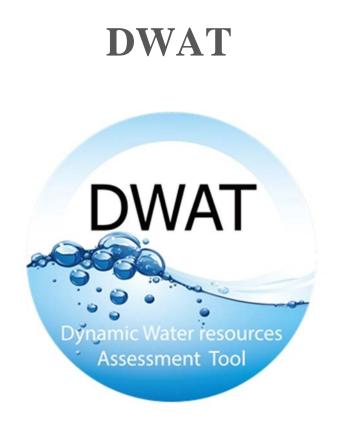
Han River Flood Control Office (Ministry of Environment, Republic of Korea)

Korea Institute of Civil Engineering and Building Technology (KICT)



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

May 2019

DWAT-User's Manual v1.1

Han River Flood Control Office (HRFCO)



KICT KOREA INSTITUTE of CIVIL ENGINEERING and BUILDING TECHNOLOGY

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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 subcatchments 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.

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KICT & HRFCO accept no responsibility and exclude all liability whatever in the aspect of the program and any person's use or reliance on any information of this publication.

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

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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
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 "<u>stationarity</u>" 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.

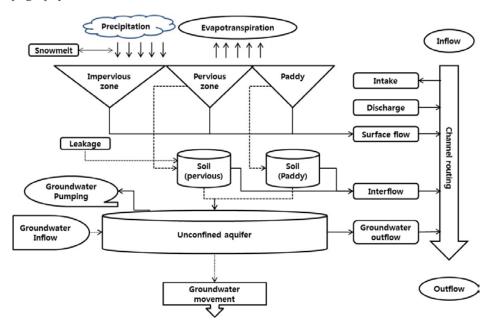
Analysis models are necessary to analysis the structures and interrelationships of water cycle systems and quantitatively assess the impact of changes in the components of water cycle systems on other parts of the water systems. In addition, common tools are required to support the political decision 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 subcatchments 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.

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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

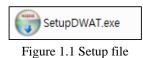
1.1 System Requirements

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.

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

Table 1.1 Minimum and recommended system requirements

1.2 Installation Procedure



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.

🕞 DWAT Setup	
Choose Components Choose which features of DWAT you want to install.	
Check the components you want to install and uncheck th install. Click Next to continue.	e components you don't want to
Select components to install: DWAT application	Description Position your mouse over a component to see its description.
Space required: 92.4 MB	
HRFCO (Han River Flood Control Office) ————————————————————————————————————	k Next > Cancel

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**.

🕞 DWAT Setup	
Choose Install Location Choose the folder in which to install DWAT.	
Setup will install DWAT in the following folder. To install in a different f select another folder. Click Next to continue.	older, click Browse and
Destination Folder	
C:₩Program Files (x86)₩DWAT₩	Browse
Space required: 92.4 MB Space available: 217.9 GB	
HRFCO (Han River Flood Control Office)	xt > Cancel

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**.

🕞 DWAT Setup	- • •
Choose Start Menu Folder Choose a Start Menu folder for the DWAT shortcuts.	
Select the Start Menu folder in which you would like to create the program's can also enter a name to create a new folder.	shortcuts. You
DWAT	
(Default) (주)소만사 30P Chip Lite Accessories Administrative Tools AhnLab AMD Gaming Evolved ArcGIS Asmedia Technology ASRock Utility Backup and Sync from Google Canon	* III
HRFCO (Han River Flood Control Office) —	Cancel

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**.

🕞 DWAT Setup	
Installing Please wait while DWAT is being installed.	
Execute: C:\Program Files (x86)\DWAT\vc_redist.x86.exe /quiet	
Show <u>d</u> etails	
HRFCO (Han River Flood Control Office)	Cancel

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.

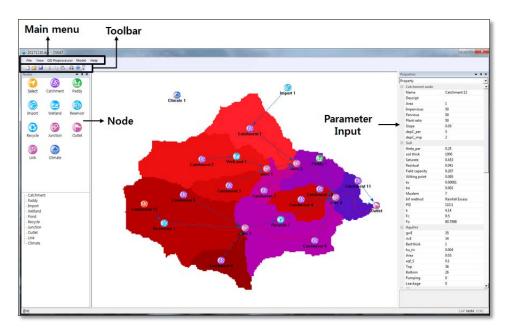


Figure 2.1 Basic configuration screen of the DWAT

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.

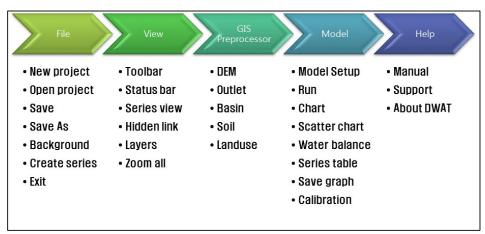


Figure 2.2 DWAT Main Menu

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.

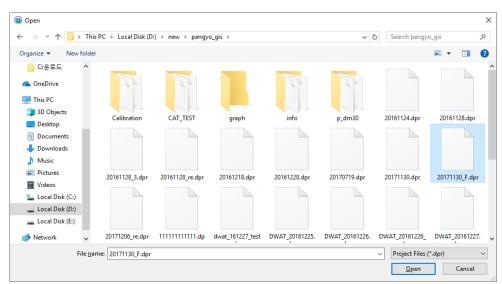


Figure 2.3 Opening a project file

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).

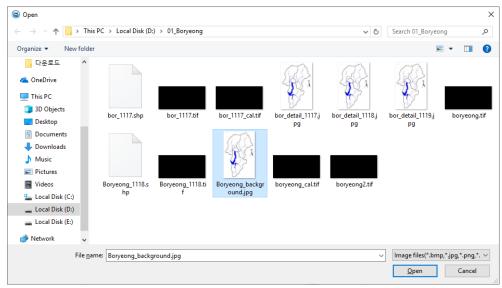


Figure 2.4 Importing a background image

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

īme step		Per	riod 2002-0	1-01 00:00		12-31 00:00
C Hour	• Day		1			
C Month	C Yea	r Fie	eld Solar		-	Add
O User define	(min)				
Observed data			Clear	Ren	nove	Date format
	Rainfall	Temperatur	Wind	Humidity	Solar	
2002/01/01 00:00	0.0000	-4.2500	4.2800	50.3800	0.3400	
2002/01/02 00:00	0.0000	-9.0400	3.5000	36.9600	0.3300	
2002/01/03 00:00	0.0000	-6.8700	1.4200	53.4600	0.2000	
2002/01/04 00:00	0.0000	1.2600	2.9800	66.0800	0.1700	
2002/01/05 00:00	0.0000	-1.0200	2.8600	41.7100	0.3400	
2002/01/06 00:00	0.0000	-1.6100	1.4300	50.7500	0.3400	
2002/01/07 00:00	0.1100	-2.3100	5.0300	57.0400	0.1000	
2002/01/08 00:00	0.0000	-6.4500	4.7600	48.9200	0.1300	
2002/01/09 00:00	0.0000	-5.1700	1.2100	56.4600	0.3400	
2002/01/10 00:00	0.0000	1.7900	1.6800	65.3800	0.0200	
2002/01/11 00:00	0.0000	2.2000	1.7500	69.4200	0.3200	
2002/01/12 00:00	0.0000	2.9600	0.6500	68.5800	0.2600	
2002/01/13 00:00	0.0000	6.5200	2.7300	65.1300	0.1000	
2002/01/14 00:00	0.0300	10.8400	2.8300	68.9600	0.1500	
2002/01/15 00:00	0.3700	11.8500	1.3800	91.2900	0.0000	
2002/01/16 00:00	0.3000	7.4800	2.7300	81.7900	0.0000	
2002/01/17 00:00	0 1000	1 8900	1 9200	84 5400	0 0000	►
e header						
ries file						

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).

ile	C:₩Users₩jan	ig₩Desktop¹	₩pangyo_gis₩	Climate_3.da	at		Load
nterv	al 1day	C S	Start time 200	2/01/01 00:0	0	Count	2191
able	Table 1		•	Decimal		•	
	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	
•	1						•

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).

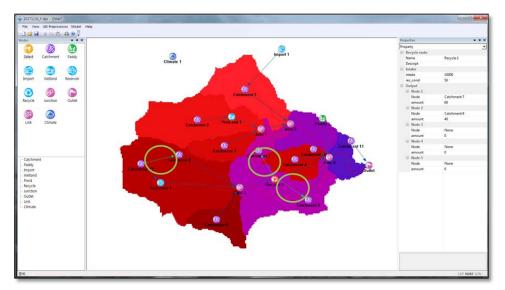


Figure 2.9 View hidden links

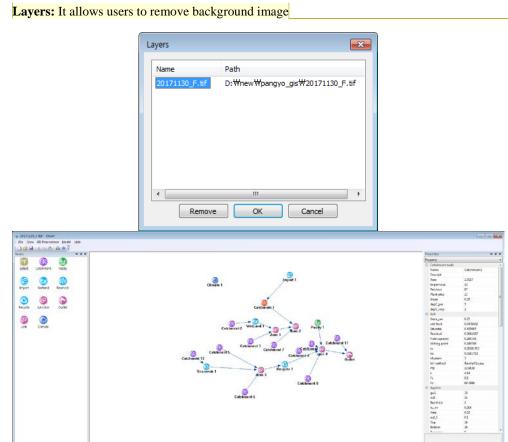


Figure 2.10 Remove background image

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.

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.
- 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

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Comment [j3]: Review 3

Comment [j4]: Review 35,

Comment [j5]: Review 36

65

First, go to Main Menu and select GIS Preprocessor.



Figure 2.11 GIS Preprocessor Toolbar

GIS Preproce	55		_			×
DEM	NOUTLET 🛛	🚺 BASIN	🎒 SOIL	LANDUSE	💿 RUN	
Layers	1					
🗖 ОЕМ						
C Accum						
🔲 Subbasin						
🗌 Stream						
🗖 Soil						
🗌 Landuse						
🔲 Outlet						
				10000.00/-14	0000.007 -999	9.0000
				100001001 11		

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.

GIS Preproces	55		23
DEM	🛿 OUTLET 🛛 📓 BASIN 🛛 🏮 SOIL 🔜 LANDUSE	💿 RUN	
Layers DEM Accum Subbasin			_
🗖 Stream	Se Open	×	
Soil Landuse	□ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □ □	Search p_dm30	0
C Outlet	Organize 👻 New folder	H • 🔟 🔞	
	Favorites Name	Date modified Type	
	Desktop	2/13/2018 11:42 AM ADF Fil	e
	▶ Downloads ₩ Recent Places E		
	Documents		
	a) Music		
	E Pictures		
	Computer + • • · · · · ·		F
	File name: hdr.adf	Raster files(*.asc,*.tif,*.tiff,hdr.a ▼	
		Open Cancel	
	<u></u>		

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.

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DEM	OUTLET	BASIN	SOIL 🍯	LANDUSE	C RUN
ayers			A 1740 19	-	
✓ DEM			325 1	and the second	
Accum				and S	
Subbasin		2		100 200	
🗂 Stream			- -	100 m	Zing &
E Landuse					
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Figure 2.14 Imported DEM

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		213844.04/ 427877.15/ -9999.00

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.

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

Comment [j6]: Review 38

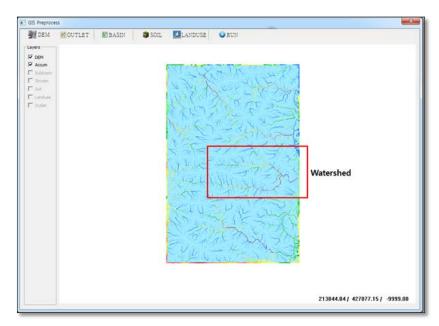


Figure 2.16 Basin outlet selection

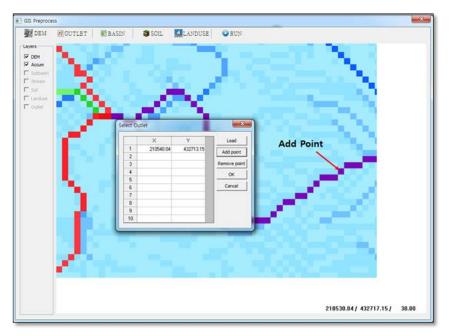


Figure 2.17 Desired basin outlet selection

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.

DEM	OUTLET		BASIN BASIN	SOIL		LANDUS	e 🛛 😳 Ri	JN					
ers DEM Accum Subbasin Stream			R.	14	7	2	3	PT-	53	13			
Soll Landuse		Stream	drop statisti	a				51				X	
Outlet:			Threshold	Dran Den	No First Ord	No High Ord	Mean D First Ord	Mean D High Ord	Std Dev High Ord	Std Dev High Ord	т		
		1	5.000000	3.970252e-003	186	53	35.403225	38.849056	41.126354	43.677311	-0.530713		
		2	8.340503	2.844119e-003	107	32	35.168224	37.218750	39.712288	40.023167	-0.255817		
		3	13.912798	2.216164e-003	70	17	33.328571	44.117645	40.151062	53.609566	-0.927801		
		4	23.207947	1.714755e-003	39	9	35.820515	42.888889	35.614063	45.087261	-0.510604		
		5	38.713192	1.311410e-003	24	7	31.791666	29.571428	43.206261	20.173061	0.130663		
		8	64.577499	9.794905e-004	9	3	40.222221	29.666666	46.542397	12.503335	0.376960		
		7		8.596037e-004		2	53.000000	27.500000	50.600395	4.949748	0.675472		
		8	179.690720	6.788122e-004	4	2	50.750000	6.000000	47.310146	8.485281	1.254473		
		Input	threshold	150			ок	Cancel					
	e		X	ÉÉ (J.	<u>a</u>		4º		, L	X	20	

Figure 2.18 Channel threshold selection

Click OK to proceed. You have a delineated basin.

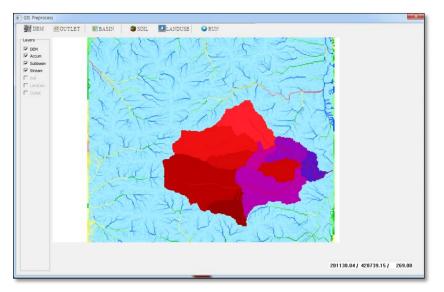


Figure 2.19 Delineated basin.

