Soil Moisture

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CONSERVB
A NUMERICAL METHOD TO COMPUTE SOIL WATER CONTENT AND TEMPERATURE PROFILES UNDER A BARE SURFACE

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For evaluating the feasibility of remotely sensing the status of soil moisture, the most promising technology is the measurement of microwave emission by the earth's surface or the backscatter of microwave radiation emitted by an airborne source. In either case, the signals characterize a rather shallow layer, variously estimated between 0.05 and 0.25 m deep. Surface configuration, moisture content, or perhaps more accurately, the specific free energy of the water present, affect not only the signal strength, but also the depth of perception.

A closely related study of the moisture movement and the water balance of deeper layers is indispensable. This classical problem of agricultural and natural hydrology has always been made intractable by the lack of facts on the surface moisture regime. Thus, the two areas of research and application are currently merging. Evidence of this trend is the development of theories, in the form of numerical models, that are combinations of atmospheric and soil physics. These may provide the foundation for models of microwave physics as well as a practical means to interpret radar signatures.

We present here a comprehensive, yet fairly simple model of water disposition in a bare soil profile under the sequential impact of rain storms and other atmospheric influences, as they occur from hour to hour. This model is intended mostly to support field studies of soil moisture dynamics by our current team, to serve as a background for the microwave measurements, and, eventually, to serve as a point of departure for soil moisture predictions for estimates based in part upon airborne measurements.

The main distinction of the current model is that it accounts not only for the moisture flow in the soil-atmosphere system, but also for the energy flow and, hence, calculates system temperatures. Also, the model is of a dynamic nature, capable of supporting any required degree of resolution in time and space.

Much critical testing of the sample is needed before the complexities of the hydrology of vegetated surface can be related meaningfully to microwave observations.
Semi-annual Report

CONSERVB
A NUMERICAL METHOD TO COMPUTE
SOIL WATER CONTENT AND TEMPERATURE
PROFILES UNDER A BARE SURFACE

By

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R. Lascano

This report describes activity carried out in support of the Soil Moisture Research activities of the Project.

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ABSTRACT

Under a contract with the National Aeronautics and Space Administration (NASA, Johnson Space Center in Houston), Texas A&M University, through its Remote Sensing Center, is one of a small group of contractors, evaluating the feasibility of remotely sensing the status of soil moisture.

At present, the most promising technology is the measurement of microwave emission by the earth's surface or the backscattering of microwave radiation emitted by an airborne source. In either case, the signals characterize a rather shallow layer, variously estimated between 0.05 and 0.25 m deep. Surface configuration, moisture content, or perhaps more accurately, the specific free energy of the water present, affect not only the signal strength, but also the depth of perception.

To support such efforts, a closely related study of the moisture movement and the water balance of deeper layers is indispensable. This classical problem of agricultural and natural hydrology has always been made intractable by the lack of facts on the surface moisture regime. Thus, the two areas of research and application are currently merging. Evidence of this trend is the development of theories, in the form of numerical models, that are combinations of atmospheric and soil physics. These may provide the foundation for models of microwave physics as well as a practical means to interpret radar signatures.

As one step in that direction, we present here a comprehensive, yet fairly simple model of water disposition in a bare soil profile under the sequential impact of rain storms and other atmospheric influences, as they occur from hour to hour. This model is intended mostly to support field
studies of soil moisture dynamics by our current team, to serve as a background for the microwave measurements, and, eventually, to serve as a point of departure for soil moisture predictions or estimates based in part upon airborne measurements.

The main distinction of the current model is that it accounts not only for the moisture flow in the soil-atmosphere system, but also for the energy flow and, hence, calculates system temperatures. Also, the model is of a dynamic nature, capable of supporting any required degree of resolution in time and space.

This work is the precursor of similar work for vegetated areas. It should be emphasized, however, that much critical testing of the simple case is needed before the complexities of the hydrology of a vegetated surface can be related meaningfully to microwave observations.

The present model is given in full detail, so as to invite its use by others and to make it possible to make adaptations, changes, and improvements. The program, as listed, can be obtained from the authors in the form of punched cards or a cassette.
INTRODUCTION

A simulation model is documented for calculating the water content and temperature profiles of a bare soil, from known initial conditions and a set of ordinary, time-dependent weather data, over a period of several days to several weeks. The model is dynamic, because the properties of the system are updated as the temperature and water content are changing in time.

The present model was adapted from a set of algorithms devised for the study of dry mulching as a water conserving treatment in the dryland farming areas of North Texas (Horton, 1977). In turn, the latter model was derived from a simulation of the concurrent flow of water and heat in soil proposed by Van Bavel and Hillel (1975, 1976) and of the infiltration and detention of rainfall suggested by Hillel et al. (1975).

The model provides a comprehensive method for the simultaneous solution of the equation of continuity for water and heat in a soil system. The solution is obtained at frequent, fixed intervals and the moisture and temperature profiles are printed when desired. The distinguishing characteristic of the model is that it does not assume a typical or average rate of evaporation, but that it, rather, generates the instantaneous rate, from the ambient weather and the momentary values of the soil moisture and temperatures. The evaporative flux is found by a combination method, that is, a combination of a surface energy balance and a model of the fluxes above and below that surface.

The model is written in the Continuous System Modeling Program III (CSMP III) language (IBM, 1975), a specific numerical simulation language suitable for time-variant systems. The model was developed for execution on the AMDAHL 470V/6 computer operated by Texas A&M University at
College Station, Texas. This system is operated with the IBM S-370 operating system.

A basic knowledge of physics and FORTRAN is desirable to understand the model. To assist the user, a glossary of variable names with their units has been provided as Appendix A, and a complete listing of the program is presented in Appendix B. Furthermore, since CSMP III is used throughout, a brief explanation will be given when CSMP III statements are used.
The inputs to calculate the heat and water balance of a soil system are divided in two parts: constant and variable inputs.

Constant inputs to the model refer to the hydraulic characteristics of the soil and the relationship between albedo (shortwave reflectance) and volumetric water content of the soil surface. The hydraulic characteristics of the soil are the functions relating pressure potential and hydraulic conductivity to volumetric water content.

Variable inputs to the model refer to the time-dependent weather variables. These are:

1. daily global radiation, based on either daily total or hourly data,
2. daily maximum and minimum air temperatures and their corresponding relative humidities, or, hourly temperature and dewpoint data (2.0 m height),
3. average daily wind speed, or hourly data if available (2.0 m height), and
4. amount and duration of precipitation.

Initial values that must be known are the initial soil moisture and heat content of the soil as a function of depth. These are obtained as follows:

1. initial heat content are calculated from an initial measured or estimated soil temperature profile, and
2. initial water contents as measured in the field.

The way in which the constant and time-dependent inputs, and the initial values are manipulated in the model will be considered in detail in section IV of this document.
DESCRIPTION OF THE SOIL

This simulation model is being applied to describe the heat and water balance of a soil classified in the Norwood series (Mixed (Calcareous), Thermic Typic Udifluvents). Specifically, the hydraulic characteristics in the model were obtained from three unpublished theses from Texas A&M University (Saffaf, 1966; Marek, 1977; and Humphreys, 1979). These reports deal with the field determination of the hydraulic conductivity of the soil and with the hydraulic characteristics of irrigation furrows. The experimental work was done on the Agronomy farm of Texas A&M University, on a Norwood soil.

In terms of its hydraulic characteristics, the soil profile being used in this simulation can be divided into two horizons (Humphreys, 1979). The characteristics of each horizon are listed below:

A. Horizon number 1:
   a. Depth 0.0 - 0.20 m
   b. Texture silty clay loam
   c. Average dry bulk density 1.54 g/cm$^3$
   d. Saturated hydraulic conductivity 5.0 x 10$^{-7}$ m/s
   e. Relationship of pressure potential versus volumetric water content as plotted in Figure 1, and
   f. Calculated hydraulic conductivity versus volumetric water content as plotted in Figure 2.

B. Horizon number 2:
   a. Depth 0.20 - 1.20 m
   b. Texture silt loam
   c. Average dry bulk density 1.46 g/cm$^3$
Figure 1. Relationship between the Log\(_{10}\) of pressure potential (-m of water column) and volumetric water content for the surface horizon, 0.0 - 0.20 m, of the Norwood soil (FUNCTION TVSP1).
Figure 2. Relationship between the calculated hydraulic conductivity in m/s and the volumetric water content of the surface horizon, 0.0 - 0.20 m, of the Norwood soil (FUNCTION TVSC1).
d. Average saturated hydraulic conductivity \(6.0 \times 10^{-6}\) m/s

e. Relationship of pressure potential versus volumetric water content as plotted in Figure 3, and

f. Calculated hydraulic conductivity versus volumetric water content as plotted in Figure 4.

The hydraulic conductivity as a function of volumetric water content for both horizons was calculated by the method of Jackson (Jackson, 1972). The WATFIV algorithm used for this calculation is included in Appendix C.
Figure 3. Relationship between the Log\(_{10}\) of pressure potential (-m of water column) and volumetric water content for the sub-soil horizon, 0.20 - 1.20 m, of the Norwood soil (FUNCTION TVSP2).
Figure 4. Relationship between calculated hydraulic conductivity in m/s and volumetric water content for the sub-soil horizon, 0.20 - 1.20 m, of the Norwood soil (FUNCTION TVSC2).
DESCRIPTION OF THE MODEL

Introduction to CSMP III:

Program statements in CSMP III can be divided into three categories: data, structure, and control statements. Data statements assign numeric values to the parameters, constants, and initial conditions of the system. Structure statements define the functional relationship between the variables of the model. Control statements deal with the duration of the simulation, the integration increment, type of output, and with the translation and execution of the program. The user does not need to specify the category of each statement.

The structure of the program can be divided into three sections: INITIAL, DYNAMIC, and TERMINAL sections. The major characteristics of these translation control statements are the following:

INITIAL Section
1. Operations specified in this section are executed only at the onset of the simulation,
2. it contains the equations that define the invariable geometry of the system, and
3. it contains values and tables for specified parameters, and provides the initial values of specified variables.

DYNAMIC Section
1. It contains the equations that are needed to update the system at every time interval, and
2. it uses an iterative procedure for the solution of implicit functions of certain variables.
TERMINAL Section

1. it specifies the finish time for simulation,
2. it specifies the time interval for output and the variables to be printed in the output, and
3. it specifies the method of integration that is to be used and the integration time interval.

Description

The program will be described in the sequence given in the listing in Appendix B. To assist the user with the identification of variables refer to Appendix A where a glossary of the variables with their corresponding units are given. The International System of Units (SI) is used throughout the program with the exception of water potential values, which are given in terms of m water column. In principle, the water potential should be specified in kPa, but the approximation that 1 kPa = 0.1 m water column is sufficiently accurate and simplifies the dimensions of the units throughout. For the purpose of the description, the program is divided into five parts:

JOB CONTROL LANGUAGE (JCL) (lines 4-10)

The JCL statements are the ones used at the Texas A&M University computer installation (AMDAHL 470V/6, IBM S370 system). The user should consult the instructions of the local installation and make the necessary changes. Note that the program requires at least 128K bytes of memory.
TITLE, MEMORY ORGANIZATION, AND ALLOCATION (lines 16-30)

Lines 16-19 are TITLE statements. This is a CSMP III label statement and allows the user to specify a heading that will appear at the top of the first page of printed output. Lines 14 and 15 are CSMP III comment statements, and can be identified by an asterisk (*) in column 1. Lines 21-30 are translation control statements to organize the memory and to initialize arrays. Lines 21-23 are the CSMP III STORAGE statement, and they represent subscripted variables with the appropriate number of storage locations contained within the parentheses. Lines 24-27 are DIMENSION statements, and are handled as in FORTRAN with the exception that a virgule (/) must appear in column 1. The virgule indicates that the DIMENSION instruction is a FORTRAN specification statement. Lines 27 and 28 are EQUIVALENCE statements and are treated in the same manner as the DIMENSION statements. The EQUIVALENCE statement allows that the variables within the parentheses be assigned to the same storage locations in the memory, that is, the variables are synonymous. Line 30 are variables specified as integers with the statement FIXED.

