168.1.—Air and subsurface temperatures and hydrograph of water-table fluctuations at the temperature-measurement site in McKnownville, N.Y.

temperature and thus have a period of 1 day. Because of their short period, their effect can be detected only 1 to 2 feet below land surface. The next longest waves are those generated by the passage of frontal weather systems. The period of these waves is variable, ranging from a few days to a week or two. Their effect on the temperature of the soil is detectable to depths of a few feet. The longest waves are those generated by seasonal changes in air temperature and thus have a period of 1 year. Depending on geologic and hydrologic conditions, these waves penetrate to depths of as much as 60 feet.

The fluctuations of subsurface temperature in response to frontal weather systems and seasonal changes in air temperature are readily apparent at depths of 1.5 and 3.0 feet below land surface (fig. 168.1). During the passage of frontal weather systems, the daily average air temperature over a period of several days may change as much as 30°F. The irregular, short-period fluctuations of soil temperature, which at a depth of 1.5 feet range from about 2°F or 3°F to as much as 10°F, show the fluctuations caused by these changes in air temperature. The fluctuations of soil temperature at a depth of 3.0 feet in response to frontal weather systems is much less than at the shallower depth.

As may be seen from its consistent position about midway between the average maximum and average minimum air temperature for each month, the soil temperature at a depth of 1.5 feet closely approximates the annual average air temperature throughout the year. In 1960, the average air temperature was 48.6°F and the average temperature at a depth of 1.5 feet was 48°F. From April to early September, when the flow of heat is downward from the land surface, the temperature at 1.5 feet generally was a degree or two above the temperature at 3.0 feet. During the fall, when the average air temperature declined rapidly, the temperature at a depth of 1.5 feet dropped progressively lower than the temperature at 3.0 feet. The divergence was greatest in December when the temperature at 1.5 feet averaged about 8 degrees lower than that at 3.0 feet. The difference remained relatively constant until the spring thaw at the end of March and then was completely eliminated within a few days. The average temperature at 3.0 feet was 52°F, or 4 degrees higher than the average temperature at 1.5 feet and about the same as the average temperature of the ground water (see table).

The ground-water temperature at three levels within the saturated zone is shown in figure 168.1. In 1960 the temperature at the uppermost level, 6.4 feet below land surface, fluctuated through a range of 16.3°F, whereas that at the lowest level, 17.7 feet below land surface, fluctuated only 3.6°F. The average ground-water temperature at all 3 levels was about 51.4°F, or 2.8°F above the annual average air temperature (see table). The graph of maximum and minimum temperatures in figure 168.2 suggests that there would be

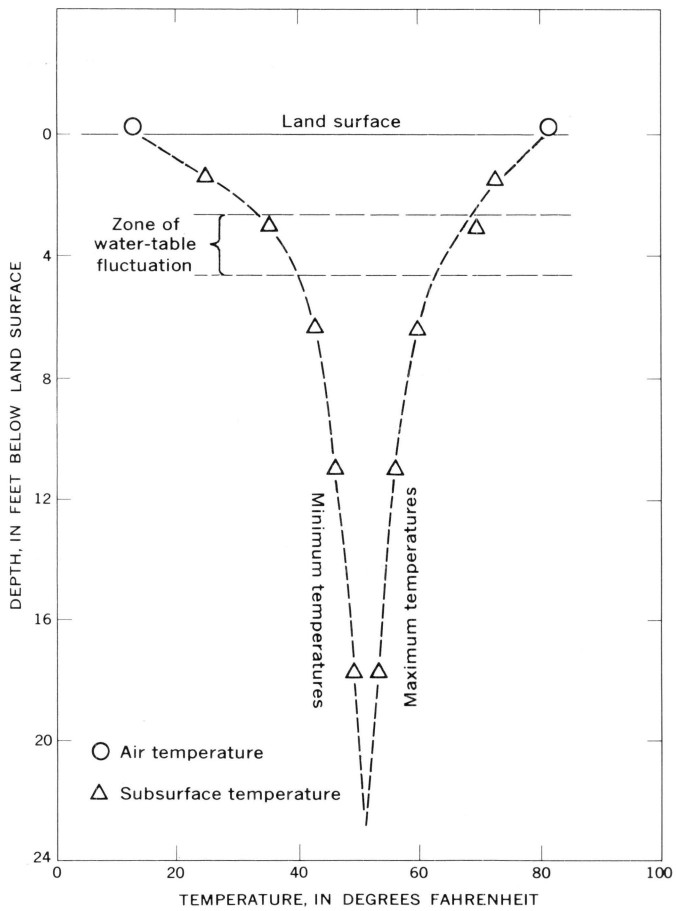

FIGURE 168.2.—Maximum and minimum air and subsurface temperatures in 1960. Air temperatures are monthly average minimum temperatures in December 1959 and monthly average maximum temperatures in July 1960.

no appreciable seasonal fluctuation below a depth of about 23 feet. This depth closely coincides with the base of the surficial sand, which the available data indicate is at a depth of about 20 to 21 feet. The relative lack of ground-water circulation in the silt and clay underlying the sand doubtless affects the depth of penetration of detectable seasonal temperature fluctuations in this area.

The temperature of recharge reaching the zone of saturation had only a small effect on the ground-water temperature. The temperature at 6.4 feet declined about 1.5°F in February 1960 in response to recharge with cold water during a brief thaw (fig. 168.1). The cooling effect at the water table, which at the time was about 2 feet above the thermometer, doubtless was much greater.