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

	rlet 🖹 basin	SOIL LANDU	SE 🛛 🕑 RUN			
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Subbasin		~	192			
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Outlet	Organize 👻 New fold	er			I 🛛 🚺	
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- 1 N	Desktop	dwat_test_1208.shp	12/8/2017 4:44 PM	SHP File		
	Documents	Idus_merge2.shp	8/23/2017 9:08 PM	SHP File		
	Downloads	outlet_point.shp	8/10/2005 3:07 PM	SHP File		
	Music	pan_stream2.shp	8/10/2005 3:50 PM	SHP File		
	Pictures	pangyo_0818.shp	8/18/2017 5:43 PM	SHP File		
_	Videos	Pangyo_CAT3.shp	8/15/2017 5:25 PM	SHP File		
<u> </u>		soil_merge2.shp	7/11/2007 2:12 PM	SHP File		
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24			Ope	en Canc		
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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)**.

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	P. C N	3	7887.152	688.443	4	119273	RCS	72	-1		12 L	
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	- Lat 🕺 🚣	8	650678.300		9	120989	SE	80	3			
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		10	6015.306	347.047	11	120476	JoB	48	3		1	
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	6 Sandal	12	1476.074	196.955	13	120476	JoB	48	3		1	
		13	7141.438	517.713	14	120476	JoB	48	3		1	
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Figure 2.21 Soil type overlay

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

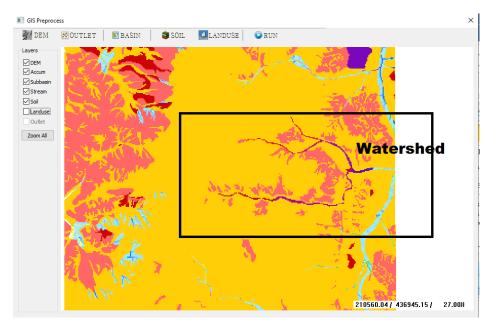


Figure 2.22 Integrated soil type with the basin boundaries.

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.

	Select	field of soil	type(numbe	r)					×
Accur		SNUM	FAOSOIL	DOMSOI	PHASE1	PHASE2	MISCLU1	MISCLU2	
Subbi	1	3717	I-Bh-U-c	1	02		4	0	0
Strea	2	3717	I-Bh-U-c	1	02		4	0	0
Soil	3	3717	I-Bh-U-c	l i	02		4	0	0
andu	4	3717	I-Bh-U-c	1	02		4	0	0
	5	3717	I-Bh-U-c	1	02		4	0	0
Dutle	6	3651	Ao80-2bc	Ao			0	0	0
om /	7	3651	Ao80-2bc	Ao			0	0	0
	8	3651	Ao80-2bc	Ao			0	0	0
	9	3662	Bd32-2bc	Bd	01		0	0	0
	10	3662	Bd32-2bc	Bd	01		0	0	0
	11	3849	Rd28-1a	Rd			0	0	0
	12	3821	Nd53-3bc	Nd			0	0	0
	 Select 	Field FAOS			-	Info	ОК	Cance	r F
		CNTN COUR DOM:	NTRY SOI						
		MISC	LU1						

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.

) Pro	operty 💿 Mat	ch table				
_	Name	depth	s_per	r_per	FC_per	W_per
1	Sand	0.20	0.437	0.020	0.09	0.03
2	Loamy Sand	0.50	0.437	0.035	0.13	0.05
3	Sandy Loam	0.20	0.453	0.041	0.21	0.09
4	Loam	0.50	0.463	0.027	0.27	0.11
5	Silt	0.50	0.489	0.050	0.30	0.12
6	Silt Loam	0.50	0.501	0.015	0.30	0.10
7	Sandy Clay Loam	0.50	0.398	0.068	0.33	0.14
8	Clay Loam	0.50	0.464	0.075	0.25	0.19
9	Silty Clay Loam	0.20	0.471	0.040	0.32	0.20
(0.50	0,400	0.400	0.07	

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

So	oil			×
(🔿 Pro	perty 💿 Match table		
ſ		FAOSOIL	Туре	
	1	Ao80-2bc	Loamy Sand 🚽 🚽	
	2	Bd32-2bc	Select	
	3	I-Bh-U-c	Loamy Sand	
	4	Nd53-3bc	Sandy Loam Loam	
	5	Rd28-1a	Silt T	
				-
	•			۱.
		Make from Load		
		Make from Load	Save OK	_

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).

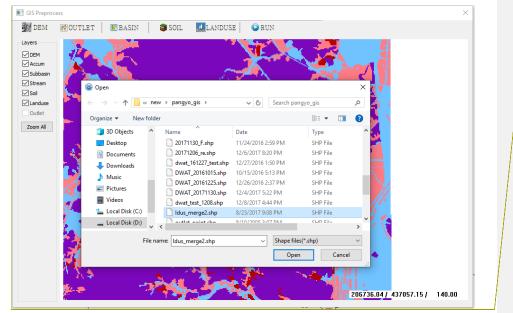


Figure 2.26 Importing land use map

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).

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Subbasin				194	211
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Outlet	Organize 👻 New folde	er		III 🔹 🔟	0
loom All	3D Objects	Name	Date	Туре	^ _
-	Desktop	20171130_F.shp	11/24/2016 2:59 PM	SHP File	
	Documents	20171206_re.shp	12/6/2017 8:20 PM	SHP File	
- N	Downloads	dwat_161227_test.shp	12/27/2016 1:50 PM	SHP File	
	Music	DWAT_20161015.shp	10/15/2016 5:13 PM	SHP File	- S
1	Pictures	DWAT_20161225.shp	12/26/2016 2:37 PM	SHP File	
		DWAT_20171130.shp	12/4/2017 5:22 PM	SHP File	
	Videos	dwat_test_1208.shp	12/8/2017 4:44 PM	SHP File	
	Local Disk (C:)	Idus_merge2.shp	8/23/2017 9:08 PM	SHP File	
- E.	Local Disk (D:)	<	071073005 3.07 DKA	CUB Las	> < \
- * A	File na	ame: Idus_merge2.shp	✓ Shape file	s(*.shp)	
<u> </u>			Oper	n Cancel	•
	*		1 204.		
- A	-	Sam Vine			

Figure 2.27 Land use overlay

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

Comment [j7]: Change figu

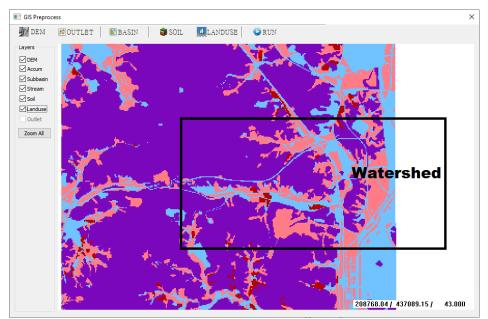


Figure 2.28 Integrated land use with the basin boundaries

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.

GIS Preprocess	8
🗱 dem 🐼 outlet 📓 basin 💲 soil 🛃 landuse 📀 run	
Leyes P EM Accum Subbasin Stream Outlet Zoem All Select field of landuse type(numbr) Image: Community of the stream I	.00

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.

	Name	Туре	
1	1110	Impervious	•
2	1120	Pervious	•
3	1210	Paddy	•
4	1220	Plant	•
5	2110	Impervious	•
6	2120	Pervious	•
7	2210	Paddy	•
8	2220	Plant	•
9	2230	Impervious	•
10	2310	Pervious	•
 ∢ [2000	B 11	7

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

	Name	Туре
1	1	Pervious 🚽 🗕
2	10	Select
3	11	Impervious Pervious
4	12	Paddy
5	13	Plant Pervious 👻
6	14	Pervious 👻
7	15	Impervious 👻
8	16	Pervious 👻
9	17	Pervious 👻
10	18	Plant 👻
•••	2	

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).

DEM 🔊 OUTL	ET 🛛 📓 BASIN	😂 SOIL 🔜 LANDUS	e 💿 run			
ayers				100 C	- -	
Subbasin		~			200 A	
Stream	🕞 Save As				×	
Soil	← → × ↑	ew > pangyo_gis >	✓ ♂ Search par	navo ais	🚺 م	
Landuse						
Outlet	Organize 🔻 🛛 New fold	der			0	
Zoom All	🗄 Documents \land	Name	Date	Туре	∧	
	🖊 Downloads	20161228.dpr	8/23/2017 9:08 PM	DPR File	1	
1 A A	h Music	20170719.dpr	7/19/2017 11:30 AM	DPR File		
	Pictures	20171130.dpr	12/4/2017 4:35 PM	DPR File		
	Videos	20171130_F.dpr	12/4/2017 4:54 PM	DPR File		
	Local Disk (C:)	20171206_re.dpr	12/6/2017 8:22 PM	DPR File		
e la charactería de la charact	Local Disk (D:)	🗋 111111111111.dpr	7/20/2017 11:31 AM	DPR File	. . .	
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	Save as type: Proje	ect file(^.dpr)			\	
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		Add Long		50 TAL		

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.

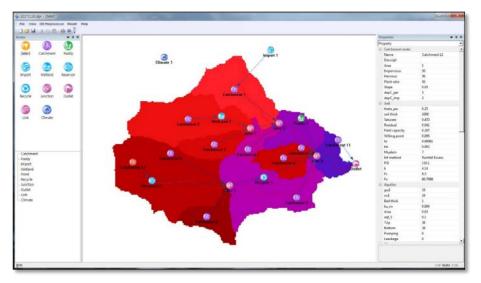


Figure 2.34 Completed hydrologic model main window

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.

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be defined and a set of the set o	7.2 40 10 10 7.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10 10 10 8.8 10			Randallown)(Current-Catalment1 (Current-Catalment1) (Current-Catalment1) (Current-Catalment1) (Current-Catalment2) 12 12 12 12 12 12 12 12 12 12
3ml Espect Zoom Al	2.8 2.8 2.4 2.2 2.3 1.8 1.6 1.4 1.4 1.4 1.4 0.8 0.4 0.4 0.4 0.4 0.4				424 44 46 46 46 50 52 52 56 56 56 56 56 56 56 56 56 56 56 56 56

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.

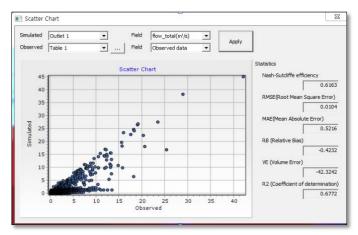


Figure 2.38 Model statistical values before calibration

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

By year 🔎 B	ly node	Node Catc	ment 1 💌		Select Outlet 1
	Average	2002	2003	2004	
Rainfall	1346.5	1231.7	1514.8	1217.0	
Inflow	0.0	0.0	0.0	0.0	Rainfall 1,346 Evapotranslation 354
ET	353.5	355.9	332.5	374.3	Infiltration
ET_imp	7.9	7.9	8.9	7.2	1,262
ET_per	345.7	348.0	323.6	367.2	Surface flow
Runoff	963.5	722.2	1166.1	844.8	Recharge 76
Surface	76.3	69.1	85.8	68.9	Total runoff
Interflow	92.1	69.2	112.6	79.8	Interflow
Groundwater	795.1	583.8	967.7	696.1	
Infiltration	1262.3	1154.7	1420.1	1140.9	Groundwater 795
Recharge	799.7	600.8	977.5	692.6	
Soil	24.8	136.7	6.4	1.4	
GW-Storage	4.6	16.9	9.9	-3.6	Groundwater movement
•				•	

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).

lodes		Fields	
Nodes	×	Field	
Catchment 1		[] Inflow(m ⁱ)	1
Catchment 2	E	Rainfall(mm)	
Catchment 3		Actual Evapotranspiration(mm)	E
Catchment 4		Potential Evapotranspiration(mm)	1
Catchment 5		Flow_Surface(mm)	
Catchment 6		Flow_Inter(mm)	
Catchment 7		Flow_Groundwater(mm)	
June 1		Flow_Total(mm)	
June 2		Infiltrate(mm)	
June 3	-	Recharge(mm)	

Figure 2.40 Model simulated time series result of several hydrological components

Click View to proceed. Table results will appear.

	A	В	С
1	Date	Catchm	ent 1
2	Date	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)

lodes		Fields	
Nodes	×	Field	
Catchment 1		Inflow(m ²)	1
Catchment 2	EE	Rainfall(mm)	
Catchment 3		Actual Evapotranspiration(mm)	
Catchment 4		Potential Evapotranspiration(mm)	
Catchment 5		Flow_Surface(mm)	
Catchment 6		Flow_Inter(mm)	
Catchment 7		Flow_Groundwater(mm)	
Junc 1		Flow_Total(mm)	
June 2		Infiltrate(mm)	
Dunc 3	-	Recharge(mm)	

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

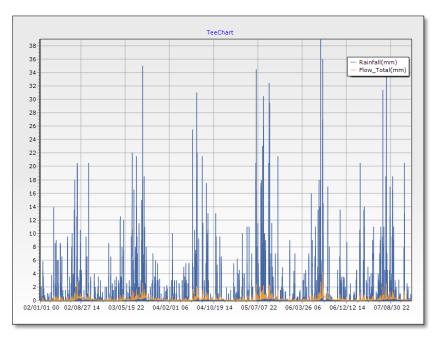


Figure 2.43 Graphical result of rainfall and total flow.

Calibration: It allows users to calibrate and optimize parameters using PEST (model-independent <u>Parameter EST</u>imation).

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.**

lode	Catchm	ent 1		 Output field 	Flov	v_Total(m	n)	👻 📃 Con	vert cms to r	nm(Observ
lame										
bservation							۱			
DServauori								•		
imulate Term	2002-0	1-010	• ~	2007-12-31 2 👻		Calibrate	Term 2002-	01-010 👻	~ 2007-1	2-31 2 👻
Parameter	Result	Tabla	Graph	Scatter						
renemeter	Result	Table				11.5		•••		
				escription		Unit	Default	Min	Max	Use
River	bed	Rivert				m	1	0.1	2	Ľ
ku_ri	v	θs of ri		-		mm/s	0.004	1e-06	1	×
S		Storage coefficient				-	0.1	0.01	0.1	Ľ
Soil de	epth	Soil depth				m	0.0476402	0.01	5	×
θs		Saturated soil moisture				-	0.455007	0.3	1	
Ks		θs of s	oil(vert	ical)		mm/s).00181713	1e-05	0.08	
Ksi	i θs of soil(lateral)			mm/s	0.0181713	1e-05	0.8	×		

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

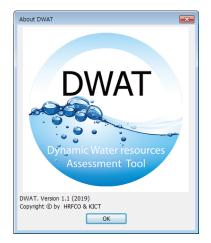


Figure 2.45 DWAT copyright and version information

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.