INITIAL Section (lines 36-210)

The INITIAL section begins with the lines (the numbers to the left refer to the corresponding number of the listing in Appendix B):

36. INITIAL
38. NOSORT

The NOSORT is a CSMP III translation control statement and it means that the subsequent statements are to be executed in the order in which they
appear. The INITIAL section will be described in paragraphs as indicated by the comment cards in the listing (Appendix B).

*** 1) DEFINITION OF PARAMETERS (lines 40-50)

Lines 40 and 42-50 are data control statements. The PARAMETER statement (lines 40-50) is used to assign numerical values to the following variables (the number to the right in parenthesis refers to the corresponding number of the variable as given in the glossary in Appendix A):

\[
\begin{align*}
40. & \quad \text{PARAMETER NL = 13} \\
42. & \quad \text{PARAMETER KONDS = 4.20} \\
43. & \quad \text{PARAMETER KONODW = 0.57} \\
44. & \quad \text{PARAMETER KONDA = 0.025} \\
45. & \quad \text{PARAMETER VHCAPS = 1.925E-06} \\
46. & \quad \text{PARAMETER VHCAPW = 4.186E06} \\
47. & \quad \text{PARAMETER SIGMA = 5.67E-08} \\
48. & \quad \text{PARAMETER ZO = 0.01} \\
49. & \quad \text{PARAMETER SATCON = 0.60E-06} \\
50. & \quad \text{PARAMETER PORSTY = 0.50}
\end{align*}
\]

The values for the heat conductivity of soil (KONDS), water (KONDW), heat conductivity by air (KONDA) and volumetric heat capacity of the soil (VHCAPS) and of water (VHCAPW) were obtained as suggested by De Vries (1966).

The value for the total porosity (PORSTY) of the soil was calculated from the average dry bulk density of the soil layers i.e.

\[
\text{PORSTY} = 1.0 - \frac{\text{Average dry bulk density}}{\text{Particle density}}
\]

*** 2) DAILY COUNTERS (lines 52-54)

Lines 52-54 initialize day counters, which are used to keep track of the daily input data that is read with lines 56-61 in the third paragraph.

*** 3) READ INPUT DATA (lines 56-61)

The input data is stored in a two dimensional array (WINPUT), and is
read in with a FORTRAN READ statement (line 57).

*** 4) SPECIFICATION OF THE GEOMETRY OF THE SYSTEM, INITIAL WATER CONTENT AND TEMPERATURE (lines 64-68)

In CSMP III, the TABLE statement is used to assign values to the subscripted variables listed on a STORAGE card. Thus, lines 64, 66, and 67 are used to initialize the values for the thickness of the compartment (TCOM), initial volumetric water content (ITHETA), and initial soil temperatures (ITEMP). Since the number of layers (NL) is 13, one value for each soil layer must be specified with the TABLE statement. Three periods (...) are used as continuation to following lines.

*** 5) CALCULATIONS OF DISTANCE AND DEPTH (lines 70-75)

The depth (DEPTH(I)) and the distance (DIST(I)) of each soil layer is calculated in lines 70-75. The depth of each layer is the vertical distance between its midpoint and the soil surface, and the distance between midpoint of adjacent layers is given by DIST(I) (lines 72-75). The depth of the first layer (DEPTH(1)) is half its thickness (line 70), and the distance of the first layer (DIST(1)) is set equal to its depth (line 71).

70. DEPTH(1) = 0.5*TCOM(1)
71. DIST(1) = DEPTH(1)
72. DO 20 I = 2,NL
73. DIST(I) = 0.5*(TCOM(I-1)+TCOM(I)) (21)
74. DEPTH(I) = DEPTH(I-1)+0.5*(TCOM(I-1)+TCOM(I)) (17)
75. 20 CONTINUE

Figure 5 shows the geometry of the system and symbols used in the program, and Table 1 lists the corresponding values of TCOM, DIST, and DEPTH.
Figure 5. Geometry of the system and symbols used in the program.
TABLE 1. Invariable geometry of the soil system.

<table>
<thead>
<tr>
<th>Layer N (I)</th>
<th>Thickness of compartment TCOM(I) (m)</th>
<th>Distance DIST(I) (m)</th>
<th>Depth DEPTH(I) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.01</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>2</td>
<td>0.02</td>
<td>0.015</td>
<td>0.020</td>
</tr>
<tr>
<td>3</td>
<td>0.02</td>
<td>0.020</td>
<td>0.040</td>
</tr>
<tr>
<td>4</td>
<td>0.03</td>
<td>0.025</td>
<td>0.065</td>
</tr>
<tr>
<td>5</td>
<td>0.03</td>
<td>0.030</td>
<td>0.095</td>
</tr>
<tr>
<td>6</td>
<td>0.04</td>
<td>0.038</td>
<td>0.130</td>
</tr>
<tr>
<td>7</td>
<td>0.05</td>
<td>0.045</td>
<td>0.175</td>
</tr>
<tr>
<td>8</td>
<td>0.05</td>
<td>0.050</td>
<td>0.225</td>
</tr>
<tr>
<td>9</td>
<td>0.10</td>
<td>0.075</td>
<td>0.300</td>
</tr>
<tr>
<td>10</td>
<td>0.10</td>
<td>0.100</td>
<td>0.400</td>
</tr>
<tr>
<td>11</td>
<td>0.15</td>
<td>0.125</td>
<td>0.525</td>
</tr>
<tr>
<td>12</td>
<td>0.30</td>
<td>0.225</td>
<td>0.750</td>
</tr>
<tr>
<td>13</td>
<td>0.30</td>
<td>0.300</td>
<td>1.050</td>
</tr>
</tbody>
</table>
6) CALCULATIONS OF INITIAL WATER AND TEMPERATURE CONDITIONS (lines 79-87)

From the parameters given, the following initial conditions for water and temperature in the soil system are calculated:

1) the initial volumetric heat capacity of each soil layer (IVHCAP(I)) is calculated from the soil porosity and its water content as suggested by De Vries (1966).

\[ IVHCAP(I) = VHCAPW \times ITHETA(I) + (1.0 - PORSTY) \times VHCAPS \]  

(54)

2) the initial water content (IWATER) for the entire soil profile is calculated by,

\[ IWATER = IWATER + TOOM(I) \times ITHETA(I) \]  

(57)

3) the initial volume of heat of each soil layer (IVOLH(I)) is calculated by,

\[ IVOLH(I) = ITEMP(I) \times TCOM(I) \times IVHCAP(I) \]  

(55)

4) the net difference between influx and outflux of soil water (NFLUX) and inflow and outflow of heat (NFLOW) is set equal to zero respectively by,

\[ NFLUX(I) = 0.0 \]  

(67)

\[ NFLOW(I) = 0.0 \]  

(66)

5) and the initial volume of water in each soil layer (IVOLW(I)) is calculated by,

\[ IVOLW(I) = ITHETA(I) \times TCOM(I) \]  

(56)

In CSMP III, a graphical relationship between pairs of x - y coordinates can be represented by the data control statement FUNCTION. Thus, lines 93, 116, 139, 164, 188, and 198 represent the following relationships:

1) FUNCTION TVSP1: Volumetric water content versus pressure potential. These data characterize the first soil horizon as given in Figure 1.

2) FUNCTION TVSC1: Volumetric water content versus calculated hydraulic conductivity. These data characterize the first soil horizon as
given in Figure 2.

3) FUNCTION TVSP2: Volumetric water content versus pressure potential. These data characterize the second soil horizon as given in Figure 3.

4) FUNCTION TVSC2: Volumetric water content versus calculated hydraulic conductivity. These data characterize the second soil horizon as given in Figure 4.

5) FUNCTION TEVSKO: Soil temperature versus heat conductivity by water vapor. This relationship is plotted in Figure 6.

6) FUNCTION TIVSAL: Volumetric water content of the first soil layer versus albedo (shortwave reflectance). This relationship is plotted in Figure 7.

*** 7) TABLE OF THE GEOMETRY OF THE SYSTEM AND ITS INITIAL STATE (lines 206-210)

The INITIAL section ends with an output of a table of the geometry of the system as given in Table 1.

DYNAMIC Section (lines 216-428)

The equations which update the system at every time interval and to perform integrations are given in the DYNAMIC section. The DYNAMIC section will be described in paragraphs as indicated by the comment cards in the listing (Appendix B).

The DYNAMIC section begins with the lines,

216. DYNAMIC
218. NOSORT
Figure 6. Heat conductivity by water vapor versus soil temperature (FUNCTION TEVSKO).
Figure 7. Albedo versus volumetric water content of first soil layer (FUNCTION T1VSAL).
As explained before, the NOSORT statement indicates that the statements are executed in the order in which they are listed.

The paragraphs are:

*** 1) DEFINITION OF TIME RELATED VARIABLES (lines 221-230)

This paragraph defines the time related variables: time in hours (HTIME) and standard time of the day in hours (STIME). Also defined is an impulse generator (IMPULS).

223. \( Y = \text{IMPULS}(86400., 86400.) \)

which increments the day index (DNUM), which is used to reference WINPUT. The first value in parentheses in the IMPULS statement is the time in seconds to the first pulse, and the second value is the time interval in seconds between pulses.

The variables DNUM, DNUM1, and DNUM2 are daily counters that are used to keep track of the input data read from the array WINPUT where the data are stored. The method used to determine to what Julian day number (JDNUM) the input data corresponds is given by line 230.

230. \( JDNUM = \text{WINPUT}(1, \text{DNUM}) \)  

*** 2) CALCULATION OF HYDRAULIC CHARACTERISTICS OF THE FIRST HORIZON (lines 232-237)

The volumetric water content (\( \text{THETA}(I) \)), hydraulic conductivity (\( \text{COND}(I) \)), pressure potential (\( \text{PPOT}(I) \)), and hydraulic potential (\( \text{HPOT}(I) \)), for the first 8 layers of the soil profile (horizon #1) are calculated from the following equations:

1) \( \text{THETA}(I) \) of each layer is obtained from the ratio of the volume of water (\( \text{VOLW}(I) \)) to the layer volume per unit area:
233. \[ \text{THETA}(I) = \frac{\text{VOLW}(I)}{\text{TOOM}(I)} \]  

2) \( \text{COND}(I) \) at the center of each layer is obtained by linear interpolation of the values in the \text{FUNCTION \textsc{tvsci}} using the water content (\text{THETA}(I)) of each layer.

234. \[ \text{COND}(I) = \text{AFGEN(TVSCI, \text{THETA}(I))} \]  

\text{AFGEN (Arbitrary Function \\ Generator)} is a \text{CSMP III} statement that allows linear interpolation from a relationship specified with a \text{FUNCTION} statement.

3) \( \text{PPOT}(I) \) is obtained by linearly interpolating values in the \text{FUNCTION TVSP1} using \text{THETA}(I) of each layer.

235. \[ \text{PPOT}(I) = \text{AFGEN (TVSP1, \text{THETA}(I)).} \]  

4) \( \text{HPOT}(I) \) is the sum of \( \text{PPOT}(I) \) and the elevation (-\text{DEPTH}(I)) of each layer.

236. \[ \text{HPOT}(I) = \text{PPOT}(I) - \text{DEPTH}(I) \]

*** 3) CALCULATION OF HYDRAULIC CHARACTERISTICS OF SECOND HORIZON (lines 239-244)

The same calculations outlined in paragraph #2 are performed for the bottom five layers of the soil profile, that is, the second horizon. In this case, \text{FUNCTIONS TVSP2} and \text{TVSC2} are used with the \text{AFGEN} statements.

