Han River Flood Control Office (Ministry of Environment, Republic of Korea)

Korea Institute of Civil Engineering and Building Technology (KICT)

DWAT

DWAT (Dynamic Water resources Assessment Tool) – User's Manual v1.1

May 2019

Han River Flood Control Office (HRFCO)	ME Ministry of Environment
Korea Institute of Civil Engineering and Building Technology (KICT)	KICT KOREA INSTITUTE of CIVIL ENGINEERING and BUILDING TECHNOLOGY

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Please refer this technical manual as:

KIM, S., JANG, CH., KIM, HJ., PARK, JH., CHO, HS and KIM, HR. (2019). DWAT - User's Manual v1.1

FOREWORD

DWAT is a software to analyze water cycle for a basin or water management unit with runoff, evapotranspiration, water use and water supply in the different aspect of space and time. DWAT uses a distributed conceptual scheme for water cycle analysis and can be used with or without observed data. As the system is linked to a GIS tool, physical input parameters can be extracted conveniently. The global analysis of a hydrologic network is essential in numerous decision-making situations such as the management or planning of water resources. DWAT makes such analyses accessible to a broad public through its user-friendly interface and its valuable possibilities.

Software was developed in a "node-link type" that enables objective considerations of runoff characteristics resulting from different geomorphological factors by dividing ranges into sub-catchments judged to be hydrologically homogenous. The user interface of the model was developed for easy access and operation of the model and it will help how to use the model to effectively simulate and analyze many scenarios simultaneously.

DWAT has been verified by applying to various rural and forest catchments, including new urban development regions in Republic of Korea. It also has been peer-reviewed by a panel of Commission for Hydrology experts, who are applying it to basins located in different geographical areas, each with different climatic characteristics. This peer-review has the objective of further testing the system to strongly enhance the model reliability.

The purpose of this user guide is to give instruction on how to use the DWAT. When using the program, please check the content of this user guide.

For any further information on this program including technical issues and questions regarding the use of the program, please contact the researchers and development team.

May 2019

Research/Development team

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VERSION INFORMATION

Date	Version	Contents
2017. 12. 31	1.0 beta	· Establish Basic Structure of the Model · Including Evapotranspiration, Infiltration, Basin Runoff, Groundwater Movement, and Channel Routing · Three Basic Nodes: Catchment, Reservoir, and Wetland · Six Functions For Catchment Configurations: Select, Outlet, Link, Junction, Recycle, Import · Automation of Input Parameters Using GIS Preprocess · User Convenience Systems
2018. 09. 30	1.0	· Hydrological process in a paddy field - Applicable to Paddy fields in Asia region · Multi-Chart function - Simultaneous checking of rainfall, evapotranspiration, soil moisture, and total runoff · Added function to display and save graphics and table results · Parameter optimization - Providing a calibration tool with parameter optimization and uncertainty analysis package PEST(Model-Independent Parameter Estimation) · Snow melt module - Applicable to the alpine region · Improving system reliability
2019. 05. 10	1.1	· Hargreaves method - Function to calculate potential evapotranspiration · Parameter optimization - Automatic calibration can be applied to downstream junction of the sub-catchment considering the result of channel routing · Added function to copy and paste the properties of one sub-catchment into the other sub-catchments · Improving by the peer-review from WMO experts

BACKGROUND AND DEVELOPMENT PROCESS

Water Resources Assessment (WRA) is the determination of the sources, extent, dependability and quality of water resources for their utilization and control (WMO, 2012, Technical Material for Water Resources Assessment, WMO-No.1095, p. 8). Traditionally (Historically) WRA has been possible by the "stationarity" assumption, but Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharges of rivers (Milly et al., Science, Feb. 2008). Therefore we need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems.

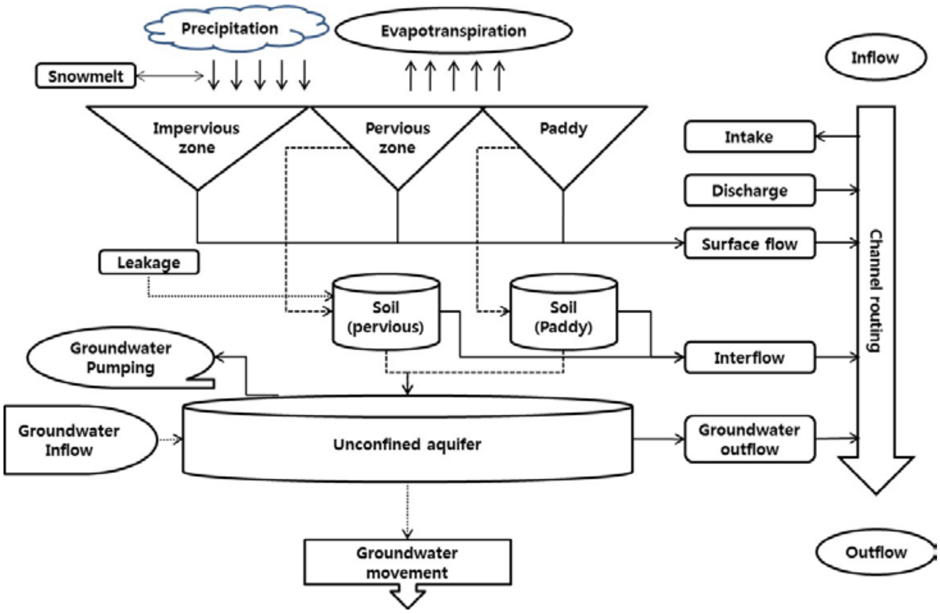
Analysis models are necessary to analysis the structures and interrelationships of water cycle systems and quantitatively assess the impact of changes in the components of water cycle systems on other parts of the water systems. In addition, common tools are required to support the political decision making, and those tools need to include modeling capacity to assess the impacts of various water cycle improvement policies and visualization of the results.

DWAT had been originally conceived to assist long-term planning and policy assessment and development. Its application can allow assessment of land-use changes within the basin over time, the impacts on water availability under differing consumptive use scenarios, and the impact on availability due to climate change through the application of scenarios. DWAT is intended to help users, particularly policy specialists and water resource managers to identify current and future water management challenges and compare these with the current and past states of water resources availability. This tool also can improve understanding of the impacts of past and present water management practices on water resources and better understand interactions between climate, water and landscape. Its use can contribute to water reform by providing nationally and regionally consistent water resources information and data, such as, surface water, groundwater, urban and agricultural water supply and use. Moreover, it will assist government policy formulation and the development of broad scale strategic plans and decision-making.

DWAT has been developed since 2012 as a part of WMO (World Meteorological Organization) RA (Regional Association) II WGHS (Working Group on Hydrological Services) activities, and it has been supported by the Han River Flood Control Office, Ministry of Environment, Republic of Korea. The beta version 1.0 of the DWAT has been available by end of 2017. This version contains sub-algorithms such as evapotranspiration, infiltration, basin runoff, groundwater movement and channel routing and user convenience systems. In September 2018, version 1.0 was developed with the addition of rice paddy node, snowmelt module and manual / automatic parameter optimization. The version 1.1 was developed in May 2019, reflecting the peer-review from WMO experts. In addition, system stability has been improved and various functions have been added to save and display graphics and table results.

CONCEPT AND STRUCTURE

The DWAT divides ranges judged to be hydrologically homogeneous into sub-catchments so that runoff characteristics resulting from geomorphological factors can be objectively reflected and infiltration, evaporation and groundwater flows can be simulated according to soil layer. The runoffs from pervious zones and impervious zones are simulated separately in the DWAT. In DWAT model, basins are divided into blocks that are considered to be uniform in terms of groundwater depths or topography.



The analysis module of DWAT are evapotranspiration, infiltration, runoff from catchment, groundwater movement and channel routing. The evapotranspiration can be imported when users have potential evapotranspiration already, or choose the Penman-Monteith and Hargreaves method embedded. The infiltration is calculated by the vertical/horizontal hydraulic conductivity. Green & Ampt method and Horton method are also provided. The groundwater movement between adjacent catchments and Muskingum method, Muskingum-Cunge method and Kinematic wave method can be applied for river or channel routing.

Table of Contents

CHAPTER 1: INTRODUCTION

This user guide provides instruction on how to use DWAT and assists water resources engineers and researchers to easily understand the program and to increase the reliability to apply the program to fields.

The chapters of this user manual are organized as follows:

1. Introduction
2. Model Interface
3. Model Input Data
4. Model Running
5. Analysis of Results

This chapter includes an introduction to program installation and its interface. In addition, all the processes to create, extract and correct input data are explained in detail and the methods to execute the model and analyze various figures and graphs are explained. However, the configurations of the model described in this user guide are those for the current version and they may be changed with further development. Characteristics of DWAT are summarized as follows:

- Physical parameter-based link-node type model
- Separate runoff simulations for pervious and impervious zones
- Analysis of infiltration, evapotranspiration, channel routing, groundwater flows relative to soil layers and aquifers
- Simple, practical and easily accessible
- Guaranteed satisfactory results with minimal data and efforts
- Easy user convenience system (GUI)
- Provision of results through diverse tables and figures

1.1 System Requirements

In order to use the DWAT program, at least 100Mb is required as the minimum available disk space. The minimum and recommended system requirements are in the following table.

Table 1.1 Minimum and recommended system requirements

System	Minimum	Recommended
Operation Systems	Windows 98, Windows ME, Windows XP, Windows 2000, Windows Vista	Windows 7, 8 and 10
Memory	512MB	1GB
CPU	P-4, 1.5hz Processor	P-4, 3.0hz Processor Core2 2.0 Processor
Hard Disk Capacity	100mb Extra Space	500mb Extra Space

1.2 Installation Procedure

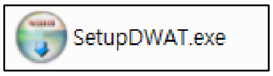


Figure 1.1 Setup file

You install the DWAT by double-clicking on the **SetupDWAT.exe** file in the installation directory.

Figure 1.2 Starting installation

When the 'DWAT Setup screen' appears, click **Next**.

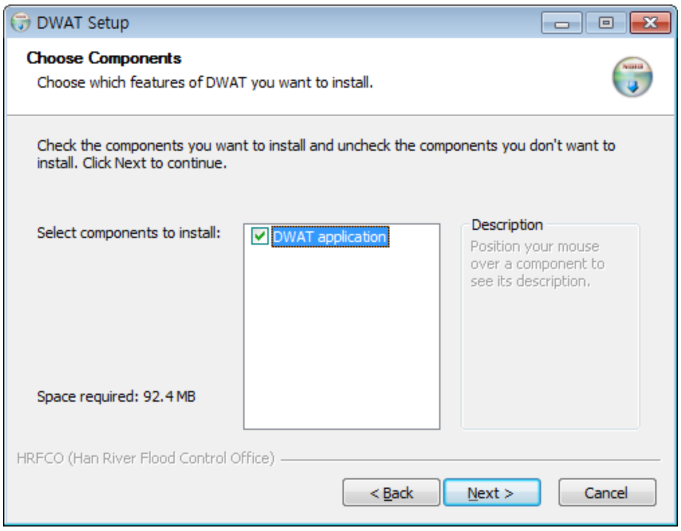


Figure 1.3 Creating sample directory

The DWAT <Sample> directory including sample files such as climate, observed streamflow, background image and etc. will be created in <my document> directory, click **Next**.

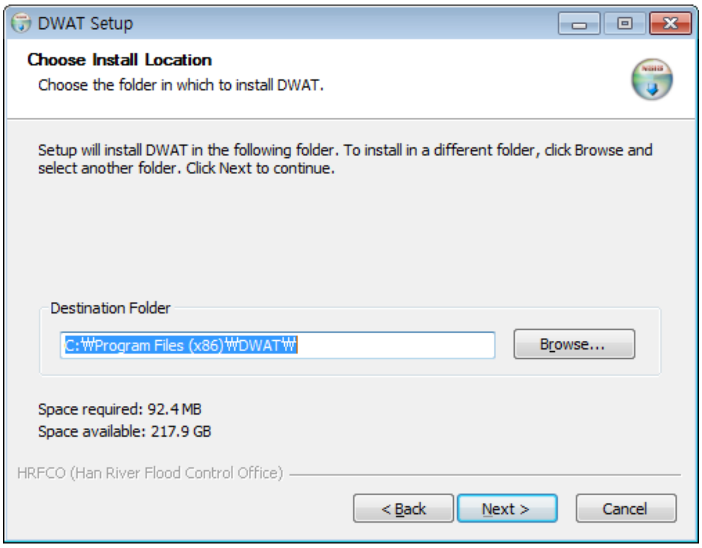


Figure 1.4 Directory selection

The DWAT install defaults to installing the program in C:\Program Files\DWAT and users can create their own directory structure. Once you've designated the directory to which the program will be installed, click **Next**.

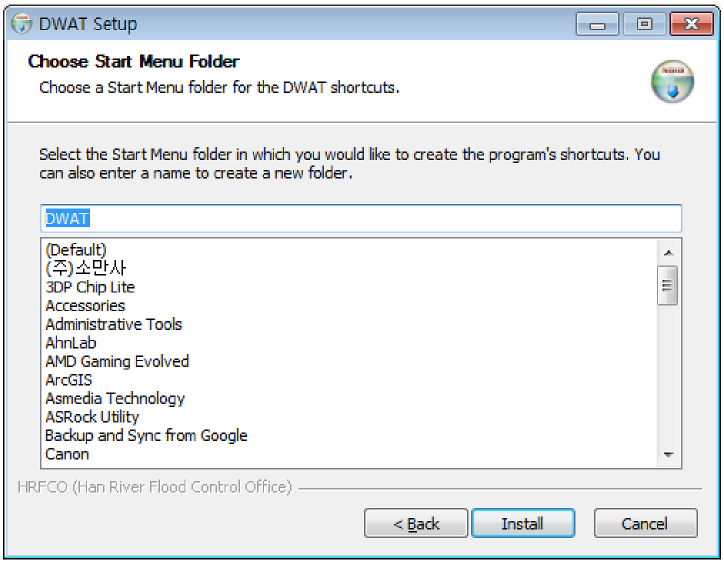


Figure 1.5 Creating shortcut

User selects the start menu folder in which user would like to create the program's shortcut. User can also enter a shortcut name, click **Install**.

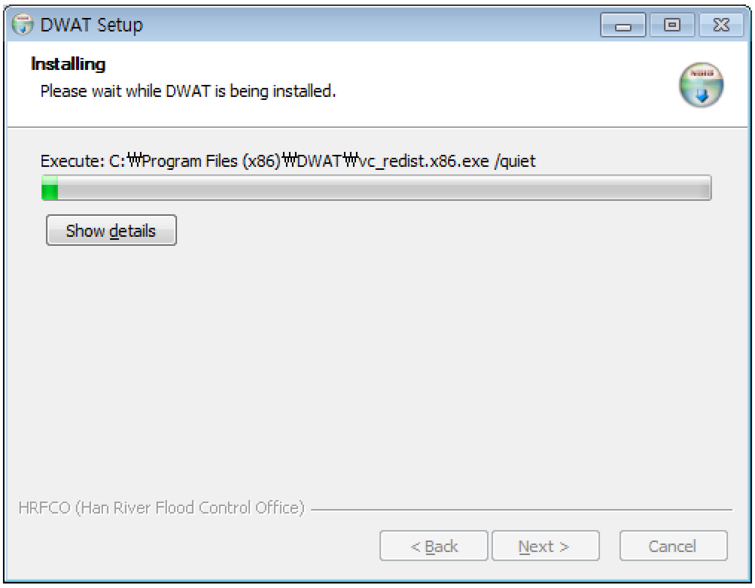


Figure 1.6 Installation progress

The 'Program installation screen will appear. If you click the cancel button, the program installation will not be completed. Please wait until the 'Completing DWAT Setup' appears.

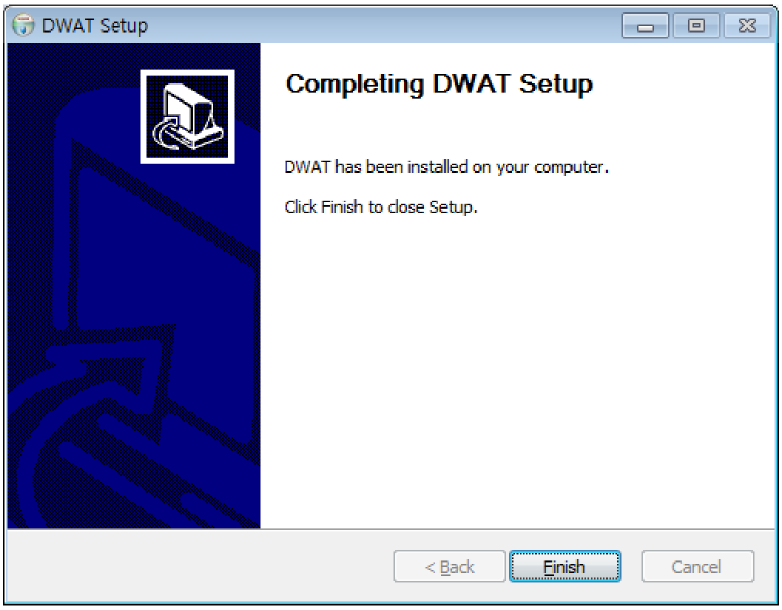


Figure 1.7 Completing installation

When the Completing DWAT Setup' appeared, click **Finish**.

The DWAT program has been successfully installed.

You may check the installation in the 'Program Start Menu'.

Windows Start Menu\Programs\ DWAT \ DWAT

CHAPTER 2: MODEL INTERFACE

The interface of the model has been developed so that it can be easily applied and managed by users and so that various scenarios can be easily applied. The model was designed to enable to copy and paste time series data from Microsoft Excel sheet. All data sets are easily managed in each project. The environment used in developing the user convenience system (Graphic User Interface, GUI) is Microsoft Visual Studio and the system was developed for Windows.

Figure 2.1 shows the DWAT basic configuration screen. The main screen of the DWAT is primarily divided into the Main Interface, Parameters, and Node. The tools are used in analysis and include the Main Menu and Toolbar, Node, etc. The Parameters window indicates the attributes of nodes and the variables of the selected nodes.

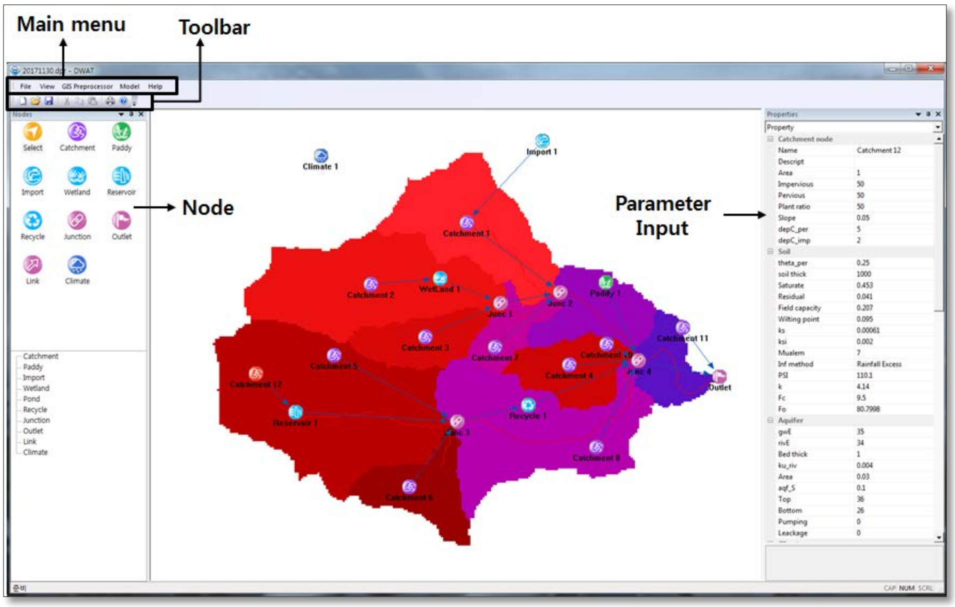


Figure 2.1 Basic configuration screen of the DWAT

2.1 Main Menu

The DWAT has five main menu items and they are shown in Figure 2.2. The main menu provides overall operation functions, including project file management, model executions, and input/output result checking.

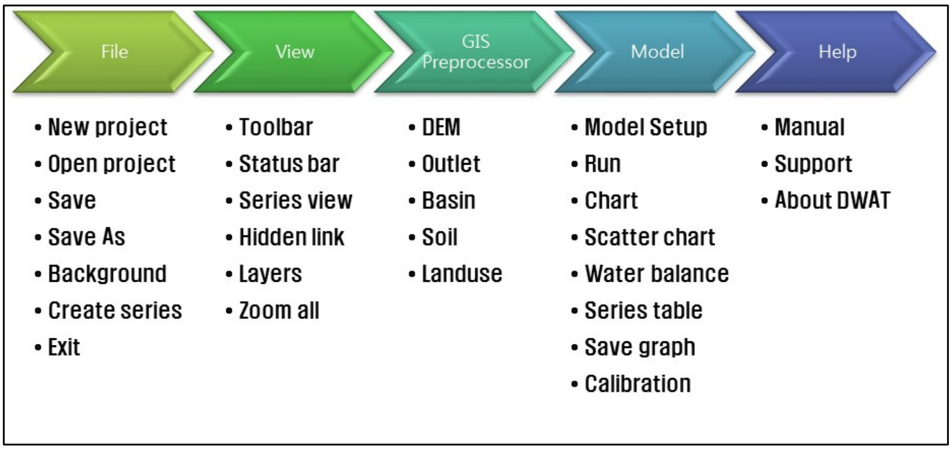


Figure 2.2 DWAT Main Menu

The functions of each menu are reviewed in the following sections.

2.1.1 File

New Project: This is a menu to create new projects. This menu clears all data in memory and interface fields and opens an empty project.

Open Project: This is a menu to display the standard file open dialog. It allows users to open existing projects stored in the certain directory and it is mainly used to revise existing data in the project. The extension of the project file is *.dpr and only project files (*.dpr) can be opened.

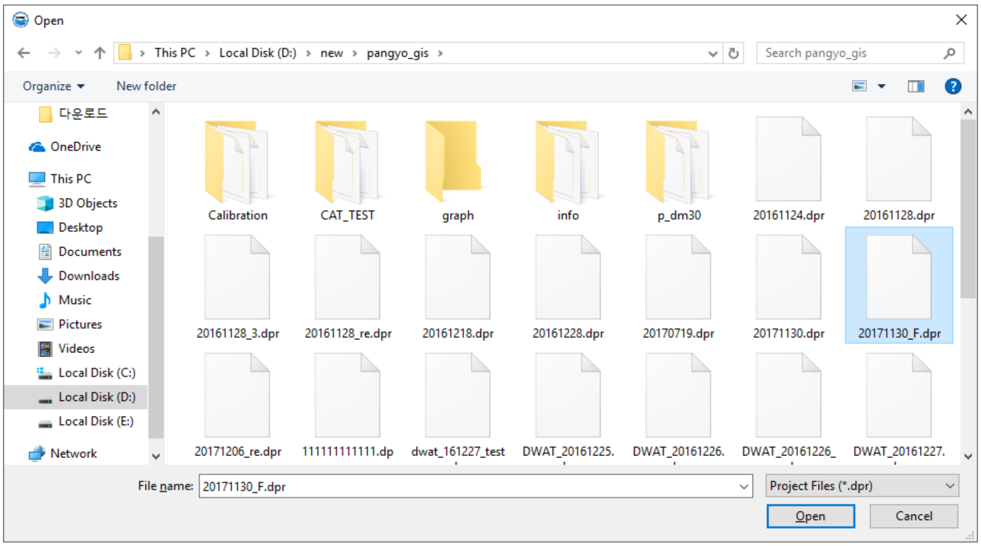


Figure 2.3 Opening a project file

Save: It allows you to save the current .dpr file (including all screens, attribute information and data of the open project).

Save as: It allows users to save the current project under another name.

Background: Background images (*.bmp, *.jpg, *.png, *.tif) can be imported. This may be

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useful for configuring each source node and link on the background (e.g. basin boundaries and rivers).

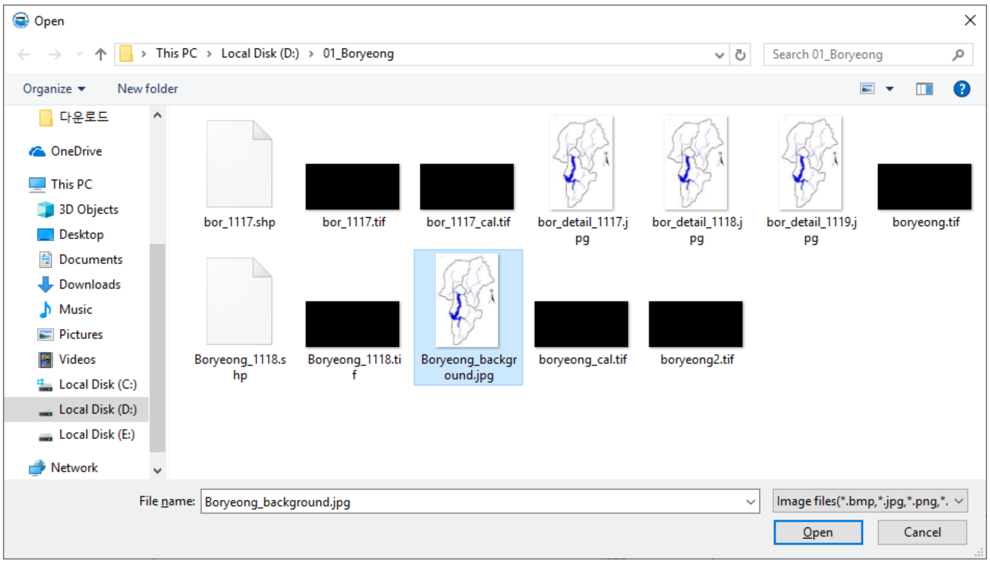


Figure 2.4 Importing a background image

Create Series: This menu creates time series (e.g. rainfall, meteorological data and observed discharges) into input data files (*.dat) in the DWAT.

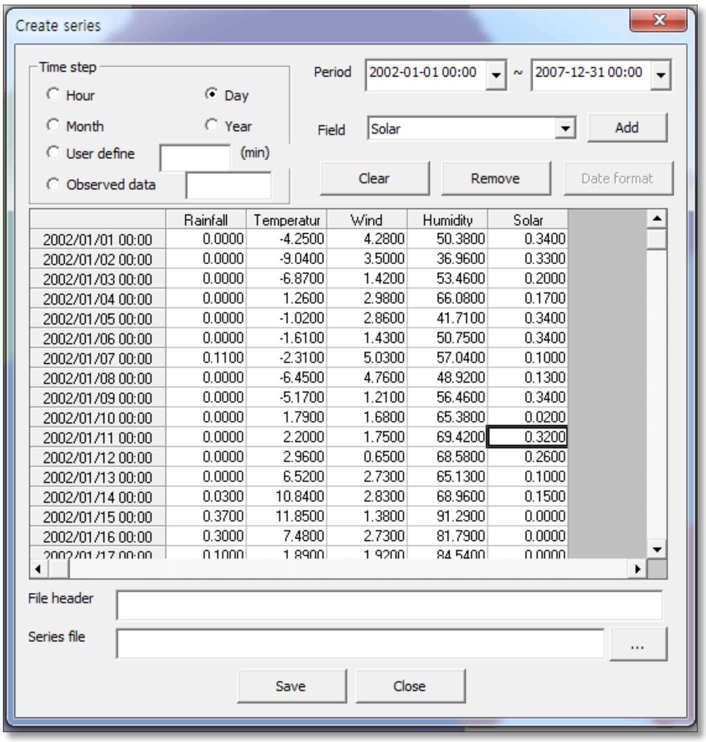


Figure 2.5 Creating time series data

2.1.2 View

View menu has various functions. These are briefly described below.

Toolbar: a function to show or hide the toolbar on the bottom of the main menu.

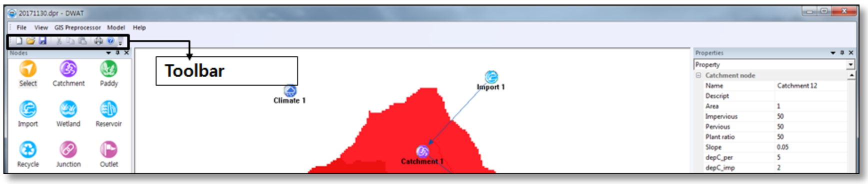


Figure 2.6 Toolbar

Status bar: a function to show or hide the display window on the bottom of the DWAT program window.

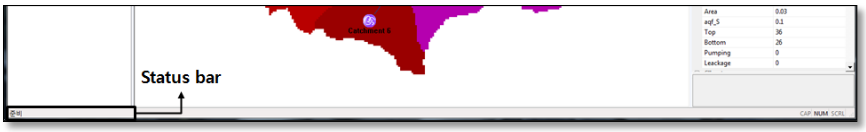
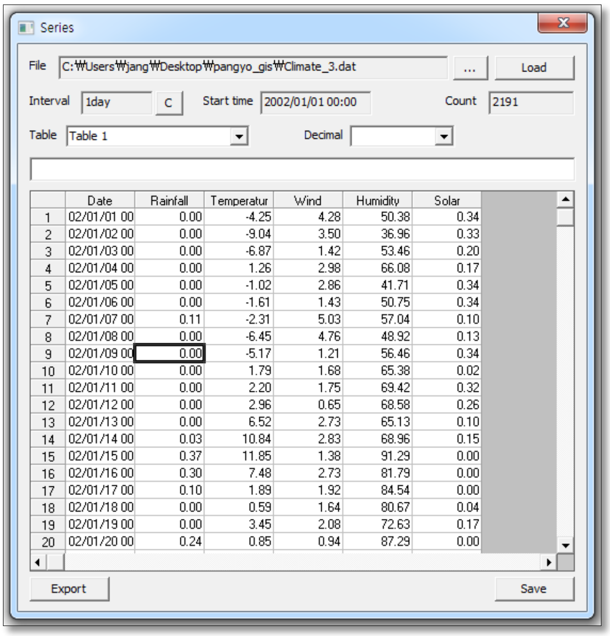


Figure 2.7 Status Bar

Series view: functions to display the time series data recreated in the DWAT; check, edit and save data files from model outputs; export the files as text (*.txt) files (since all files created in the DWAT are stored in the form of data files, *.dat (binary type format), this is a function to facilitate users' checking).



	Date	Rainfall	Temperatur	Wind	Humidity	Solar
1	02/01/01 00	0.00	-4.25	4.28	50.38	0.34
2	02/01/02 00	0.00	-9.04	3.50	36.96	0.33
3	02/01/03 00	0.00	-6.87	1.42	53.46	0.20
4	02/01/04 00	0.00	1.26	2.98	66.08	0.17
5	02/01/05 00	0.00	-1.02	2.86	41.71	0.34
6	02/01/06 00	0.00	-1.61	1.43	50.75	0.34
7	02/01/07 00	0.11	-2.31	5.03	57.04	0.10
8	02/01/08 00	0.00	-6.45	4.76	48.92	0.13
9	02/01/09 00	0.00	-5.17	1.21	56.46	0.34
10	02/01/10 00	0.00	1.79	1.68	65.38	0.02
11	02/01/11 00	0.00	2.20	1.75	69.42	0.32
12	02/01/12 00	0.00	2.96	0.65	68.58	0.26
13	02/01/13 00	0.00	6.52	2.73	65.13	0.10
14	02/01/14 00	0.03	10.84	2.83	68.96	0.15
15	02/01/15 00	0.37	11.85	1.38	91.29	0.00
16	02/01/16 00	0.30	7.48	2.73	81.79	0.00
17	02/01/17 00	0.10	1.89	1.92	84.54	0.00
18	02/01/18 00	0.00	0.59	1.64	80.67	0.04
19	02/01/19 00	0.00	3.45	2.08	72.63	0.17
20	02/01/20 00	0.24	0.85	0.94	87.29	0.00

Figure 2.8 View time series data

Hidden link: a function to view groundwater flows and the water convey and supply links of other improvement facility nodes (Import, Recycle) in addition to the links edited by the user (displayed in separate colors; Green).

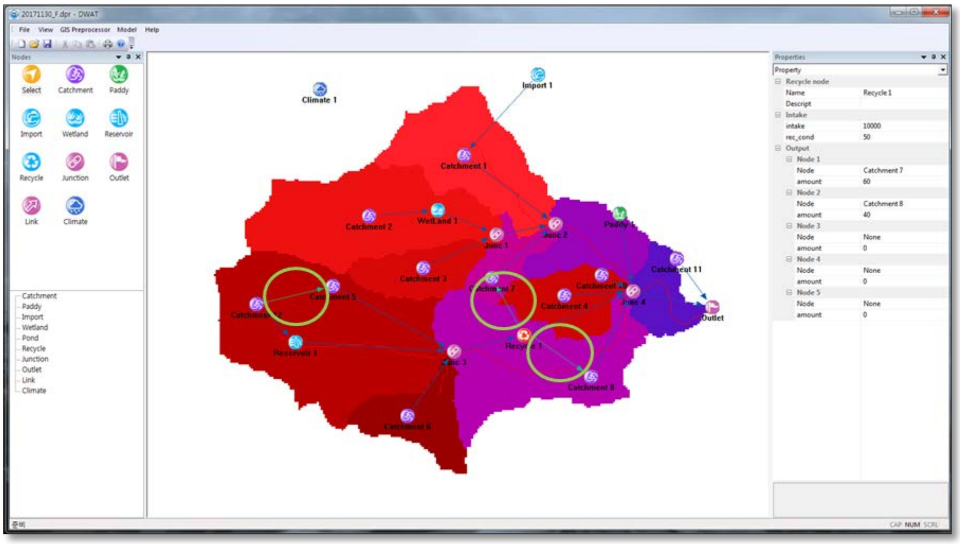


Figure 2.9 View hidden links

Layers: It allows users to remove background image

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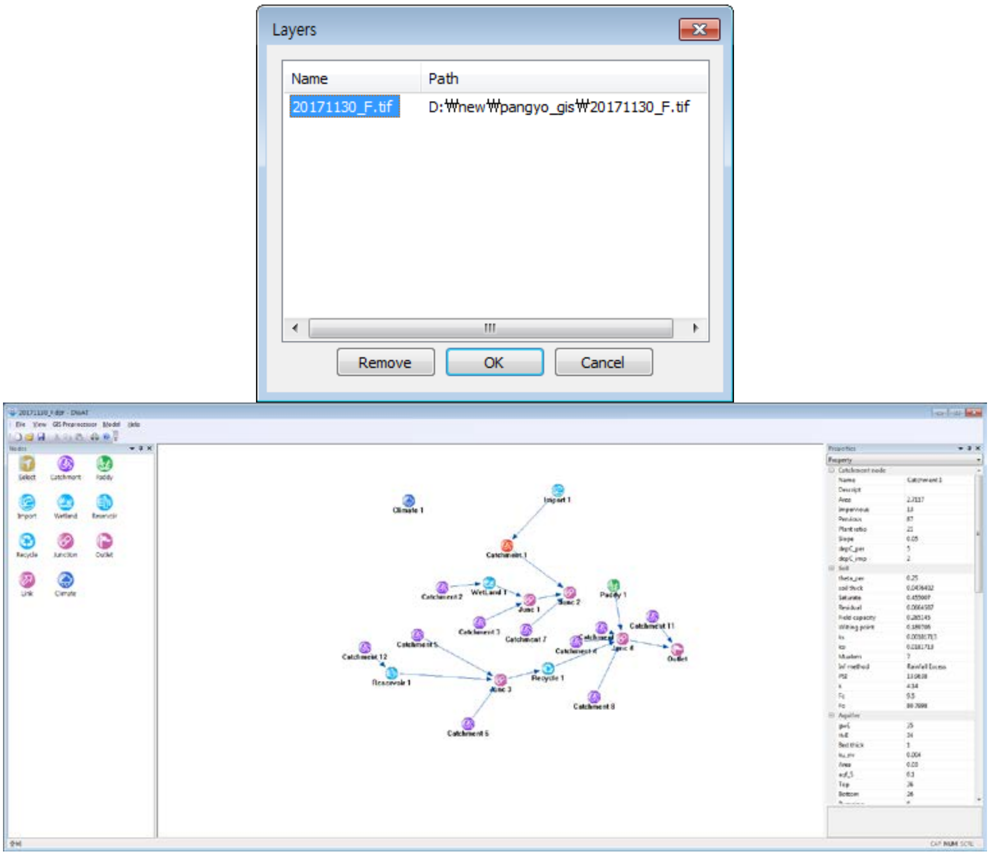

Figure 2.10 Remove background image

2.1.3 GIS Preprocessor

The physical parameters of the model can be searched and extracted automatically using GIS Preprocessor menu. This tool allows users to load land use and soil themes into the current project and determines the land use/soil class combinations and distributions for the delineated basin and each respective sub-basin.

GIS data such as DEM, boundary, outlet point, soil and land use required to automatically extract physical parameters must have the same Universal Transverse Mercator (UTM) coordinate system.

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The complete process of basin delineation and input parameters using GIS Preprocessor menu involves a sequence of steps:

1. It is important to use a DEM with no depressions or sinks, so users have to fill DEM using other GIS Tools such as QGIS, ArcView and ArcGIS, etc.
   - To create an accurate representation of flow direction and, therefore, accumulated flow, it is best to use a dataset that is free of sinks. A DEM that has been processed to remove all sinks is called a depressionless DEM. The identification and removal of sinks, when creating a depressionless DEM, is an iterative process. When a sink is filled, the boundaries of the filled area may create new sinks that need to be filled.
   - The user needs to adjust the grid size of the DEM considering the size of the watershed. This is related to the performance of the GIS Preprocessor.

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2. Determining the slope direction at each pixel, i.e. the "aspect" of the terrain.
3. Determining the "flow accumulation", that is, the number of upgradient pixels that slope toward each point in the DEM grid.
4. Calculation of preliminary stream network raster using a flow accumulation.
5. Add a point that represents the outlet of the basin. You need to add and load a "shapefile “that has the outlet for the basin.
6. Determining basin area using channel threshold value.
   - Set the channel formation threshold value to something like 100 or 1000 or 5000 depending on the size of your basin and goals of your analysis. There is no standard threshold value.
7. Overlay Soil map.
   - In this model, the concept of surface soil indicates the depth (range) where pores exist to temporarily store intermediate runoff. In the DWAT, infiltration and evapotranspiration into/from soil are analyzed based on the physical characteristics of the soil, and thus surface soil parameters should be established. The physical characteristics of soil (including soil depth, saturated hydraulic conductivity, horizontal hydraulic conductivity, saturated moisture contents, residual moisture contents and Mualem's n) are used in this model. The information on the surface soil depths and parameters is used after being classified by soil texture based on the soil map.
8. Overlay Land use map
   - Input data for land use conditions include ground surface slopes, impervious area ratios, and depression storage. The information on topological parameters is based on the land use map

First, go to Main Menu and select GIS Preprocessor.

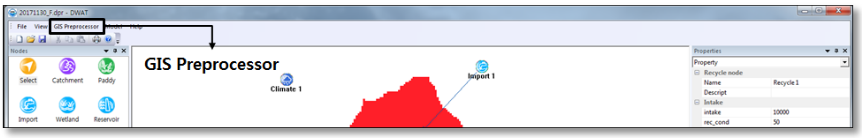

Figure 2.11 GIS Preprocessor Toolbar

Figure 2.12 GIS Preprocessor menu

DEM: A browser will be displayed allowing the user to select the DEM grid (Raster file: hdr.adf).

This file format (*.adf) is the internal binary format for Arc/GIS Grid and takes the form of a coverage level directory in an Arc/GIS database. To open the coverage select the coverage directory, or hdr.adf from within it.

