Mathematical Model for Predicting Moisture Movement in Pavement Systems

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A comprehensive moisture model for predicting moisture conditions in pavement systems, based on the Philip and de Vries equations for non-isothermal moisture movement and heat conduction, was developed. By using numerical methods, the implicit finite difference approximations to the moisture movement and heat-transfer equations were programmed for computer solution. Validation studies indicated that the moisture model could be used to accurately predict isothermal moisture conditions in pavement systems. The model was also used to show the relative influence of nonisothermal conditions on pavement moisture content. The model was applicable to a wide range of boundary conditions and could be used with climatic input data to predict the moisture-temperature regime in pavement systems.

The behavior of pavement systems in response to moisture changes, especially with reference to the mechanisms of moisture movement and the consequences of such moisture changes, has been widely studied. The chief task is that of quantitatively and qualitatively predicting moisture movement and equilibria in pavement systems at any particular place, depth, and time.

The dominant factor influencing space-moisture conditions in pavement systems is climate. Other factors are permeability through the pavement profile, the type of ground cover and surrounding vegetation, the local topography, surface runoff from the pavement, drainage conditions, water table location, and pavement edge conditions. Low and Lovell ($\underline{1}$) have presented a generalized concept of the sources of moisture in pavement systems (Figure 1).

Moisture movement and equilibria in soils have been major concerns in the field of soil science and agriculture for some time ($\underline{2}, \underline{3}, \underline{4}, \underline{5}, \underline{6}$), but only in recent years have investigators ($\underline{7}, \underline{8}, \underline{9}, \underline{10}$) attempted to analyze moisture conditions in pavement systems. Thus, this research has the following objectives:

1. To develop, based on climatic factors, a theoretical model for predicting moisture movement and equilibria in pavement systems; and

2. To validate the moisture model by means of available laboratory data.

FLOW IN SOIL-WATER SYSTEMS

Darcy's Law

Analysis of soil-water flow systems is a highly empirical science based almost entirely on the universality of an empirically derived statement, known as Darcy's law, that has the following general differential form:

$$q = -K\nabla H \tag{1}$$

This law states that the rate of flow of water, q, in any direction in a porous medium is proportional to the change in the hydraulic potential H. The hydraulic conductivity, K, is the proportionality constant for flow.

The symbols used in all equations are defined as

$$
\begin{aligned}
a &= \text{volumetric air content (cm}^3\text{/cm}^3) \\
C &= \text{volumetric heat capacity (cal/cm}^3\text{/C)} \\
D_\Theta &= \text{isothermal moisture diffusivity (cm}^2\text{/s)} \\
D_T &= \text{thermal moisture diffusivity (cm}^2\text{/s/C)} \\
D_{\Theta liq} &= \text{isothermal liquid diffusivity (cm}^2\text{/s)} \\
D_{\Theta vap} &= \text{isothermal vapor diffusivity (cm}^2\text{/s)} \\
D_{Tliq} &= \text{thermal liquid diffusivity (cm}^2\text{/s/C)} \\
D_{Tvap} &= \text{thermal vapor diffusivity (cm}^2\text{/s/C)} \\
D_{atm} &= \text{molecular diffusion coefficient of water} \\
&\quad \text{vapor in air (cm}^2\text{/s)} \\
g &= \text{acceleration due to gravity (cm/s}^2) \\
H &= \text{total water potential (cm)} \\
h &= \text{capillary potential (cm)} \\
h_0 &= \text{relative humidity} \\
K \text{ and } K_\Theta &= \text{unsaturated hydraulic conductivity (cm/s)} \\
L &= \text{heat of vaporization (cal/g)} \\
q \text{ and } Q &= \text{water flux (cm/s)} \\
Q_a &= \text{heat flux resulting from long-wave radia-} \\
&\quad \text{tion emitted by the atmosphere (cal/m}^2\text{/h)} \\
Q_c &= \text{heat flux resulting from convection heat} \\
&\quad \text{transfer (cal/m}^2\text{/h)} \\
Q_e &= \text{heat flux resulting from long-wave radia-} \\
&\quad \text{tion emitted by the pavement surface} \\
&\quad \text{(cal/m}^2\text{/h)}
\end{aligned}
$$