*** 4) CALCULATION OF THERMAL PROPERTIES (lines 246-253)

In this paragraph, the volumetric heat capacity (\text{VHCAP}(I)), temperature (\text{TEMP}(I)), and thermal conductivity (\text{KOND}(I)) are calculated for the 13 layers in the soil profile. The equations used are:

1) \( \text{VHCAP}(I) \) is calculated from the porosity (\text{PORSTY}) and the water
content (THETA(I)) as suggested by De Vries (1966). Soil air is not considered in the calculation.

247. \[ \text{VHCAP}(I) = \text{VHCAPW} \times \text{THETA}(I) + (1.0 - \text{PORSTY}) \times \text{VHCAPS} \] (101)

2) \( \text{TEMP}(I) \) of each soil layer is calculated by dividing the volumetric heat content per unit area (\( \text{VOLH}(I) \)) by the product of volumetric heat capacity (\( \text{VHVAP}(I) \)) and layer thickness (\( \text{TCOM}(I) \)).

248. \[ \text{TEMP}(I) = \frac{\text{VOLH}(I)}{\text{VHCAP}(I) \times \text{TCOM}(I)} \] (91)

3) The contribution of the water vapor phase to the thermal conductivity (\( \text{KONDV} \)) is obtained by linear interpolation of values in \text{FUNCTION TEVSKO} and \( \text{TEMP}(I) \) for each layer.

249. \[ \text{KONDV} = \text{AFGEN}(\text{TEVSKO}, \text{TEMP}(I)) \] (62)

4) \( \text{KOND}(I) \) of each soil layer is found by the formula suggested by De Vries (1966) using the values of \( \text{KONDS} \), \( \text{KONDA} \), and \( \text{KONDW} \) assigned in the \text{INITIAL} section.

250. \[ \text{KOND}(I) = \frac{((1.0 - \text{PORSTY}) \times \text{KONDS} \times 0.4 + \text{THETA}(I) \times \text{KONDW} + \ldots \times \text{PORSTY} - \text{THETA}(I)) \times 1.4 \times (\text{KONDA} + \text{KONDV})}{((1.0 - \text{PORSTY}) \times 0.4 + \text{THETA}(I) + ((\text{PORSTY} - \text{THETA}(I)) \times 1.4 \times (\text{KONDA} + \text{KONDV}))} \] (59)

*** 5) CALCULATIONS OF AVERAGE CONDUCTIVITIES (lines 255-260)

The average thermal conductivity (\( \text{AVKOND} \)) and average hydraulic conductivity (\( \text{AVCOND} \)) for transport between adjacent layers is taken to be the average of layer conductivities, weighted according to their relative thickness.

For the flow of heat, \( \text{AVKOND}(I) \) is calculated from:

256. \[ \text{AVKOND}(I) = \frac{(\text{TCOM}(I-1) + \text{TCOM}(I))}{(\text{TCOM}(I-1) / \text{KOND}(I-1) + \text{TCOM}(I) / \text{KOND}(I))} \] (4)

For the flux of liquid water, \( \text{AVCOND}(I) \) is calculated from:
258. \[ AVCOND(I) = (COND(I-1) \times TCOM(I-1) + COND(I) \times TCOM(I)) / (TCOM(I-1) + TCOM(I)) \] (3)

*** 6) SPECIFICATIONS OF BOUNDARY CONDITIONS FOR FLOW OF HEAT AND FLUX OF WATER (lines 263-264)

The boundary conditions at the bottom layer (NLL) of the soil profile are defined by the following:

1) The flux of water at the bottom boundary is taken to be equal to the hydraulic conductivity of the bottom layer. That is, the flux of water is driven by unit hydraulic potential gradient.

263. \[ FLUX(NLL) = COND(NL) \] (39)

2) The flow of heat at the bottom boundary is calculated by Fourier's law assuming that the temperature at 1.20 m depth remains constant, and that this temperature is set equal to ITEMP(NL).

264. \[ FLOW(NL) = (TEMP(NL) - ITEMP(NL) \times KOND(NL)/TCOM(NL)/2.0) \] (37)

*** 7) CALCULATION OF FLOW OF HEAT AND FLUX OF WATER (lines 266-269)

The flow of heat between layers is calculated by Fourier's law.

267. \[ FLOW(I) = (TEMP(I-1) - .TEMP(I)) \times AVKOND(I)/DIST(I) \] (36)

The flux of water between layers is calculated by Darcy's law.

268. \[ FLUX(I) = (HPOT(I-1) - HPOT(I)) \times AVCOND(I)/DIST(I) \] (33)

Note that flow of heat and flux of water is calculated for all layers except the top one.

*** 8) USE DAILY RAINFALL DATA, AND CALCULATE DAILY RAINFALL DISTRIBUTION (lines 272-285)

The daily rainfall distribution is assumed to follow the pattern illustrated in Figure 8. The necessary inputs to calculate the rainfall distribution are given by,
Figure 8. Pattern of daily rainfall distribution. For definition of symbols see text.
The logical branching used to calculate the rainfall distribution as a function of time is illustrated by the flow chart of Figure 9. In the program this is calculated by lines 272-285.

*** 9) USE DAY LENGTH AND CALCULATE DAILY DISTRIBUTION OF GLOBAL RADIATION (lines 288-292)

The daily distribution of global radiation (GR) is spread out over the daylength (DL) period using a sine function. An example of this distribution is given in Figure 10.

\[ GR = 436.33 \times WINPUT(3, DNUM)/DL \times \sin((STIME - 12 + DL/2) \times 3.141/DL) \]

Note: 436.33 is a simplification of \((24 \times 10^6/86400) \times (\pi/2)\)

***10) CALCULATION OF ALBEDO (lines 294-295)

Albedo (ALB) is obtained by linear interpolation of values in TABLE T1V5AL and the volumetric water content of the first soil layer (T1).

\[ T1 = \text{THETA}(1) \]

\[ ALB = \text{AFGEN}(T1V5AL, T1) \]

***11) CALCULATION OF WINDSPEED AND BOUNDARY LAYER RESISTANCE (lines 297-305)

Values of the average windspeed (SA) are set at noon (line 297) and linear interpolation produces values at other times (lines 299-302). The boundary layer resistance (RA) is calculated as the quotient of the logarithm of 2.0 divided by the roughness factor (ZO) squared and the
Figure 9. Flow chart showing the logical branching used to calculate the pattern of rainfall distribution.
Figure 10. Example of daily distribution of global radiation (GR) over time. (Total irradiance 10.0 MJ/m², day length = 10.7 hours).
product of windspeed at 2.0 meters and a stability factor (Sellers, 1965).

305. \[ RA = \frac{(\text{ALOG}(2.0/Z_0)^{2.0})}{(0.16*SA)} \] (73)

***12) CALCULATION OF DEWPOINT TEMPERATURE AND ABSOLUTE HUMIDITY
(lines 307-314)

Dewpoints at time of minimum air temperature (DPMIN) are set at 5:00 hours standard time and dewpoints at time of maximum air temperature (DPMAX) are set at 15:00 hours standard time allowing linear interpolation of dewpoints (DPTC) at other times (line 311 and 313).

The absolute humidity of the air (HA) is calculated from the equation (Murray, 1967), and is plotted in Figure 11.

314. \[ HA = 1.323*\text{EXP}(17.27*DPTC/(237.3*DPTC))/(273.16*TAC) \] (42)

***13) CALCULATION OF TEMPERATURE OF THE AIR AND VOLUMETRIC HEAT CAPACITY OF THE AIR (lines 316-324)

Minimum air temperature values (TAMIN) are set at 5:00 hours standard time and maximum air temperatures (TAMAX) are set at 15:00 hours standard time allowing linear interpolation of air temperatures (TAC) at other times.

The volumetric heat capacity of the air (SH), as a function of air temperature in degrees Kelvin (TAK) is calculated from the following equation, and is plotted in Figure 12.

324. \[ SH = \frac{(1154.8*303.16)}{(TAK)} \] (81)

***14) CALCULATION OF SKY IRRADIANCE (line 326)

The sky irradiance (SKL) is found from a formula suggested by Brunt (1932), as modified by Sellers (1965).
Figure 11. Relationship between absolute humidity of the air (HA) and temperature as calculated with Murray's equation.
Figure 12. Volumetric heat capacity or specific heat of the air (SH) as a function of temperature.
326. \[ SKL = (\sigma_{MA} \cdot TAK^4) \cdot (0.605 + 0.039 \cdot \sqrt{410 \cdot HA}) \] (83)

**15) IMPLICIT CALCULATION OF THE SOIL SURFACE TEMPERATURE (lines 328-335)

The temperature of the soil surface (TSC) is calculated by an implicit function (line 328) using the air temperature (TAC) as a first estimate and calculating the energy balance at the surface:

1) Sensible heat flux (A)

329. \[ A = (TSC - TAC) \cdot SH/RA \] (1)

2) Murray's equation (Murray, 1967) to calculate the saturated humidity (HO) at the soil surface.

330. \[ HO = 1.323 \cdot \exp\left(17.27 \cdot \frac{TSC}{273.3 + TSC}\right) / (273.16 \cdot TSC) \] (44)

3) Absolute humidity is calculated as suggested by Van Bavel and Hillel (1976).

33. \[ HO = HO \cdot \exp\left(PPOT(1) / (46.97 \cdot (TSC + 273.16))\right) \] (44)

4) The evaporation (EV) is the quotient of the difference in humidities of surface and atmosphere and the boundary layer resistance.

332. \[ EV = (HO - HA) / (RA \cdot 1000.) \] (33)

5) The conduction into the soil (S) is calculated as the difference in net radiation and the sum of sensible and latent heat fluxes.

333. \[ S = GR \cdot (1. - ALB) + SKL \cdot \sigma_{MA} \cdot (TSC + 273.16)^4 \cdot 4 - A \cdot LH \cdot EV \] (78)

6) The final temperature of the soil surface (FTSC) as calculated in the implicit loop is given by Fourier's law for conduction.

335. \[ FTSC = TEMP(1) + S \cdot DEPTH(1) / KOND(1) \] (40)

**16) CALCULATIONS OF EVAPORATION AND NET RADIATION (lines 337-344)

The flow of heat into the center of layer one (FLOW(1)) is calculated as the product of heat conductivity (KOND(1)) and the differences in surface (TSC) and layer temperatures (TEMP(1)) divided by
distance (DIST(1)).

337. \[ \text{FLOW}(1) = (\text{TSC-TEMP}(1)) \times \text{KOND}(1)/\text{DIST}(1). \]

The saturated humidity of the air at the soil surface (HS) is calculated with Murray's equation.

338. \[ \text{HS} = 1.323 \times \text{EXP}(17.27 \times \text{TSC}/(237.3 \times \text{TSC}))/\text{(273.16+TSC)} \]  (46)

The absolute humidity (HS) is calculated by,

340. \[ \text{HS} = \text{HS} \times \text{EXP} (\text{PPOT}(1))/(46.97 \times (\text{TSC} + 273.16)) \]  (46)

Evaporation (EVAP) is the quotient of the difference in humidities of soil surface and the atmosphere and the boundary layer resistance.

342. \[ \text{EVAP} = (\text{HS} - \text{HA})/(\text{RA} \times 1000.0) \]  (34)

The latent heat of vaporization (LH) as a function of the soil surface temperature is given by (Forsythe, 1964).

343. \[ \text{LH} = 2.94963 \times 10^9 - 2.247 \times 10^6 \times \text{TSC} \]  (64)

and LH as a function of temperature in plotted in Figure 13.

Net radiation (NR) at the soil surface is calculated by difference from the energy balance equation.