Nodes			×
	3		
Select	Catchment	Paddy	
Ē		en	
Import	Wetland	Reservoir	
	Ø		
Recycle	Junction	Outlet	
\bigtriangledown			
Link	Climate		
Paddy Import	nt		
Wetland			
Reservoir			
Recycle			
Junction Outlet			
- Outlet			
Climate			

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.

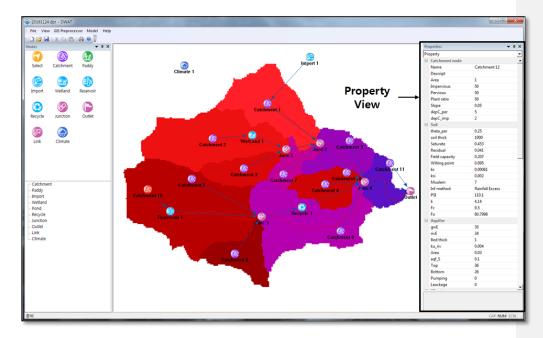


Figure 2.47 Property View displays

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.

Division		Input variable	Description of variable	Unit
		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
D .		spill_ht	Height of spillway	m
Reservoir		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	$m-m^3-m^2$
		vol_init	Initial storage	m ³
vol_max flood_bypass Wetland Kgw		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	$m-m^3-m^2$
rec_intake		rec_intake	Total intake volume	m ³ /day
Recycle		rec_cond	Restriction for intake rate according to streamflow	%
	ater	import_water	Constant volume or time series data of imported from outside	m ³ /day
supply		Leakage	Leakage rate	%
Meteorological		Latitude, Elevation, Height	The location, elevation, and height of the observatory	m
condition		Climate data	Rainfall, wind velocity, sunshine hours, lowest/highest temperatures, relative humidity	-

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Division	Input variable	Description of variable	Unit
Subject basin	Area	Area	Km ²
	Slope	Catchment average slope	-
	Aratio_imp	Impervious area ratio	%
Ground surface	Aratio_per	Pervious area ratio	%
condition	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
	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	-
Surface soil	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
	rivE	Riverbed elevation	m
	Area_riv	Area of riverbed	Km ²
River	riv_th	Thickness of riverbed	m
	ku_riv	Riverbed material permeability coefficient	mm/s
	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
Groundwater	aquifer slope	Average slope of the aquifer	-
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	-
	irr_start	Date of start of irrigation	April 1 st .
	irr_end	Date of end of irrigation	September 30 th .
	Surf_dr_ht	Monthly drainage outlet height	m
	surf_dr_cf	Coefficients of drainage outlet	-
Paddy	udgw_dr_cf	Coefficient of drainage pipe	-
	Diameter	Diameter of drainage pipe	mm
	Rain Max.	Threshold rainfall to open the drainage pipe	mm
			211111
	Coef. A	Number of drainage pipe	-
	Coef. B	Runoff coefficient of drainage pipe	-
	Melting	Melting factor	mm/°C/day
	Refreezing	Refreezing factor	-
now melt	CWH Thrashold Tomp	Critical relative water content of the snow pack	- °C
now melt	Threshold Temp.	Threshold temperature of rain/snow	°C
	Interval Temp.	Temperature interval for rain/snow mixing	°C

Table 3.2 Model parameter (Catchment nodes)

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

Table 3.3 Model parameter (link, channel routing)

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.

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3.1.1 Background Image



Figure 3.1 Background icon

Load: It allows users to insert background images

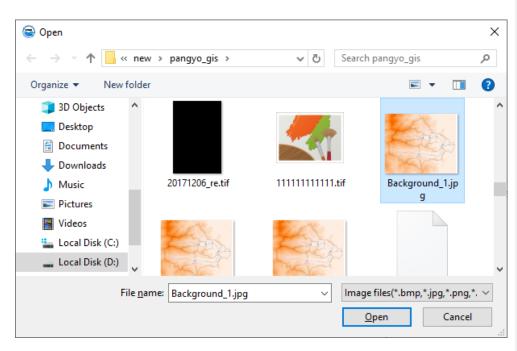


Figure 3.2 Loading background image

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

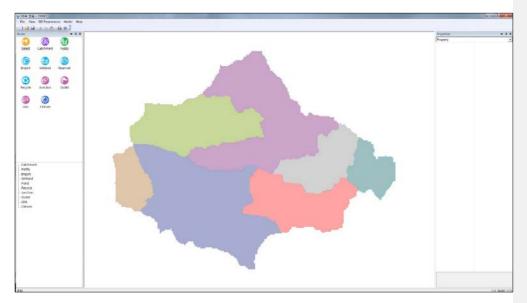


Figure 3.3 Imported background image

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

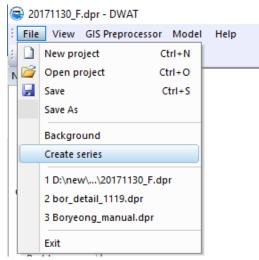


Figure 3.4 Tools for creating time series

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.

Time step		Period	2015-01-01 00:00	~ 2016-12-23 00:00
C Hour	Day	Period	2013-01-01 00:00	~ 2018-12-23 00:00
C Month	C Year	Field	Rainfall	▼ Add
C User define	(min)		Rainfall Evaporation	
C Observed data		(Humidity	Date format
	Rainfall	,	Wind	= _
2015/01/01 00:00			Temperature(Avg) Temperature(Min)	-
2015/01/02 00:00			Temperature(Max)	
2015/01/03 00:00			User defined	
2015/01/04 00:00			Observed data	*
2015/01/05 00:00				
2015/01/06 00:00				
2015/01/07 00:00				
2015/01/08 00:00				
2015/01/09 00:00				
2015/01/10 00:00				
2015/01/11 00:00				
2015/01/12 00:00				
2015/01/13 00:00				
2015/01/14 00:00				
2015/01/15 00:00				
2015/01/16 00:00				
2015/01/17 00:00				•
File header				
rile fieauer				
Series file				
,				

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.

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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.

xI	1 5· 0·	Ŧ			Book	:1 - Excel				?	<u>a</u> – C	×
FI	LE HOME	INSERT P/	AGE LAYOUT	FORMUL	AS DATA	REVIEW	VIEW					Sign in
Pas +			atxi - € +		\$ • %		itional Forma at as Table = tyles = Styles	tting *	Ensert			^
B1	• :	XV	f_x Rain	fall								¥
	А	В	С	D	E	F	G	н	1	J	К	
1	Date	Rainfall	Temperatu	Wind	Humidity	Solar						
2	2/1/2001 0:00	0	-4.25	4.28	50.38	0.34						
3	2/1/2002 0:00	0	-9.04	3.5	36.96	0.33						
4	2/1/2003 0:00	0	-6.87	1.42	53.46	0.2						
5	2/1/2004 0:00	0	1.26	2.98	66.08	0.17						
6	2/1/2005 0:00	0	-1.02	2.86	41.71	0.34						
7	2/1/2006 0:00	0	-1.61	1.43	50.75	0.34						
8	2/1/2007 0:00	0.11	-2.31	5.03	57.04	0.1						
9	2/1/2008 0:00	0	-6.45	4.76	48.92	0.13						
10	2/1/2009 0:00	0	-5.17	1.21	56.46	0.34						
11	2/1/2010 0:00	0	1.79	1.68	65.38	0.02						
12	2/1/2011 0:00	0	2.2	1.75	69.42	0.32						
10	C > Shee		2.06	0.65	60 50	0.26	: •					×
REA	DY		AVER	AGE: 15.88418	53 COUNT:	10960 SUM	: 174011.25	Ⅲ			+	100%

Figure 3.6 Time series data in Microsoft excel

Time step	~		riod 2002-0	1-01 00:00	~ 2007- ○	12-31 00:0
C Hour	Day		,			
C Month	C Yea	r Fi	eld Solar		-	Add
○ User define	()	nin)	,			
C Observed data			Clear	Ren	nove	Date for
	Rainfall	Temperatur	Wind	Humidity	Solar	
2002/01/01 00:00	0.0000	-4.2500	4.2800	50.3800	0.3400	
2002/01/02 00:00	0.0000	-9.0400	3.5000	36.9600	0.3300	
2002/01/03 00:00	0.0000	-6.8700	1.4200	53.4600	0.2000	
2002/01/04 00:00	0.0000	1.2600	2.9800	66.0800	0.1700	
2002/01/05 00:00	0.0000	-1.0200	2.8600	41.7100	0.3400	
2002/01/06 00:00	0.0000	-1.6100	1.4300	50.7500	0.3400	
2002/01/07 00:00	0.1100	-2.3100	5.0300	57.0400	0.1000	
2002/01/08 00:00	0.0000	-6.4500	4.7600	48.9200	0.1300	
2002/01/09 00:00	0.0000	-5.1700	1.2100	56.4600	0.3400	
2002/01/10 00:00	0.0000	1.7900	1.6800	65.3800	0.0200	
2002/01/11 00:00	0.0000	2.2000	1.7500	69.4200	0.3200	
2002/01/12 00:00	0.0000	2.9600	0.6500	68.5800	0.2600	
2002/01/13 00:00	0.0000	6.5200	2.7300	65.1300	0.1000	
2002/01/14 00:00	0.0300	10.8400	2.8300	68.9600	0.1500	
2002/01/15 00:00	0.3700	11.8500	1.3800	91.2900	0.0000	
2002/01/16 00:00	0.3000	7.4800	2.7300	81.7900	0.0000	
2002/01/17 00:00	0 1000	1 8900	1 9200	84 5400	0 0000	
e header						
ries file						

Figure 3.7 Creating time series database

Series file	D:₩CAT-U_jang₩penman_0202₩climate_0228.dat	
		····)

Click and enter the saving directory and file name.

File header Climate_data

Enter the file description.