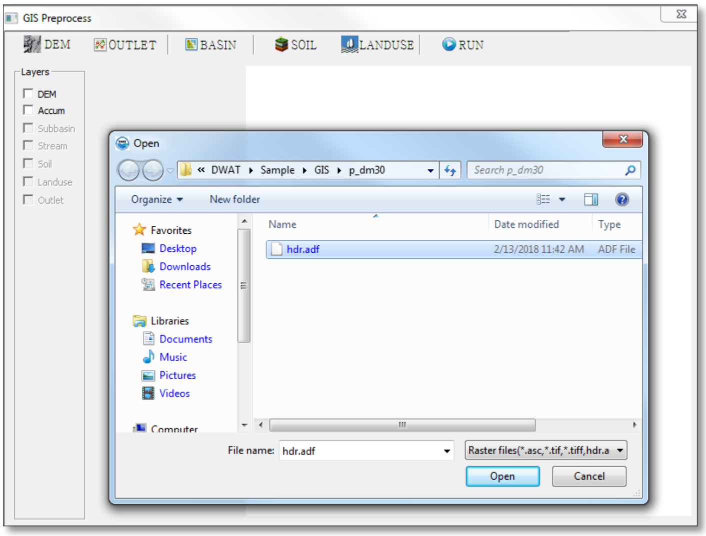

Figure 2.13 DEM importing

Click Open to proceed. When this step is complete, DEM and flow accumulation theme is added to the GIS Preprocessor view.

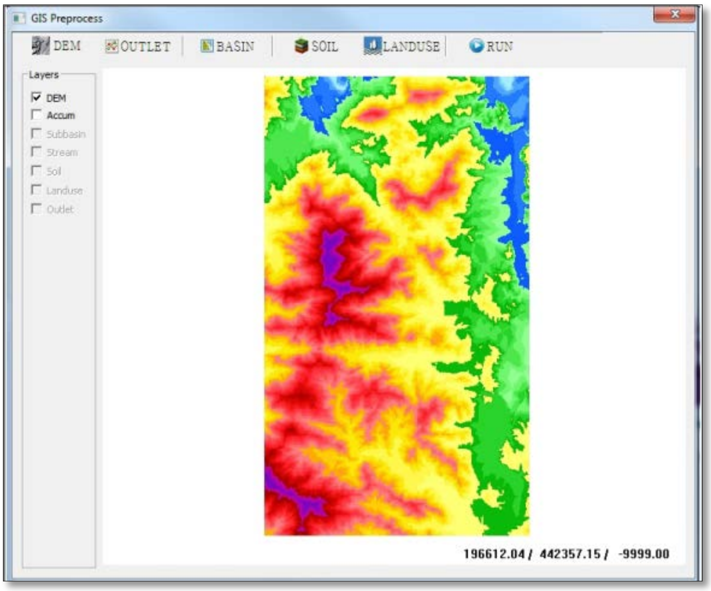

Figure 2.14 Imported DEM

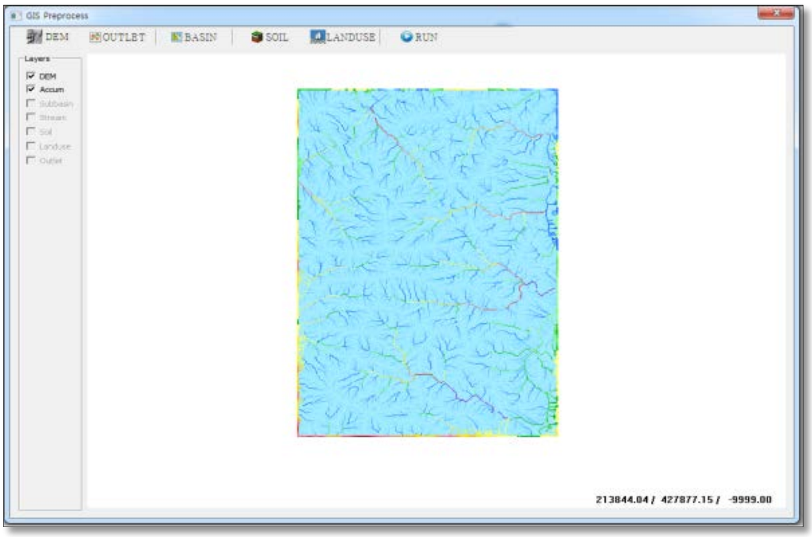

Figure 2.15 Computed flow accumulation

OUTLET: It allows users to add an outlet point.

Once you have zoomed in, go to the Select outlet browser. Click "Add point", directly user placed from add point using left-clicking on a stream pixel. If you are off the stream channel by so much as one pixel you will not be able to delineate the correct drainage area. Your outlet point must be in a flow channel pixel.

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If you have a shape file for the outlet point, you can create the outlet point by loading the shape file using "Load" button.

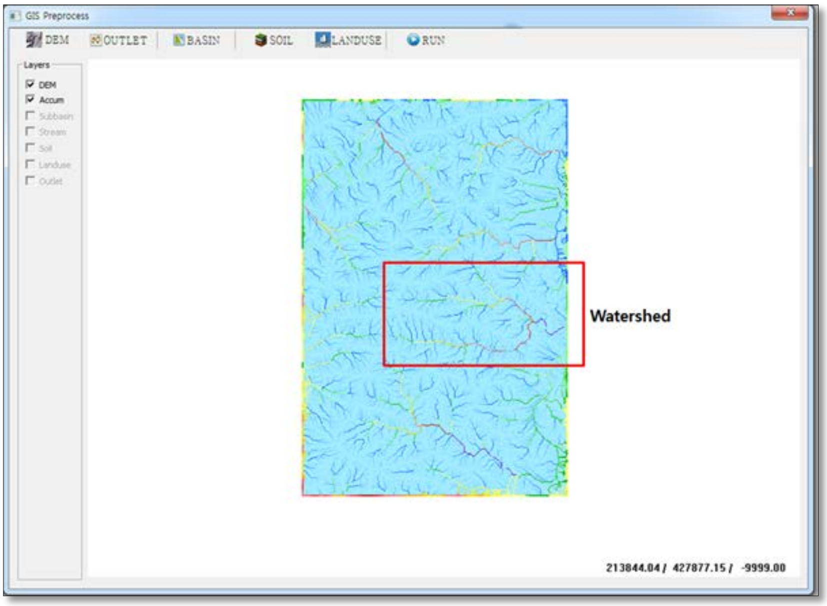

Figure 2.16 Basin outlet selection

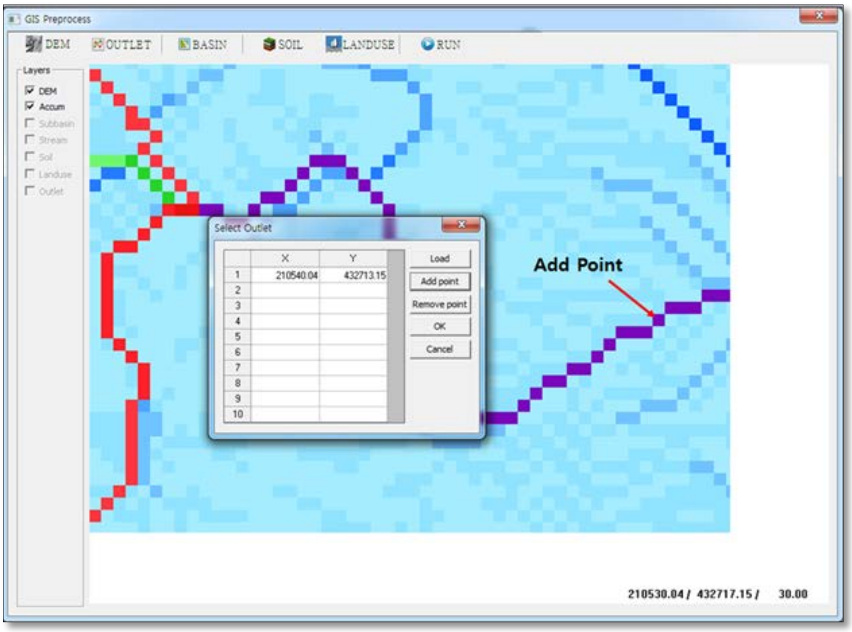

Figure 2.17 Desired basin outlet selection

Click OK to proceed. You are ready to delineate the basin area.

BASIN: It allows you to delineate basin area using channel threshold value.

The threshold affects the size and number of sub-basins to be created. In other words, a small threshold will allow you to extract many sub-basins with small areas.

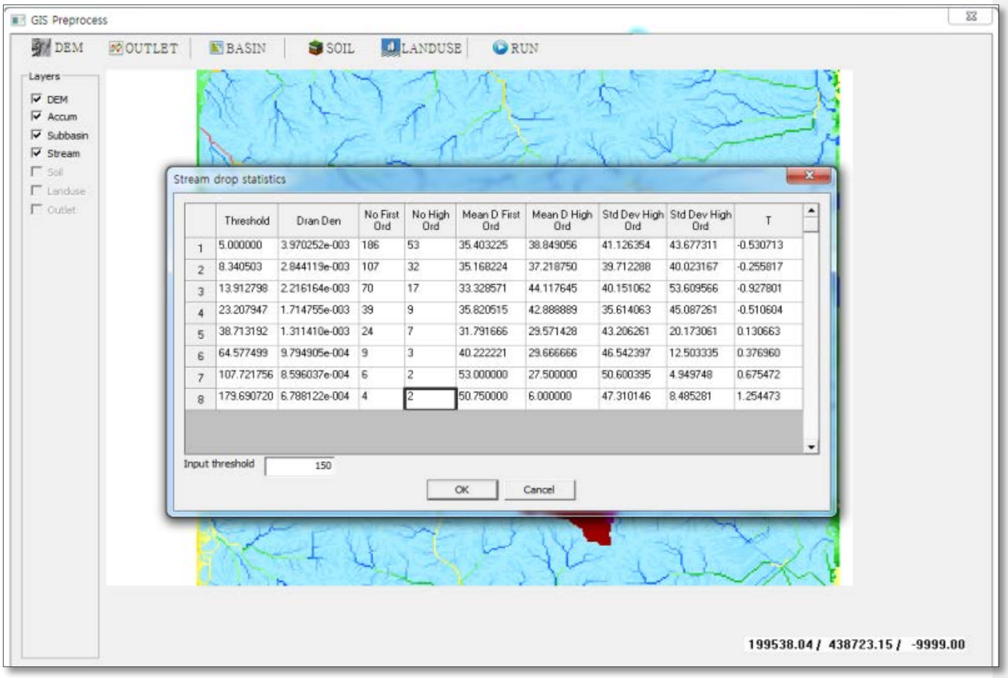

Figure 2.18 Channel threshold selection

Click OK to proceed. You have a delineated basin.

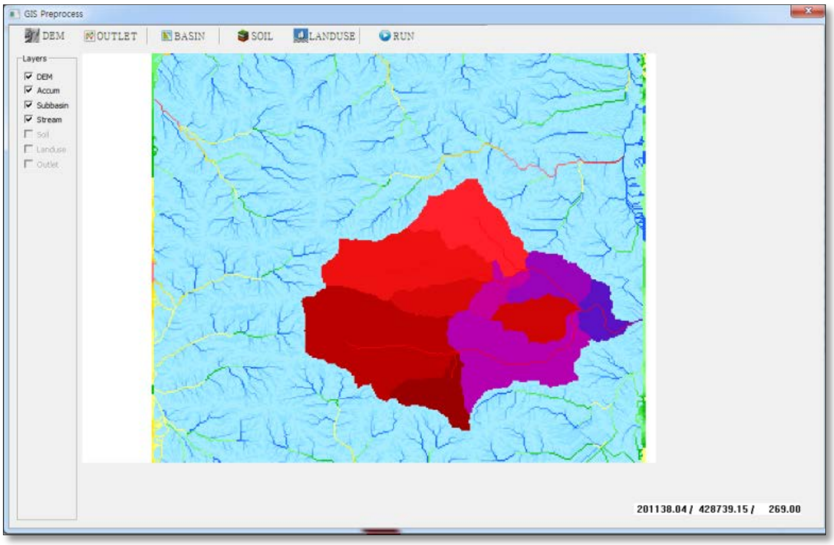

Figure 2.19 Delineated basin.

SOIL: It allows you to overlay soil type theme to the basin boundaries.

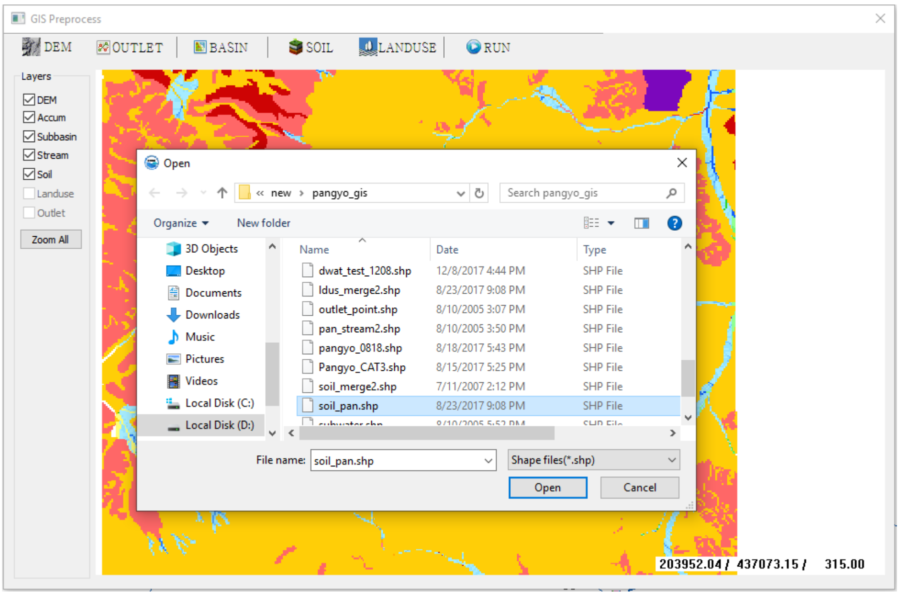

Figure 2.20 Importing soil type map

DWAT require the land use and soil data to determine the area and the basic hydrologic parameters of each land-soil category simulated within each sub-basin. If the soil and land use are defined in the same projection (UTM) as the DEM, select shapefile (*.shp) in the file browser. If soil map is not projected as the DEM, This will stop map processing.

When this step is complete, a dialog box will pop up listing database files from which soil type can be selected. The user needs to define DWAT soil type associated with soil type theme categories. Select the attribute field containing the codes/category values to be reclassified: **SOILSY (in case of Republic of Korea)**.

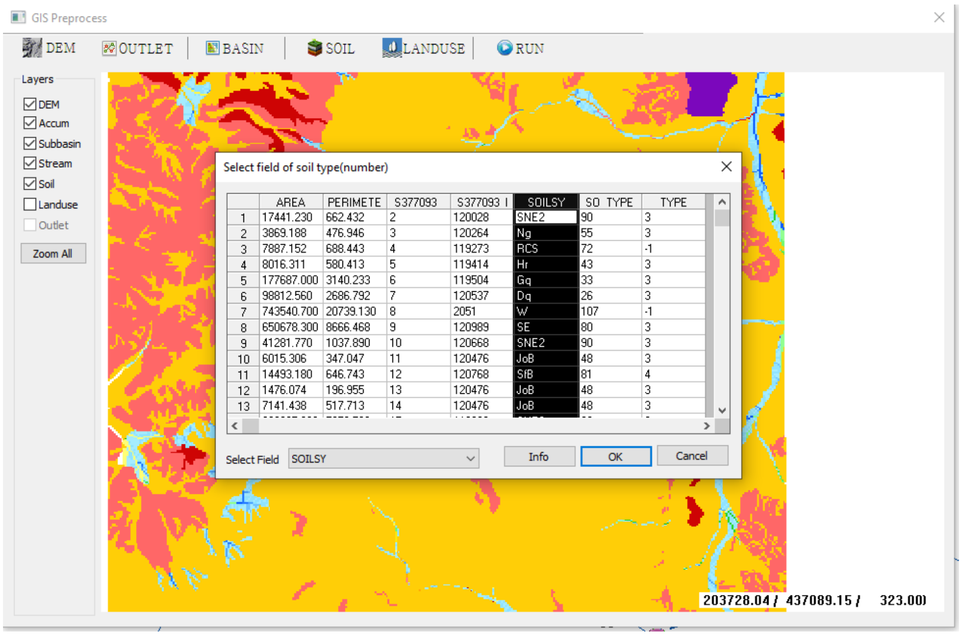

Figure 2.21 Soil type overlay

Click OK to proceed. Soil type theme is added to the basin boundaries.

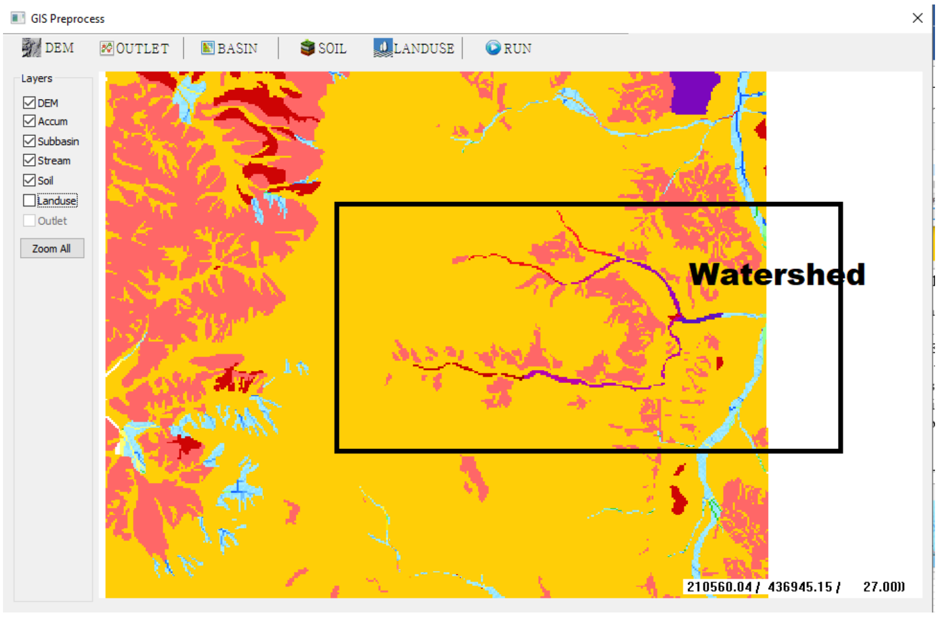

Figure 2.22 Integrated soil type with the basin boundaries.

In other countries, User needs to match the soil category with the basic hydrological parameters provided by DWAT using "Info" button in "Select field of soil type" window, as shown in figure 2.23.

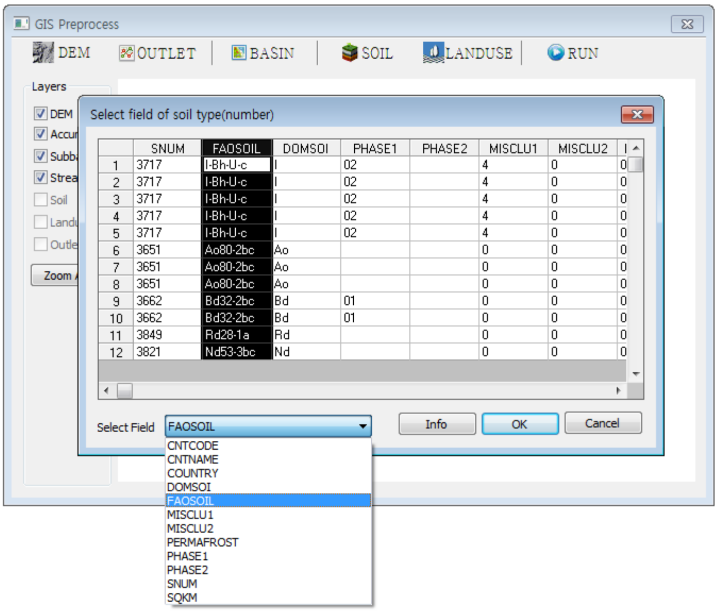

Figure 2.23 Soil category selection (example of Bhutan).

Click Select field to proceed. Choose the soil type field (FAOSOIL in Bhutan) in your country.

Click "Info" button. In this soil property window, user can see parameters according to soil texture provided by DWAT.

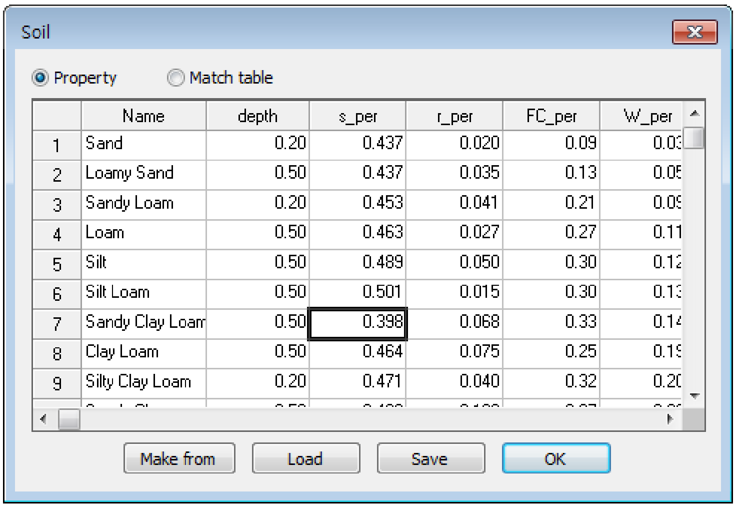

Figure 2.24 Parameters for each soil texture in DWAT.

Select "Match table" to proceed. When this step is done, you are ready to match the type and parameters of DWAT.

Click "Make from" button. When this step is complete, the soil category selected in previous step appears on the left field, and you should select the soil texture in the Type field.

User can save and load the newly created soil texture using the "Save" or "Load" button

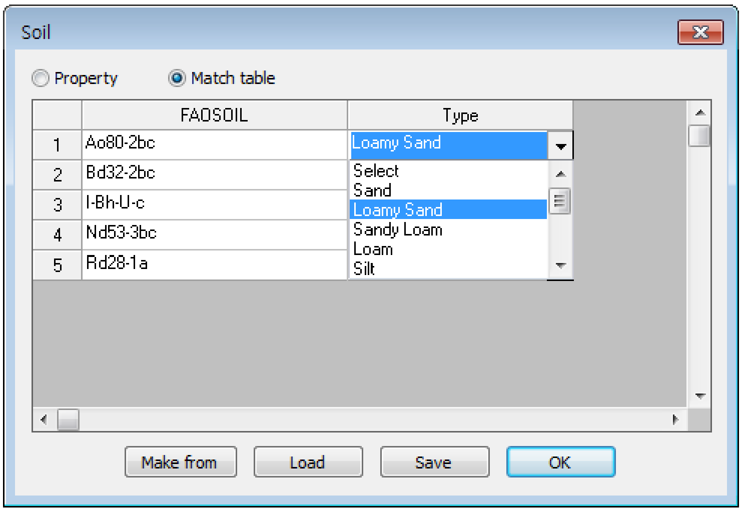

Figure 2.25 Soil texture matching (example of Bhutan).

Click OK to proceed. Soil type theme of your country is added to the basin boundaries.

LANDUSE: It allows you to overlay land use theme to the basin boundaries.

Select land use theme (*.shp).

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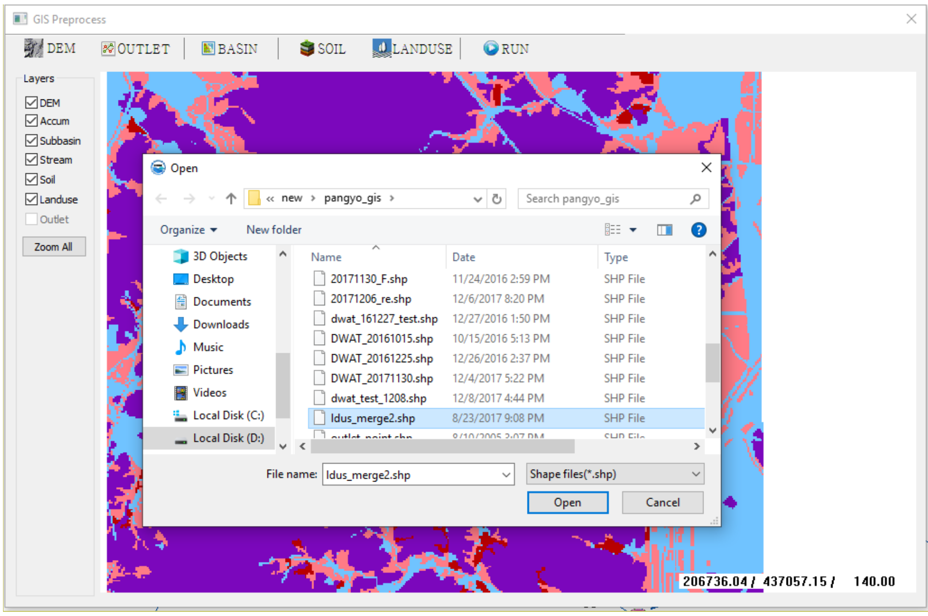


Figure 2.26 Importing land use map

When this step is complete, a dialog box will pop up listing database files from which land use type can be selected. Select the attribute field containing the codes/category values to be reclassified: **UCB (in case of Republic of Korea)**.

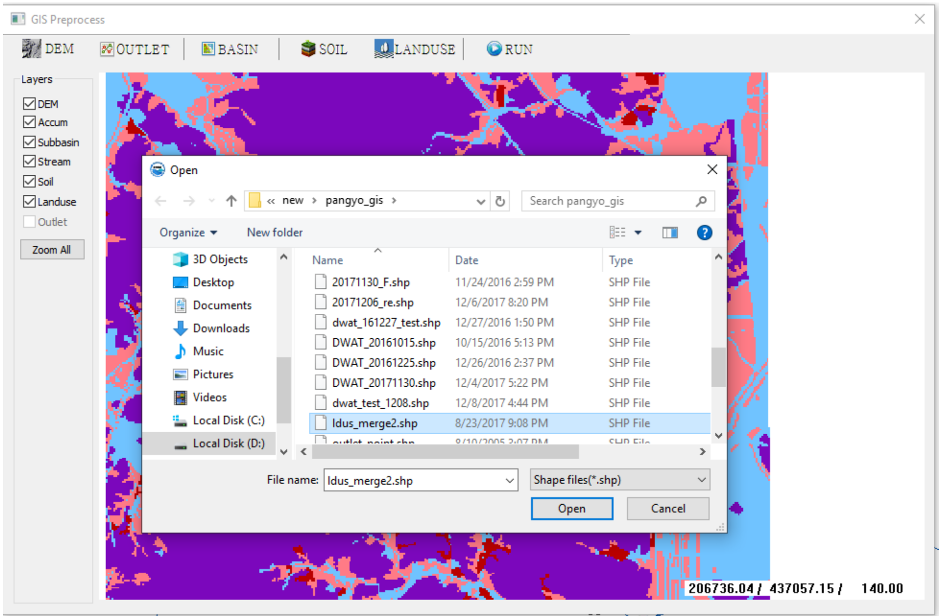


Figure 2.27 Land use overlay

Click OK to proceed. Land use theme is added to the basin boundaries.

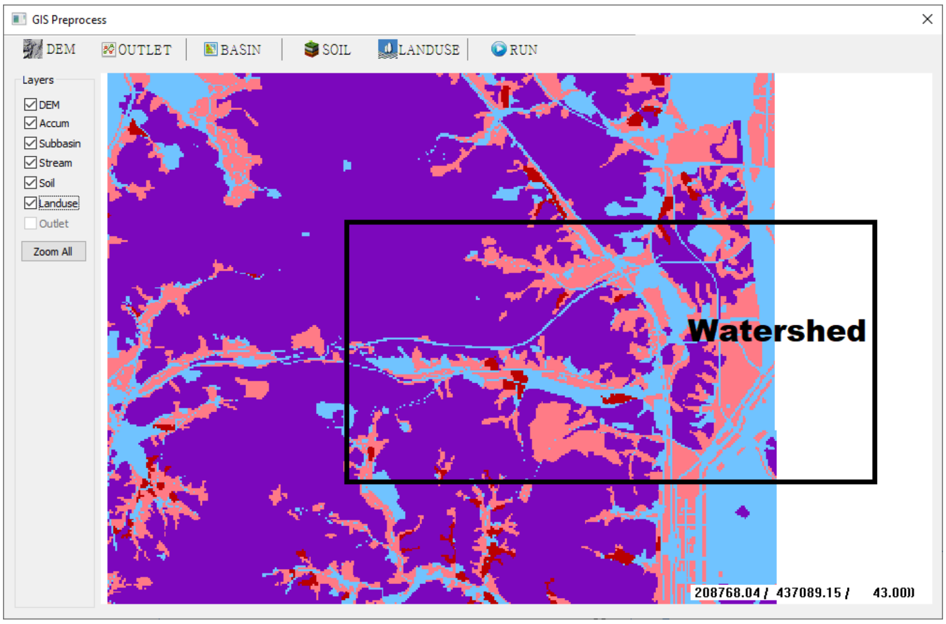


Figure 2.28 Integrated land use with the basin boundaries

In other countries, User needs to match the land use with the basic hydrological parameters provided by DWAT using "Info" button in "Select field of land use type" window, as shown in figure 2.29.

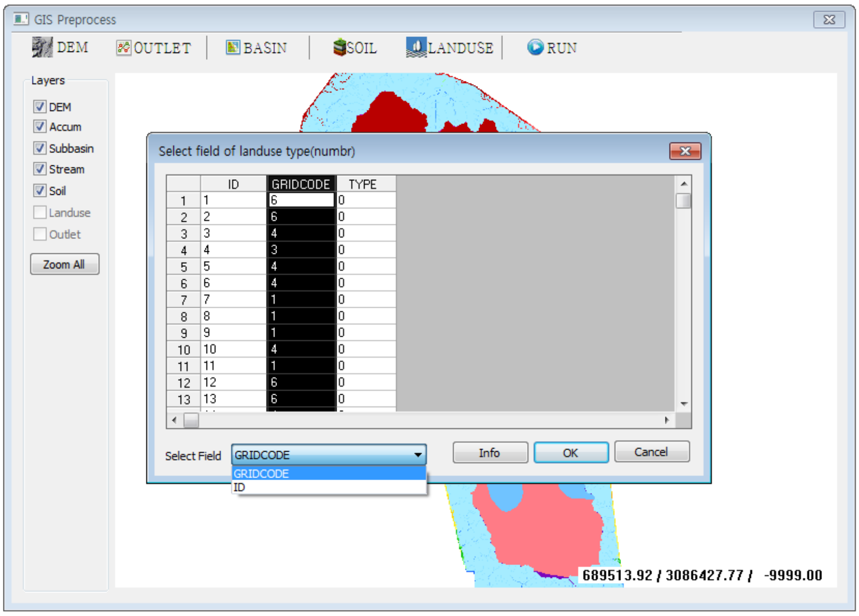


Figure 2.29 Land use category selection (example of Bhutan).

Click Select field to proceed. Choose the land use field (GRIDCODE in Bhutan) in your country.

Click "Info" button. In this land use property window, user can see types (Pervious, Impervious, Paddy and Plant) according to land use name provided by DWAT.

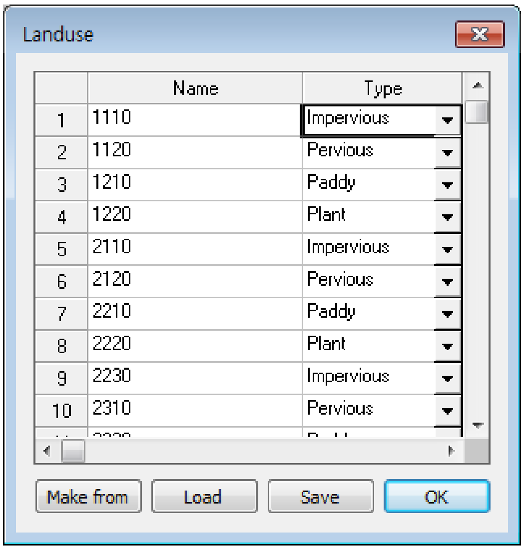


Figure 2.30 Types for each land use name in DWAT.

Select "Match table" to proceed. When this step is done, you are ready to match the name and type of DWAT.

Click "Make from" button. When this step is complete, the land use category selected in previous step appears on the left field, and you should select the land use type in the Type field.

User can save and load the newly created land use type using the "Save" or "Load" button

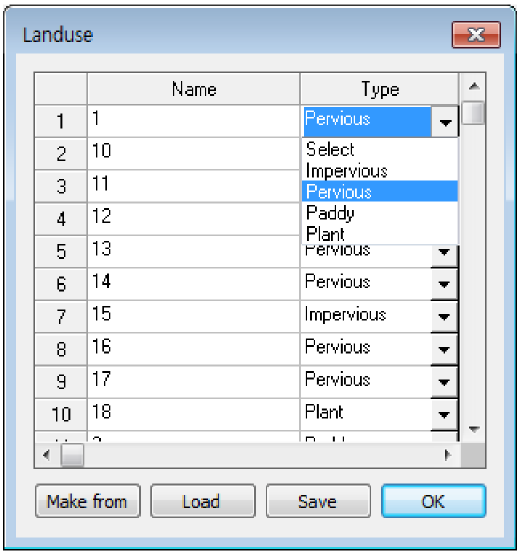


Figure 2.31 Land use type matching (example of Bhutan).

Click OK to proceed. Land use theme of your country is added to the basin boundaries.

RUN: It allows you to determine the area and the hydrologic parameters of each land-soil category simulated within each sub-basin. Once the joining attribute codes have been assigned to all map categories, the file browser will appear. It allows the current file to save in *.dpr file format (attribute information and parameters of the basin).

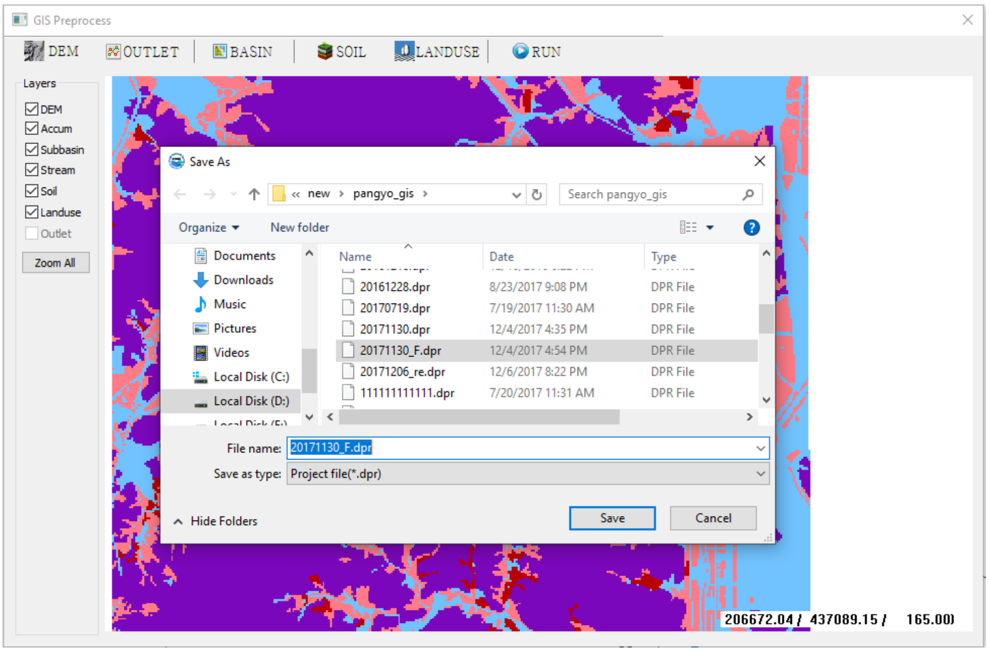


Figure 2.32 Fully integrated hydrologic model

Click SAVE to proceed. A hydrologic model is created.

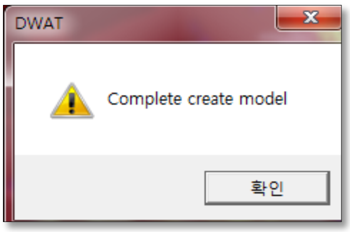


Figure 2.33 Completed hydrologic model

Click OK to proceed. When you close the GIS Preprocessor window, the Delineated basin will appear.

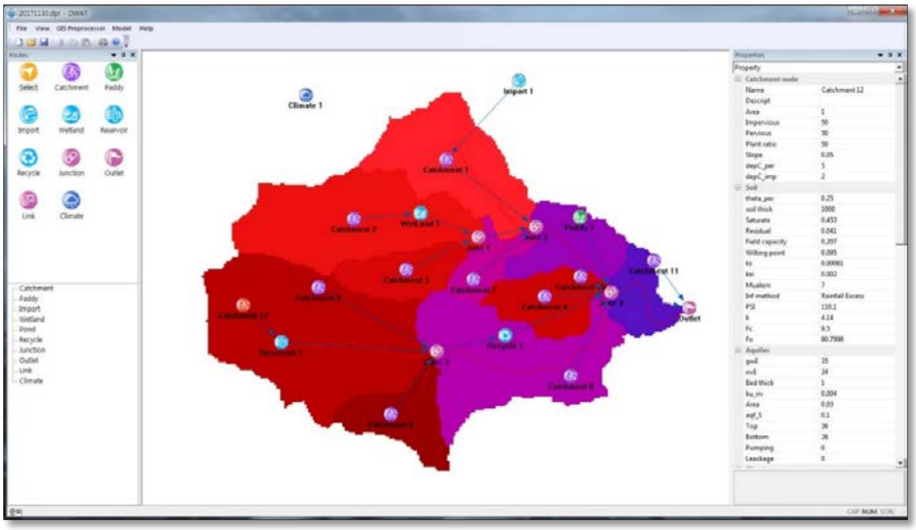


Figure 2.34 Completed hydrologic model main window

2.1.4 Model

Model Setup: It allows users to set up environments for running the model (e.g. simulation time and period).

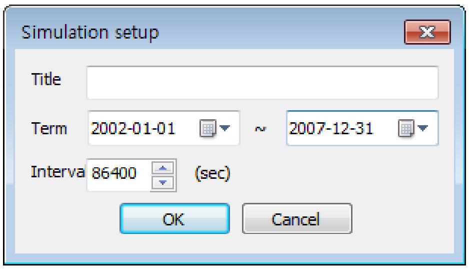


Figure 2.35 Model simulation time and period

Run: It allows users to execute the model simulation.

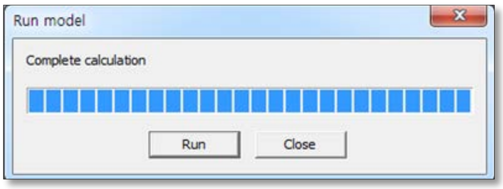


Figure 2.36 Completed model simulation

Chart: Graphs of the simulation results after running the model will appear on the screen.

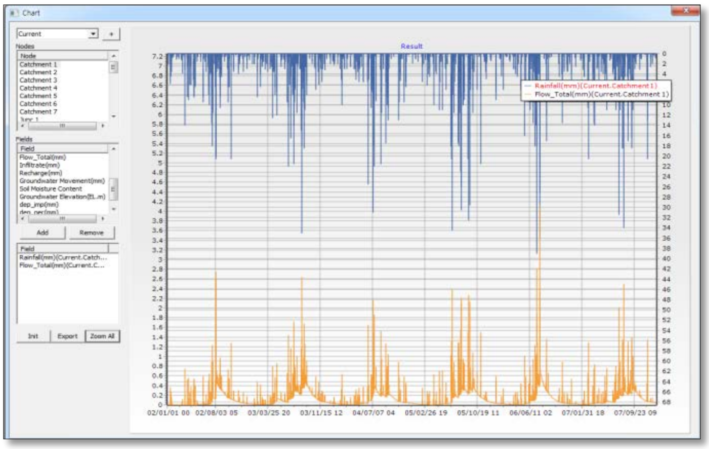


Figure 2.37 Model simulation results

Scatter chart: The statistical values for simulation results and the measure of dispersion of observed values and simulated values will appear on the screen.