344. \[ \text{NR} = \text{FLOW}(1) + (\text{TSC-TAC}) \times \text{SH}/\text{RA+LH*EVAP} \]  (70)

A diagram illustrating the energy and water flux in the top two layers of the soil system is given in Figure 14.

**17) CALCULATION OF DETAIN, INFILTRATION, AND INCAP (lines 346-359)

The amount of water that remains on the soil surface (DETAIN) is defined as the integral between the initial value and the difference between the rainfall rate (RAIN) and the infiltration rate (INFILT). In CSMP III, this is accomplished by an INTGRL statement.

346. \[ \text{DETAIN} = \text{INTGRL}(0.0, \text{RAIN} - \text{INFILT}) \]  (18)

The infiltration capacity (INCAP) is the Darcian flux to the center.
Figure 13. Latent heat of vaporization ($L_H$) as a function of temperature.
Figure 14. Schematic diagram of the energy and mass flux in the top two layers of the soil system.
of the first layer from the saturated soil surface, at which the pressure potential is assigned a value of zero.

347. \[ \text{INCAP} = (0.0 - \text{HPOT}(1)) \times 0.5 \times (\text{SATCON} + \text{COND}(1)) / \text{DIST}(1) \]  

Since the model assumes no runoff, only two possibilities exist with rainfall, and these are:

1) When the rainfall rate does not exceed the infiltration capacity and there is no detention on the soil surface, then the rainfall rate controls the infiltration rate.

358. \[ \text{IF(RAIN.LT.INCAP.AND.DETAIN.LE.0) INFILT=RAIN} \]

2) When the rainfall rate exceeds the infiltration capacity of the soil and water is detained on the soil surface, the infiltration capacity controls the infiltration rate.

357. \[ \text{INFILT} = \text{INCAP} \] (51)

The logical branching of the above calculations is illustrated by the flow chart in Figure 15.

***18) CALCULATION OF NET FLOW OF HEAT AND NET FLUX OF WATER (lines 361-365)

The flux of water into the middle of the soil surface layer is equal to the difference in the rate of infiltration and the rate of evaporation.

361. \[ \text{FLUX}(1) = \text{INFILT} - \text{EVAP} \]

The heat flow into the bare soil surface \( \text{FLOW}(1) \) was previously defined as,

337. \[ \text{FLOW}(1) = (\text{TSC-TEMP}(1)) \times \text{KOND}(1) / \text{DIST}(1) \]

The flux of water \( \text{FLUX}(I) \) and flow of heat \( \text{FLOW}(I) \) for the rest of the layers must obey the continuity equation that is,

36. \[ \text{NFLow}(I) = \text{FLOW}(I) - \text{FLOW}(I-1) \] (66)
Figure 15. Flowchart showing the logical branching used to calculate INFILT and DETAIN.
NFLUX(I) = FLUX(I) - FLUX(I+1)  \hfill (67)

***19) INTEGRATION OF VOLUMETRIC HEAT CONTENT AND VOLUMETRIC WATER CONTENT (lines 368-369)

The 13 integrations to keep track of the volumetric heat contents (VOLH(I)) and volumetric water contents (VOLW(I)) are carried out by the CSMP III INTGRL function.

368. VOLH1 = INTGRL(IVOLH1,NFLOW1,13) \hfill (105)
369. VOLW1 = INTGRL(IVOLW1,NFLUX1,13) \hfill (106)

The third argument of the integral function indicates that there are 13 integrals to keep track of the volumetric heat content and water content of the 13 layers. The heat contents are stored in an array VOLH(I) and the water contents are stored in an array VOLW(I). Note that these arrays are named in the INITIAL section (lines 28 and 29). The first argument of the integral function states that the initial value of the volumetric heat content and volumetric water content is given by an array IVOLH(I) and IVOLW(I), respectively. The second argument states that the flow and flux rate into the integral is given by the array NFLOW(I) for heat and NFLUX(I) for water.

***20) CALCULATION OF CUMULATIVE RAIN, INFILTRATION, EVAPORATION, AND DRAINAGE (lines 372-375)

Cumulative rain (CUMRN), cumulative infiltration (CUMINF), cumulative evaporation (CUMEVP), and cumulative drainage (CUMDRN) are calculated with the CSMP III INTGRL function.

372. CUMRN = INTGRL(0.0, RAIN) \hfill (11)
373. CUMINF = INTGRL(0.0, INFILT) \hfill (10)
\begin{align*}
\text{CUMEVP} &= \text{INTGRL}(0.0, \text{EVAP}) \\
\text{CUMDRN} &= \text{INTGRL}(0.0, \text{FLXNLL}) \\
\end{align*} 

***21) CALCULATION OF TOTAL WATER FOR DIFFERENT LAYERS (lines 377-392)

The integrated volume of water in the profile, from a given depth to the bottom of the profile, is the sum of the volume of water in each layer starting at the specified depth.

1) From 0.0 - 1.20 m (\text{CUMWT}) (I=1, NL)
\begin{align*}
\text{CUMWT} &= \text{CUMWT} + \text{VOLW}(I)
\end{align*} 

2) From 0.13 - 1.20 m (\text{CUMWT1}) (I = 6, NL)
\begin{align*}
\text{CUMWT1} &= \text{CUMWT1} + \text{VOLW}(I)
\end{align*} 

3) From 0.30 - 1.20 m (\text{CUMWT2}) (I=9,NL)
\begin{align*}
\text{CUMWT2} &= \text{CUMWT2} + \text{VOLW}(I)
\end{align*} 

4) From 0.75 - 1.20 m (\text{CUMWT3}) (I=12,NL)
\begin{align*}
\text{CUMWT3} &= \text{CUMWT3} + \text{FLOW}(I)
\end{align*} 

***22) CALCULATION OF DAILY TOTALS (lines 394-404)

The daily totals of infiltration (DINF), rain (DRN), evaporation (DEVP), and drainage (DDRN) are calculated by difference from the accumulated totals and the values at the previous midnight.

\begin{align*}
\text{DINF} &= \text{CUMINF} - \text{INF(DNUM} - 2) \\
\text{DRN} &= \text{CUMRN} - \text{RN(DNUM} - 2) \\
\text{DEVP} &= \text{CUMEVP} - \text{EVP(DNUM} - 2) \\
\text{DDRN} &= \text{CUMDRN} - \text{DRAIN(DNUM} - 2)
\end{align*} 

The daily totals are calculated only at the end of a day and the calculations are controlled by the IMPULS statement.
\begin{align*}
\text{ZBHJS} &= \text{IMPULS}(86400., 86400.)
\end{align*}
The water balance for the soil system (BALANS) is calculated as the difference in the sum of cumulative water in the profile (CUMTWR), cumulative evaporation (CUMEVP), and cumulative drainage (CUMDRN) and the sum of the initial water content (IWATER) and the cumulative infiltration (CUMINF).

\[ \text{BALANS} = \text{CUMTWR} - \text{IWATER} - \text{CUMINF} + \text{CUMEVP} + \text{CUMDRN} \] (5)

The deviation of BALANS from zero provides an indication of the error produced in the solution of the equations in the model.

The last paragraph of the DYNAMIC section deals with output of calculated variables. Specifically, the following variables are printed at 8:00 and 16:00 hours, standard time: DEPTH(I), THETA(I), PPOT(I), FLUX(I), NFLUX(I), and TEMP(I).

The output at 8:00 hours is controlled by the IMPULS statement.

\[ Z = \text{IMPULS}(28800.0, 86400.) \]

and the output at 16.0 hours is controlled by the IMPULS statement.

\[ ZZ = \text{IMPULS}(57600.0, 86400.0) \]

The terminal section is mainly composed of execution control statements. The statements that appear in the TERMINAL section are:

1) TIMER FINTIM = 259200., PRDEL = 84600.0, DELT = 100.0
The TIMER card is used to specify the variables that control the run-time, print increment, and integration interval (step-size):

a) FINTIM determines the value of TIME (independent variable) at which the run is terminated. FINTIM is set equal to the desired simulation time.

b) PRDEL. This TIMER variable controls the increment for the output of the PRINT statement.

c) DELT. This TIMER variable specifies the integration interval.

2) PRINT. The PRINT card is used to specify the variables that will be printed at each specified interval (PRDEL) during the simulation.

3) METHOD TRAPZ. The integration technique is specified by the use of the METHOD card with the appropriate CSMP III integration name. In this case, the selected method is the trapezoidal (TRAPZ) method that uses a fixed integration interval (DELT).

4) END. The END card specifies the end of the program.

The last segment of the program is a list of the input data stored in the two dimensional array WINPUT. It is specified between the lines INPUT and ENDINPUT. This array must match the FORMAT statement of line 58.

The program ends with the lines

464. STOP
465. ENDJOB
466. /*END

The ENDJOB card must begin in the first column.
DESCRIPTION OF THE OUTPUT OF THE MODEL

To provide the user with an example of the output of this model, the program described in section IV of this document was executed for a period of three days.

The output of the model consists of two parts:

1) The first part is generated in the DYNAMIC section (paragraph 24), and for each simulated day an output at 8:00 am and 4:00 pm is printed. The variables printed for each soil layer are: DEPTH, THETA, PPOT, FLUX, NFLUX, and TEMP.

2) The second part of the output is generated with the PRINT card the TERMINAL section. The variables printed for midnight at the end of each day of the simulation period are: JNUM, XDNUM, DRN, DINF, DEVP, DDRN, CUMWTR, CUMWT1, CUMWT2, CUMWT3, BALANS, CUMRN, CUMDRN, CUMINF, CUMEVP, and FLOW(14).

It should be noted that for a fixed integration method, such as TRAPZ, the integration interval (DELT) necessary for execution of the model may have to be adapted to the input data. Our experience with this model, using TRAPZ, suggests a DELT of 100 seconds for input data with rain, and 200 seconds for input data with no rain. However, the user has a choice of other integration methods and should consult the CSMP III manual for proper use.
### Water and Heat Balance of Bare Soil - No Runoff