sries file C+WI IsersWianoWDesktonWnangvo.gisWClimate 5.dat	Time step			riod 2002-0	1-01 00:00	- ~ 2007-	12-31 00:00
Clear Remove Date forma 0bserved data Clear Remove Date forma 2002/01/01 00:00 0.0000 4.2500 4.2800 50.3800 0.3400 2002/01/02 00:00 0.0000 9.4000 2.6900 0.3300 0.2400 2002/01/02 00:00 0.0000 9.4000 2.6900 0.3300 0.3400 2002/01/02 00:00 0.0000 2.6900 0.3300 0.3400 1000 0.3400 2002/01/02 00:00 0.0000 0.0000 0.4000 1000 0.3400 2002/01/02 00:00 0.0000 0.4000 1000 0.3400 1000 0.3400 2002/01/02 00:00 0.0000 0.4000 1000 0.3400 1000 0.3400 1000 0.2000 1000 0.3400 1000 0.3200 1000 0.2000 1000 0.2000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 1000 10000 1000	C Hour	Day		· ·	-		
C Observed data Clear Remove Date forma 2002/01/01 00:00 0.0000 4.2500 4.2800 50.3800 0.3400 2002/01/02 00:00 0.0000 4.2500 4.2800 50.3800 0.3400 2002/01/02 00:00 0.0000 4.2500 4.2800 50.3800 0.3400 2002/01/02 00:00 0.0000 9.0400 3.000 5600 0.2000 2002/01/02 00:00 0.0000 0.0000 0.0000 9.0400 3.600 1.700 2002/01/02 00:00 0.0000 0.0000 0.0000 1.000 1.000 2.000 1.000 2002/01/02 00:00 0.0000 0.0000 0.0000 2.000 0.0000 2.000 0.0000 2.000 0.0000 2.000 0.0000 2.000 0.0200 0.0200 0.0200 0.0200 0.0200 0.0200 0.0200 0.0200 2.000 2.000 2.000 2.000 2.000 2.000 2.000 2.000 2.000 2.000 2.000 2.000 2.000<	C Month	C Yea	r Fi	eld Solar		-	Add
Coserver data Reinfall Temeeratur Wind Humidity Solar 2002/01/01 000 0.0000 4.2500 50.3800 0.3400 2002/01/02 00.00 0.0000 4.2500 56.9600 0.3300 2002/01/02 00.00 0.0000 2.500 56.9600 0.3300 2002/01/02 00.00 0.0000 2.500 56.9600 0.3300 2002/01/05 00.00 0.0000 2.500 56.00 0.2000 2002/01/06 00.00 0.0000 2.500 56.00 0.3400 2002/01/08 00.00 0.0000 2.500 50.00 0.3400 2002/01/10 00.00 0.0000 2.7300 63.9600 0.2000 2002/01/12 00.00 0.0000 2.7300 63.9600 0.5800 2002/01/12 00.00 0.0000 1.8500 1.8300 91.2900 0.0000 2002/01/14 00.00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/14 00.00 0.3000 7.4800 2.7300 81.7900 0.0000	C User define	(nin)				
2002/01/01 00:00 2002/01/02 00:00 2002/01/12	C Observed data			Clear	Ren	nove	Date forma
2002/01/02 00:00 0.0000 2002/01/03 00:00 0.0000 2002/01/05 00:00 0.0000 2002/01/05 00:00 0.0000 2002/01/05 00:00 0.0000 2002/01/05 00:00 0.0000 2002/01/05 00:00 0.0000 2002/01/05 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/16 00:00 0.3000 7.4600 2.7300 61.7900 0.00000 2002/01/16 00:00 0.3000 7.4600 2.7300 61.7900 0.0000 2002/01/16 00:00 0.3000 7.4600 2.7300 61.7900 0.0000 2002/01/16 00:00 0.3000 7.4600 2.7300 61.7900 0.00000 2002/01/16 00:00 0.3000 7.4600 2.7300 61.7900 0.0000 2002/01/16 00:00 0.3000 7.4600 2.7300 61.7900 0.0000 2002/01/16 00:00 0.3000 2002/01/16 00:00 0.3000 2002/0		Rainfall	Temperatur	Wind	Humidity	Solar	
2002/01/02 00:00 0.0000 DWAT ■ 600 0.2000 2002/01/02 00:00 0.0000 DWAT ■ 600 0.2000 2002/01/02 00:00 0.0000 DWAT ■ 600 0.2000 2002/01/02 00:00 0.0000 DWAT ■ ■ 600 0.2000 2002/01/06 00:00 0.0000 DWAT ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ ■ <t< td=""><td>2002/01/01 00:00</td><td>0.0000</td><td>-4.2500</td><td></td><td>50.3800</td><td>0.3400</td><td></td></t<>	2002/01/01 00:00	0.0000	-4.2500		50.3800	0.3400	
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2002/01/06 00:00 0.0000 2002/01/07 00:00 0.0100 2002/01/07 00:00 0.0100 2002/01/09 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/12 00:00 0.0000 2002/01/12 00:00 0.0000 2002/01/12 00:00 0.0000 2002/01/14 00:00 0.0000 2002/01/14 00:00 0.0300 10.4400 2.4300 658 9600 0.1500 2002/01/15 00:00 0.3700 11.8500 11.2900 0.0000 2002/01/15 00:00 0.3700 11.8500 11.2900 0.0000 2002/01/15 00:00 0.3700 11.8500 11.2900 0.0000 2002/01/15 00:00 0.							
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2002/01/09 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/10 00:00 0.0000 호·호·200 2.7300 651 300 0.0200 2002/01/12 00:00 0.0000 5·호·200 2.7300 651 300 0.1000 2002/01/14 00:00 0.0300 10.8400 2.8300 68 9600 0.1500 2002/01/16 00:00 0.3700 11.8500 1.3800 91.2900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81 7900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81 7900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81 7900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81 7900 0.0000	2002/01/07 00:00	0.1100		Complete		0.1000	
2002/01/10 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/10 00:00 0.0000 2002/01/13 00:00 0.0000 2002/01/13 00:00 0.0000 2002/01/13 00:00 0.0300 2002/01/14 00:00 0.0300 2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/16 00:00 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/16 00:00 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/16 00:00 0.000 2002/01/16 00:00 0.000 2002/01/16 00:00 0.3000 2002/01/16 00:00 0.000 2002/01/16 00:000 2002/01/16 00:000 2002/01/16 00:000 2002/01/16	2002/01/08 00:00	0.0000			9200	0.1300	
2002/01/11 00:00 0.0000 2002/01/12 00:00 0.0000 2002/01/20 00:00 0.0000 2002/01/30 00:00 0.0000 2002/01/15 00:00 0.03000 2002/01/15 00:00 0.3300 11.8500 21.2900 88.9500 0.1500 2002/01/15 00:00 0.3300 1.8500 21.2900 0.0000 2002/01/15 00:00 0.3300 1.8500 1.3800 81.2900 0.0000 2002/01/15 00:00 0.3000 2.4300 81.2900 0.0000 2002/01/15 00:00 0.03000 2.4300 81.2900 0.0000 2.4300 81.2900 0.0000 2.0000 2.4300 81.2900 0.0000 2.4300 81.2900 0.0000 2.4300 81.2900 0.0000 2.4300 81.2900 0.0000 2.4600 2.2300 81.2900 0.0000 2.4300 81.2900 0.0000 2.4400 81.2900 0.00000 2.4400 81.290	2002/01/09 00:00	0.0000			4600	0.3400	
202201/12 00:00 0.0000 52200 27/300 551300 0.0000 202201/13 00:00 0.0000 52200 27/300 551300 0.1000 202201/15 00:00 0.3700 11.8500 1.3800 91.2900 0.0000 202201/15 00:00 0.3700 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 202201/15 00:00 0.0000 202201/15 00:00 0.0000 202201/15 00:00 0.0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:0000 202201/15 00:00000 202201/15 00:00000 202201/15 00:00000 202201/15 00:00000 202201/15 00:00000000 202201/15 00:0000000000000000000000000000000000	2002/01/10 00:00	0.0000			3800	0.0200	
2002/01/13 00:00 0.0000 b:5200 2.7300 b31300 0.1000 2002/01/14 00:00 0.0300 10.9400 2.8300 68.9500 0.1500 2002/01/15 00:00 0.3700 11.8500 1.3800 91.2900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 pmp/mt/2 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.00000 0.00000 0.000000	2002/01/11 00:00	0.0000		확인	4200	0.3200	
2002/01/14 00:00 0.0300 10.8400 2.8300 68 9600 0.1500 2002/01/15 00:00 0.3700 11.8500 1.3600 91.2900 0.0000 2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/16 00:00 0.0000 7.4800 2.7300 81.7900 0.0000 e header	2002/01/12 00:00	0.0000			5800	0.2600	
2002/01/15 00:00 0.3700 11.8500 1.3800 91.2900 0.0000 2002/01/16 00:00 0.3000 7.4600 2.7300 81.7900 0.0000 2002/01/15 00:00 0.1000 1.9900 84.5400 0.0000	2002/01/13 00:00	0.0000	6.5200	2.7300	65.1300	0.1000	
2002/01/16 00:00 0.3000 7.4800 2.7300 81.7900 0.0000 2002/01/16 00:00 0.1000 1.9900 1.9000 0.0000 P002/01/17 00:00 0.1000 e header ries file C:W1 lears Wians WDeskton Winannun, nic WClimate 5.dat	2002/01/14 00:00	0.0300	10.8400	2.8300	68.9600	0.1500	
2002/01/17 00-00 0.1000 1.9900 1.9200 84.5400 0.0000 ▶ e header ries Rie	2002/01/15 00:00	0.3700	11.8500	1.3800	91.2900	0.0000	
	2002/01/16 00:00	0.3000	7.4800	2.7300	81.7900	0.0000	
ries file [2002/01/17 00:00	0 1000	1.8900	1 9200	84 5400	0 0000	•
	e header						
	Series file C:\Users\u00e4jang\u00fcDesktop\u00e4pangyo_gis\u00fcClimate_5.dat						

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:

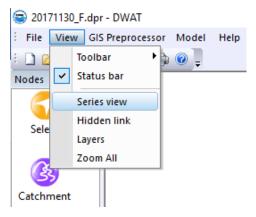


Figure 3.9 Time series database checking tool

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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.

		inpang/o_gion	Climate_3.da	at		Load
1day	C S	Start time 200	2/01/01 00:0	00	Count	2191
Table 1		•	Decimal		•	
-		-				
02/01/17 00			1.92		0.00	
	0.00	0.59	1.64	80.67	0.04	
02/01/20 00	0.00	0.85	0.94	87.29	0.00	
	Date 1 Date 1 22/01/01 00 22/01/02 00 22/01/02 00 22/01/03 00 22/01/05 00 22/01/05 00 22/01/09 00 22/01/09 00 22/01/10 00 22/01/11 00 22/01/15 00 22/01/15 00 22/01/17 00 22/01/17 00 22/01/17 00	Date Rainfall D2/01/01 00 0.00 02/01/02 00 0.00 02/01/03 00 0.00 02/01/03 00 0.00 02/01/03 00 0.00 02/01/03 00 0.00 02/01/05 00 0.00 02/01/06 00 0.00 02/01/07 00 0.00 02/01/07 00 0.00 02/01/12 00 0.00 02/01/12 00 0.00 02/01/14 00 0.00 02/01/15 00 0.33 02/01/17 00 0.01 02/01/17 00 0.01 02/01/17 00 0.01 02/01/14 00 0.03 02/01/14 00 0.03 02/01/14 00 0.01 02/01/14 00 0.01 02/01/17 00 0.01 02/01/17 00 0.01 02/01/17 00 0.01 02/01/18 00 0.00	Date Rainfall Temperatur 02/01/01 00 0.000 -4.25 02/01/01 00 0.000 -4.25 02/01/01 00 0.000 -8.87 02/01/03 00 0.000 -6.87 02/01/04 00 0.000 -1.02 02/01/05 00 0.000 -1.61 02/01/07 00 0.11 -2.31 02/01/07 00 0.000 -5.17 02/01/12 00 0.000 -5.17 02/01/12 00 0.000 -5.12 02/01/12 00 0.000 -5.12 02/01/12 00 0.000 -5.12 02/01/12 00 0.000 -5.12 02/01/12 00 0.000 -5.12 02/01/14 00 0.000 -5.20 02/01/15 00 0.37 11.85 02/01/17 00 0.30 7.48 02/01/17 00 0.00 6.59 02/01/17 00 0.00 6.59 02/01/18 00 0.00 6.59 02/01/18 00 0.00 6.59 </td <td>Date Rainfall Temperatur Wind 02/01/01 00 0.00 -4.25 4.28 02/01/01 00 0.00 -4.25 4.28 02/01/02 00 0.00 -9.04 3.50 02/01/03 00 0.00 -6.87 1.42 02/01/03 00 0.00 -1.61 1.43 02/01/05 00 0.00 -1.61 1.43 02/01/07 00 0.11 -2.21 5.03 02/01/07 00 0.00 -5.17 1.21 02/01/07 00 0.00 -5.17 1.21 02/01/07 00 0.00 -5.17 1.21 02/01/07 00 0.00 -5.17 1.21 02/01/10 00 0.00 -5.20 1.75 02/01/12 00 0.00 2.20 1.75 02/01/12 00 0.00 2.96 0.65 02/01/14 00 0.33 10.84 2.83 02/01/14 00 0.37 11.85 1.38 02/01/14 00 0.30 10.84</td> <td>Date Rainfall Temperatur Wind Humidity 02/01/01 00 0.00 4.25 4.28 50.38 02/01/01 00 0.00 4.25 4.28 50.38 02/01/02 00 0.00 9.04 3.50 36.96 02/01/03 00 0.00 6.87 1.42 53.46 02/01/03 00 0.00 1.26 2.98 66.608 02/01/05 00 0.00 1.162 2.86 41.71 02/01/05 00 0.00 -1.62 2.86 44.78 02/01/07 00 0.11 -2.31 50.3 57.04 02/01/09 00 0.00 -5.17 1.21 56.48 02/01/10 00 0.00 -5.17 1.21 56.48 02/01/12 00 0.00 2.20 1.75 65.32 02/01/12 00 0.00 2.26 0.65 1.88 02/01/12 00 0.03 1.044 2.83 68.96 02/01/14 00 0.33 1.48 51.23</td> <td>Date Rainfall Temperatur Wind Humidity Solar 02/01/01 00 0.00 -4.25 4.28 50.38 0.34 02/01/01 00 0.00 -4.25 4.28 50.38 0.34 02/01/02 00 0.00 -9.04 3.50 35.96 0.33 02/01/02 00 0.00 -9.04 3.50 35.96 0.33 02/01/03 00 0.00 -6.87 1.42 53.46 0.20 02/01/05 00 0.00 -1.02 2.86 41.71 0.34 02/01/07 00 0.10 -2.286 41.71 0.34 0.10 02/01/07 00 0.00 -5.47 1.43 50.75 0.34 02/01/07 00 0.00 -5.47 4.76 48.92 0.11 02/01/07 00 0.00 5.77 1.21 56.46 0.34 02/01/12 00 0.00 2.20 1.75 68.42 0.32 02/01/12 00 0.00 5.22 7.3 6.10</td>	Date Rainfall Temperatur Wind 02/01/01 00 0.00 -4.25 4.28 02/01/01 00 0.00 -4.25 4.28 02/01/02 00 0.00 -9.04 3.50 02/01/03 00 0.00 -6.87 1.42 02/01/03 00 0.00 -1.61 1.43 02/01/05 00 0.00 -1.61 1.43 02/01/07 00 0.11 -2.21 5.03 02/01/07 00 0.00 -5.17 1.21 02/01/07 00 0.00 -5.17 1.21 02/01/07 00 0.00 -5.17 1.21 02/01/07 00 0.00 -5.17 1.21 02/01/10 00 0.00 -5.20 1.75 02/01/12 00 0.00 2.20 1.75 02/01/12 00 0.00 2.96 0.65 02/01/14 00 0.33 10.84 2.83 02/01/14 00 0.37 11.85 1.38 02/01/14 00 0.30 10.84	Date Rainfall Temperatur Wind Humidity 02/01/01 00 0.00 4.25 4.28 50.38 02/01/01 00 0.00 4.25 4.28 50.38 02/01/02 00 0.00 9.04 3.50 36.96 02/01/03 00 0.00 6.87 1.42 53.46 02/01/03 00 0.00 1.26 2.98 66.608 02/01/05 00 0.00 1.162 2.86 41.71 02/01/05 00 0.00 -1.62 2.86 44.78 02/01/07 00 0.11 -2.31 50.3 57.04 02/01/09 00 0.00 -5.17 1.21 56.48 02/01/10 00 0.00 -5.17 1.21 56.48 02/01/12 00 0.00 2.20 1.75 65.32 02/01/12 00 0.00 2.26 0.65 1.88 02/01/12 00 0.03 1.044 2.83 68.96 02/01/14 00 0.33 1.48 51.23	Date Rainfall Temperatur Wind Humidity Solar 02/01/01 00 0.00 -4.25 4.28 50.38 0.34 02/01/01 00 0.00 -4.25 4.28 50.38 0.34 02/01/02 00 0.00 -9.04 3.50 35.96 0.33 02/01/02 00 0.00 -9.04 3.50 35.96 0.33 02/01/03 00 0.00 -6.87 1.42 53.46 0.20 02/01/05 00 0.00 -1.02 2.86 41.71 0.34 02/01/07 00 0.10 -2.286 41.71 0.34 0.10 02/01/07 00 0.00 -5.47 1.43 50.75 0.34 02/01/07 00 0.00 -5.47 4.76 48.92 0.11 02/01/07 00 0.00 5.77 1.21 56.46 0.34 02/01/12 00 0.00 2.20 1.75 68.42 0.32 02/01/12 00 0.00 5.22 7.3 6.10

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).