Q_g = heat flux into the pavement (cal/m²/h)
Q_h = heat flux from transpiration, condensation, evaporation, and sublimation (cal/m²/h)
Q_i = heat flux resulting from incident short-wave radiation (cal/m²/h)
Q_r = heat flux resulting from reflected short-wave radiation (cal/m²/h)
R = gas constant for water vapor (erg/g/C)
T = temperature (C)
t = time (s)
x and y = horizontal coordinates (cm)
z = vertical coordinate (cm)
Z = water gravity term (cm)
α = tortuosity factor for diffusion of gases in soils
β = g/cm³/C
γ = temperature coefficient (C⁻¹)
Θ = volumetric water content (cm³/cm³)
λ = thermal conductivity (cal/cm/s/C)
ν = mass flow factor
ρ = density of water vapor (g/cm³)
$\rho\mu$ = density of liquid water (g/cm³)
∇ = differential operator

In terms of the x, y, and z coordinates Darcy's law is expressed as follows:

$$q_x = -K_x(\partial H/\partial x) \tag{2}$$

$$q_y = -K_y(\partial H/\partial y) \tag{3}$$

$$q_z = -K_z(\partial H/\partial z) \tag{4}$$

The hydraulic conductivities K_x, K_y, and K_z in equations 2, 3, and 4 respectively may or may not be equal. If they are all equal, the porous medium is isotropic; if they are not, it is anisotropic. [Childs (11) has indicated that equations 2, 3, and 4 are valid for anisotropic porous media only if x, y, and z are the principle axes of the medium with respect to hydraulic conductivity.]

Darcy's law, although originally conceived for saturated flow only, has been extended by Richards (12) to unsaturated flow. This equation, in which the conductivity is a function of the matrix suction head, is expressed as follows:

$$q = -K_\Theta \nabla H \tag{5}$$

In equation 5, K_Θ is a function of the unsaturated water content and ∇H is the hydraulic head, which is a function of the suction head and the gravitational head as follows:

$$H = h + Z \tag{6}$$

Equation 5 has been found to be valid for unsaturated flow by Childs and Collis-George (13) and Kirkham and Powers (14), and for nonsteady flow by Rogers and Klute (15).

Transient Flow

The mathematical laws necessary for consideration of transient flow systems are the extension of Darcy's law to unsteady flow systems and the principle of the conservation of matter. The equation of continuity, which is a statement of the law of conservation of matter, can be written as follows:

$$\partial\Theta/\partial t = \nabla \cdot (-K_\Theta \nabla H) \tag{7}$$

Since the total head is equal to the sum of the pressure head and the gravitational head (equation 6), equation 7 can be written as follows for one-dimensional transient moisture flow in the vertical direction:

$$\partial\Theta/\partial t = \partial[K_\Theta(\partial h/\partial z)]/\partial z + (\partial K_\Theta/\partial z) \tag{8}$$

or

$$\partial\Theta/\partial t = \partial[D_\Theta(\partial\Theta/\partial z)]/\partial z + (\partial K_\Theta/\partial z) \tag{9}$$

In equation 9, D_Θ is the soil-water diffusivity, and it is equal to $K_\Theta(\partial h/\partial\Theta)$. A detailed description of the derivation of the diffusivity and hydraulic conductivity terms is presented elsewhere in this Record.

Simultaneous Flow

The flow equations that have been considered thus far do not include the influence of solutes or temperature gradients on moisture movement. Hillel (16) has discussed simultaneous water and solute movement in soils, and this area will not be considered further. However, in pavement systems the simultaneous movement of heat and water is a common occurrence, and very important to the development of design methodologies to resist the influence of climatic effects.

The fact that temperature gradients can induce water movement in soils has been generally known for the last 50 years. Studies of the relative importance and interaction of thermal and suction gradients in transporting soil moisture have been made by Hutchinson, Dixon, and Denbigh (17), Philip and de Vries (18), Taylor and Cary (19, 20), Cassel (21), Cary (22), Hoekstra (23), and Jumikis (24). Taylor and Cary (19) applied the theories of irreversible thermodynamics to the study of the transport of water, heat, and salts through soil systems to develop a linear flow equation for each component of the soil system. This equation has the following general form:

$$J_i = \sum_{k=1}^{n} L_{ik}X_k \tag{10}$$

In equation 10, J_i represents the mutually interacting fluxes resulting from forces such as diffusion, temperature, and pressure. The term L_{ik} represents the transmission coefficients, such as the diffusion coefficient, hydraulic conductivity, and thermal conductivity, of the various fluxes and n is the number of driving forces.

