HYDROL-INF Modeling System

User's Manual

Version 6.10

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Introduction to HYDROL-INF Version 6.10

A modified Green-Ampt infiltration-runoff model (Chu and Mariño, 2005) is the central part of the Windows-based HYDROL-INF. A new algorithm is proposed for determining the ponding condition, simulating infiltration into a layered soil profile of arbitrary initial water distributions under unsteady rainfall, and partitioning the rainfall input into infiltration and surface runoff. Two distinct periods, pre-ponding and post-ponding, are taken into account. The model tracks the movement of the wetting front along the soil profile, checks the ponding status, and, in particular, handles the shift between ponding and non-ponding conditions. Furthermore, the model has been extended to complex rainfall patterns that include both wet time periods with unsteady rainfall and dry time periods without rainfall. In addition, the SCS-CN model is also included in the Windows system and some useful hydrologic tools have been developed and incorporated in HYDROL-INF.

Funded by the National Science Foundation, this new version of HYDROL-INF is developed based on the previous one. Particularly, the modified Green-Ampt model in this new HYDROL-INF accounts for the hydraulic effects of surface ponded water on infiltration and unsaturated flow.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. EAR-0907588. The new verion of HYDROL-INF has been incorporated into the P2P Modeling System as a part of the NSF-funded project, titled “CAREER: Microtopography-Controlled Puddle-filling to Puddle-merging (P2P) Overland Flow Mechanism: Discontinuity, Variability, and Hierarchy.” Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

It is gratefully acknowledged that permissions to use some published data for estimating model input parameters have been granted by the Food and Agriculture Organization of the United Nations (FAO) and the American Society of Agricultural Engineers (ASAE). Special thanks also to the students in the Watershed Modeling class (CE 476/676) at North Dakota State University and the Hydrology class (NRM 680-A) at Grand Valley State University, for testing the software and providing their feedbacks that have been incorporated in this new version. This software also has been used in the Fluid Mechanics class (CE 309) at North Dakota State University.

Notes for Windows Vista and Windows 7 Users

The compatibility of HYDROL-INF with the Windows Vista and Windows 7 operating systems has been tested. It works well in both new Windows systems. But, two issues have been noticed:

1. Due to the use of higher security technologies, Windows Vista and Windows 7 do not allow any application programs to copy and write files to the folder: C:\Program

Files. Thus, users cannot select any folder within C:\Program Files as their working directory.

2. The Help files in the software require the Windows Help (WinHlp32.exe) program. Starting with the release of Windows Vista and Windows Server 2008, Microsoft has decided to no longer include in WinHlp32.exe as a component of the Windows operating system. For details, please refer to: http://support.microsoft.com/kb/917607

   Solution: Users need to download and install WinHlp32.exe.

   For the Windows Vista operating system, the Windows Help program is available at:

   http://go.microsoft.com/fwlink/?LinkID=82148.

   For the Windows 7 operating system, please visit:

   http://www.microsoft.com/downloads/details.aspx?familyid=258AA5EC-E3D9-4228-8844-008E02B32A2C&displaylang=en#top

Contact Information for limited technical support

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1. Installation of HYDROL-INF

Double click the file named “Setup.exe” on the CD drive and then just follow the instructions. After the installation, the HYDROL-INF software can be started from “Start” and “Programs.” One example data file (HYDROL-INF.TXT) is included in the package for testing.
If you are using the Windows Vista or Windows 7 operating system, please install the Windows Help program (WinHlp32.exe) (see the Introduction of this document).

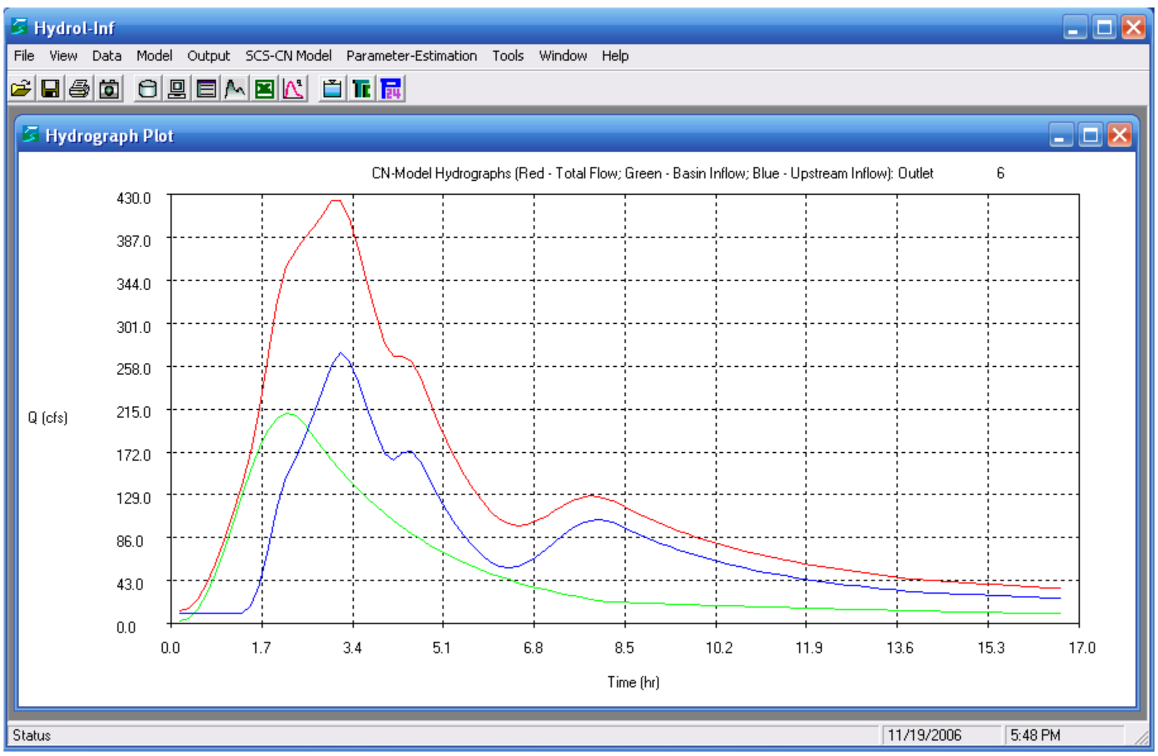
2. Instructions for Using HYDROL-INF

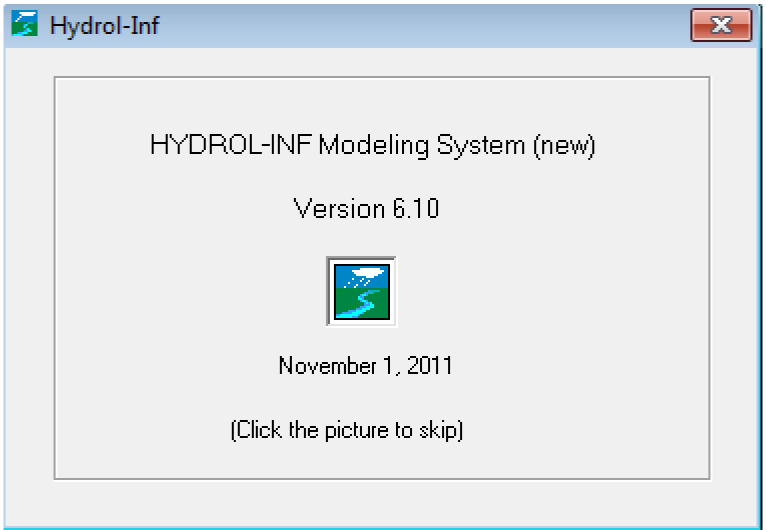
Use of the interfaced HYDROL-INF is quite simple, which includes three major steps:
Step 1: prepare all input data via menu “Data” or import data from an existing data file via menu “File-Open Data” (or button Open Data). Then save the data via menu “Save Data” (or button Save Data) or “Save As”.
Step 2: check data and run the model via menus “Model-Check Data” and “Model-Run” (or button Check Data and button Run Model). All time-dependent data, such as rainfall, can be input manually or imported from an existing text or excel file. The data can also be exported to a file.
Step 3: Conduct post-processing via menu “Output.” The water mass balance table and graphs of incremental and cumulative rainfall, infiltration, and runoff can be shown via the menu “Water Mass Balance Table” (or button Output Table) and the menu “Rainfall/Infiltration/Runoff Graph” (or button Output Graphs) These outputs can also be exported to Microsoft Excel for further processing (either spreadsheets or graphs) via the menu “Water Mass Balance Excel” (or button Transfer Output to Excel). The graphs can be printed out using menu “File-Print Graph” (or button Print Graph). A graph on the screen can be captured and copied to Clipboard. Additionally, a water table for the surface zone and vadose zone, soil water content, soil water flow velocity, as well as detailed model output information can also be shown via menus. All text-formatted input data and the simulated outputs can be opened and printed via menu “File-Print a Text File.”

3. Overview of the HYDROL-INF Interface

3.1. Main Interface

The HYDROL-INF menus are organized according to the three fundamental modeling steps: Data, Model, and Output. The SCS-CN model can be accessed via the menu SCS-CN Model. The menu "Parameter-Estimation" is a special component, which serves as a database and helps users to estimate all input data. It provides explanation and estimation methods for all parameters. It also provides a number of links to some existing databases. Additionally, some hydrologic tools/calculators have been incorporated in the modeling system. The help system covers all information related to the three major modeling steps as well as the HYDROL-INF documentation.



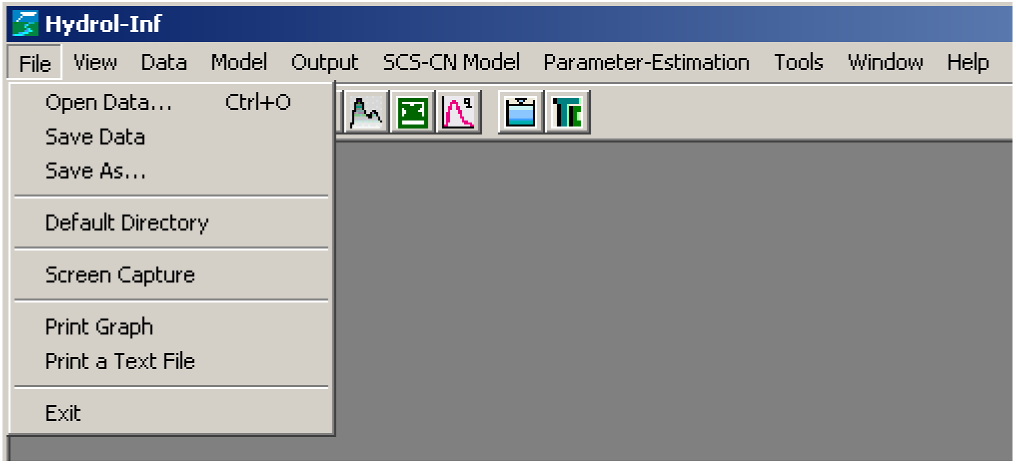


3.2. Tool Bar

The buttons in the tool bar (from left to right) are Open Data, Save Data, Print Graph, Screen Capture, Check Data, Run Model, Output Table, Output Graphs, Transfer Output to Excel, Hydrograph, Computation of Measured Flow, and Time of Concentration Calculator.

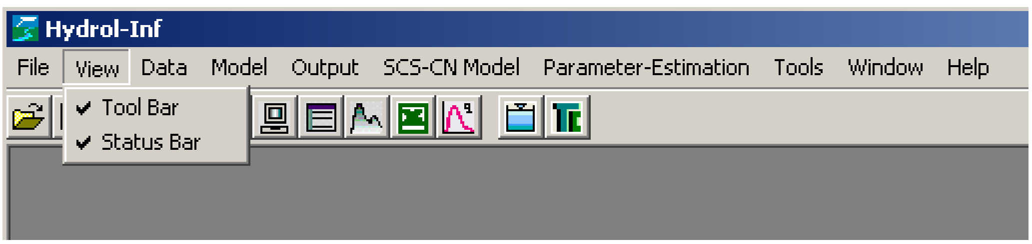
3.3. File

Open Data (button Open Data): Open an existing data file
Save Data (button Save Data): Save the current data
Save As: Save the current data to a user-specified data file
Default Directory: Specify a working directory. The default directory is "C:\HYDROL-INF\".
Screen Capture (button Screen Capture): Copy a screen image, such as a graph to Clipboard.
Print Graph (button Print Graph): Print the current graph.
Print a Text File: Open and print a text-formatted input/output file.
Exit: Exit the HYDROL-INF.



3.4. View

Tool Bar: Show/hide the toolbar.
Status Bar: Show/hide the status bar.



3.5. Data

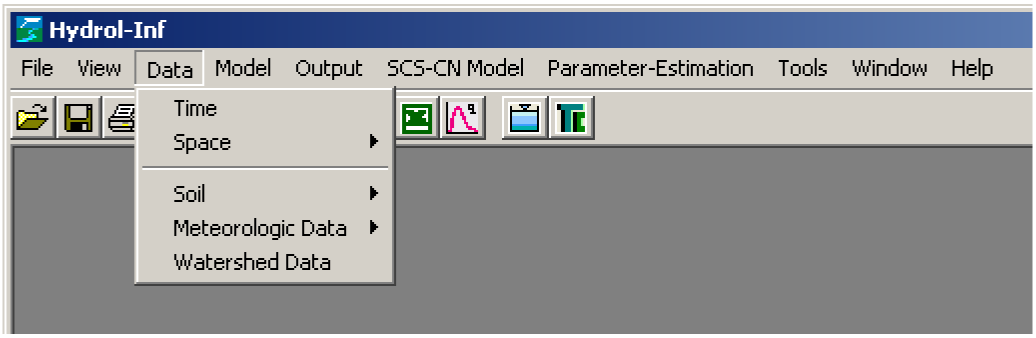
Time: Time-related parameters.
Space: Space-related parameters.
- Space Parameters
- Number of Cells in Each Soil Layer
- Thickness of a Soil Layer

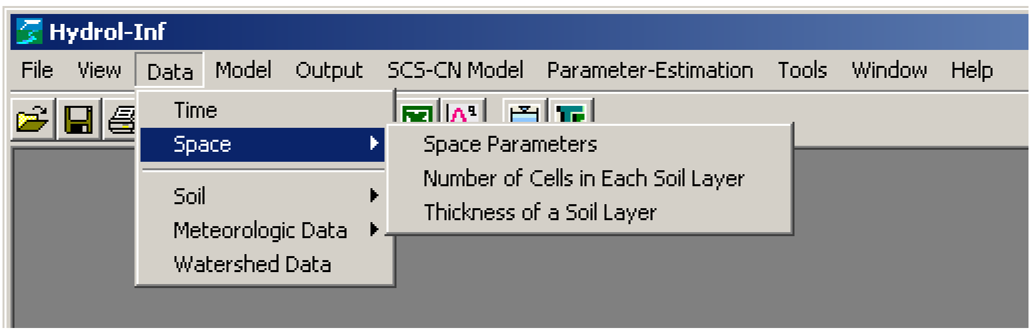
Soil: Soil-related parameters.
- Saturated Hydraulic Conductivity KS
- Effective Hydraulic Conductivity KE
- Capillary Head (Suction) HWT
- Saturated Water Content WS
- Residual Water Content WR
- Soil Retention Parameter (n) VN
- Soil Retention Parameter (α) ALF
- Field Capacity FC
- Wilting Point WP
- Initial Water Content W0

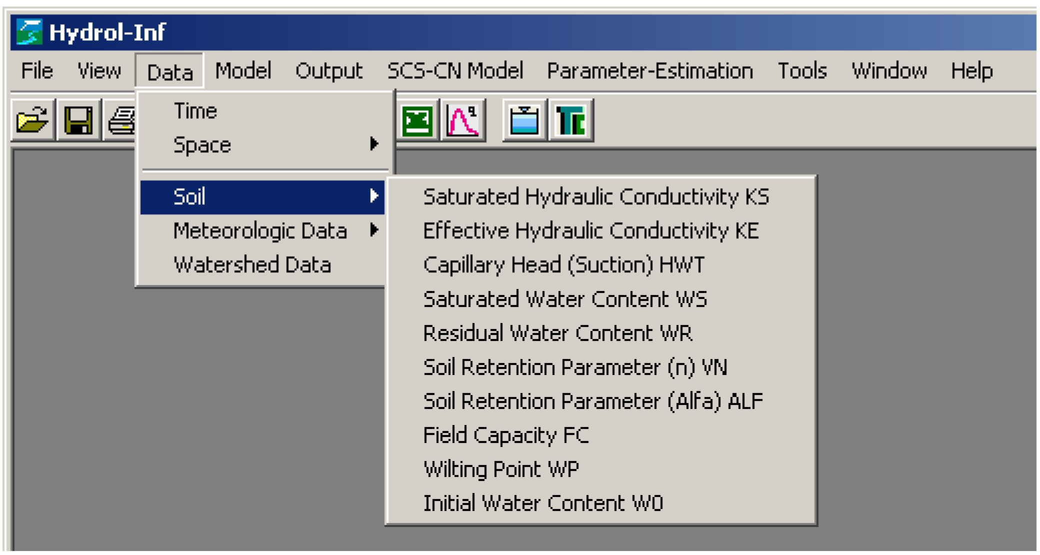
Meteorological Data:

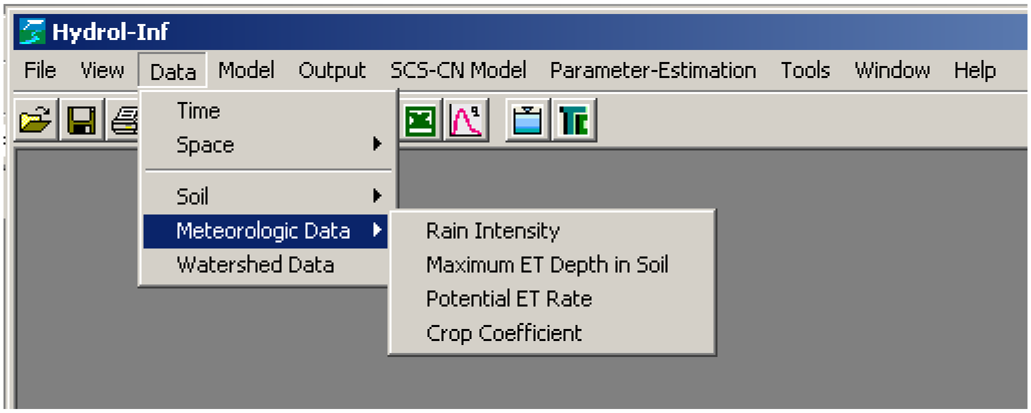
<u>Rainfall Intensity</u> (time-dependent data)
<u>Maximum ET Depth in Soil</u>
<u>Potential ET Rate</u> (time-dependent data)
<u>Crop Coefficient</u> (time-dependent data)

<u>Watershed Data</u>:



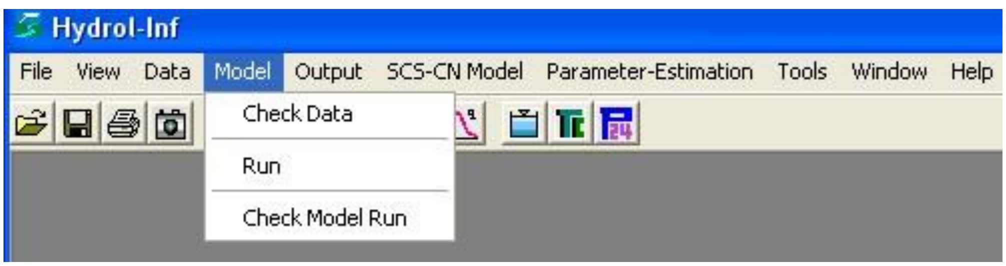






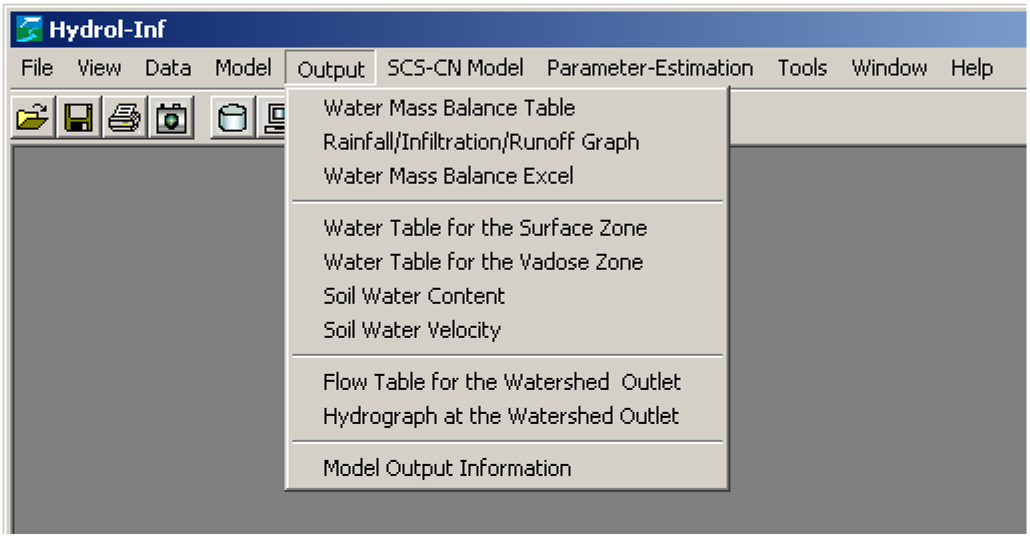
3.6. Model

Check Data (button Check Data): Check all input data.
Run (button Run Model): Execute the model.
Check Model Run: Check if the model run is successful.

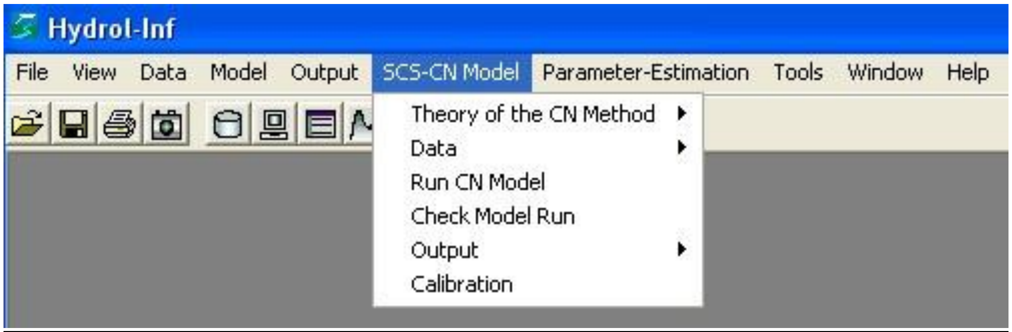


3.7. Output

Water Mass Balance Table (button Output Table)
Rainfall/Infiltration/Runoff Graph (button Output Graphs)
Water Mass Balance Excel (button Transfer Output to Excel)
Water Table for the Surface Zone
Water Table for the Vadose Zone
Soil Water Content
Soil Water Flow Velocity
Flow Table for the Watershed Outlet
Hydrograph at the Watershed Outlet
Model Output Information



3.8. SCS-CN Model


Hydrol-Inf
File
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Output
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Parameter-Estimation
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Theory of the CN Method
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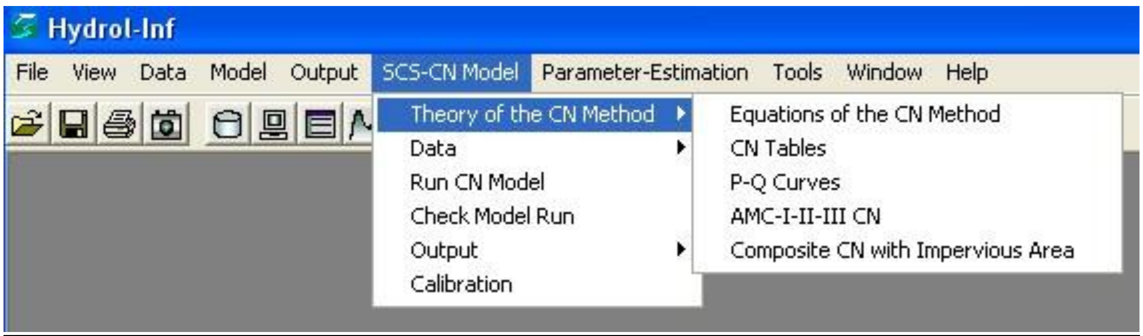
Run CN Model
Check Model Run
Output
Calibration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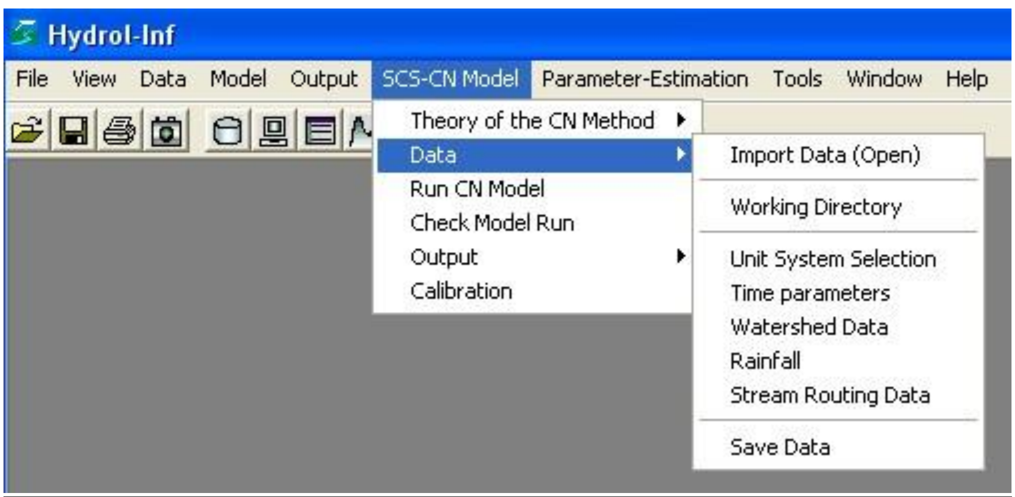
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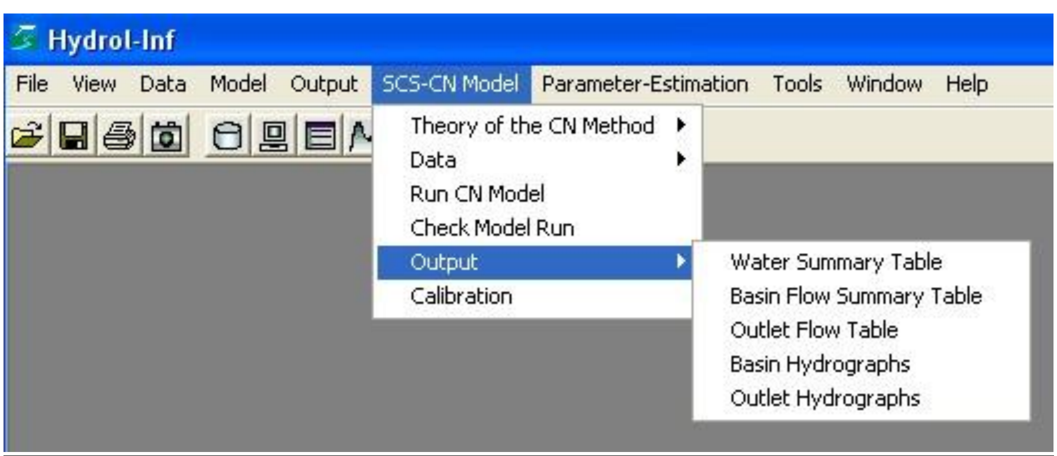
Working Directory
Unit System Selection
Time parameters
Watershed Data
Rainfall
Stream Routing Data
Save Data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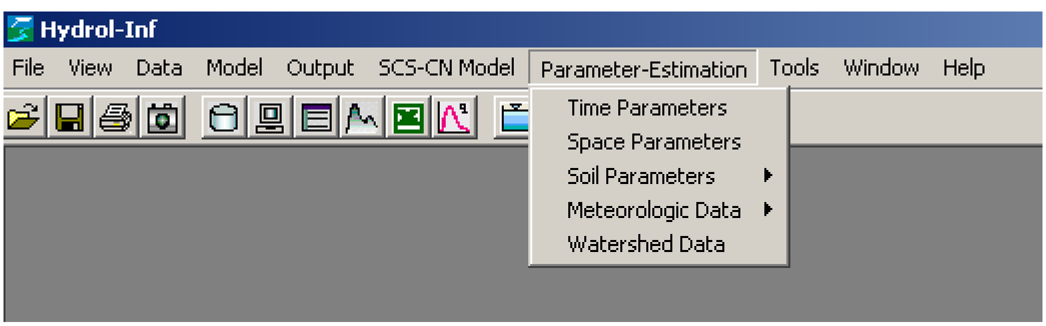
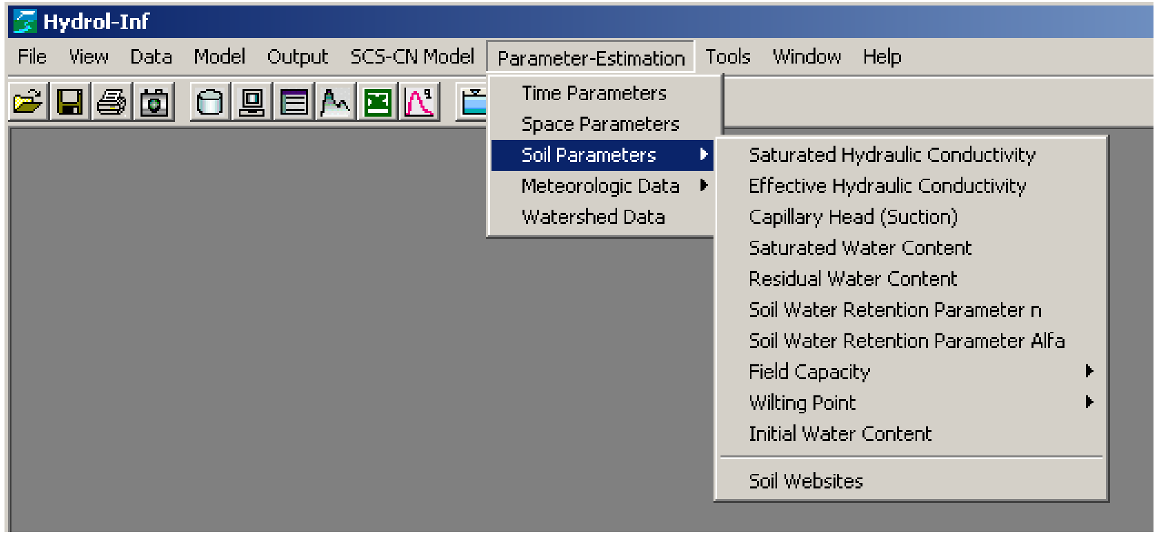
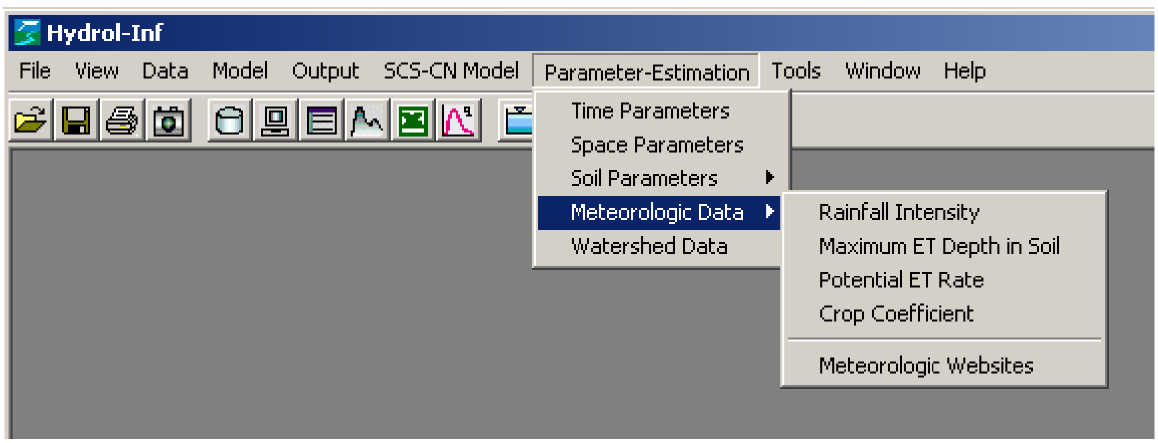
Data
Model
Output
SCS-CN Model
Parameter-Estimation
Tools
Window
Help
Theory of the CN Method
Data
Run CN Model
Check Model Run
Output
Calibration
Water Summary Table
Basin Flow Summary Table
Outlet Flow Table
Basin Hydrographs
Outlet Hydrographs