File C:\Users\jang\Desk	top₩pangyo_gis₩Climate_3.dat	Load
Interval Iday C	Start time 2002/01/01 00:00	Count 2191
Table Table 1	Decimal	•

Figure 3.11 Time series database information

C: 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.

Change int	erval	x
Currnet	1440	ОК
New	1440	Cancel
Method	Sum 💌	

Figure 3.12 Tab to change the time series data

Export : 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.

🗧 🔿 🕐 🚹 « ne	w > pangyo_gis >	V ひ Search par	ngyo_gis	م
Organize 🔻 New fold	er		8== ▼	?
🗄 Documents \land	Name	Date	Туре	
🖶 Downloads	Calibration	12/5/2017 6:56 PM	File folder	
👌 Music	CAT_TEST	8/23/2017 9:08 PM	File folder	
E Pictures	📙 graph	12/5/2017 3:19 PM	File folder	
📕 Videos	info	8/23/2017 9:09 PM	File folder	
Local Disk (C:)	p_dm30	8/23/2017 9:09 PM	File folder	
Local Disk (D:)	111111.txt	12/26/2016 6:14 PM	Text Document	
Local Dick (E)	<			>
File name: 1130	F			~
Save as type: Text F	iles(*.txt)			`
Save as type: Text P	iles(.DXL)			
 Hide Folders 		Save	Cancel	

Figure 3.13 Export data

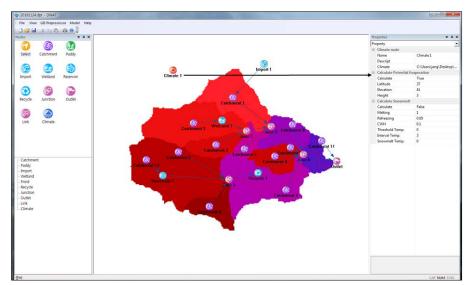
Save In addition, meteorological data imported into the 'Series View' may be revised and the revised data may be saved under another name.

3.2.3 Climate Node Entry

multiple climate stations.

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

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.

Pro	Properties 🔻 🕈 🗙		
Property -			
Ξ	Climate node		
	Name	Climate 1	
	Descript		
	Climate	C:\Users\jang\Desktop\p	
-	Calculate Potent	ial Evapotranspiration	
	Method	Penman-Monteith	
	Latitude	37	
	Elevation	41	
	Height	3	

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.

🕽 Open				×]	figure
← → × ↑ 📙 « nev	w > pangyo_gis >	マ ひ Search pa	ngyo_gis	P		
Organize 👻 New folde	er			?		
3D Objects ^	Name	Date	Туре	^		
Desktop	p_dm30	8/23/2017 9:09 PM	File folder			
🗄 Documents	Climate_3.dat	12/23/2016 5:13 PM	DAT File			
Downloads	Climate_5.dat	12/23/2016 7:39 PM	DAT File			
h Music	climate_0502.dat	5/2/2019 7:10 PM	DAT File			
Pictures	climate_day.dat	11/24/2016 4:06 PM	DAT File			
Videos	climate_day2.dat	11/24/2016 4:07 PM	DAT File			
-	obsdata_day.dat	12/26/2016 6:02 PM	DAT File			
Local Disk (C:)	obsdata_hour.dat	12/26/2016 6:12 PM	DAT File	~		
Local Disk (D:)	<	10/06/0016 6 10 001	B. 17 P.	>		
File <u>n</u> a	ame: Climate_5.dat	✓ Data files	(*.dat)	\sim		
		<u>O</u> pe	n Cance			

Figure 3.18 Loading meteorological data

Comment [HJ13]: Change

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.

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.

			Clim	Table Chart Multi ch Water ba Remove	alance			
Se ile	ries						Load	->
	Ľ						Load	
nter	val 1day	С	Start time 2	002/01/01 00	:00	Count	2191	
able	•		Y	Decimal 0.00	•	Save	Export	
	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	
5 6	02/01/06 00	0.00	-1.61	1.43	50.75	0.34	1.73	
5 6 7	02/01/06 00 02/01/07 00	0.00 0.11	-1.61 -2.31	1.43 5.03	50.75 57.04	0.34 0.10	1.73 2.55	
5 6 7 8	02/01/06 00 02/01/07 00 02/01/08 00	0.00 0.11 0.00	-1.61 -2.31 -6.45	1.43 5.03 4.76	50.75 57.04 48.92	0.34 0.10 0.13	1.73 2.55 2.83	
5 6 7 8 9	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00	0.00 0.11 0.00 0.00	-1.61 -2.31 -6.45 -5.17	1.43 5.03 4.76 1.21	50.75 57.04 48.92 56.46	0.34 0.10 0.13 0.34	1.73 2.55 2.83 1.38	
5 6 7 8 9	02/01/06 00 02/01/07 00 02/01/08 00	0.00 0.11 0.00	-1.61 -2.31 -6.45	1.43 5.03 4.76	50.75 57.04 48.92	0.34 0.10 0.13	1.73 2.55 2.83	
5 7 8 9 10	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00	0.00 0.11 0.00 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79	1.43 5.03 4.76 1.21 1.68	50.75 57.04 48.92 56.46 65.38	0.34 0.10 0.13 0.34 0.02	1.73 2.55 2.83 1.38 1.49	
5 7 8 9 10 11 12	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00 02/01/11 00	0.00 0.11 0.00 0.00 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20	1.43 5.03 4.76 1.21 1.68 1.75	50.75 57.04 48.92 56.46 65.38 69.42	0.34 0.10 0.13 0.34 0.02 0.32	1.73 2.55 2.83 1.38 1.49 1.42	
5 7 8 9 10 11 12 13	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00 02/01/11 00 02/01/12 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96	1.43 5.03 4.76 1.21 1.68 1.75 0.65	50.75 57.04 48.92 56.46 65.38 69.42 68.58	0.34 0.10 0.13 0.34 0.02 0.32 0.26	1.73 2.55 2.83 1.38 1.49 1.42 1.01	
5 7 8 9 10 11 12 13 14	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00 02/01/11 00 02/01/12 00 02/01/13 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96 6.52	1.43 5.03 4.76 1.21 1.68 1.75 0.65 2.73	50.75 57.04 48.92 56.46 65.38 69.42 68.58 65.13	0.34 0.10 0.13 0.34 0.02 0.32 0.26 0.10	1.73 2.55 2.83 1.38 1.49 1.42 1.01 1.94 1.91 0.88	
5 6 7 8 9 10 11 12 13 14 15	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00 02/01/11 00 02/01/12 00 02/01/13 00 02/01/14 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96 6.52 10.84	1.43 5.03 4.76 1.21 1.68 1.75 0.65 2.73 2.83	50.75 57.04 48.92 56.46 65.38 69.42 68.58 65.13 68.96	0.34 0.10 0.13 0.34 0.02 0.32 0.26 0.10 0.15	1.73 2.55 2.83 1.38 1.49 1.42 1.01 1.94 1.91	
5 6 7 8 9 10 11 12 13 14 15 16	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00 02/01/11 00 02/01/12 00 02/01/12 00 02/01/13 00 02/01/14 00 02/01/15 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96 6.52 10.84 11.85 7.48 1.89	1.43 5.03 4.76 1.21 1.68 1.75 0.65 2.73 2.83 1.38 2.73 1.38 2.73 1.92	50.75 57.04 48.92 56.46 65.38 69.42 68.58 65.13 68.96 91.29	0.34 0.10 0.33 0.34 0.02 0.32 0.26 0.10 0.15 0.00	1.73 2.55 2.83 1.38 1.49 1.42 1.01 1.94 1.91 0.88 1.25 0.94	
5 6 7 8	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00 02/01/12 00 02/01/12 00 02/01/13 00 02/01/14 00 02/01/15 00 02/01/16 00 02/01/17 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00 0.03 0.37 0.30 0.10 0.10	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96 6.52 10.84 11.85 7.48 1.89 0.59	1.43 5.03 4.76 1.21 1.68 1.75 0.65 2.73 2.83 1.38 2.73 1.92 1.64	50.75 57.04 48.92 56.46 65.38 65.38 65.42 68.58 65.13 68.96 91.29 81.79 84.54 80.67	0.34 0.10 0.13 0.34 0.22 0.26 0.10 0.15 0.00 0.00 0.00 0.00 0.00	1.73 2.55 2.83 1.38 1.49 1.42 1.01 1.94 1.91 0.88 1.25 0.94 1.00	
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	02/01/06 00 02/01/07 00 02/01/09 00 02/01/09 00 02/01/10 00 02/01/10 00 02/01/12 00 02/01/13 00 02/01/15 00 02/01/15 00 02/01/16 00 02/01/17 00 02/01/18 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00 0.03 0.37 0.30 0.10 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96 6.52 10.84 11.85 7.48 1.89 0.59 3.45	1.43 5.03 4.76 1.21 1.68 1.75 0.65 2.73 2.83 1.38 2.73 1.92 1.64 2.08	50.75 57.04 48.92 56.46 65.38 69.42 68.58 65.13 68.96 91.29 81.79 84.54 80.67 72.63	0.34 0.10 0.13 0.32 0.32 0.26 0.10 0.15 0.00 0.00 0.00 0.00 0.04 0.17	1.73 2.55 2.83 1.38 1.49 1.42 1.01 1.94 1.91 0.98 1.25 0.94 1.00 1.44	
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	02/01/06 00 02/01/07 00 02/01/08 00 02/01/09 00 02/01/10 00 02/01/10 00 02/01/13 00 02/01/13 00 02/01/14 00 02/01/15 00 02/01/16 00 02/01/18 00 02/01/18 00 02/01/18 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00 0.03 0.37 0.30 0.10 0.00 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96 6.52 10.84 11.85 7.48 1.89 0.59 3.45 0.85	1.43 5.03 4.76 1.21 1.68 1.75 0.65 2.73 2.83 1.38 2.73 1.92 1.64 2.08 0.94	50.75 57.04 48.92 56.46 65.38 69.42 68.58 65.13 68.96 91.29 81.79 84.54 80.67 72.63 87.29	0.34 0.10 0.13 0.34 0.02 0.26 0.10 0.15 0.00 0.00 0.00 0.00 0.04 0.04	1.73 2.55 2.83 1.38 1.49 1.49 1.42 1.01 1.94 1.91 0.88 1.25 0.94 1.00 1.44 0.73	
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	02/01/06 00 02/01/07 00 02/01/09 00 02/01/09 00 02/01/10 00 02/01/10 00 02/01/12 00 02/01/13 00 02/01/15 00 02/01/15 00 02/01/16 00 02/01/17 00 02/01/18 00	0.00 0.11 0.00 0.00 0.00 0.00 0.00 0.03 0.37 0.30 0.10 0.00 0.00	-1.61 -2.31 -6.45 -5.17 1.79 2.20 2.96 6.52 10.84 11.85 7.48 1.89 0.59 3.45	1.43 5.03 4.76 1.21 1.68 1.75 0.65 2.73 2.83 1.38 2.73 1.92 1.64 2.08	50.75 57.04 48.92 56.46 65.38 69.42 68.58 65.13 68.96 91.29 81.79 84.54 80.67 72.63	0.34 0.10 0.13 0.32 0.32 0.26 0.10 0.15 0.00 0.00 0.00 0.00 0.04 0.17	1.73 2.55 2.83 1.38 1.49 1.42 1.01 1.94 1.91 0.98 1.25 0.94 1.00 1.44	

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.

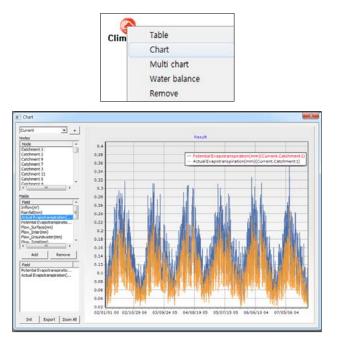


Figure 3.16 Graphical result of calculated evapotranspiration

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.

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	-

Table 3.4 Classification of land cover

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.

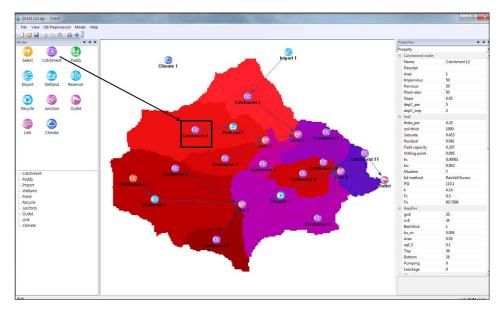


Figure 3.17 Catchment node entry

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.

Pro	operty		;
Pr	operty		•
	i ĝ↓ 🔳 🗲		
	Catchment node		
	Name	Catchment 1	
	Descript		
	Area	2.7117	
	Impervious	13	
	Pervious	87	
	Plant ratio	21	
	Slope	0.05	
	depC_per	5	
	depC_imp	2	

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 (km²).

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).

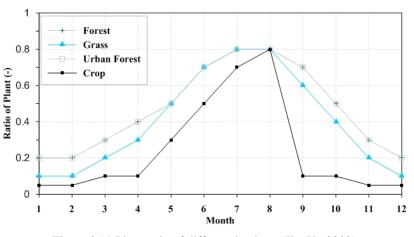


Figure 3.19 Plant ratio of different land use (Jia, Y., 2002)

DepC_imp: depression capacity in the impervious zone (generally 2nm) **DepC_per**: depression capacity in pervious zone (nm)

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 subcatchment node and clicking the 'Copy to' menu.

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Figure 3.29 Select menu to copy catchment characteristics

The following window will appear.

Copy to	
Catchment 1 Catchment 7 Catchment 3 Catchment 1 Catchment 5 Catchment 4 Catchment 8 Catchment 8 Catchment 6 Catchment 12	Select All Clear Switch Select
	OK Cancel

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).

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

Table 3.5 Surface soil input parameters by soil texture

* Rawls & Brakensiek Soil parameter estimates (1985).

3.4.1 Parameter Entry

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

Soil	
theta_per	0.25
soil thick	47.6402
Saturate	0.455007
Residual	0.0664587
Field capacity	0.285145
Wilting point	0.189706
ks	0.00181713
ksi	0.0181713
Mualem	7
Inf method	Rainfall Excess
PSI	13.9638
k	4.14
Fc	9.5
Fo	80,7998

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).