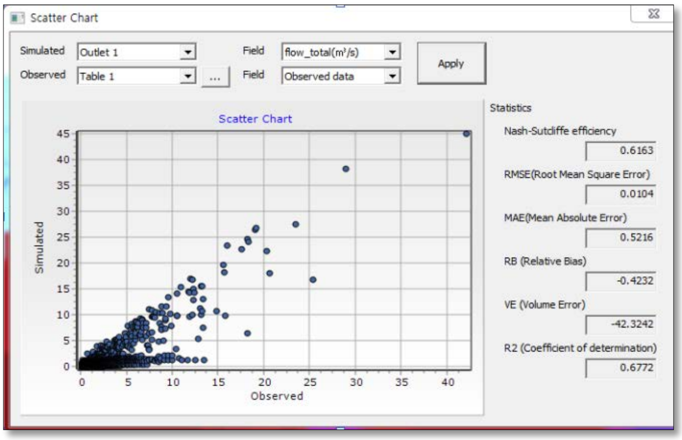


Figure 2.38 Model statistical values before calibration

Water balance: Water balance at basin outlets can be identified.

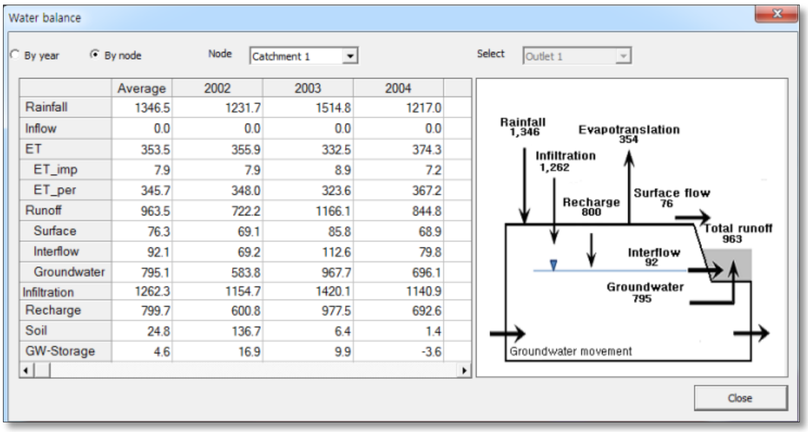


Figure 2.39 Water balance at basin outlets

Series table: Check the table for the results of each hydrological component in the sub-basin (The sub-basin node can be selected from the left side, and the hydrology component per node can be selected from the right side).

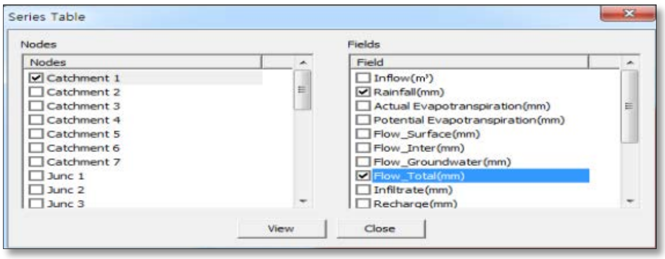
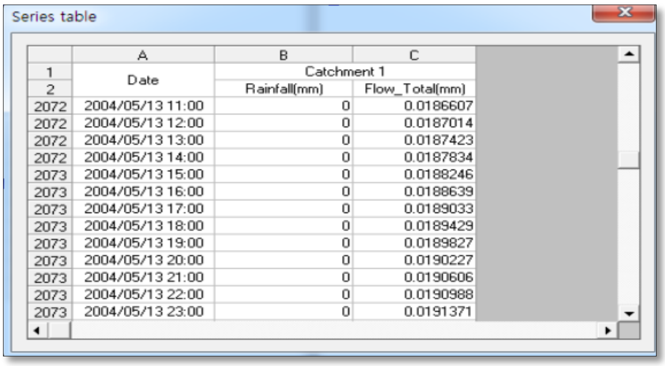


Figure 2.40 Model simulated time series result of several hydrological components

Click View to proceed. Table results will appear.


Series table

	A	B	C
1	Date	Catchment 1	
2		Rainfall(mm)	Flow_Total(mm)
2072	2004/05/13 11:00	0	0.0186607
2072	2004/05/13 12:00	0	0.0187014
2072	2004/05/13 13:00	0	0.0187423
2072	2004/05/13 14:00	0	0.0187834
2073	2004/05/13 15:00	0	0.0188246
2073	2004/05/13 16:00	0	0.0188639
2073	2004/05/13 17:00	0	0.0189033
2073	2004/05/13 18:00	0	0.0189429
2073	2004/05/13 19:00	0	0.0189827
2073	2004/05/13 20:00	0	0.0190227
2073	2004/05/13 21:00	0	0.0190606
2073	2004/05/13 22:00	0	0.0190988
2073	2004/05/13 23:00	0	0.0191371

Figure 2.41 Rainfall and total flow time series results

Save graph: Save the graph for the results of each hydrological component in the sub-basin (The sub-basin node can be selected from the left side, and the hydrology component per node can be selected from the right side)

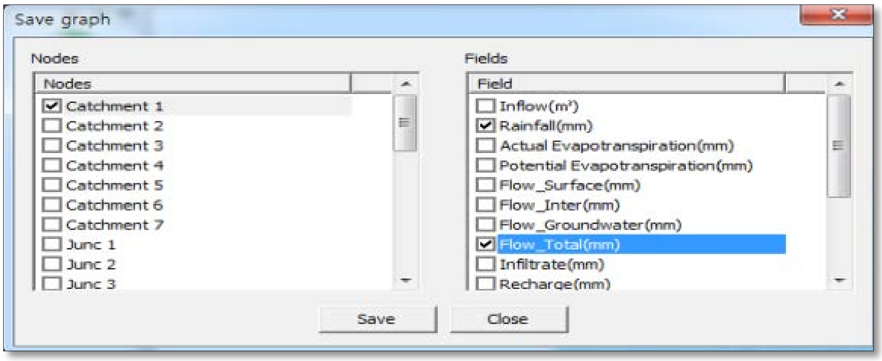


Figure 2.42 Model simulated graphical result of several hydrological components

The file browser will appear. It allows the current file to save in *.bmp file format

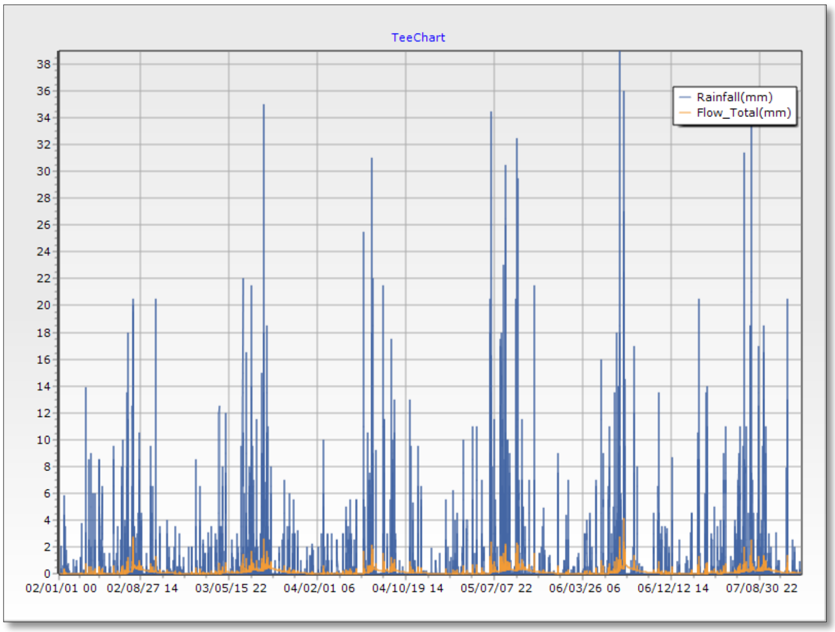


Figure 2.43 Graphical result of rainfall and total flow.

Calibration: It allows users to calibrate and optimize parameters using PEST (model-independent Parameter ESTimation).

DWAT automatically optimizes parameters for soil and aquifer for single basin with observed streamflow. A detailed description for the automatic optimization is given in **Section 5.6.**

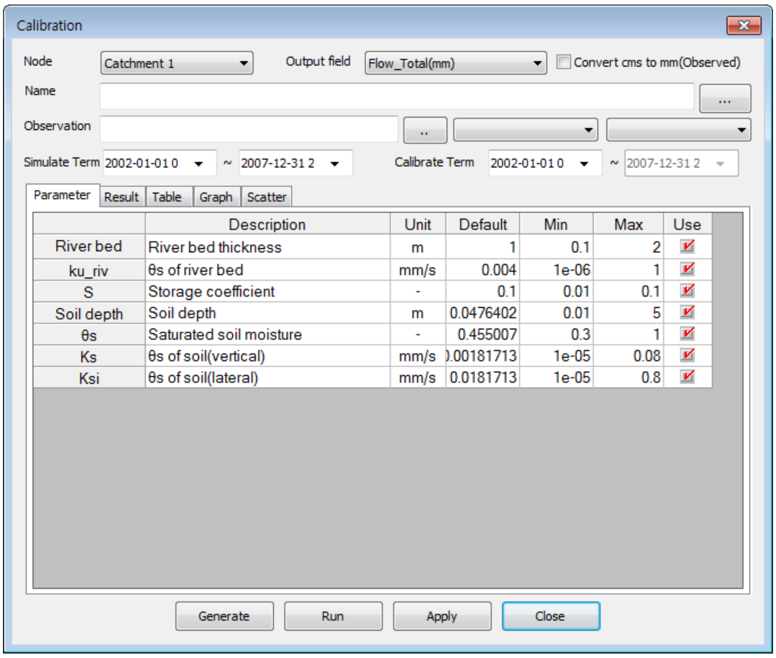


Figure 2.44 Parameter calibration tool in DWAT.

2.1.5 Help

Manual: It is a view menu for the DWAT user manual

Support: It allows users to link to the DWAT development team

About DWAT: It is a menu to identify the copyright and version information of the DWAT

Figure 2.45 DWAT copyright and version information

2.2 Icon

The user interface of the DWAT basically includes 11 icons. There are four basic nodes (i.e. Catchment, Paddy, Reservoir, Wetland); and five functions for catchment configurations (i.e. Link, Junction, Recycle, Import and Outlet to connect between nodes). In addition, Select and Climate icons are included to check attributes.

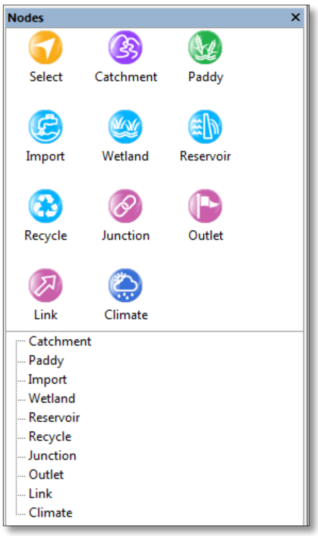


Figure 2.46 DWAT basic icons

2.3 Property View

The Property View displays the attribute information of each node, link, and junction. That is, an attribute information screen automatically appears on the left when a node, link or junction is individually selected on the main screen. Information on parameter values can be identified and corrected.

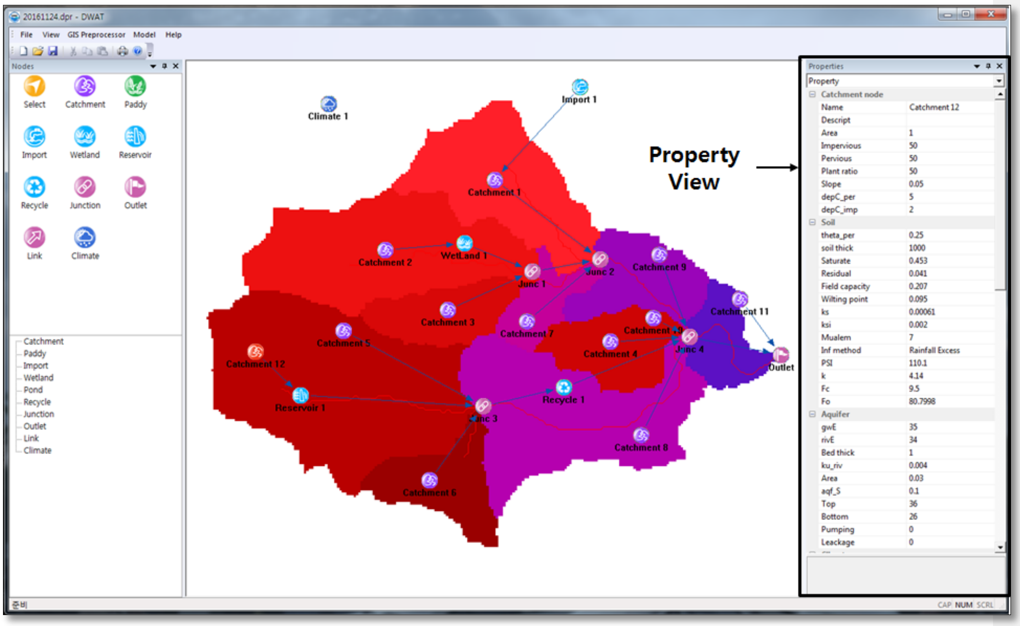


Figure 2.47 Property View displays

CHAPTER 3: MODEL INPUT DATA

The DWAT requires various input data to describe the basin characteristics, such as topology, geological features, hydrologic and hydraulic features, artificial systems for water use and drainage, in the analysis of water cycle.

In the analysis, the DWAT uses physical parameters based on physiographic factors, soil, and groundwater as shown in Table 3.1. Physical parameter values can be established using land use data, soil diagrams, and river data, etc. Table 3.1 - 3.3 contain a list of input data at source nodes (i.e. urban, forest, paddy and water cycle improving facilities) and links. In this chapter, the processes to create, extract and process these input data are explained in detail.

Table 3.1 Model parameters (Other node)

Comment [j8]: Review 42

Division	Input variable	Description of variable	Unit
Reservoir	vol_init	Initial storage	m^3
	vol_eff	Effective storage	m^3
	intake_vol	Intake volume	m^3/day
	Kgw	Saturated hydraulic conductivity of the aquifer	mm/s
	spill_ht	Height of spillway	m
	spill_length	Length of spillway	m
	spill_coef	Overflow coefficient of the spillway	-
	pipe_ht	Height of outlet pipe	m
	pipe_area	Area of outlet pipe	m^2
	pipe_coef	Runoff coefficient of outlet pipe	
	H-V-A	Stage-storage-area relationship	m-m^3-m^2
Wetland	vol_init	Initial storage	m^3
	vol_max	Maximum storage	m^3
	flood_bypass	High flow bypass during flood	m^3/sec
	Kgw	Saturated hydraulic conductivity of the aquifer	mm/s
	pipe_ht	Height of outlet pipe	m
	pipe_area	Area of outlet pipe	m^2
	pipe_coef	Runoff coefficient of outlet pipe	-
	H-V-A	Stage-storage-area relationship	m-m^3-m^2
Recycle	rec_intake	Total intake volume	m^3/day
	rec_cond	Restriction for intake rate according to streamflow	%
External water supply	import_water	Constant volume or time series data of imported from outside	m^3/day
	Leakage	Leakage rate	%
Meteorological condition	Latitude, Elevation, Height	The location, elevation, and height of the observatory	m
	Climate data	Rainfall, wind velocity, sunshine hours, lowest/highest temperatures, relative humidity	-

Table 3.2 Model parameter (Catchment nodes)

Division	Input variable	Description of variable	Unit
Subject basin	Area	Area	Km^2
Ground surface condition	Slope	Catchment average slope	-
	Aratio_imp	Impervious area ratio	%
	Aratio_per	Pervious area ratio	%
	Aratio_per_plant	Vegetation area ration in pervious zone	%
	DepC_imp	Depression capacity in impervious zone	mm
	DepC_per	Depression capacity in pervious zone	mm
Surface soil	theta_per	Current soil moisture content	-
	soil_th_per	Soil thickness	m
	s_per	Saturated soil moisture content	-
	r_per	Residual soil moisture content	-
	FC_per	SMC at field capacity	-
	W_per	SMC at wilting point	-
	ks_per	Saturated hydraulic conductivity	mm/s
	ksi_per	Saturated horizontal hydraulic conductivity	mm/s
	Mualem	Index for Mualem Eq.	-
	PSI	Wetting front soil suction head	mm
	fo	Maximum or initial value of infiltration capacity into the soil	mm/hr
	fc	Maximum or ultimate value of infiltration capacity into the soil	mm/hr
	k	Decay coefficient	hr^{-1}
River	rivE	Riverbed elevation	m
	Area_riv	Area of riverbed	Km^2
	riv_th	Thickness of riverbed	m
	ku_riv	Riverbed material permeability coefficient	mm/s
Groundwater aquifer	gwE	Current groundwater level	m
	aqf_S	Storage coefficient of the aquifer	-
	aqf_Top	Top elevation of the aquifer	m
	aqf_Bot	Bottom elevation of the aquifer	m
	aquifer slope	Average slope of the aquifer	-
	node length	Average node length	m
	conj. length	Conjugated length between nodes	m
	Kgw	Saturated hydraulic conductivity of the aquifer	mm/s
	GW_pump_rate	Groundwater pumping rate	m^3/day
	leakage_rate	Leakage rate of water supply networks	-
Paddy	irr_start	Date of start of irrigation	April 1st.
	irr_end	Date of end of irrigation	September 30th.
	Surf_dr_ht	Monthly drainage outlet height	m
	surf_dr_cf	Coefficients of drainage outlet	-
	udgw_dr_cf	Coefficient of drainage pipe	-
	Diameter	Diameter of drainage pipe	mm
	Rain Max.	Threshold rainfall to open the drainage pipe	mm
	Coef. A	Number of drainage pipe	-
	Coef. B	Runoff coefficient of drainage pipe	-
Snow melt	Melting	Melting factor	mm/℃/day
	Refreezing	Refreezing factor	-
	CWH	Critical relative water content of the snow pack	-
	Threshold Temp.	Threshold temperature of rain/snow	℃
	Interval Temp.	Temperature interval for rain/snow mixing	℃
	Snowmelt Temp.	Threshold temperature for snow melt	℃

Table 3.3 Model parameter (link, channel routing)

Division		Input variable	Description of variable	Unit
Channel Routing	Muskingum	DT	Time step for calculation	unit time
		X	Routing factor (0.0 - 0.5)	-
		K	Wave travel time	hr
	Muskingum Cunge	Channel length	Length of channel	m
		Channel slope	Bed slope of channel	-
		Manning N	Manning roughness coefficient	-
		Bottom width	Bottom width of the channel	m
		Top width	Top width of the channel	m
	Kinematic Wave	Manning N	Manning roughness coefficient	-
		Channel slope	Bed slope of channel	-
		Channel length	Length of channel	m
		Bottom width	Bottom width of the channel	m
		Top width	Top width of the channel	m
		Channel depth	Channel depth	m

3.1 Subject Catchment

The range of water cycle assessment primarily consists of basin systems, including stream network. In the stage of composing a basin system, catchment information is required and information on observed streamflow is needed to compare simulation results to observed data. The user can import images of basin systems including catchment information as the background. It allows users to configure links and source nodes easily.

Comment [j9]: Review 26

3.1.1 Background Image

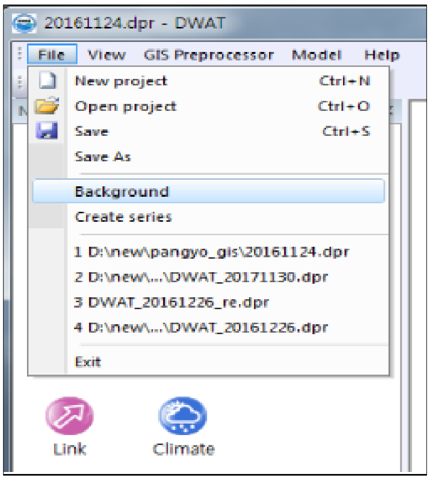


Figure 3.1 Background icon

Load: It allows users to insert background images

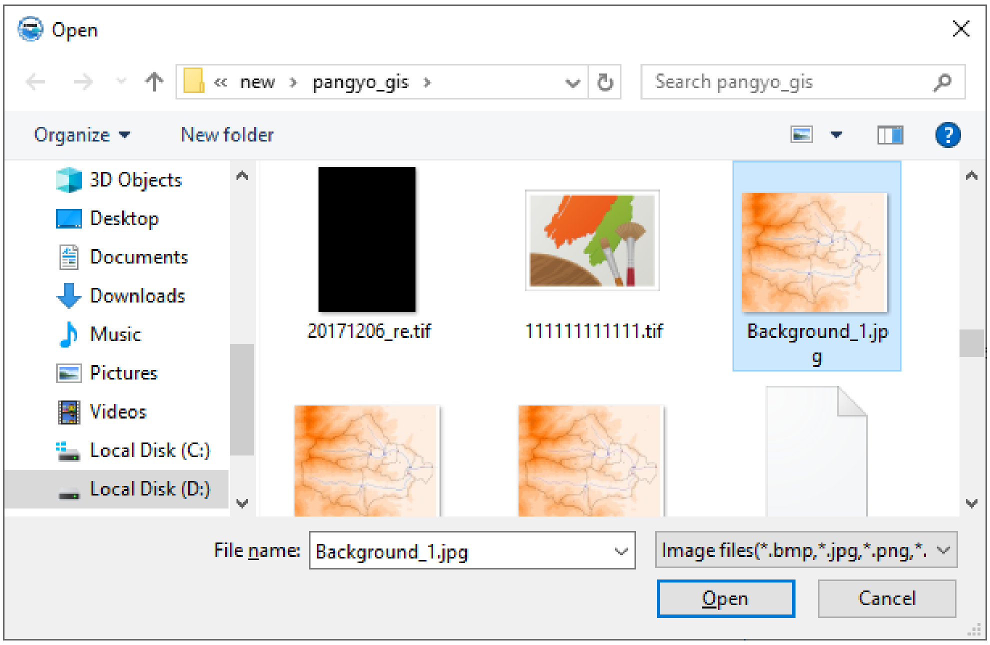


Figure 3.2 Loading background image

When a background image has been loaded, a screen as shown below is created.

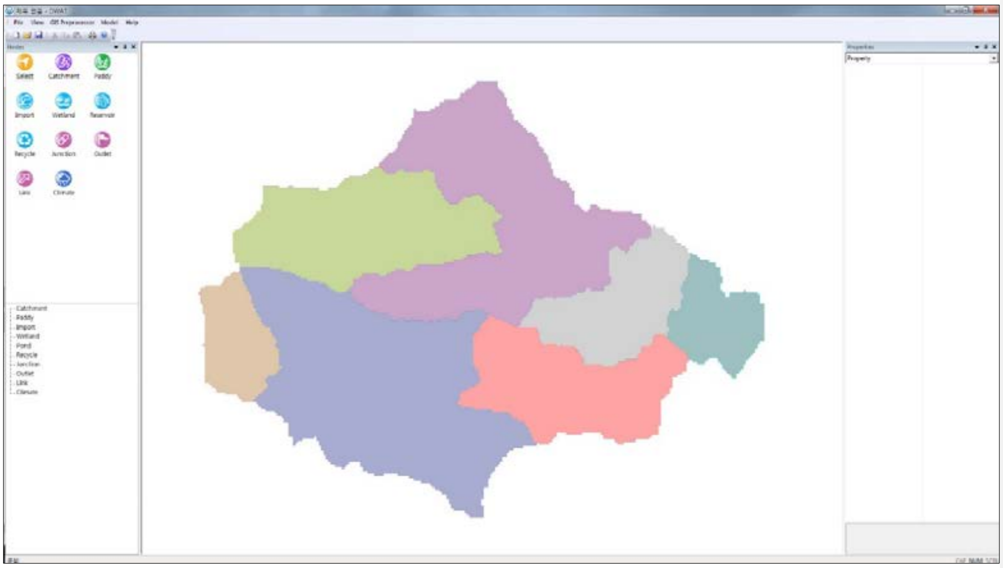


Figure 3.3 Imported background image

3.2 Climate

In order to calculate potential evapotranspiration using the Penman-Monteith method, DWAT requires the meteorological time series such as the maximum/minimum temperatures, wind velocities, sunshine hours, humidity, etc., but only maximum/minimum temperatures is required for the Hargreaves method. The model was designed to enable to copy and paste time series data from Microsoft Excel sheet. In addition, the user can not only choose weather

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stations but also can allocate weighted values from the Thissen networks at each node.

The location of each weather station, the height from the ground of each observing device and the latitudes should also be collected. They are necessary to calculate potential evapotranspiration by the Penman-Monteith method.

3.2.1 Climate Data Create

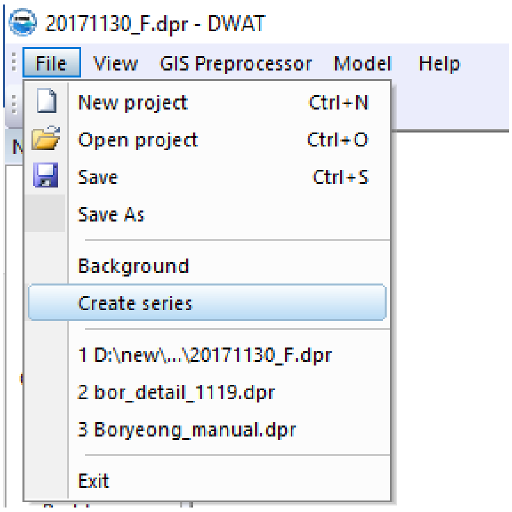


Figure 3.4 Tools for creating time series

Create series: It allows users to create the DWAT input data file (*.dat) format from Excel (*.xls), text (*.txt), and DBF (*.dbf) formats of meteorological data. Firstly, the user must check the time step of his/her own data with format of *.xls, and then enter the data period.

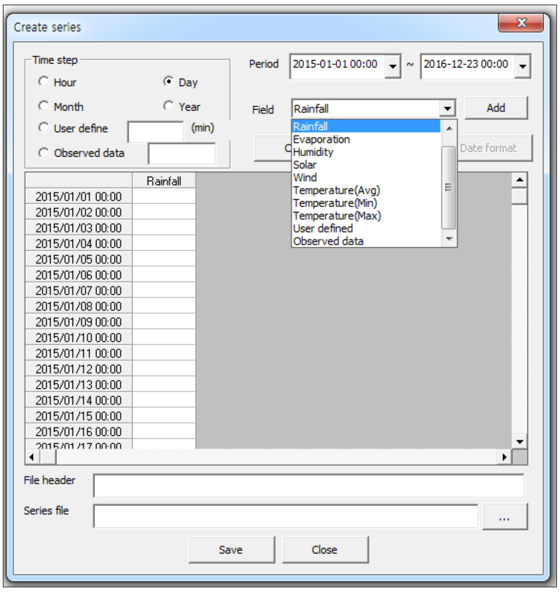


Figure 3.5 Selecting the time series data to be created

Time step: time step for climate data (minute, hour, day, month, year)

Period: time to start and finish

Field: specify the type of field for input (to calculate the potential evapotranspiration, temperature, wind speed, humidity and sunshine hours selected. After select the field name and click the Add), only maximum/minimum temperatures is required for the Hargreaves method. The user can prepare his/her own data with format of *.xls or *.txt and Copy & Paste can be carried on.

Comment [j11]: Review 12

When creating the climate data, you do not need to select 'Date' field because it will be automatically created when you add another field after entering the data period.

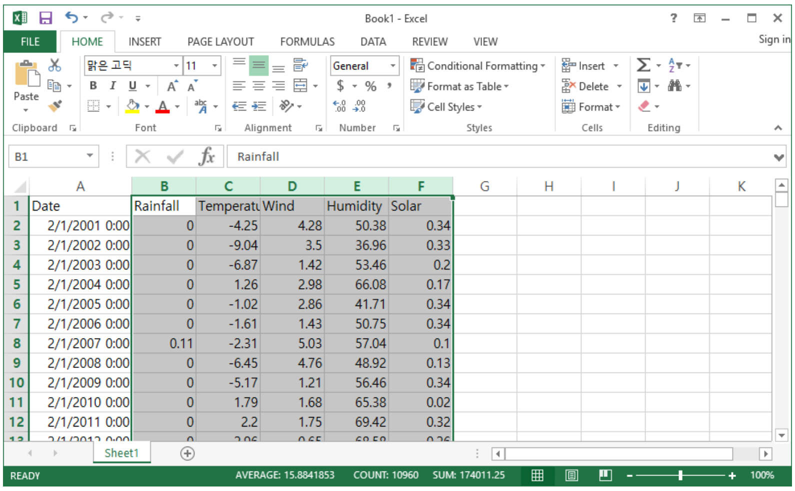


Figure 3.6 Time series data in Microsoft excel

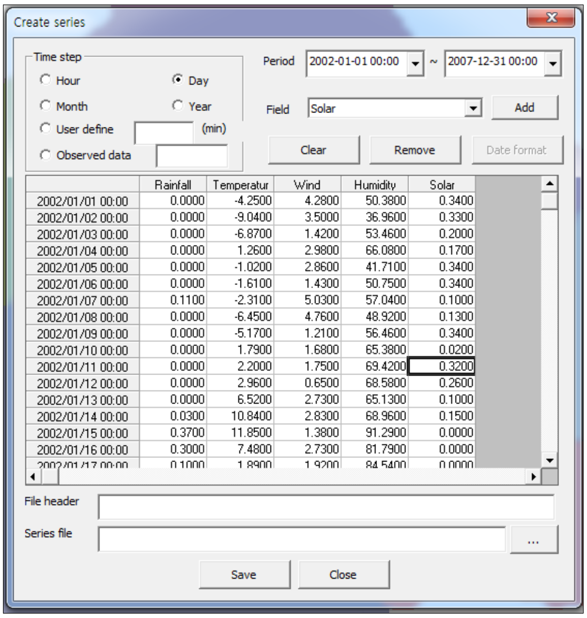
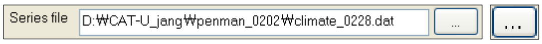


Figure 3.7 Creating time series database



Click and enter the saving directory and file name.

Enter the file description.

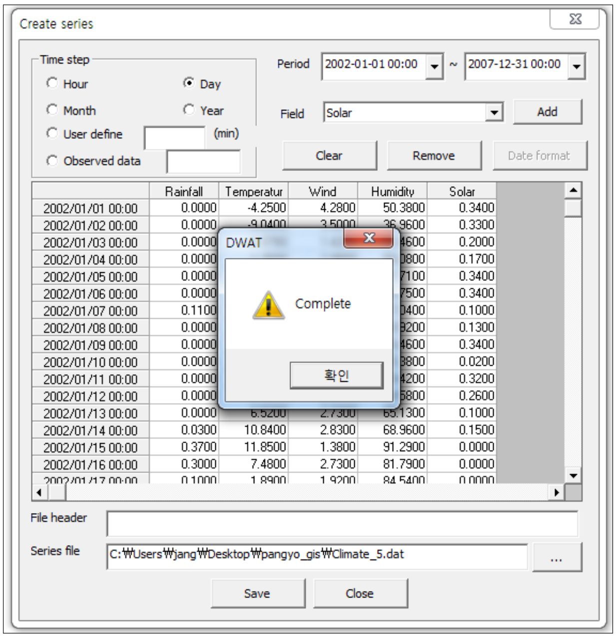


Figure 3.8 Completed time series database

Save: The file will be saved as DWAT time series input data by pressing the 'Save' button. When the saving has been completed, Press the 'OK' Button.

3.2.2 Climate Data Checking

To check whether data have been properly saved or not, the following process should be performed:

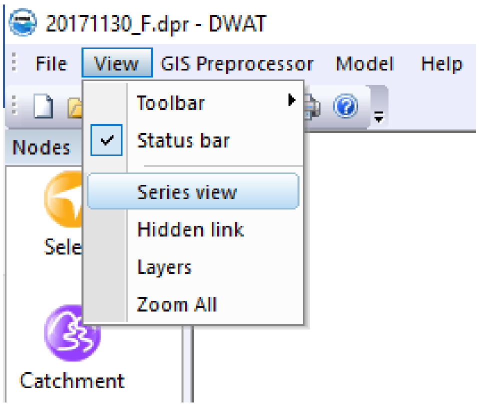
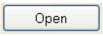


Figure 3.9 Time series database checking tool

Series view: It allows users to display all data files created in the DWAT screen. View Series gives the following window.  Pressing the button to display the meteorological data previously saved, and then pressing this button  to load the time series data in the spreadsheet of the window as shown in the following figure.

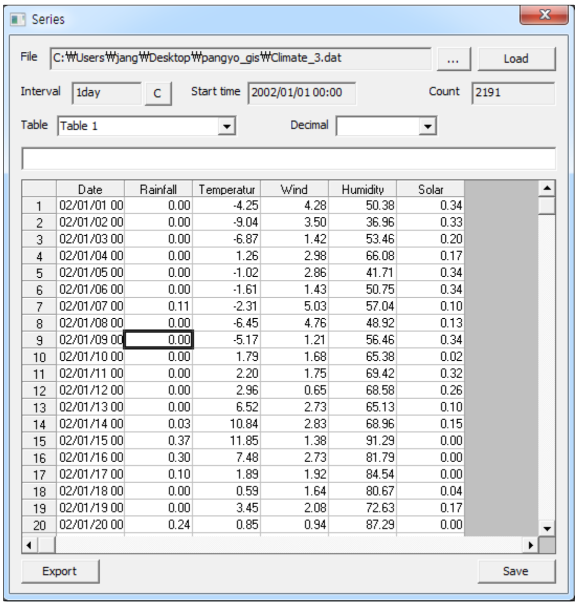


Figure 3.10 Saved time series database

The following figure appears on the upper part of the 'Series View' window. It shows the information about the data file: the time interval (one day), the number of data rows (2,191) and the data start time (2002/01/01 00:00).

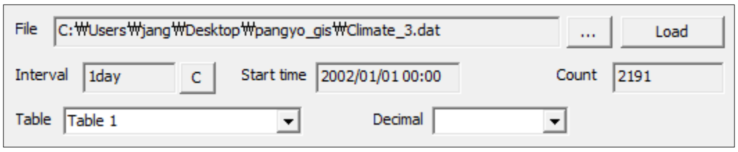


Figure 3.11 Time series database information

: This is a function to modify the time interval for input data. Once it has been selected, the current time interval appears. The process is: change the time interval in the 'NEW' tab; select whether to show the sum, average, maximum or minimum in the 'Method' tab; and then press 'OK'. The changed time interval will be displayed.

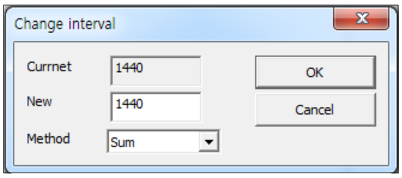


Figure 3.12 Tab to change the time series data

: If the meteorological data imported by the DWAT have been checked, these data may be exported in text file format (*.txt). These text format data may be opened and checked in general text editors.

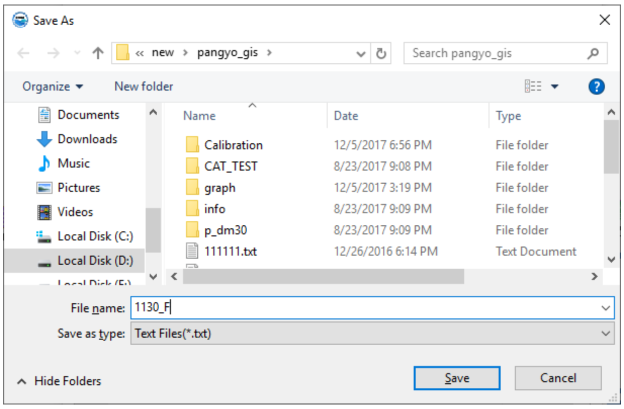
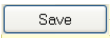


Figure 3.13 Export data



In addition, meteorological data imported into the 'Series View' may be revised and the revised data may be saved under another name.

Comment [j12]: Review 33 58

3.2.3 Climate Node Entry

 After completing the processes of setting the catchment system and creating meteorological data, the user will reach the stage to enter meteorological nodes. As mentioned earlier, the DWAT is a node-link model and the user can select icons (e.g. link, source, and junction) with a mouse to easily configure catchment information. A climate node will be created by clicking the left mouse button on the appropriate position in the 'Main Interface' after selecting the climate icon  in the menu. The same process is required to configure multiple climate stations.

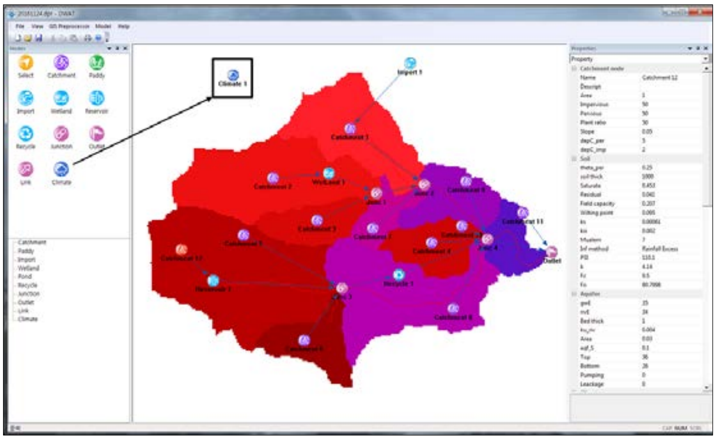


Figure 3.14 Climate node entry

After left-clicking on a meteorological node, the following window will appear on 'Property View'.

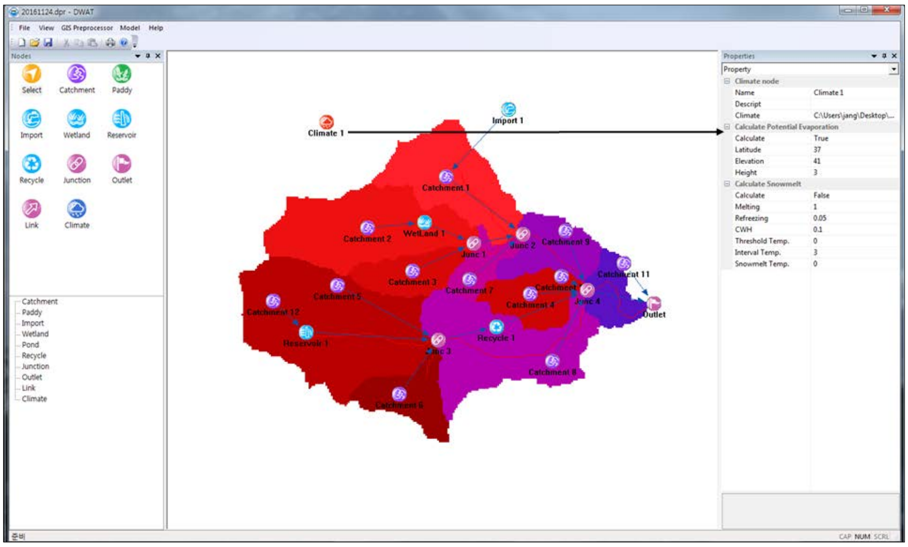


Figure 3.16 Climate data entry property view

Property: This is a menu to import meteorological data and enter climate station information.

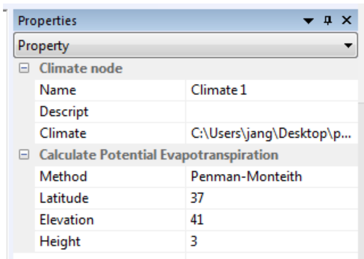


Figure 3.17 Property view to import meteorological data

Climate station names may be modified in the 'Name' column and a brief description is to be entered into the 'Descript' column. After that, press a ... button under 'Climate' to import meteorological data.