From a mechanistic approach, Philip and de Vries (18) developed the following equation for water movement under combined moisture and temperature gradients:

$$Q = D_\Theta \nabla\Theta + D_T \nabla T + K_\Theta \tag{11}$$

In equation 11, Q is the net water flux, D_Θ is the isothermal moisture diffusivity, $\nabla\Theta$ is the moisture content gradient, D_T is the thermal moisture diffusivity, and ∇T is the temperature gradient. The terms D_Θ and D_T are made up of two components each, one for vapor flow and one for liquid flow. The term K_Θ is the gravity term.

Cassel (21) has compared his experimental results to the predictions made by the use of Philip and de Vries and Taylor and Cary models and, in general, obtained better results from the Philip and de Vries theory.

DEVELOPMENT OF A MATHEMATICAL MOISTURE MODEL

In studies of moisture movement and equilibria, experimental and empirical relations will often be inaccurate and impractical because of changing climatic conditions

that will affect the pavement systems. Formal mathematical procedures based on thermodynamic principles and incorporating the necessary daily environmental boundary conditions of a given geographical area are needed.

Several investigators ($\underline{18}$, $\underline{25}$, $\underline{26}$, $\underline{27}$, $\underline{28}$, $\underline{29}$) have proposed mathematical formulas based on thermodynamic principles for predicting moisture movements caused by nonisothermal and isothermal conditions. In these formulas the important liquid and vapor diffusivity parameters for defining the potential that causes moisture movement are expressed quantitatively in terms of soil properties and soil suction.

Klute ($\underline{25}$) and Selim ($\underline{27}$) have developed reasonable models for predicting moisture movement in soils subjected to isothermal conditions. These models are based on finite difference solutions to the differential equations for one-dimensional and two-dimensional moisture movement. Richards ($\underline{26}$) has been successful in using computer methods for predicting the time-space moisture conditions in pavement systems subjected to isothermal conditions in a two-dimensional model. Lytton and Kher ($\underline{28}$) have developed a model to predict moisture movement in expansive clay subgrades. They analyzed only the isothermal case but used both one- and two-dimensional programs and validated the model by a field study.

However, the moisture movement theory of Philip and de Vries ($\underline{18}$) provides the most comprehensive basis for the development of a moisture model to predict transient flow in pavement systems. By differentiating equation 11 and applying the continuity requirement, the general partial differential equation describing moisture movement in porous materials under combined temperature and moisture gradients can be stated as follows:

$$\partial\Theta/\partial t = \nabla \cdot (D_T \nabla T) + \nabla \cdot (D_\Theta \nabla \Theta) + (\partial K_\Theta / \partial z) \tag{12}$$

In equation 12 the thermal diffusivity, D_T, has two components, which can be expressed by the following equation:

$$D_T = D_{Tliq} + D_{Tvap} \tag{13}$$

Similarly, the moisture diffusivity, D_Θ, has two components as follows:

$$D_\Theta = D_{\Theta liq} + D_{\Theta vap} \tag{14}$$

The liquid diffusivities are the more important at high moisture contents, while the vapor diffusivities are the more important at low moisture contents ($\underline{18}$).

The equation describing heat transfer is

$$C(\partial T/\partial t) = \nabla \cdot \lambda \nabla T - L\nabla \cdot D_{\Theta vap}\nabla\Theta \tag{15}$$

Equation 15 is similar to that used by Dempsey ($\underline{30}$) and Dempsey and Thompson ($\underline{31}$) to develop a heat-transfer model for predicting temperatures and evaluating frost action in multilayered pavement systems.

Equations 12 and 15 are the basic equations used to describe moisture movement and heat transfer in the mathematical moisture model.

Finite Difference Approximation for Water Movement and Heat-Transfer Equations

In the moisture model the water flow equation (equation 12) and the heat-transfer equation (equation 15) are nonlinear second-order parabolic partial differential equations. Since exact solutions to nonlinear equations are difficult and sometimes impossible to obtain, numerical

methods were used to develop the model.