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).

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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 $0.1 \times 10-4 - 0.7 \times 10-1$ (mm/s, refer to Table 3.5).

ksi: This is the horizontal hydraulic conductivity in a range of $0.1 \times 10-3 - 0.7$ (mm/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.

-	Soil	
	theta_per	0.25
	soil thick	47.6402
	Saturate	0.455007
	Residual	0.0664587
	Field capacity	0.285145
	Wilting point	0.189706
	ks	0.00181713
	ksi	0.0181713
	Mualem	7
	Inf method	Rainfall Excess 🔹
	PSI	Rainfall Excess
	k	Green&Ampt
	Fc	Horton
	Fo	80.7998

Figure 3.32 Infiltration method selection

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

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)				

 \mathbf{k} : Decay constant for soil used by Horton method (generally 4.14 hour⁻¹)

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

Fo : Maximum infiltration capacity by Horton method (mm/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)	(1111/111)
	Sandy Soil	127.0
	Loam Soil	76.2
	Clay Soil	25.4
B. DRY soils (with dense veg	getation)	
	Sandy Soil	254.0
	Loam Soil	152.4
	Clay Soil	50.8
C. MOIST soils		
Soils which have drained by not dried out	Sandy Soil	84.7
Soils close to saturation	Loam Soil	Choose value close to minimum infiltration rate
Soils which have partially dri out	^{ed} 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.

Aquifer				
gwE	35			
rivE	34			
Bed thick	1			
ku_riv	0.004			
Area	0.03			
aqf_S	0.1			
Тор	36			
Bottom	26			
Pumping	0			
Leackage	0.15			

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 (mm/s, the range of 1.0×10^{-4} - 1.0×10^{-6} is generally used)

Area: Riverbed area (km²).

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

Aquifer	
gwE	35
rivE	34
Bed thick	1
ku_riv	0.004
Area	0.03
aqf_S	0.1
Тор	36
Bottom	26
Pumping	0
Leackage	0.15

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 $1.0 \times 10^{-2} - 1.0 \times 10^{-1}$ 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 (m³/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

Climate	
 Evapotranspiration 	n
Method	Monthly Coefficient 🔹
Jan	Monthly Coefficient
Feb	Leaf Area Index
Mar	FAO56
Apr	0.7
May	0.7
Jun	0.7
Jul	0.7
Aug	0.7
Sep	0.7
Oct	0.7
Nov	0.7
Dec	0.7

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

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

🗆 CI	imate	
-	Evaporate	
	Method	Monthly Coefficient 🔹
	Jan	0.7
	Feb	0.7
	Mar	0.7
	Apr	0.7
	May	0.7
	Jun	0.7
	Jul	0.7
	Aug	0.7
	Sep	0.7
	Oct	0.7
	Nov	0.7
	Dec	0.7

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.

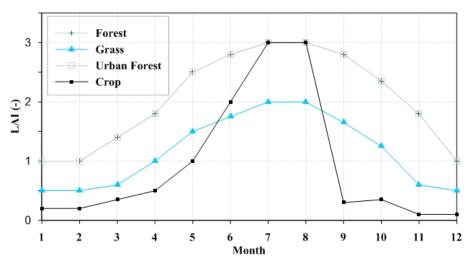


Figure 3.37 Leaf area indexes of different land use (Jia, Y., 2002)

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.

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Figure 3.38 Thiessen weight coefficient allocation

3.8 Snow melt Parameter Entry

-	Calculate Snowme	lt	
	Calculate	False	
	Melting	0.5	
	Refreezing	0.05	
	CWH	0.1	-
	Threshold Temp.	0	=
	Interval Temp.	0	
	Snowmelt Temp.	0	

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 (°C)

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

Snowmelt Temp.: Threshold temperature for snowmelt (°C)

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.

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-	G١	V Move		
	Co	nnect	Not use	
		Use Auifer slop		
		Use slope	False	
		Auifer slope	0.05	
	No	de length	1000	
	Co	nj. length	3000	
	Kg	w	5e-007	-

Figure 3.40 Parameters for groundwater movement

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

-	GV	V Move		
	Co	nnect	Not use	
Co			Catchment 1 Catchment 2 Catchment 9 Catchment 7 Catchment 7 Catchment 11 Catchment 5 Catchment 4 Catchment 8 Catchment 8 Catchment 6	-

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(mn/s). A value in a range of $1.0 \times 10^{-6} - 1.0 \times 10^{-4}$ 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).

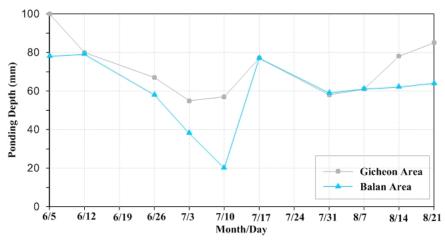


Figure 3.42 Monthly ponding depth in Korean paddy field

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.

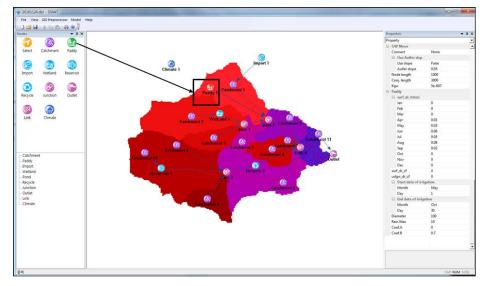


Figure 3.43 Paddy nodes Parameter Entry

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.

🖃 Pa	ddy		
-	surf_dr_ht(m)		
	Jan	0	
	Feb	0	
	Mar	0	
	Apr	0.01	
	May	0.03	
	Jun	0.06	
	Jul	0.05	
	Aug	0.08	
	Sep	0.02	
	Oct	0	
	Nov	0	
	Dec	0	
su	rf_dr_cf	4.000000	=
=	Start date of irrigat	ion	
	Month	May	
	Day	1	
=	End date of irrigation	'n	
	Month	Oct	
	Day	30	
			Ŧ

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.

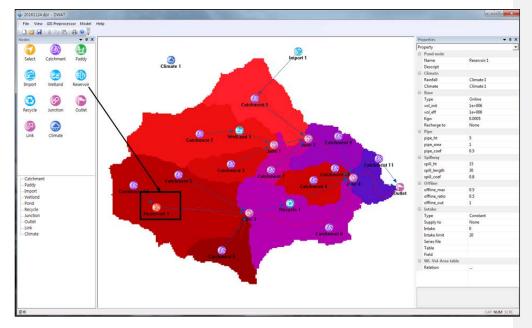


Figure 3.45 Reservoir Node Parameters Entry

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 (M^{3})

vol_eff: Effective storage (M^3)

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

_	-	es							×
_	operty								•
-	Pond node								
	Nam	ie			Reser	voir 1			
	Desc	ript							
-	Clim	ate							
	Rain	fall			Clima	te 1			
	Clim	ate			Climate 1				
-	Base	3							
	vol_i	nit			1e+06	5			
	vol	eff			1e+06	5			
	Kgw				0.000	5			
		arge t	0		None				
-	Pipe	-							
	pipe				5				
		area			1				
		coef			0.5				
	Spill	_							
	spill_ht			15					
		lengt	h		30				
		coef			0.8				
	Inta								
	Туре				Const	tant			
		oly to			None				
	Intak	-			0				
	Intak	ce limi	t		20				
	Serie	s file							
	Tabl	e							
	Field								
-	WL-	Vol-A	rea tab	ole					
	Relat	tion			Stage	-Stora	ge-Are	a relat	i
					_		- -		
VL-V	ol-Area	relation							×
		1	2	3	4	5	6	7	
V	VL(m)	0.00	2.50	3.00	3.50	4.00	4.50	5.00	5.5
	DL(m3)	0.00	0.00	6000.00		47000.00			
	EA(m2)	0.00	0.00	22500.00	42500.00	60000.00	77500.00	100000.0	
•		_							•

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.

Base	
vol_init	1e+06
vol_eff	1e+06
Kgw	0.0005
Recharge to	None 🔹
Pipe	None
pipe_ht	Catchment 1
pipe_area	Catchment 2 Catchment 7
pipe_coef	Catchment 3
Spillway	Catchment 11
spill_ht	Catchment 5
spill_length	Catchment 4 Catchment 10
spill_coef	Catchment 8
Intake	Catchment 6
Туре	Catchment 12
Supply to	Paddy 1 None
Intake	0

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).

Intake					
Туре	Constant 🔹				
Supply to	Constant				
Intake	Series				
Intake limit	20				
Series file					
Table					
Field					

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*

	1	2	3	4	5	6	7	
WL(m)	0.00	2.50	3.00	3.50	4.00	4.50	5.00	5.
VOL(m3)	0.00	0.00	6000.00	22000.00	47000.00	82000.00	125000.00	18
AREA(m2)	0.00	0.00	22500.00	42500.00	60000.00	77500.00	100000.00	13

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.

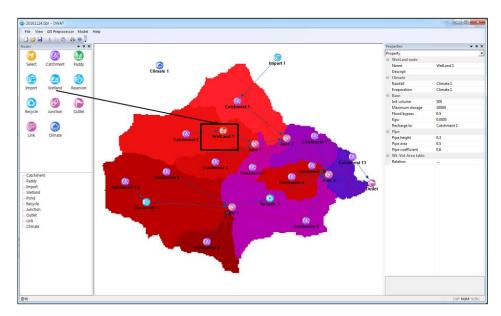


Figure 3.50 Wetland Node Main Window

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

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Pro	Properties 👻 🕈 🗙					
Pro	operty	•				
-	Wetland node					
	Name	WetLand 1				
	Descript					
-	Climate					
	Rainfall	Climate 1				
	Climate	Climate 1				
-	Base					
	Init volume	500				
	Maximum storage	10000				
	Flood bypass	0.5				
	Kgw	0.0005				
	Recharge to	Catchment 1				
-	Pipe					
	Pipe height	0.3				
	Pipe area	0.5				
	Pipe coefficient	0.6				
	WL-Vol-Area table					
	Relation	Stage-Storage-Area relati				

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 (m³)

Maximum storage: Maximum storage (m³)

Flood_bypass: High flow bypass during flood (m³/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.

- Base	
Init volume	10000
Maximum storage	100000
Flood bypass	1
Kgw	0.0005
Recharge to	Catchment 9
Pipe	Catchment 1
Pipe height	Catchment 2
Pipe area	Catchment 9
Pipe coefficient	Catchment 7 Catchment 3
	Catchment 11
	Catchment 5
	Catchment 4
	Catchment 10
	Catchment 8
	Catchment 6

Figure 3.52 Wetland recharge to adjacent sub-catchment

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pipe_height: Height of outlet pipe (m)

pipe_area: Area of the outlet pipe (m²)

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

	1	2	3	4	5	6	7	
WL(m)	0.10	1.00	2.00	3.00				Τ
VOL(m3)	100.00	3000.00	8000.00	10000.00				T
AREA(m2)	100.00	3000.00	5000.00	8000.00				t
								T

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 from the intake restriction ratios.

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.

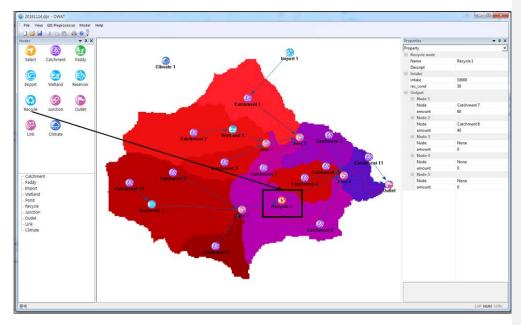


Figure 3.54 Recycle node in the main interface

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

∋≕ A	rty		_
	1 🛛 🗲		-
	ecycle node	Denvela 1	
		Recycle 1	
∃ In	escript		
	take	10000	
	c_cond	5e+007	
	itput	JE+007	
	Node 1		
	Node	Catchment 2	
	amount	20	
	Node 2	20	
_	Node	Catchment 3	
	amount	20	
	Node 3		
	Node	Catchment 4	
	amount	20	
	Node 4		
	Node	Catchment 6	
	amount	20	_
	Node 5		
	Node	Catchment 5	
	amount	20	
intak	P		-

Figure 3.55 Parameters for recycle

Name: This indicates Recycle node name.

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Descript: Information about the Recycle node can be entered.

Intake: Total intake volume (m³)

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.

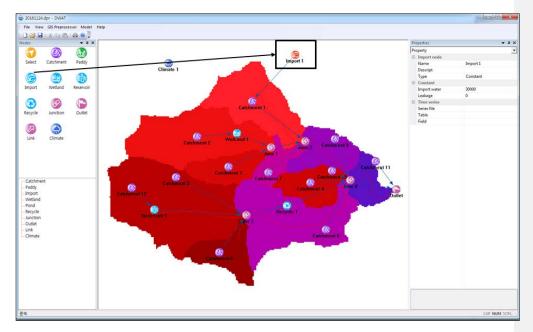


Figure 3.56 Import node in the main interface

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

<u>⊉</u> ↓ 🔳 🗲	
Import node	
Name	Import 1
Descript	
Туре	Constant 🔹
Constant	
mport water	10000
Leakage	0
Time series	
Series file	
Table	
Field	
	Name Descript Type Constant mport water .eakage Time series Series file Fable

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)

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.

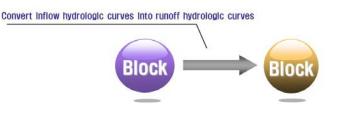


Figure 3.58 Channel routing link

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

Properties 🗸 🗸					
Pro	operty	•			
-	Link node				
	Name	Link 6			
	Descript				
	Routing	No routing			
-	Muskngum				
	DT	1			
	Х	0.25			
	Y	1.5			
-	Muskingum Cunge				
	Channel length	1000			
	Channel slope	0.005			
	Top width	15			
	Bottom width	10			
	Manning N	0.03			
-	Kinematic				
	Channel length	1000			
	Channel slope	0.005			
	Top width	15			
	Bottom width	10			
	Manning N	0.03			
	Channel depth	5			

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.