3.9. Parameter-Estimation

- Time Parameters:
- Space Parameters:
- Soil Parameters:
  - Saturated Hydraulic Conductivity
  - Effective Hydraulic Conductivity
  - Capillary Head (Suction)
  - Saturated Water Content
  - Residual Water Content
  - Soil Water Retention Parameter n
  - Soil Water Retention Parameter α
  - Field Capacity
    - Table
    - Figure
  - Wilting Point
    - Table
    - Figure
  - Initial Water Content
  - Soil Websites
- Meteorologic Parameters:
  - Rainfall Intensity
  - Maximum ET Depth in Soil
  - Potential ET Rate
  - Crop Coefficient
  - Meteorologic Websites
- Watershed Data:

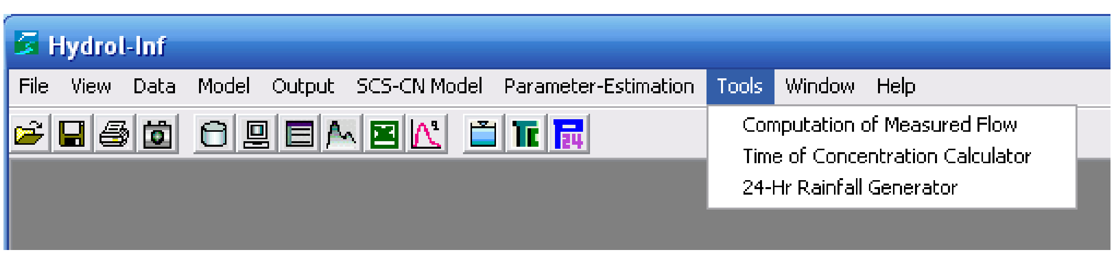






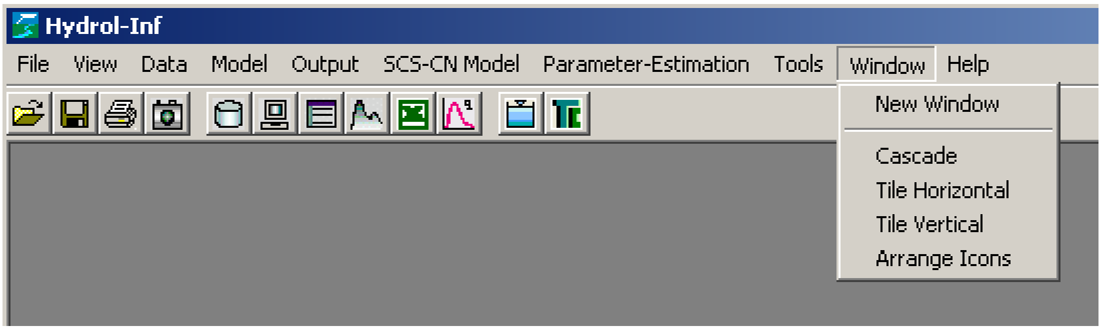
3.10. Tools

<u>Computation of Measured Flow (button)</u>:
<u>Time of Concentration Calculator (button)</u>:
<u>24-Hour Rainfall Generator (button)</u>:



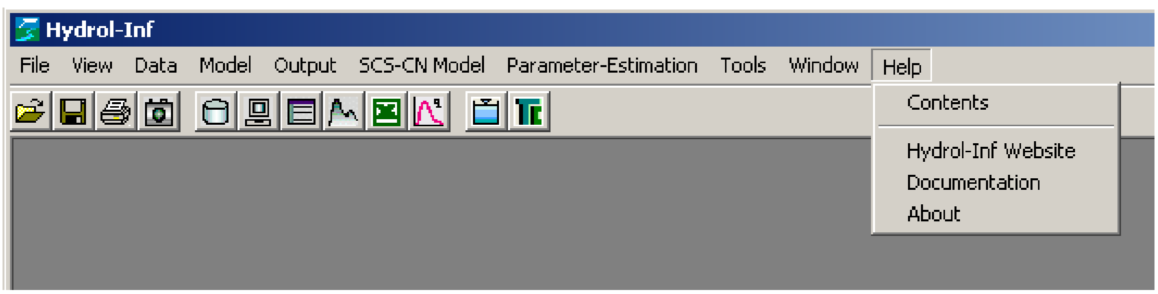
3.11. Window

New Window:
Cascade:
Tile Horizontal:
Tile Vertical:
Tile Horizontal:
Arrange Icons:



3.12. Help

Contents:
Hydrol-Inf Website:
Documentation:
About:



4. File Management

4.1 Open an Existing Data File

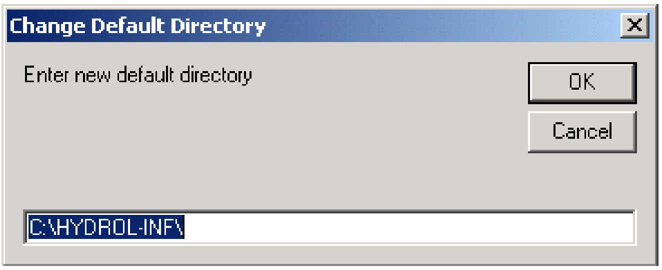
If a data file already exists, you can open the file and import all data through menu File-Open Data or button Open Data in the toolbar. When you open an input data file from a directory, that directory will be automatically set as your working directory.

4.2 Save Your Input Data

Save your current input data using menu File-Save Data or button Save Data in the toolbar. The default data file name is "HYDROL-INF.TXT" that will be saved in the default directory (C:\HYDROL-INF) unless you specify a different working directory. Whenever you modify the data, you need to save the data before running the model. The current data can also be saved to a user-specified directory and file name by using menu File-Save As. That directory will be set as your working directory.

4.3 Change the Default Directory

The default project directory of HYDROL-INF is "C:\HYDROL-INF\". You can change it and specify your own project directory through menu File-Default Directory. Then your input data and all output files will be stored in that directory.



4.4 Capture a Screen Picture and Copy It to Clipboard

You can make a screen capture and copy the graph/text image to clipboard. Then you can paste it to anywhere, such as your Word Document and Powerpoint presentation.

4.5 Print a Graph

After creating a graph (e.g., rainfall/infiltration/runoff graph), you can print it through menu File-Print Graph or button Print Graph in the toolbar. You are also able to select your printer, specify its properties, as well as paper size and orientation. Note that this menu works only when a graph window is active.

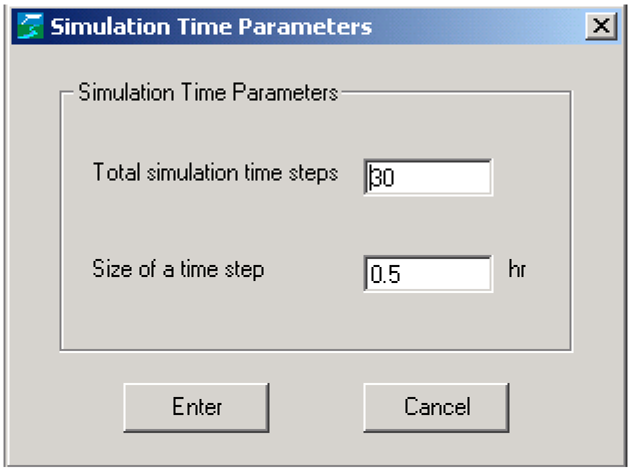
4.6 Print a Text File (any input data and output files)

Using menu File-Print a Text File, you can open and print a text file (any input data and output files).

5. Input Data and Parameter Estimation

5.1 Time Parameters

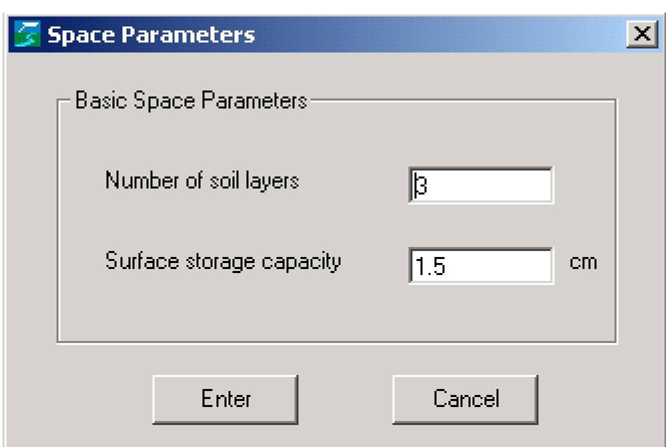
Total simulation time steps: NT (In the current program, NT_{max}=15000)
Size of a time step (hr): DT

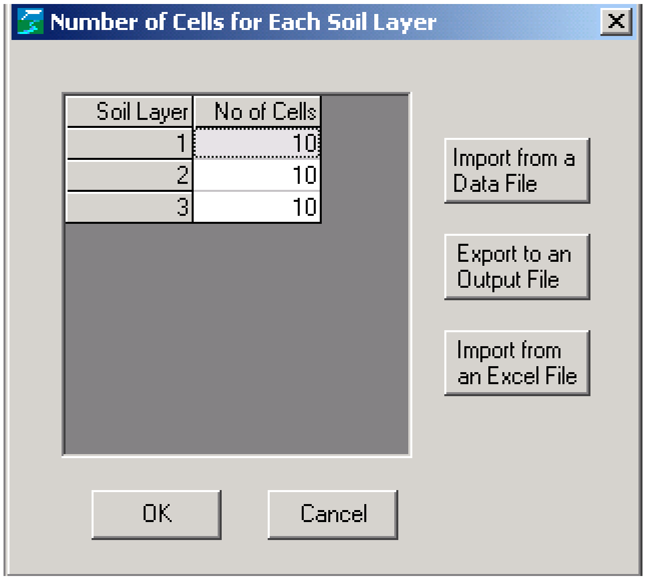


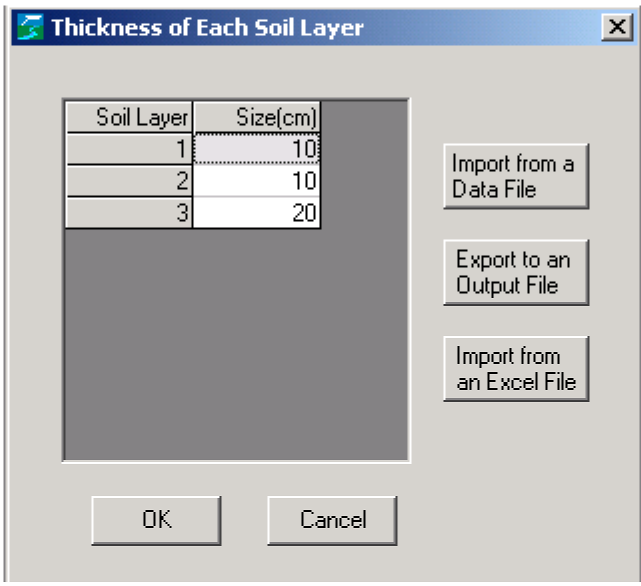
5.2 Space Parameters

Number of soil layers: NL (In the current program, NL_{max} = 50)
Number of cells for each soil layer: NC(I) (In the current program, the maximum number of the total soil cells is set as 1000)
Thickness of each soil layer (cm): ZNL(I)
Surface storage capacity (cm): SSMAX

Based upon soil properties, the entire soil profile is divided into a number of soil layers. Each soil layer further consists of computation cells.



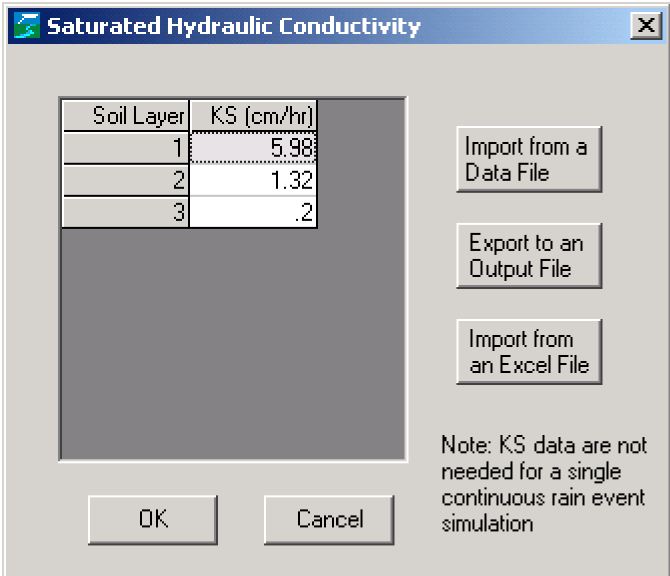




5.3 Soil Parameters

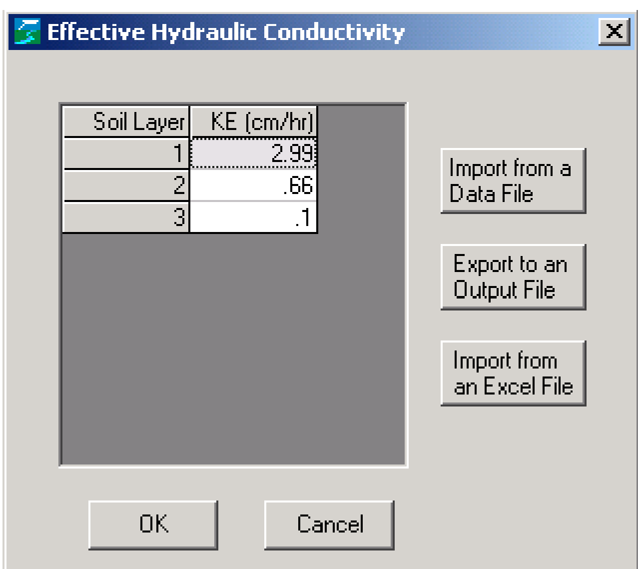
5.3.1 Saturated Hydraulic Conductivity

Saturated Hydraulic Conductivity (cm/hr): KS
Input KS value for each soil layer. KS can be estimated using Table 1.



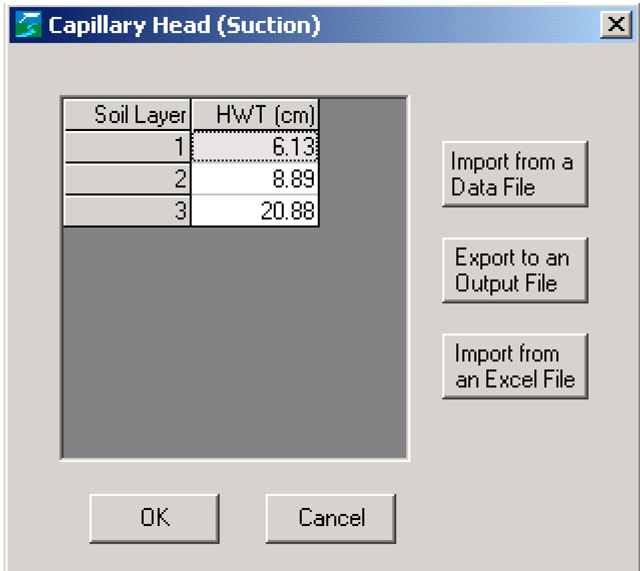
5.3.2 Effective Hydraulic Conductivity

Effective Hydraulic Conductivity (cm/hr): KE
Input KE value for each soil layer. KE can be estimated from KS using Table 1.



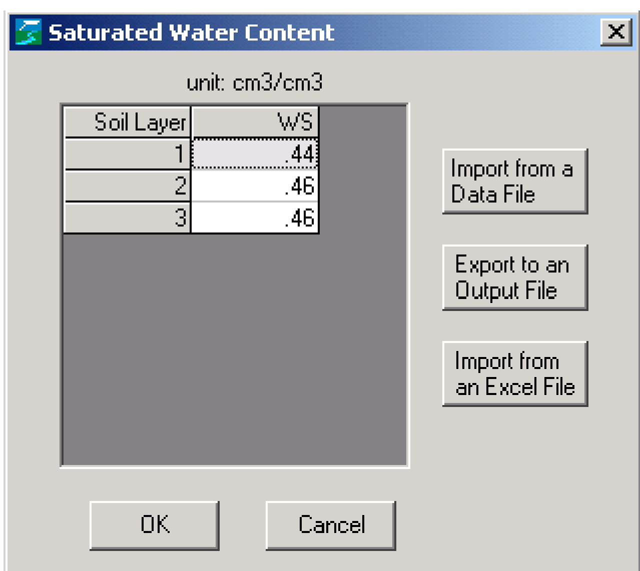
5.3.3 Capillary Head (Suction)

Capillary Head (Suction) (cm): HWT
Input HWT value for each soil layer. HWT can be estimated using Table 2.



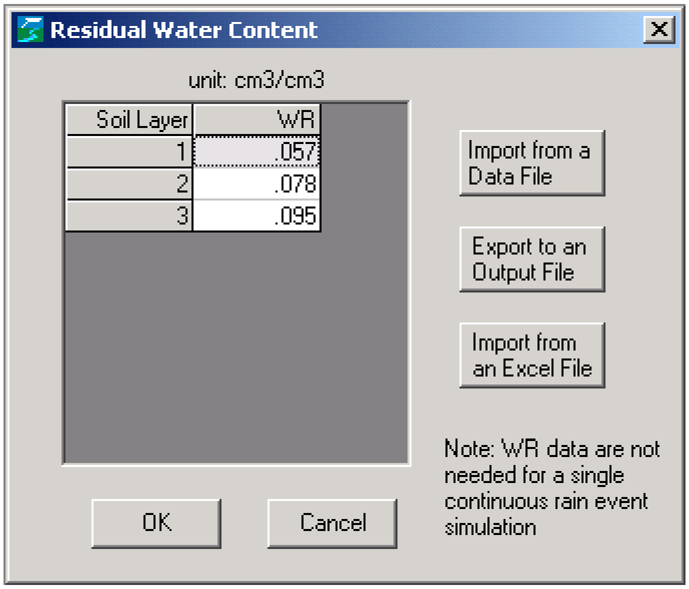
5.3.4 Saturated Water Content

Saturated Water Content (cm^3/cm^3): WS
Input WS value for each soil layer. WS can be estimated using Table 3.



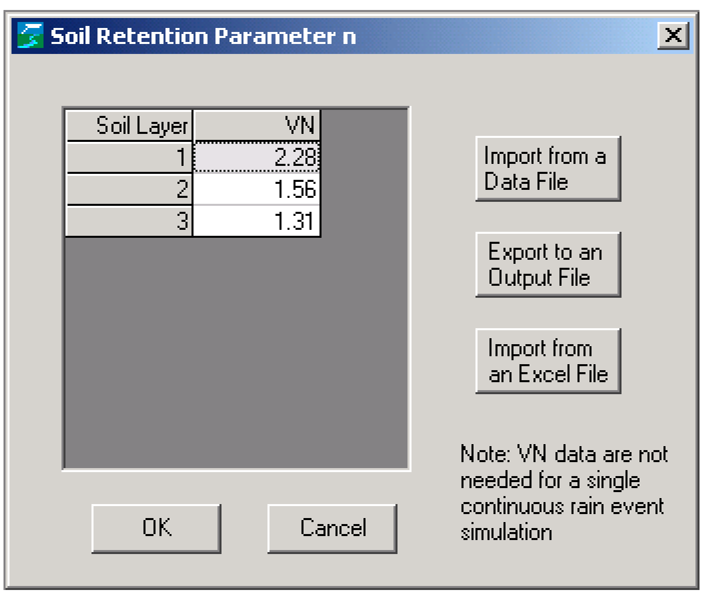
5.3.5 Residual Water Content

Residual Water Content (cm^3/cm^3): WR
Input WR value for each soil layer. WR can be estimated using Table 4.



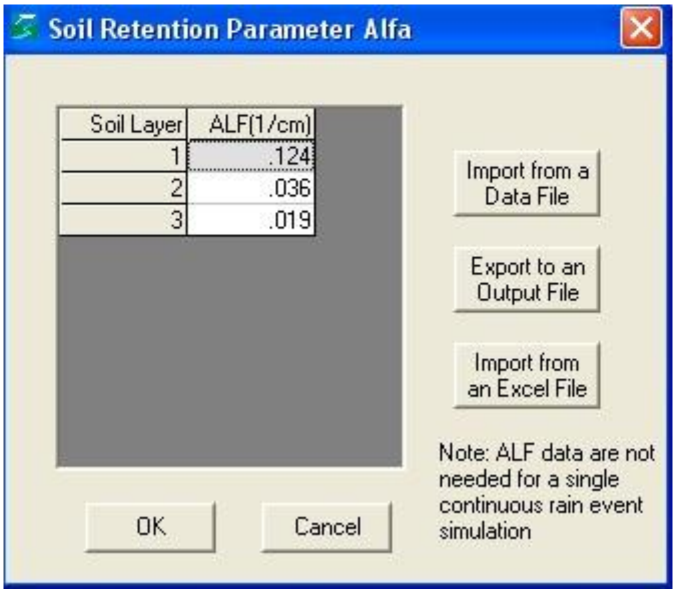
5.3.6 Soil Water Retention Parameter n

Soil Water Retention Parameter n: VN
"n" is a soil water retention parameter in the van Genuchten model. Input VN values for both surface/root zone and deep vadose zone. VN can be estimated by using Table 5.



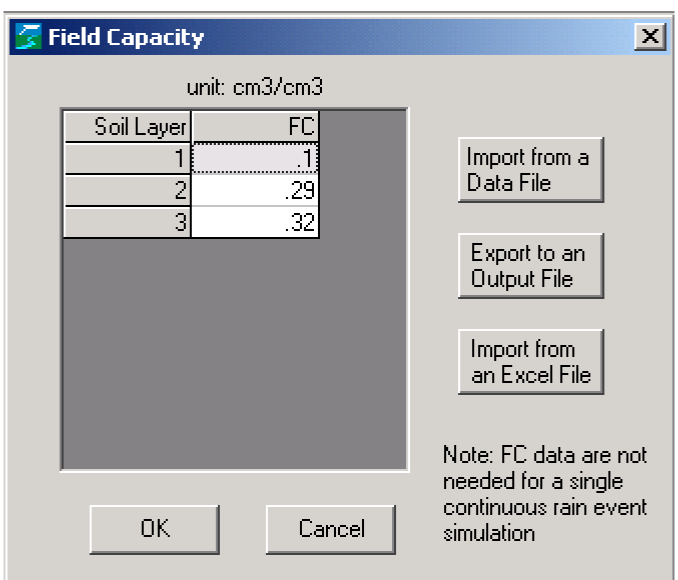
5.3.7 Soil Water Retention Parameter α

Soil Water Retention Parameter α (1/cm): ALF
"α" is a soil water retention parameter in the van Genuchten model. Input ALF value for each soil layer. ALF can be estimated using Table 6.



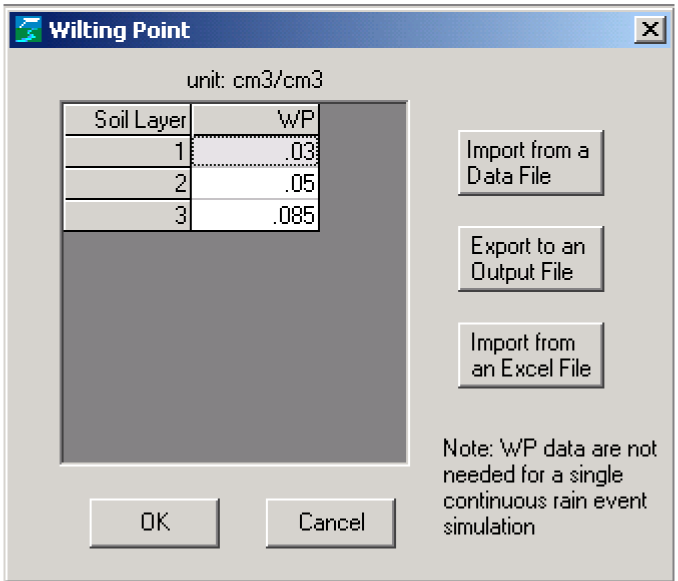
5.3.8 Field Capacity

Field Capacity (cm^3/cm^3): FC
Input FC value for each soil layer. FC can be estimated using Table 7. FC can also be estimated by using Figure 1 (Source: Carsel et al. 2003)



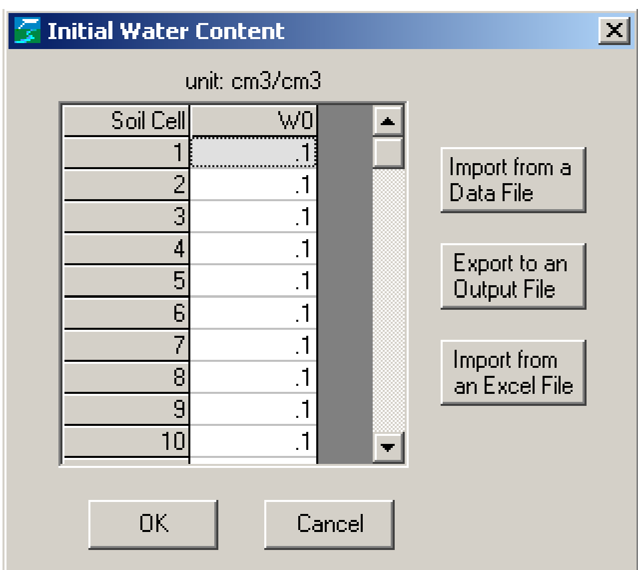
5.3.9 Wilting Point

Wilting Point (cm^3/cm^3): WP
Input WP values for each soil layer. WP can be estimated by using Table 8. WP can also be estimated by using Figure 2 (Source: Carsel et al. 2003).



5.3.10 Initial Water Content

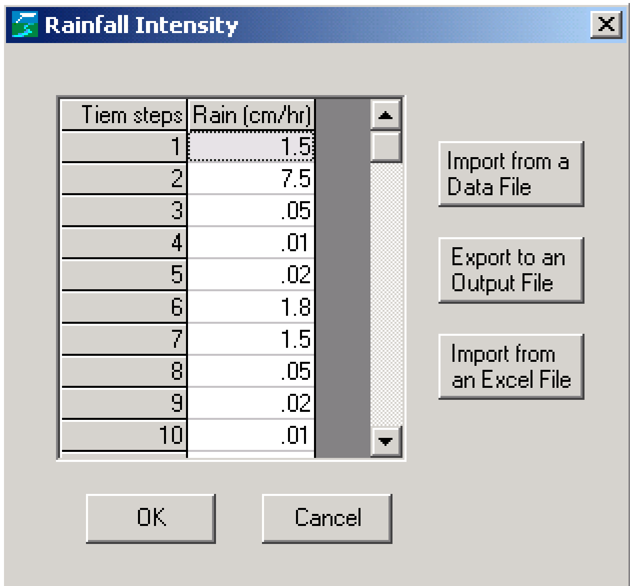
Initial Water Content (cm^3/cm^3): W0
Initial water content represents the average soil moisture condition in each discretized soil cell at the initial simulation time (t = 0).
Input W0 values for each soil cell.