Comment [HJ13]: Change figure

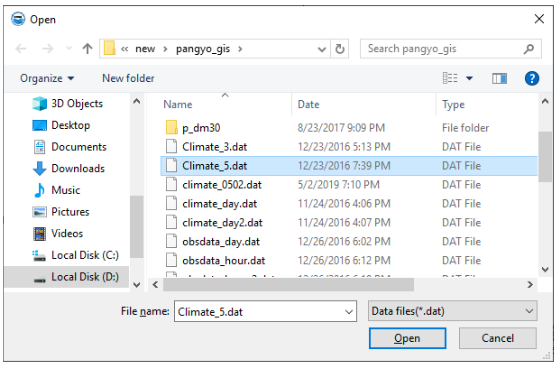


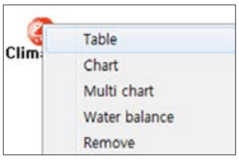
Figure 3.18 Loading meteorological data

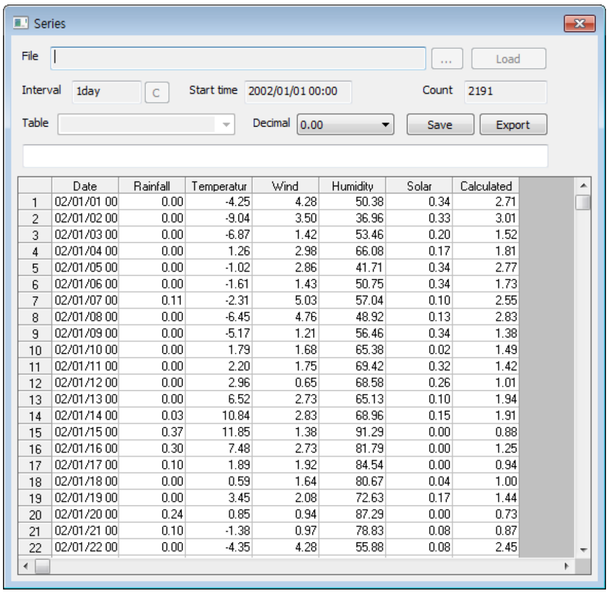
Method: By selecting ‘Penman-Monteith’ or ‘Hargreaves’, parameters to calculate potential evapotranspiration can be brought from meteorological data. If ‘None’ is selected, the program will use the potential evapotranspiration entered by users.

Comment [j14]: Review 4

Latitude, Elevation, and Height: This a dialog box to enter the location of the climate station (latitude, elevation and height). This function is used when the ‘Penman-Monteith’ option has been selected.

Table: This is a menu to identify meteorological data and calculated evapotranspiration in a table. This function may be used once the model has been executed. That is, this menu is used to view results after running the model.

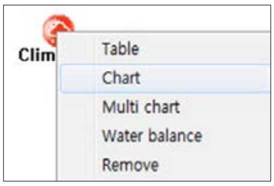




	Date	Rainfall	Temperatur	Wind	Humidity	Solar	Calculated
1	02/01/01 00	0.00	-4.25	4.28	50.38	0.34	2.71
2	02/01/02 00	0.00	-9.04	3.50	36.96	0.33	3.01
3	02/01/03 00	0.00	-6.87	1.42	53.46	0.20	1.52
4	02/01/04 00	0.00	1.26	2.98	66.08	0.17	1.81
5	02/01/05 00	0.00	-1.02	2.86	41.71	0.34	2.77
6	02/01/06 00	0.00	-1.61	1.43	50.75	0.34	1.73
7	02/01/07 00	0.11	-2.31	5.03	57.04	0.10	2.55
8	02/01/08 00	0.00	-6.45	4.76	48.92	0.13	2.83
9	02/01/09 00	0.00	-5.17	1.21	56.46	0.34	1.38
10	02/01/10 00	0.00	1.79	1.68	65.38	0.02	1.49
11	02/01/11 00	0.00	2.20	1.75	69.42	0.32	1.42
12	02/01/12 00	0.00	2.96	0.65	68.58	0.26	1.01
13	02/01/13 00	0.00	6.52	2.73	65.13	0.10	1.94
14	02/01/14 00	0.03	10.84	2.83	68.96	0.15	1.91
15	02/01/15 00	0.37	11.85	1.38	91.29	0.00	0.88
16	02/01/16 00	0.30	7.48	2.73	81.79	0.00	1.25
17	02/01/17 00	0.10	1.89	1.92	84.54	0.00	0.94
18	02/01/18 00	0.00	0.59	1.64	80.67	0.04	1.00
19	02/01/19 00	0.00	3.45	2.08	72.63	0.17	1.44
20	02/01/20 00	0.24	0.85	0.94	87.29	0.00	0.73
21	02/01/21 00	0.10	-1.38	0.97	78.83	0.08	0.87
22	02/01/22 00	0.00	-4.35	4.28	55.88	0.08	2.45

Figure 3.15 Time series result of calculated evapotranspiration

Chart: This is a menu to view graphs from the model runs. This function is provided in not only a meteorological node but also all links, nodes, and junctions. No matter which of them is selected, an identical window will appear (i.e. no matter which source node, link or junction is selected, graphs at all points can be identified). A detailed description for the Chart view is given in **Section 5.2.** Following graph shows the result of potential evapotranspiration (PET) and actual evapotranspiration (AET) at the source node.



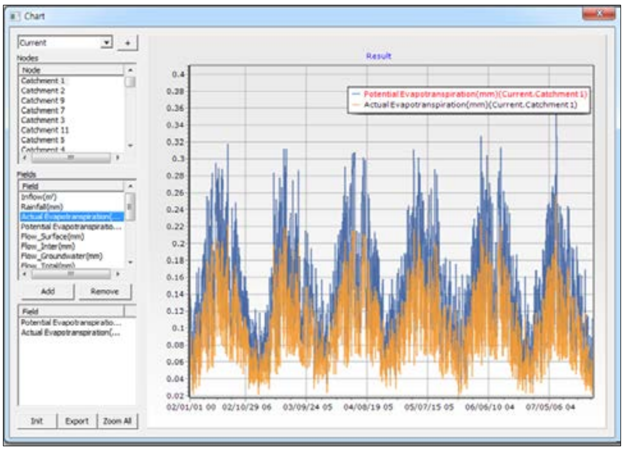


Figure 3.16 Graphical result of calculated evapotranspiration

3.3 Ground Surface

Once entries of the meteorological nodes have been completed, information on the source nodes, links and junctions configured about sub-catchments is to be entered one by one. Input data for ground surface conditions include ground surface slopes, impervious area ratios and depression storage as shown in Table 3.2. In general, depression storage in impervious zones is understood as 2mm. Examples of impervious area ratios by land use are shown in Table 3.4.

Table 3.4 Classification of land cover

Classification	Class 1	Class 2	Ratio Impervious area * (%)
1	Urban	Residential	65
2		Industrial	72
3		Commercial	85
4		Recreation	50
5		Road	100
6		Public	60
7	Agriculture	Paddy	-
8		Upland	-
9		Green House	-
10		Orchid	-
11		Etc.	-
12	Forest	Deciduous	-
13		Coniferous	-
14		Mixed	-

15	Grass	Natural	-
16		Golf Course	-
17		Etc.	-
18	Wetland	Inland	-
19		Coastal	-
20	Bare soil	Mines	-
21		Etc	-
22	Water	Inland	-
23		Sea	-

* Ratio of impervious area (Guideline for river planning, KWRA, 2009)

In this chapter, entry processes for the basic ground surface condition of the catchment node will be explained in detail.

3.3.1 Catchment Node Entry

Catchment node will be located by placing each of the catchment node icons at an appropriate position on the main Interface and left-clicking the mouse after selecting each node icon.

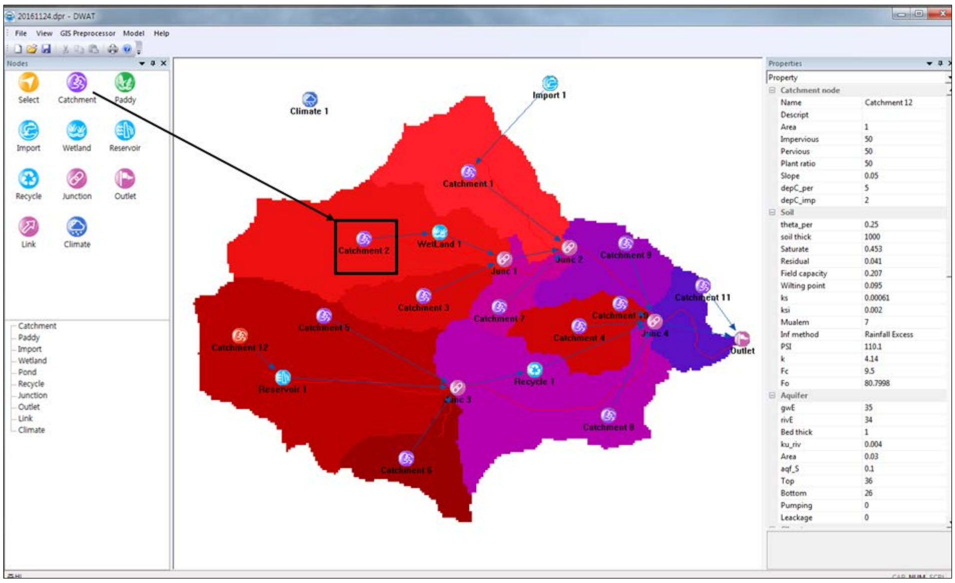


Figure 3.17 Catchment node entry

3.3.2 Parameter Entry

In the following Figure, the ‘Property View’ will show the information on the catchment node.

The ‘Property View’ is used to enter or revise all catchment node data (ground surface, soil, groundwater aquifer, etc). Basic ground surface conditions are to be entered under the node.

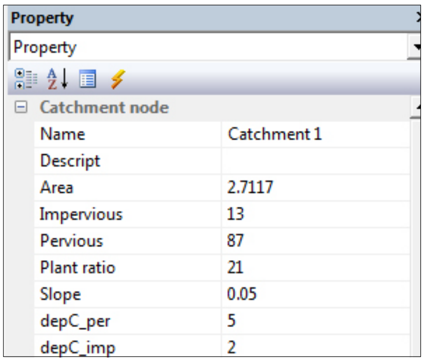


Figure 3.18 Parameters for catchment node

Name: This indicates source node (sub-catchment) names.

Descript: Information about the source node (sub-catchment) can be entered.

Area: source node (sub-catchment) area (㎢).

Slope: basin's average slope.

Impervious: impervious area ratio.

Pervious: pervious area ratio.

Plant_ratio: vegetation area ratio in pervious zone (This parameter is an evapotranspiration-related variable that is divided into four types, including forest, grassland, urban forest and crop, and the range of the variable and these values are shown in the following figure (Jia, Y., 2002).

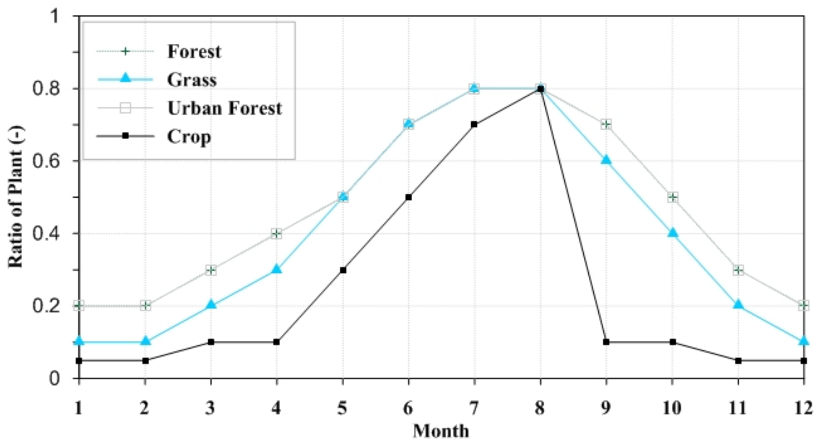


Figure 3.19 Plant ratio of different land use (Jia, Y., 2002)

DepC_imp: depression capacity in the impervious zone (generally 2㎜)

DepC_per: depression capacity in pervious zone (㎜)

It is possible to take advantage of the properties defined for one sub-catchment for using them for another sub-catchment to be further edited as necessary. Right-clicking on the sub-catchment node and clicking the ‘Copy to’ menu.

Comment [j15]: Review 56

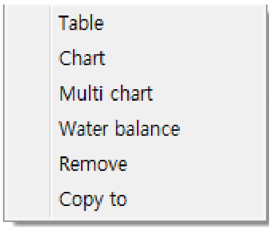


Figure 3.29 Select menu to copy catchment characteristics

The following window will appear.

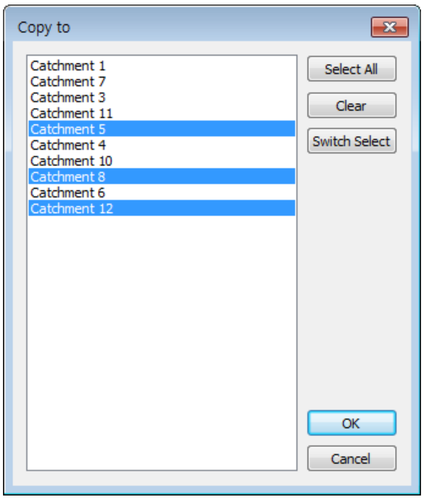


Figure 3.30 Dialogue window to copy catchment characteristics

The possibility of copying and pasting the properties of one sub-catchment into a second one would be highly useful.

3.4 Soil

In this model, the concept of surface soil indicates the depth (range) where pores exist to temporarily store intermediate runoff. In DWAT, infiltration and evapotranspiration into/from soil are analyzed based on the physical characteristics of the soil, and thus surface soil parameters should be established. The physical characteristics of soil (including soil depth, saturated hydraulic conductivity, horizontal hydraulic conductivity, saturated moisture contents, residual moisture contents and Mualem's n) are used. The information on the surface soil depths and parameters is used after being classified by soil texture based on the 1:25,000 precise soil map in the Republic of Korea. The following table is utilized based on the study (A study on the development of basin diagnosis methods for establishing healthy water cycle systems, 2005).

Table 3.5 Surface soil input parameters by soil texture

Soil Texture	Saturated Moisture Content Ratio s_per	Residual Moisture Content Ratio r_per	SMC, Field Capacity FC_per	SMC, Wilting Point W_per	Saturated Hydraulic Conductivity Ks_per (mm/s)	Horizontal Hydraulic Conductivity Ksi_per (mm/s)	Mualem's n
Sand	0.437	0.020	0.091	0.033	6.5E-02	6.5E-01	3.37
Loamy Sand	0.437	0.035	0.125	0.055	1.7E-02	1.7E-01	3.64
Sandy Loam	0.453	0.041	0.207	0.095	6.1E-03	6.1E-02	3.91
Loam	0.463	0.027	0.27	0.117	3.7E-03	3.7E-02	4.17
Silty Loam	0.501	0.015	0.3	0.133	1.9E-03	1.9E-02	4.20
Sandy Clay Loam	0.398	0.068	0.33	0.148	8.3E-04	8.3E-03	4.23
Clay Loam	0.464	0.075	0.255	0.197	5.6E-04	5.6E-03	4.26
Silty Clay Loam	0.471	0.040	0.318	0.208	5.6E-04	5.6E-03	4.29
Sandy Clay	0.430	0.109	0.366	0.239	3.3E-04	3.3E-03	4.32
Silty Clay	0.479	0.056	0.339	0.250	2.8E-04	2.8E-03	4.35
Clay	0.475	0.090	0.384	0.272	1.7E-04	1.7E-03	4.38

* Rawls & Brakensiek Soil parameter estimates (1985).

3.4.1 Parameter Entry

The 'Property' window is opened by left-clicking on each source node.

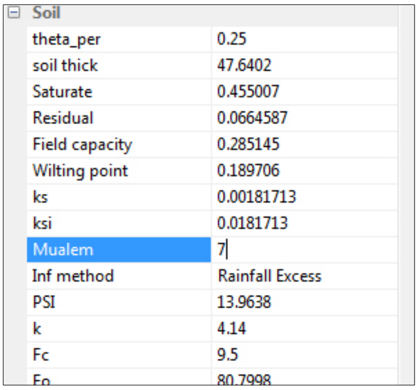


Figure 3.31 Parameters for soil characteristics

theta_per: This is the current moisture content of the soil. 0.25 is a default value and this value may change at each time step. It is a computed value between saturated moisture content ratio and residual moisture content ratio.

soil_thick: This is the soil thickness generally in a range of 1 - 5 (m).

Comment [j16]: Review 51

Saturate: This is the saturated soil moisture content ratio in a range of 0.4 - 0.6 (refer to Table 3.5).

Residual: This is the residual soil moisture content ratio in a range of 0.01 - 0.2 (refer to Table 3.5).

Field capacity: This is the soil moisture content at field capacity in a range of 0.1 - 0.5 (refer to Table 3.5).

Wilting point: This is the soil moisture content at a wilting point in a range of 0.03 - 0.3 (refer to Table 3.5).

ks: This is the saturated hydraulic conductivity in a range of 0.1×10-4 – 0.7×10-1 (㎜/s, refer to Table 3.5).

ksi: This is the horizontal hydraulic conductivity in a range of 0.1×10-3 - 0.7 (㎜/s, refer to Table 3.5).

Mualem: When calculating vertical and horizontal infiltration, this model uses the Mualem equation, which utilizes unsaturated hydraulic conductivity. This shows the n index value of the Mualem equation, which is the input parameter. This value is in a range of 3 - 5 (refer to Table 3.5).

Inf_method: Selection for infiltration method, Rainfall Excess, Green & Ampt, Horton method are provided.

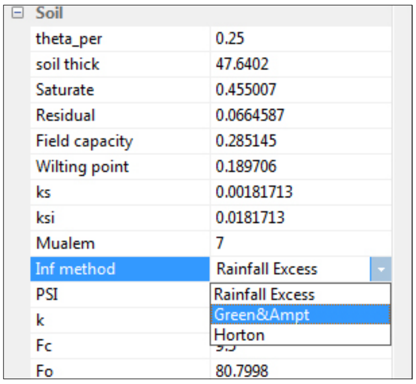


Figure 3.32 Infiltration method selection

PSI: Capillary suction head for Green and Ampt method. Table 3.6 shows the typical values of PSI (㎜)

Table 3.6 PSI values for each soil texture

Soil texture	PSI (mm)
Sand	49.5
Loamy Sand	61.3
Sandy Loam	110.1
Loam	88.9
Silt	130.7
Silty Loam	166.8
Sandy Clay Loam	218.5
Clay Loam	208.8
Silty Clay Loam	273.0
Sandy Clay	239.0
Silty Clay	292.2
Clay	316.3

* Rawls & Brakensiek Soil parameter estimates (1985)

k : Decay constant for soil used by Horton method (generally 4.14 $hour^{-1}$)

Fc : Minimum infiltration capacity for Horton method (㎜/hr). See Table 3.7

Fo : Maximum infiltration capacity by Horton method (㎜/hr). It is affected by the type of soil, initial soil moisture, and the surface condition. See Table 3.8

Table 3.7 Typical minimum infiltration capacity (Fc)

Soil Drainage Classes	Minimum Infiltration (Fc) (mm/hr)
A (Excessively drained)	11.43 - 7.62
B (Well drained)	7.62 -3.81
C (Poorly drained)	3.81 - 1.27
D (Very Poorly drained)	1.27 - 0.0

* XP-SWMM User's Manual (2007)

Table 3.8 Typical maximum infiltration capacity (F_o)

Soil Type		Maximum Infiltration (F_o) (mm/hr)
A. Dry soils (with little or no vegetation)		
	Sandy Soil	127.0
	Loam Soil	76.2
	Clay Soil	25.4
B. DRY soils (with dense vegetation)		
	Sandy Soil	254.0
	Loam Soil	152.4
	Clay Soil	50.8
C. MOIST soils		
Soils which have drained but not dried out	Sandy Soil	84.7
Soils close to saturation	Loam Soil	Choose value close to minimum infiltration rate
Soils which have partially dried out	Clay Soil	33.9

* XP-SWMM User's Manual (2007)

3.5 River

Since the parameters related to channels in the DWAT are closely related to groundwater aquifers, the model was designed to enter the parameters in the ‘Property View’ window shown in the figure below. Channel specifications can be entered using the existing report or field survey. In this section, channel specification related variables will be explained and groundwater aquifer input parameters will be addressed in the next section.

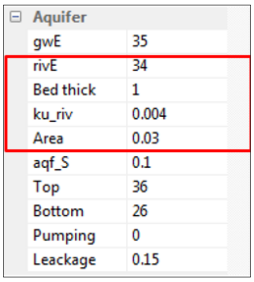


Figure 3.33 Parameters for riverbed

rivE: Riverbed elevation (EL.m)

Bed thick: Riverbed material thickness (m, 1.0 is a default value and this value is in a range of 0.1 - 1.0 depending on river elevation)

ku_riv: Saturated hydraulic conductivity of riverbed material (㎜/s, the range of 1.0×10^{-4}-1.0×10^{-6} is generally used)

Area: Riverbed area (㎢).

3.6 Groundwater Aquifer

In the DWAT, groundwater and river runoff are simulated using the relationship between groundwater and river levels. That is, if the groundwater level is higher than the river level, water will flow into the river depending on soil hydraulic conductivity. Conversely, if the river level is higher than the groundwater level, water will percolate into the aquifer. The model was designed to consider groundwater pumping and leakage from water supply networks. The leakage is simulated to flow into soil layer. In addition, moisture content movements between aquifers are considered. That is, level changes in groundwater by moisture content movements between aquifers in each sub-catchment can be analyzed. As shown in the following figure, parameters related to aquifer specification may be entered under the ‘Aquifer’ tab while comparing with channel specifications in order to determine the mutual relationship between groundwater and river levels. Each parameter will be reviewed in detail in the following section.

3.6.1 Aquifer Specification Entry

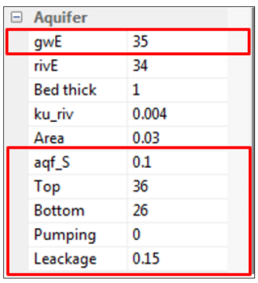


Figure 3.34 Parameters for aquifer

gwE: This indicates the initial groundwater level. This value will vary through the year if there is no initial groundwater level in each modeling period. Thus it is necessary to start the calculation from approximately one year before the analysis period in order to minimize the effect of uncertainty from the initial groundwater values during simulation (EL.m).

aqf_S: This indicates storage coefficient of the aquifer. If there are records, a value in a range of 1.0×10^{-2} – 1.0×10^{-1} is recommended.

Top: The elevation of aquifer shall be determined by deducting the surface soil thickness from the ground surface elevation (EL.m).

Bottom: The bottom elevation of aquifer shall be determined by referring to existing examinations. When there are no field surveyed data, this value is generally assumed to be 20m ~ 30m below the top elevation of the aquifer. For existing records, groundwater survey reports for sub-catchment or field data can be used (EL.m).

Pumping: This indicates the groundwater pumping rate (m^3/day).

Leakage: This indicates the leakage rate from water supply networks. 15% is generally recommended and 0.15 is a default value.

3.7 Actual Evapotranspiration

Method: It allows users to select actual evapotranspiration calculation methods

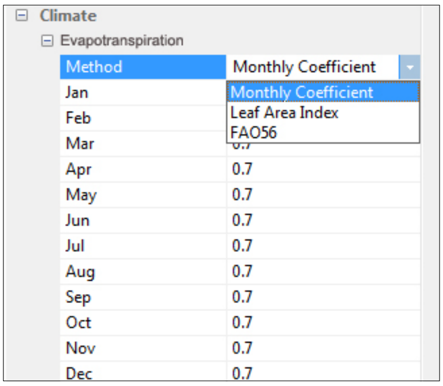


Figure 3.35 Actual evapotranspiration calculation methods

Monthly Coefficient: A method to calculate actual evapotranspiration by multiplying the potential evapotranspiration with monthly coefficients.

Leaf Area Index: A method to calculate actual evapotranspiration considering monthly leaf area indexes (LAI, Leaf Area Index) and soil moisture contents (the same method used in the SWAT, Soil and Water Assessment Tool)

FAO 56: The potential evapotranspiration is calculated by the Penman-Monteith method in

FAO56 using climate data (Max. & Min. air temperature, sunshine hour, humidity and wind speed).

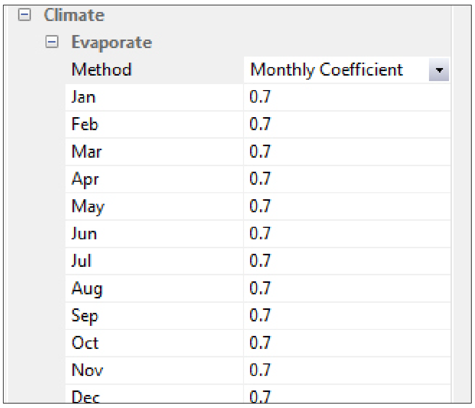


Figure 3.36 Monthly coefficient allocation

The above figure shows how to enter monthly coefficients. Monthly evapotranspiration correction coefficients and monthly leaf area indexes (LAI) are entered in the monthly method and the AETSWAT, respectively. The types of vegetation used in the model are divided into four groups: forest, grassland, urban forest and crop (Jia, Y., 2002). The leaf area indexes are values from a previous study (A study on the development of basin diagnosis methods for establishing healthy water cycle systems, 2005). The following figure shows the leaf area indexes (LAI) applied to the model.

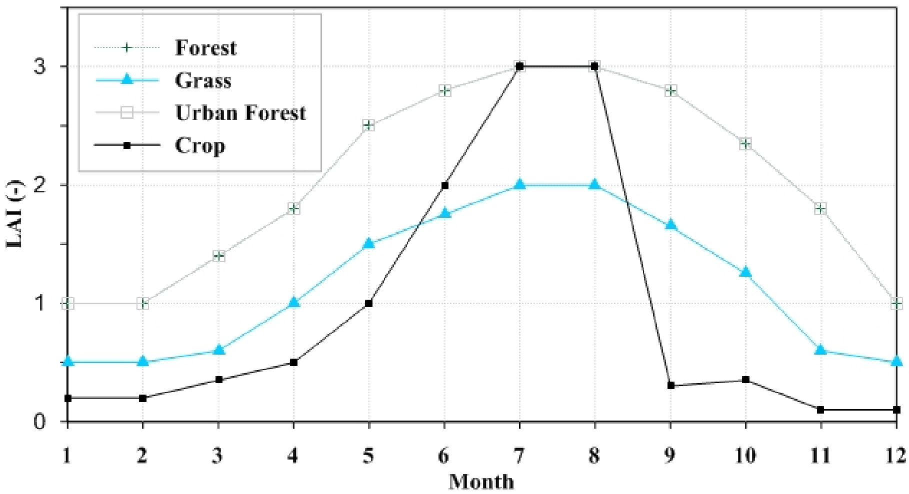


Figure 3.37 Leaf area indexes of different land use (Jia, Y., 2002)

When meteorological data is used in the DWAT, the user not only can choose climate stations having meteorological data but also may allocate weighted values from the thiessen network at each node. DWAT can use the rainfall gauges in the network. The thiessen weight coefficient can be specified for each source node. In addition, it can specify different stations climate and rainfall data. The maximum gauging stations to apply climate and rainfall are five.

Comment [j17]: Review 41

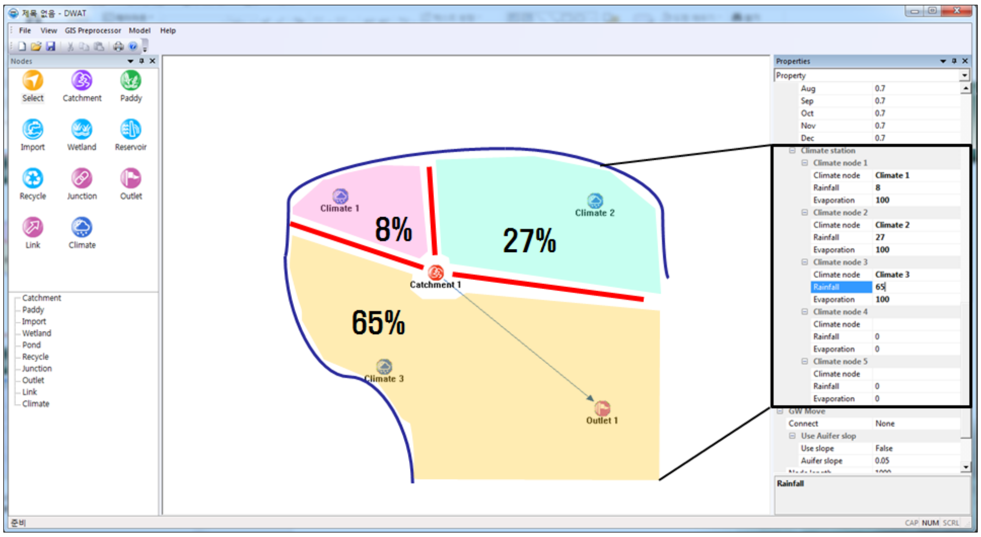


Figure 3.38 Thiessen weight coefficient allocation

3.8 Snow melt Parameter Entry

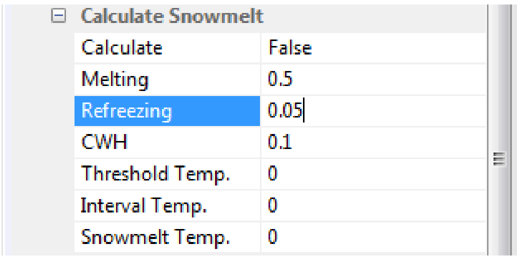


Figure 3.39 Parameters for snow melt

Snowmelt: In the DWAT model, precipitation is divided by temperature into snowfall and rainfall. The following six parameters are required for snow melting simulation.

Melting: Melting factor for degree day (mm/°C/day)

Refreezing: Refreezing factor

CWH: Critical relative Water content of the snowpack

Threshold Temp.: Threshold temperature for rain/snow (℃)

Interval Temp.: Temperature interval for rain/snow mixing (℃)

Snowmelt Temp.: Threshold temperature for snowmelt (℃)

3.9 Groundwater Movement Parameter Entry

Parameters related to groundwater movement between adjacent sub-catchments are entered through a separated ‘Property View’. It is shown in the figure below.

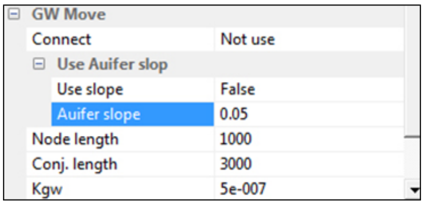


Figure 3.40 Parameters for groundwater movement

Connect: This is a window for selecting adjacent sub-catchment nodes to consider groundwater movement.

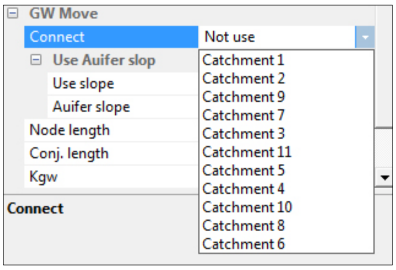


Figure 3.41 Groundwater movement to adjacent sub-catchment

Use_slope: This indicates groundwater hydraulic gradient. It can be estimated if the groundwater level of the catchment is known. However, if there is no information, it is generally recommended to use values smaller than ground surface slope.

Node_length: This indicates an average distance between adjacent sub-catchments (m).

Conj._length: This indicates a conjuncted length between adjacent sub-catchments (m).

Kgw: This indicates hydraulic conductivity of aquifer(㎜/s). A value in a range of 1.0×10^{-6} - 1.0×10^{-4} is recommended.

3.10 Paddy Node Entry

The DWAT has a paddy module reflecting the runoff characteristics of paddies by considering the ponding depth (which changes daily in paddies) and drainage outlet heights. The module was designed to be applicable to cases where drainage outlet is used for drainage in most paddies.

In general, paddy fields in the Republic of Korea are characterized by the fact that runoff is drained through drainage outlet. Drainage outlet serves the role of adjusting ponding depths in paddy fields and they are periodically adjusted by farmers. According to Lim (2002), drainage outlet is low in July because of heavy rains and they are high in other times in order to hold large amounts of water in paddy fields (See table 3.9). The following figure shows the change in monthly ponding depth in Korean paddy fields (Lim, 2002).

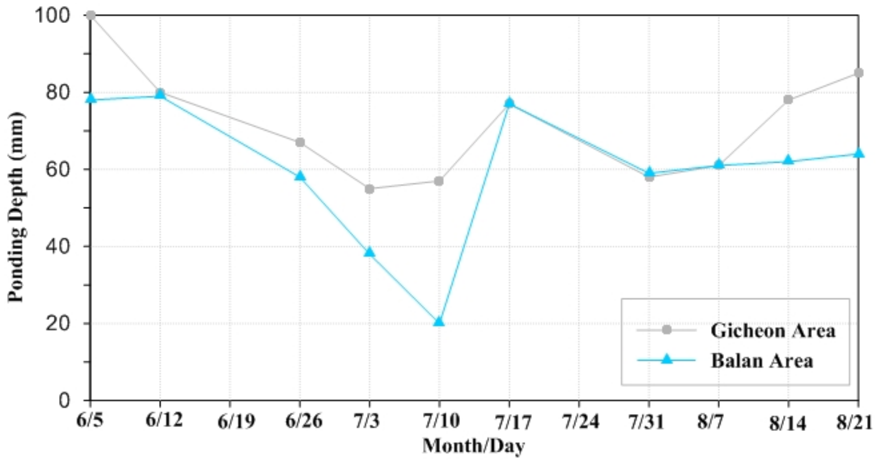


Figure 3.42 Monthly ponding depth in Korean paddy field

Table 3.9 Sample of the parameter in paddy field (Jia et al., 2005)

Parameter	Coefficient Of Surface Drainage Outlet, surf_dr_cf ($mm^{0.5}/h$)
Value	0.01 - 5.0

3.10.1 Parameter Entry

The Paddy nodes are entered by selecting the 'Paddy' icon and placing it in an appropriate position in the 'Main Interface' by clicking the left button on a mouse.

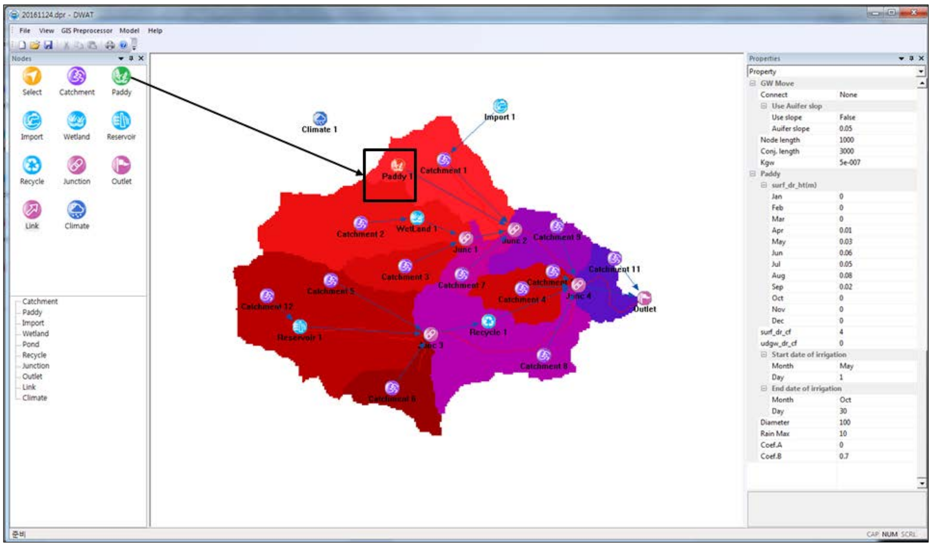


Figure 3.43 Paddy nodes Parameter Entry

If the paddy node is left-clicked, the ‘Property View’ will show the information on the paddy node. The ‘Property View’ is used to enter or revise all paddy node data.

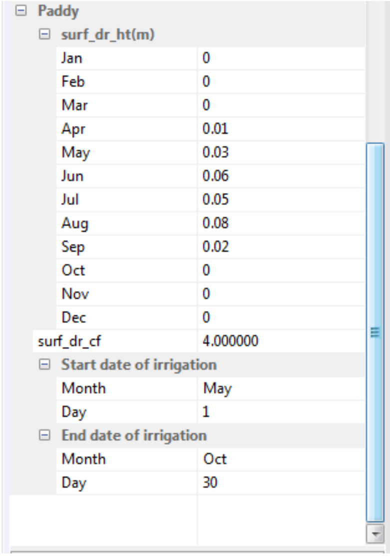


Figure 3.44 Parameters for paddy

surf_dr_ht: This indicates monthly ponding depth in the paddy (m, refer to existing study reports)

surf_dr_cf: This indicates the coefficient of surface drainage outlet in a range of 0.01 - 5.0 (refer to Table 3.9).

irr_start: This indicates the date of the start for irrigation. 1st April is a default value.

irr_end: This indicates the date of the end for irrigation. 30th September is a default value.

3.11 Reservoir

In the case of reservoirs, evaporation from the water surface is considered. The reservoir storage, water level, and discharge are calculated using the initial storage, effective storage, intake (*here, water is taken only when the storage is at least 20% of the effective storage volume*), the specifications of spillways and a discharge outlet in the reservoir.

Storage and water levels for both of the types are renewed by inflows based on the relationships of stage-storage-area.

The reservoir nodes are entered by selecting the ‘Reservoir’ icon and placing at the appropriate position in the ‘Main Interface’ by clicking the left button on a mouse.

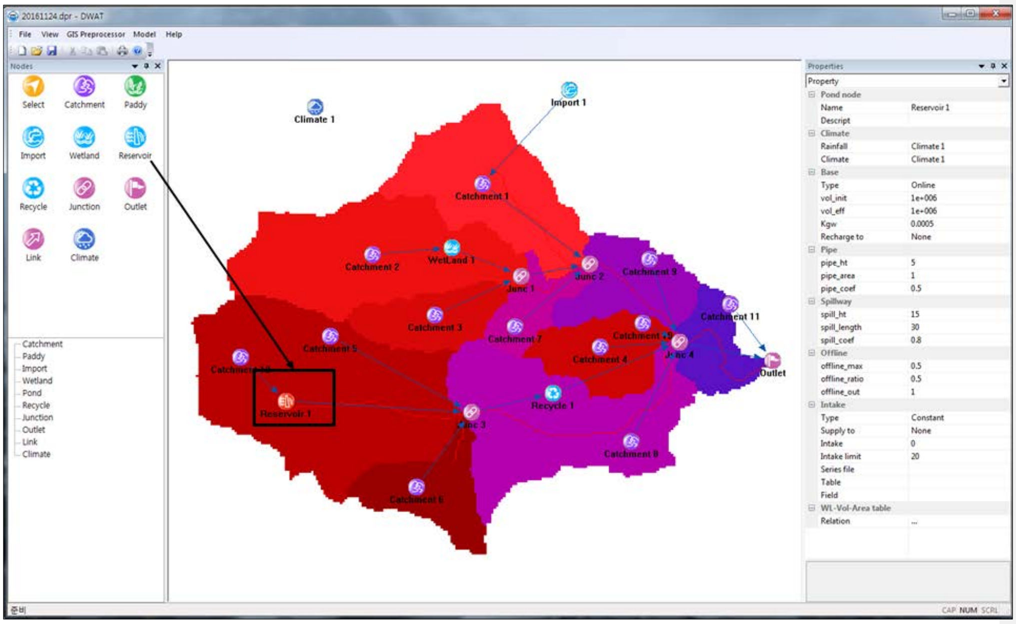


Figure 3.45 Reservoir Node Parameters Entry

If the reservoir node is left-clicked, the ‘Property View’ will show the information on the reservoir node. The ‘Property View’ is used to enter or revise all reservoir node data.

Name: This indicates reservoir name.

Descript: Information about the reservoir can be entered.

Rainfall: Rainfall station for the rainfall on the surface of the reservoir. It uses the selected adjacent rainfall station.

Climate: Climate station for evapotranspiration from the surface of the reservoir. It uses the selected adjacent weather station.

vol_init: Initial storage (㎥)

vol_eff: Effective storage (㎥)

Kgw: This indicates reservoir's bottom saturated hydraulic conductivity (㎜/s). This parameter is used to calculate the amount of loss in the bottom of the reservoir. The value is in a range of 1.0×10^{-5} - 1.0×10^{-3}.

