# Quantitative Evaluation of Climatic Factors in Relation to Soil Moisture Regime

H. C. S. THOM, Environmental Data Service,
U.S. Environmental Science Services Administration

The use of hourly precipitation for determining subgrade moisture variations is proposed. Data discussed include examples for Ames, Iowa, and Tulsa County, Oklahoma, of the correlation between hourly frequency of amounts of assumed infiltration rates with soil moisture between 1 and 2 ft. The development of design data for the effect of temperature variation requires development of better relationships with observed meteorological data. Some empirical relationships are given that could be useful in preliminary studies.

•ALTHOUGH THE PROBLEM of subgrade moisture variation that causes changes in volume and strength of subgrade soils is far from solved, it appeared desirable to give more detailed information on the climatic factors that may ultimately be needed in design. Marks and Haliburton (1) have summarized previous studies on subgrade moisture in their paper discussing several series of soil moisture measurements with nuclear gages under pavements and in shoulders. One of their series of soil moisture measurements in a shoulder is correlated with more detailed precipitation observations. A series of measurements with uncovered soil at Ames, Iowa, is also correlated with the same type of meteorological data.

Mickle and Spangler (2) found that soil moisture changes, caused by temperature variation, were very small under covered areas. This does not seem to agree with a number of cursory reports of water on pavements on warm, sunny days although such water could have resulted from another cause. Marks and Haliburton (1) reported variations in moisture of 1 to 5 percent caused by temperature. In any event, the problem is a complicated one requiring data on the relationship between radiation or maximum and minimum air temperatures and maximum and minimum soil and pavement surface temperatures, neither of which is presently available. Without one of these relationships, practical design could not be found from regularly observed meteorological observations. Some rough empirical relationships with air temperature are given that could serve as approximations in design problems. Still needed, however, are adequate data on soil-water movement in the subgrade as a function of soil temperature.

## THE PRECIPITATION REGIME

Because infiltration is the principal factor of the soil moisture regime in any event, it would appear that use of more detailed precipitation data might be desirable. The U.S. Environmental Science Services Administration (ESSA) collects hourly precipitation data at some 3,400 observation stations. These records range up to 30 years in length and constitute a fairly dense network that might be useful in design problems. At about 100 of the first-order stations, summaries of the hourly precipitation and other observations by monthly and annual periods have been published for a 10-year

Paper sponsored by Committee on Environmental Factors Except Frost and presented at the 49th Annual Meeting.

record. Examples for Tulsa and Oklahoma City airports are given in Table 1. The published table does not contain the last column, but the information is readily added by summing along the rows. By taking a suitable threshold for infiltration, some data useful for design might be obtained from this table, the information of which is also recorded elsewhere (3). The original hourly amounts (4) from more than 3,000 other stations could be used to prepare similar tables that might be employed in soil moisture research or design. Two simple examples of application of such data are given in the following: one at Ames, Iowa, for natural soil; and the other on a highway shoulder in Tulsa County at site 29C of the study made by Marks and Hailburton (1).