The numerical solutions to equations 12 and 15 are obtained by first expressing them as finite difference approximations. The three main types of methods commonly used to provide finite difference approximations are the fully implicit, fully explicit, and implicit-explicit methods. The moisture model was developed by using the implicit finite difference approximation (Figure 2). This method is always stable. The implicit finite difference approximation of the water flow equation (equation 12) can be expressed as follows for the one-dimensional case:

$$(\Theta_i^{n+1} - \Theta_i^n)/\Delta t = [D(T_{i+\frac{1}{2}}^{n+\frac{1}{2}})(T_{i+1}^n - T_i^n)]/(\Delta z)^2$$
$$- [D(T_{i-\frac{1}{2}}^{n+\frac{1}{2}})(T_i^n - T_{i-1}^n)]/(\Delta z)^2$$
$$+ [D(\Theta_{i+\frac{1}{2}}^{n+\frac{1}{2}})(\Theta_{i+1}^{n+1} - \Theta_i^{n+1})]/(\Delta z)^2$$
$$- [D(\Theta_{i-\frac{1}{2}}^{n+\frac{1}{2}})(\Theta_i^{n+1} - \Theta_{i-1}^{n+1})]/(\Delta z)^2$$
$$- [K(\Theta_{i+\frac{1}{2}}^{n+\frac{1}{2}}) - K(\Theta_{i-\frac{1}{2}}^{n+\frac{1}{2}})]/\Delta z \tag{16}$$

Similarly, the finite difference approximation for the heat-flow equation (equation 15) can be expressed as follows for the one-dimensional condition:

$$[C(T_i^{n+1} - T_i^n)]/\Delta t = [\lambda(T_{i+\frac{1}{2}}^{n+\frac{1}{2}})(T_{i+1}^{n+1} - T_i^{n+1})]/(\Delta z)^2$$
$$- [\lambda(T_{i-\frac{1}{2}}^{n+\frac{1}{2}})(T_i^{n+1} - T_{i-1}^{n+1})]/(\Delta z)^2$$
$$- L[D_{\Theta vap}(\Theta_{i+\frac{1}{2}}^{n+\frac{1}{2}})(\Theta_{i+1}^n - \Theta_i^n)]/(\Delta z)^2$$
$$- L[D_{\Theta vap}(\Theta_{i-\frac{1}{2}}^{n+\frac{1}{2}})(\Theta_i^n - \Theta_{i-1}^n)]/(\Delta z)^2 \tag{17}$$

The numerical solution to these equations gives the water content $\Theta(z, t)$ and temperature $T(z, t)$ at incremental distances, Δz, and incremental time steps, Δt, where $z = i\Delta z$ and $t = n\Delta t$. Equation 16 can be solved for the water content, Θ_i^{n+1}, at time step $n + 1$, where Θ_i^n and T_i^n are known from the initial boundary conditions. Equation 17 can be solved for the temperature, T_i^{n+1} at time step $n + 1$ by using the water content computed from equation 16 and values of T_i^n. Repeated solutions of equations 16 and 17 give the water content and temperature distribution at any particular time desired, with the temperature computation lagging behind the moisture computation by one time step. The numerical solution to the implicit finite difference equations results in a set of simultaneous equations that can be solved by the Gauss elimination method.

In the moisture model the temperature and moisture diffusivities each has two components as described by equations 13 and 14. The procedure for obtaining the liquid moisture diffusivity, $D_{\Theta liq} = K(\partial h/\partial\Theta)$, is described by Elzeftawy and Dempsey in a paper in this Record. The vapor moisture diffusivity, $D_{\Theta vap}$, is obtained from the following equation of Philip and de Vries ($\underline{18}$):

$$D_{\Theta vap} = D_{atm}\nu\alpha ag\rho(\partial h/\partial\Theta)/(\rho_w)RT \tag{18}$$

and the thermal liquid diffusivity, D_{Tliq}, and thermal vapor diffusivity, D_{Tvap}, are computed from

$$D_{Tliq} = K\gamma h \tag{19}$$

and

$$D_{Tvap} = D_{atm}\nu\alpha ah_o(\beta/\rho) \tag{20}$$

Computer Program

The numerical solution to the implicit finite difference equations (equations 16 and 17) was programmed on a