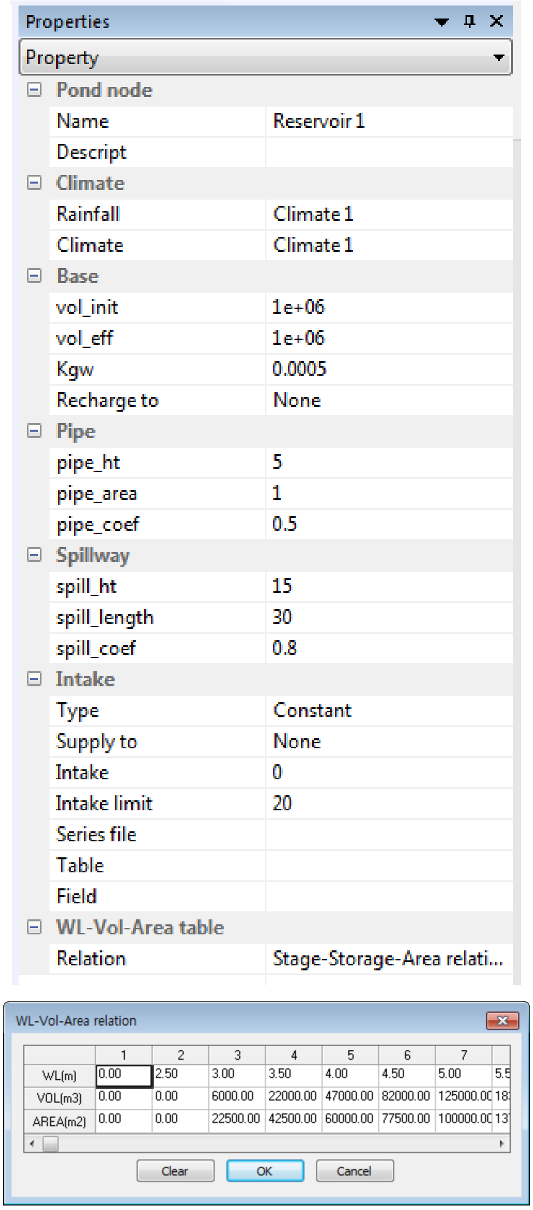


Figure 3.46 Reservoir parameters entry

Recharge to: The loss from the bed of reservoir can be calculated by hydraulic conductivity (Kgw). If "*Recharge to*" is selected, the recharged water can be transferred to catchment node to recharge groundwater.

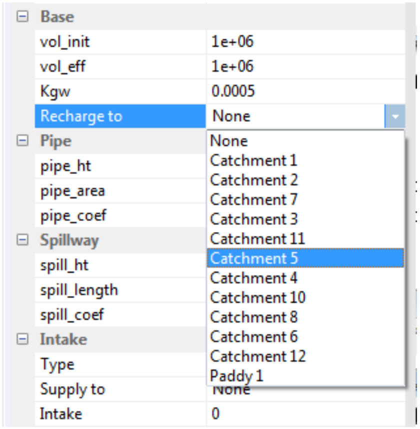


Figure 3.47 Recharge to adjacent sub-catchment

pipe_ht: Reservoir's outlet height (m)

pipe_area: Reservoir's outlet area (m)

pipe_coef: Reservoir's outlet runoff coefficient in a range of 0.5 - 1.0

spill_ht: Height of spillway (m)

spill_length: Length of spillway (m)

spill_coef: Overflow coefficient of the spillway in a range of 0.3 - 1.7

Type (Intake tab): This is to select the type of the intake type (Constant/Time series).

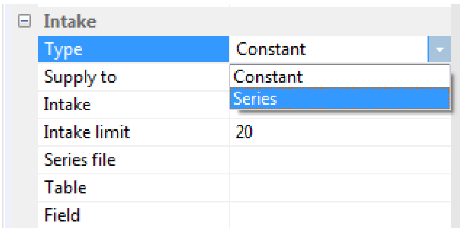


Figure 3.48 Intake type selection

Supply to: The intake from the reservoir can be transferred to the selected node. To use this function the Recycle node must be located at the downstream of the reservoir node.

Intake: This is intake volume from the reservoir. *Water is taken only when the storage is at least 20% of the effective storage*

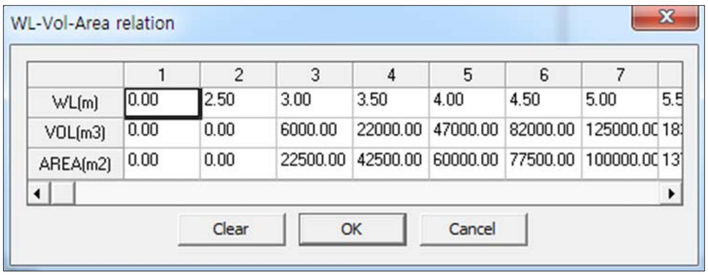


Figure 3.49 Water levels-storage volume-areas relationships

As shown in the above Figure, the amount of storage volume and the storage water level relative to the volume of inflows are based on the relationships among water levels-storage volume-areas.

3.12 Wetland

The storage of wetlands was assumed to be the initial condition. It was also assumed that the excess flow is to be sent to the downstream node when inflow is larger than the high flow bypass during the flood. After calculating the volume of the remaining inflow, all of the volumes will be overflowed when the volume is larger than the maximum storage. The module was designed to calculate water level, area, evaporation from the water surface and discharge through the outlet based on the final remaining storage volume.

The wetlands node is entered by selecting the icon shown in the following figure, placing at the appropriate position in the 'Main Interface' by clicking the left button on a mouse.

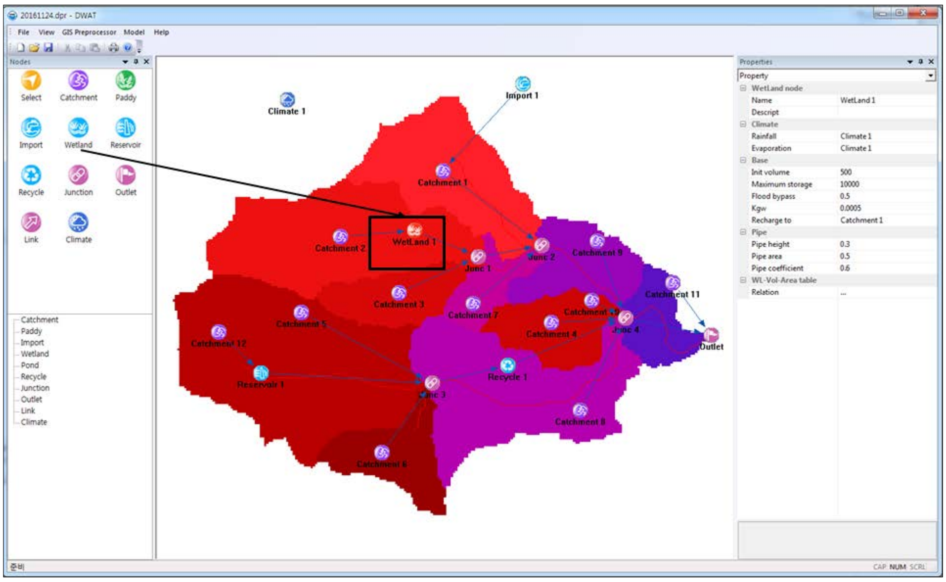


Figure 3.50 Wetland Node Main Window

If the wetland node is left-clicked, a window to set the parameters related to wetlands will appear.

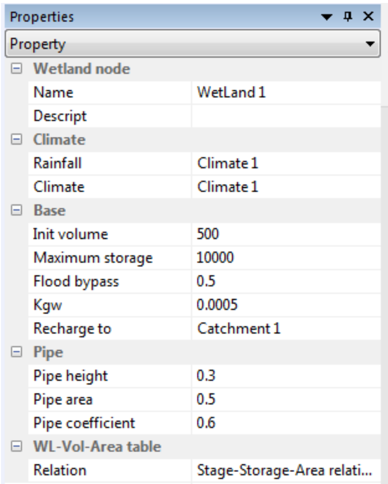


Figure 3.51 Parameters for wetland

Name: This indicates wetland name.

Descript: Information about the wetland can be entered and overviewed.

Rainfall: Rainfall station for the rainfall on the surface of wetland. It uses the selected adjacent rainfall station.

Climate: Weather station for evapotranspiration from the surface of wetland. It uses the selected adjacent weather station.

Init Volume: Initial storage (m^3)

Maximum storage: Maximum storage (m^3)

Flood_bypass: High flow bypass during flood (m^3/s)

Kgw: This indicates pond's bottom saturated hydraulic conductivity (mm/s). This parameter is used to calculate the amount of loss in the bottom of ponds. The value is in a range of 1.0×10^{-5} - 1.0×10^{-3}.

Recharge to: The loss from the bed of wetland can be calculated by hydraulic conductivity (Kgw). If "*Recharge to*" is selected, the recharged water can be transferred to catchment node to recharge groundwater.

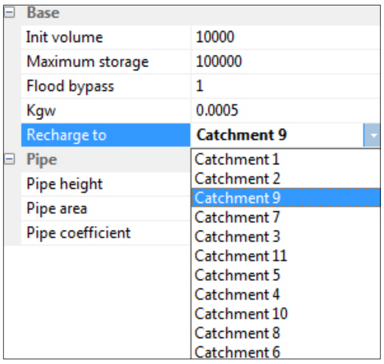


Figure 3.52 Wetland recharge to adjacent sub-catchment

pipe_height: Height of outlet pipe (m)

pipe_area: Area of the outlet pipe (m^2)

pipe_coefficient: Runoff coefficient of outlet pipe in a range of 0.5-1.0

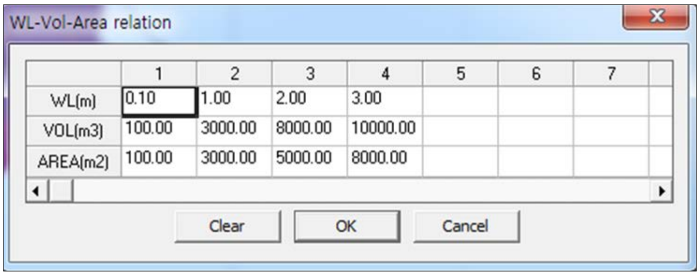


Figure 3.53 Water levels-storage volume-areas relationships

Evaporation from water surfaces and the discharge in the wetland are calculated through a renewal of storage and water level of wetlands based on the stage-storage-area relationships. It is similar to the calculation process of reservoirs.

3.13 Recycle

In order to review the processes for designing recycle, the inflow is calculated and the daily used intake volume is then distributed to individual nodes. Water intake is restricted by defining intake restriction for intake rate determined by streamflow discharge rate.

That is, if the value obtained by considering the inlet inflow amount and the intake restriction ratios is larger than the intake amount, the recycling inflow amount will be the same as the intake amount and the amount of runoff to the toe will become the value obtained by deducting the intake amount from the inlet inflow amount. If the inlet inflow amount, considering the intake restriction ratios, is lesser than the intake amount, the recycling inflow amount will be the same as the inlet inflow amount considering the intake restriction ratios. The amount of runoff to the toe is the value obtained by deducting the intake amount from the inlet inflow amount.

The Recycle node will be entered by selecting the icon shown in the following figure, placing the appropriate position in the ‘Main Interface’ by clicking the left button on a mouse.

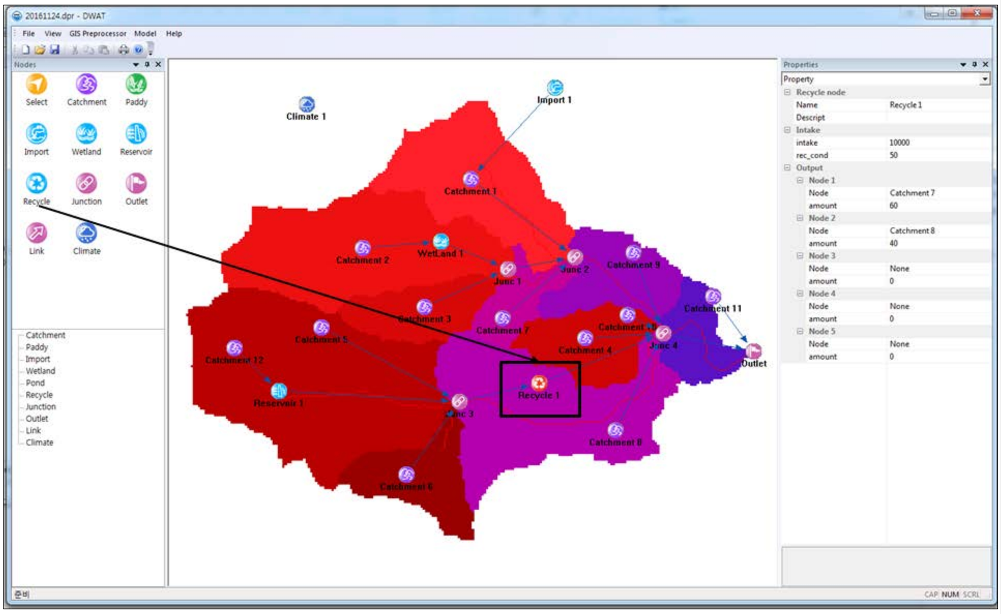


Figure 3.54 Recycle node in the main interface

If the Recycle node is left-clicked, a property window to set the parameters related to the Recycle will appear.

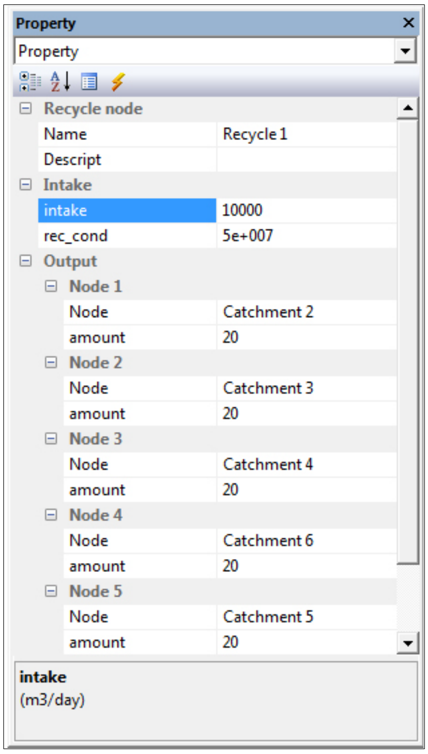


Figure 3.55 Parameters for recycle

Name: This indicates Recycle node name.

Descript: Information about the Recycle node can be entered.

Intake: Total intake volume (m^3)

rec_cond: Restriction for intake rate according to mainstream flow rate.

The DWAT has a function to send the determined discharge to several catchment nodes (maximum five nodes) using Recycle.

3.14 Import

Parameters related to the water use from outside of catchments are used to design the import function. A constant amount on a daily basis is used, and time series data for water supply data can be loaded.

The Import node may be entered by selecting the icon shown in the following figure, placing at the appropriate position in the ‘Main Interface’ by clicking the left button on a mouse.

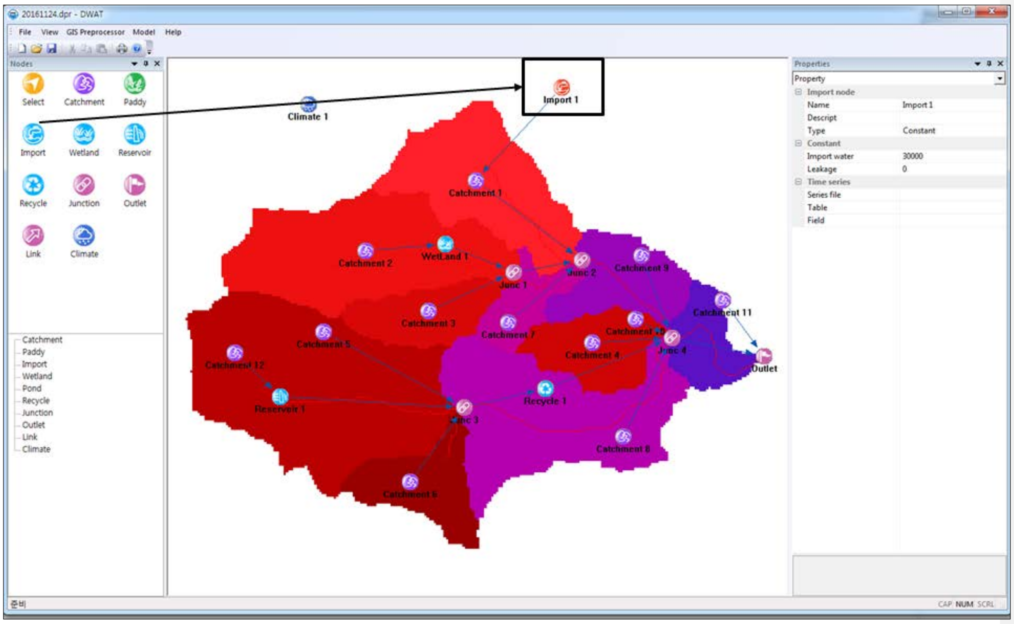


Figure 3.56 Import node in the main interface

If the import node is left-clicked, a property window to set the parameters related to the Import will appear.

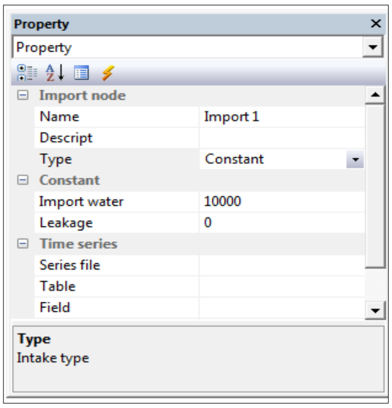


Figure 3.57 Parameters for import

Name: This indicates a node name

Descript: Information about the Node can be entered.

Type: This is to select the type of data to be imported: 'constant' for a constant daily amount; 'series data' for time series data for water supply.

Import water: This indicates imported water supply amounts. It is activated when the constant type is selected (m^3/day).

Leakage: Leakage from pipe network can be considered (The leaked water added to soil moisture in pervious area)

Series file: This is to load the time series data for water supply. This is activated when the series data type is selected. A screen to choose the file appears and the data can be loaded by pressing 'Time Series Data Open'. The data file should be created using the 'Create series' menu as with the process to create meteorological data described (The 'Type' should be set as 'User define').

3.15 Channel Routing (Link)

Comment [j18]: Review 43

In the DWAT, the channel routing is a process to convert inflow hydrologic curves into runoff hydrologic curves in channel sections using the Muskingum, Muskingum-Cunge and Kinematic wave methods. In this section, the selections of methods of inputting data and routing methods in the Link are described in detail.

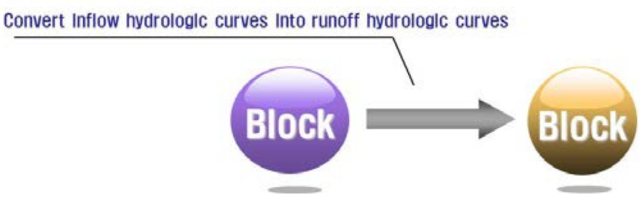


Figure 3.58 Channel routing link

If the Link that connects nodes together is left-clicked, a window to set the parameters for the Link will appear.

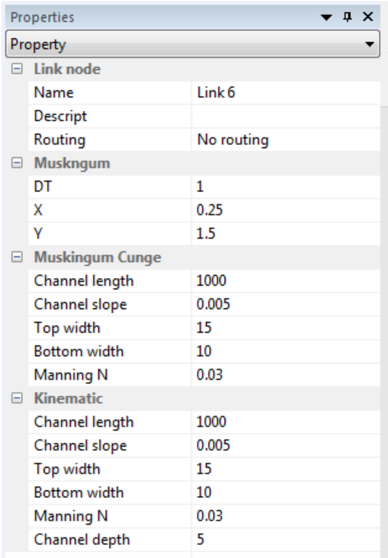


Figure 3.59 Channel routing method selection

Name: This indicates a link name.

Descript: Information about the Link can be entered.

Routing Methods: This is to set channel routing methods. ‘No routing’ is a default value and any channel routing methods can be chosen by the user.

Muskingum: When the Muskingum method is selected. The user may enter various parameters to fit channel characteristics.

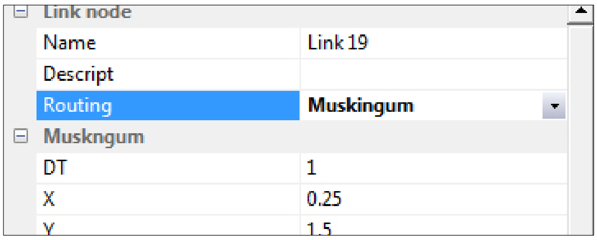


Figure 3.60 Muskingum method parameter entry

DT: Time interval (unit time)

X: Dimensionless constant in a range of 0.0 - 0.5 that indicates the relative importance of the inflow and runoff contributed to the total storage

Y: Storage constant in the dimension of time (hour) that indicates the ratio of the storage to the runoff in the routing section.

Muskingum Cunge: The Muskingum Cunge method's attribute window appears and the user can enter the parameters of the channel characteristics.

Muskingum Cunge	
Channel length	1000
Channel slope	0.005
Top width	15
Bottom width	10
Manning N	0.03

Figure 3.61 Muskingum Cunge method parameter entry

Channel length: Channel length (m)

Channel slope: Riverbed slope

Top width: Top width of the channel (m)

Bottom width: Bottom width of the channel (m)

Manning n: Manning's roughness coefficient

Kinematic wave: The Kinematic wave method's attribute window appears and the user can enter each parameter to fit channel characteristics. Computational demanding in running the model is required in the Kinematic wave method due to the effect of iteration for channel routing.

Kinematic	
Channel length	1000
Channel slope	0.005
Top width	15
Bottom width	10
Manning N	0.03
Channel depth	5

Figure 3.62 Kinematic wave method parameter entry

Channel length: Channel section length (m)

Channel slope: Riverbed slope

Top width: Top width of the channel (m)

Bottom width: Bottom width of the channel (m)

Manning n: Manning's roughness coefficient

Channel depth: Channel depth (m)

3.16 Junction and Outlet

3.16.1 Junction

The Junction in DWAT model has two functions. The first one is to simply combine the flow from upstream. The second one combines sewer system, which is a unique feature of the model.

The Junction node may be entered by selecting the icon shown in the following figure, placing at the appropriate position in the 'Main Interface' by clicking the left button on a

mouse.

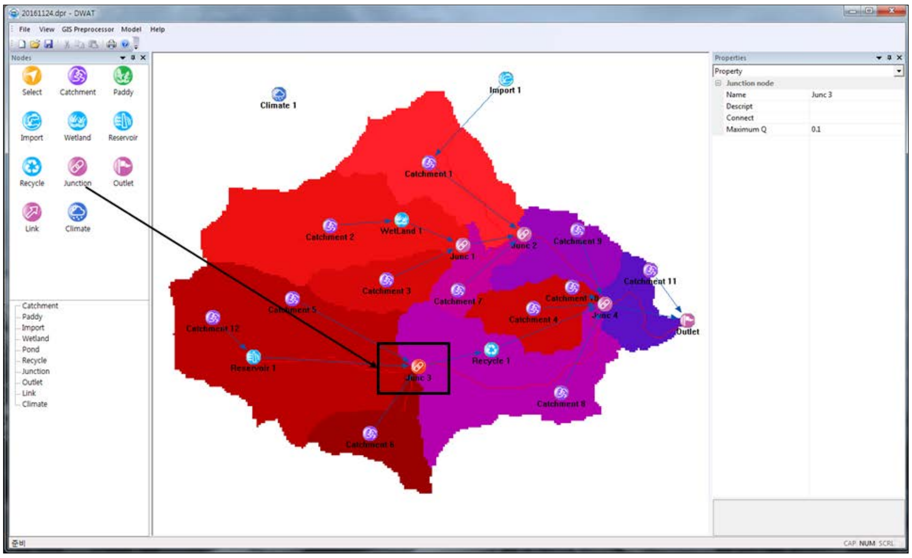


Figure 3.63 Junction node in the main interface

If the Junction node is left-clicked, a property window to set the parameters related to the junction will appear.

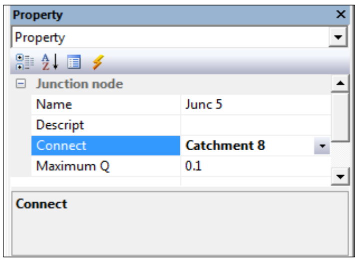


Figure 3.64 Junction information

Name: Name of Junction

Descript: Information about the Junction can be entered.

Connect: Select node to water transfer (for example, treatment plant), it is used for combined sewer **networks**. The flow less than specified rate can be moved to the selected node. Water quality module will be added in next version.

Maximum Q: The maximum flow rate to other catchment using **Connect** (m^3/s).

3.16.2 Outlet

The Outlet is a final exit of the system. Basically, the Outlet node is similar to Junction except combined sewer function. The Outlet can be multiple. The Outlet node may be entered by selecting the icon shown in the following figure, placing at the appropriate position in the 'Main Interface' by clicking the left button on a mouse.

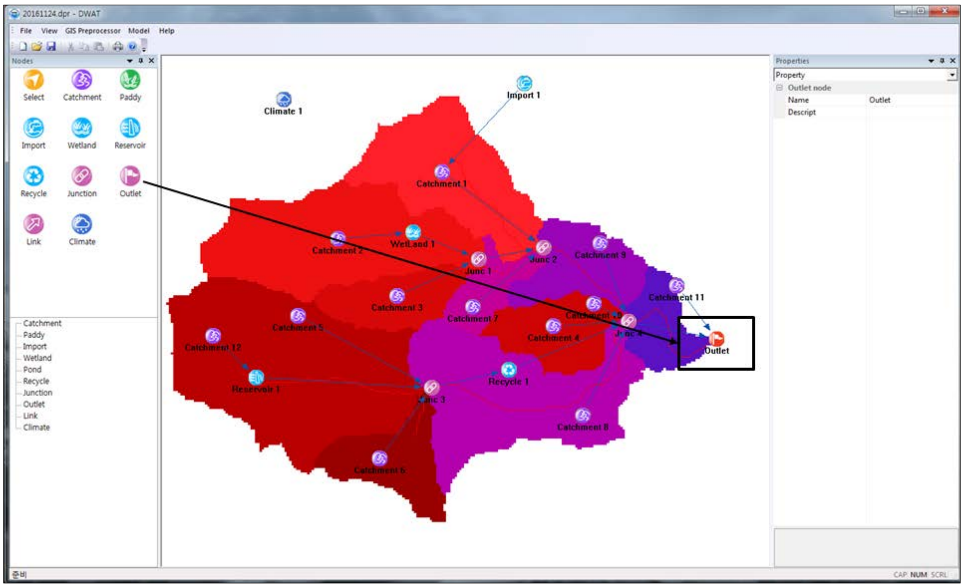


Figure 3.65 Outlet node in the main interface

If the outlet button is left-clicked, a property window to set the parameters related to the outlet will appear.

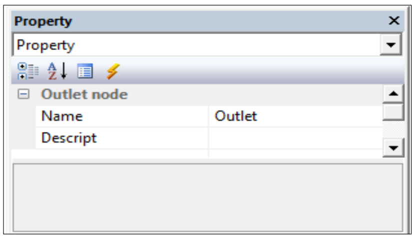


Figure 3.66 Outlet information

Name: Name of Outlet node

Descript: Information about the outlet can be entered.

CHAPTER 4: MODEL RUNNING

If all input data have been completed, now you are ready to run the model. In the chapter, matters related to the model run will be explained.

4.1 Analysis Condition Setting

If the ‘Model’ menu is selected in the main menu, the ‘Model Setup’ menu for selecting analysis conditions and running the model will appear as follows:

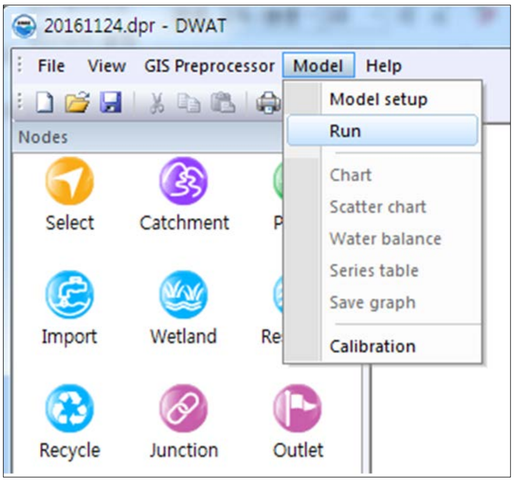


Figure 4.1 Model setup

If the ‘Model setup’ menu is selected, a window for setting analysis conditions before running the model will appear as follows:

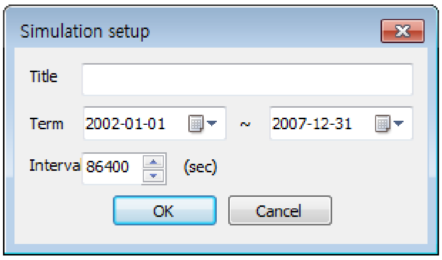


Figure 4.2 Model simulation setup

Title: This indicates a simulation title.

Term : A simulation period is needed to be selected. The total data period appears in the window and a user can define the simulation period. After clicking, the following data entry window will appear. It allows user to select a simulation period shorter than the input time series length. model runs can be performed without using this menu.

Comment [j19]: Review 27

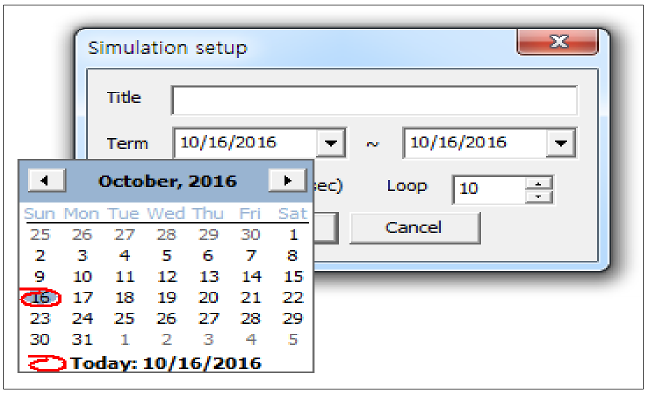


Figure 4.3 Model simulation interval setup

Interval: A user can revise a simulation time step for the model run. The default unit is a second. The time step is imposed by the time series. It is possible to ask for a different time step than the time series interval. In this case, the model interpolate the input series in order to become consistent with this time interval.

Comment [j20]: Review 27

4.2 Model Execution

Once the analysis conditions have been set as above, the model is run by pressing 'OK' and selecting 'Run' in the 'Model' menu. Now, the model is ready to run. When 'Run' is pressed, the model will be executed.

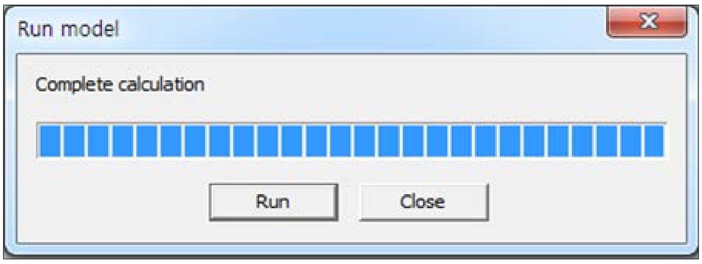


Figure 4.4 Completed Model simulation

Once 'Complete execute model' has appeared, press the 'Close' button.

CHAPTER 5: ANALYSIS OF RESULTS

Comment [j21]: Review 2

If all the executions have been completed, now you are ready to analyze the result. The DWAT enables users to freely compare outputs at each node, junction, and link including hydrologic components. This configuration is very helpful to users in analyzing the results.

Table 5.1 Output variables (catchment nodes)

Catchment node	Description of output variables
Inflow (m^3)	Inflow volume
Rainfall (mm)	Rainfall
Actual Evapotranspiration (mm)	Actual evapotranspiration
Potential Evapotranspiration (mm)	Potential evapotranspiration
Infiltrate (mm)	Infiltration
Soil moisture content	Current soil moisture content
Flow surface (mm)	Surface runoff
Flow_inter (mm)	Interflow
Flow groundwater (mm)	Groundwater runoff
Recharge (mm)	Groundwater recharge
Flow total (mm)	Total runoff
Groundwater Movement (mm)	Groundwater movement
Groundwater Elevation (El. m)	Groundwater level elevation

Table 5.2 Output variable (Other nodes)

Node		Description of output variables
Reservoir	Inflow (㎥)	Inflow volume
	Downstream Outflow (m^3)	Mainstream discharge that did not flow into the reservoir
	Intake (m^3)	Intake volume
	Evaporation Water surface (mm)	Evaporation from the water surface
	Spillway Outflow (m^3)	Overflow from spillway
	Pipe_Outflow (m^3)	Discharge from the outlet pipe
	Aquifer Loss (m^3)	Loss from the bottom of the reservoir
	Volume (m^3)	Storage volume
	Water Level (m)	Water level
Wetland	Inflow (m^3)	Inflow volume
	Bypass Volume (m^3)	High flow bypass during flood season
	Evaporation Water surface (mm)	Evaporation from the water surface
	Spillway Outflow (m^3)	Overflow from spillway
	Pipe Outflow (m^3)	Discharge from the outlet pipe
	Aquifer Loss (m^3)	Loss from the bottom of the wetland
	Volume (m^3)	Storage volume
	Water Level (m)	Water level
Recycle	Inflow (m^3)	Inflow volume
	Intake (m^3)	Intake volume
	Downstream Outflow (m^3)	Downstream discharge after intake
	water supply node name	Node name that receives supplied water
Import	Water Supply (m^3)	Water supply from outside

The DWAT basically has three types' outputs features: water balance, graphs, and tables. In this chapter, the methods to analyze the model results are explained in detail. The output variables by source node that are created after executing the DWAT are summarized in Table 5.1-5.2.

5.1 Water Balance

The results of water balance in a basin may be viewed based on two methods. The first is to view the results in the main menu and it is shown in the following figure. The second is to view the results at each sub-catchment node in the catchment node configuration screen of the 'Main Interface'.

Pressing 'Model'> 'Water-balance' menu in the main menu.

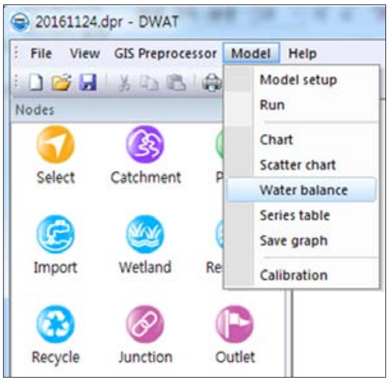
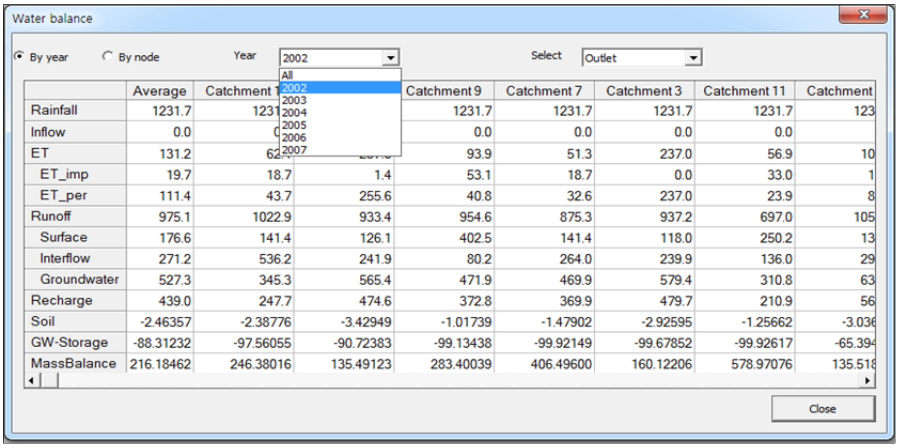


Figure 5.1 Water balance main interface

By year: This is a tab to control output formats. Analysis results are displayed on an annual basis. As shown in the above figure, each hydrologic component is displayed on the left side and water balance is displayed by a node on the right side along with average value.



	Average	Catchment 1		Catchment 9	Catchment 7	Catchment 3	Catchment 11	Catchment
Rainfall	1231.7	1231		1231.7	1231.7	1231.7	1231.7	123
Inflow	0.0	0		0.0	0.0	0.0	0.0	
ET	131.2	62.		93.9	51.3	237.0	56.9	10
ET_imp	19.7	18.7	1.4	53.1	18.7	0.0	33.0	1
ET_per	111.4	43.7	255.6	40.8	32.6	237.0	23.9	8
Runoff	975.1	1022.9	933.4	954.6	875.3	937.2	697.0	105
Surface	176.6	141.4	126.1	402.5	141.4	118.0	250.2	13
Interflow	271.2	536.2	241.9	80.2	264.0	239.9	136.0	29
Groundwater	527.3	345.3	565.4	471.9	469.9	579.4	310.8	63
Recharge	439.0	247.7	474.6	372.8	369.9	479.7	210.9	56
Soil	-2.46357	-2.38776	-3.42949	-1.01739	-1.47902	-2.92595	-1.25662	-3.03
GW-Storage	-88.31232	-97.56055	-90.72383	-99.13438	-99.92149	-99.67852	-99.92617	-65.39
MassBalance	216.18462	246.38016	135.49123	283.40039	406.49600	160.12206	578.97076	135.51

Figure 5.2 Annual water balance results

By node: This is a tab to control output formats. Analysis results are displayed by sub-catchment. As shown in the following figure, each hydrologic component is displayed on the left side and resultant values are displayed on the right side on an annual basis.

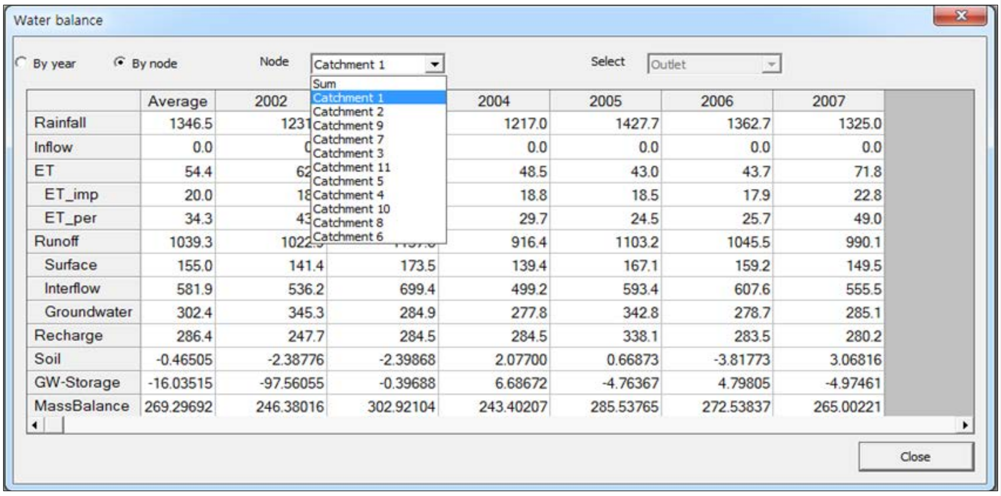


Figure 5.3 Annual water balance results of sub-catchment

Select: This is to select the outlets of a catchment. If the catchment has many outlets, the results on the water balance may be identified for each catchment outlet.

In the second method for viewing water balance results, water balance may be viewed by right-clicking on each sub-catchment node as mentioned above. However, the water balance output from sub-catchment nodes does not provide information on the entire water balance, but rather provides only the resultant water balance of the relevant sub-catchment. Right-clicking on the sub-catchment node and clicking the ‘Water balance’ menu.

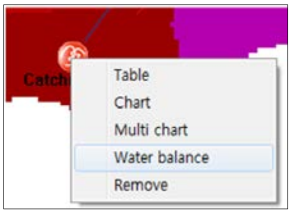


Figure 5.4 Water balance results by catchment

The following window will appear.