TABLE 1

FREQUENCY OF OCCURRENCE OF PRECIPITATION

| Hour Ending at | Intensities (in.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trace | 0.01 | 0.02 to 0.09 | 0.10 to 0.24 | 0.25 to 0.49 | 0.50 to 0.99 | 1.00 to 1.99 | >2.00 | Total |
| Tulsa Airport, Oklahoma | | | | | | | | | |
| 1 a.m. | 5 | | 8 | 1 | 3 | 1 | | | 18 |
| 2 a.m. | 11 | 3 | 1 | 1 | 2 | 2 | | | 20 |
| 3 a.m. | 7 | 4 | 5 | 3 | 4 | | | | 23 |
| 4 a.m. | 11 | 3 | 6 | 7 | 1 | | | | 28 |
| 5 a.m. | 11 | 3 | 8 | 5 | 1 | | | | 28 |
| 6 a.m. | 14 | 1 | 7 | 3 | 1 | 1 | | | 27 |
| 7 a.m. | 13 | 2 | 8 | 4 | | | 1 | | 28 |
| 8 a.m. | 8 | | 10 | 1 | | | 1 | | 20 |
| 9 a.m. | 12 | 5 | 5 | 1 | | | | | 23 |
| 10 a.m. | 12 | | 7 | 1 | 1 | | | | 21 |
| 11 a.m. | 12 | 4 | 3 | 1 | 1 | | | | 21 |
| Noon | 12 | 2 | 7 | 1 | | 1 | | | 23 |
| 1 p.m. | 12 | 2 | 4 | 2 | | | | | 20 |
| 2 p.m. | 11 | 4 | 2 | | 2 | | 1 | | 20 |
| 3 p.m. | 17 | 1 | 3 | 1 | 3 | 1 | | | 26 |
| 4 p.m. | 13 | 1 | 6 | 3 | 3 | 1 | | | 27 |
| 5 p.m. | 12 | 3 | 9 | 2 | | 2 | 1 | | 29 |
| 6 p.m. | 14 | 4 | 8 | 4 | 2 | | | | 32 |
| 7 p.m. | 14 | 2 | 9 | 2 | 2 | | | | 29 |
| 8 p.m. | 12 | 2 | 4 | 3 | | 1 | | | 22 |
| 9 p.m. | 7 | 3 | 9 | | 1 | | | | 20 |
| 10 p.m. | 4 | 2 | 6 | 1 | 2 | | | | 15 |
| 11 p.m. | 8 | 1 | 5 | 1 | | 1 | | | 16 |
| Midnight | 9 | — | 5 | 2 | 1 | — | 1 | – | 18 |
| Total Hours | 261 | 52 | 145 | 50 | 30 | 11 | 5 | 0 | 554 |
| Oklahoma City Airport, Oklahoma | | | | | | | | | |
| 1 a.m. | 5 | 4 | 3 | 2 | 2 | 1 | 1 | | 18 |
| 2 a.m. | 6 | 2 | 2 | 2 | | 1 | | | 13 |
| 3 a.m. | 3 | 3 | 3 | 2 | | | 1 | | 12 |
| 4 a.m. | 13 | 3 | 3 | 2 | | | | | 21 |
| 5 a.m. | 14 | 2 | 4 | 3 | 1 | 1 | | | 25 |
| 6 a.m. | 17 | 4 | 5 | 3 | 1 | | | | 30 |
| 7 a.m. | 20 | 3 | 6 | 4 | | | | | 33 |
| 8 a.m. | 16 | 6 | 5 | 7 | | | | | 34 |
| 9 a.m. | 18 | 4 | 6 | 4 | | 1 | | | 33 |
| 10 a.m. | 23 | 3 | 2 | 4 | | | | | 32 |
| 11 a.m. | 17 | 5 | 3 | 2 | 2 | 1 | | | 30 |
| Noon | 11 | 5 | 5 | 2 | | | | | 23 |
| 1 p.m. | 21 | 1 | 5 | | | | | | 27 |
| 2 p.m. | 20 | 2 | 2 | 1 | 1 | 2 | | | 28 |
| 3 p.m. | 13 | 3 | 2 | 2 | 3 | 1 | 1 | | 25 |
| 4 p.m. | 14 | 2 | 4 | 1 | 2 | | | | 23 |
| 5 p.m. | 9 | 2 | 6 | | 1 | | | | 18 |
| 6 p.m. | 7 | 2 | 4 | | | 1 | | | 14 |
| 7 p.m. | 9 | 1 | 1 | 2 | 1 | 2 | | | 16 |
| 8 p.m. | 7 | 2 | 3 | 2 | 1 | | | | 15 |
| 9 p.m. | 9 | 2 | 2 | 3 | 1 | | | | 17 |
| 10 p.m. | 7 | 1 | 3 | 2 | 1 | 1 | 1 | | 16 |
| 11 p.m. | 10 | 1 | 3 | 2 | 1 | | | | 17 |
| Midnight | 4 | 3 | 2 | 5 | 1 | — | 1 | – | 16 |
| Total Hours | 293 | 66 | 84 | 57 | 19 | 12 | 5 | 0 | 536 |