**Van Davel - Lasean**
21 May 1979

**Program Used for User's Guide Preparation**

#### Conserved Variations

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REFERENCES


APPENDICES
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<th>Term</th>
<th>Definition</th>
<th>Units</th>
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<tr>
<td>1.</td>
<td>A</td>
<td>Sensible heat flux into the air</td>
<td>W/m**2</td>
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<tr>
<td>2.</td>
<td>ALB</td>
<td>Albedo</td>
<td></td>
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<td>3.</td>
<td>AVCOND(I)</td>
<td>Average hydraulic conductivity between adjacent layers</td>
<td>M/s</td>
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<td>4.</td>
<td>AVKOND(I)</td>
<td>Average thermal conductivity between adjacent layers</td>
<td>W/(m*C)</td>
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<td>5.</td>
<td>BALANS</td>
<td>Water balance</td>
<td>M</td>
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<td>6.</td>
<td>BEGIN</td>
<td>Beginning of rainfall period</td>
<td>HOURS</td>
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<td>COND(I)</td>
<td>Hydraulic conductivity of layer (I)</td>
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<td>CUMDRN</td>
<td>Cumulative drainage</td>
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<td>CUMEVP</td>
<td>Cumulative evaporation</td>
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<td>CUMINF</td>
<td>Cumulative infiltration</td>
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<td>Cumulative rain</td>
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<td>CUMWT1</td>
<td>Total water in soil profile</td>
<td>M</td>
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<td>CUMWT2</td>
<td>Total water (I=6, NL)</td>
<td>M</td>
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<td>14.</td>
<td>CUMWT3</td>
<td>Total water (I=9, NL)</td>
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<td>DDRN</td>
<td>Daily drainage</td>
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<td>DEPTH(I)</td>
<td>Vertical distance between midpoint of layer (I) and the surface</td>
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<td>17.</td>
<td>DETAIN</td>
<td>Depth of water on the soil surface</td>
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<td>18.</td>
<td>DEVAP</td>
<td>Daily evaporation</td>
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<td>19.</td>
<td>DINF</td>
<td>Daily infiltration</td>
<td>M</td>
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<td>DIST(I)</td>
<td>Distance between midpoints of adjacent soil layers (I, I+1)</td>
<td>M</td>
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<tr>
<td>21.</td>
<td>DL</td>
<td>Day length</td>
<td>HOURS</td>
</tr>
<tr>
<td>22.</td>
<td>DNUM</td>
<td>Day counter</td>
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</tr>
<tr>
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<td>DNUM1</td>
<td>Day counter</td>
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<td>25.</td>
<td>DEMAX</td>
<td>Dewpoint temp. at time of TMAX</td>
<td>C</td>
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<tr>
<td>26.</td>
<td>DMIN</td>
<td>Dewpoint temperature at time of TMIN</td>
<td>C</td>
</tr>
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<td>27.</td>
<td>DPTC</td>
<td>Dewpoint temperature</td>
<td>C</td>
</tr>
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<td>28.</td>
<td>DRAIN</td>
<td>Drainage</td>
<td>M/S</td>
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<td>29.</td>
<td>DRN</td>
<td>Daily pain</td>
<td>M</td>
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<td>30.</td>
<td>DNSLOP</td>
<td>Rainfall slope between midpoint and</td>
<td>M</td>
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<td>31.</td>
<td>END</td>
<td>End of rainfall period</td>
<td>HOURS</td>
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<td>EV</td>
<td>Evaporation (dummy variable)</td>
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<td>EVAP</td>
<td>Evaporation</td>
<td>M/S</td>
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<tr>
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<td>EVP</td>
<td>Evaporation (dummy variable)</td>
<td>M/S</td>
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<td>FLOW(I)</td>
<td>Flow of heat into layer (I)</td>
<td>W/m**2</td>
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<td>36.</td>
<td>FLOW(NLL)</td>
<td>Flow of heat across the lower boundary</td>
<td>W/m**2</td>
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<td>37.</td>
<td>FLUX(I)</td>
<td>Flux of water into layer (I)</td>
<td>M/S</td>
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<tr>
<td>38.</td>
<td>FLUX(NLL)</td>
<td>Flux of water across the lower</td>
<td>M/S</td>
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</table>
BOUNDARY M/S

FTSC...FINAL TEMPERATURE OF SOIL SURFACE...
...AS CALCULATED IN THE IMPLICIT LOOP..C

GR...GLOBAL RADIATION.................W/M**2

HA...ABSOLUTE HUMIDITY OF THE AIR........KG/M**3

HEIGHT...RAINFALL RATE AT MIDPOINT........MM/HOUR

HD...SATURATED HUMIDITY AT THE SOIL......

HI...SURFACE AND ABSOLUTE HUMIDITY........KG/M**3

HPOT(I)...HYDRAULIC POTENTIAL OF SOIL LAYER...M OF WATER

HS...ABSOLUTE HUMIDITY...................KG/M**3

HSO...ABSOLUTE HUMIDITY, DUMMY VARIABLE...KG/M**3

HTIME...TIME.............................HOURS

INCAP.....INFILTRATION CAPACITY.........M/S

INF......INFILTRATION.......................M

INFILT...INFILTRATION RATE..............M/S

ITEMP(I)...INITIAL "TEMPERATURE OF LAYER (I)....C

IPHETA(I)...INITIAL VOLUMETRIC WATER CONTENT....
..OF LAYER (I).............................M**3/M**3

IVHCAP(I)...INITIAL VOLUMETRIC HEAT CAPACITY....
..OF LAYER (I).............................J/(M**3*C)

IVOLH(I)...INITIAL AMOUNT OF HEAT IN LAYER (I).J/M**2

IVOLW(I)...INITIAL VOLUME OF WATER IN ......
..LAYER (I)................................M

I WATER...INITIAL TOTAL WATER CONTENT OF......
...THE SOIL PROFILE.......................M

JNUM.....JULIAN DAY NUMBER.................

KOND(I)...THERMAL CONDUCTIVITY OF LAYER (I)....W/(M*C)

KONDA...THERMAL CONDUCTIVITY OF AIR.......W/(M*C)

KONDS...THERMAL CONDUCTIVITY OF SOIL.........W/(M*C)

KONDV...THERMAL CONDUCTIVITY BY WATER VAPOR.W/(M*C)

LATENT HEAT OF VAP. OF WATER.............J/M**3

MIDPNT...MIDPOINT OF RAINFALL PERIOD.......HOURS

NFLUX(I)...NET FLUX OF WATER INTO LAYER (I)....M/S

NFLOW(I)...NET FLOW OF HEAT INTO LAYER (I).....W/M**2

NL...NUMBER OF LAYERS....................

NL1...NL * 1............................

NR...NET RADIATION AT THE SOIL SURFACE...W/M**2

PORSTY...POTENTIAL OF THE SOIL............

PPOT(I)...PRESSURE POTENTIAL OF LAYER (I)....M OF WATER

RA...BOUNDARY LAYER RESISTANCE.............S/M
RAIN. RAINFALL RATE..................N/S
RFF. TOTAL RAINFALL BETWEEN BEGIN AND END..........................MM
RHS. RELATIVE HUMIDITY OF THE SOIL SURFACE..................M
RN. RAIN (DUMMY VARIABLE)..........................M

S. CONDUCTION OF ENERGY INTO THE SOIL SURFACE..................W/M**2
SA. WINDSPEED..................................M/S
SATCON. SATURATED HYDRAULIC CONDUCTIVITY OF THE SURFACE HORIZON..........................M/S
SH. RELATIVE HUMIDITY OF THE SOIL SURFACE - DUMMY VARIABLE..........................M
SIA. SATURATION CONDUCTION OF ENERGY INTO THE SOIL SURFACE• W/M**2
SIN. RELATIVE HUMIDITY OF THE SOIL SURFACE..........................M
STINE. TIME....................................HOURS

T1. WATER CONTENT OF FIRST LAYER (DUMMY VARIABLE)..........................M**3/M**3
TAC. TEMPERATURE OF THE AIR..................................................C
TAK. TEMPERATURE OF THE AIR..................................................K
TAMAX. MAXIMUM AIR TEMPERATURE..................................................C
TAMIN. MINIMUM AIR TEMPERATURE..................................................C
TCOM (I). THICKNESS OF LAYER (I)..........................M
TEMP (I). TEMPERATURE OF LAYER (I)..........................C
TEVSKO. SOIL TEMPERATURE VS. THERMAL CONDUCTIVITY BY WATER VAPOR..........................C VS. W/(M*C)
THETA (I). VOLUMETRIC WATER CONTENT OF LAYER (I)..........................M**3/M**3
T1VSAL. VOLUMETRIC WATER CONTENT OF FIRST SOIL LAYER VS ALBEDO..................-
TVSC1. VOLUMETRIC WATER CONTENT VS. HYDRAULIC CONDUCTIVITY FOR FIRST HORIZON..................-
TVSC2. VOLUMETRIC WATER CONTENT VS. HYDRAULIC CONDUCTIVITY FOR SECOND HORIZON.............-
TVSP1. VOLUMETRIC WATER CONTENT VS. PRESSURE POTENTIAL FOR FIRST HORIZON..................-
TVSP2. VOLUMETRIC WATER CONTENT VS. PRESSURE POTENTIAL FOR SECOND HORIZON.............-

UPSLOP. RAINFALL SLOPE BETWEEN BEGIN AND MIDPOINT..........................MM/HR**2

VHCA (I). VOLUMETRIC HEAT CAPACITY OF LAYER (I) . J/(M**3*C)
VHCAPS. VOLUMETRIC HEAT CAPACITY OF THE SOIL . J/(M**3*C)
VHCAPW. VOLUMETRIC HEAT CAPACITY OF WATER . J/(M**3*C)
VOLH (I). VOLUME OF WATER CONDUCTIVITY OF LAYER (I) . J/M**2
VOLW (I). VOLUME OF WATER PER UNIT AREA OF LAYER (I)..........................M**3/M**2

WINPUT. ARRAY FOR WEATHER INPUT DATA..........................-

Z3. SURFACE ROUGHNESS COEFFICIENT..........................-
**** A. JOB CONTROL LANGUAGE
****
****
//SCS-DRYJA JOB (R042,403A,003,020,RL),* VAN BAVEL - LASCANO*
/**LEVEL 0
/*** JOBPARM R=128
// EXEC CSM33CLG
//COMMENT DD DUMMY
//SYSPRINT DD DUMMY
//SYSIN DD *
****
****
**** B. TITLE, MEMORY ORGANIZATION AND ALLOCATION
****
****
TITLE WATER AND HEAT BALANCE OF BARE SOIL- NO RUNOFF
TITLE VAN BAVEL - LASCANO 21 MAY 1979
TITLE PROGRAM USED FOR USER'S GUIDE PREPARATION
TITLE CONSERVATION VARIATION
****
****
STORAGE TCOMC25), ITHETA(25), DEPTH(25), COND(25), HPOT(25)
STORAGE AVCOND(25), FLUX(25), PPOT(25), DIST(25)
STORAGE AVKONDC25), FLOWC25), KOND(25), TEMP(25), VHCAP(25), IVHCAP(25)
/ DIMENSION VOLW(25), IVOLW(25), NFlUX(25), ITHETA(25)
/ DIMENSION TEMP(25), IVOLH(25), VOLH(25), NFLOW(25)
/ DIMENSION WINPUT(11,37)
/ DIMENSION INF(38), RN(38), EVP(38), DRAIN(38)
/ EQUIVALENCE (VOLW(1), VOLW(1)), (IVOLW(1), IVOLW(1)), (NFlUX(1), NFlUX(1))
/ EQUIVALENCE (VOLH(1), VOLH(1)), (IVOLH(1), IVOLH(1)), (NFLOW(1), NFLOW(1))
****
**** C. INITIAL SECTION
****
****
INITIAL NOSORT
****
****
1) DEFINITION OF PARAMETERS
PARAMETER NL=13
PARAMETER NL= NL + 1
PARAMETER KOND = 4.2
PARAMETER KONDW = 0.57
PARAMETER KONDA = 0.025
PARAMETER VHCAPS= 1.925E06
PARAMETER VHCPW= 4.106E06
PARAMETER SIGMA = 5.67E-08
PARAMETER ZD = 0.01
PARAMETER SATCON= 0.50E-06
PARAMETER PORSTY= 0.42
****
2) DAILY COUNTERS
DNUM = 1
DNUM = 2
DNUM2 = 3
****
3) READ INPUT DATA
DO 10 K=1,37
READ(5,1000)(WINPUT(J,K), J=1,11)
1000 FORMAT(F5.0,IX,F5.2,9(I,X,F4.1))
IF(WINPUT(1,K), EQ.0,0) GO TO 11
10 CONTINUE
**** 4) SPECIFICATION OF THE GEOMETRY OF THE SYSTEM.

*** INITIAL WATER CONTENT AND TEMPERATURE

TABLE TCOM(1-13)=0.01,0.02,0.02,0.03,0.03,0.04,0.05,0.05,...

TABLE ITHETA(1-13)=13*0.42

TABLE ITEMP(1-13)=3.57,4.92,6.52,8.17,9.66,10.84,11.69,...