5.4 Meteorologic Data

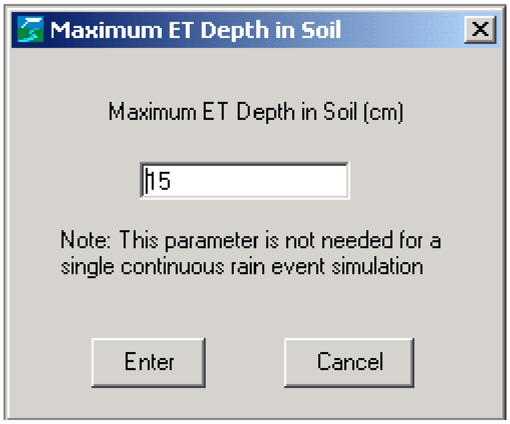
5.4.1 Rainfall Intensity

Rainfall Intensity (cm/hr): RAINS
Rainfall intensity data are needed in the model. The data can be obtained from government agencies' climate centers, such as NOAA National Climatic Data Center (NCDC) and USDA-NRCS National Water and Climate Center (PRISM). Links to these websites can be found in menu Parameter Estimation.



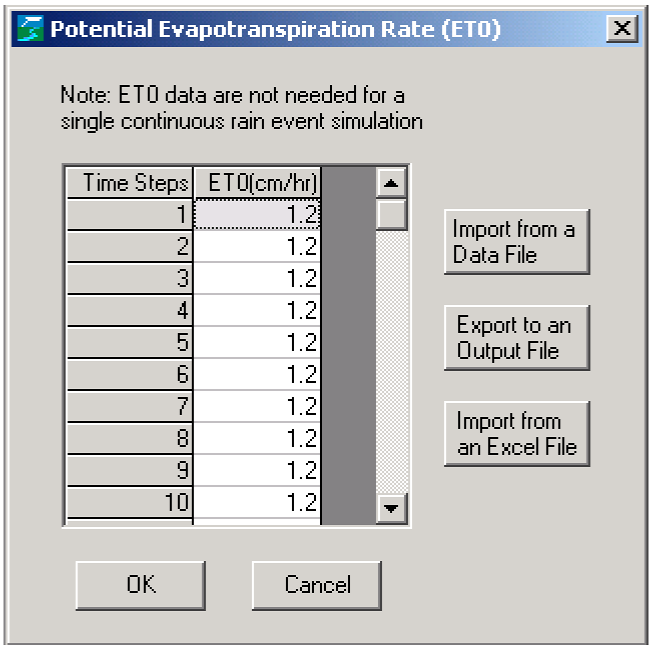
5.4.2 Maximum ET Depth in Soil

Maximum ET Depth in Soil (cm): DMET
The maximum ET depth in soil is generally equal to the maximum depth of the crop root zone. The value depends on crop types.



5.4.3 Potential Evapotranspiration Rate

Potential Evapotranspiration Rate (cm/hr): ET0
Potential evapotranspiration rate data are needed in the model. The data can be obtained from government agencies' climate centers, such as NOAA National Climatic Data Center (NCDC) and USDA-NRCS National Water and Climate Center (PRISM). Links to these websites can be found in menu Parameter Estimation.

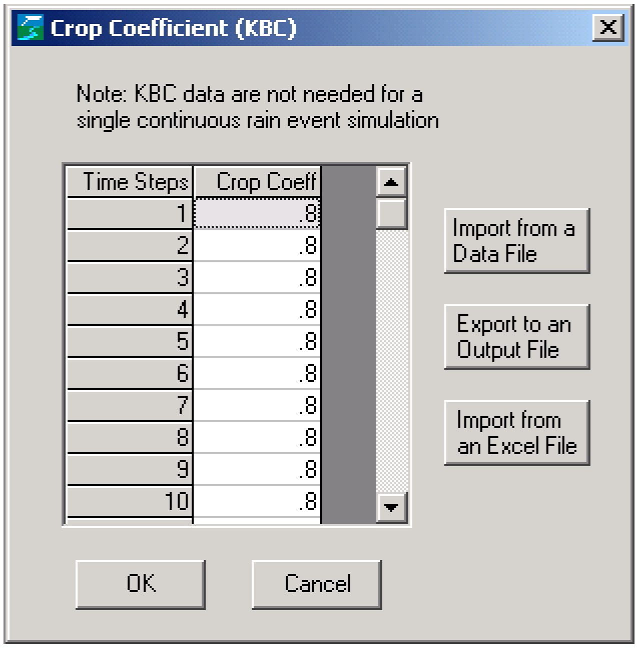


5.4.4. Crop Coefficient

Crop Coefficient: KBC
Crop coefficient is the ratio of actual crop evapotranspiration ET_c to the standard reference crop evapotranspiration (potential evapotranspiration) ET_0.

$$KBC = ET_c/ET_0$$

The value of KBC can change with crop types and stages of crop growth. The KBC value is small during the initial crop stage, often less than 0.4. The value increases with rapid plant development and reaches a maximum value at the time of maximum or near maximum plant development (it generally ranges from 1.0 to 1.2). As leaves begin to age during the late period, the value begins to decease until it reaches a lower value at the end of the growing period (Allen et al., 1998). The FAO Paper 56 (Allen et al., 1998) provides details on how to determine the crop coefficient. Users can access this reference via the menu Plant Websites. Single (time-averaged) crop coefficients for three typical stages of crop growth (initial, mid, and end) and mean maximum plant heights for non stressed, well-managed crops in subhumid climates (RHmin ≈ 45%, u2 ≈ 2 m/s) can be found from Table 9 (Note: following the original notation, Kc denotes crop coefficient in this table).



5.5 Watersed Data

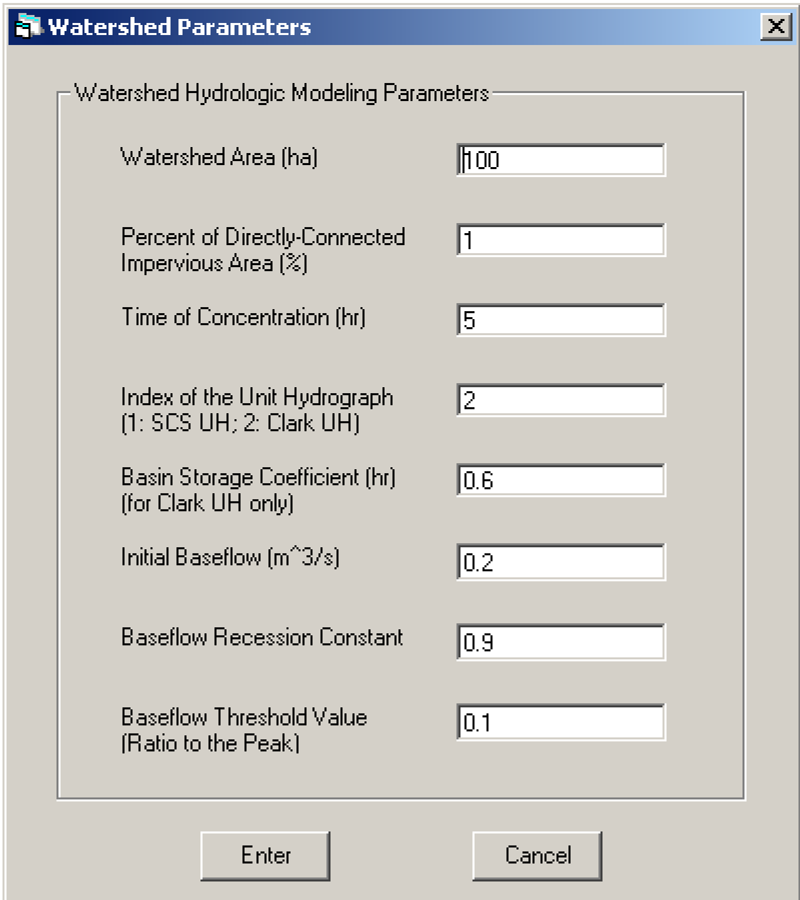
Watershed area (ha): AHA
Percentage of directly-connected impervious area (%): IMP
Time of concentration (hr): TC
Index of the unit hydrograph (1: SCS UH; 2: Clark UH): IUH
Basin storage coefficient in the Clark UH (hr): RC
Initial baseflow (m^3/s): QB0
Baseflow recession constant: RB
Baseflow threshold value (ratio to the peak): RTHRE

Note that RC is required for the Clark unit hydrograph method only.

For watershed modeling, two unit hydrograph techniques (SCS UH and Clark UH) are available for selection. Baseflow is simulated by using the recession method as follows:

$$Q_B = Q_{B0}\, r_B^t$$

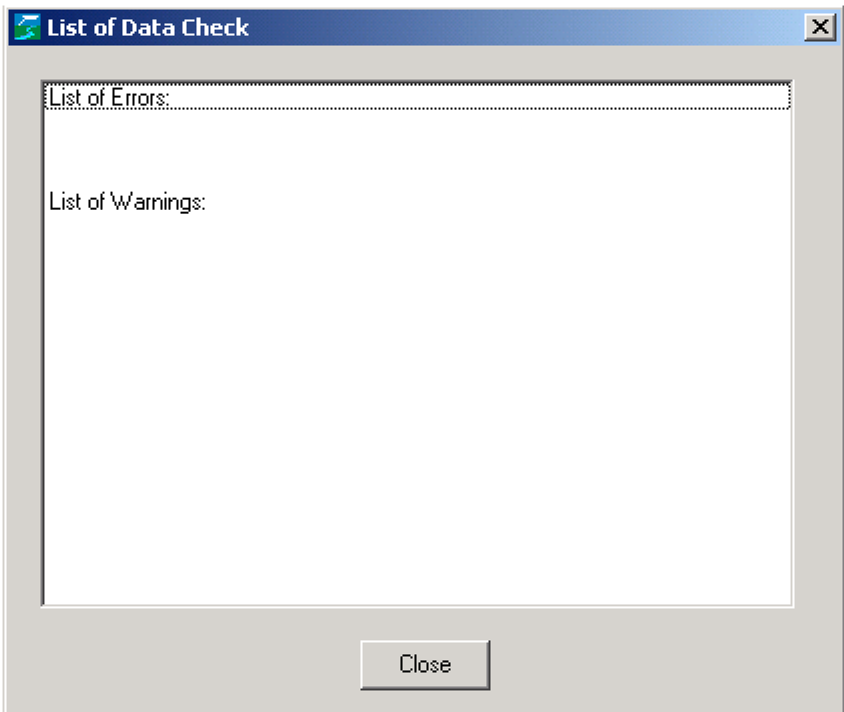
where Q_{B0} = initial baseflow; r_B = daily recession constant; and t = time (hr). Baseflow is constant (Q_{B0}) for r_B = 1. Note that the recession constant is dependent on the unit of time (Maidment 1993, page 9.5). A daily recession constant is used in this progam.


Watershed Parameters
Watershed Hydrologic Modeling Parameters
Watershed Area (ha)
100
Percent of Directly-Connected Impervious Area (%)
1
Time of Concentration (hr)
5
Index of the Unit Hydrograph (1: SCS UH; 2: Clark UH)
2
Basin Storage Coefficient (hr) (for Clark UH only)
0.6
Initial Baseflow (m^3/s)
0.2
Baseflow Recession Constant
0.9
Baseflow Threshold Value (Ratio to the Peak)
0.1
Enter
Cancel

6. Data Check and Model Execution

6.1 Data Check

To make sure that all input data and relationship of some interrelated data are in reasonable ranges, the data should be checked by menu Check Data or button Check Data in the toolbar before running the model. Then, a list of warnings and errors will be shown. It is advised that you run the model after eliminating all warnings and errors.



6.2 Model Run

Once all data are checked, the model can be executed by clicking Model-Run or button Run Model in the toolbar.

6.3 Check Model Run

Check whether or not the model run is successful.

7. Output and Post-Processing

7.1 Water Mass Balance Table and Graph

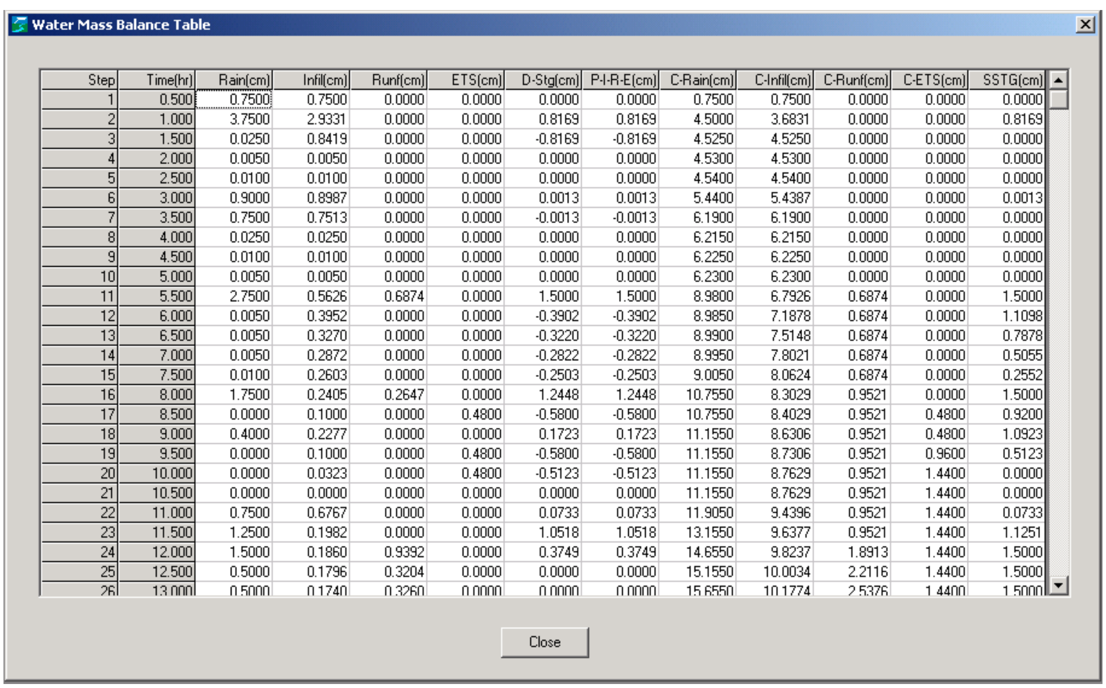
Water Mass Balance Table (button Output Table in the toolbar)
Rainfall/Infiltration/Runoff Graph (button Output Graphs in the toolbar)
Water Mass Balance Excel (button Transfer Output to Excel in the toolbar)

A water mass balance table shows incremental and cumulative rainfall (Rain, C-Rain), infiltration (Infil, C-Infil), runoff (Runf, C-Runf), and evapotranspiration from the surface water storage (ETS, C-ETS), as well as surface storage (SSTG) and the change in surface storage (D-Stg) for each time step.

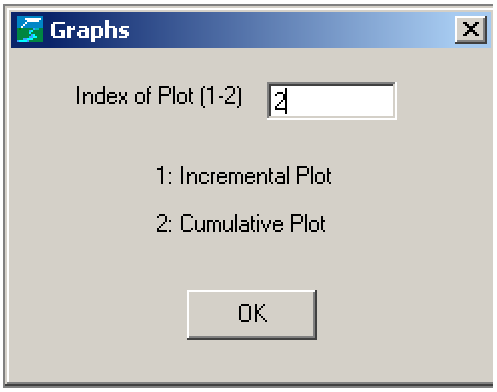
Both incremental and cumulative rainfall and the simulated infiltration and runoff can also be shown in form of graphs. A set of plot parameters will be automatically determined, which include minimum and maximum x values (time), minimum and maximum y values, number of x ticks, number of y ticks, decimal digit of marked x values, decimal digit of marked y values, index of gridlines (0 solid; 1 dash; 2 dot; 3 dash + dot; 4 dash + two dots; and 5 no gridline).

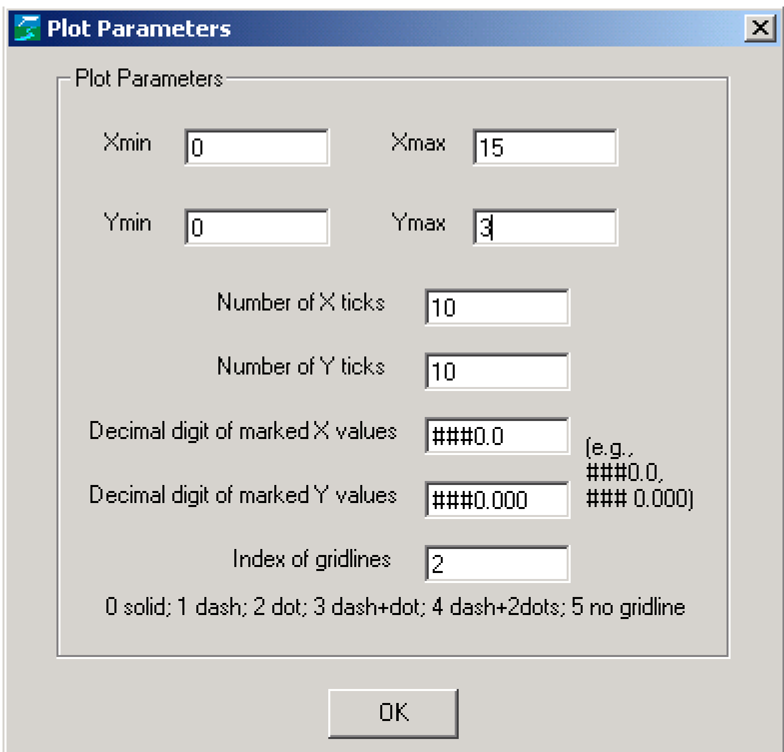
The simulated outputs can also be transferred to Microsoft Excel via menu Water Mass Balance Excel or button Transfer Output to Excel in the toolbar. Then these data can be analyzed by using Excel spreadsheet and graphs can also be created within Excel. Note that the data transfer may take a long time for a large data set.

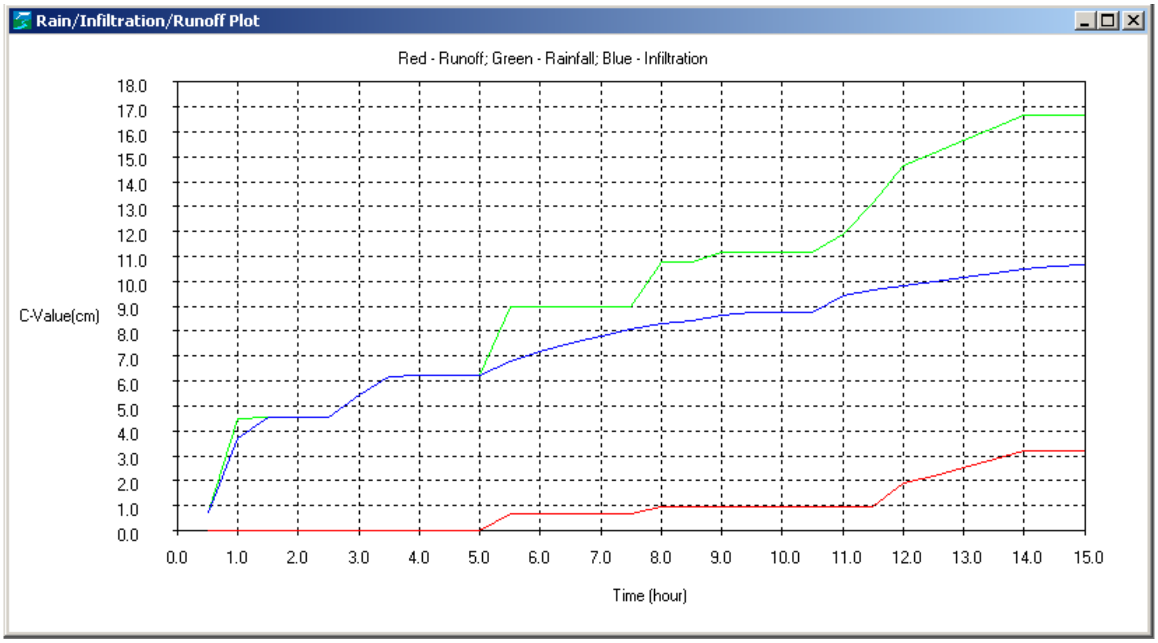
Note that the mass balance terms in the aforementioned table and graph (e.g., runoff) are the depths of water over the pervious soil area only. For watershed modeling, total depth of runoff should include the quantities from both pervious area [(1-IMP/100)A] and directly-connected impervious area [IMP/100*A].

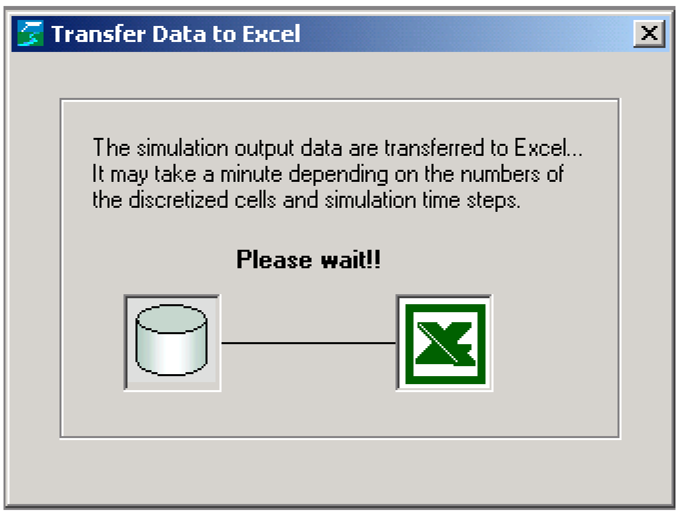


Step	Time(hr)	Rain(cm)	Infil(cm)	Runf(cm)	ETS(cm)	D-Stg(cm)	P-I-R-E(cm)	C-Rain(cm)	C-Infil(cm)	C-Runf(cm)	C-ETS(cm)	SSTG(cm)
1	0.500	0.7500	0.7500	0.0000	0.0000	0.0000	0.0000	0.7500	0.7500	0.0000	0.0000	0.0000
2	1.000	3.7500	2.9331	0.0000	0.0000	0.8169	0.8169	4.5000	3.6831	0.0000	0.0000	0.8169
3	1.500	0.0250	0.8419	0.0000	0.0000	-0.8169	-0.8169	4.5250	4.5250	0.0000	0.0000	0.0000
4	2.000	0.0050	0.0050	0.0000	0.0000	0.0000	0.0000	4.5300	4.5300	0.0000	0.0000	0.0000
5	2.500	0.0100	0.0100	0.0000	0.0000	0.0000	0.0000	4.5400	4.5400	0.0000	0.0000	0.0000
6	3.000	0.9000	0.8987	0.0000	0.0000	0.0013	0.0013	5.4400	5.4387	0.0000	0.0000	0.0013
7	3.500	0.7500	0.7513	0.0000	0.0000	-0.0013	-0.0013	6.1900	6.1900	0.0000	0.0000	0.0000
8	4.000	0.0250	0.0250	0.0000	0.0000	0.0000	0.0000	6.2150	6.2150	0.0000	0.0000	0.0000
9	4.500	0.0100	0.0100	0.0000	0.0000	0.0000	0.0000	6.2250	6.2250	0.0000	0.0000	0.0000
10	5.000	0.0050	0.0050	0.0000	0.0000	0.0000	0.0000	6.2300	6.2300	0.0000	0.0000	0.0000
11	5.500	2.7500	0.5626	0.6874	0.0000	1.5000	1.5000	8.9800	6.7926	0.6874	0.0000	1.5000
12	6.000	0.0050	0.3952	0.0000	0.0000	-0.3902	-0.3902	8.9850	7.1878	0.6874	0.0000	1.1098
13	6.500	0.0050	0.3270	0.0000	0.0000	-0.3220	-0.3220	8.9900	7.5148	0.6874	0.0000	0.7878
14	7.000	0.0050	0.2872	0.0000	0.0000	-0.2822	-0.2822	8.9950	7.8021	0.6874	0.0000	0.5055
15	7.500	0.0100	0.2603	0.0000	0.0000	-0.2503	-0.2503	9.0050	8.0624	0.6874	0.0000	0.2552
16	8.000	1.7500	0.2405	0.2647	0.0000	1.2448	1.2448	10.7550	8.3029	0.9521	0.0000	1.5000
17	8.500	0.0000	0.1000	0.0000	0.4800	-0.5800	-0.5800	10.7550	8.4029	0.9521	0.4800	0.9200
18	9.000	0.4000	0.2277	0.0000	0.0000	0.1723	0.1723	11.1550	8.6306	0.9521	0.4800	1.0923
19	9.500	0.0000	0.1000	0.0000	0.4800	-0.5800	-0.5800	11.1550	8.7306	0.9521	0.9600	0.5123
20	10.000	0.0000	0.0323	0.0000	0.4800	-0.5123	-0.5123	11.1550	8.7629	0.9521	1.4400	0.0000
21	10.500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	11.1550	8.7629	0.9521	1.4400	0.0000
22	11.000	0.7500	0.6767	0.0000	0.0000	0.0733	0.0733	11.9050	9.4396	0.9521	1.4400	0.0733
23	11.500	1.2500	0.1982	0.0000	0.0000	1.0518	1.0518	13.1550	9.6377	0.9521	1.4400	1.1251
24	12.000	1.5000	0.1860	0.9392	0.0000	0.3749	0.3749	14.6550	9.8237	1.8913	1.4400	1.5000
25	12.500	0.5000	0.1796	0.3204	0.0000	0.0000	0.0000	15.1550	10.0034	2.2116	1.4400	1.5000
26	13.000	0.5000	0.1740	0.3260	0.0000	0.0000	0.0000	15.6550	10.1774	2.5376	1.4400	1.5000


Graphs
Index of Plot (1-2)
2
1: Incremental Plot
2: Cumulative Plot
OK


Plot Parameters
Plot Parameters
Xmin
0
Xmax
15
Ymin
0
Ymax
3
Number of X ticks
10
Number of Y ticks
10
Decimal digit of marked X values
###0.0
Decimal digit of marked Y values
###0.000
(e.g., ###0.0, ### 0.000)
Index of gridlines
2
0 solid; 1 dash; 2 dot; 3 dash+dot; 4 dash+2dots; 5 no gridline
OK





7.2 Water Table for the Surface Zone

Water Table for the Surface Zone

A cumulative water mass balance table for the surface zone shows cumulative rainfall (C-Rain), infiltration (C-Infil), runoff (C-Runf), evapotranspiration from the surface water storage (C-ETS), and the surface storage (SSTG) for each time step. Note that the mass balance terms in the table (e.g., runoff) are the depths of water over the pervious soil area only.

MassB-Surf

-------- Mass Balance Table for the Surface Zone of the Pervious Soil Area --------

Step	T(hr)	C-Rain(cm)	C-Infil(cm)	C-Runf(cm)	C-ETS(cm)	SSTG(cm)	P-I-R-E(cm)
1	.5000	.750000	.750000	.000000	.000000	.000000	.000000
2	1.0000	4.500000	3.683087	.000000	.000000	.816913	.816913
3	1.5000	4.525000	4.525000	.000000	.000000	.000000	.000000
4	2.0000	4.530000	4.530000	.000000	.000000	.000000	.000000
5	2.5000	4.540000	4.540000	.000000	.000000	.000000	.000000
6	3.0000	5.440000	5.438715	.000000	.000000	.001285	.001285
7	3.5000	6.190000	6.190000	.000000	.000000	.000000	.000000
8	4.0000	6.215000	6.215000	.000000	.000000	.000000	.000000
9	4.5000	6.225000	6.225000	.000000	.000000	.000000	.000000
10	5.0000	6.230000	6.230000	.000000	.000000	.000000	.000000
11	5.5000	8.980000	6.792608	.687392	.000000	1.500000	1.500000
12	6.0000	8.985000	7.187781	.687392	.000000	1.109826	1.109826
13	6.5000	8.990000	7.514826	.687392	.000000	.787781	.787781
14	7.0000	8.995000	7.802062	.687392	.000000	.505546	.505546
15	7.5000	9.005000	8.062367	.687392	.000000	.255240	.255240
16	8.0000	10.755000	8.302892	.952108	.000000	1.500000	1.500000
17	8.5000	10.755000	8.402892	.952108	.480000	.920000	.920000
18	9.0000	11.155000	8.630575	.952108	.480000	1.092316	1.092316
19	9.5000	11.155000	8.730575	.952108	.960000	.512316	.512316
20	10.0000	11.155000	8.762892	.952108	1.440000	.000000	.000000

7.3 Water Table for the Vadose Zone

Water Table for the Vadose Zone

A cumulative water mass balance table for the vadose zone shows cumulative infiltration (C-Infil), evapotranspiration from the soil profile (C-ET), discharge to the underlying groundwater (C-GW), and changes in the soil water storage (soil water content) (D-WC) for each time step. Note that the mass balance terms in the table are the depths of water over the pervious soil area only.