Link node				
Name	Link 19			
Descript				
Routing	Muskingum	•		
Muskngum				
DT	1			
Х	0.25			
V	15			

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

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```



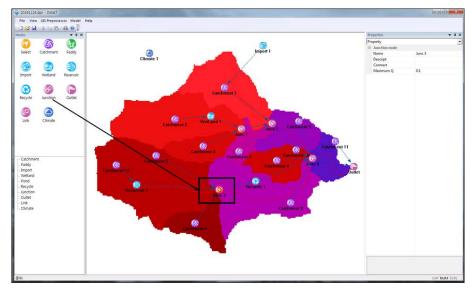


Figure 3.63 Junction node in the main interface

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

Property		
8∎ 2↓ 🔳 🗲		
Junction node		
Name	Junc 5	
Descript		
Connect	Catchment 8	-
Maximum Q	0.1	
Connect		

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 (m³/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.

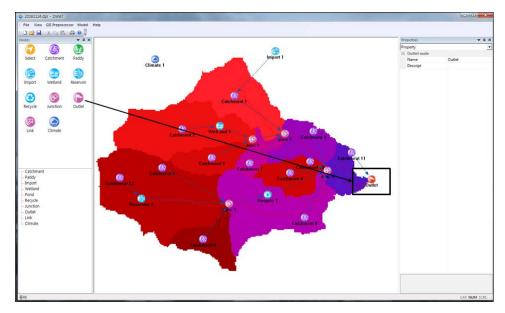


Figure 3.65 Outlet node in the main interface

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

Property		-
8∎ ⊉↓ 🔳 🗲		
Outlet node		-
Name	Outlet	
Descript		-

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:

Simulation setup	—X
Title	
Term 2002-01-01 🗐 🗸 ~ 2007-12-31	
Interva 86400 (sec)	
OK Cancel	

Figure 4.2 Model simulation setup

Title: This indicates a simulation title.

Term \checkmark : 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

	Si	imula	atior	n setu	qu						×	
		Title	Γ									
		Term	n [10/16	/2010	5	•	~	10/	16/201	16 👻]
•	•	Octo	ber,	201	5	F	ec)	L	оор	10	÷	
		Tue			Fri	Sat			ance	É L		
25	26	27	28	29	30	1			ance			
2	3	4	5	6	7	8						
9	10	11	12	13	14	15	_	_	_	_		
(16)	17	18	19	20	21	22						
23	24	25	26	27	28	29						
30	31	1	2	3	4	5						
D	Тос	lay:	10/1	16/2	016							

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.

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.

tun model			×
Complete calcul	lation		
	Run	Close	

Figure 4.4 Completed Model simulation

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

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CHAPTER 5: ANALYSIS OF RESULTS

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				
	Inflow (m [°])	Inflow volume				
	Downstream Outflow (m ³)	Mainstream discharge that did not flow into the reservoir				
	Intake (m ³)	Intake volume				
Reservoir	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				
	Inflow (m ³)	Inflow volume				
	Bypass Volume (m ³)	High flow bypass during flood season				
	Evaporation Water surface (mm)	Evaporation from the water surface				
Wetland	Spillway Outflow (m ³)	Overflow from spillway				
wettallu	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				
	Inflow (m ³)	Inflow volume				
Recycle	Intake (m ³)	Intake volume				
Recycle	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

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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.

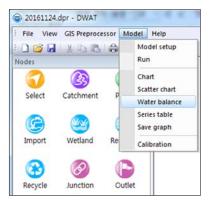


Figure 5.1 Water balance main interface

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.

By year C B	ly node		2002	<u>-</u>	Select	utlet 💌		
	Average	Catchment 1	2002 2003	Catchment 9	Catchment 7	Catchment 3	Catchment 11	Catchmen
Rainfall	1231.7	1231	2004	1231.7	1231.7	1231.7	1231.7	12
Inflow	0.0	C	2005	0.0	0.0	0.0	0.0	
ET	131.2		2007	93.9	51.3	237.0	56.9	1
ET_imp	19.7	18.	7 1.4	53.1	18.7	0.0	33.0	
ET_per	111.4	43.	7 255.6	40.8	32.6	237.0	23.9	
Runoff	975.1	1022.	9 933.4	954.6	875.3	937.2	697.0	10
Surface	176.6	141.	4 126.1	402.5	141.4	118.0	250.2	1
Interflow	271.2	536.	2 241.9	80.2	264.0	239.9	136.0	2
Groundwater	527.3	345.	3 565.4	471.9	469.9	579.4	310.8	e
Recharge	439.0	247.	7 474.6	372.8	369.9	479.7	210.9	E
Soil	-2.46357	-2.3877	6 -3.42949	-1.01739	-1.47902	-2.92595	-1.25662	-3.0
GW-Storage	-88.31232	-97.5605	5 -90.72383	-99.13438	-99.92149	-99.67852	-99.92617	-65.3
MassBalance	216.18462	246.3801	6 135.49123	283.40039	406.49600	160.12206	578.97076	135.5

Figure 5.2 Annual water balance results

By node: This is a tab to control output formats. Analysis results are displayed by subcatchment. 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.

By year 🔶 B	ly node	1	Catchment 1 💌		Select Outle	t <u>-</u>	
	Average		Catchment 1	2004	2005	2006	2007
Rainfall	1346.5	12310	atchment 9	1217.0	1427.7	1362.7	1325.0
nflow	0.0		Catchment 7 Catchment 3	0.0	0.0	0.0	0.0
ET	54.4		atchment 11	48.5	43.0	43.7	71.8
ET_imp	20.0	180	atchment 4	18.8	18.5	17.9	22.8
ET_per	34.3	430	Catchment 10 Catchment 8	29.7	24.5	25.7	49.0
Runoff	1039.3	1022	atchment 6	916.4	1103.2	1045.5	990.1
Surface	155.0	141.4	4 173.5	139.4	167.1	159.2	149.5
Interflow	581.9	536.2	699.4	499.2	593.4	607.6	555.5
Groundwater	302.4	345.3	3 284.9	277.8	342.8	278.7	285.1
Recharge	286.4	247.7	7 284.5	284.5	338.1	283.5	280.2
Soil	-0.46505	-2.38776	-2.39868	2.07700	0.66873	-3.81773	3.06816
GW-Storage	-16.03515	-97.56055	-0.39688	6.68672	-4.76367	4.79805	-4.97461
MassBalance	269.29692	246.38016	302.92104	243.40207	285.53765	272.53837	265.00221

Figure 5.3 Annual water balance results of sub-catchment

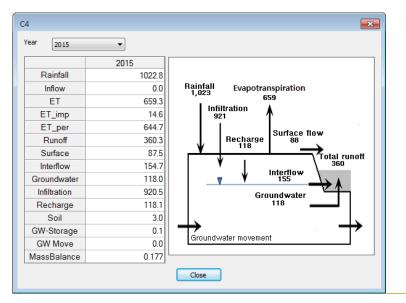
Select: This is to select the outlets of a catchment. If the catchment has many outlets, the results on the water balance may be identified for each catchment outlet.

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.



Comment [j22]: Review 54

Figure 5.5 Water balance results for the selected catchment

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.

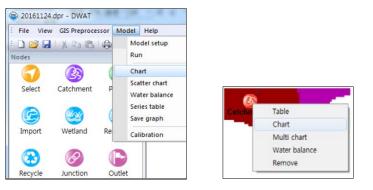


Figure 5.6 Graphical results main menu

A Chart result window will appear.

urrent +	Result
	- Color
atchment 1 E	
atchment 2	
Catchment 9 Catchment 7	
atchment 7 atchment 3	
Catchment 11 Catchment 5	
atchment 5	
atchment 4	
And a second sec	
eld	
Tield A	
nflow(m ⁱ)	
lainfall(mm)	
actual Evapotranspiration(
otential Evapotranspiratio	
low_Surface(mm)	
low_Inter(mm)	
low Groundwater(mm)	
low Total(mm)	
(m +	
Add Remove	
Field	

Figure 5.7 Graphical results window

Current 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.





: This attribute window shows the information of each node, junction, link

and outlet of the relevant project.



SurDrainage Calver(mm) : 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

Comment [j23]: Review 52 59 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.

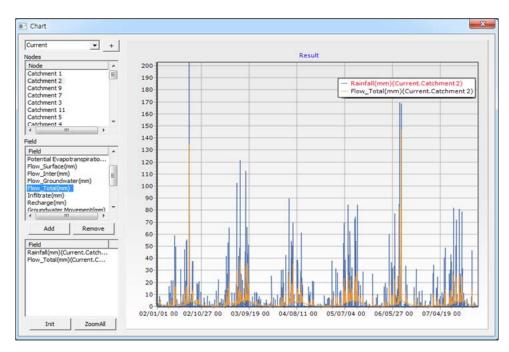


Figure 5.8 Graphical results of rainfall and total flow on the same axis

Field Raintall(mm)(Current Paddy 1) Flow_Total(mm)(Current Pad	I				
	Remove	Init	Zoom All	. 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.

DWAT-User's Manual v1.1

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tchment 1	330			T YNN PT			10
tchment 2							20
tchment 9	320						
tchment 7	310	-	1. 1			- Rainfall(mm	(Current.Catchment 2)
tchment 3	300					- Flow_Totai(n	nm)(Current.Catchment 2)
tchment 11	290						50
tchment 5	280		-				60
III F	100000						70
	270						80
ls	260						90
* bł	250						100
ow(m')	240						110
nfall(mm) 🗉	230						120
ual Evapotranspiration(220						
w_Surface(mm)	210						130
w_Inter(mm)							140
w_Groundwater(mm)	200	_					150
w Total(mm)	190		 				160
	180		 		2		170
Add Remove	170			-			180
	160						190
łd	150						200
infall(mm)(Current.Catch							210
w_Total(mm)(Current.C	140						
	130						220
	120						230
	110						240
	100						250
	90	-					260
	80						270
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Init Export Zoom All	70						290
	60						
	50						300
	40						310
	30						320
							330
	20						340
	10						350

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

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

port method	
Data to clipboard	OK
C Data to file C Graph to clipboard	Cancel
Graph to file	

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

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	2)	atchment 2), Potenti	al Evapotranspiration(mm)(Curr	ent.Catchment		
	2002/01/01 00, 0, 0.13266					
	2002/01/01 01, 0, 0.13266					
	2002/01/01 02, 0, 0.13266					
	2002/01/01 03, 0, 0.13266					
	2002/01/01 04, 0, 0.13266					
	2002/01/01 05, 0, 0.13266					
	2002/01/01 06, 0, 0.13266					
	2002/01/01 07, 0, 0.13266					
	2002/01/01 08, 0, 0.13266					
	2002/01/01 09, 0, 0.13266					
	2002/01/01 10, 0, 0.13266					
	2002/01/01 11, 0, 0.13266					
	2002/01/01 12, 0, 0.13266					
	2002/01/01 13, 0, 0.13266					
	2002/01/01 14, 0, 0.13266					
	2002/01/01 15, 0, 0.13266					

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).

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h Music	20161005.txt	10/5/2016 10:	21 AM	Text Document	- 1
Pictures	20161006.txt	10/23/2016 3:	06 PM	Text Document	
Videos	20161007.txt	10/14/2016 3:	02 PM	Text Document	
	20161011.txt	10/11/2016 10):57 AM	Text Document	
Local Disk (C:)	20161011_2.txt	10/13/2016 7:	33 PM	Text Document	
Local Disk (D:)	20161023 +++	10/23/2016 6	RO DM	Text Document	
Local Dick (E)	<				>
File <u>n</u> ame: Rain	_EVT				~
Save as type: Tab	separated file(*.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

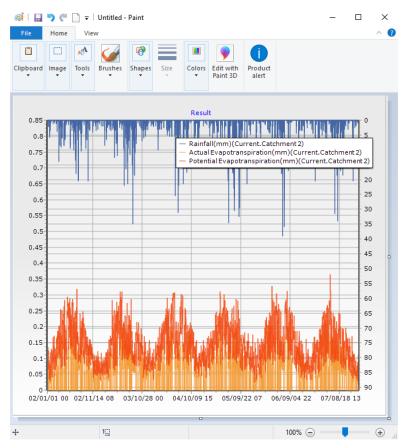


Figure 5.13 Export results to any image formats

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

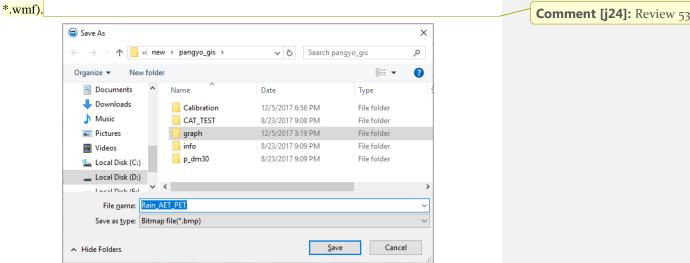


Figure 5.14 Export results to image formats

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

Flow_Total(mm)(Set main-axis
	Set sub-axis(normal)
	Set sub-axis(Reverse)
	Scale
	Remove

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.

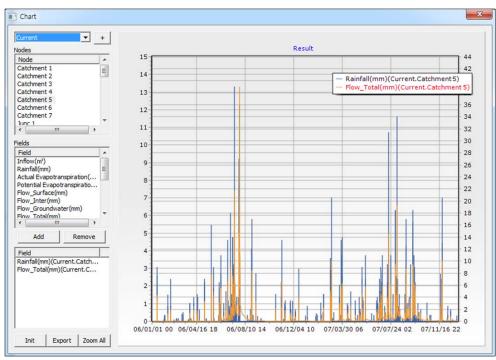


Figure 5.16 Graphical result on the same axis

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.

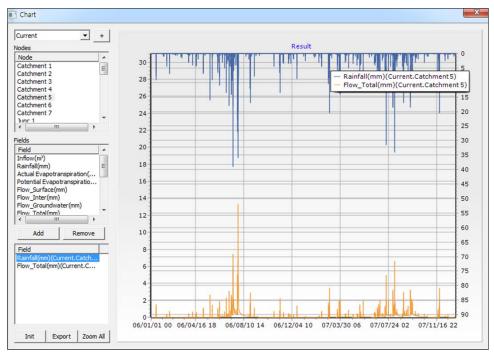


Figure 5.17 Graphical result on the subsidiary axis.