12,08,12,18,12,26,12,69,13,81,15,22

**** 5) CALCULATION OF DISTANCE AND DEPTH

DEPTH(I) = 0.5*TCOM(I)

DIST(I) = DEPTHC1)

DO 20 I=2,NL

DIST(I) = 0.5*(TCOM(I-1)+TCOM(I))

DEPTH(I) = DEPTH(I-1) + 0.5*(TCOM(I-1)+TCOM(I))

20 CONTINUE

**** 6) CALCULATION OF INITIAL WATER AND TEMPERATURE CONDITIONS

FLOW REFERS TO WATER

I WATER = 0.0

DO 30 I=1,NL

IVHCAP(I) = VHCAP*ITHETA(I)+(1.0-PORSTY)*VHCAPS

I WATER = I WATER + TCOM(I)*ITHETA(I)

IVOLH(I) = ITEMP(I)*TCOM(I)*IVHCAP(I)

NFLUX(I) = 0.0

NFLOW(I) = 0.0

IVOLW(I) = ITHETA(I)*TCOM(I)

30 CONTINUE

****

****

**** HYDRAULIC CHARACTERISTICS OF FIRST HORIZON 0.0-0.20 M

**** VOLUMETRIC WATER CONTENT VS. PRESSURE POTENTIAL

**** IN M WATER COLUMN

FUNCTION TVSP1 = ( 0.030, -29000.00,...

( 0.050, -16000.00,...

( 0.070, -10000.00,...

( 0.090, -6000.00,...

( 0.110, -3000.00,...

( 0.130, -1500.00,...

( 0.150, -700.00,...

( 0.170, -370.00,...

( 0.190, -160.00,...

( 0.210, -74.00,...

( 0.230, -45.00,...

( 0.250, -30.00,...

( 0.270, -18.00,...

( 0.290, -11.00,...

( 0.310, -7.20,...

( 0.330, -3.60,...

( 0.350, -1.20,...

( 0.370, -0.60,...

( 0.390, -0.22,...

( 0.410, -0.07,...

( 0.430, 0.00,...

( 1.000, 0.00)

FUNCTION TVSCI = ( 0.040, 0.1980432E-18),...

( 0.060, 0.1867095E-17),...

( 0.080, 0.9219115E-17),...

( 0.100, 0.3565605E-16),...

( 0.120, 0.141493E-15),...

( 0.140, 0.6032844E-15),...
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<th>Pressure Potential</th>
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<td>0.160</td>
<td>0.2846457E-14</td>
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<td>0.180</td>
<td>0.1263317E-13</td>
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<tr>
<td>0.220</td>
<td>0.3265092E-12</td>
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<tr>
<td>0.240</td>
<td>0.1312614E-11</td>
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<tr>
<td>0.260</td>
<td>0.4195633E-11</td>
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<tr>
<td>0.280</td>
<td>0.1239914E-10</td>
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<tr>
<td>0.300</td>
<td>0.3590753E-10</td>
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<td>0.320</td>
<td>0.9914647E-10</td>
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<td>0.340</td>
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**FUNCTION TVSP2**

Volumetric Water Content vs. Pressure Potential

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<th>Hydraulic Conductivity</th>
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<td>-130.00</td>
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<tr>
<td>0.080</td>
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<tr>
<td>0.100</td>
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<td>0.120</td>
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<tr>
<td>0.140</td>
<td>-10.00</td>
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<td>0.160</td>
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<td>0.180</td>
<td>-5.40</td>
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<td>-4.40</td>
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<td>0.220</td>
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<tr>
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<td>-1.20</td>
</tr>
<tr>
<td>0.340</td>
<td>-0.94</td>
</tr>
<tr>
<td>0.360</td>
<td>-0.70</td>
</tr>
<tr>
<td>0.380</td>
<td>-0.45</td>
</tr>
<tr>
<td>0.400</td>
<td>-0.27</td>
</tr>
<tr>
<td>0.420</td>
<td>-0.15</td>
</tr>
<tr>
<td>0.440</td>
<td>-0.06</td>
</tr>
<tr>
<td>0.460</td>
<td>0.00</td>
</tr>
<tr>
<td>0.480</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**FUNCTION TVSC2**

Volumetric Water Content vs. Hydraulic Conductivity

<table>
<thead>
<tr>
<th>Volumetric Water Content</th>
<th>Hydraulic Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.030</td>
<td>0.1200167E-14</td>
</tr>
<tr>
<td>0.050</td>
<td>0.1599529E-13</td>
</tr>
<tr>
<td>0.070</td>
<td>0.1516890E-12</td>
</tr>
<tr>
<td>0.090</td>
<td>0.1062001E-11</td>
</tr>
<tr>
<td>0.110</td>
<td>0.7476516E-11</td>
</tr>
<tr>
<td>0.130</td>
<td>0.3470373E-10</td>
</tr>
<tr>
<td>0.150</td>
<td>0.1199559E-09</td>
</tr>
<tr>
<td>0.170</td>
<td>0.3375351E-09</td>
</tr>
<tr>
<td>0.190</td>
<td>0.8332817E-09</td>
</tr>
<tr>
<td>0.210</td>
<td>0.1842094E-08</td>
</tr>
<tr>
<td>0.230</td>
<td>0.3760615E-08</td>
</tr>
<tr>
<td>0.250</td>
<td>0.7218816E-08</td>
</tr>
<tr>
<td>0.270</td>
<td>0.1315320E-07</td>
</tr>
<tr>
<td>0.290</td>
<td>0.2300420E-07</td>
</tr>
<tr>
<td>0.310</td>
<td>0.3924749E-07</td>
</tr>
<tr>
<td>0.330</td>
<td>0.660643E-07</td>
</tr>
<tr>
<td>0.350</td>
<td>0.1105985E-06</td>
</tr>
<tr>
<td>0.370</td>
<td>0.1068858E-06</td>
</tr>
<tr>
<td>0.390</td>
<td>0.3336319E-06</td>
</tr>
</tbody>
</table>
**SOIL TEMPERATURE VS. HEAT CONDUCTIVITY BY VAPOR IN W/(M*C)**

FUNCTION TEVSKO =

```
(-1.000, 0.02000),
(0.000, 0.02470),
(10.000, 0.04190),
(20.000, 0.07990),
(30.000, 0.12600),
(40.000, 0.24700),
(50.000, 0.38100),
(60.000, 0.65000),
(70.000, 0.917000)
```

**VOLUMETRIC WATER CONTENT OF FIRST LAYER VS. ALBEDO**

FUNCTION TIVSAL =

```
(0.00, 0.22),
(0.10, 0.22),
(0.25, 0.17),
(1.00, 0.17)
```

7) **TABLE OF THE GEOMETRY OF THE SYSTEM AND ITS INITIAL STATE**

WRITE(6,1100)

```
1100 FORMAT(40I1,TCOM,DEPTH,I,I,I,I)
```

DO 40 I=1,NL

```
40 WRITE(6,1200) I,TCOM(I),DEPTH(I),I,T,I,I,I)
```

```
1200 FORMAT(4H ,I2.4F10.5)
```

**DEFINITION OF TIME RELATED VARIABLES**

```
HTIME = TIME/3600.
STIME = AMOD(HTIME,24.)
Y = IMPULS(64000.,64000.)
IF(Y.LT.0.5) GO TO 22
DNUM = DNUM + 1
DNUM1 = DNUM1 * 1
DNUM2 = DNUM2 + 2
22 CONTINUE
XDNUM = FLOAT(DNUM)
JDNUM = WINPUT(l,DNUM)
```

**HYDRAULIC CHARACTERISTICS OF FIRST HORIZON**

```
DO 50 I=1,8
THETA(I) = VOLW(I)/TCOM(I)
COND(I) = AFGEN(TVSC1,THETA(I))
PPOT(I) = AFGEN(TVSP1,THETA(I))
HPOT(I) = PPOT(I) - DEPTH(I)
```

```
50 CONTINUE
```

**HYDRAULIC CHARACTERISTICS OF SECOND HORIZON**

```
DO 60 I=9,NL
THETA(I) = VOLW(I)/TCOM(I)
COND(I) = AFGEN(TVSC2,THETA(I))
PPOT(I) = AFGEN(TVSP2,THETA(I))
HPOT(I) = PPOT(I) - DEPTH(I)
```

```
60 CONTINUE
```
**** 4) CALCULATION OF THERMAL PROPERTIES

DO 70 I=1,NL

VHCAP(I) = VHCAPW*THETA(I) + (1.0 - PORSTY)*VHCAPS

TEMP(I) = VOLH(I)/(VHCAP(I)*TCOM(I))

KONDV = AFGEN(TEVSK0,TEMP(I))

KOND(I) = ((1.0 - PORSTY)*KONOS*0.4*THETA(I) + THETAH)*(PORSTY - THETA(I)) + 1.4*(KONDA + KONDV) + ...

(1.0 - PORSTY)*0.4*THETA(I) + THETAH) + (PORSTY - THETA(I)) + 1.4*(KONDA + KONDV) + ...

70 CONTINUE

**** 5) CALCULATION OF AVERAGE CONDUCTIVITIES

DO 80 I = 2,NL

AVKOND(I) = (TCOM(I-1)+TCOM(I))/(TCOM(I-1)/KOND(I-1) + TCOM(I)/KOND(I))

AVCONDU = CONDU(I-1)*TCOM(I-1)/KOND(I) + TCOM(I)/KOND(I))

80 CONTINUE

**** 6) SPECIFICATION OF BOUNDARY CONDITIONS FOR FLOW OF HEAT AND FLUX OF WATER

FLUX(NLL) = COND(NL)

FLOW(NLL) = (TEMP(NLL) - TEMP(NL) - TEMP(NLL))/KOND(NL)

**** 7) CALCULATION OF FLOW OF HEAT AND FLUX OF WATER

DO 90 I = 2,NL

FLOW(I) = (TEMP(I-1) - TEMP(I))/AVKOND(I)/DIST(I)

FLUX(I) = (HPOT(I-1) - HPOT(I))/AVCOND(I)/DIST(I)

90 CONTINUE

**** 8) USE DAILY RAINFALL DATA, AND CALCULATE DAILY RAINFALL DISTRIBUTION

BEGIN = WINPUT(9,DNUM)

END = WINPUT(10,DNUM)

RFT = WINPUT(11,DNUM)

RAIN = 0.0

IF(RFT.EQ.0.0) GO TO 33

UPSLOP = (4.0*RFT)/((END-BEGIN)**2)

DWSLOP = UPSLOP

MDPNT = (BEGIN + END)/2.0

HEIGHT = (2.0*RFT)/((END-BEGIN)

IF(STIME.GE.BEGIN.AND.STIME.LE.MDPNT) RAIN =...

(UPSLOP*(STIME-BEGIN))/3600000.0

IF(STIME.GT.MDPNT.AND.STIME.LE.END) RAIN =...

(DWSLOP*(STIME-END))/3600000.0

33 CONTINUE

**** 9) USE DAY LENGTH AND CALCULATE DAILY DISTRIBUTION OF GLOBAL RADIATION

DL = WINPUT(2,DNUM)

DGR = 86400.0*E06/DL + 12*436.33*GDR/DL

GR = 436.33*WINPUT(3,DNUM)/DL*SIN(12.0+DL/2.)

S3,141/DL

IF(GR.LE.0.0) GR = 0.0

**** 10) CALCULATION OF ALBEDO

TI = THETA(I)

ALB = AFGEN(TI,VLAS.TI)

**** 11) CALCULATION OF WINDSPEED AND BOUNDARY LAYER RESISTANCE

IF(STIME.LE.12.) SA = WINPUT(8,DNUM)

IF(TIME.LE.12.) GO TO 44

IF(STIME.LE.12.) SA = WINPUT(8,DNUM-1) + (STIME+12.)/24.***...

WINPUT(8,DNUM-1) + (STIME+12.)/24.***WINPUT(8,DNUM-1)

IF(STIME.LE.12.) GO TO 44

SA = WINPUT(8,DNUM) + (STIME+12.)/24.***WINPUT(8,DNUM-1)...