MassB-Soil

-------- Mass Balance Table for the Vadose Zone under the Pervious Soil Area --------

Step	T(hr)	C-Infil(cm)	C-ET(cm)	C-GW(cm)	D-WC(cm)	I-ET-GW(cm)
1	.5000	.750000	.000000	.000000	.750000	.750000
2	1.0000	3.683087	.000000	.000000	3.683087	3.683087
3	1.5000	4.525000	.000000	.000000	4.525000	4.525000
4	2.0000	4.530000	.000000	.000000	4.530000	4.530000
5	2.5000	4.540000	.000000	.000000	4.540000	4.540000
6	3.0000	5.438715	.000000	.000000	5.438715	5.438715
7	3.5000	6.190000	.000000	.000000	6.190000	6.190000
8	4.0000	6.215000	.000000	.000000	6.215000	6.215000
9	4.5000	6.225000	.000000	.000000	6.225000	6.225000
10	5.0000	6.230000	.000000	.000000	6.230000	6.230000
11	5.5000	6.792608	.000000	.000000	6.792608	6.792608
12	6.0000	7.187781	.000000	.000000	7.187781	7.187781
13	6.5000	7.514826	.000000	.000000	7.514826	7.514826
14	7.0000	7.802062	.000000	.000000	7.802062	7.802062
15	7.5000	8.062367	.000000	.000000	8.062367	8.062367
16	8.0000	8.302892	.000000	.000000	8.302892	8.302892
17	8.5000	8.402892	.000000	.000000	8.402892	8.402892
18	9.0000	8.630575	.000000	.000000	8.630575	8.630575
19	9.5000	8.730575	.000000	.000000	8.730575	8.730575

7.4 Soil Water Content

Soil Water Content

The soil water content table shows both temporal and spatial variations of soil moisture conditions.

WT.txt

Soil Water Content (cm3/cm3)

NO.	T(hr)	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9
0	.00	.100	.100	.100	.100	.100	.100	.100	.100	
1	.50	.440	.440	.170	.100	.100	.100	.100	.100	
2	1.00	.440	.440	.440	.440	.440	.440	.440	.440	
3	1.50	.440	.440	.440	.440	.440	.440	.440	.440	
4	2.00	.440	.440	.440	.440	.440	.440	.440	.440	
5	2.50	.440	.440	.440	.440	.440	.440	.440	.440	
6	3.00	.440	.440	.440	.440	.440	.440	.440	.440	
7	3.50	.440	.440	.440	.440	.440	.440	.440	.440	
8	4.00	.440	.440	.440	.440	.440	.440	.440	.440	
9	4.50	.440	.440	.440	.440	.440	.440	.440	.440	
10	5.00	.440	.440	.440	.440	.440	.440	.440	.440	
11	5.50	.440	.440	.440	.440	.440	.440	.440	.440	
12	6.00	.440	.440	.440	.440	.440	.440	.440	.440	
13	6.50	.440	.440	.440	.440	.440	.440	.440	.440	
14	7.00	.440	.440	.440	.440	.440	.440	.440	.440	
15	7.50	.440	.440	.440	.440	.440	.440	.440	.440	
16	8.00	.440	.440	.440	.440	.440	.440	.440	.440	
17	8.50	.440	.440	.440	.440	.440	.440	.440	.440	
18	9.00	.440	.440	.440	.440	.440	.440	.440	.440	
19	9.50	.440	.440	.440	.440	.440	.440	.440	.440	
20	10.00	.372	.440	.440	.440	.440	.440	.440	.440	
21	10.50	.100	.132	.440	.440	.440	.440	.440	.440	
22	11.00	.440	.440	.440	.440	.440	.440	.440	.440	
23	11.50	.440	.440	.440	.440	.440	.440	.440	.440	

7.5 Soil Water Flow Velocity

Soil Water Flow Velocity

The soil water flow velocity table shows both temporal and spatial variations of soil water flow velocities.

V.txt

Soil Water Flow Velocity (cm/hr)

NO.	T(hr)	.000	1.000	2.000	3.000	4.000	5.000	6.000	7.000
1	.50	1.500	.820	.140	.000	.000	.000	.000	.000
2	1.00	5.866	5.866	5.866	5.326	4.646	3.966	3.286	2.606
3	1.50	1.684	1.684	1.684	1.684	1.684	1.684	1.684	1.684
4	2.00	.010	.010	.010	.010	.010	.010	.010	.010
5	2.50	.020	.020	.020	.020	.020	.020	.020	.020
6	3.00	1.797	1.797	1.797	1.797	1.797	1.797	1.797	1.797
7	3.50	1.503	1.503	1.503	1.503	1.503	1.503	1.503	1.503
8	4.00	.050	.050	.050	.050	.050	.050	.050	.050
9	4.50	.020	.020	.020	.020	.020	.020	.020	.020
10	5.00	.010	.010	.010	.010	.010	.010	.010	.010
11	5.50	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125
12	6.00	.790	.790	.790	.790	.790	.790	.790	.790
13	6.50	.654	.654	.654	.654	.654	.654	.654	.654
14	7.00	.574	.574	.574	.574	.574	.574	.574	.574
15	7.50	.521	.521	.521	.521	.521	.521	.521	.521
16	8.00	.481	.481	.481	.481	.481	.481	.481	.481
17	8.50	.200	2.040	2.720	3.400	4.080	4.760	5.440	5.980
18	9.00	.455	.455	.455	.455	.455	.455	.455	.455
19	9.50	.200	1.225	1.905	2.585	3.265	3.945	4.625	5.305
20	10.00	.065	.200	.745	1.425	2.105	2.785	3.465	4.145
21	10.50	.000	.077	.453	.395	1.011	1.659	2.322	2.994
22	11.00	1.353	.673	.058	.058	.058	.058	.058	.058
23	11.50	.396	.396	.396	.396	.396	.396	.396	.396

7.6 Flow Table for the Watershed Outlet

Mass balance table for the entire watershed. Note that the infiltration and runoff from the pervious and directly-connected impervious areas are the depths of water over the entire watershed area.

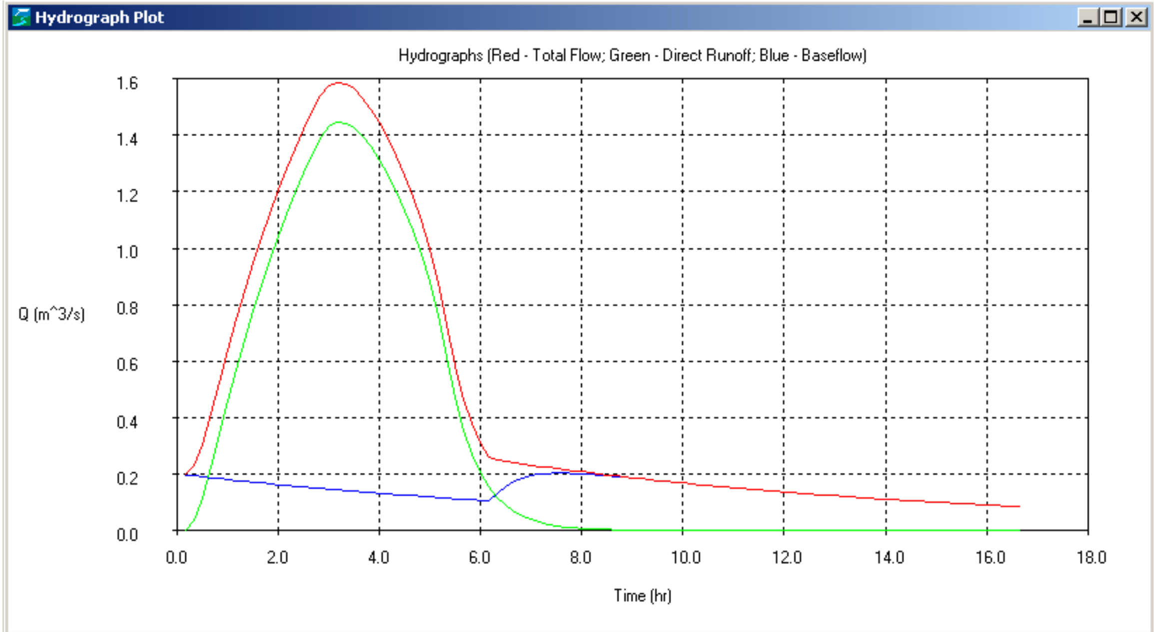
Flow

-------- Water Table for the Entire Watershed --------

Step	Time(hr)	Rain(cm)	Infl(cm)	Runoff-P(cm)	Runoff-IMP(cm)	Direct-Q(m3/s)	Baseflow(m3/s)	Total-Q(m3/s)
1	.50000	.750000	.749250	.000000	.000750	.000466	.189737	.190203
2	1.00000	3.750000	2.930154	.000000	.003750	.003630	.180000	.183630
3	1.50000	.025000	.841071	.000000	.000025	.007807	.170763	.178570
4	2.00000	.005000	.004995	.000000	.000005	.007170	.162000	.169170
5	2.50000	.010000	.009990	.000000	.000010	.003581	.153687	.157267
6	3.00000	.900000	.897816	.000000	.000900	.002057	.145800	.147857
7	3.50000	.750000	.750534	.000000	.000750	.002653	.138318	.140971
8	4.00000	.025000	.024975	.000000	.000025	.003129	.131220	.134349
9	4.50000	.010000	.009990	.000000	.000010	.002232	.124486	.126718
10	5.00000	.005000	.004995	.000000	.000005	.001080	.118098	.119178
11	5.50000	2.750000	.562045	.686705	.002750	.428902	.112038	.540940
12	6.00000	.005000	.394779	.000000	.000005	1.194788	.106288	1.301076
13	6.50000	.005000	.326718	.000000	.000005	1.190105	.100834	1.290939
14	7.00000	.005000	.286949	.000000	.000005	.598445	.095659	.694105
15	7.50000	.010000	.260045	.000000	.000010	.246438	.090750	.337189
16	8.00000	1.750000	.240284	.264451	.001750	.266916	.086093	.353009
17	8.50000	.000000	.099900	.000000	.000000	.503037	.081675	.584713
18	9.00000	.400000	.227456	.000000	.000400	.476931	.077484	.554415
19	9.50000	.000000	.099900	.000000	.000000	.238823	.073508	.312330
20	10.00000	.000000	.032284	.000000	.000000	.098744	.069736	.168479
21	10.50000	.000000	.000000	.000000	.000000	.040722	.075739	.116461

7.7 Hydrograph at the Watershed Outlet

Hydrograph at the outlet



7.8 Model Output Information

Model Output Information

It shows all input data, computation details of the model execution, such as determination of ponding condition.

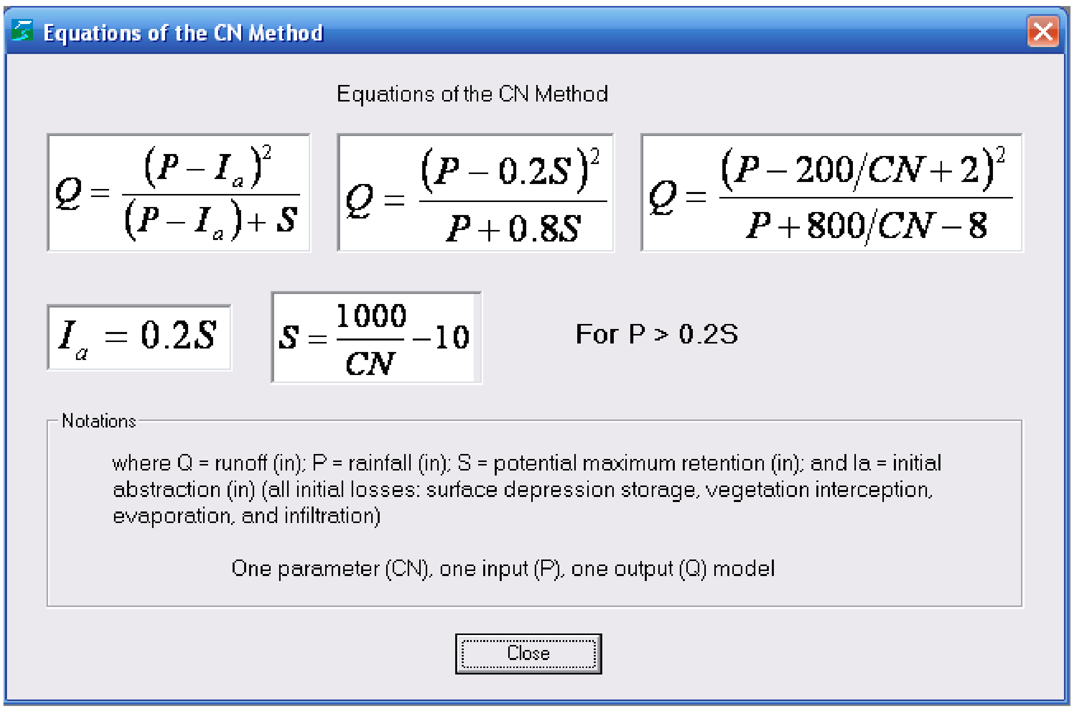
Output-Info.txt

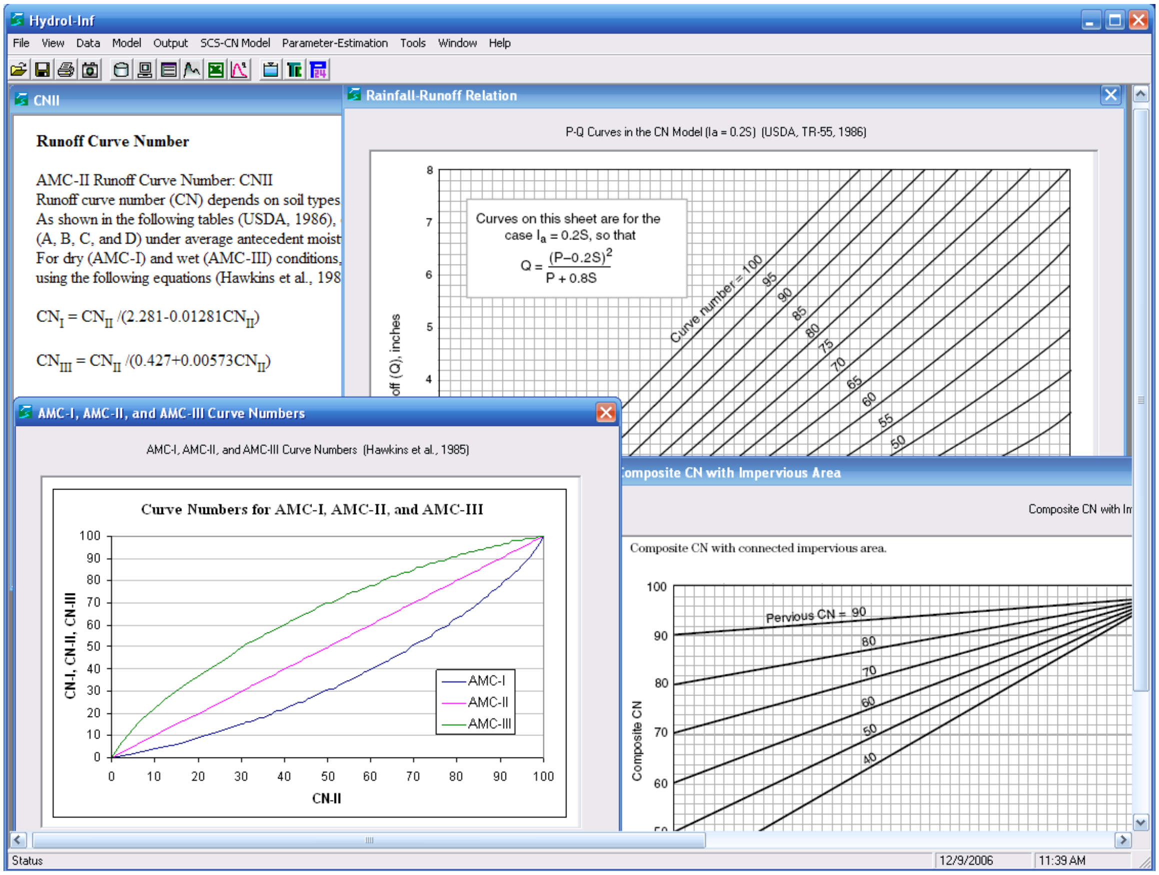
```
-------- Pre-Ponding Computation: Determination of Ponding Condition --------

   NP=         5
   ZP=   4.06401
  IZP=   7.50000
  ICP=   1.38176
   TP=    .58424
  TPD=    .10760
   TO=    .47663


  No.      T(h)        tz(h)      z(cm)   Rain(cm/h)  Inf-Ca(cm/h)     C-Inf(cm)
    1     .5000      .036579     2.2059     1.50000     11.29901        .75000
    2     .5842      .107601     4.0640     7.50000      7.50000       1.38176

Ponding status is broken!
   KT=         4
 RAIN=    .01000
STGCW=    .00000
   IZ=   2.34504

-------- Pre-Ponding Computation: Determination of Ponding Condition --------

   NP=        18
   ZP=  17.45101
  IZP=   1.80000
```

8. SCS-CN Model

8.1 Theory of the Curve Number Method

The SCS-CN model is a separate model, in which the SCS-CN method is used to simulate surface runoff. The relevant theoretical information can be accessed via the menu of Theory of the CN Method, including equations, CN tables, P-Q curves, CN values for AMC-I, AMC-II, and AMC-III, and composite curve numbers with impervious areas. Note that the SCS-CN model should be used for event rainfall-runoff modeling only.

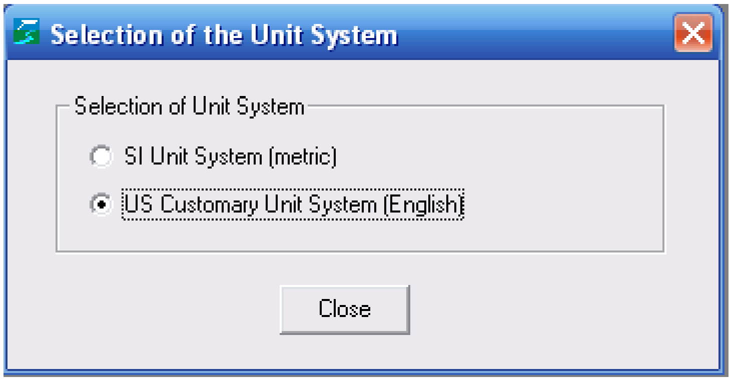


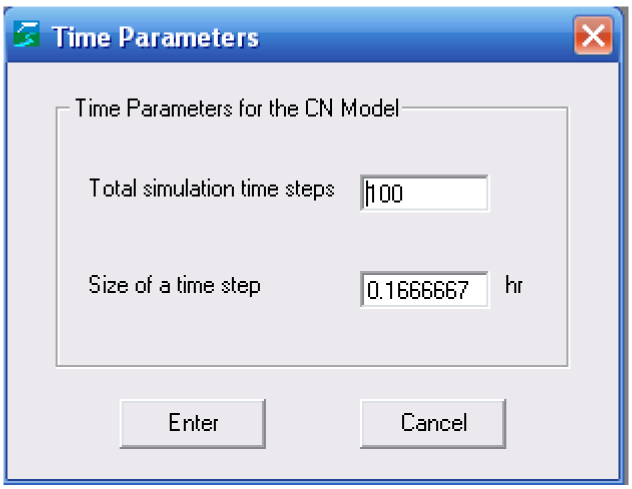


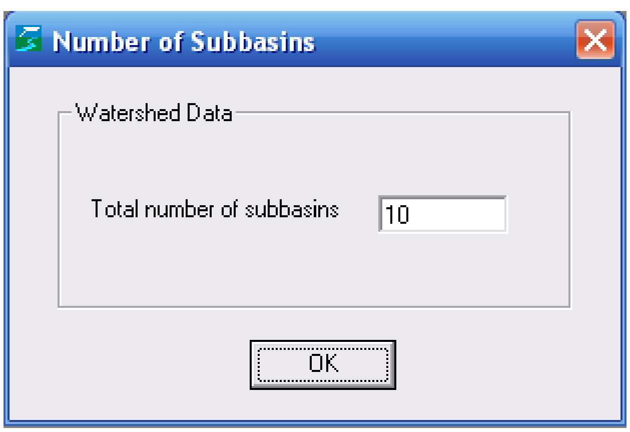
8.2 CN Rainfall-Runoff Modeling

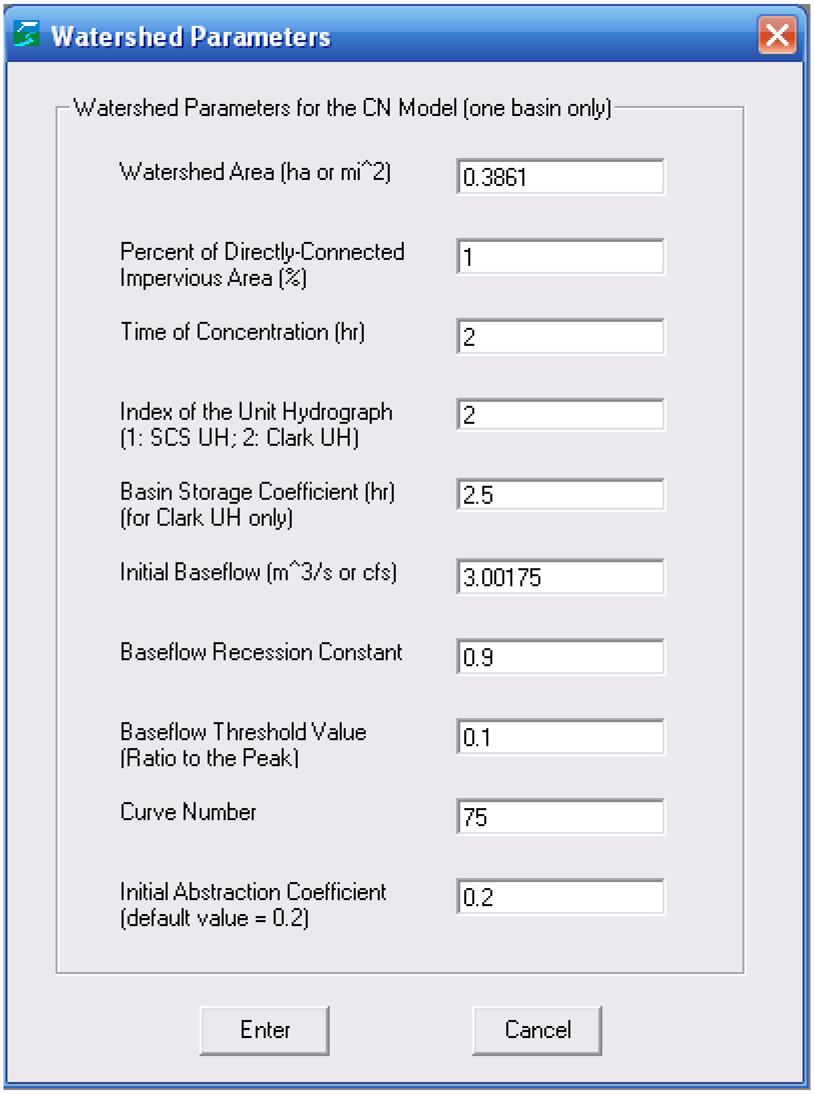
In the CN rainfall-runoff modeling, two different unit systems (SI system and US customary unit system) can be selected. All modeling steps, including data preparation (import data, change working directory, input data, save data), model run and check, and output (view simulation summary tables and hydrographs) can be accessed through the menu SCS-CN Model. The modeling can be conducted for a single watershed or multiple watersheds. Comparison between the simulated and observed hydrographs can also be performed via the menu Calibration.

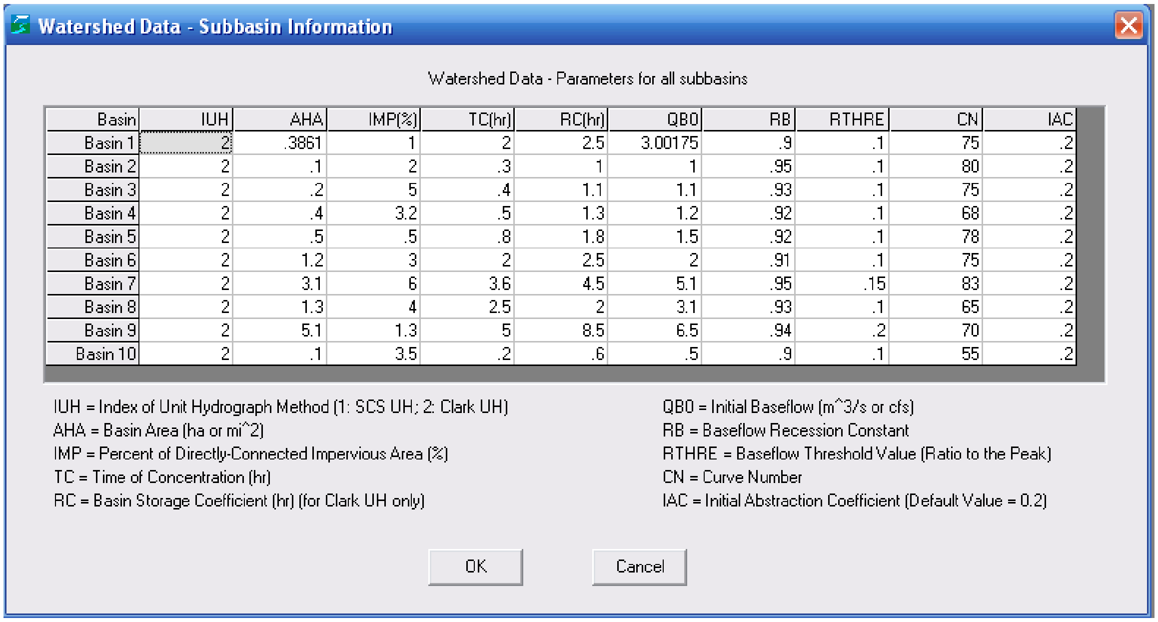
For watershed modeling, either SCS unit hydrograph or Clark unit hydrograph can be selected. Baseflow is simulated by using the recession method (see pages 28-29 for details). Note that the recession constant is dependent on the unit of time (Maidment 1993, page 9.5). A daily recession constant is used in this progam.