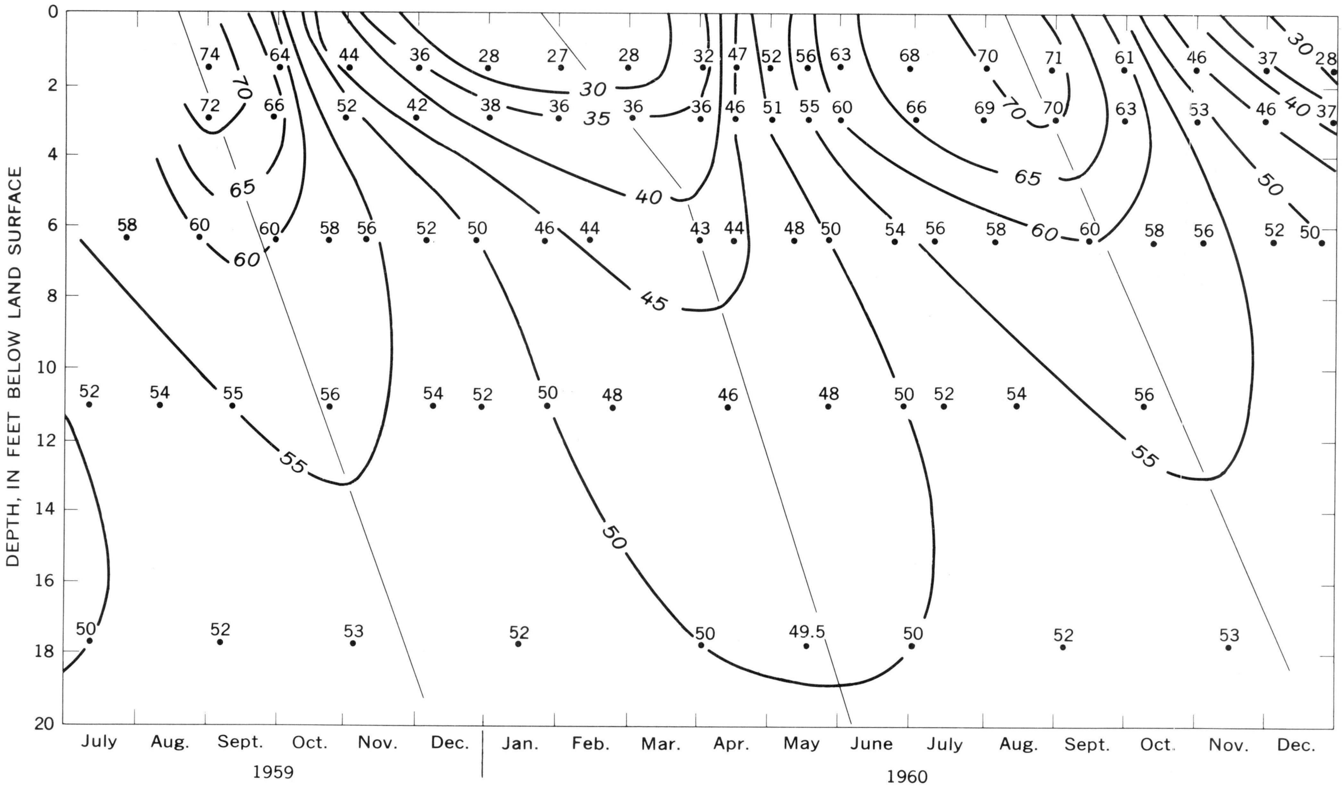

FIGURE 168.3.—Isotherms of subsurface temperatures, in degrees Fahrenheit. (Interval) 5°F.

The differences in the temperature gradient of soil between the depths of 1.5 and 3.0 feet in summer and winter is one of the most striking features of the graphs shown in figure 168.1. The downward gradient during the spring and summer was only about one-eighth the upward gradient during the fall and winter. However, the temperature gradient of water in the zone of saturation, as shown by the temperatures at depths of 6.4, 11.1, and 17.7 feet, was not significantly different in summer and winter. The explanation for the steeper thermal gradient across the zone of aeration during the fall and winter is not readily apparent. It suggests either a marked decrease in thermal diffusivity or the disturbing influence of septic-tank discharge.

Figure 168.3 shows the differences in temperature with respect to time of year and depth. The diffusivity can be computed from the relationship of the lag in time of either the maximum or the minimum temperature with depth (Singer and Brown, 1956, p. 747). Sloping straight lines representing the lag in temperature with depth are shown in the figure. Note that the slopes of the lines through the maximum isotherms and the slope of the line through the minimum isotherms in the zone of saturation (from 5 to 20 feet) are virtually the same. The diffusivity as determined from the maximum isotherms in the fall of 1960 is 0.007 cm^2 per second. The slope of the line through the minimum isotherms in the zone of aeration is difficult to determine, but the line drawn in figure 168.3 seems to fit the data fairly well. The diffusivity based on this line is 0.005 cm^2 per second.

Because of the higher moisture content of the soil during the winter, as indicated by the intermittent rises in the water table starting in late October 1959 (fig. 168.1), and the presence of ice in the soil to a depth of 2 to 3 feet, the diffusivity during the winter should be substantially higher than during the summer. Therefore, the diffusivity of 0.005 cm^2 per second computed for the zone of aeration during the winter probably is considerably less than the actual value.

Although this anomaly cannot be definitely explained, it probably reflects the influence of septic-tank discharge. As noted above, a septic tank is located about 32 feet from the temperature-measurement site. However, the position of the septic-tank drain field with respect to the site is not known. Even if the position of the drain field were known, it would be difficult if not impossible to determine the effect of stratification of the soil zone on the movement of the septic-tank effluent. If the septic-tank effluent does affect the temperatures in the zone of aeration, the anomalous changes in gradient might be explained by assuming that the effluent acts as a weak heat source in the spring and summer and as a strong heat source in the fall and winter.

The writer wishes to acknowledge the assistance of Charles O'Donnell, U.S. Geological Survey, in the computation of diffusivities.

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