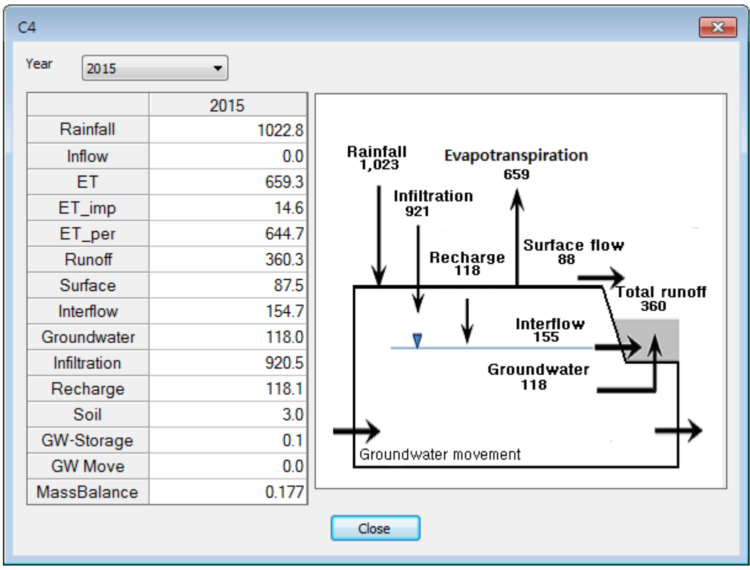


Figure 5.5 Water balance results for the selected catchment

Comment [j22]: Review 54

Year: The relevant year may be selected. As shown in the above figure, the water balance results at hydrologic component may be identified by clicking each relevant year.

5.2 Chart

Analysis results are shown in various forms of graphs in the DWAT. Similar to the water balance results, there are two methods to view the graphical results of the entire catchments. The graphical results for individual sub-catchments, links, junctions, and outlets can be viewed by the setting tab of the left window, no matter which method the user selects to view the results. The method to check results in the main menu is as follows:

Select 'Model' > 'Chart' in the main menu.

Right-clicking on the sub-catchment node and clicking the 'Chart' menu.

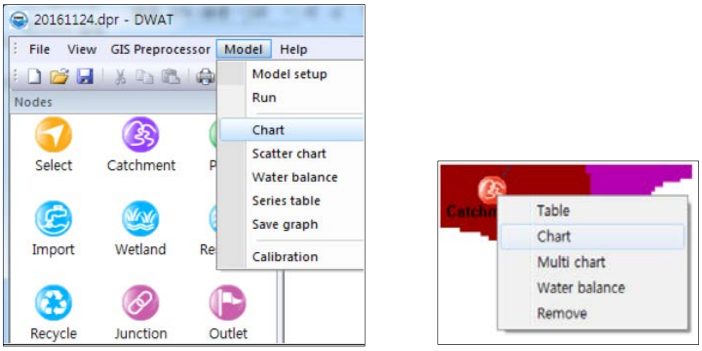


Figure 5.6 Graphical results main menu

A Chart result window will appear.

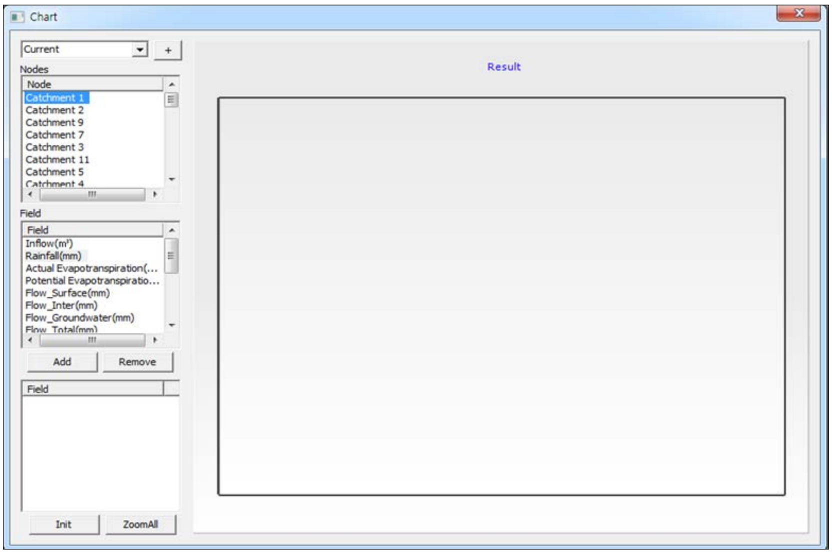
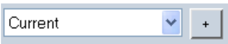
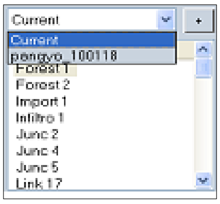


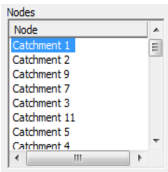
Figure 5.7 Graphical results window



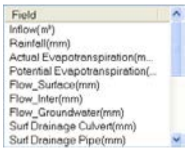
: This is a project selection window. In ’Current’, the results of the current project may be viewed. When the plus button is selected, the results of other projects are opened and displayed for comparison. That is, a function to compare the result of the current project with those of other projects is provided. As shown in the following figure, all graphic results of the current project and other projects are displayed when other projects are opened and selected.

Comment [j23]: Review 52 59





: This attribute window shows the information of each node, junction, link and outlet of the relevant project.



: This is located below the node attribute window and shows the field attribute window. They are the output parameters mentioned earlier in Tables 5.1 and 5.2. The user can select the relevant sub-catchment or the link and junction through the node attribute window and then select output variables in the field attribute window to see graphic results. The user may press the ‘Add’ button to display the graphic results when the sub-catchment and output variable have been selected. It is shown in the following figure.

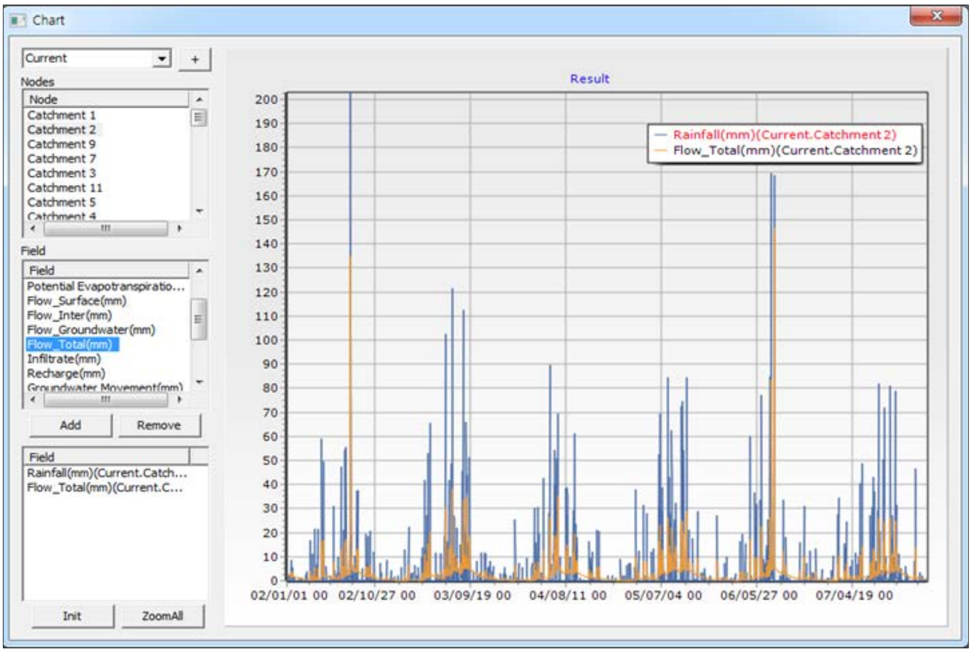


Figure 5.8 Graphical results of rainfall and total flow on the same axis

: The left bottom window displays the names of the current output variables. The user may also select multiple nodes and output variables and display them simultaneously on the same screen. If the user wishes to delete some output items from the graph, the user may click on the item or right-click the button and select ’Remove‘. If the user wishes to delete all items, the user may just select the ‘init’ button. In addition, the interested region in the graph may be expanded by using the dragging function of the mouse. Once expanded, the region may be moved using the scroll bar on the bottom of the graphic result. The user can go back to the entire view by pressing the ‘Zoom All’ button. The form of an expended graph is as shown in the following figure.

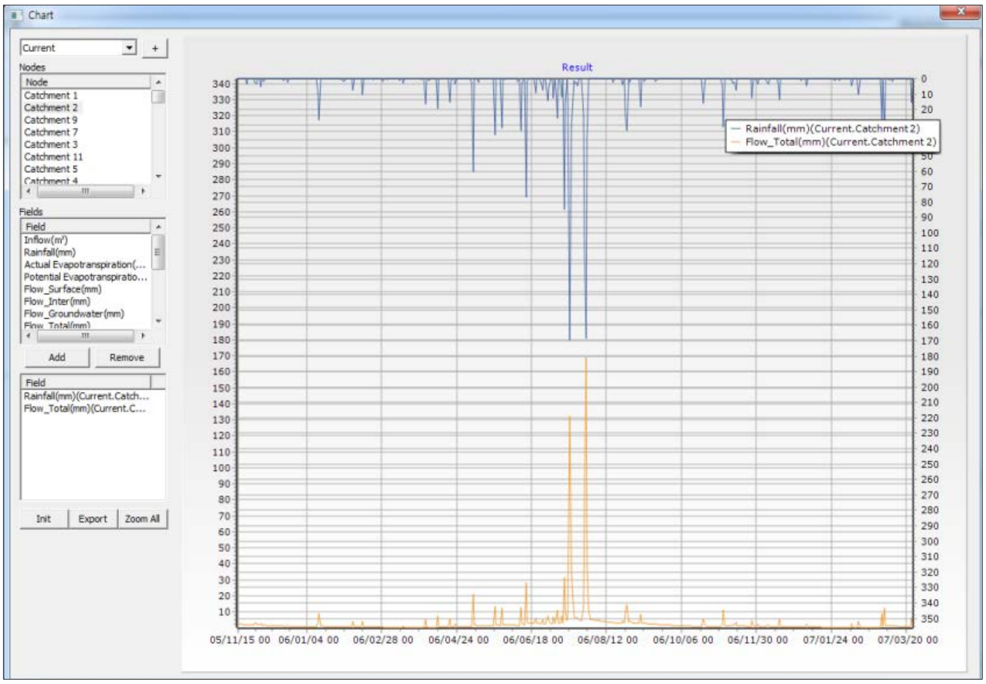


Figure 5.9 Graphical results of rainfall and total flow on different axis

: Graphs may be exported into various forms using the ‘Export’ button. Once the ‘Export’ button has been selected, the following window will appear.

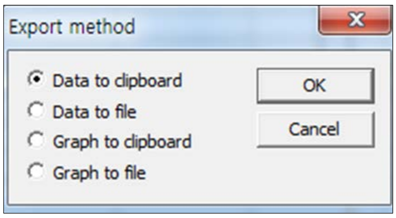


Figure 5.10 Export results to different formats

Data to clipboard: Graphic results can be saved to the clipboard and then pasted in the text editor by selection of this option. The data of all the graphs is copied as follows

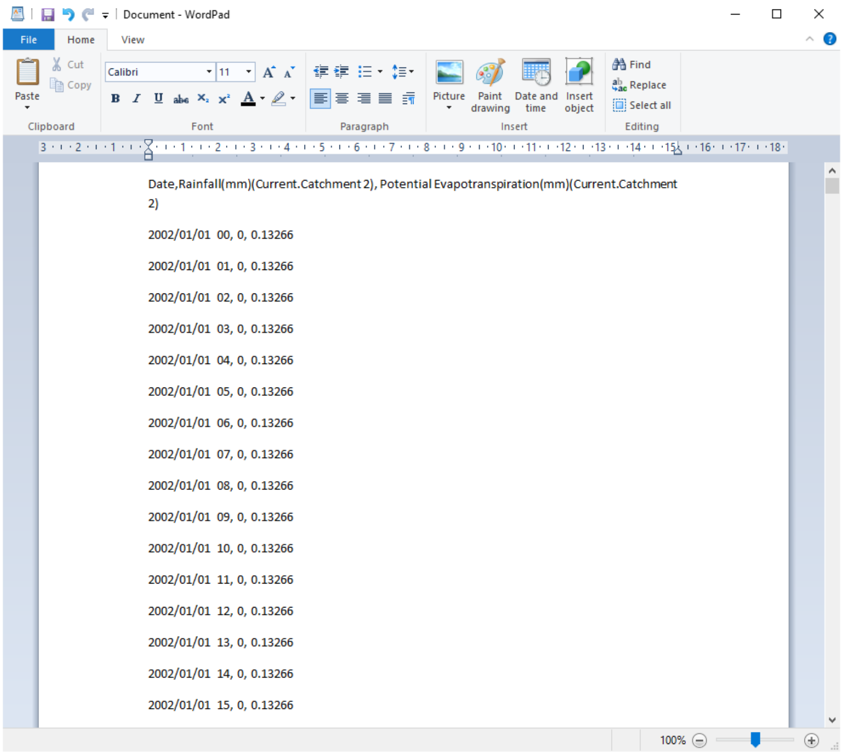


Figure 5.11 Export results to any formats

Data to file: The current graphics results may be saved in the form of text files (*.txt).

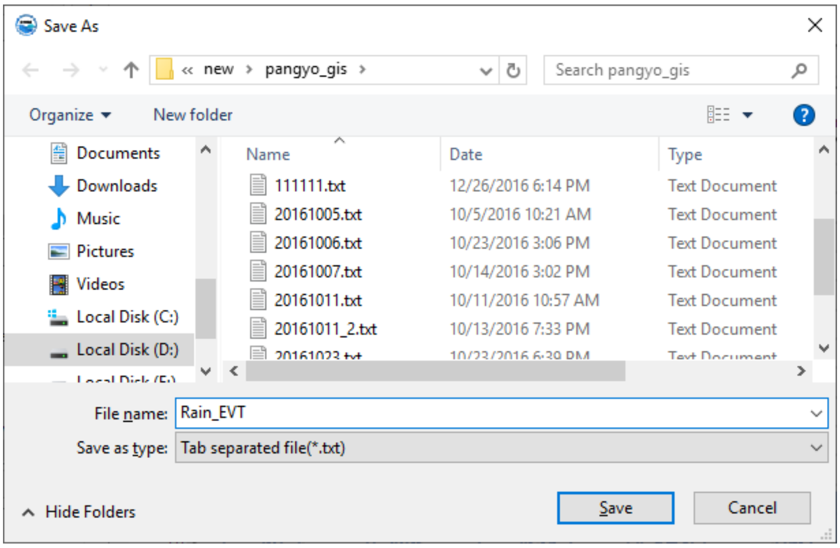


Figure 5.12 Export results to text formats

Graph to clipboard: Graphic results can be saved to the clipboard and then pasted in the windows figure plate by selection of this option. The screens of all the graphs are copied as follows

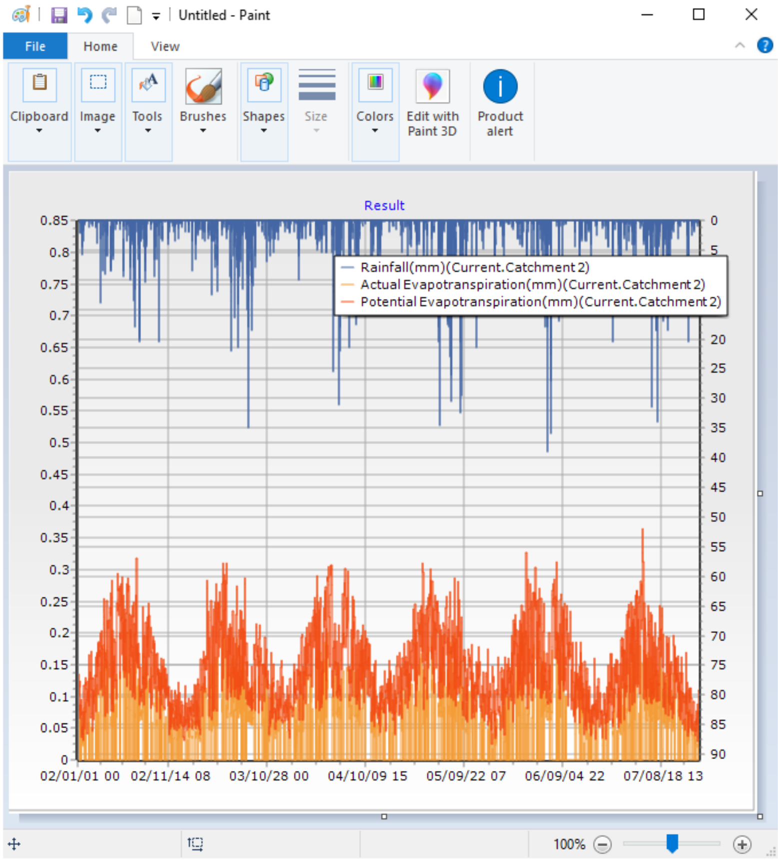


Figure 5.13 Export results to any image formats

Graph to file: The current graphical results may be saved in the form of image files (*.bmp, *.wmf).

Comment [j24]: Review 53

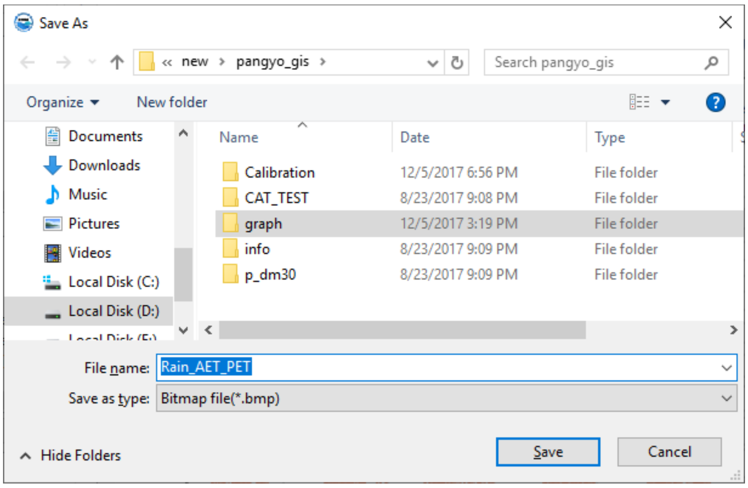


Figure 5.14 Export results to image formats

When the output variable attribute window on the bottom left-hand side is right-clicked, the screen appears as follows.

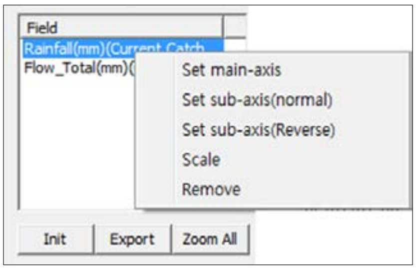


Figure 5.15 Axis selection tools

Set to main axis: This is a function to display selected result graphs on the main axis

Set to sub axis (normal): This function displays the graph on the same axis and displays the value on the subsidiary axis. The form displayed using this function is shown in the following figure.

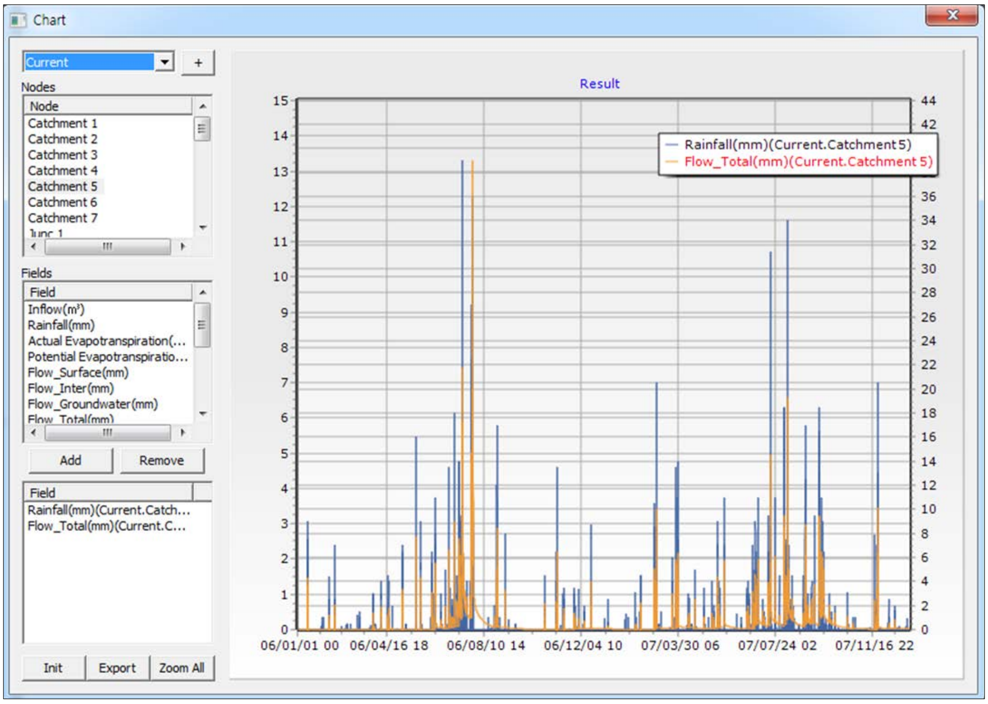


Figure 5.16 Graphical result on the same axis

Set to sub axis (Reverse): This is a function to display selected result graphs on the subsidiary axis. This function can be used to display rainfall on the upper side as a subsidiary axis when rainfall and discharge graphs are displayed simultaneously. The form displayed using this function is shown in the following figure.

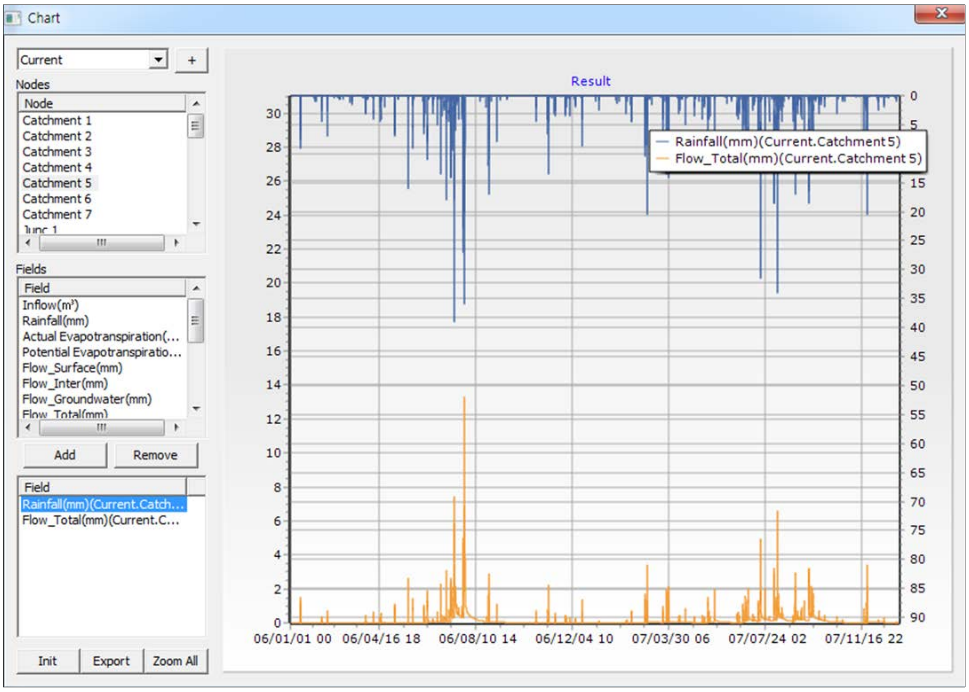


Figure 5.17 Graphical result on the subsidiary axis.

Scale: This is a function to adjust spaces in the graph. The following screen appears with a selection of this function. The space unit for displays will be adjusted after setting the display spaces and pressing the confirm button.

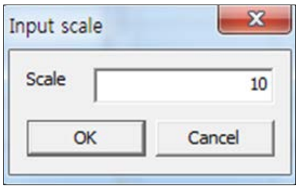


Figure 5.18 Graphical scale adjust

Remove: This is a function to delete a field

Multi chart: Users can simultaneously check the graphs of rainfall, evapotranspiration, soil moisture, and total runoff for each node using Multi chart function. The following window appears by right-clicking on a node in the configuration screen of the main interface.

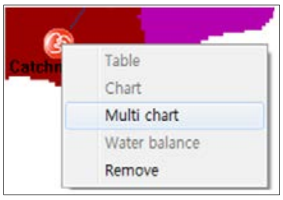


Figure 5.19 Multi chart view

When the ‘Multi-chart’ menu has been selected, the following result window is displayed.

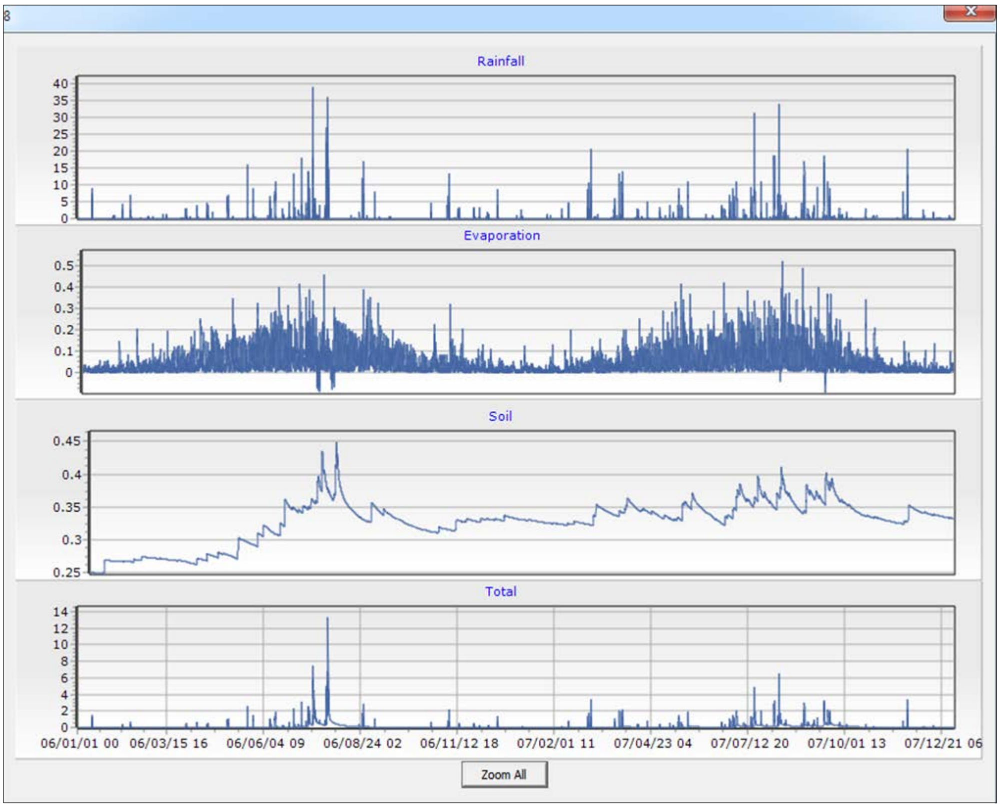


Figure 5.20 Multi chart result

The Zoom in/out can be confirmed by dragging only the graph of the total outflow amount, which is the bottom graph of the Multi chart, with the mouse.

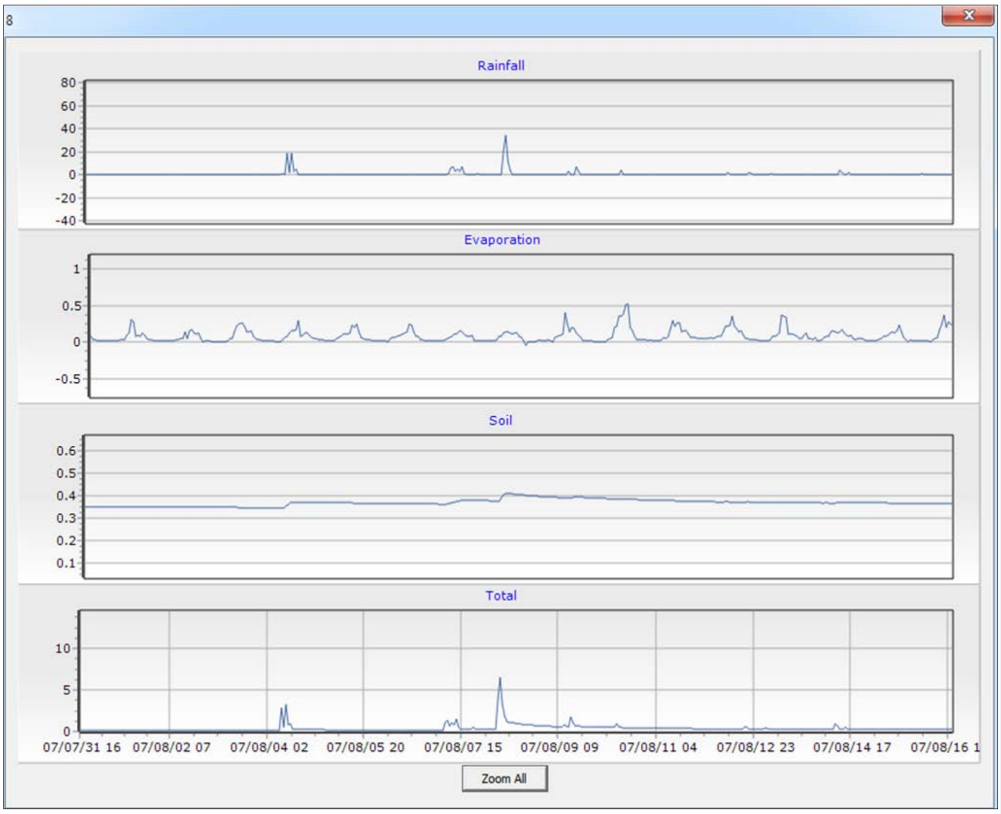


Figure 5.21 Multi chart result zoom out view

5.3 Table

The DWAT contains a function to view result values in the form of tables at all nodes, junctions, links, and outlets.

Unlike water balance and graphic results, table results can be viewed only through right mouse clicks on the nodes, links, and junctions of the main screen. In addition, information on all nodes cannot be seen and only the results for an individual node are displayed including the results specified.

The following window appears by right-clicking on a node in the configuration screen of the main interface.

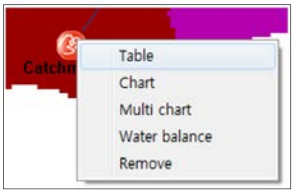
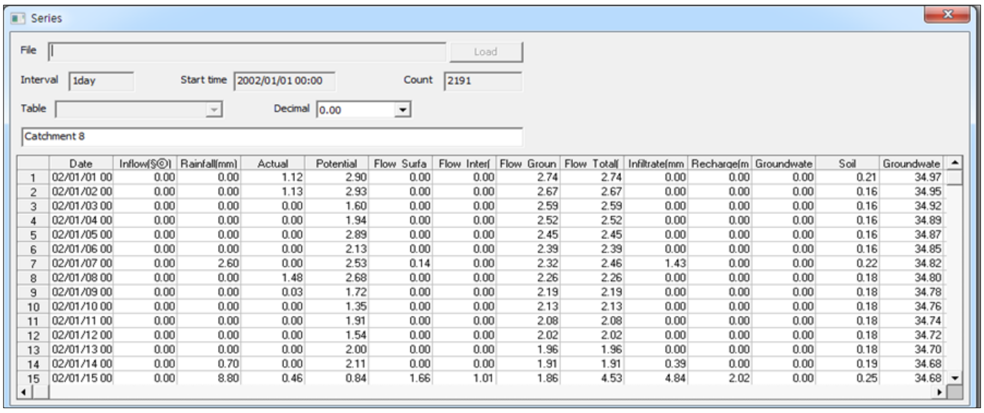


Figure 5.22 Time series result view

When the 'Table' menu has been selected, the following table result window is displayed. As shown in the figure, the names of the output variable for each time series appear on the top and time series data are displayed.



	Date	Inflow(§©)	Rainfall(mm)	Actual	Potential	Flow Surfa	Flow Inter(	Flow Groun	Flow Total(	Infiltrate(mm	Recharge(m	Groundwate	Soil	Groundwate
1	02/01/01 00	0.00	0.00	1.12	2.90	0.00	0.00	2.74	2.74	0.00	0.00	0.00	0.21	34.97
2	02/01/02 00	0.00	0.00	1.13	2.93	0.00	0.00	2.67	2.67	0.00	0.00	0.00	0.16	34.95
3	02/01/03 00	0.00	0.00	0.00	1.60	0.00	0.00	2.59	2.59	0.00	0.00	0.00	0.16	34.92
4	02/01/04 00	0.00	0.00	0.00	1.94	0.00	0.00	2.52	2.52	0.00	0.00	0.00	0.16	34.89
5	02/01/05 00	0.00	0.00	0.00	2.89	0.00	0.00	2.45	2.45	0.00	0.00	0.00	0.16	34.87
6	02/01/06 00	0.00	0.00	0.00	2.13	0.00	0.00	2.39	2.39	0.00	0.00	0.00	0.16	34.85
7	02/01/07 00	0.00	2.60	0.00	2.53	0.14	0.00	2.32	2.46	1.43	0.00	0.00	0.22	34.82
8	02/01/08 00	0.00	0.00	1.48	2.68	0.00	0.00	2.26	2.26	0.00	0.00	0.00	0.18	34.80
9	02/01/09 00	0.00	0.00	0.03	1.72	0.00	0.00	2.19	2.19	0.00	0.00	0.00	0.18	34.78
10	02/01/10 00	0.00	0.00	0.00	1.35	0.00	0.00	2.13	2.13	0.00	0.00	0.00	0.18	34.76
11	02/01/11 00	0.00	0.00	0.00	1.91	0.00	0.00	2.08	2.08	0.00	0.00	0.00	0.18	34.74
12	02/01/12 00	0.00	0.00	0.00	1.54	0.00	0.00	2.02	2.02	0.00	0.00	0.00	0.18	34.72
13	02/01/13 00	0.00	0.00	0.00	2.00	0.00	0.00	1.96	1.96	0.00	0.00	0.00	0.18	34.70
14	02/01/14 00	0.00	0.70	0.00	2.11	0.00	0.00	1.91	1.91	0.39	0.00	0.00	0.19	34.68
15	02/01/15 00	0.00	8.80	0.46	0.84	1.66	1.01	1.86	4.53	4.84	2.02	0.00	0.25	34.68

Figure 5.23 Time series result

5.4 Statistics

Statistical values such as the Nash-Sutcliffe model efficiency, RMSE (Root Mean Square Error), MAE (Mean Absolute Error), RE (Relative Error), VE (Volume Efficiency) and R^2 (Coefficient of determination) are provided so that users can easily identify the results of the model. The statistical values can be viewed in the 'Model Scatter chart' menu under the main menu.

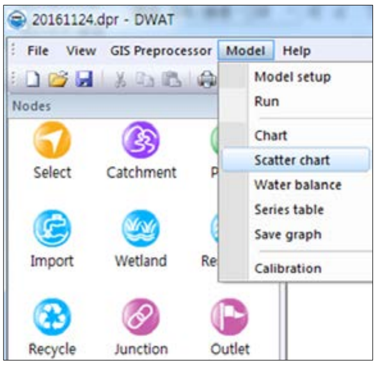


Figure 5.24 Scatter chart menu view

The 'Scatter chart' window is shown in the following figure. The upper part of the chart window is used to select simulation results and observed data. The lower part is a graphic space to display the 1:1 dispersion of the simulated and observed values. Each calculated statistical value is displayed on the right side.

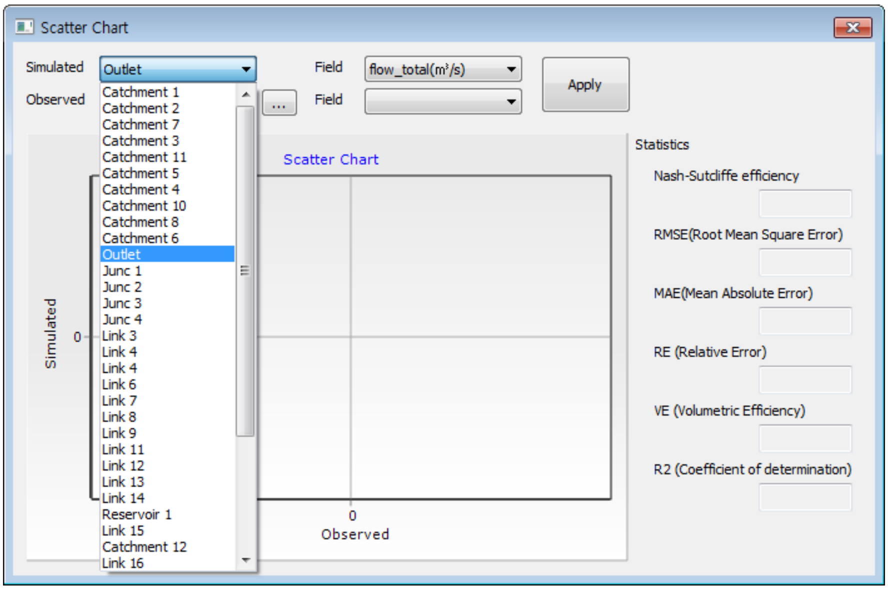


Figure 5.25 Scatter chart window

The following process is used to load and compare observed data.

Simulated: Select a catchment, link, or outlet etc., having observed data in order to compare with simulated values.

Field: Select the output parameters of the simulated values from the box.

Observed : Click to import the observed streamflow data. When the observed data have been imported, the name of the table for the observed values is entered into the box. In this case, the observed data are brought in by selecting the ‘Time step’ as ‘Observed data’ in the ‘File > Create Series’ menu and then importing the data file (*.dat).

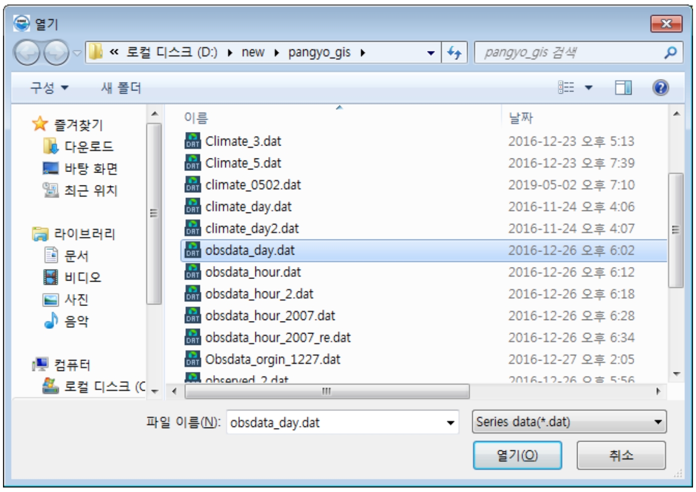


Figure 5.26 Import observed streamflow data

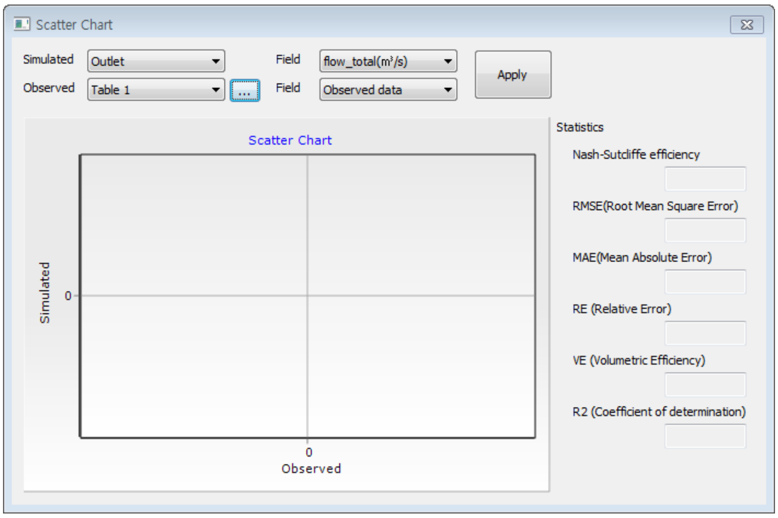
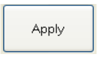


Figure 5.27 Observed streamflow data preparing



: When the ‘Apply’ button is clicked, the 1:1 dispersion is displayed as shown in the following figure and various statistical results appear on the right side.