digital computer to provide a comprehensive and flexible moisture model. Numerous pavement geometric variables and hydrologic parameters are programmed into the model. Both one-dimensional and two-dimensional studies can be conducted. It is also possible to specify whether isothermal or nonisothermal moisture movement is to be predicted in the pavement system. Stationary or moving water table conditions can be specified in the moisture model. The data are programmed into the computerized model by using a free-form scan program that allows substantial flexibility in changing various inputs to the computer program. Climatic conditions can be put into the moisture model by using standard weather bureau data such as year and month of study, day of month, maximum and minimum daily temperature, rainfall, snowfall, wind velocity, percentage of possible daily sunshine, time of sunrise and sunset, and theoretical extraterrestrial radiation.

Most of the temperature computation procedures used in the moisture model are based on a heat-transfer

model developed by Dempsey that considers meteorological parameters such as radiation and convection into or out of the pavement system (Figure 3) (30). A meteorological energy balance approach described by Berg (32) and previously used by Dempsey (30) is used to relate the climatic parameters to the pavement surface as follows:

$$Q_i - Q_r + Q_a - Q_e \pm Q_c \pm Q_h \pm Q_g = 0 \qquad (21)$$

Precipitation at the pavement surface is considered either as snow or rain. The amount of rainwater that infiltrates the pavement is a function of the rainfall intensity and duration, the surface runoff, and the pavement surface permeability. Water infiltration from snow is considered only if the temperature rises above freezing.

VALIDATION OF THE MOISTURE MODEL

The validation of the moisture model using data from

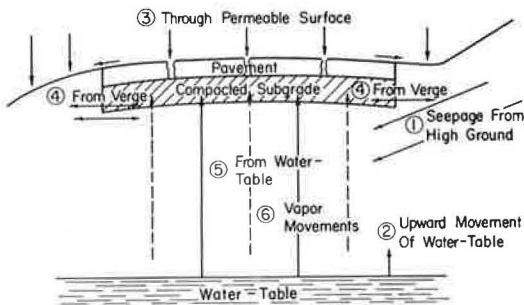Figure 1. Sources of moisture in pavement systems.

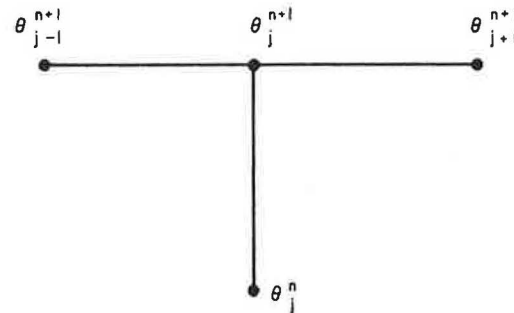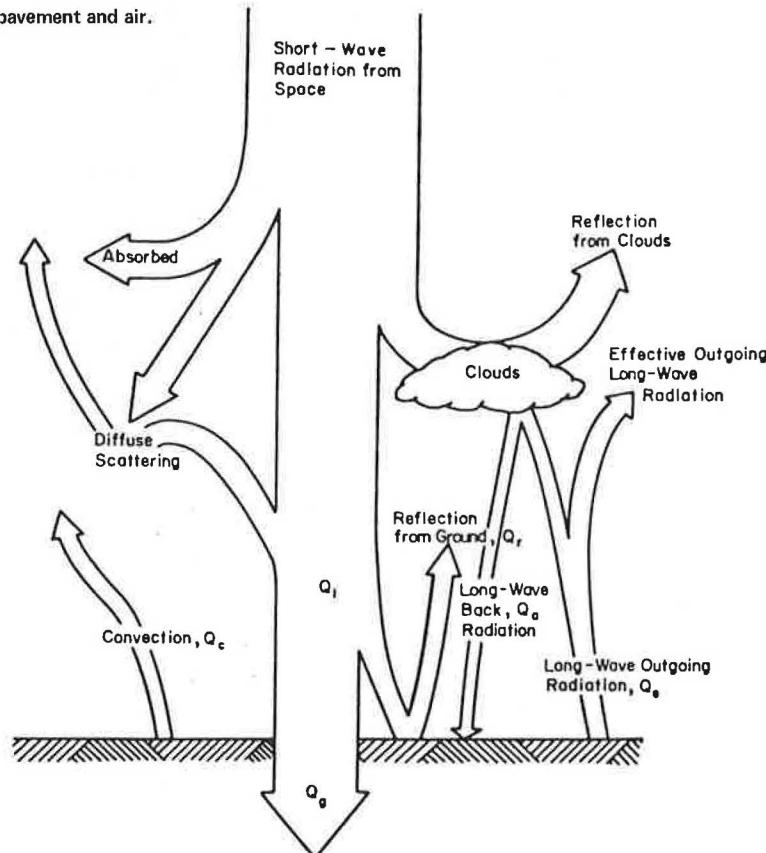Figure 2. Implicit system for diffusion equation.