TABLE 2

RELATIONSHIP OF SOIL MOISTURE TO HOURLY FREQUENCY OF PRECIPITATION HIGHER THAN 0.10 INCH

| Ames, Iowa | | | Tulsa County, Oklahoma | | |
|---|---|---|---|---|---|
| Date of Measurement | Soil Moisture (in.) | Hourly Frequency | Date of Measurement | Soil Moisture (in.) | Hourly Frequency |
| July 1954 | 0.1 | 1 | Sept. 1, 1966 | 1.97 | 10 |
| July 1955 | 1.4 | 8 | Oct. 1, 1966 | 2.02 | 7 |
| July 1956 | 0.0 | 3 | Nov. 1, 1966 | 2.05 | 4 |
| July 1957 | 1.7 | 9 | Dec. 1, 1966 | 1.96 | 1 |
| July 1958 | 1.3 | 23 | Jan. 1, 1967 | 1.90 | 10 |
| July 1959 | 0.8 | 4 | Feb. 1, 1967 | 1.91 | 5 |
| July 1960 | 0.9 | 8 | March 1, 1967 | 1.93 | 2 |
| July 1961 | 1.1 | 21 | April 1, 1967 | 1.92 | 4 |
| July 1962 | 1.3 | 11 | May 1, 1967 | 1.90 | 15 |
| July 1963 | 1.4 | 12 | June 1, 1967 | 1.93 | 18 |
| | | | July 1, 1967 | 2.02 | 12 |
| | | | Aug. 1, 1967 | 2.20 | 20 |

The results for Ames in silt clay loam soil are given in Table 2. The soil moisture values are in inches depth of water in the 1- to 2-ft depth on about August 1. It was assumed that at this time of year hourly precipitation amounts less than 0.10 in. would not infiltrate but would be evaporated almost immediately on reaching the soil surface. Thus, because the infiltration rate of this soil would be somewhere in the range of the next higher class, internal 0.10 to 0.24 in. of Table 1, it was assumed that the threshold for infiltration was 0.10 in. per hour. Although this may appear to be a somewhat arbitrary choice of threshold, it is clear that if there is a correlation with the true threshold, there will also be correlations with thresholds near the true one. Every hour with 0.10 in. or more is then counted as an hour of infiltration. These were counted for all measurements in July, 1954 to 1963, and are given in Table 2 in relationship to the corresponding soil moisture depths in the 1- to 2-ft layer. Some correlation is evident, the higher frequencies in general being associated with high depths of soil moisture. The very high frequencies, however, do not lead necessarily to the highest depths of soil moisture and this could be explained in several ways, one of which is by previous saturation.

The results for the highway shoulder at site 29C in Tulsa County are also shown in Table 2. Marks and Hailburton's soil moisture percentages (1) have been converted to inches of water in the depth from 1 to 2 ft by using the value at 1 ft 6 in. as an average for this layer. The correlation here is poor because, although the hourly frequency of precipitation at the infiltration rate is high for some months, this is not generally reflected in the soil moisture depths. These depths remain fairly constant around the field capacity except on August 1 when it rises to 2.2 in. with a high hourly frequency during July. One explanation for this constancy might be the good slope from the shoulder that would allow rapid removal of runoff. This complicates the development of data for design because factors affecting the runoff will have to be added. Many other factors could, of course, affect the soil moisture, further complicating the problem of obtaining experimental data.

## THE TEMPERATURE REGIME

The simplest way of approximating the temperature regime in the subgrade would appear to be by using maximum and minimum daily temperatures of the pavement or soil surface and by propagating these temperatures to the subgrade by Fourier's law of heat transmission. This law is discussed in detail by Carslaw and Jaeger (5) and others.

Although there are some difficulties in the application of Fourier's law itself, the principal difficulties arise from the estimation of the required maximum and minimum surface temperatures needed for its application. The minimum temperature of the surface is the simplest because it can be assumed to be approximately equal to the minimum shelter temperature at all times of the year for all surfaces. The maximum temperature is much more difficult because the absorption properties vary more with radiation. After review of a number of papers on the problem, Gloyne (6) concluded that, for bare ground and grass cover, the daily maximum temperature in degrees F for the uppermost few millimeters would be approximately given by T = 2t - 50, where t is the shelter maximum temperature. For skin temperature of the same surfaces, he states that $T' = 2t - 35$. For asphalt skin-surface maximum temperature, the Johnson and Davies (7) data suggest that $T'' = 2t - 25$. For concrete surfaces, the formula for skin-soil surface may be employed. These formulas, together with Fourier's law, should serve to approximate the diurnal temperature waves at required depths. Daily maximum and minimum temperatures are available for some 6,000 stations for many years of record (8).

## CONCLUSIONS

Others have concluded that the problem of subgrade moisture variation is a very difficult one and requires much more data before answers to design problems can be given. See, for example, the conclusion and recommendations of Marks and Haliburton (1). If we were to conclude anything from this brief study, it would be (a) that use could possibly be made of more detailed data sources referred to in the preceding, and (b) that more attention could be given to the solution of the drainage problem that has provided the basis for design in other circumstances (9).

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