Selection of the Unit System
Selection of Unit System
SI Unit System (metric)
US Customary Unit System (English)
Close


Time Parameters
Time Parameters for the CN Model
Total simulation time steps
100
Size of a time step
0.1666667
hr
Enter
Cancel


Number of Subbasins
Watershed Data
Total number of subbasins
10
OK


Watershed Parameters
Watershed Parameters for the CN Model (one basin only)
Watershed Area (ha or mi^2)
0.3861
Percent of Directly-Connected Impervious Area (%)
1
Time of Concentration (hr)
2
Index of the Unit Hydrograph (1: SCS UH; 2: Clark UH)
2
Basin Storage Coefficient (hr) (for Clark UH only)
2.5
Initial Baseflow (m^3/s or cfs)
3.00175
Baseflow Recession Constant
0.9
Baseflow Threshold Value (Ratio to the Peak)
0.1
Curve Number
75
Initial Abstraction Coefficient (default value = 0.2)
0.2
Enter
Cancel



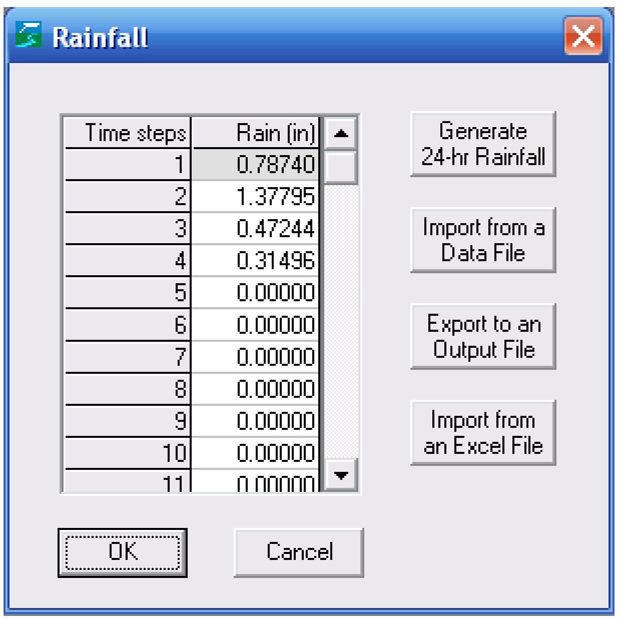
Watershed Data - Subbasin Information

Watershed Data - Parameters for all subbasins

Basin	IUH	AHA	IMP(%)	TC(hr)	RC(hr)	QB0	RB	RTHRE	CN	IAC
Basin 1	2	.3861	1	2	2.5	3.00175	.9	.1	75	.2
Basin 2	2	.1	2	.3	1	1	.95	.1	80	.2
Basin 3	2	.2	5	.4	1.1	1.1	.93	.1	75	.2
Basin 4	2	.4	3.2	.5	1.3	1.2	.92	.1	68	.2
Basin 5	2	.5	.5	.8	1.8	1.5	.92	.1	78	.2
Basin 6	2	1.2	3	2	2.5	2	.91	.1	75	.2
Basin 7	2	3.1	6	3.6	4.5	5.1	.95	.15	83	.2
Basin 8	2	1.3	4	2.5	2	3.1	.93	.1	65	.2
Basin 9	2	5.1	1.3	5	8.5	6.5	.94	.2	70	.2
Basin 10	2	.1	3.5	.2	.6	.5	.9	.1	55	.2

IUH = Index of Unit Hydrograph Method (1: SCS UH; 2: Clark UH)
AHA = Basin Area (ha or mi^2)
IMP = Percent of Directly-Connected Impervious Area (%)
TC = Time of Concentration (hr)
RC = Basin Storage Coefficient (hr) (for Clark UH only)
QB0 = Initial Baseflow (m^3/s or cfs)
RB = Baseflow Recession Constant
RTHRE = Baseflow Threshold Value (Ratio to the Peak)
CN = Curve Number
IAC = Initial Abstraction Coefficient (Default Value = 0.2)

OK Cancel

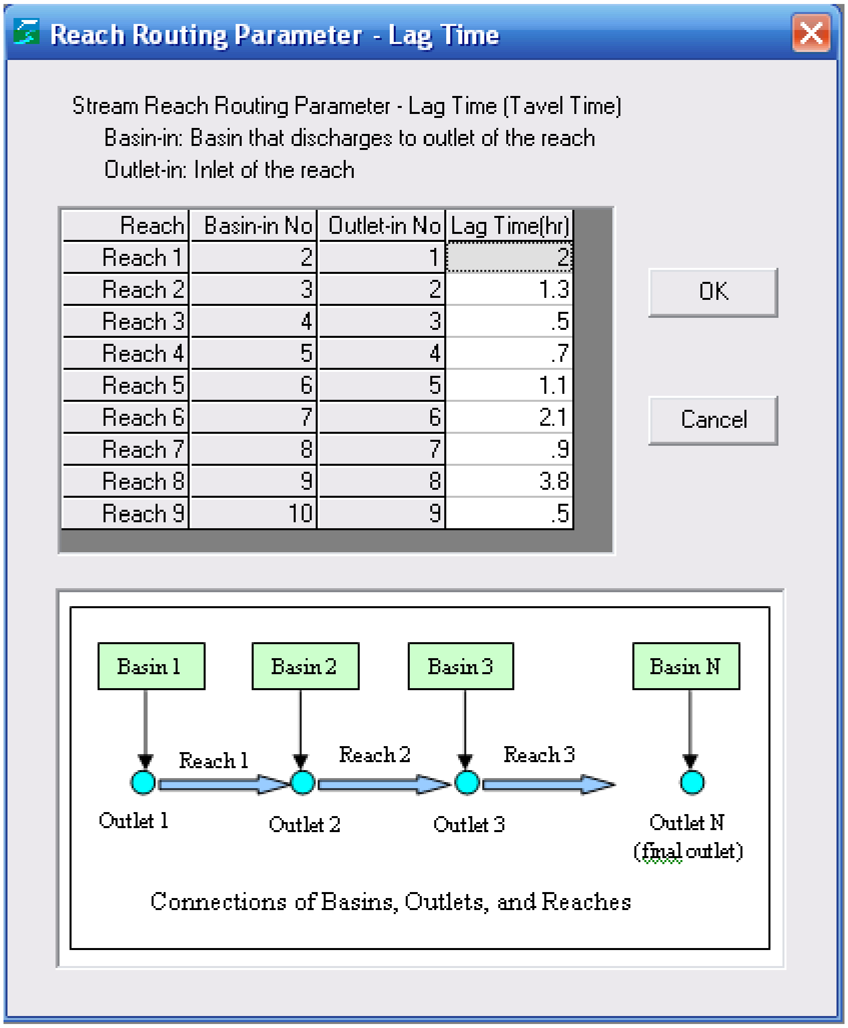


Rainfall

Time steps	Rain (in)
1	0.78740
2	1.37795
3	0.47244
4	0.31496
5	0.00000
6	0.00000
7	0.00000
8	0.00000
9	0.00000
10	0.00000
11	0.00000

Generate 24-hr Rainfall
Import from a Data File
Export to an Output File
Import from an Excel File

OK Cancel

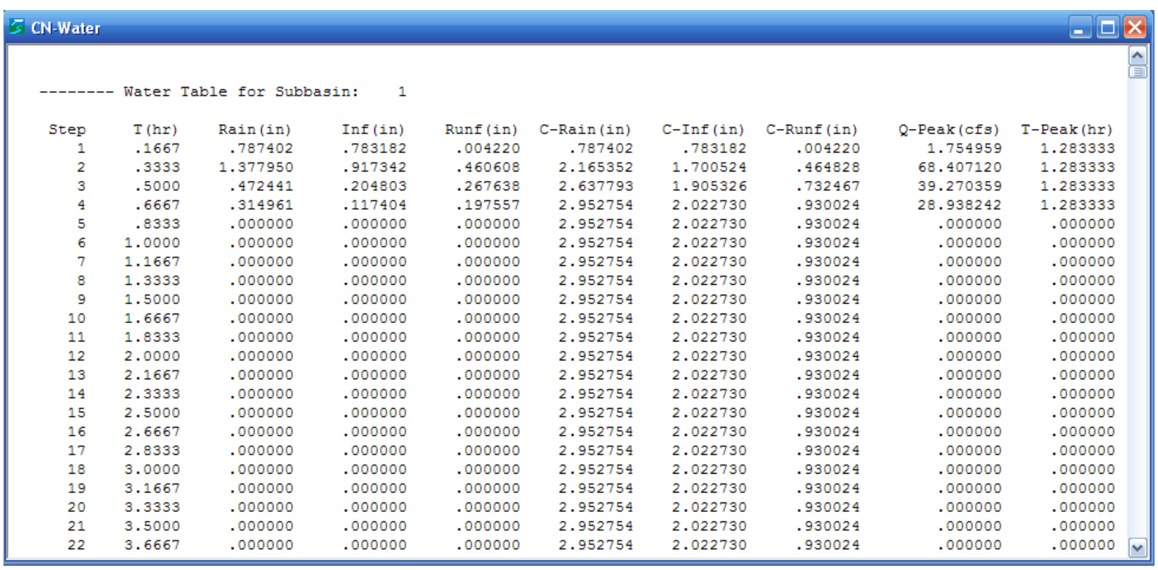


Reach Routing Parameter - Lag Time

Stream Reach Routing Parameter - Lag Time (Tavel Time)
Basin-in: Basin that discharges to outlet of the reach
Outlet-in: Inlet of the reach

Reach	Basin-in No	Outlet-in No	Lag Time(hr)
Reach 1	2	1	2
Reach 2	3	2	1.3
Reach 3	4	3	.5
Reach 4	5	4	.7
Reach 5	6	5	1.1
Reach 6	7	6	2.1
Reach 7	8	7	.9
Reach 8	9	8	3.8
Reach 9	10	9	.5

OK
Cancel



CN-Water

-------- Water Table for Subbasin: 1

Step	T(hr)	Rain(in)	Inf(in)	Runf(in)	C-Rain(in)	C-Inf(in)	C-Runf(in)	Q-Peak(cfs)	T-Peak(hr)
1	.1667	.787402	.783182	.004220	.787402	.783182	.004220	1.754959	1.283333
2	.3333	1.377950	.917342	.460608	2.165352	1.700524	.464828	68.407120	1.283333
3	.5000	.472441	.204803	.267638	2.637793	1.905326	.732467	39.270359	1.283333
4	.6667	.314961	.117404	.197557	2.952754	2.022730	.930024	28.938242	1.283333
5	.8333	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
6	1.0000	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
7	1.1667	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
8	1.3333	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
9	1.5000	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
10	1.6667	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
11	1.8333	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
12	2.0000	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
13	2.1667	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
14	2.3333	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
15	2.5000	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
16	2.6667	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
17	2.8333	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
18	3.0000	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
19	3.1667	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
20	3.3333	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
21	3.5000	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000
22	3.6667	.000000	.000000	.000000	2.952754	2.022730	.930024	.000000	.000000

CN-Flow

-------- Flow Summary Table for Subbasin: 1

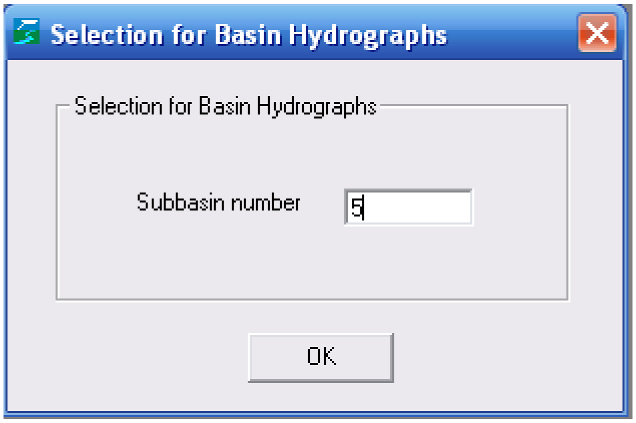
Peak Time (hour) = 2.16667
Peak Flow (cfs) = 66.978622

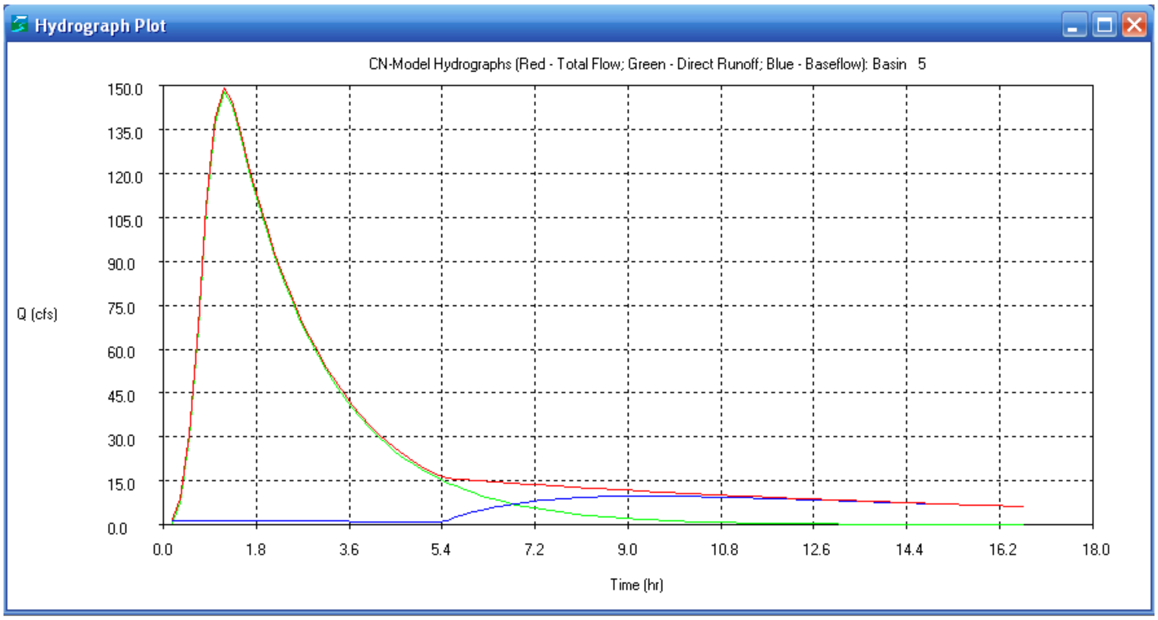
Step	Time(hr)	Rain(in)	Runoff-P(in)	Runoff-IMP(in)	Direct-Q(cfs)	Baseflow(cfs)	Total-Q(cfs)
1	.16667	.787402	.004220	.007874	.019770	2.949499	2.969269
2	.33333	1.377950	.460608	.013779	.845045	2.898158	3.743203
3	.50000	.472441	.267638	.004724	3.495555	2.847710	6.343265
4	.66667	.314961	.197557	.003150	8.183248	2.798141	10.981389
5	.83333	.000000	.000000	.000000	14.537407	2.749434	17.286841
6	1.00000	.000000	.000000	.000000	21.999426	2.701575	24.701001
7	1.16667	.000000	.000000	.000000	30.216844	2.654549	32.871393
8	1.33333	.000000	.000000	.000000	38.738695	2.608342	41.347037
9	1.50000	.000000	.000000	.000000	46.816668	2.562939	49.379607
10	1.66667	.000000	.000000	.000000	53.767044	2.518326	56.285370
11	1.83333	.000000	.000000	.000000	59.197112	2.474490	61.671602
12	2.00000	.000000	.000000	.000000	62.906268	2.431417	65.337686
13	2.16667	.000000	.000000	.000000	64.589528	2.389094	66.978622
14	2.33333	.000000	.000000	.000000	63.812315	2.347508	66.159822
15	2.50000	.000000	.000000	.000000	61.059850	2.306645	63.366495
16	2.66667	.000000	.000000	.000000	57.446502	2.266494	59.712996
17	2.83333	.000000	.000000	.000000	53.740276	2.227041	55.967317

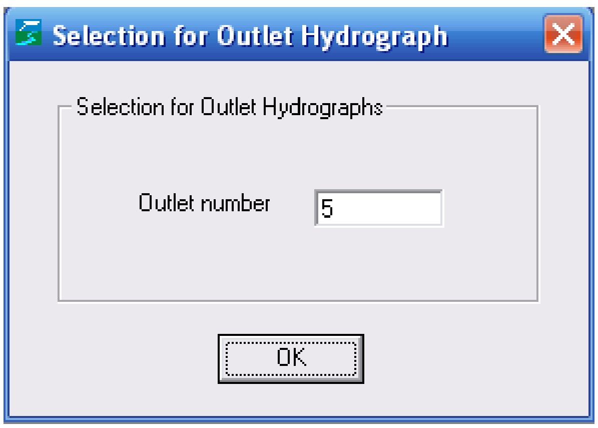
CN-QOutlet

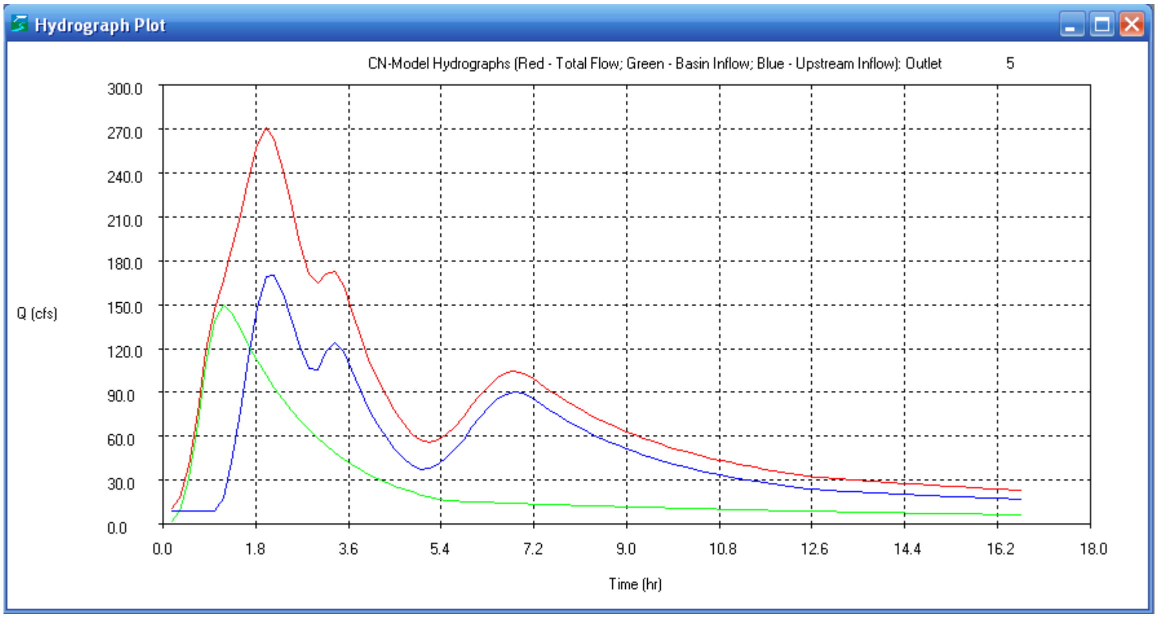
-------- Flow at Outlet 1

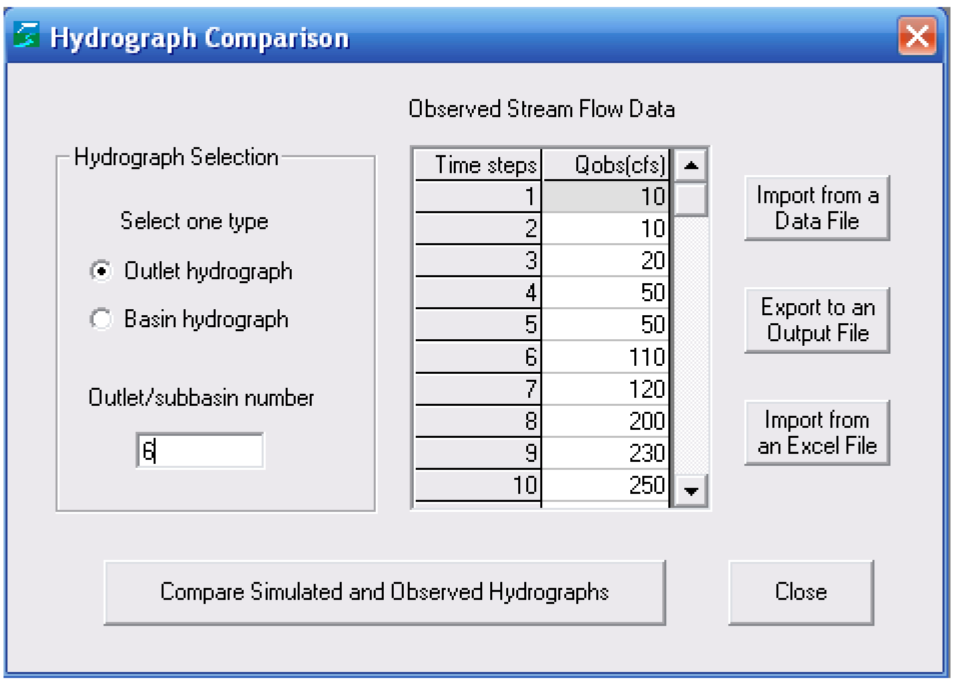
Time(hr)	Q(cfs)
.16667	2.969269
.33333	3.743203
.50000	6.343265
.66667	10.981389
.83333	17.286841
1.00000	24.701001
1.16667	32.871393
1.33333	41.347037
1.50000	49.379607
1.66667	56.285370
1.83333	61.671602
2.00000	65.337686
2.16667	66.978622
2.33333	66.159822
2.50000	63.366495
2.66667	59.712996
2.83333	55.967317
3.00000	52.461436
3.16667	49.179915

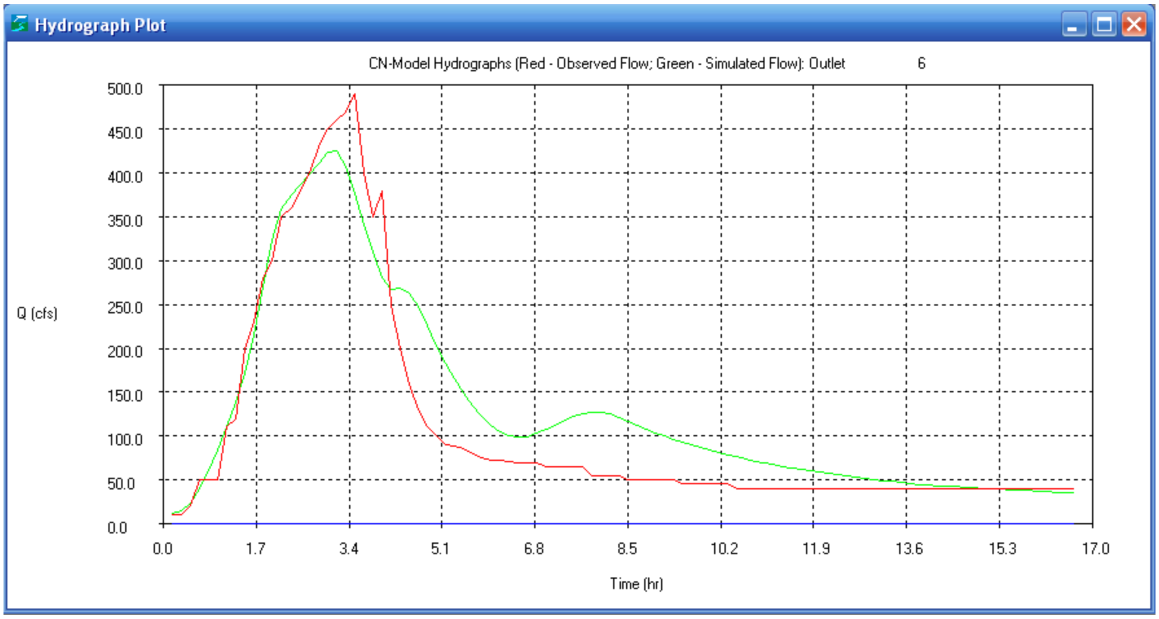

Selection for Basin Hydrographs
Selection for Basin Hydrographs
Subbasin number
5
OK


Hydrograph Plot
CN-Model Hydrographs (Red - Total Flow; Green - Direct Runoff; Blue - Baseflow): Basin 5
Q (cfs)
150.0
135.0
120.0
105.0
90.0
75.0
60.0
45.0
30.0
15.0
0.0
0.0
1.8
3.6
5.4
7.2
9.0
10.8
12.6
14.4
16.2
18.0
Time (hr)


Selection for Outlet Hydrograph
Selection for Outlet Hydrographs
Outlet number
5
OK


Hydrograph Plot
CN-Model Hydrographs (Red - Total Flow; Green - Basin Inflow; Blue - Upstream Inflow): Outlet 5
Q (cfs)
300.0
270.0
240.0
210.0
180.0
150.0
120.0
90.0
60.0
30.0
0.0
0.0
1.8
3.6
5.4
7.2
9.0
10.8
12.6
14.4
16.2
18.0
Time (hr)

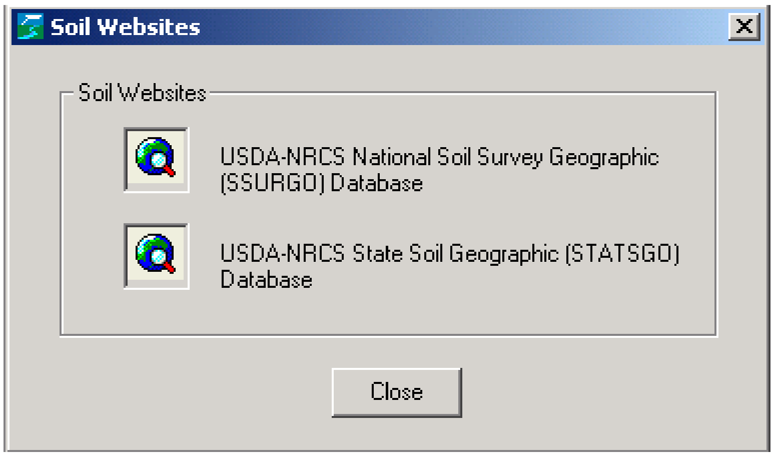

Hydrograph Comparison
Observed Stream Flow Data
Hydrograph Selection
Select one type
Outlet hydrograph
Basin hydrograph
Outlet/subbasin number
6
Time steps
Qobs(cfs)
1 10
2 10
3 20
4 50
5 50
6 110
7 120
8 200
9 230
10 250
Import from a Data File
Export to an Output File
Import from an Excel File
Compare Simulated and Observed Hydrographs
Close

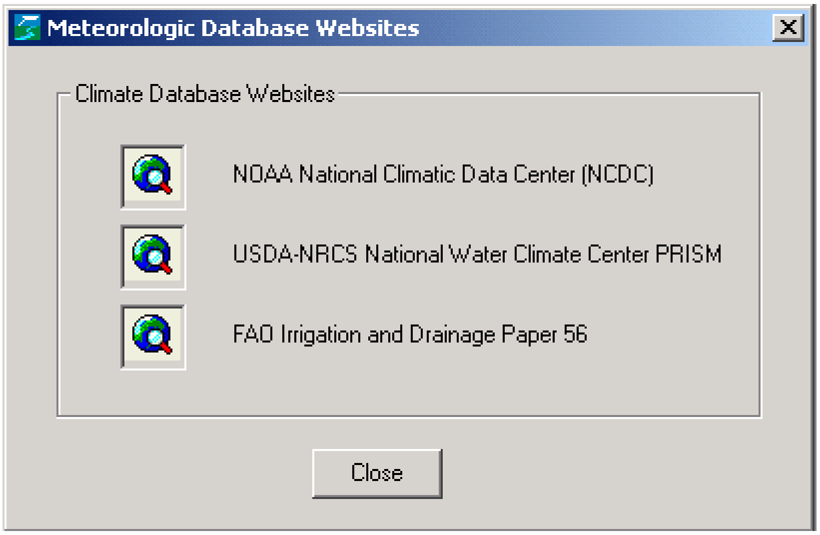

Hydrograph Plot
CN-Model Hydrographs (Red - Observed Flow; Green - Simulated Flow): Outlet 6
Q (cfs)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0.0
1.7
3.4
5.1
6.8
8.5
10.2
11.9
13.6
15.3
17.0
Time (hr)

9. Introduction to the Data Supporting System: Parameter Estimation

To facilitate parameter estimation, a comprehensive data supporting system is developed and incorporated in Hydrol-Inf. All parameters/data used in the model are detailed in the data supporting system. It covers all basic data information, tables, and figures related to soil properties and meteorologic conditions that are included in this document.

The data supporting system also includes links to some useful database websites concerning soils and climate.





10. Hydrologic Tools

10.1 Computation of Measured Flow

<u>*Computation of Discharge*</u>

Generally, both velocity and depth of a stream change significantly over a cross-sectional area. The velocity near the water surface is greater than one close to the bottom and the water in the center of the stream flows faster than on the edges. Discharge of a stream through a cross-sectional area *A* can be expressed as:

$$Q = \iint_A V dA = \iint_A V(x, y) dx dy$$

in which Q = water discharge [L^3/T]; V = velocity [L/T]; and A = area [L^2].

A number of methods can be used for estimating discharge of a stream. Velocity-area methods are commonly used. Midsection method and mean-section method are two velocity-area methods and the former is generally recommended. As shown in the figure on the following page, the midsection method for calculating water discharge in a stream channel can be written as:

$$q_i = \overline{V}_i A_i = \overline{V}_i \left(\frac{L_{i+1} - L_i}{2} + \frac{L_i - L_{i-1}}{2} \right) d_i = \overline{V}_i \frac{L_{i+1} - L_{i-1}}{2} d_i \qquad (i = 2, 3, \ldots, n\text{-}1)$$

For the first and last sections, following equations are used for calculating the corresponding discharge (Gupta, 1989):

$$q_1 = \overline{V}_1 \frac{L_2 - L_1}{2} d_1$$

in which $\overline{V}_1 = 0.65 \overline{V}_2$

$$q_n = \overline{V}_n \frac{L_n - L_{n-1}}{2} d_n$$

in which $\overline{V}_n = 0.65 \overline{V}_{n-1}$

Hence, the total discharge can be given by:

$$Q = \sum_{i=1}^{n} q_i$$

in which q_i = water discharge of section i [L^3/T]; $\overline{V}_i$ = mean velocity at observation point/vertical i [L/T]; L_i = distance from the initial point to observation point/vertical i [L]; and d_i = depth of water at observation point/vertical i [L].

The number of observation points/verticals or the size of each section depends on the entire width of the stream, variability in the stream depth and velocity, and the degree of precision required (research purposes). Usually, the number of sections/verticals may range from 5 to 20. Some references suggest that 20-30 verticals of equidistant or variable spacings be used to divide a stream width. These spacings also should be arranged so that no section contains more than 10% of the total flow.

Computation of Mean Velocity:

(1) One-Point Method (0.6D): A velocity is measured at a depth of 0.6D (D is the total depth of water) and it is assumed that this velocity is equal to the mean velocity as shown in the flowing equation. This method is suitable for $D \leq 2\,ft$

$$\bar{V}_i = v_i^{0.6D}$$

(2) Two-Point Method (0.2D & 0.8D): Two velocities are measured at depths of 0.2D and 0.8D. The mean velocity is estimated as follows. This method is suitable for $D = 2 - 10\,ft$

$$\bar{V}_i = \frac{1}{2} v_i^{0.2D} + \frac{1}{2} v_i^{0.8D}$$

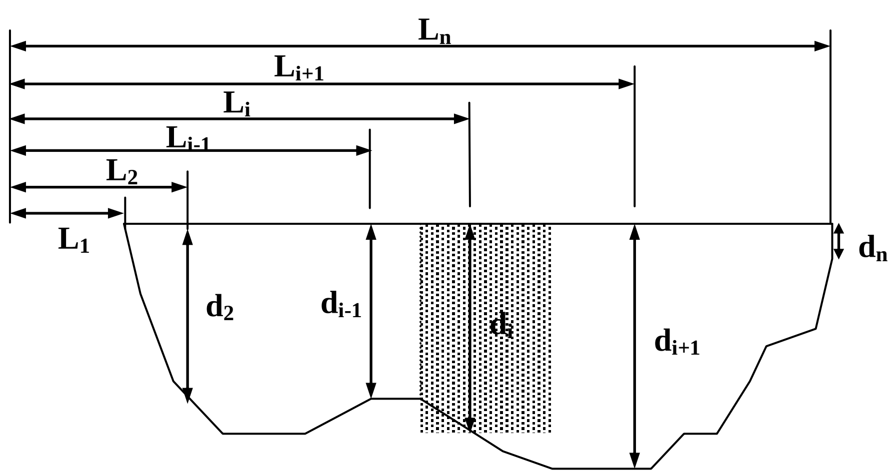
(3) Three-Point Method (0.2D, 0.6D, & 0.8D): Three velocities are measured at depths of 0.2D, 0.6D, and 0.8D. The mean velocity is estimated as follows. This method is suitable for $D = 10 - 20\,ft$

$$\bar{V}_i = \frac{1}{4} v_i^{0.2D} + \frac{1}{2} v_i^{0.6D} + \frac{1}{4} v_i^{0.8D}$$

(4) 0.2-Depth Method (0.2D): In this method, it is assumed that the mean velocity equals 0.87 of the velocity measured at a depth of 0.2D.

$$\bar{V}_i = \alpha v_i^{0.2D} = 0.87 v_i^{0.2D}$$

The first two methods are widely used in practice.