Figure 3. Heat transfer between pavement and air.

controlled laboratory and field studies is not completed at this time. However, comparisons between predicted and measured moisture contents have been made using laboratory data from one-dimensional studies.

Figure 4 shows the comparisons between the predicted and measured moisture contents at varying depths in Lakeland fine sand (AASHO Classification A-3) for one-dimensional, isothermal conditions. The composition and some physical properties of the sand are given below.

Component	Percentage
Sand	98.00
Silt	2.00
Clay	0.00
Liquid limit	Nonplastic
Plastic limit	Nonplastic
Compacted water content	0.65
HYGR	0.65

Property	Value
Compacted dry density (kg/m^3)	1560
Saturated hydraulic conductivity (cm/s)	4.11×10^{-3}

The boundary conditions for the program were

1. The moisture content at the surface remained constant at 0.26 cm^3/cm^3 (gravimetric water content = 16.6 percent) during $0 \le t \le t_{final}$,
2. The water table was sufficiently deep so that the moving water front did not reach to that depth, and
3. The average initial water content distribution at $t = 0$ was 0.109 cm^3/cm^3 (gravimetric water content = 7.0 percent).

From Figure 4 it is apparent that the isothermal moisture contents predicted by the moisture model compare favorably with the measured moisture contents.

Figure 5 shows a comparison between the predicted and measured isothermal moisture contents for an Illinoian till soil (AASHO Classification A-4) above a water table condition. The composition and some physical properties of the till are given below.

Component	Percentage
Sand	62.00
Silt	20.00
Clay	18.00
Liquid limit	22.20
Plastic limit	14.70
Compacted water content	11.70
w_{HYGR}	1.40

Property	Value
Compacted dry density (kg/m^3)	1720
Saturated hydraulic conductivity (cm/s)	8.61×10^{-5}

The boundary conditions for the program were

1. The average initial water content distribution at $t = 0$ was 0.21 cm^3/cm^3 (gravimetric water content = 12.2 percent),
2. An instantaneous water table moved upward to a depth of 120 cm (3.94 ft) below the surface at $t = 0$, and
3. The surface moisture was not allowed to evaporate during $0 \le t \le t_{final}$.

From Figure 5, it would appear that the moisture model was adequate in predicting moisture content changes with time in a fine-grained soil for one-dimensional, isothermal conditions. By comparing Figure 4 with

Figure 5, it is possible to observe the differences in the rate of moisture movement caused by soil type and gravitational force. The downward movement of water shown in Figure 4 is assisted by gravity while the upward migration of water from the water table shown in Figure 5 must move against gravity: It appears that more than 60 days may be required for the Illinoian till soil to reach equilibrium for the given boundary conditions.

Nonisothermal moisture data are not readily available to validate the moisture model. Figure 6 shows the influence of a temperature gradient of approximately 0.2° C/cm (0.9° F/in) on the Illinoian till soil for the same initial boundary conditions as specified for Figure 5. The temperature increased from the top downward in the pavement system. Comparison of Figures 5 and 6 shows that temperature can exert substantial influence on moisture movement in a soil with time. Apparently, the model has the potential to simulate nonisothermal conditions.

DISCUSSION OF MOISTURE MODEL

The moisture model is a comprehensive and flexible method for predicting moisture conditions in pavement systems. As additional laboratory and field data become available, further validation work will be possible for both one-dimensional and two-dimensional moisture movement.

The ultimate objective of the application of moisture flow theory to field flow situations is the understanding of the soil water regime as a tool for the improvement of pavement design. In the process of developing the theoretical concepts that can model the soil-water flow system, there is an increased understanding of the system, and these concepts can be used to make predictions about the response of a soil-water flow system to the imposition of particular boundary conditions or modifications of the properties of the system. Making an adequate prediction makes it possible to manage the behavior of the soil-water system within the saturated to the unsaturated range.