WINPUT(8,DNUM)

44 CONTINUE
RA = (ALOG(2.0/ZO)**2.0)/(0.16*SA)

**** 12) CALCULATION OF DEEPPOINT TEMPERATURE AND ABSOLUTE HUMIDITY

DPMAX=WINPUT(6,DNUM)
DPMIN=WINPUT(7,DNUM)

DPTC=DPMIN+(DPMAX-DPMIN)*(STIME-5.)/10.

IF(STIME.GT.15.)DPMIN=WINPUT(7,DNUM+1)
IF(STIME.GT.15.)DPTC=DPMAX-(DPMAX-DPMIN)*(STIME-15.)/14.

IF(STIME.LT.5. AND DNUM.GE.2.)DPMAX=WINPUT(6,DNUM-1)
IF(STIME.LT.5.)DPTC=DPMAX-(DPMAX-DPMIN)*(STIME+9.)/14.

HA = 1.323*EXP(17.27*DPTC/(237.3+DPTC))/(273.16+DPTC)

**** 13) CALCULATION OF DEWPOINT TEMPERATURE AND ABSOLUTE HUMIDITY

TAMAX=WINPUT(4,DNUM)
TAMIN=WINPUT(5,DNUM)

TAC=TAMIN+(TAMAX-TAMIN)*(STIME-5.)/10.

IF(STIME.GT.15.)TAMIN=WINPUT(5,DNUM+1)
IF(STIME.GT.15.)TAC=TAMAX-(TAMAX-TAMIN)*(STIME-15.)/14.

IF(STIME.LT.5. AND DNUM.GE.2.)TAMAX=WINPUT(4,DNUM-1)
IF(STIME.LT.5.)TAC=TAMAX-(TAMAX-TAMIN)*(STIME+9.)/14.

TAK=TAC+273.16

SH=(1154.8*303.16)/(TAK)

**** 14) CALCULATION OF TEMPERATURE OF THE AIR AND SH OF THE AIR

TAMAX=WINPUT(4,DNUM)
TAMIN=WINPUT(5,DNUM)

TAC= TAC*(TAMAX-TAMIN)*(STIME-5.)/10.

IF(STIME.GT.15.)TAMIN=WINPUT(5,DNUM+1)
IF(STIME.GT.15.)TAC=TAMAX-(TAMAX-TAMIN)*(STIME-15.)/14.

IF(STIME.LT.5. AND DNUM.GE.2.)TAMAX=WINPUT(4,DNUM-1)
IF(STIME.LT.5.)TAC=TAMAX-(TAMAX-TAMIN)*(STIME+9.)/14.

TAK=TAC+273.16

SH=(1154.8*303.16)/(TAK)

**** 15) IMPLICIT CALCULATION OF THE SOIL SURFACE TEMPERATURE

TSC = IMPL (TAC,0.01,FTSC)
A = (TSC - TAC)*SH/RA

MO = 1.323*EXP(17.27*TSC/(237.3+TSC))/(273.16+TSC)
MO=MO*EXP(P POT(1)/(46.97*(TSC+273.16)))

EV = (MO - HA)/(RA*1000.)

S = GR*(1.0 - ALB) + SKL - SIGMA*(TSC + 273.16)**4

FTSC = TEMP(1) + S*DEPTH(1)/KOND(1)

**** 16) CALCULATION OF EVAPORATION AND NET RADIATION

FLOW(1) = (TSC - TEMP(1))*KCOND(1)/DIST(1)
HS = 1.323*EXP(17.27*TSC/(237.3+TSC))/(273.16+TSC)
HS=HS*EXP(P POT(1)/(46.97*(TSC+273.16)))
RHS = HS/HSO
EVP = (HS - HA)/(RA*1000.)

LH=-2.4943300-2.247060*TSC

NR = FLOW(1) + (TSC - TAC)*SH/RA + LH*EVP

**** 17) CALCULATION OF DETAIN, INFILTRATION, AND INCAP

DETAIN = INTGRL (0.0, RAIN-INFILT)
INCAP = (0.0, HPOT(1))*0.5*(S*TCON+COND(1))/DIST(1)
IF (RAIN.GT.0.0) GO TO 55
IF (DETAIN.LE.0.0) GO TO 66
INFILT=INCAP
GO TO 77

66 CONTINUE

DETAIN = 0.0
INFILT=0.0
GO TO 77

55 CONTINUE

INFILT = INCAP
IF (RAIN. LT. INCAP. AND. DETAIN. LE. 0.) INFILT=RAIN
77 CONTINUE

**** 18) CALCULATION OF NET FLOW OF HEAT AND NET FLUX OF WATER

FLUX(1)=INFILT-EVAP
DO 100 I = 1, NL
NFLOW(I) = FLOW(I) - FLOW(I+1)
NFLUX(I)=FLUX(I)-FLUX(I+1)
100 CONTINUE
**19** Integration of Volumetric Heat Content and Volumetric Water Content

Volh1 = INTGRL(IVOLH1.NFLOW1,13)
Volw1 = INTGRL(IVOLW1.NFLUX1,13)

**20** Calculation of Cumulative Rain, Infiltration, Evaporation and Drainage

Cumrn = INTGRL(0.0, RAIN)
Cuminf = INTGRL(0.0, INFILT)
Cumevp = INTGRL(0.0, EVAP)
Cumdrn = INTGRL(0.0, FLUX(NLL))

**21** Calculation of Total Water for Different Layers

Cumwtr = 0.0
Cumwt1 = 0.0
Cumwt2 = 0.0
Cumwt3 = 0.0

DO 110 i=1,NL
CUMWTR = CUMWTR + VOLW(I)
110 CONTINUE

DO 120 i=6,NL
CUMWT1 = CUMWT1 + VOLW(I)
120 CONTINUE

DO 130 i=9,NL
CUMWT2 = CUMWT2 + VOLW(I)
130 CONTINUE

DO 140 i=12,NL
CUMWT3 = CUMWT3 + VOLW(I)
140 CONTINUE

**22** Calculation of Daily Totals

Zbhjs = IMPULS(86400., 86400.)
If(ZBHJS.LT.0.5) GO TO 88

Inf(DNUM-1) = Cuminf
Rn(DNUM-1) = Cumrn
Evp(DNUM-1) = Cumevp
Drain(DNUM-1) = Cumdrn
Dinf = Cuminf - Inf(DNUM-2)
Drn = Cumrn - Rn(DNUM-2)
Devp = Cumevp - Evp(DNUM-2)
Ddrn = Cumdrn - Drain(DNUM-2)

**23** Check Water Balance

Balans = CUMWTR - IWATER - CUMINF + CUMEVP + CUMDRN

**24** Output of Desired Variables

Z = IMPULS(28800., 86400.)
If(Z.LT.0.5) GO TO 99

Write(6,1300) Winput(), DNUM, TIME, XDNUM, STIME
1300 Format(' JULIAN DAY NUMBER = ', F4.0, ' TIME = ', F10.1,
$ ' XDNUM = ', F11.0, ' STIME = ', F7.4)
Write(6,1400)
1400 Format(' I ', 5X, 'DEPTH', 10X, 'THETA', 11X, 'PPOT', 11X,
$ 'FLUX', 9X, 'NET FLUX', 10X, 'TEMP')
Do 150 I=1,NL
Write(6,1500) I, DEPTH(I), THETA(I), PPOT(I), FLUX(I), ...
150 Format( 13,6E15.4)
Write(6,1600)
1600 Format(1H ////)
Go TO 111

99 CONTINUE

Zz = IMPULS(57600., 86400.)
If(Zz.LT.0.5) Go TO 111

60
GO TO 222
111 CONTINUE

****************** TERMINAL SECTION ******************
TERMINAL

****************** TERMINAL SECTION ******************
TIMER FNTIM=259200.0,PRDEL=86400.0,DELT=100.0
PPINT JNNUM, XDNUM, DPN, DINK, DEVP, DDPN, CUMWTR,...
CUMWT1, CUMWT2, CUMWTJ, BALANS, CUMRN, CUMDRN, CUMINF, CUMEVP,...
FLOW(14)
METHOD TRAPZ
END

* WEATHER INPUT DATA, STORED IN ARRAY WINPUT(11,37)
* JNM DL DGR TMAX TMIN DMAX DMIN SA BEGIN END RFT
INPT

1. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
2. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 9.0 12.0 25.0
3. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
4. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
5. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
6. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
7. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
8. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
9. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
10. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
11. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
12. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
13. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
14. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
15. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0
16. 10.70 10.0 16.0 0.5 3.0 -2.5 3.0 0.0 0.0 0.0

ENDINPT
STOP
ENDJOB
APPENDIX C - CALCULATION OF UNSATURATED HYDRAULIC CONDUCTIVITY
PURPOSE: This WATFIV program is designed to calculate the unsaturated hydraulic conductivity as a function of water content using Jackson's method (Jackson, 1972; Bouwer and Jackson, 1974). It also states the relationship between water content vs. pressure potential and water content vs. hydraulic conductivity in the form required for a CSMP III FUNCTION statement. Note, that the symbols used for variables in this program are different from those used in the general model.

INTRODUCTION: In order to use this program, three parameters must be known. These are:

1. the saturated hydraulic conductivity of the soil, \( \text{COND}(1) \), in m/s,

2. The relationship between pressure potential, \( \text{PP}(I) \), in m water column and volumetric water content, \( \text{TH}(I) \), and

3. the maximum value of water content, \( \text{TH}(1) \).

The first two parameters are obtained experimentally and the third one is estimated by calculating the porosity of the soil, i.e.

\[
\text{TH}(1) = \text{porosity} = 1 - \frac{\text{DB}}{\text{PD}}
\]

where DB is the dry bulk density of the soil in g/cm\(^3\), and PD is the particle density of the soil, usually taken as 2.65 g/cm\(^3\).

It should be noted that Jackson's method requires detailed information on the relationship between pressure potential vs. water content for high values of pressure potential, i.e. \( > - 0.50 \text{ m} \).

Experience has shown that this information has a critical effect on the results.
PROCEDURE: This section outlines the procedure that should be followed to obtain the values of pressure potential for different values of water content from experimental data.

1. Plot the relationship between pressure potential vs. volumetric water content for values of pressure potential > - 5.0 m on a linear scale. To the value of 0.0 pressure potential assign the maximum water content (TH(1)). A semi-log graph of pressure potential vs. water content is used for the remaining values of pressure potential.

2. Select an increment for the volumetric water content (DELTTH), i.e. 0.01, 0.02.

3. Calculate the number of values of water content (M) for which the hydraulic conductivity is to be calculated.

   \[ M = \frac{\text{TH(MAXIMUM)} - \text{TH(MINIMUM)}}{\text{DELTTH}} + 1.0 \]

4. From the graphs, read the values of pressure potential that correspond to the midpoint of each equal increment of volumetric water content. This is illustrated with an example.

**EXAMPLE:** DELTH = 0.02, TH(1) = 0.42

<table>
<thead>
<tr>
<th>WATER CONTENT INTERVAL</th>
<th>MIDPOINT</th>
<th>PP(I) (-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.42 - 0.40</td>
<td>0.41</td>
<td>0.07</td>
</tr>
<tr>
<td>0.40 - 0.38</td>
<td>0.39</td>
<td>0.22</td>
</tr>
<tr>
<td>0.38 - 0.36</td>
<td>0.37</td>
<td>0.60</td>
</tr>
<tr>
<td>0.36 - 0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.04 - 0.02</td>
<td>0.03</td>
<td>29000.00</td>
</tr>
</tbody>
</table>
INPUT TO THE WATFIV PROGRAM: The following input cards must be specified, in the sequence given, after the //DATA card.