<u>Computation of Other Hydraulic Parameters:</u>

(1) Overall Average Velocity:

$$\bar{V} = \frac{Q}{A} = \sum_{i=1}^{n} q_i \Big/ \sum_{i=1}^{n} A_i$$

(2) Wetted Perimeter:

$$WP = d_1 + \sum_{i=2}^{n} \sqrt{(d_i - d_{i-1})^2 + (L_i - L_{i-1})^2} + d_n$$

(3) Hydraulic Radius:

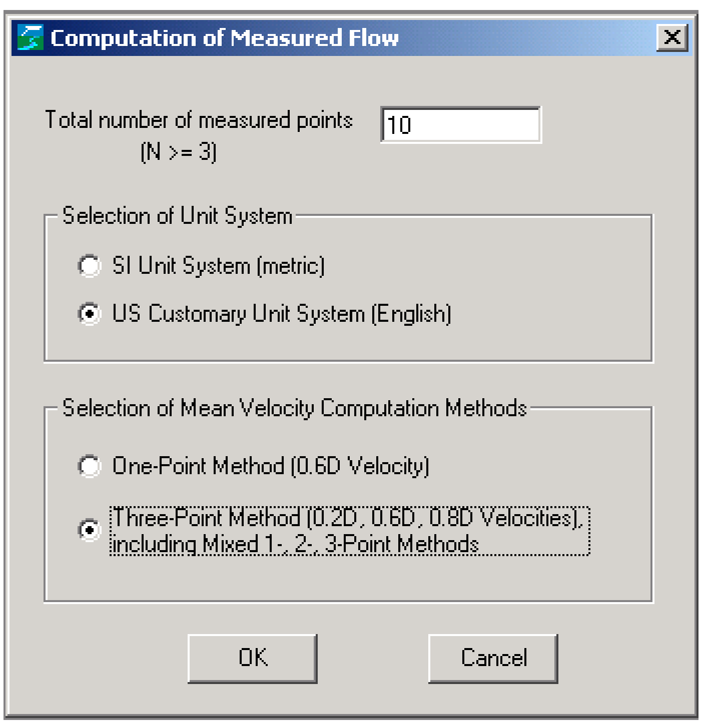
$$R = \frac{A}{WP}$$

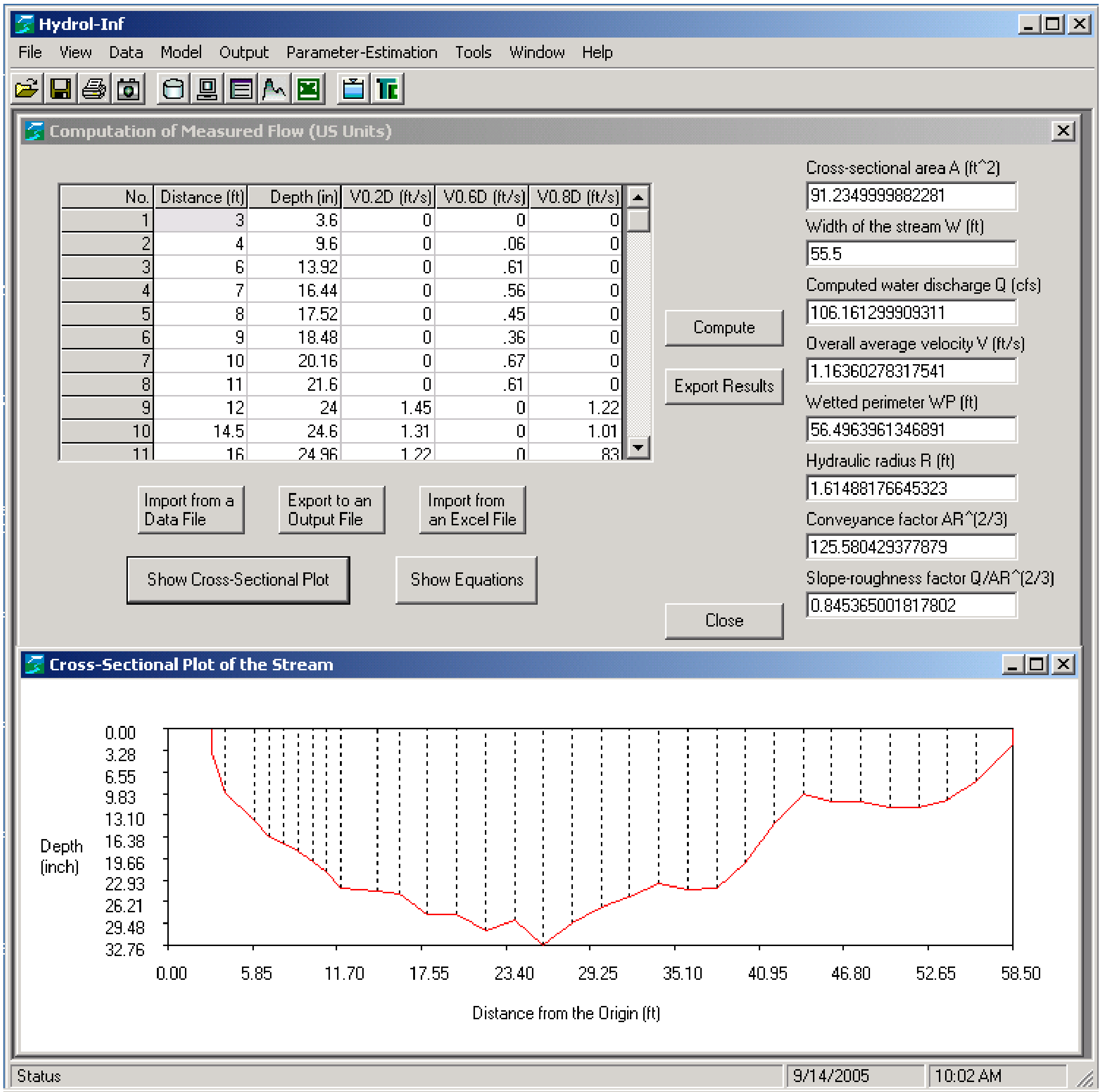
(4) Conveyance Factor:

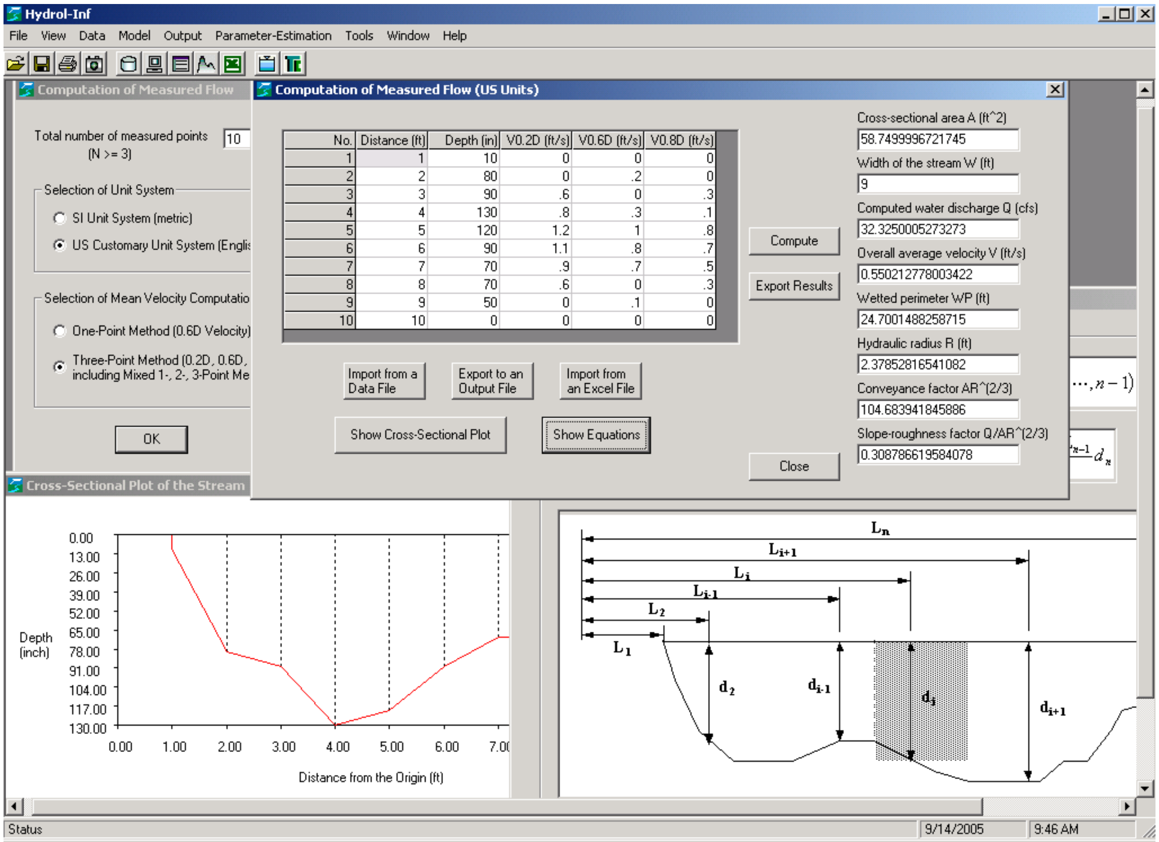
$$f_K = AR^{2/3}$$

(5) Slope-Roughness Factor:

$$f_{sr} = \frac{Q}{AR^{2/3}}$$




Hydrol-Inf
File View Data Model Output Parameter-Estimation Tools Window Help
Computation of Measured Flow (US Units)
No. Distance (ft) Depth (in) V0.2D (ft/s) V0.6D (ft/s) V0.8D (ft/s)
1 3 3.6 0 0 0
2 4 9.6 0 .06 0
3 6 13.92 0 .61 0
4 7 16.44 0 .56 0
5 8 17.52 0 .45 0
6 9 18.48 0 .36 0
7 10 20.16 0 .67 0
8 11 21.6 0 .61 0
9 12 24 1.45 0 1.22
10 14.5 24.6 1.31 0 1.01
Compute
Export Results
Cross-sectional area A (ft^2)
91.2349999882281
Width of the stream W (ft)
55.5
Computed water discharge Q (cfs)
106.161299909311
Overall average velocity V (ft/s)
1.16360278317541
Wetted perimeter WP (ft)
56.4963961346891
Hydraulic radius R (ft)
1.61488176645323
Conveyance factor AR^(2/3)
125.580429377879
Slope-roughness factor Q/AR^(2/3)
0.845365001817802
Import from a Data File
Export to an Output File
Import from an Excel File
Show Cross-Sectional Plot
Show Equations
Close
Cross-Sectional Plot of the Stream
Depth (inch)
0.00
3.28
6.55
9.83
13.10
16.38
19.66
22.93
26.21
29.48
32.76
0.00
5.85
11.70
17.55
23.40
29.25
35.10
40.95
46.80
52.65
58.50
Distance from the Origin (ft)
Status
9/14/2005
10:02 AM



10.2 Time of Concentration Calculator

Time of concentration can be estimated by using the following methods depending upon actual conditions (ASCE, 1996; USDA, 1986; Wanielista et al., 1997).

1) Kirpich

$$T_c = 0.0078 \frac{L^{0.77}}{S^{0.385}}$$

where L = length of flow (ft) and S = slope (ft/ft)
Application Conditions: small rural basins (1.2-112 acres); steep slopes (3%-10%); overland flow on bare soil; for overland flow on concrete or asphalt surfaces multiply by 0.4; for concrete channels multiply by 0.2.

2) Izzard

$$T_c = \frac{41.025(0.0007i + c_r)L^{1/3}}{S^{1/3} i^{2/3}}$$

where i = rainfall intensity (in/hr), c_r = retardation coefficient, L = length of flow (ft), and S = slope (ft/ft)
Application Conditions: overland flow on roadway and turf surface; iL < 500 in. ft/hr; Requires iteration; c_r = 0.007 for very smooth pavement (asphalt); c_r =

0.0075 for tar and sand pavement; c_r = 0.012 for concrete pavement; c_r = 0.06 for dense turf.

3) Kerby

$$T_c = 0.8262 \frac{L^{0.467} n^{0.467}}{S^{0.2335}}$$

where n = Manning roughness coefficient or retardation coefficient, L = length of flow (ft), and S = mean slope of the basin (ft/ft).
Application Conditions: overland flow on small watersheds (<4.047 ha or 10 ac); L< 1000 ft; n = 0.02 for smooth pavement; n = 0.3 for poor grass; n = 0.4 for average grass; n = 0.8 for dense grass.

4) Federal Aviation Agency

$$T_c = \frac{0.3884(1.1 - C)L^{0.5}}{S^{0.333}}$$

where C = rational runoff coefficient, L = length of overland flow (ft), and S = average overland slope (ft/ft).
Application Conditions: overland flow; frequently used for urban basins.

5) Kinematic Wave

$$T_c = \frac{0.93 L^{0.6} n^{0.6}}{i^{0.4} S^{0.3}}$$

where n = Manning roughness coefficient for overland flow, L = length of overland flow (ft), i = rainfall intensity (in/hr), and S = average overland slope (ft/ft).
Application Conditions: overland flow; L < 300 ft; requires iteration.

6) SCS Lag Equation

$$T_c = \frac{L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7}}{189.62 S^{0.5}}$$

where L = watershed hydraulic length (ft), CN = runoff curve number, and S = average watershed slope (ft/ft).
Application Conditions: agricultural watersheds; small urban basins (< 2000 acres); assuming $T_c = 1.67\ T_L$.

7) NRCS TR-55

Sheet flow travel time (min), T_{st}

$$T_{st} = \frac{0.42(n_{st} L_{st})^{0.8}}{P_2^{\ 0.5} S_{st}^{\ 0.4}}$$

where n_{st} = Manning's roughness coefficient for sheet flow, L_{st} = sheet flow length (ft) ($L_{st} \leq 300$ ft); P_2 = 2-year, 24-hour rainfall (in), and S_{st} = slope of hydraulic grade line (land slope, ft/ft).
Shallow concentrated flow travel time (min), T_{sc}

$$T_{sc} = \frac{L_{sc}}{60 C_c S_{sc}^{0.5}}$$

where L_{sc} = shallow concentrated flow length (ft), C_c = channel type coefficient (unpaved channel: C_c = 16.1345; paved channel: C_c = 20.3282), and S_{sc} = slope of hydraulic grade line (watercourse slope, ft/ft).

Open Channel flow travel time (min), T_{oc}

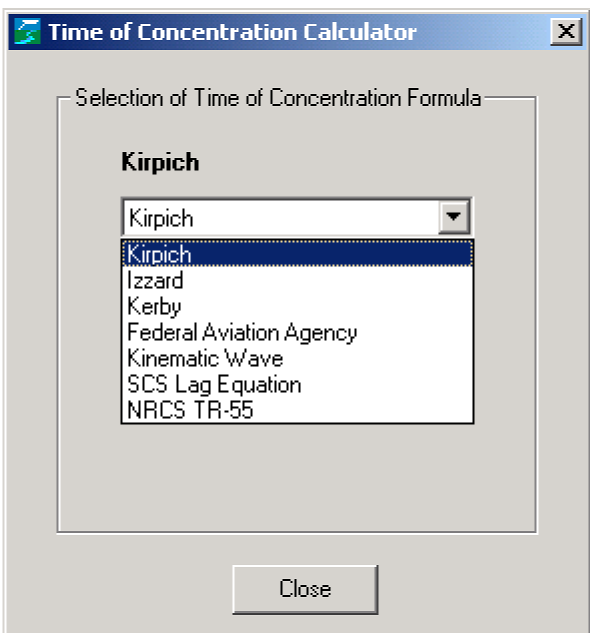
$$T_{oc} = \frac{L_{oc} n_{oc} P_w^{2/3}}{89.4 A_c^{2/3} S_{oc}^{1/2}}$$

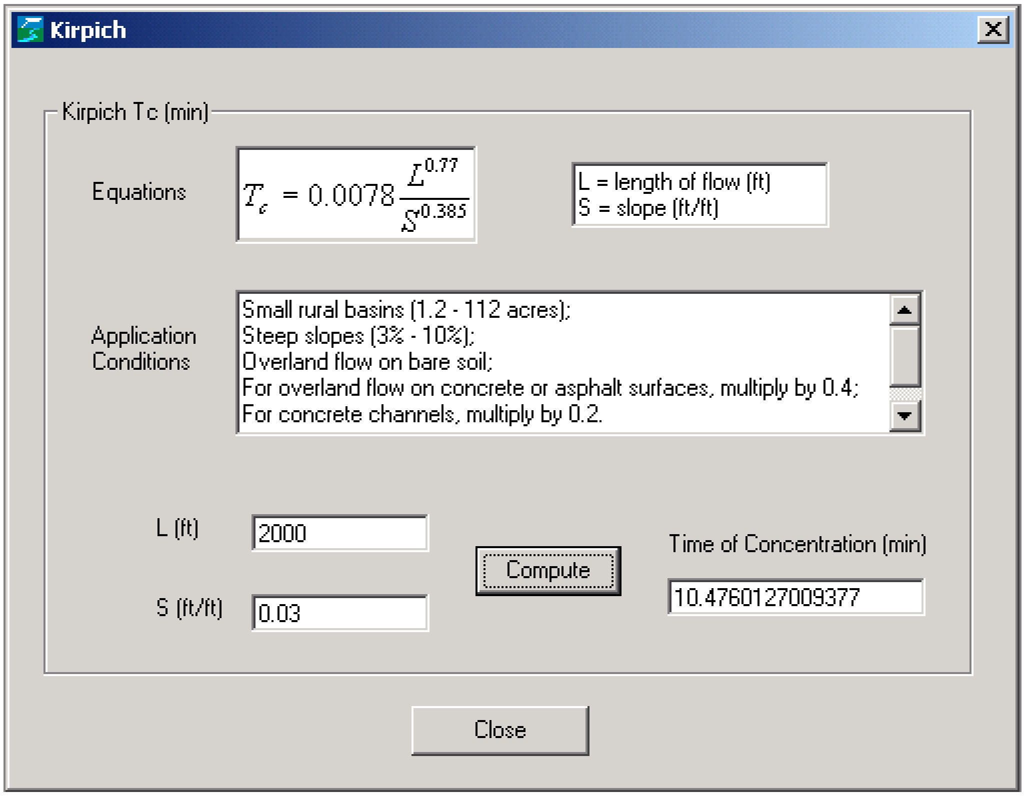
where L_{oc} = open channel flow length (ft), n_{oc} = Manning's roughness coefficient for open channel flow, P_w = wetted perimeter (ft), A_c = cross sectional area (ft^2), and S_{oc} = slope of hydraulic grade line (channel slope, ft/ft).

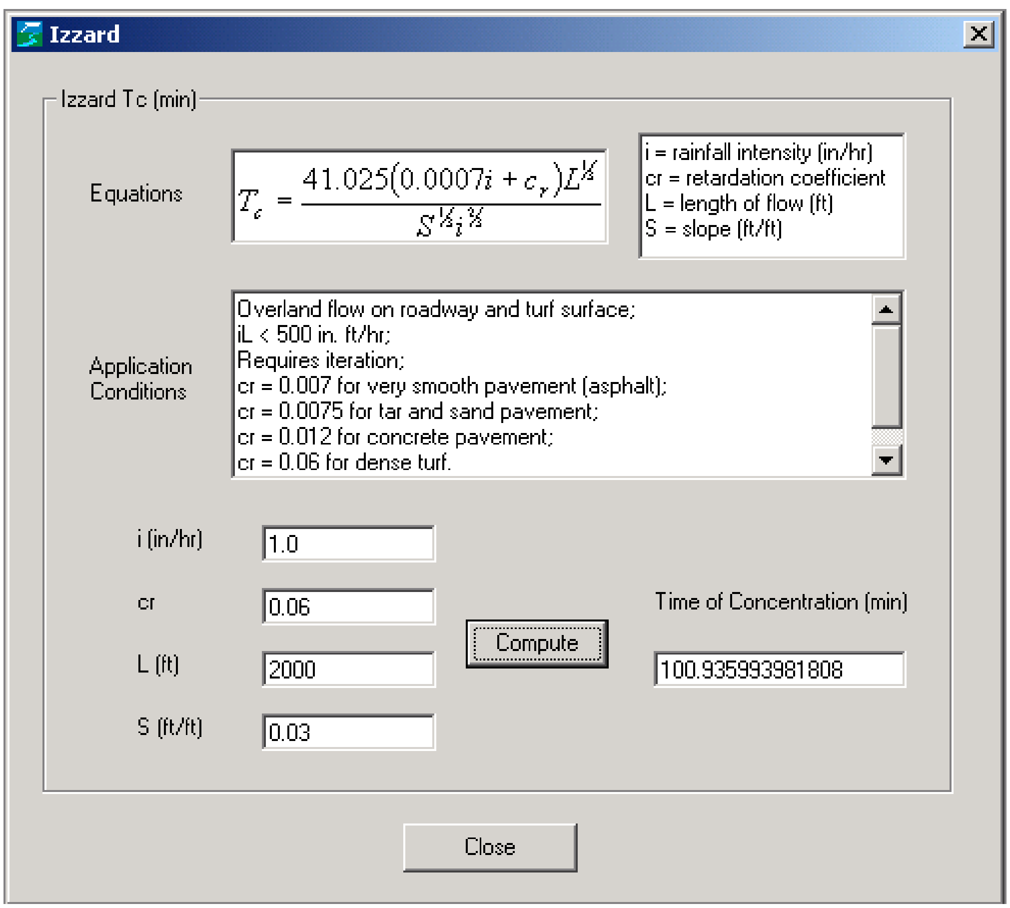
Total time of concentration (min), T_c

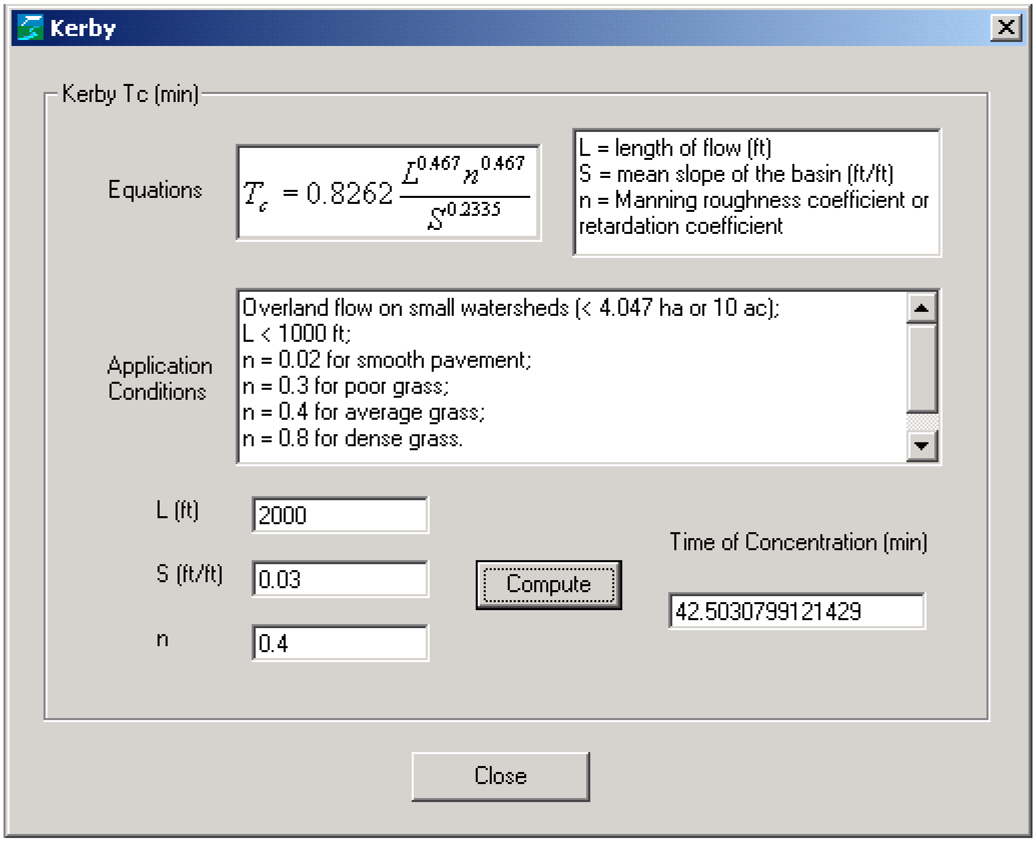
$$T_c = T_{st} + T_{sc} + T_{oc}$$

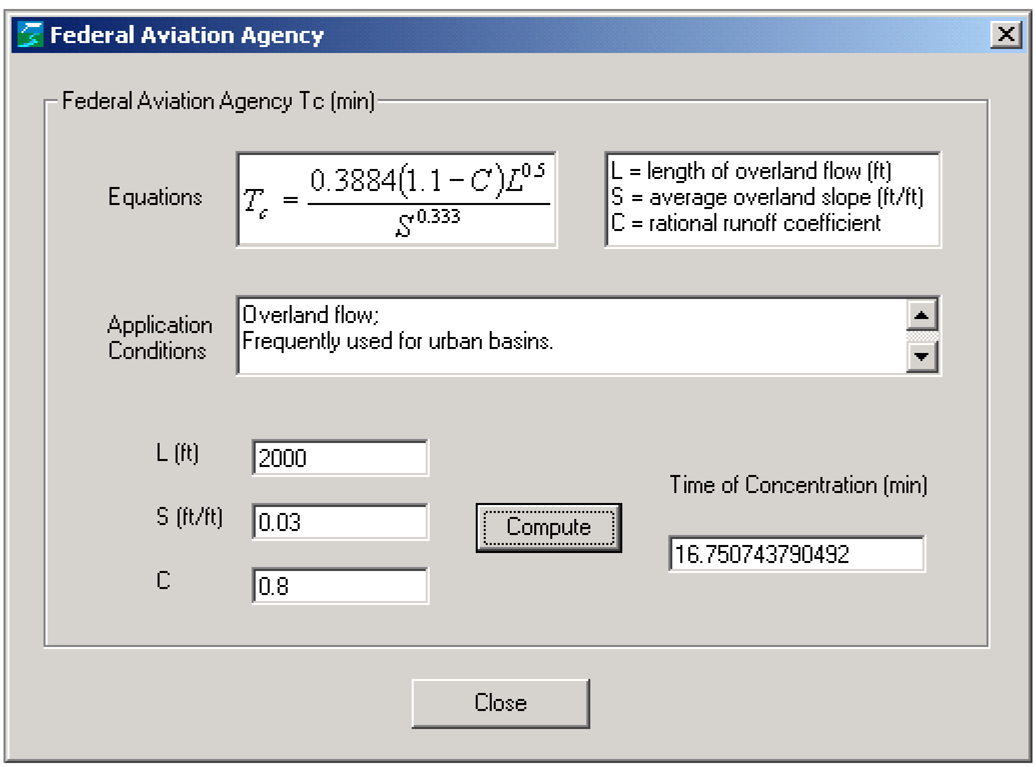
Application Conditions: Movement of the surface water in a watershed is characterized by three major types of flow: sheet flow, shallow concentrated flow, and open channel flow; after a maximum of 300 ft, sheet flow becomes shallow concentrated flow; steady uniform sheet flow.