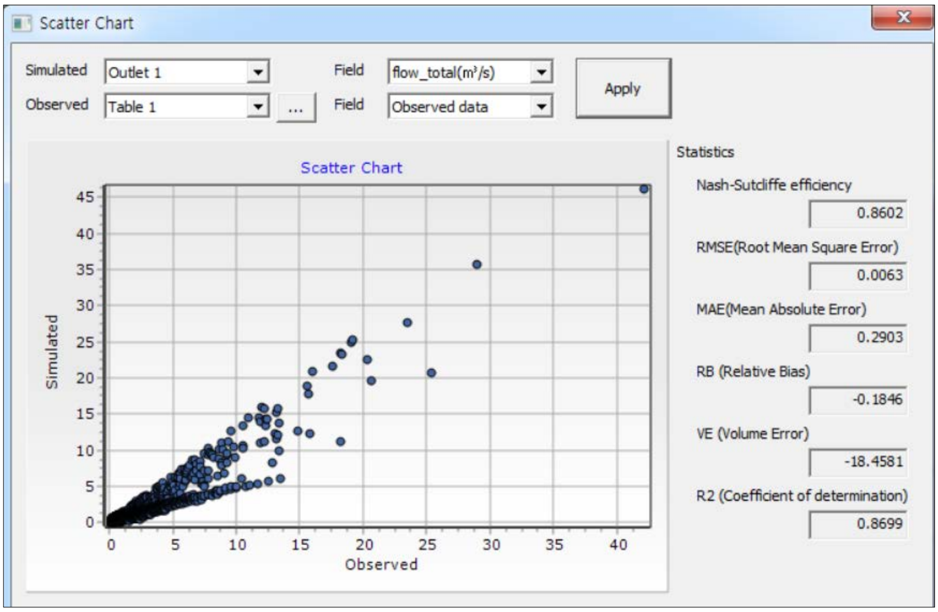


Figure 5.28 Scatter chart statistical values

The following process is to create observed data file (*.dat) format from Excel (*.xls) formats of streamflow data. Firstly, the user must check the time step of his/her own data with format of *.xls. When you create observed streamflow data, you do not need to select the data period. Because there may be missing dates in the observed data, the number of observed data should be entered correctly, and the field of date and observed data should be copied from the excel

Comment [j25]: Review 31

file to the DWAT data file.

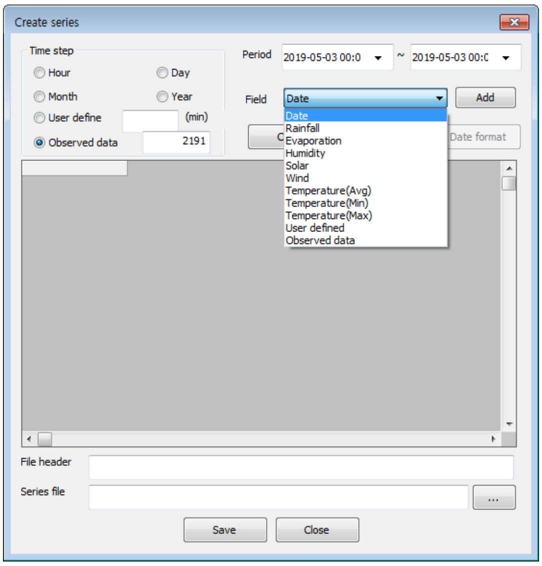


Figure 5.29 Create observed streamflow data

Time step: In this case, 2191 is the number of observed data (the number of rows in Excel sheet)

Period: User does not need to select the data period when creating the observed data

Field: Specify the type of field for input. If you select the 'Date' field and click the Add button, the following dialog appears. You should enter the same separator and check the date format as the Excel sheet. Click 'OK' to proceed. The Date field will be created.

And then add the 'observed data' from the field box. Date and observed data should be copied from the excel sheet to the DWAT data field.

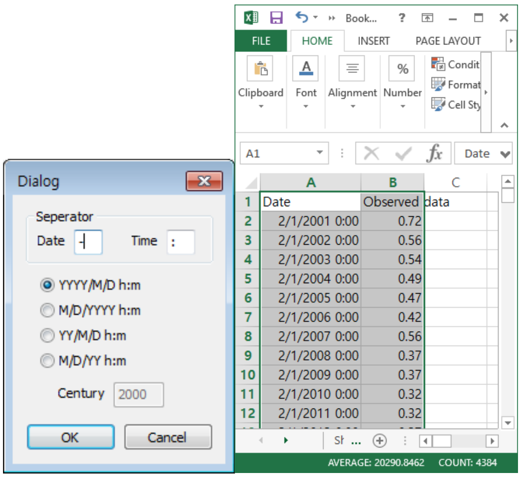


Figure 5.30 Select separator and date format

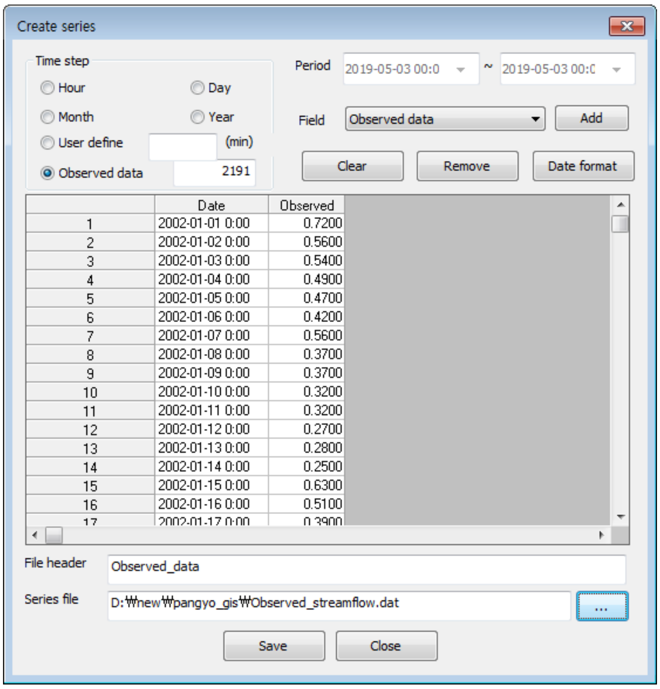


Figure 5.31 Creating observed database

File header: Enter the file description.

Series file: Click and enter the saving directory and file name.

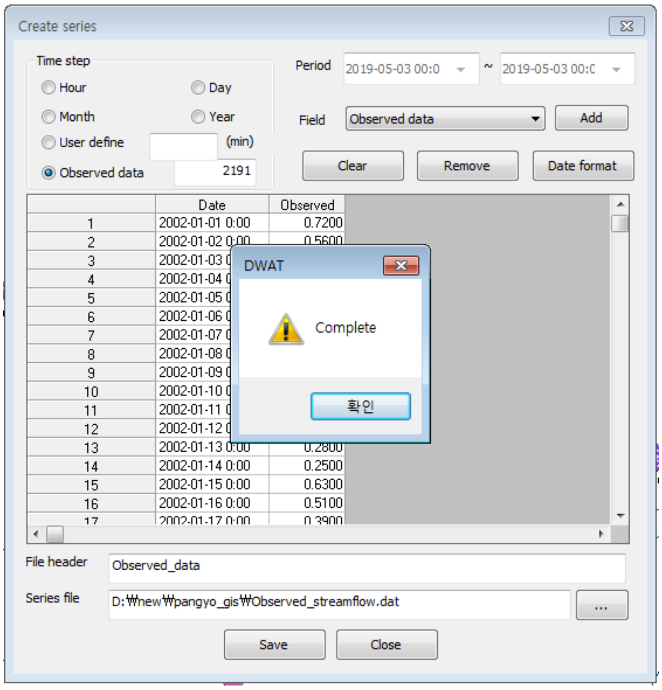


Figure 5.32 Completed observed database

Save: The file will be saved as DWAT observed data by pressing the 'Save' button. When the saving has been completed, Press the 'OK' Button.

5.5 Series Table and Save Graph

The Series table and Save graph can be viewed in the 'Series table & Save graph' menu under the Model menu.

Figure 5.33 Select series table menu

Series table: Check the table for the results of each hydrological component in the sub-catchment (The sub-catchment node can be selected from the left side, and the hydrological component per node can be selected from the right side).

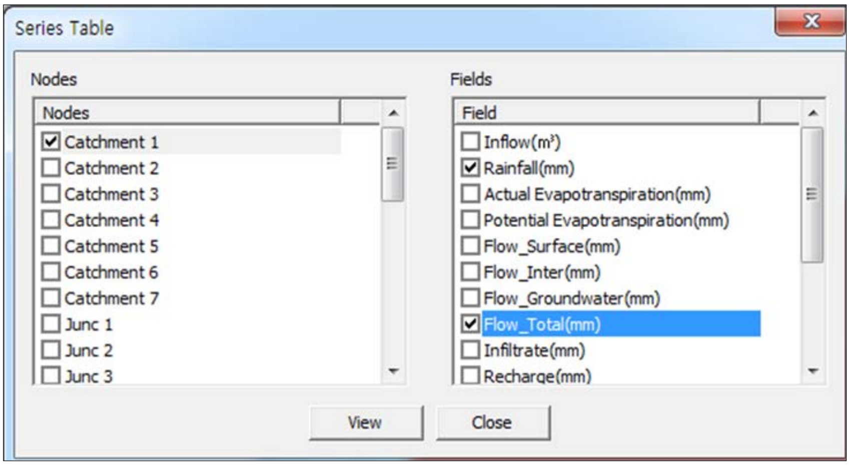
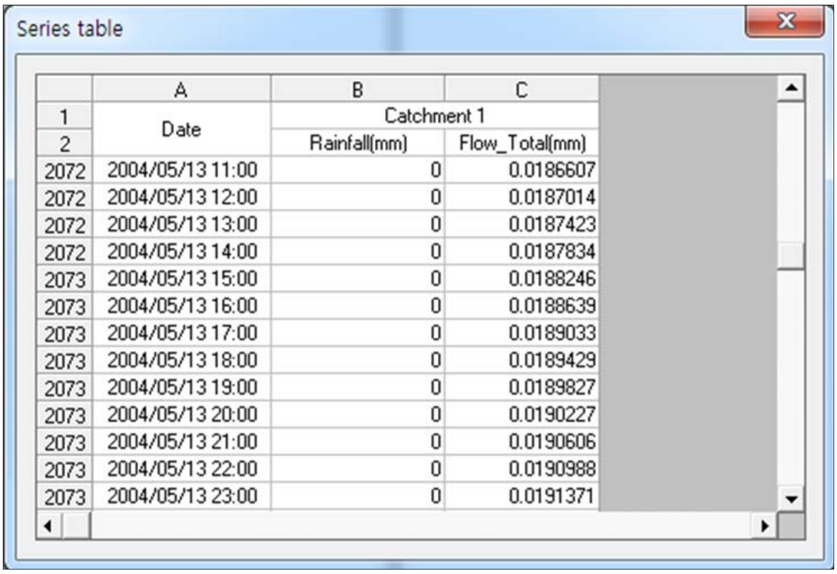


Figure 5.34 Selected time series results

Click View to proceed. Table with the result will appear.



	A	B	C
1	Date	Catchment 1	
2		Rainfall(mm)	Flow_Total(mm)
2072	2004/05/13 11:00	0	0.0186607
2072	2004/05/13 12:00	0	0.0187014
2072	2004/05/13 13:00	0	0.0187423
2072	2004/05/13 14:00	0	0.0187834
2073	2004/05/13 15:00	0	0.0188246
2073	2004/05/13 16:00	0	0.0188639
2073	2004/05/13 17:00	0	0.0189033
2073	2004/05/13 18:00	0	0.0189429
2073	2004/05/13 19:00	0	0.0189827
2073	2004/05/13 20:00	0	0.0190227
2073	2004/05/13 21:00	0	0.0190606
2073	2004/05/13 22:00	0	0.0190988
2073	2004/05/13 23:00	0	0.0191371

Figure 5.35 Time series results view

Save graph: Save the graph for the results of each hydrological component in the sub-catchment (The sub-catchment node can be selected from the left side, and the hydrological component per node can be selected from the right side)

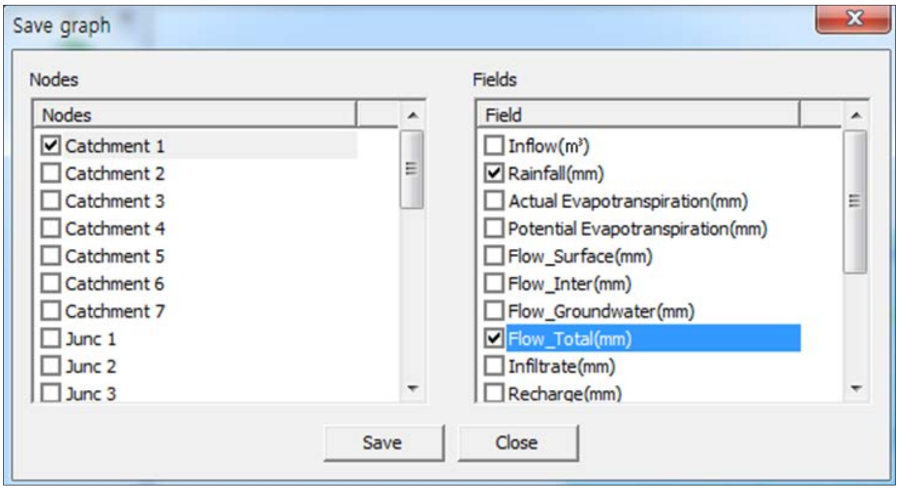


Figure 5.36 Select graphical results

The file browser will appear. It allows the current file to save in *.bmp file format

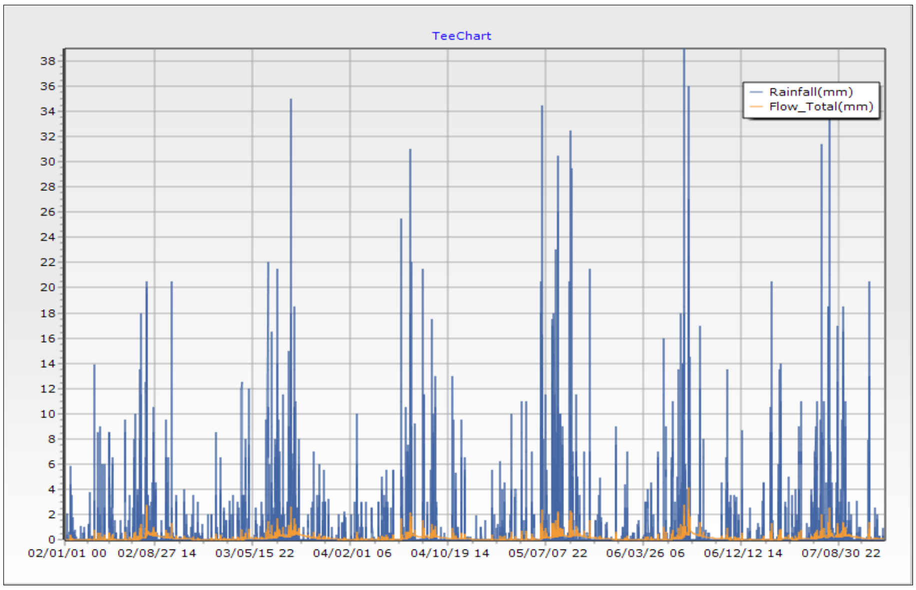


Figure 5.37 Graphical results view

5.6 Calibration

DWAT provides a calibration tool with parameter optimization and uncertainty analysis package PEST (model-independent Parameter ESTimation). PEST is a parametric optimization and uncertainty analysis package for nonlinear functions (Doherty, 2009). It has a great advantage in terms of efficiency because it can estimate the parameters by fewer iterations than the existing parameter optimization model. It also supports advanced techniques used for estimating multidimensional parameters such as pilot points, regularization, and so on (http://www.pesthomepage.org).

DWAT automatically optimizes parameters for soil and aquifer for single basin with observed streamflow.

In the DWAT, the calibration process using PEST involves a sequence of steps.

1. To apply the PEST, three files: a model input template file (*.tpl), a model output reading instruction file (*.ins), and a PEST control file (*.pst) should be generated.
    - When the user enters the sub-catchment node, observation data, and information about the parameters (initial values, maximum and minimum values of the estimated range), DWAT calibration tool automatically generates the above three files.
2. When the calibration tool is executed, an iterative calculation is performed to find the optimal parameter within the estimation range.

3. Once the iteration is complete, the calibration tool reports the optimal parameters in the result file (*.par).
4. If calibration step has been completed, now you are ready to analyze the result. The calibration tool basically has outputs of three types: table, graph and scatter chart.

In this section, the methods to use the calibration tool are explained in detail. The calibration can be viewed in the ‘Model > Calibration’ menu under the main menu

Figure 5.38 Model calibration menu

The ‘Calibration’ window is shown in the following figure. The upper part of the chart window is used to select simulation results and observed data. The lower part displays information for parameters (names, initial values, maximum and minimum values of the estimated range).

The user can select the parameters to optimize in the ‘Parameter’ tab.

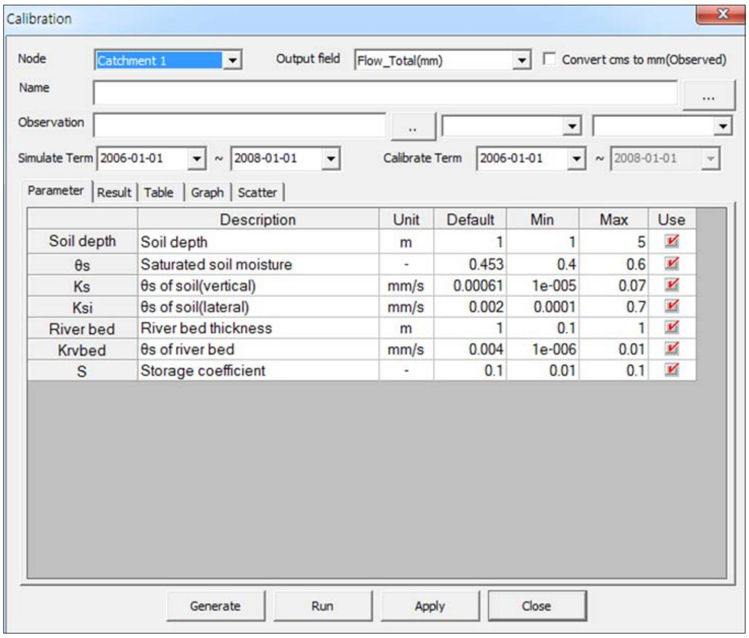


Figure 5.39 Calibration tool in DWAT

The following figure appears on the upper part of the 'Calibration' window.

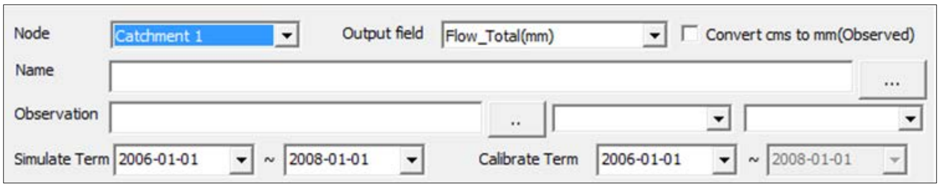


Figure 5.40 Model calibration period

Node: This is a sub-catchment selection window. The user can select the relevant sub-catchment to be calibrated through the selection window (DWAT can only calibrate on sub-catchment at a time).

Output field: It allows users to select the output (total runoff, soil moisture, groundwater level, routing result) to be compared with the observed data from sub-catchment simulation results.

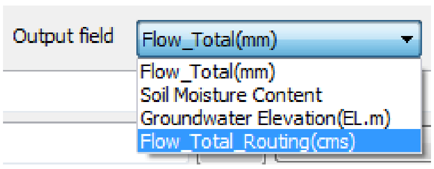


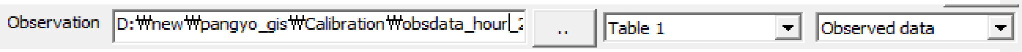
Figure 5.41 Model output fields to be calibrated

If there are no discharge observations at internal sub-catchment outlet, the calibration capability can be able to be applied to downstream outlet and junction by selecting 'Flow_Total_Routing' in the output field box.

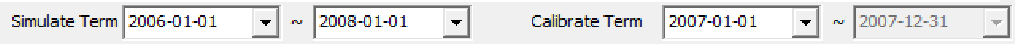
Comment [j26]: Review 63

Convert cms to mm (Observed): This checkbox allows the user to convert the unit to a comparison of the simulated and observed values. In general, the observed data is provided in cubic meter per second(CMS), but in DWAT, the simulation results for each sub-catchment are provided in (㎜) units for annual water balance calculation.

: Click and enter the saving directory and file name. It allows the user to enter the directory and file name where the result files will be stored.

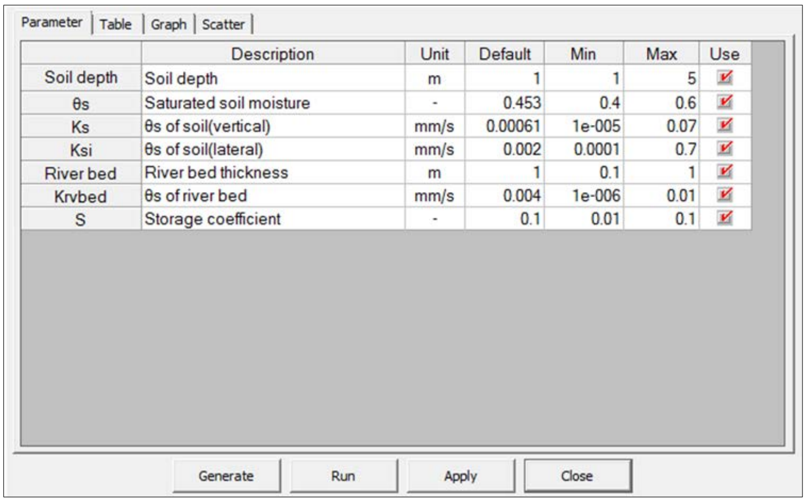


: In this window, the user loads the observation data to be compared with the simulated values. The table and field names appear on the right side when you load the observation data.



: It allows users to set up environments for simulation and calibration period.

In the parameter tab in the center of the calibration window, the user can select parameters to be calibrated and edit the relevant information (initial values, maximum and minimum values of the estimated range). The following figure appears on the lower part of the 'Calibration' window.



	Description	Unit	Default	Min	Max	Use
Soil depth	Soil depth	m	1	1	5	☑
θs	Saturated soil moisture	-	0.453	0.4	0.6	☑
Ks	θs of soil(vertical)	mm/s	0.00061	1e-005	0.07	☑
Ksi	θs of soil(lateral)	mm/s	0.002	0.0001	0.7	☑
River bed	River bed thickness	m	1	0.1	1	☑
Krvbed	θs of river bed	mm/s	0.004	1e-006	0.01	☑
S	Storage coefficient	-	0.1	0.01	0.1	☑

Figure 5.42 Model parameters to be optimized

Generate: This button will automatically generate the three input files (*.ins, *.pst, *.tpl) required to run the PEST calibration tool. These files can be found in the directory where the result files are stored, as shown in the following figure.

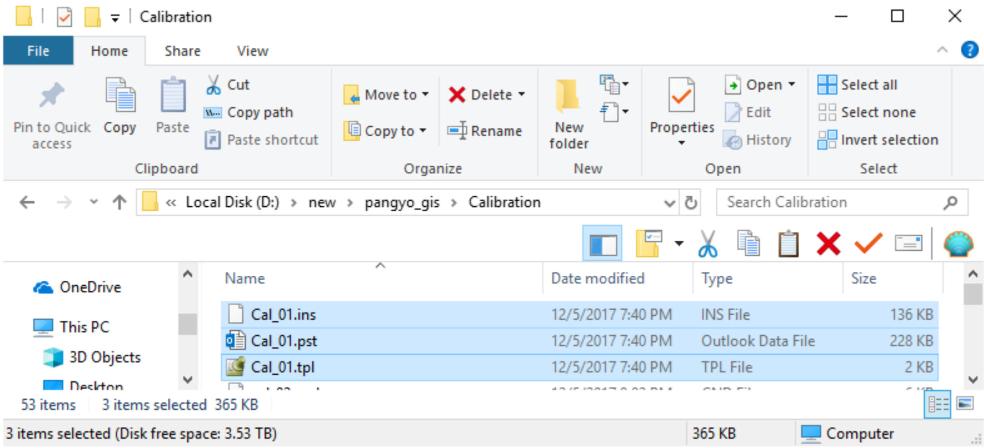


Figure 5.43 PEST automatically generate the three input files

RUN: When you run the calibration tool by pressing this button, an iterative calculation is performed to find the optimal parameter within the parameter estimation range.

The following figure shows how the calibration tool is executed to optimize the parameters.

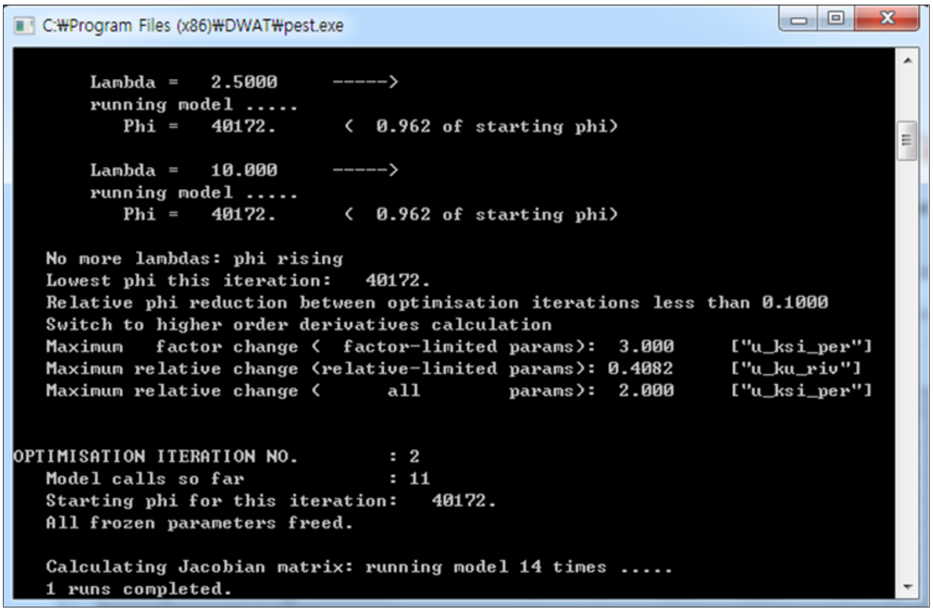


Figure 5.44 Model iterative process

Once the iteration is complete, the calibration tool reports the optimal parameters in the result file (*.par). This file can be found in the directory where the result files are stored, as shown in the following figure.

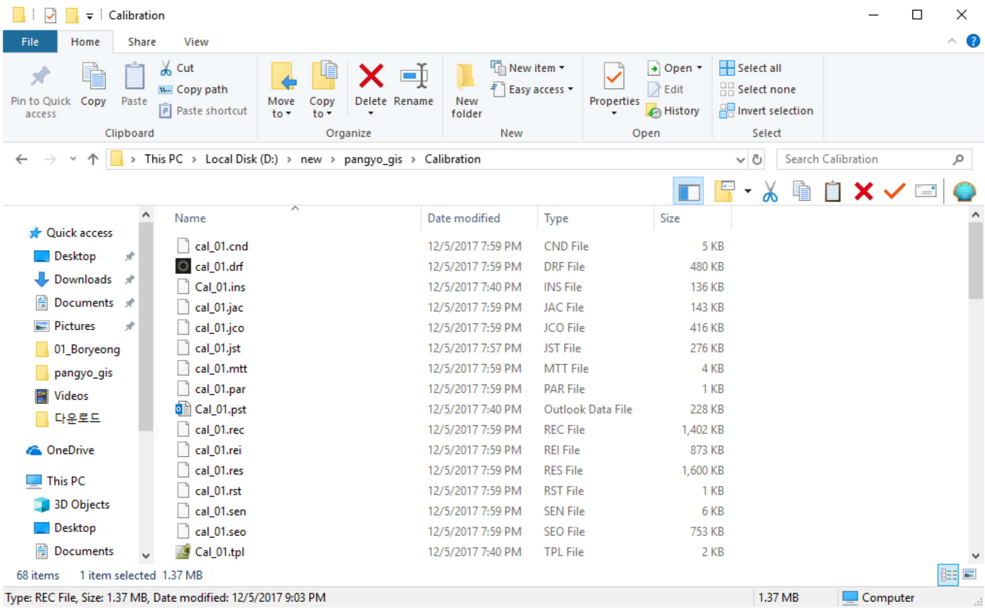


Figure 5.45 Optimal parameters

When you open the parameter file (*.par), you can see the optimized parameters as shown in the following figure.

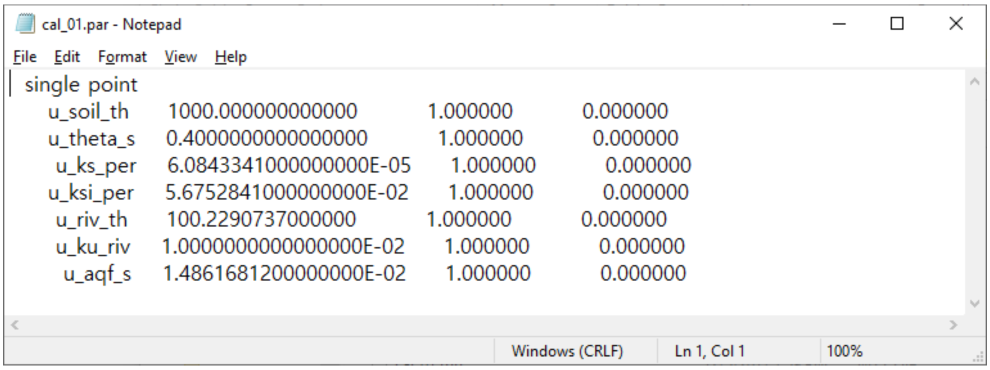


Figure 5.46 Model optimal parameters view

If calibration step has been completed, now you are ready to analyze the result. The calibration tool basically has outputs of three types: table, graph and scatter chart.

The following figure shows the table results with parameter optimization results.

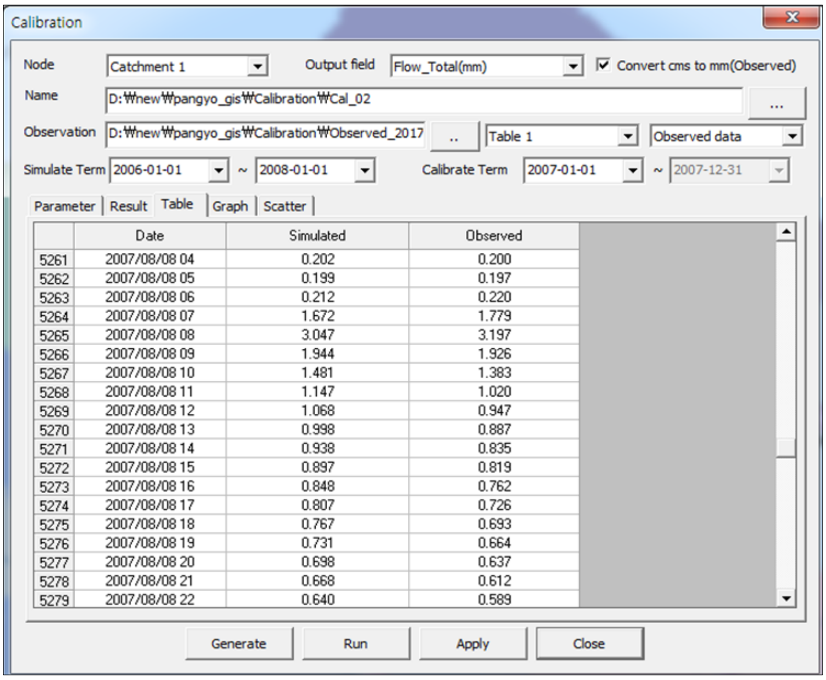


Figure 5.47 Time series result after calibration

The following figure is a graphical result with parameter optimization results applied.

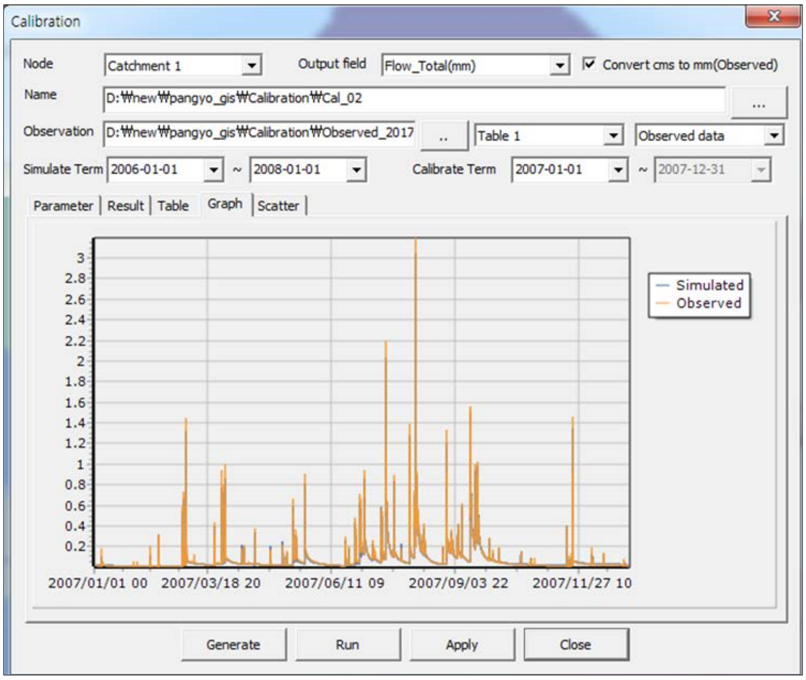


Figure 5.48 Graphical result after calibration

The 1:1 dispersion is displayed as shown in the following figure and various statistical results appear on the right side.

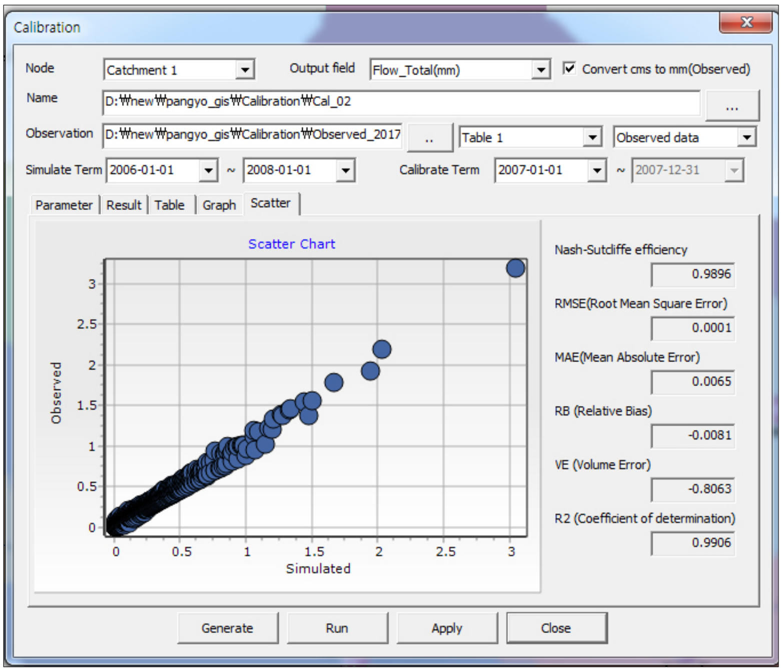


Figure 5.49 Statistical results after calibration

Apply: Finally, when the user presses the Apply button, the optimized parameters are applied to the sub-catchment.
The following figure shows the results before optimization.

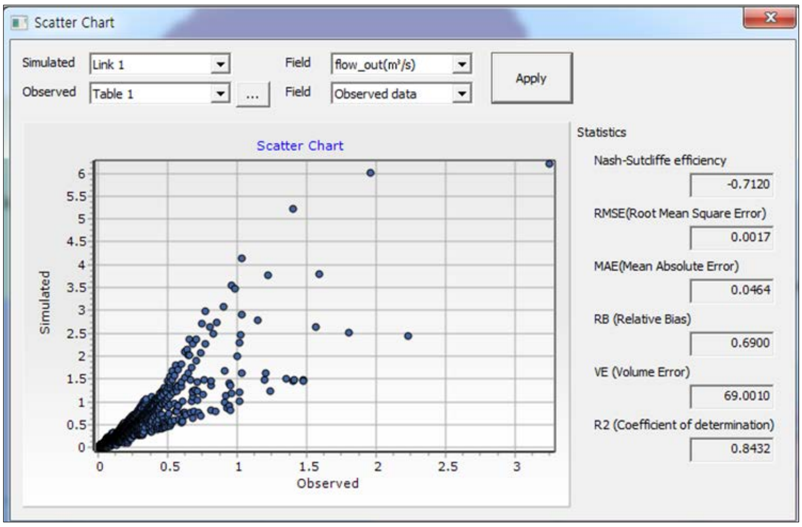


Figure 5.50 Statistical results before calibration

Appendix : BASIC THEORIES of DWAT

Comment [j27]: Review 1

A-1 Characteristics of the Model

The Dynamic Water Resources Assessment Tool (DWAT) accounts for water balance on dynamic (hourly or daily) as well as static (monthly or yearly) bases. It can be applied to a small or a mid-sized basin for water resources planning and management with consideration of surface water as well as groundwater.

The DWAT classifies a watershed into hydrologically homogeneous sub-basins so that runoff characteristics resulting from geomorphological factors can be objectively represented, and infiltration, evaporation and groundwater flows can be simulated according to soil layers. In addition, as the physical input parameters can be easily extracted by the GIS preprocessing module within the system, it can be applied to areas in various hydrological, geophysical and climatic conditions, such as tropical, rural, forest or newly developed urban areas.

The user interface of the model was developed for easy access and operation of the model and it will help how to use the model to effectively simulate and analyze many scenarios simultaneously.

Comment [j28]: Review 10 11

Evapotranspiration, infiltration, runoff, groundwater movement and channel routing modules were developed in the DWAT. Potential evapotranspiration can be directly loaded by importing datasets from outside the system, or the Penman-Monteith method can be used to estimate potential evapotranspiration. Vertical infiltration and flows in slope directions relative to the hydraulic conductivity of soil can be considered. The limitations of existing link-node type models in analyzing long-term runoff were supplemented in order to consider groundwater movements in nodes. The Muskingum, Muskingum-Cunge and Kinematic wave methods are used for channel routing. In addition, the model supports the analysis of runoff processes in paddies and changes in water cycles resulting from water intake and water transfers from/to rivers. These characteristics are summarized as follows:

- Physical parameter-based link-node type model
- Quantitative assessment of the characteristics of the short/long-term changes in water cycle before and after development
- Separate runoff simulations for pervious and impervious zones
- Analysis of infiltration, evaporation, groundwater flows relative to soil layers and groundwater aquifers and simulations of channel routing
- Runoff simulations reflecting the characteristics of rice paddy fields
- Provision of snowmelt module applicable to the Alpine region
- Simple, practical and easily accessible
- Guaranteed satisfactory results with minimal data and efforts
- Spatial analysis of subject regions is possible
- Parameters relative to urban development can be quantitatively estimated as

physical parameters are used

- Easy user convenience system (GUI)
- Provision of results through diverse tables and figures

A-2 Concept and Structure

The DWAT classifies a watershed into hydrologically homogeneous sub-basins so that runoff characteristics resulting from geomorphological factors can be objectively represented, and infiltration, evaporation and groundwater flows can be simulated according to soil layers.