In a broad way there would seem to be two purposes for the quantitative analysis and prediction of the performance of a given flow system. These are the verification of the validity of the flow theory and the practical prediction of the hydraulic performance of a given body of soil material in the pavement system.

The theory of soil-water movement is often used in a qualitative manner. As the basic concepts of flow in unsaturated soils become more generally known and understood, more use can and will be made of these concepts. For example, the recognition that the hydraulic conductivity decreases rapidly with decreasing water content can be of great use in qualitative and quantitative ways to analyze the behavior of a soil-water system.

The moisture model represents an important and necessary step in the development of a better understanding of climatic effects on pavement systems. Stating the moisture flow theory in mathematical terms as embodied in the partial differential equations of flow provides a basis for a more quantitative prediction of behavior. The classical mathematical-physical approach requires mathematical statements of the initial and boundary conditions that describe the specific flow situations and knowledge of the conductivity and water capacity functions that characterize the soil. It is then possible to obtain a solution to the flow equation and predict the behavior of the flow system by using analytical or numerical methods. The solution is in the form of the spatial and temporal distribution of the water content or the pressure head of the soil water or both. From these, such quantities as flux and cumulative flows can be derived at any point in the pavement system.

APPLICATIONS OF THE MOISTURE MODEL

Moisture is an important factor affecting the durability properties and the resilient properties of highway soils and materials, and the performance and fundamental behavior of pavement systems. Water directly governs the mechanical properties of most pavement materials and soils; therefore, any variation in water content will alter the properties of most pavement materials and soils. Methods for predicting moisture movement and equilibria in pavement systems are needed to fully describe material and pavement behavior. The increased use of subsurface drains also requires a better understanding of moisture movement and moisture equilibria in pavement systems as sound decisions concerning the

Figure 4. Comparison between predicted and measured moisture contents for Lakeland fine sand.
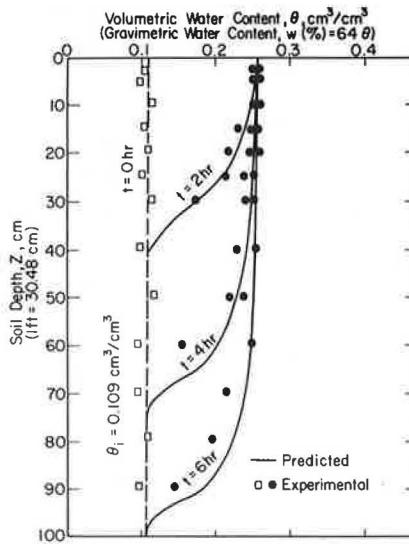
Figure 5. Comparison between predicted and measured moisture contents for Illinoian till above water table.
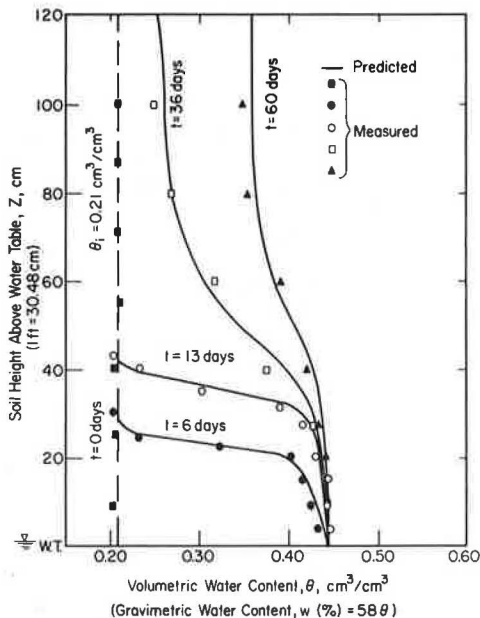
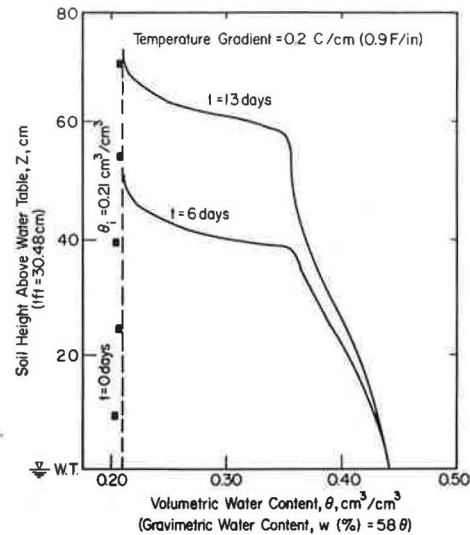Figure 6. Predicted nonisothermal moisture movement for Illinoian till above water table.