<table>
<thead>
<tr>
<th>DATA CARD NO.</th>
<th>IDENTIFICATION</th>
<th>RESTRICTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TITLE</td>
<td>up to 80 alphabetic or numeric characters</td>
</tr>
<tr>
<td>2.</td>
<td>TH(1)</td>
<td>Real variable</td>
</tr>
<tr>
<td>3.</td>
<td>DELTH</td>
<td>Real variable</td>
</tr>
<tr>
<td>4.</td>
<td>M</td>
<td>Integer</td>
</tr>
<tr>
<td>5.</td>
<td>PP(1)</td>
<td>Positive real variables</td>
</tr>
<tr>
<td>M+4</td>
<td>PP(I)</td>
<td></td>
</tr>
<tr>
<td>M+5</td>
<td>COND(I)</td>
<td>Real variable</td>
</tr>
</tbody>
</table>

OUTPUT: The output of the program is in three parts. The first part lists the title and the input data. Note that in the first table the values of PP(I), LOG10 PP(I), and RH(I) correspond to THETAM(I), the midpoint water content. The second part lists the results. Note that in the second table the calculated value of hydraulic conductivity, (COND(I)), corresponds to THETA(I). The maximum hydraulic conductivity (COND(1)) should correspond to the maximum value of water content (TH(1)). The third part is a table of volumetric water content vs. pressure potential, and volumetric water content vs. hydraulic conductivity, in the form required for a CSMP FUNCTION statement.
REFERENCES:


1. //JACKSON JOR (R942, 402E, 402, 001, PL), LASCANO
2. /*WATFIV
3. C
4. CALCULATE HYDRAULIC CONDUCTIVITY
5. C JACKSON 1972 SSAP 36: 380-382
6. C
7. C
8. C
9. C THE NECESSARY INPUT FOR THIS CALCULATION IS GIVEN BELOW
10. C THE EXPLANATION OF INPUT VARIABLES IS GIVEN IN THE PROGRAM
11. C
12. C
13. C
14. C DATA CARD # IDENTIFICATION
15. C
16. C
17. C
18. C
19. C
20. C
21. C
22. C
23. C
24. C
25. C
26. C
27. C
28. C
29. C
30. C
31. C REAL NOMBRE, NOMJ, LCOND, LPP
32. C
33. C DIMENSION TH(70), PP(70), LCON(70), LCOND(70), PH(70)
34. C
35. C
36. C
37. C INPUT DATA
38. C
39. C READ TITLE (NAME OF SOIL, DEPTH, OTHER INFORMATION)
40. C READ(5,11)TITLE
41. C 11 FORMAT(20A2)
42. C
43. C MAXIMUM VALUE OF WATER CONTENT
44. C READ, TH(1)
45. C
46. C M IS THE TOTAL NUMBER OF VALUES OF WATER CONTENT FOR WHICH THE
47. C HYDRAULIC CONDUCTIVITY IS CALCULATED
48. C M CAN BE CALCULATED FROM THE FOLLOWING EXPRESSION:
49. C M = (TH(MAXIMUM) - TH(MINIMUM)) / DELTH * 1.0
50. C READ, M
51. C
52. C PPROGRAM
53. C
54. DO 10 I = 1, M
55. TH(I) = TH(1) - (I-1) * DELTH
56. C
57. C READ PRESSURE POTENTIAL VALUES IN M, CORRESPONDING TO THEIR
58. C RESPECTIVE VALUES FOR THE CENTER OF EACH INCREMENT THETA.
59. C READ, PP(I)
60. PP(I) = -PP(I)
61. RH(I) = EXP(PP(I) / 14091.)
LPP(I) = ALOG10(-PP(I))

DO 10 J = 1,M
   DEMOMJ = (2*J-1)/(PP(J)**2)
   DENOM = DEMOM + DEMOMJ
20 CONTINUE

GIVE MAXIMUM CONDUCTIVITY IN M/S (SAT. CONDUCTIVITY).

READ COND(I)

DO 100 J = 1,H
   DEMOJ = (2*J-1) / (PP(J)**2)
   DF.NOM = DEMO * DEMCMJ
20 CONTINUE

CONDUCTIVITY IN H/S (SAT. CONDUCTIVITY).

WRITE(6,850) TITLE
WRITE(6,900)
WRITE(-,/-,45X,'INPUT DATA',//)
WRITE(6,1000) TH(I)
WRITE(-,/-,20X,'MAXIMUM VALUE OF WATER CONTENT =',F4.2)
WRITE(6,1100) DENH
WRITE(-,/-,20X,'INCREMENT OF WATER CONTENT =',F5.3)
WRITE(6,1200) N
WRITE(-,/-,20X,'NUMBER OF VALUES OF WATER CONTENT, FOR WHICH K IS
CALCULATED = ',I3)
WRITE(6,1300) COND(I)
WRITE(-,/-,20X,'MAXIMUM CONDUCTIVITY (SAT. COND.) = ',E14.5
WRITE(-,/-,20X,'THE VALUES OF THETAM ARE THE MIDPOINTS',//
WRITE(-,/-,20X,'OF EACH INCREMENT TO WHICH THE VALUES OF PP(I)',//
WRITE(-,/-,20X,'CORRESPOND ACCORDING TO EXPERIMENTAL DATA')
WRITE(6,1450)
WRITE(-,/-,20X,'THETA(I) ',2X,'THETA(I) ',4X,'PP(I) (K) ',2X,
WRITE(-,/-,20X,'LOG10 PP(I) ',F9.2,6X,F6.2)
DO 50 I = 1,M
WRITE(6,1400) TH(I),THTA(I),PP(I),LOG10 PP(I),RH(I)
50 CONTINUE
WRITE(6,1700)
WRITE(-,/-,20X,'RESULTS',//)
WRITE(6,1900)
WRITE(-,/-,20X,'THETA(I) ',4X,'COND(I) ',4X,'LCOND(I) ',4X)
WRITE(-,/-,20X,'LOG10 COND(I) ')
DO 90 I = 1,M
WRITE(6,1600) TH(I),THETA(I),PP(I),LPP(I),RH(I)
90 CONTINUE
WRITE(6,2000)
WRITE(-,/-,20X,'K=0'
DO 90 J=1,M
90 CONTINUE
KK = N - 1

THX (J) = THETAM (KK)

CONDX (J) = COND (KK)

THY (J) = TH (KK)

PPX (J) = PP (KK)

K = K + 1

9C CONTINUE

WRITE (6, 2100)

2100 FORMAT (1HI1)

DO 100 J = 1, M

WRITE (6, 2200) THX (J), PPX (J)

2200 FORMAT (' ', 20X, '(', 'F6.3, ', 'E10.2, '), ..., ')

100 CONTINUE

WRITE (6, 2300)

2300 FORMAT (1HI1)

DO 110 J = 1, M

WRITE (6, 2400) THY (J), CONDX (J)

2400 FORMAT (' ', 20X, '(', 'F6.3, ', 'E14.7, '), ..., ')

110 CONTINUE

WRITE (6, 2500)

2500 FORMAT (1HI1)

STOP

END

//SD1TA

NORWOOD SILT LOAM, AGRONOMY FARM, 0.00 - 0.20 M DEPTH

0.42

0.020

20

0.07

0.22

0.60

1.29

3.60

7.20

11.0

18.0

30.0

45.0

74.0

160.0

370.0

700.0

1500.0

3000.0

6000.0

10000.0

16000.0

29000.0

5.0E-07

END
TITLE: NORWOOD Silt Loam, Agricultural Farm, 0.00 - 0.20 m Depth

INPUT DATA

MAXIMUM VALUE OF WATER CONTENT = 0.42

INCREMENT OF WATER CONTENT = 0.020

NUMBER OF VALUES OF WATER CONTENT, FOR WHICH K IS CALCULATED =

MAXIMUM CONDUCTIVITY (SAT. COND.) = 0.50000E-06 \( \text{K/s} \)

THE VALUES OF \( \Theta_M \) ARE THE MIDPOINTS OF EACH INCREMENT TO WHICH THE VALUES OF PP(I) CORRESPOND ACCORDING TO EXPERIMENTAL DATA.

THE \( \log_{10} \) VALUE OF PP(I) AND PH(I) CORRESPOND TO THE VALUE OF \( \Theta_M(I) \)

<table>
<thead>
<tr>
<th>( \Theta(I) )</th>
<th>( \Theta_M(I) )</th>
<th>PP(I) (M)</th>
<th>( \log_{10} ) PP(I)</th>
<th>PH(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12</td>
<td>0.11</td>
<td>-3000.00</td>
<td>3.48</td>
<td>0.01</td>
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<tr>
<td>0.10</td>
<td>0.09</td>
<td>-6000.00</td>
<td>3.78</td>
<td>0.64</td>
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<tr>
<td>0.08</td>
<td>0.07</td>
<td>-10000.00</td>
<td>4.00</td>
<td>0.49</td>
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<tr>
<td>0.06</td>
<td>0.05</td>
<td>-16000.00</td>
<td>4.20</td>
<td>0.32</td>
</tr>
<tr>
<td>0.04</td>
<td>0.03</td>
<td>-29000.00</td>
<td>4.46</td>
<td>0.13</td>
</tr>
<tr>
<td>( \theta (I) )</td>
<td>RELCOH (I)</td>
<td>COND (I)</td>
<td>LOG10 COND (I)</td>
<td></td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
<td>----------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td>0.4260</td>
<td>0.1000E+01</td>
<td>0.5000E-06</td>
<td>-6.29</td>
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<tr>
<td>0.4000</td>
<td>0.1111E+00</td>
<td>0.5503E-07</td>
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<tr>
<td>0.3800</td>
<td>0.1746E-01</td>
<td>0.8728E-03</td>
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<tr>
<td>0.3600</td>
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<td>0.1694E-04</td>
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<tr>
<td>0.3400</td>
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<td>0.3065E-09</td>
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<tr>
<td>0.3200</td>
<td>0.1932E-03</td>
<td>0.9155E-10</td>
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<tr>
<td>0.3000</td>
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<td>0.3591E-10</td>
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<tr>
<td>0.2800</td>
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<td>0.1240E-10</td>
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<tr>
<td>0.2600</td>
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<td>0.4196E-11</td>
<td>-11.38</td>
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<tr>
<td>0.2400</td>
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<tr>
<td>0.2200</td>
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<td>0.3265E-12</td>
<td>-12.49</td>
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<tr>
<td>0.2000</td>
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<td>0.6311E-13</td>
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<tr>
<td>0.1800</td>
<td>0.2527E-07</td>
<td>0.1263E-13</td>
<td>-13.90</td>
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<tr>
<td>0.1600</td>
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<tr>
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<td>0.6033E-15</td>
<td>-15.22</td>
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<tr>
<td>0.1200</td>
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<td>0.1411E-15</td>
<td>-15.85</td>
<td></td>
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<tr>
<td>0.1000</td>
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<td>0.3566E-16</td>
<td>-16.45</td>
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<tr>
<td>0.0800</td>
<td>0.1843E-10</td>
<td>0.9215E-17</td>
<td>-17.04</td>
<td></td>
</tr>
<tr>
<td>0.0600</td>
<td>0.3734E-11</td>
<td>0.1867E-17</td>
<td>-17.73</td>
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<td>0.0400</td>
<td>0.7961E-12</td>
<td>0.3980E-18</td>
<td>-18.70</td>
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</table>
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(0.070, -1000.00), ...
(0.090, -600.00), ...
(0.110, -300.00), ...
(0.130, -150.00), ...
(0.150, -70.00), ...
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(0.190, -16.00), ...
(0.210, -7.00), ...
(0.230, -3.00), ...
(0.250, -1.00), ...
(0.270, -0.00), ...
(0.290, -0.00), ...
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(0.380, 0.8728055E-08), ...
(0.400, 0.5553067E-07), ...
(0.420, 0.3000000E-06), ...

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