The runoffs from pervious zones and impervious zones are simulated separately in the DWAT. The model can simulate essential hydrological modeling components in water cycles In DWAT model, basins are divided into blocks that are considered to be uniform in terms of groundwater depths or topography. The blocks are then divided into three parts (see table 1.1)

Table 1.1 Classification of ground surface in DWAT model

<table>
<tr><th>Classification of ground surfaces</th><th>Overview</th><th>Corresponding module</th></tr>
<tr><td>Impervious zone</td><td>Roofs or roads</td><td>Impervious zone module</td></tr>
<tr><td>Pervious zone</td><td>Infiltration zones for land use such as forests, grasslands, urban green belts</td><td rowspan="2">Pervious zone module</td></tr>
<tr><td>Rice paddy</td><td>Rice paddies have special soil and runoff processes</td></tr>
</table>

In order to consider the interaction between groundwater and surface water in the DWAT, a concept of partial runoff contribution regions (see Figure 1.1) was applied to generate the different runoff responses in regions having low groundwater level in flatlands (i.e. sub-catchments are principally divided into regions close to rivers (discharge area) and outer regions (recharging area), see Figure 1.1).

Comment [j29]: Review 13

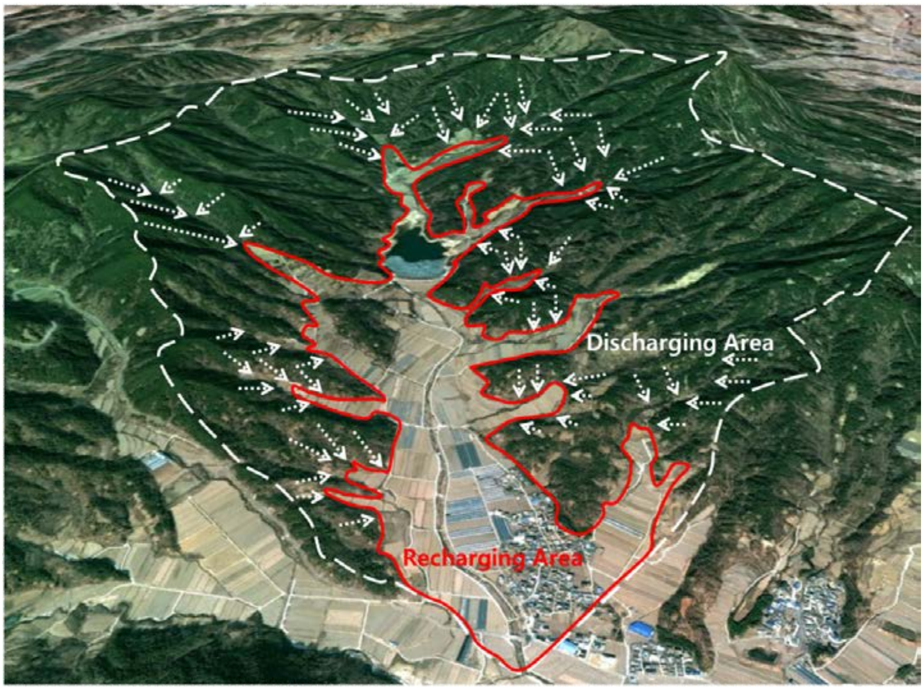


Figure 1.1 Catchment delineation in DWAT model

A-3 Modeling of Water Cycle Processes

The water cycle processes in DWAT were considered both of pervious and impervious zone. In each zone, the infiltration, evapotranspiration and the movement of groundwater were simulated. DWAT has one soil layer and unconfined aquifer layer in vertically. The intake from aquifer is also considered.

The analysis module of DWAT are evapotranspiration, infiltration, runoff from catchment, groundwater movement and channel routing. The evapotranspiration can be imported when users have potential evapotranspiration already, or choose the Penman-Monteith method embedded. The infiltration is calculated by the vertical/horizontal hydraulic conductivity. Green & Ampt method and Horton method are also provided. The groundwater movement between adjacent catchments and Muskingum method, Muskingum-Cunge method and Kinematic wave method can be applied for river or channel routing.

A-3-1 Runoff

1) Impervious zones

The basic equation of the impervious zone module (see Figure 1.2, 1.3) is shown as follows:

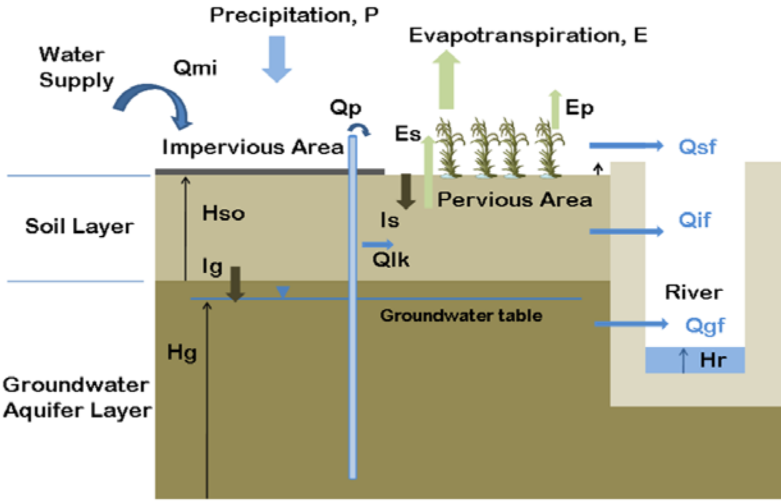


Fig. 1.2 Schematic diagram of water movement in catchment block

$$\frac{dS_{imp}}{dt} = P - D_{imp} - E_{imp} \qquad (1.1)$$

where,

P : precipitation (mm/hr)

S_{imp} : amount of depression storage in an impervious zone (mm)

D_{imp} : surface runoff from an impervious zone (mm/hr)

E_{imp} : amount of evaporation from depression storage in an impervious zone (mm/hr)

When the precipitation is greater than the depression storage capacity, the surplus amount is deemed to be the surface runoff. That is, the amount of water exceeding the depression storage capacity becomes the surface runoff after comparison of the water depth on the ground surface and the depression storage capacity. Figure 1.4 shows a conceptual diagram of a rainfall-runoff process and a surface soil layer model, respectively.

The model can use directly measured values of potential evapotranspiration or potential evapotranspiration can be estimated from the Penman-Monteith method on the basis of users' convenience. The Muskingum, Muskingum-Cunge, and Kinematic wave methods are used for channel routing between blocks where the channel routing is required and it can be ignored depending on users' needs.

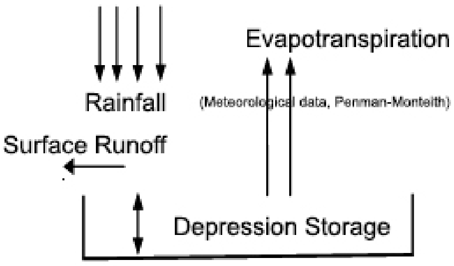


Figure 1.3 Concept of the impervious zone model

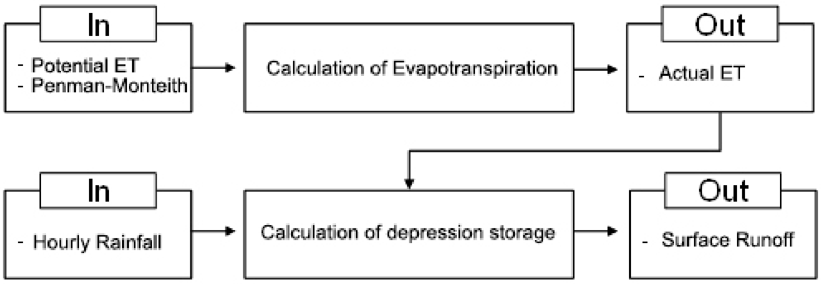


Figure 1.4 Flow chart of the calculation in the impervious zone model and the relationship between inputs and outputs

2) Pervious Zone

Regions where infiltration is possible on the ground surface are largely composed of pervious zone models (In general, runoffs to rivers are composed of surface flow, interflow and baseflow) and groundwater models (Figure 1.5). Figure 1.5 shows conceptual diagrams of rainfall-runoff process in soil layer model and groundwater layer models, respectively. The flows in the soil layer are expressed using the Richards equation. The amount of water is calculated by a simple numerical analysis method. Figure 1.6 shows a flow chart of the calculation with the relationship between input and output in each step. The user may use directly the values of potential evapotranspiration or the Penman-Monteith method can be used for estimation of potential evapotranspiration in impervious areas, according to the user's convenience. The user can select one method among the Muskingum, Muskingum-Cunge, Kinematic wave methods for channel routing and the channel routing can be ignored depending on the user's needs.

In pervious zones, the storage is divided into three types: storage in depressions, soil layer and groundwater aquifer layers. The calculation is based on the following equations:

$$\frac{dS_1}{dt} = U_s - E_1 - D_s \tag{1.2}$$

$$\frac{dS_2}{dt} = P - E_2 - R - U_s + P_{a1} \tag{1.3}$$

$$\frac{dS_g}{dt} = R - D_g - P_{a2} \tag{1.4}$$

where,

S_1 : storage in depressions (mm/hr)

S_2 : storage in soil layer (mm/hr)

S_g : storage in groundwater layer (mm/hr)

D_s : surface runoff (mm/hr)

E_1 : evaporation from depressions (mm/hr)

E_2 : evapotranspiration from soil (mm/hr)

P : seepage into soil (precipitation) (mm/hr)

R : recharge (amount of descending infiltrating water) (mm/hr)

I : interflow (lateral infiltrating flows) (mm/hr)

U_s : the amount of water recovered on the ground surface (mm/hr)

D_g : groundwater runoff (mm/hr)

P_{a1} : leakage from artificially water use (mm/hr)

(the sum of the amount of water for irrigation (only in the case of paddies) and the amount of service water seepage, etc.)

P_{a2} : artificial water use pumped from aquifers (mm/hr)

(the sum of the amount of water pumped from wells and the amount of water infiltrating into sewerage conduits, etc.)

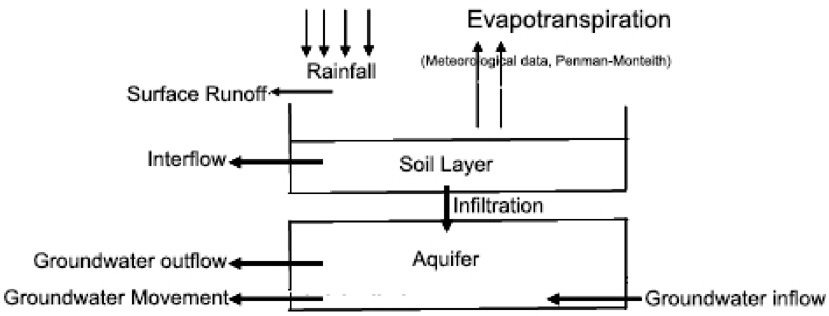


Figure 1.5 Concept of the pervious zone model

The following Figure shows a calculation process of hydrological modeling components including evapotranspiration, vertical infiltration, lateral infiltration, returned flows and groundwater runoff.

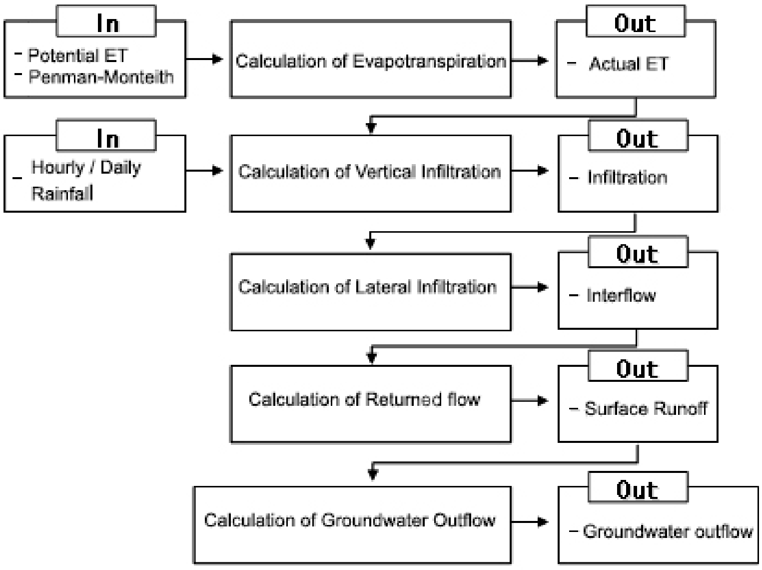


Figure 1.6 Flow chart of calculation in pervious zone model and the relationship between input and output

A-3-2 Infiltration

Three methods are applied for infiltration at pervious area in DWAT model. The first one is the Rainfall Excess method (SHER User's Manual, 2001). Green & Ampt method and Horton method (Horton, 1933) were also provided.

1) Rainfall Excess method

It is well known the infiltration rate through the ground surface is changed by the soil moisture content. Generally, the rate of infiltration is higher at low soil moisture and the speed is decreased when soil is saturated and is close to saturated hydraulic conductivity. CAT model uses unsaturated hydraulic conductivity for vertical and horizontal infiltration. And the Mualem(1978) equation which is also applied by SHER(2001) is adopted.

$$k_r(\theta) = \left(\frac{\theta - \theta_r}{\theta_s - \theta_r} \right)^n \qquad (1.5)$$

$$k = K_0 \, k_r(\theta) \quad \text{(vertical direction)} \qquad (1.6)$$

$$k = K_{0l} \, k_r(\theta) \quad \text{(lateral direction)} \qquad (1.7)$$

where,

k : unsaturated hydraulic conductivity[cm/s]

$k_r(\theta)$: relative hydraulic conductivity

K_0 : vertical saturated hydraulic conductivity[cm/s]

Comment [j30]: Review 14 15

K_{0l}: horizontal(slope direction) hydraulic saturated hydraulic conductivity[㎝/s]

n : Mualem’s coefficient

θ : current volumetric soil moisture[㎤/㎤]

θ_s : saturated soil moisture[㎤/㎤]

θ_r : residual soil moisture[㎤/㎤]

a) Vertical Infiltration

Although water in soil is drained vertically by gravity, if drainage continues to reduce moisture contents, the unsaturated hydraulic conductivity of soil will decrease and thus drainage will also decrease. In order to structure the relevant hydrological processes, they are simplified by explicit differential calculations where ∆T (specified as one hour) is divided into ten equal parts. The volume of soil moisture content is renewed successively. The calculation procedure is as follows:

① Calculate the unsaturated hydraulic conductivity from the soil moisture content.

② For dt(=∆T/10), the unsaturated permeability coefficient is maintained (thus, the water in the soil is drained in the direction of gravity). The flow velocity is assumed to be (unsaturated hydraulic conductivity) × (1.0).

③ Renew the volumetric moisture content of the soil by deducting the amount of drained water from the soil moisture content.

④ Go back to ① and repeat this process.

$$R = \int_{T}^{T+\Delta T} K_0 \cdot k_r(\theta) dt \qquad (1.8)$$

where,

K_0 : saturated hydraulic conductivity (m/hr)

$K_r(\theta)$: relative hydraulic conductivity

θ : current volumetric soil moisture

Comment [j31]: Review 15

b) Lateral Infiltration

The flow velocity vectors are generated in slope directions, and the water infiltrated into soil is vertically drained by gravity, simultaneously. The flow velocity vector includes fast interflows representing direct runoff and slow interflow components. The fast interflows represent the flows that pass through large pores in the soil (holes made by animals or plants), cracks, and waterways (called pipe flows). On the other hand, the slow interflows represent the flows caused by infiltration that progresses constantly through the soil (which is called lateral infiltration flows) and contribute baseflow.

The flows in slope directions occur simultaneously with vertical infiltration. In order to simplify the calculation of the flows in slope directions in this model, the vertical infiltration is used to estimate the flows in slope directions. In addition, there are two assumptions in order to consider the existence of pipe flows. The first is that the saturated hydraulic conductivity in vertical directions and that of slope directions are assumed to be different. The other is that the hydraulic conductivity in slope directions is assumed to be greater in general. The calculation procedure is as follows:

① Calculate the unsaturated hydraulic conductivity (slope direction) from the moisture content of the soil.

②For dt(=△T/10), the unsaturated permeability coefficient is maintained (thus, the amount of flow based on the unsaturated permeability coefficient is calculated). The flow velocity is calculated by (unsaturated permeability coefficient) × (slope degree of downslope).

③ Deduct the amount of flow from the soil moisture content of the soil and then renew the volumetric moisture content of the soil based on the result.

④ Go back to ① and repeat this process.

$$I = \int_{T}^{T+\Delta T} K_{0I} \cdot k_r(\theta) \cdot s\, dt \qquad (1.9)$$

where,

K_{oI} : saturated hydraulic conductivity in slope directions (m/hr)

$K_r(\theta)$: relative hydraulic conductivity

s : slope degree of downslope (dimensionless)

Comment [j32]: Review 16

c) Return flow

The excessive content of soil moisture is considered as return flow and it contributes to generate surface flow when the soil moisture content is larger than the saturated moisture content in the stage where the calculation of the lateral infiltration flows has been completed. The calculation procedure is as follows: (Figure 1.7).

① The moisture content of the soil is compared with its saturated moisture content in the stage where the calculation of the lateral infiltration flow has been completed. The excessive content of the soil moisture is considered as surface runoff when the soil moisture content is larger than the saturated moisture content.

② The water depth in the ground surface is compared with the depression storage capacity and the amount of water exceeding the depression storage capacity is considered as surface runoff.

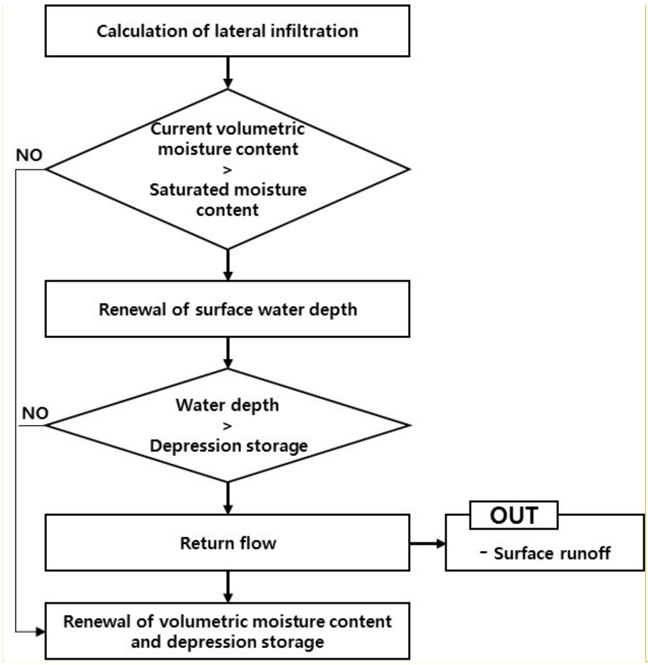


Figure 1.7 Flow chart of the calculation of return flows

2) Green & Ampt method

When infiltration begins into the soil of initial soil moisture θi, then the soil moisture will increase until saturated θs as the wetting front passed. Therefor the initial moisture deficiency (IMD) is the difference between θs and θi. And applying the Darcy equation, the infiltrated flux may be expressed

$$f_p = K_s \frac{L+S}{L} \quad (1.10)$$

Where Ks: saturated hydraulic conductivity, L: depth to wet front from surface, S: capillary suction head the cumulative infiltration is expressed by the depth of increased water depth in the soil.

$$F(t) = L(\theta_s - \theta_i) = L \times IMD \quad (1.11)$$

To combine and rearrange above two equations, eq. (1.12) may be derived and given Ks, t, S, IMD, F(t) can be calculated using eq. (1.13). The Ks and S are defined by the soil type and θs is equivalent to porosity of soil.

$$f_p(t) = K_s(1 + S \times IMD / F(t)) \quad (1.12)$$

$$F(t) = K_s t + (S \times IMD) \times \ln(1 + \frac{F(t)}{S \times IMD}) \quad (1.13)$$

Comment [j33]: Review 17

3) Horton method

Horton(1933) suggested an empirical equation that infiltration begins at a constant rate, f_0, and is decreasing exponentially with time, t. After some time when the soil saturation level reaches a certain value, the rate of infiltration will level off to the rate fc.

$$f_p = f_c + (f_o - f_c)e^{-kt} \qquad (1.14)$$

where,

f_p: infiltration capacity at time t (mm/hr)

f_0: initial infiltration rate or maximum infiltration rate (mm/hr)

f_c: the constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate (mm/hr)

k: decay constant specific to the soil (hr^{-1})

Using Eq. (1.14), cumulative infiltration F(t) is approximately calculated.

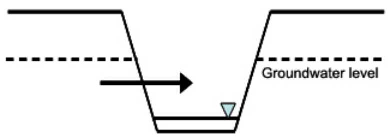
$$F = \int_0^T f_p dt = \int_0^T f_c dt + \int_0^T (f_o - f_c)e^{-kt}dt$$
$$= f_c T + \frac{1}{k}(f_o - f_c)(1 - e^{-kt}) \qquad (1.15)$$

For more information about Horton method, see textbooks as Viessman and Lewis (1977) or Bras (1990).

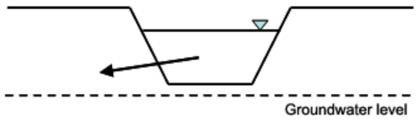
Comment [j34]: Review 18

A-3-3 Groundwater

Equations 1.16 and 1.17 shows the relationship between river stages and groundwater levels. Equation 1.17 is used when a river stage is higher than surrounding groundwater levels and equation 1.16 is used in other cases. That is, water flows into the river depending on the hydraulic conductivity where the groundwater level is higher than the river stage as shown in Figure 1.8(a). On the other hand, the water percolates from the river to the aquifer where the river water level is higher than the groundwater level as shown in Figure 1.8(b). However, in the case of recharges, maximum limits are established so that recharges would not reach more than the amount of water in the channels while renewing the values of groundwater levels using equation 1.19.



(a) Cases where the groundwater level is higher than the river water level



(b) Cases where the river water level is higher than the groundwater level

Figure 1.8 Conceptual diagram of the interaction between groundwater and surface water

$$Q_d = k_0 A_{bed} \tag{1.16}$$

$$Q_d = k_0 \frac{h - H_{rivbed}}{b_{bed}} A_{bed} \tag{1.17}$$

where,

Q_d : inflow into the river or recharges from the river (m^3/s)

k_0 : saturated hydraulic conductivity of riverbed material (m/s)

Comment [j35]: Review 19

A_{bed} : seepage area (m^2)

b_{bed} : thickness of riverbed material (m)

H_{rivbed} : riverbed elevation (m)

h : initial water level of river (m)

$$Q_g = K_0 \frac{\partial h}{\partial x} \cdot l \cdot T \tag{1.18}$$

where,

Qg : groundwater flow (groundwater movement between adjacent sub-catchments) (m^3/s)

K_0 : saturated hydraulic conductivity of aquifer (m/hr)

Comment [j36]: Review 19

$\frac{\partial h}{\partial x}$: slope of groundwater level, hydraulic gradient (dimensionless)

ℓ : conjuncted length between divided catchments (m)

T : average aquifer thickness in the catchment (m)

$$A \cdot S \frac{dh}{dt} = Q_{in} - Q_{out} \tag{1.19}$$

where,

Q_{in} : inflow into the aquifer (㎥/s)(recharge)

Q_{out} : outflow from the aquifer (㎥/s)(pumping)

A : catchment area (㎡)

S : storage coefficient(dimensionless)

h : groundwater level (m)

A-3-4 Evapotranspiration

1) Penman-Monteith Method

The Penman-Monteith is used to estimate the potential evapotranspiration from soil, vegetation covers, transpiration and sublimation. The Penman-Monteith method considers the energy necessary to maintain evapotranspiration, the intensity of the mechanism to remove steam, aerodynamic resistance and factors to explain surface resistance.

$$\lambda E = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot [e_z^o - e_z]/r_a}{\Delta + \gamma \cdot (1 + r_c/r_a)} \qquad (1.20)$$

where,

λ: latent heat energy (MJm-2d-1)

E: depth of evaporation rate (mm/d)

Δ: slope of saturated vapour pressure-temperature curve de/dT (kPa/℃)

H_{net}: net radiation (MJm-2d-1)

G: heat flux density to the ground (MJm-2d-1)

ρ_{air}: air density (kg/㎥)

c_p: specific heat at a certain pressure (MJkg-2d-1)

e^o_z: saturated steam pressure at height z (kPa)

e_z: steam pressure at height z (kPa)

γ: the psychrometric constant (kPa/℃)

r_c: vegetation coverage resistance (s/m)

r_a: air layer diffusion resistance (aerodynamic resistance) (s/m)

The actual evapotranspiration is estimated based on the following process.

① The possible amount of evaporation during rainfalls is assumed as zero.

② The actual evaporation is obtained using Equation 1.21 when the saturated potential evapotranspiration is assumed as the maximum limit.

$$T_{Ta} = k \cdot E_T \qquad (1.21)$$

Comment [j37]: Review 20

where,

k = constant that is related to months or seasons

③ The possible amount of evaporation is compared with the actual evaporation obtained from the previous step ②. The surplus is assumed as the possible amount of evaporation from the soil where the possible amount of evaporation is larger.

④ The possible amount of evaporation from the soil is compared with the moisture content of the soil in order to obtain the actual evaporation using the moisture content of the soil as the maximum limit. This value is then added to the evaporation from the depression storage obtained from the step ② and the resulting value is assumed as the actual evaporation from the basin.

⑤ The volumetric moisture content of the soil is renewed by deducting the actual evaporation.

2) Hargreaves Method

Comment [j38]: Review 4

The Penman-Monteith is used to estimate the potential evapotranspiration from soil, vegetation covers, transpiration and sublimation. The Penman-Monteith method considers the energy necessary to maintain evapotranspiration, the intensity of the mechanism to remove steam, aerodynamic resistance and factors to explain surface resistance.

The Penman-Monteith equation ranges from the most complex energy balance equations requiring detailed climatological data (Penman-Monteith, Allen, 1989) to simpler equations requiring limited data (Blaney-Criddle, 1950, Hargreaves-Samani, 1982,1985). The Penman-Monteith equation is widely recommended because of its detailed theoretical base and its accommodation of small time periods. However, the detailed climatological data required by the Penman-Monteith, are not often available especially in developing nations. Even in more developed nations, the climatological data are often limited. Hargreaves equation is one of empirical methods for reference ET using air temperature data.

The Hargreaves method was originally derived from eight years of cool season Alta fescue grass lysimeter data from Davis, California (Hargreaves, 1975). Several improvements were made to the original equation (Hargreaves and Samani, 1982 and 1985). It has a link to solar radiation.

$$ET_o = 0.0023 \times R_A \times TD^{0.5} \times (TC + 17.8) \qquad (1.22)$$

where:

R_A : mean extra-terrestrial radiation [mm/day], which is a function of the latitude (Figure 1.9)

TD : temperature difference = maximum temperature - minimum temperature [℃].

TC : mean air temperature [℃].

This equation gives reasonable estimates of reference crop evapotranspiration because it has a link to solar radiation through Ra and takes into account the impact of radiation warming the surface near the ground by the term, TD.

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Figure 1.9 mean extra-terrestrial radiation according to latitude

A-3-5 Channel Routing

The Muskingum, Muskingum-Cunge and Kinematic wave methods are used for channel routing to convert the hydrologic curve of inflows into the outflow hydrograph in channel sections.

1) Muskingum Method

The Muskingum method is a flood routing method used by McCarthy in order to establish flood control plans for Muskingum Conservancy District by the US Army Engineer Corps. The Muskingum method divides the total storage in the area into the prism storage in order to consider the effect of the flood inflows on the storage during the routing period. The wedge storage is shown in Figure 1.9. In this method, the prism storage is proportional to the runoff only while the total storage includes the wedge storage as indicated by the following equation 1.22.

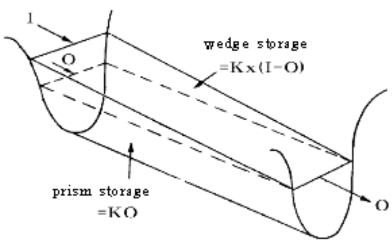


Figure 1.10 concept of wedge storage and prism storage

$$S = KO + Kx(I - O) \\ = K[xI + (1-x)O] \tag{1.23}$$

where,

K : proportionality coefficient, this is a storage coefficient that indicates the ratio of the storage to the outflow in the routing section, including a temporal dimension (hr)

x : weighting factor on inflow versus outflow (0≤x≤0.5), this is a dimensionless constant that indicates the relative importance of the inflows and the outflow contributing to the total storage in the routing section (0≤x≤0.3 in natural stream)

The value of x depends on the shape of the modeled wedge storage. It is zero for reservoir type storage (zero wedge storage or level pool case S = KO) and 0.5 for a full wedge. In natural streams mean value of X is near 0.2. The parameter K is the time of travel of the flood wave through the channel reaches also known as storage time constant and has the dimensions of time.

2) Muskingum-Cunge Method

The Muskingum-Cunge method is a revision of the Muskingum method (based on kinematic waves) into a quasi-diffusion model predicting the attenuation of hydrolograph through parameter calculations for flood routing. In the Muskingum-Cunge method, since the continuity equation with lateral inflows is dispersed as shown in Figure 1.10 on the x-t plane, it is indicated by equation 1.23 as follows:

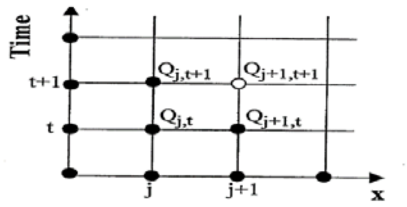


Figure 1.11 Dispersion of Muskingum-Cunge model variables on the x-t plane

$$Q_{i+1}^{n+1} = C_0 Q_i^{n+1} + C_1 Q_i^n + C_2 Q_{i+1}^n + C_3 Q_L \tag{1.24}$$

$$C_o = \frac{-(Kx - 0.5\Delta t)}{K - Kx + 0.5\Delta t} \quad C_1 = \frac{-(Kx + 0.5\Delta t)}{K - Kx + 0.5\Delta t}$$

$$C_2 = \frac{K - Kx - 0.5\Delta t}{K - Kx + 0.5\Delta t} \quad C_3 = \frac{K - Kx - 0.5\Delta t}{K - Kx + 0.5\Delta t}$$

Comment [j39]: Review 22

$$\frac{\Delta t}{K(1-x)} < 0.5$$

Comment [j40]: Review 21

where,

C_0, C_1, C_2, C_3 : routing coefficient

2) Kinematic Wave Method

In many cases the dominant forces in natural streamflow are gravity and frictional force and the other forces are negligible. Unsteady non-uniform flow approximation is based on this assumption to route flows and its governing equation is made using the Manning's formula as the following equation 1.24.

$$Q = \frac{1}{n} B y^{5/3} S_o^{1/2} = \alpha A^m \quad (1.25)$$

$$\frac{\partial A}{\partial t} + \alpha m A^{(m-1)} \frac{\partial A}{\partial x} = q \quad (1.26)$$

where,

B : channel width (m)

y : water depth (m)

S_o : riverbed slope

A : flow cross-sectional area (m^2)

q : lateral inflows (m^3/s)

α, m : coefficients that are determined by the flow characteristics and roughness coefficient of the channel

In Kinematic Wave method, hydraulic radius can be approximated by water depth only in the case where channel width is much larger than water depth.

Comment [j41]: Review 23

A-3-6 Paddy

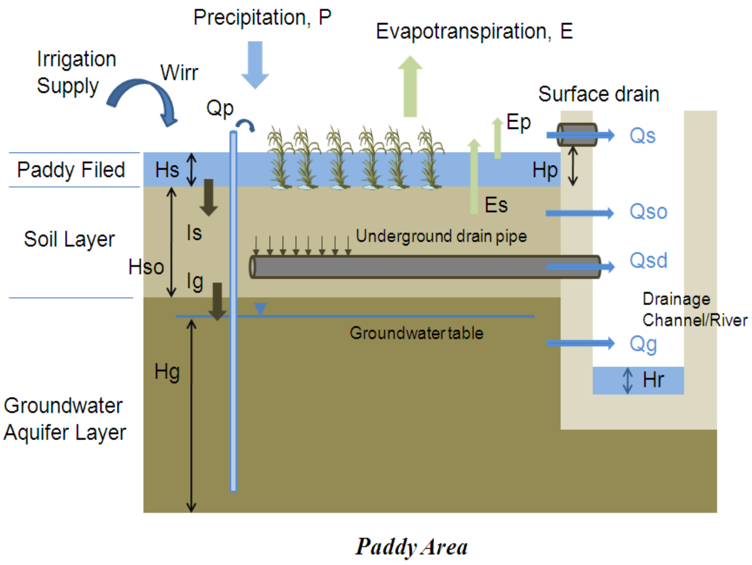


Fig 1.12 Concept of rice paddy fields

To simulate runoff processes in paddy fields, the paddy area in a catchment was divided into one soil layer and one ground aquifer as with infiltration regions. Additionally, artificial drainage facilities were included in the soil layer in order to reflect drainage culvert in paddies. It reflects the fact that surface runoff in paddies occurs through surface drainage management. Thus the module was developed to designate monthly surface drain weir (Mulggo) heights.

The equation related to surface drain in paddies is given by:

$$\begin{aligned} Q_s &= \alpha_0 \sqrt{(H_s - H_p)} \quad (H_s > H_p) \\ Q_s &= 0 \quad (H_s \le H_p) \end{aligned} \qquad (1.27)$$

Comment [j42]: Review 24

where,

Q_s : discharge from surface (m^3/sec)

α_0 : drainage coefficient of surface drain weir in paddy ($mm^{0.5}$/hr)

H_s: ponding depth of paddy (m)

H_p: height of surface drain weir of paddy (m)

According to eq. (1.26), the surface drain weir can be occurred when the ponding depth is higher than the height of surface drain weir.

The equation related to drainage culvert in paddies is given by:

$$Q_{sd} = \min\left(K(\theta), \alpha_p \sqrt{H_s + H_{so}}\right) \qquad (1.28)$$

where,

Q_{sd} : discharge through underground culvert(m^3/sec)

$K(\theta)$: hydraulic conductivity(mm/hr)

α_p : runoff coefficient of underground culvert($mm^{0.5}$/hr)

H_s: ponding depth of paddy(m)

H_{so}: soil depth of paddy(m)

A-3-7 Wetland

Comment [j43]: Review 25

Wetlands reflect vegetation and evaporation from water surface. The module was designed to have any amount of water exceeding the storage capacity of wetlands overflow and discharge to the downstream. In addition, it was designed to have water to be discharged from wetlands to the downstream based on certain criteria. Equation 1.28 represents the governing equation of wetlands.

$$\frac{dS_w}{dt} = Q_w - Q_{wdis} - Q_{wovf} + R - E \quad (1.29)$$

where,

Sw : storage in wetland (m^3)

Qw : inflow into wetland (m^3/s)

Qwdis : outflow from wetland (m^3/s)

Qwovf : overflow from wetland (m^3/s)

R : rainfalls onto the water surfaces of wetland (mm)

E : the evaporation from the water surfaces of wetland (mm)

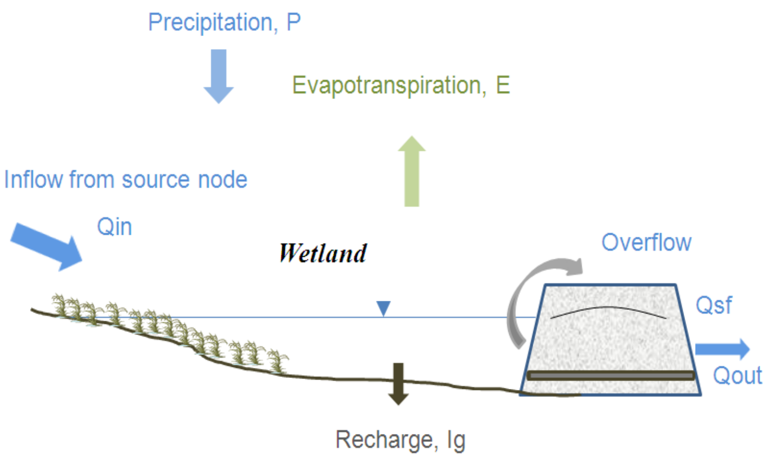


Fig 1.13 Concept of wetland

A-3-8 Reservoir

Comment [j44]: Review 25

In the case of reservoir, evaporation from the water surface is considered. The reservoir storage, water level, and discharge are calculated using the initial storage, effective storage, intake (here, water is taken only when the storage is at least 20% of the effective storage volume), the specifications of spillways and a discharge outlet in the reservoir.

Storage and water levels for both of the types are renewed by inflows based on the relationships of stage-storage-area.

$$\frac{dS_s}{dt} = Q_s - Q_{dis} - Q_{sovf} + R - E \quad (1.30)$$

where,

Ss : storage of pond (m^3)

Qs : inflow into pond (m^3/s)

Qdis : outflow from pond (m^3/s)

Qsovf : overflow by the spillway of pond (m^3/s)

R : rainfall onto the surface of pond (mm)

E : evaporation from surface of pond (mm)

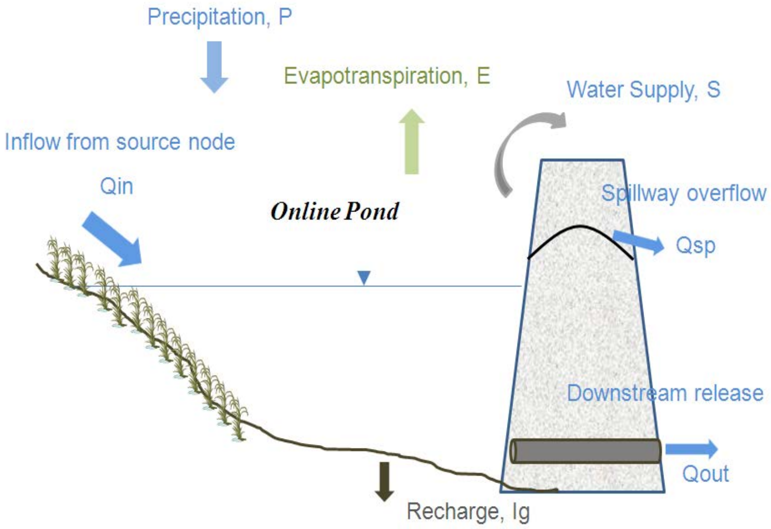


Fig 1.14 Concept of reservoir

A-3-9 Recycle and Import

Comment [j45]: Review 25

A recycle node was planned so that water can be taken from rivers and supplied to catchment. It was assumed that recycle would be supplied to demanding regions based on the purposes of water use, including the water extracted for environmental flow in the river and supplied to any upstream or downstream regions. In addition, the model was designed to reflect water supply from outside of catchment.

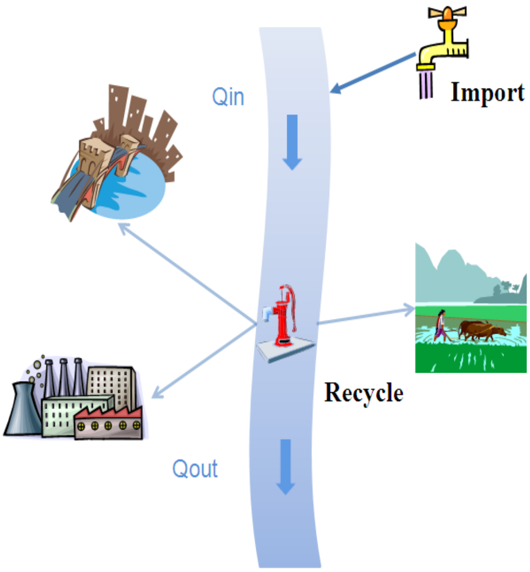


Fig 1.15 Concept of recycle and import

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