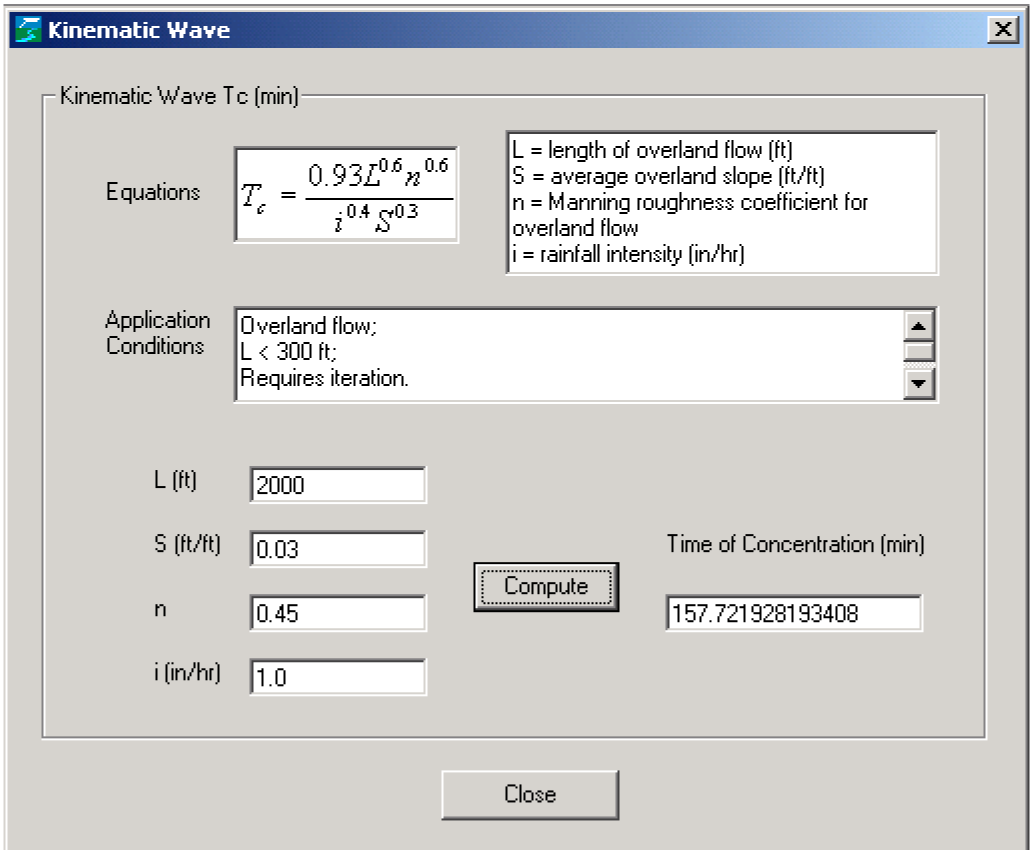


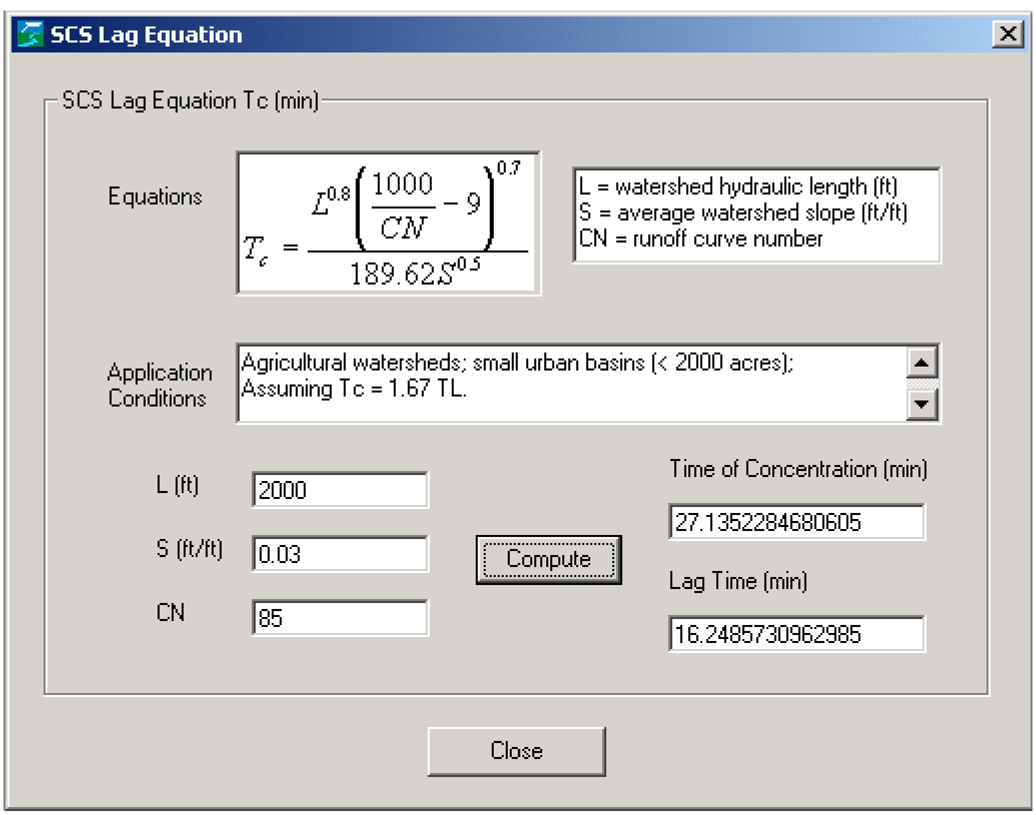

Kirpich
Kirpich Tc (min)
Equations
$T_c = 0.0078 \frac{L^{0.77}}{S^{0.385}}$
L = length of flow (ft)
S = slope (ft/ft)
Application Conditions
Small rural basins (1.2 - 112 acres);
Steep slopes (3% - 10%);
Overland flow on bare soil;
For overland flow on concrete or asphalt surfaces, multiply by 0.4;
For concrete channels, multiply by 0.2.
L (ft)
2000
S (ft/ft)
0.03
Compute
Time of Concentration (min)
10.4760127009377
Close

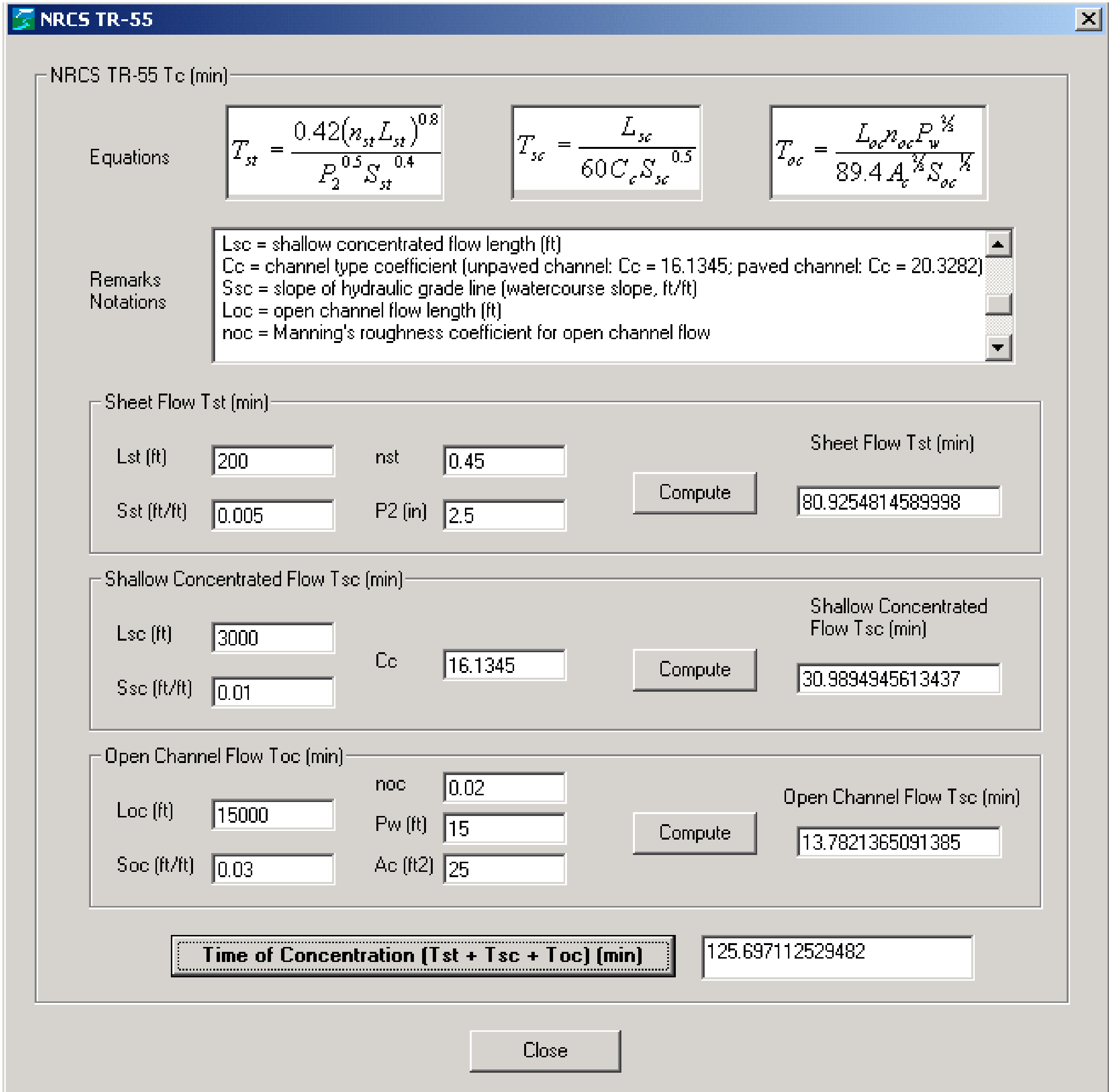

Izzard
Izzard Tc (min)
Equations
$T_c = \frac{41.025(0.0007i + c_r)L^{1/3}}{S^{1/3} i^{2/3}}$
i = rainfall intensity (in/hr)
cr = retardation coefficient
L = length of flow (ft)
S = slope (ft/ft)
Application Conditions
Overland flow on roadway and turf surface;
iL < 500 in. ft/hr;
Requires iteration;
cr = 0.007 for very smooth pavement (asphalt);
cr = 0.0075 for tar and sand pavement;
cr = 0.012 for concrete pavement;
cr = 0.06 for dense turf.
i (in/hr)
1.0
cr
0.06
L (ft)
2000
S (ft/ft)
0.03
Compute
Time of Concentration (min)
100.935993981808
Close


Kerby
Kerby Tc (min)
Equations
$T_c = 0.8262 \frac{L^{0.467} n^{0.467}}{S^{0.2335}}$
L = length of flow (ft)
S = mean slope of the basin (ft/ft)
n = Manning roughness coefficient or retardation coefficient
Application Conditions
Overland flow on small watersheds (< 4.047 ha or 10 ac);
L < 1000 ft;
n = 0.02 for smooth pavement;
n = 0.3 for poor grass;
n = 0.4 for average grass;
n = 0.8 for dense grass.
L (ft)
2000
S (ft/ft)
0.03
n
0.4
Compute
Time of Concentration (min)
42.5030799121429
Close


Federal Aviation Agency
Federal Aviation Agency Tc (min)
Equations
$T_c = \frac{0.3884(1.1 - C)L^{0.5}}{S^{0.333}}$
L = length of overland flow (ft)
S = average overland slope (ft/ft)
C = rational runoff coefficient
Application Conditions
Overland flow;
Frequently used for urban basins.
L (ft)
2000
S (ft/ft)
0.03
C
0.8
Compute
Time of Concentration (min)
16.750743790492
Close

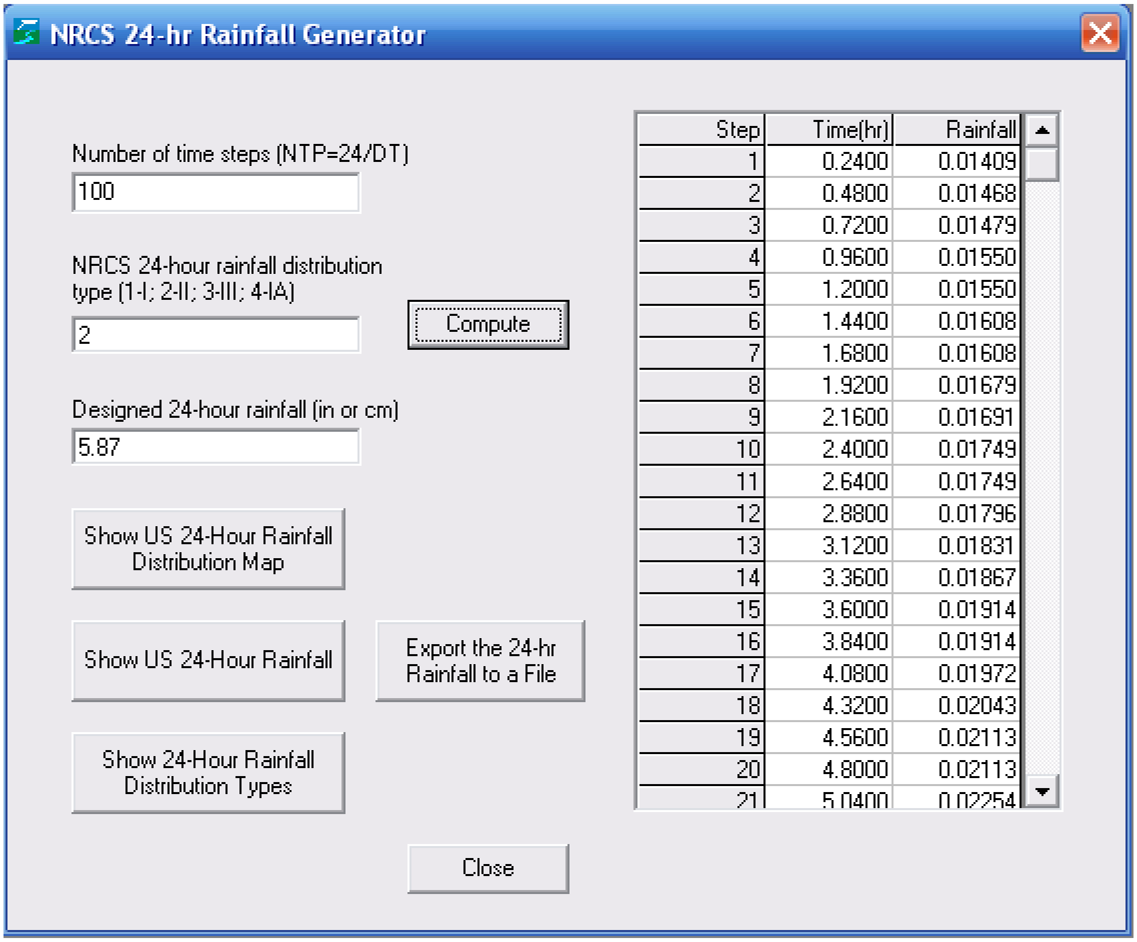

Kinematic Wave
Kinematic Wave Tc (min)
Equations
$T_c = \frac{0.93 L^{0.6} n^{0.6}}{i^{0.4} S^{0.3}}$
L = length of overland flow (ft)
S = average overland slope (ft/ft)
n = Manning roughness coefficient for overland flow
i = rainfall intensity (in/hr)
Application Conditions
Overland flow;
L < 300 ft;
Requires iteration.
L (ft)
2000
S (ft/ft)
0.03
n
0.45
i (in/hr)
1.0
Compute
Time of Concentration (min)
157.721928193408
Close

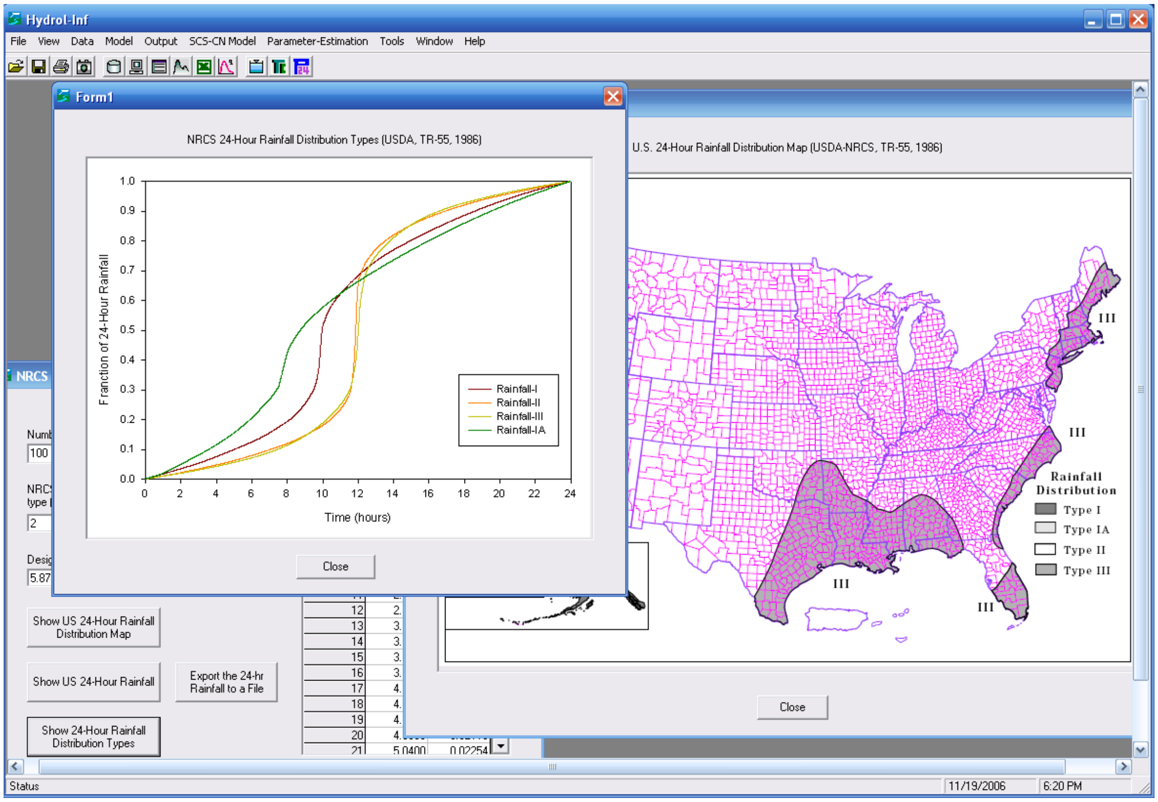

SCS Lag Equation
SCS Lag Equation Tc (min)
Equations
$T_c = \frac{L^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7}}{189.62 S^{0.5}}$
L = watershed hydraulic length (ft)
S = average watershed slope (ft/ft)
CN = runoff curve number
Application Conditions
Agricultural watersheds; small urban basins (< 2000 acres);
Assuming Tc = 1.67 TL.
L (ft)
2000
S (ft/ft)
0.03
CN
85
Compute
Time of Concentration (min)
27.1352284680605
Lag Time (min)
16.2485730962985
Close

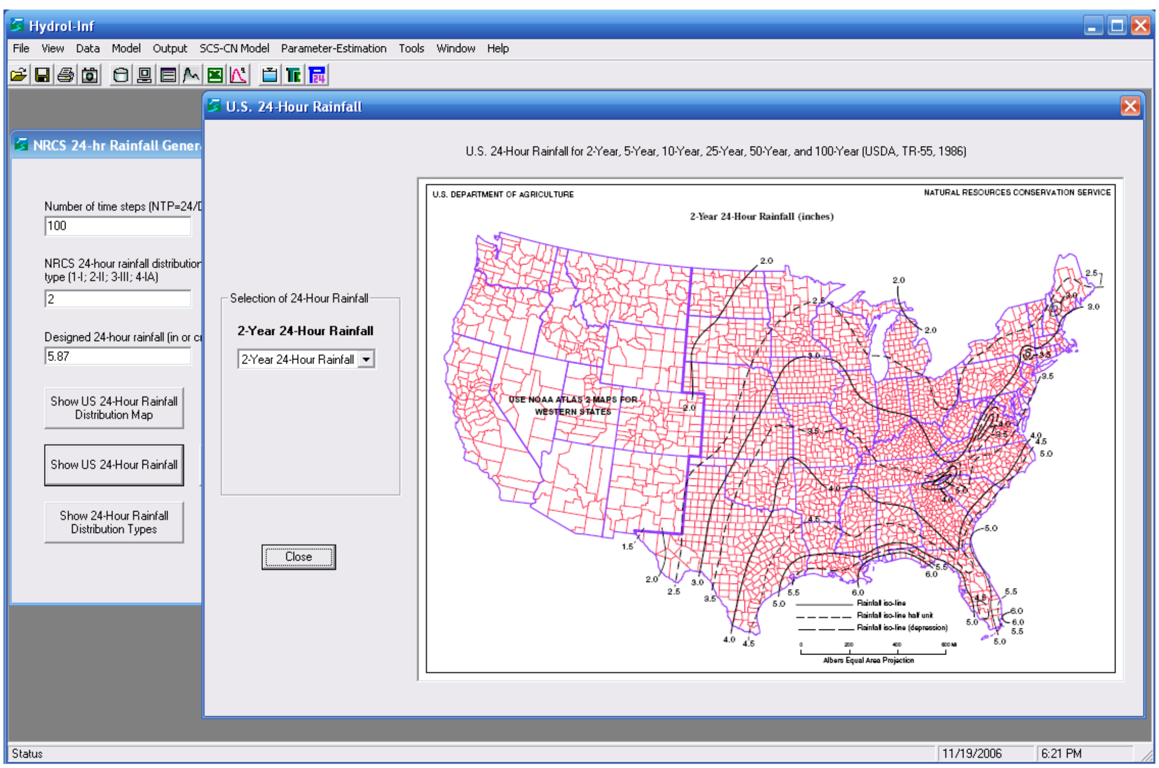


10.3 24-Hour Rainfall Generator

For a designed rainfall (2-year, 5-year, 10-year, 25-year, 50-year, or 100-year), the USDA-NRCS (SCS) 24-rainfall distributions (USDA, 1986) can be applied to generate the corresponding rainfall time series. In this tool, three parameters need to be specified, which include the number of time points for 24 hours, type of the rainfall distribution (I, II, III, or IA), and the total 24-hour rainfall. The relevant information can be easily accessed via buttons on the interface of the tool. The calculated 24-hour rainfall can also be exported to an EXCEL file.


NRCS 24-hr Rainfall Generator
Number of time steps (NTP=24/DT)
100
NRCS 24-hour rainfall distribution type (1-I; 2-II; 3-III; 4-IA)
2
Compute
Designed 24-hour rainfall (in or cm)
5.87
Show US 24-Hour Rainfall Distribution Map
Show US 24-Hour Rainfall
Export the 24-hr Rainfall to a File
Show 24-Hour Rainfall Distribution Types
Close
Step Time(hr) Rainfall
1 0.2400 0.01409
2 0.4800 0.01468
3 0.7200 0.01479
4 0.9600 0.01550
5 1.2000 0.01550
6 1.4400 0.01608
7 1.6800 0.01608
8 1.9200 0.01679
9 2.1600 0.01691
10 2.4000 0.01749
11 2.6400 0.01749
12 2.8800 0.01796
13 3.1200 0.01831
14 3.3600 0.01867
15 3.6000 0.01914
16 3.8400 0.01914
17 4.0800 0.01972
18 4.3200 0.02043
19 4.5600 0.02113
20 4.8000 0.02113
21 5.0400 0.02254

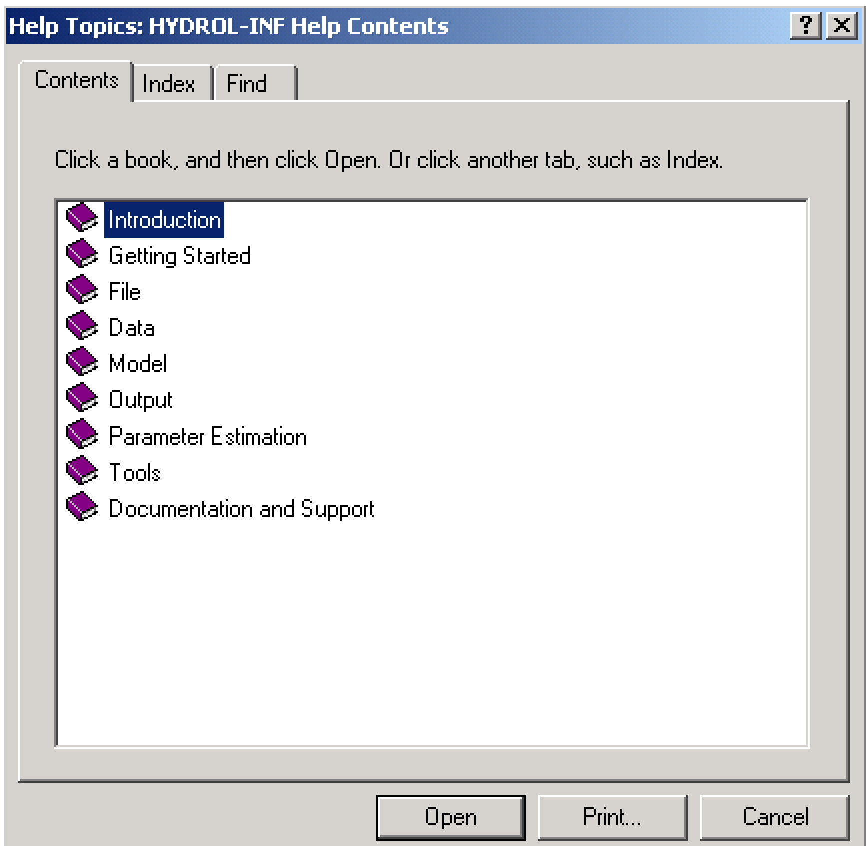


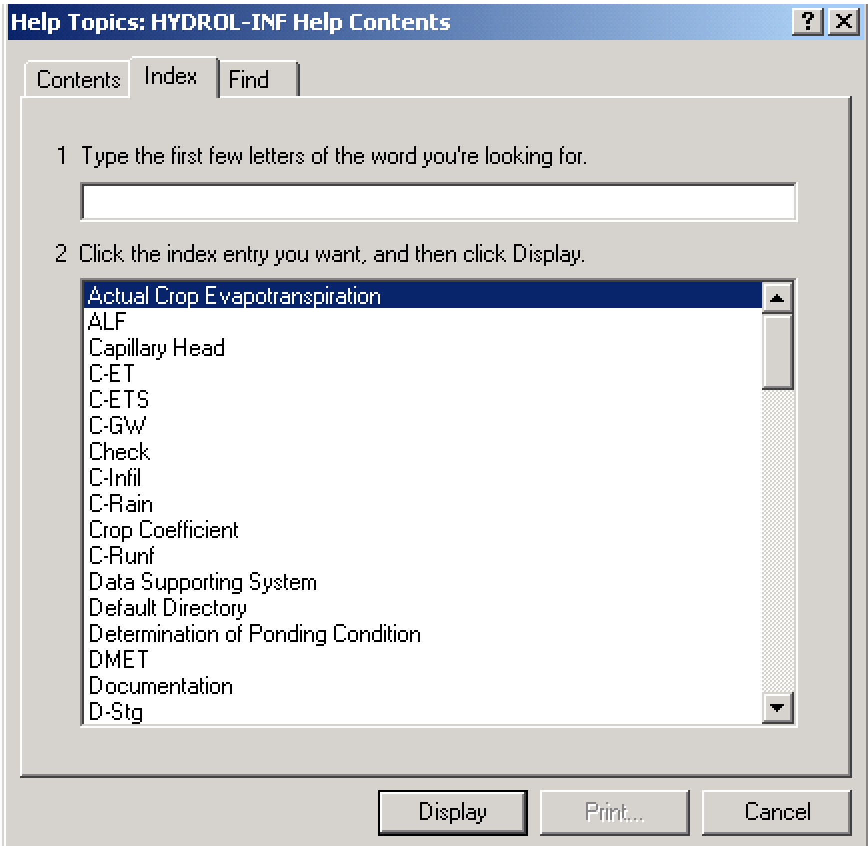


11. Help and Documentation

11.1 Help System

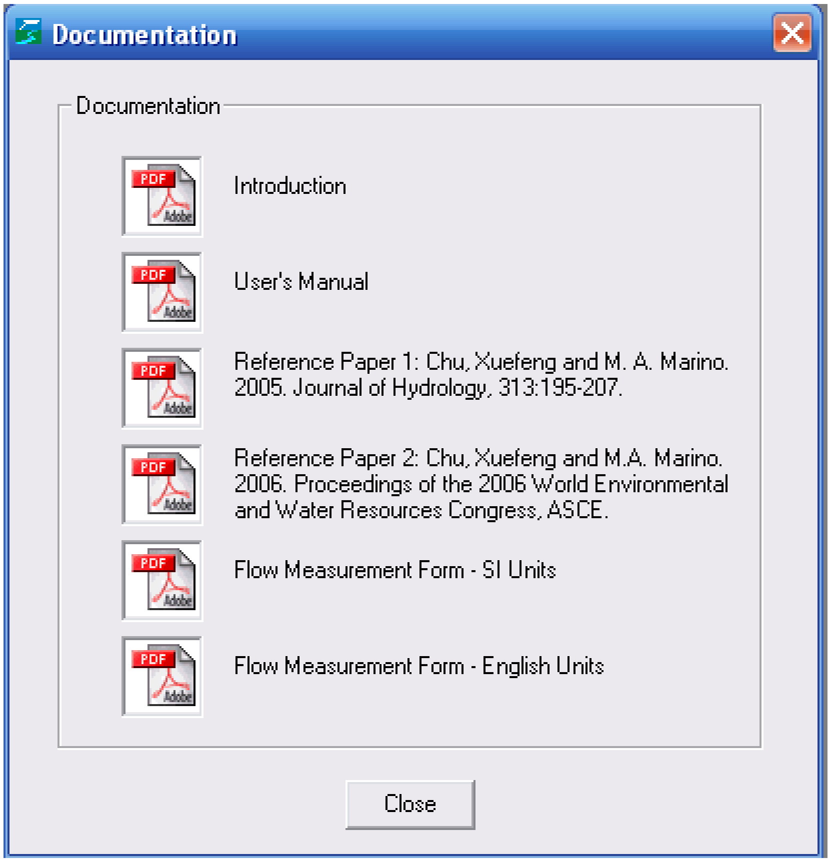
The help system covers all major topics associated with use of the model, input data and parameter estimation, as well as hydrologic tools and documentation. Users can find the answers to most of their questions from the help system.

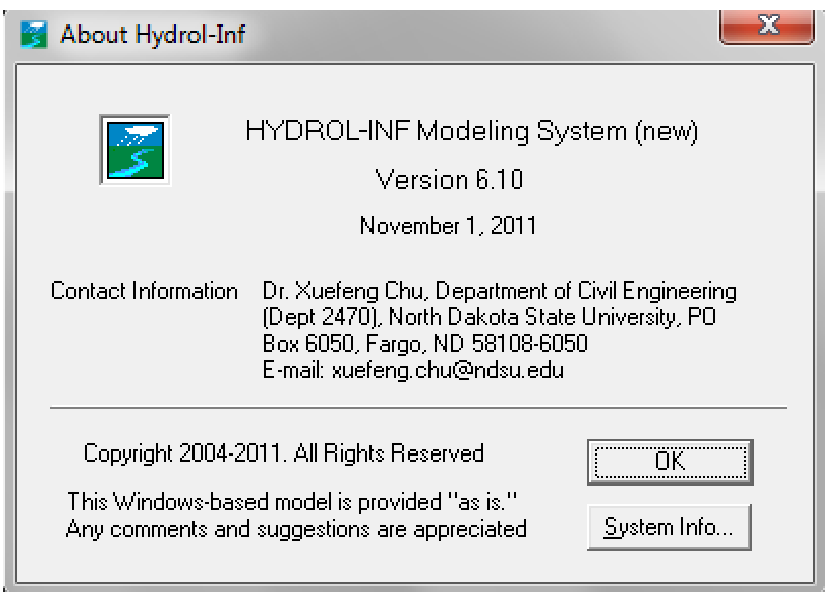




11.2 Documentation and Support

This User's Manual is the primary documentation. To help users understand the underlying theoretical background, relevant papers also are included in this Windows-based model. Additionally, users can visit our Hydrol-Inf website to check any updated information. Limited technical support can be available via e-mail (xuefeng.chu@ndsu.edu). Any comments and improvement suggestions on HYDROL-INF are greatly appreciated.