Figure 7. Changes in nonisothermal pavement moisture content as a function of depth, climate, and time.
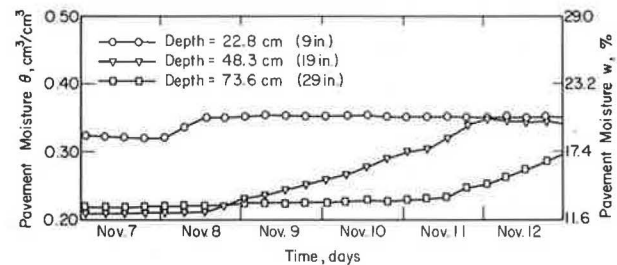
Figure 8. Changes in pavement temperature as a function of depth, climate, and time.
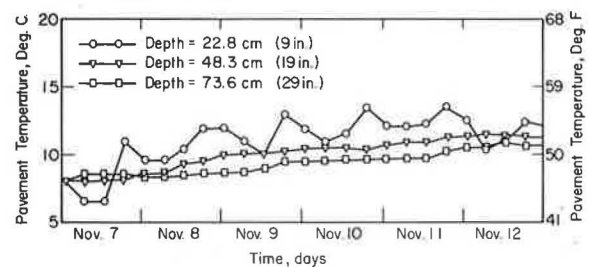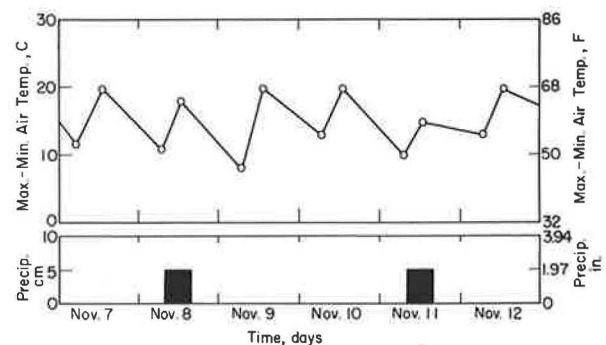
Figure 9. Air temperature and precipitation input for moisture model.

location of such drains require a thorough knowledge of the time-dependent moisture regime of the pavement system.

The moisture model can be used to study the changes in moisture content in a pavement system with time under varying climatic conditions. Figures 7 and 8 show variations in subgrade moisture content and temperature respectively for a 6-d period (the air temperatures and precipitation for the period are shown in Figure 9). The physical properties of the soil used to develop Figures 7 and 8 are the same as those for the Illinoian till in Figure 5. The subgrade moisture changes shown in Figure 7 reflect the influence of the rainfall shown in Figure 9. Although it is not readily evident, the water table position and temperature also have an effect on the moisture changes shown in Figure 7.

It is expected that the findings from this investigation will be helpful in making decisions related to moisture problems in pavement systems. The moisture model can be used to determine how various design modifications influence the moisture regime in a pavement system. It is anticipated that use of the model and related field and laboratory studies will lead to a less empirical approach for incorporating moisture effects into pavement design, construction, and behavior.

CONCLUSIONS

1. The moisture model provides a comprehensive procedure for predicting moisture conditions in pavement systems.

2. The Philip and de Vries equation for moisture movement provides a sound basis for predicting moisture conditions in pavement systems.

3. The moisture model gives valid results for predicting isothermal moisture movement.

4. Although it is not yet validated, the moisture model has the potential for predicting nonisothermal water movement.

5. The model can be used with climatic input data to predict the moisture-temperature regime in pavement systems.

6. The moisture model is potentially useful for many types of pavement research related to climatic effects.

ACKNOWLEDGMENTS

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