Documentation
Documentation
Introduction
User's Manual
Reference Paper 1: Chu, Xuefeng and M. A. Marino. 2005. Journal of Hydrology, 313:195-207.
Reference Paper 2: Chu, Xuefeng and M.A. Marino. 2006. Proceedings of the 2006 World Environmental and Water Resources Congress, ASCE.
Flow Measurement Form - SI Units
Flow Measurement Form - English Units
Close


About Hydrol-Inf
HYDROL-INF Modeling System (new)
Version 6.10
November 1, 2011
Contact Information
Dr. Xuefeng Chu, Department of Civil Engineering (Dept 2470), North Dakota State University, PO Box 6050, Fargo, ND 58108-6050
E-mail: xuefeng.chu@ndsu.edu
Copyright 2004-2011. All Rights Reserved
This Windows-based model is provided "as is." Any comments and suggestions are appreciated
OK
System Info...

12 References

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Appendix 1. Tables

Table 1 Saturated Hydraulic Conductivity KS (cm/hr)

Soil Texture Class	KS (cm/hr) [a]	KS (cm/hr) [b, c]
Sand	29.7	23.56
Loamy Sand	14.59	5.98
Sandy Loam	4.42	2.18
Loam	1.04	1.32
Silt	0.25	
Silt Loam	0.45	0.68
Sandy Clay Loam	1.31	0.30
Clay Loam	0.26	0.20
Silty Clay Loam	0.07	0.20
Sandy Clay	0.12	0.12
Silty Clay	0.02	0.10
Clay	0.20	0.06

[a] Carsel and Parrish, 1988.
[b] Rawls and Brakensiek, 1983.
[c] Maidment, 1993.

Table 2 Capillary Head HWT (cm)

Soil Texture Class	HWT (cm) [a, b]
Sand	4.95 (0.97-25.36)
Loamy Sand	6.13 (1.35-27.94)
Sandy Loam	11.01 (2.67-45.47)
Loam	8.89 (1.33-59.38)
Silt Loam	16.68 (2.92-95.39)
Sandy Clay Loam	21.85 (4.42-108.0)
Clay Loam	20.88 (4.79-91.10)
Silty Clay Loam	27.30 (5.67-131.50)
Sandy Clay	23.90 (4.08-140.2)
Silty Clay	29.22 (6.13-139.4)
Clay	31.63 (6.39-156.5)

[a] Rawls and Brakensiek, 1983.
[b] Maidment, 1993.

Table 3 Saturated Water Content WS (cm^3/cm^3)

Soil Texture Class	WS (cm^3/cm^3) [a]
Sand	0.43
Loamy Sand	0.41
Sandy Loam	0.41

Loam	0.43
Silt	0.46
Silt Loam	0.45
Sandy Clay Loam	0.39
Clay Loam	0.41
Silty Clay Loam	0.43
Sandy Clay	0.38
Silty Clay	0.36
Clay	0.38

[a] Carsel and Parrish, 1988.

Table 4 Residual Water Content WR (cm^3/cm^3)

Soil Texture Class	WR (cm^3/cm^3) [a]
Sand	0.045
Loamy Sand	0.057
Sandy Loam	0.065
Loam	0.078
Silt	0.034
Silt Loam	0.067
Sandy Clay Loam	0.100
Clay Loam	0.095
Silty Clay Loam	0.089
Sandy Clay	0.100
Silty Clay	0.070
Clay	0.068

[a] Carsel and Parrish, 1988.

Table 5 Soil Water Retention Parameter n VN [a]

Soil Type	VN
Sand	2.68
Loamy Sand	2.28
Sandy Loam	1.89
Loam	1.56
Silt	1.37
Silt Loam	1.41
Sandy Clay Loam	1.48
Clay Loam	1.31
Silty Clay Loam	1.23
Sandy Clay	1.23
Silty Clay	1.09
Clay	1.09

[a] Carsel and Parrish, 1988.

Table 6 Soil Water Retention Parameter α ALF (1/cm) [a]

Soil Type	α (1/cm) [a]
Sand	0.145
Loamy Sand	0.124
Sandy Loam	0.075
Loam	0.036
Silt	0.016
Silt Loam	0.020
Sandy Clay Loam	0.059
Clay Loam	0.019
Silty Clay Loam	0.010
Sandy Clay	0.027
Silty Clay	0.005
Clay	0.008

[a] Carsel and Parrish, 1988.

Table 7 Field Capacity FC (cm^3/cm^3) [a]

Soil Texture Class	Textural Properties (%)			FC (Water Retained at -0.33 Bar Tension)
	Sand	Silt	Clay	
Sand	85-100	0-15	0-10	0.091 (0.018-0.164)
Loamy Sand	70-90	0-30	0-15	0.125 (0.060-0.190)
Sandy Loam	45-85	0-50	0-20	0.207 (0.126-0.288)
Loam	25-50	28-50	8-28	0.270 (0.195-0.345)
Silt Loam	0-50	50-100	8-28	0.330 (0.258-0.402)
Sandy Clay Loam	45-80	0-28	20-35	0.257 (0.186-0.324)
Clay Loam	20-45	15-55	28-50	0.318 (0.250-0.386)
Silty Clay Loam	0-20	40-73	28-40	0.366 (0.304-0.428)
Sandy Clay	45-65	0-20	35-55	0.339 (0.245-0.433)
Silty Clay	0-20	40-60	40-60	0.387 (0.332-0.442)
Clay	0-45	0-40	40-100	0.396 (0.326-0.466)

[a] Rawls et al., 1982.

Table 8 Wilting Point WP (cm^3/cm^3) [a]

Soil Texture Class	Textural Properties (%)			WP (Water Retained at -15.0 Bar Tension)
	Sand	Silt	Clay	
Sand	85-100	0-15	0-10	0.033 (0.007-0.059)
Loamy Sand	70-90	0-30	0-15	0.055 (0.019-0.091)
Sandy Loam	45-85	0-50	0-20	0.095 (0.031-0.159)

Loam	25-50	28-50	8-28	0.117 (0.069-0.165)
Silt Loam	0-50	50-100	8-28	0.133 (0.078-0.188)
Sandy Clay Loam	45-80	0-28	20-35	0.148 (0.085-0.211)
Clay Loam	20-45	15-55	28-50	0.197 (0.115-0.279)
Silty Clay Loam	0-20	40-73	28-40	0.208 (0.138-0.278)
Sandy Clay	45-65	0-20	35-55	0.239 (0.162-0.316)
Silty Clay	0-20	40-60	40-60	0.250 (0.193-0.307)
Clay	0-45	0-40	40-100	0.272 (0.208-0.336)

[a] Rawls et al., 1982.

Table 9 Crop Coefficients and Mean Maximum Plant Heights [a]

Crop	Kc ini [1]	Kc mid	Kc end	Maximum Crop Height h (m)
a. Small Vegetables	0.7	1.05	0.95	
Broccoli		1.05	0.95	0.3
Brussel Sprouts		1.05	0.95	0.4
Cabbage		1.05	0.95	0.4
Carrots		1.05	0.95	0.3
Cauliflower		1.05	0.95	0.4
Celery		1.05	1.00	0.6
Garlic		1.00	0.70	0.3
Lettuce		1.00	0.95	0.3
Onions - dry - green - seed		1.05 1.00 1.05	0.75 1.00 0.80	0.4 0.3 0.5
Spinach		1.00	0.95	0.3
Radish		0.90	0.85	0.3
b. Vegetables – Solanum Family (*Solanaceae*)	0.6	1.15	0.80	
Egg Plant		1.05	0.90	0.8
Sweet Peppers (bell)		1.05[2]	0.90	0.7
Tomato		1.15[2]	0.70-0.90	0.6
c. Vegetables – Cucumber Family (*Cucurbitaceae*)	0.5	1.00	0.80	
Cantaloupe	0.5	0.85	0.60	0.3

Cucumber - Fresh Market - Machine harvest	0.6 0.5	1.00[2] 1.00	0.75 0.90	0.3 0.3
Pumpkin, Winter Squash		1.00	0.80	0.4
Squash, Zucchini		0.95	0.75	0.3
Sweet Melons		1.05	0.75	0.4
Watermelon	0.4	1.00	0.75	0.4
d. Roots and Tubers	0.5	1.10	0.95	
Beets, table		1.05	0.95	0.4
Cassava - year 1 - year 2	0.3 0.3	0.80[3] 1.10	0.30 0.50	1.0 1.5
Parsnip	0.5	1.05	0.95	0.4
Potato		1.15	0.75[4]	0.6
Sweet Potato		1.15	0.65	0.4
Turnip (and Rutabaga)		1.10	0.95	0.6
Sugar Beet	0.35	1.20	0.70[5]	0.5
e. Legumes (*Leguminosae*)	0.4	1.15	0.55	
Beans, green	0.5	1.05[2]	0.90	0.4
Beans, dry and Pulses	0.4	1.15[2]	0.35	0.4
Chick pea		1.00	0.35	0.4
Fababean (broad bean) - Fresh - Dry/Seed	0.5	1.15[2] 1.15	1.10 0.30	0.5 0.5
Grabanzo	0.4	1.15	0.35	0.8
Green Gram and Cowpeas		1.05	0.60-0.35[6]	0.4
Groundnut (Peanut)		1.15	0.60	0.4
Lentil		1.10	0.30	0.5
Peas - Fresh - Dry/Seed	0.5	1.15[2] 1.15	1.10 0.30	0.5 0.5
Soybeans		1.15	0.50	0.5-1.0
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)	0.5	1.00	0.80	
Artichokes	0.5	1.00	0.95	0.7
Asparagus	0.5	0.95[7]	0.30	0.2-0.8
Mint	0.6	1.15	1.10	0.6-0.8
Strawberries	0.4	0.85	0.75	0.2
g. Fibre Crops	0.35			

Cotton		1.15-1.2	0.70-0.50	1.2-1.5
Flax		1.10	0.25	1.2
Sisal[8]		0.4-0.7	0.4-0.7	1.5
h. Oil Crops	0.35	1.15	0.35	
Castorbean (*Ricinus*)		1.15	0.55	0.3
Rapeseed, Canola		1.00-1.15[9]	0.35	0.6
Safflower		1.00-1.15[9]	0.25	0.8
Sesame		1.10	0.25	1.0
Sunflower		1.00-1.15[9]	0.35	2.0
i. Cereals	0.3	1.15	0.4	
Barley		1.15	0.25	1
Oats		1.15	0.25	1
Spring Wheat		1.15	0.25-0.4[10]	1
Winter Wheat - with frozen soils - with non-frozen soils	0.4 0.7	1.15 1.15	0.25-0.4[10] 0.25-0.4[10]	1
Maize, Field (grain) *(field corn)*		1.20	0.60,0.35[11]	2
Maize, Sweet *(sweet corn)*		1.15	1.05[12]	1.5
Millet		1.00	0.30	1.5
Sorghum - grain - sweet		1.00-1.10 1.20	0.55 1.05	1-2 2-4
Rice	1.05	1.20	0.90-0.60	1
j. Forages				
Alfalfa Hay - averaged cutting effects - individual cutting periods - for seed	0.40 0.40 0.40	0.95 1.20 0.50	0.90 1.15 0.50	0.7 0.7 0.7
Bermuda hay - averaged cutting effects - Spring crop for seed	0.55 0.35	1.00 0.90	0.85 0.65	0.35 0.40
Clover hay, Berseem - averaged cutting effects - individual cutting periods	 0.40 0.40[14]	 0.90[13] 1.15[14]	 0.85 1.10[14]	 0.6 0.6
Rye Grass hay - averaged cutting effects	0.95	1.05	1.00	0.3
Sudan Grass hay (annual) - averaged cutting effects - individual cutting periods	 0.50 0.50[14]	 0.90[14] 1.15[14]	 0.85 1.10[14]	 1.2 1.2
Grazing Pasture - Rotated Grazing - Extensive Grazing	0.40 0.30	0.85-1.05 0.75	0.85 0.75	0.15-0.30 0.10

Turf grass - cool season[15] - warm season[15]	0.90 0.80	0.95 0.85	0.95 0.85	0.10 0.10
k. Sugar Cane	0.40	1.25	0.75	3
l. Tropical Fruits and Trees				
Banana - 1st year - 2nd year	0.50 1.00	1.10 1.20	1.00 1.10	3 4
Cacao	1.00	1.05	1.05	3
Coffee - bare ground cover - with weeds	0.90 1.05	0.95 1.10	0.95 1.10	2-3 2-3
Date Palms	0.90	0.95	0.95	8
Palm Trees	0.95	1.00	1.00	8
Pineapple[16] - bare soil - with grass cover	0.50 0.50	0.30 0.50	0.30 0.50	0.6-1.2 0.6-1.2
Rubber Trees	0.95	1.00	1.00	10
Tea - non-shaded - shaded[17]	0.95 1.10	1.00 1.15	1.00 1.15	1.5 2
m. Grapes and Berries				
Berries (bushes)	0.30	1.05	0.50	1.5
Grapes - Table or Raisin - Wine	0.30 0.30	0.85 0.70	0.45 0.45	2 1.5-2
Hops	0.3	1.05	0.85	5
n. Fruit Trees				
Almonds, no ground cover	0.40	0.90	0.65[18]	5
Apples, Cherries, Pears[19] -no ground cover, killing frost -no ground cover, no frosts -active ground cover, killing frost -active ground cover, no frosts	 0.45 0.60 0.50 0.80	 0.95 0.95 1.20 1.20	 0.70[18] 0.75[18] 0.95[18] 0.85[18]	 4 4 4 4
Apricots, Peaches, Stone Fruit[19, 20] -no ground cover, killing frost -no ground cover, no frosts -active ground cover, killing frost -active ground cover, no frosts	 0.45 0.55 0.50 0.80	 0.90 0.90 1.15 1.15	 0.65[18] 0.65[18] 0.90[18] 0.85[18]	 3 3 3 3
Avocado, no ground cover	0.60	0.85	0.75	3
Citrus, no ground cover[21] - 70% canopy - 50% canopy - 20% canopy	 0.70 0.65 0.50	 0.65 0.60 0.45	 0.70 0.65 0.55	 4 3 2

Citrus, with active ground cover or weeds[22] - 70% canopy - 50% canopy - 20% canopy	 0.75 0.80 0.85	 0.70 0.80 0.85	 0.75 0.80 0.85	 4 3 2
Conifer Trees[23]	1.00	1.00	1.00	10
Kiwi	0.40	1.05	1.05	3
Olives (40 to 60% ground coverage by canopy)[24]	0.65	0.70	0.70	3-5
Pistachios, no ground cover	0.40	1.10	0.45	3-5
Walnut Orchard[19]	0.50	1.10	0.65[18]	4-5
o. Wetlands – temperate climate				
Cattails, Bulrushes, killing frost	0.30	1.20	0.30	2
Cattails, Bulrushes, no frost	0.60	1.20	0.60	2
Short Veg., no frost	1.05	1.10	1.10	0.3
Reed Swamp, standing water	1.00	1.20	1.00	1-3
Reed Swamp, moist soil	0.90	1.20	0.70	1-3
p. Special				
Open Water, < 2 m depth or in subhumid climates or tropics		1.05	1.05	
Open Water, > 5 m depth, clear of turbidity, temperate climate		0.65[25]	1.25[25]	

1. These are general values for Kc ini under typical irrigation management and soil wetting. For frequent wettings such as with high frequency sprinkle irrigation or daily rainfall, these values may increase substantially and may approach 1.0 to 1.2. Kc ini is a function of wetting interval and potential evaporation rate during the initial and development periods and is more accurately estimated using Figures 29 and 30, or Equation 7-3 in Annex 7, or using the dual Kcb ini + Ke.
2. Beans, Peas, Legumes, Tomatoes, Peppers and Cucumbers are sometimes grown on stalks reaching 1.5 to 2 meters in height. In such cases, increased Kc values need to be taken. For green beans, peppers and cucumbers, 1.15 can be taken, and for tomatoes, dry beans and peas, 1.20. Under these conditions h should be increased also.
3. The midseason values for cassava assume non-stressed conditions during or following the rainy season. The Kc end values account for dormancy during the dry season.
4. The Kc end value for potatoes is about 0.40 for long season potatoes with vine kill.
5. This Kc end value is for no irrigation during the last month of the growing season. The Kc end value for sugar beets is higher, up to 1.0, when irrigation or significant rain occurs during the last month.
6. The first Kc end is for harvested fresh. The second value is for harvested dry.

7. The Kc for asparagus usually remains at Kc ini during harvest of the spears, due to sparse ground cover. The Kc mid value is for following regrowth of plant vegetation following termination of harvest of spears.
8. Kc for sisal depends on the planting density and water management (e.g., intentional moisture stress).
9. The lower values are for rainfed crops having less dense plant populations.
10. The higher value is for hand-harvested crops.
11. The first Kc end value is for harvest at high grain moisture. The second Kc end value is for harvest after complete field drying of the grain (to about 18% moisture, wet mass basis).
12. If harvested fresh for human consumption. Use Kc end for field maize if the sweet maize is allowed to mature and dry in the field.
13. This Kc mid coefficient for hay crops is an overall average Kc mid coefficient that averages Kc for both before and following cuttings. It is applied to the period following the first development period until the beginning of the last late season period of the growing season.
14. These Kc coefficients for hay crops represent immediately following cutting; at full cover; and immediately before cutting, respectively. The growing season is described as a series of individual cutting periods (Figure 35).
15. Cool season grass varieties include dense stands of bluegrass, ryegrass, and fescue. Warm season varieties include bermuda grass and St. Augustine grass. The 0.95 values for cool season grass represent a 0.06 to 0.08 m mowing height under general turf conditions. Where careful water management is practiced and rapid growth is not required, Kc's for turf can be reduced by 0.10.
16. The pineapple plant has very low transpiration because it closes its stomates during the day and opens them during the night. Therefore, the majority of ETc from pineapple is evaporation from the soil. The Kc mid < Kc ini since Kc mid occurs during full ground cover so that soil evaporation is less. Values given assume that 50% of the ground surface is covered by black plastic mulch and that irrigation is by sprinkler. For drip irrigation beneath the plastic mulch, Kc's given can be reduced by 0.10.
17. Includes the water requirements of the shade trees.
18. These Kc end values represent Kc prior to leaf drop. After leaf drop, Kc end ≈ 0.20 for bare, dry soil or dead ground cover and Kc end ≈ 0.50 to 0.80 for actively growing ground cover (consult Chapter 11).
19. Refer to Eq. 94, 97 or 98 and footnotes 21 and 22 for estimating Kc for immature stands.
20. Stone fruit category applies to peaches, apricots, pears, plums and pecans.
21. These Kc values can be calculated from Eq. 98 for Kc min = 0.15 and Kc full = 0.75, 0.70 and 0.75 for the initial, mid season and end of season periods, and fc eff = fc where fc = fraction of ground covered by tree canopy (e.g., the sun is presumed to be directly overhead). The values listed correspond with those in Doorenbos and Pruitt (1977) and with more recent measurements. The midseason value is lower than initial and ending values due to the effects of stomatal closure during periods of peak ET. For humid and subhumid climates where there is less stomatal control by citrus,

values for Kc ini, Kc mid, and Kc end can be increased by 0.1 - 0.2, following Rogers et al. (1983).

22. These Kc values can be calculated as Kc = fc Kc ngc + (1 - fc) Kc cover where Kc ngc is the Kc of citrus with no active ground cover (calculated as in footnote 21), Kc cover is the Kc for the active ground cover (0.95), and fc is defined in footnote 21. The values listed correspond with those in Doorenbos and Pruitt (1977) and with more recent measurements. Alternatively, Kc for citrus with active ground cover can be estimated directly from Eq. 98 by setting Kc min = Kc cover. For humid and subhumid climates where there is less stomatal control by citrus, values for Kc ini, Kc mid, and Kc end can be increased by 0.1 - 0.2, following Rogers et al. (1983). For non-active or only moderately active ground cover (active indicates green and growing ground cover with LAI > about 2 to 3) , Kc should be weighted between Kc for no ground cover and Kc for active ground cover, with the weighting based on the "greenness" and approximate leaf area of the ground cover.
23. Confers exhibit substantial stomatal control due to reduced aerodynamic resistance. The Kc can easily reduce below the values presented, which represent well-watered conditions for large forests.
24. These coefficients represent about 40 to 60% ground cover. Refer to Eq. 98 and footnotes 21 and 22 for estimating Kc for immature stands. In Spain, Pastor and Orgaz (1994) have found the following monthly Kc's for olive orchards having 60% ground cover: 0.50, 0.50, 0.65, 0.60, 0.55, 0.50, 0.45, 0.45, 0.55, 0.60, 0.65, 0.50 for months January through December. These coefficients can be invoked by using Kc ini = 0.65, Kc mid = 0.45, and Kc end = 0.65, with stage lengths = 30, 90, 60 and 90 days, respectively for initial, development, midseason and late season periods, and sing Kc during the winter ("off season") in December to February = 0.50.
25. These Kc's are for deep water in temperate latitudes where large temperature changes in the water body occur during the year, and initial and peak period evaporation is low as radiation energy is absorbed into the deep water body. During fall and winter periods (Kc end), heat is released from the water body that increases the evaporation above that for grass. Therefore, Kc mid corresponds to the period when the water body is gaining thermal energy and Kc end when releasing thermal energy. These Kc's should be used with caution.

[a] Allen et al., 1998.

Appendix 2. Figures

Figure 1 Field Capacity (Rawls and Brakensiek, 1983; Carsel et al., 2003)

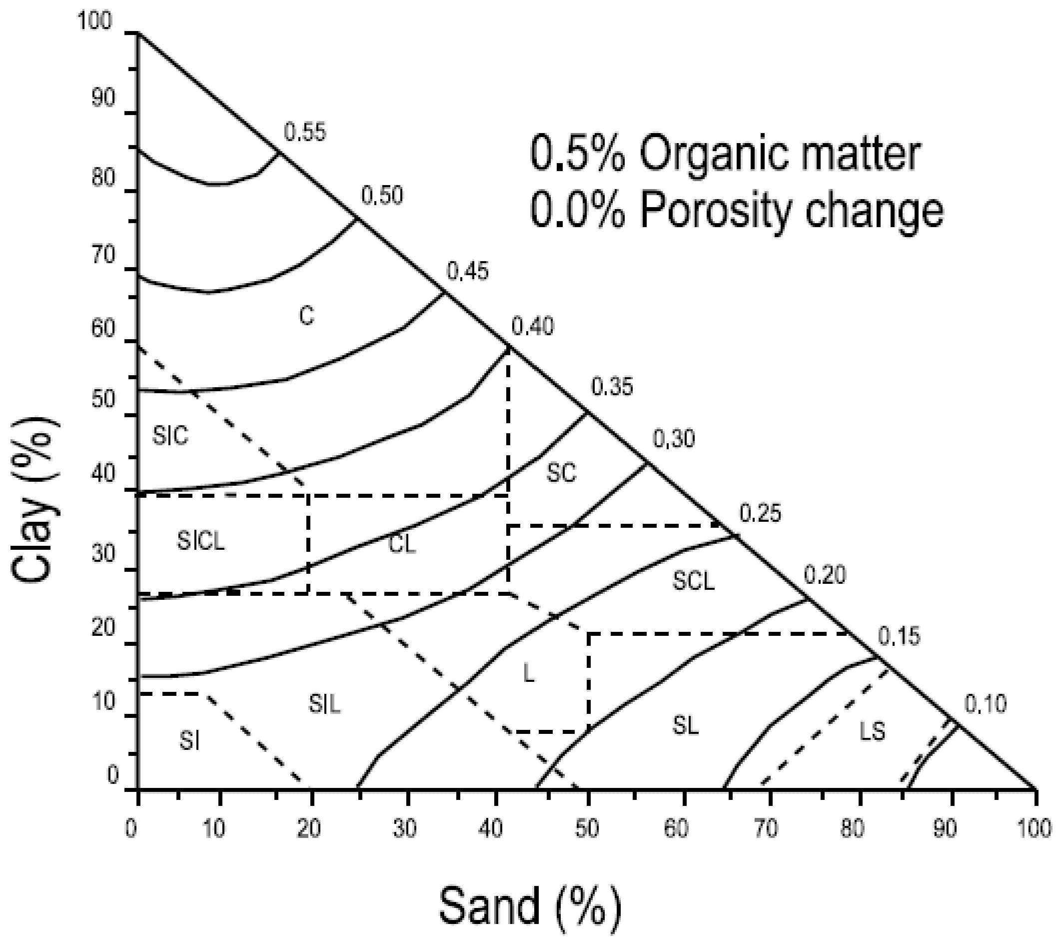
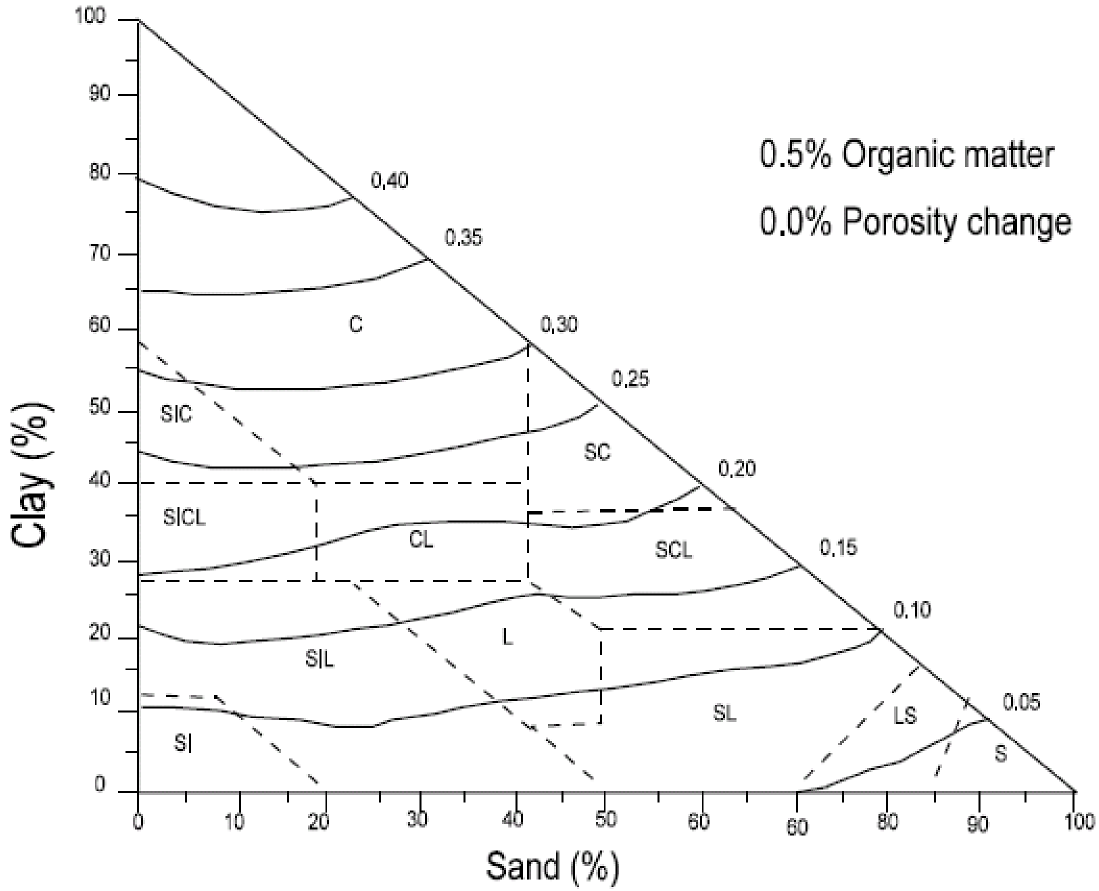


Figure 2 Wilting Point (Rawls and Brakensiek, 1983; Carsel et al., 2003)



Appendix 3. List of Input Data

AHA: Watershed area (ha)
ALF(I): Soil retention parameter (1/cm)
DMET: Maximum ET depth in soil (cm)
DT: Size of a time step (hr)
FC(I): Field capacity (cm^3/cm^3)
ET0(I): Potential evapotranspiration rate (cm/hr)
HWT(I): Capillary head (suction) (cm)
IMP: Percentage of directly-connected impervious area (%)
IU: Index of the UH method (1: SCS UH; 2: Clark UH)
KE(I): Effective hydraulic conductivity (cm/hr)
KBC(I): Crop coefficient
KS(I): Saturated hydraulic conductivity (cm/hr)
NC(I): Number of computation cells for each soil layer
NL: Number of soil layers
NT: Number of time steps
QB0: Initial baseflow (m^3/s)
RAINS(I): Rainfall intensity (cm/hr)
RC: Basin storage coefficient in the Clark UH (hr)
RB: Baseflow recession constant
RTHRE: Threshold value (ratio to the peak)
SSMAX: Surface storage capacity (cm)
TC: Time of concentration (hr)
VN(I): Soil water retention parameter
W0(I): Initial volumetric water content (cm^3/cm^3)
WP(I): Wilting point (cm^3/cm^3)
WR(I): Volumetric residual water content (cm^3/cm^3)
WS(I): Volumetric saturated water content (cm^3/cm^3)
ZNL(I): Thickness of each soil layer (cm)