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.

nput scale	×
Scale	10
ОК	Cancel

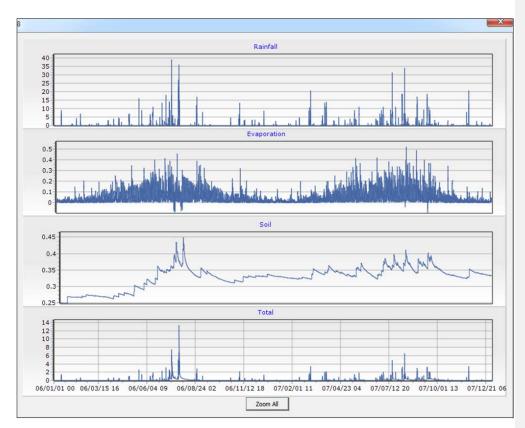
Figure 5.18 Graphical scale adjust

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.

Catche	Table
	Chart
	Multi chart
	Water balance
	Remove

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.

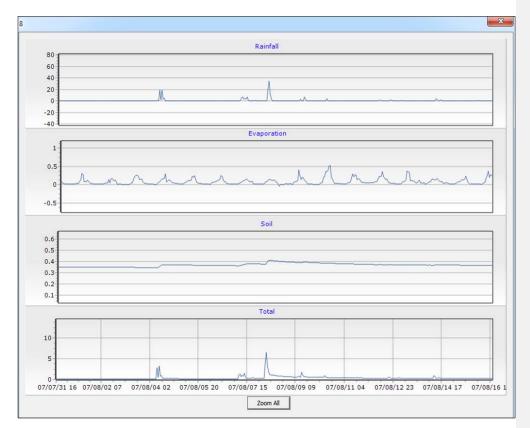


Figure 5.21 Multi chart result zoom out view

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.

. 1		_					Load							
nterv	al 1day		Start time 20	02/01/01 00	:00	Count	2191							
able			Ψ.	Decima	0.00	-								
Catch	ment 8													
	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			0.00	0.00		0.16	
7	02/01/07 00	0.00	2.60	0.00	2.53	0.14	0.00	2.32		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	2.26		0.00	0.00		0.18	
	02/01/09 00	0.00	0.00	0.03	1.72		0.00	2.19	2.19	0.00	0.00		0.18	
	02/01/10 00	0.00	0.00	0.00	1.35		0.00	2.13	2.13	0.00	0.00		0.18	
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	
	02/01/12 00	0.00	0.00	0.00	1.54	0.00	0.00	2.02		0.00	0.00		0.18	
	02/01/13 00	0.00	0.00	0.00	2.00		0.00			0.00	0.00		0.18	
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	

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.

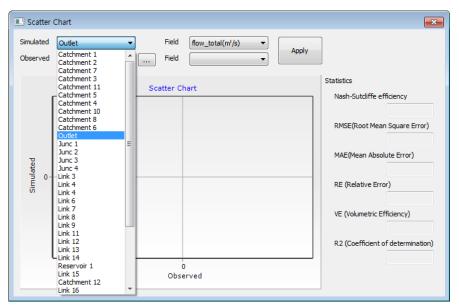


Figure 5.25 Scatter chart window

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).

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☆ 즐겨찾기	*	이름		날짜	^
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	🌉 바탕 화면	👪 Climate_5.dat		2016-12-23 오후 7:39	
💷 최근 위치		👪 climate_0502.dat		2019-05-02 오후 7:10	
	=	👪 climate_day.dat		2016-11-24 오후 4:06	
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📑 문서		🚮 obsdata_day.dat		2016-12-26 오후 6:02	
😸 비디오		🚮 obsdata_hour.dat		2016-12-26 오후 6:12	
) 사진		🚮 obsdata_hour_2.dat		2016-12-26 오후 6:18	
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Figure 5.26 Import observed streamflow data

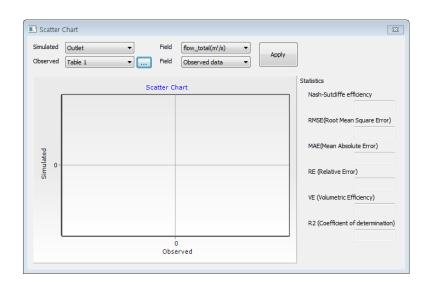


Figure 5.27 Observed streamflow data preparing

Apply: 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.

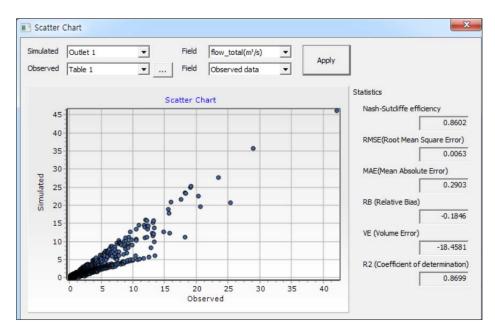


Figure 5.28 Scatter chart statistical values

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

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file to the DWAT data file.

Create series			×
Time step	🔘 Day	Period 2019-05-03 00:0 🔻	~ 2019-05-03 00:0 🔻
Month User define Observed data	© Year (min) 2191	Field Date Obte Rainfall Cevaporation Humidity Solar Wind Temperature(Min) Temperature(Min) Temperature(Max) User defined Observed data	Add Date format
File header Series file	S	/e Close	•

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.

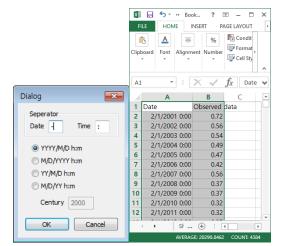


Figure 5.30 Select separator and date format

Fime step		Period	2019-05-03 00:0 - 2019-05-03 00:0 -
Hour	🔘 Day		
Month	Year	Field	Observed data
🔘 User define	(min)		
Observed data	2191		Clear Remove Date format
	Date	Observed	
1	2002-01-01 0:00	0.7200	0
2	2002-01-02 0:00	0.5600	
3	2002-01-03 0:00	0.5400	0
4	2002-01-04 0:00	0.4900	-
5	2002-01-05 0:00	0.4700	-
6	2002-01-06 0:00	0.4200	
7	2002-01-07 0:00	0.5600	
8	2002-01-08 0:00	0.3700	-
9	2002-01-09 0:00	0.3700	-
10	2002-01-10 0:00	0.3200	
11	2002-01-11 0:00	0.3200	
12	2002-01-12 0:00	0.2700	
13	2002-01-13 0:00	0.2800	
14	2002-01-14 0:00	0.2500	
15	2002-01-15 0:00	0.6300	
16	2002-01-16 0:00	0.5100	
17	2002-01-17 0-00	0.3900	n
e header Observ	ved_data		
ries file D:₩ne	ew₩pangyo_gis₩Ob	served_strea	amflow.dat

Figure 5.31 Creating observed database

File header: Enter the file description.

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

Time step		Period	2019-05-03 00:	0 - ~ 2	019-05-03 00:0
Hour	🔘 Day				
Month	Year	Field	Observed data	•	▼ Add
O User define	(min)				
Observed data	2191		Clear	Remove	Date forma
	Date	Observed			
1	2002-01-01 0:00	0.7200)		
2	2002-01-02 0:00	0.5600	1		
3	2002-01-03 C DW	AT	×		
4	2002-01-04 0				
5	2002-01-05 0				
6	2002-01-06 0	A -			
7	2002-01-07 0	Con Con	nplete		
8	2002-01-08 0				
9	2002-01-09 0				
10	2002-01-10 0	_			
11	2002-01-11 0		확인		
12	2002-01-120	_			
13	2002-01-13 0:00	0.2800	,		
14	2002-01-14 0:00	0.2500)		
15	2002-01-15 0:00	0.6300)		
16	2002-01-16 0:00	0.5100)		
17	2002-01-17 0:00	0.3900	1		
					P.
e header Observ	ved_data				
eries file D:₩ne	ew₩pangyo_gis₩Ob	served_strea	amflow.dat		

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.

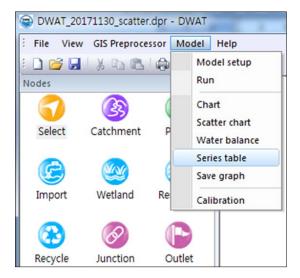


Figure 5.33 Select series table menu

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

Vodes		Fields	
Nodes	•	Field	
Catchment 1		Inflow(m ³)	1
Catchment 2	E	Rainfall(mm)	
Catchment 3		Actual Evapotranspiration(mm)	:
Catchment 4		Potential Evapotranspiration(mm)	
Catchment 5		Flow_Surface(mm)	
Catchment 6		Flow_Inter(mm)	
Catchment 7		Flow_Groundwater(mm)	
Junc 1		Flow_Total(mm)	
June 2		Infiltrate(mm)	
June 3	*	Recharge(mm)	

Figure 5.34 Selected time series results

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

	A	В	C	
1	Date	Catchm	ent 1	
2	Date	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 subcatchment (The sub-catchment node can be selected from the left side, and the hydrological component per node can be selected from the right side)

lodes		Fields	
Nodes	A	Field	
Catchment 1		Inflow(m ³)	ſ
Catchment 2	E	Rainfall(mm)	
Catchment 3		Actual Evapotranspiration(mm)	:
Catchment 4		Potential Evapotranspiration(mm)	
Catchment 5		Flow_Surface(mm)	
Catchment 6		Flow_Inter(mm)	
Catchment 7		Flow_Groundwater(mm)	
Junc 1		Flow_Total(mm)	
Junc 2		Infiltrate(mm)	
June 3		Recharge(mm)	

Figure 5.36 Select graphical results

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

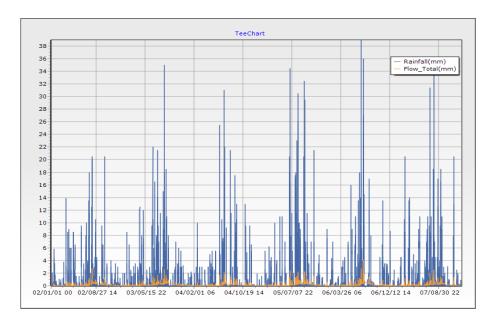


Figure 5.37 Graphical results view

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 parameter estimation range.

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- 3. Once the iteration is complete, the calibration tool reports the optimal parameters in the result file (*.par).
- 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

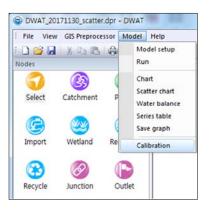


Figure 5.38 Model calibration menu

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.

Observation					·		•			
imulate Term	2006-0	01-01	•~	2008-01-01 👻	Calibrate	Term 2006-0	• • • • • •	~ 2008-0	01-01	Ŧ
Parameter	Result	Table	Graph	Scatter						
			D	escription	Unit	Default	Min	Max	Use	
Soil de	pth	Soil de	pth		m	1	1	5	V	l.
θs		Satura	ted soil	moisture	-	0.453	0.4	0.6	V	1
Ks		θs of soil(vertical)			mm/s	0.00061	1e-005	0.07	V	
Ksi		θs of soil(lateral)			mm/s	0.002	0.0001	0.7	¥	
Rivert	bed	River bed thickness			m	1	0.1	1	V	
Krvbe	ed	θs of ri	ver bec		mm/s	0.004	1e-006	0.01	Ľ	
S		Storag	e coeff	cient	-	0.1	0.01	0.1	V	

Figure 5.39 Calibration tool in DWAT

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

Node	Catchment 1	•	Output field	Flow_Total(mm)	• 「	Convert cms to m	m(Observed)
Name							
Observation						•	-
Simulate Tern	2006-01-01	▼ ~ 2008	3-01-01 •	Calibrate Term	2006-01-01	▼ ~ 2008-03	1-01 💌

Figure 5.40 Model calibration period

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

Output field	Flow_Total(mm) -
	Flow_Total(mm) Soil Moisture Content
	Groundwater Elevation(EL.m) Flow_Total_Routing(cms)

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.

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 (mm) units for annual water balance calculation.

Name D:\mew\mew\meangyo_gis\Calibration\Cal_01 : 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.

Observation D:\movembracktrianskippingyo_gis\Calibration\condotsdata_hour		Table 1	-	Observed data	•	
---------------------------------------------------------------------------	--	---------	---	---------------	---	--

: 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.

Simulate Term 2006-01-01 • 2008-01-01 • Calibrate Term 2007-01-01 • 2007-12-31 • 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	V
Ks	θs of soil(vertical)	mm/s	0.00061	1e-005	0.07	V
Ksi	θs of soil(lateral)	mm/s	0.002	0.0001	0.7	V
River bed	River bed thickness	m	1	0.1	1	V
Krvbed	θs of river bed	mm/s	0.004	1e-006	0.01	Ľ
S	Storage coefficient	-	0.1	0.01	0.1	V
3	Storage coencient		0.1	0.01	0.1	
3	Storage coentcient		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.

Comment [j26]: Review 63

📕 🗹 📑 🗸 🗸 I Cali	bration				– 🗆 X
File Home	Share View				~ 🕐
Pin to Quick Copy Pa access	Cut Copy path Paste shortcut	Move to • Delete •	► New folder	Properties	Select all Select none Invert selection
Clipb	ooard	Organize	New	Open	Select
← → · ↑ 📙	≪ Local Disk (D:) → ne	w > pangyo_gis > Calibratio	n	✓ Ö Search Cal	ibration 🔎
				🖣 🗸 🖌 🕇	X 🗸 🖃 🌍
a OneDrive	^ Name	~	Date modified	а Туре	Size
This PC	Cal_01.ins		12/5/2017 7:4	0 PM INS File	136 KB
	Cal_01.pst		12/5/2017 7:4	0 PM Outlook Data F	ile 228 KB
🗊 3D Objects	Cal_01.tpl		12/5/2017 7:4	0 PM TPL File	2 KB
53 items 3 items se	elected 365 KB		40/5/0047.0.0		
3 items selected (Disk fre	ee space: 3.53 TB)			365 KB	Computer

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.

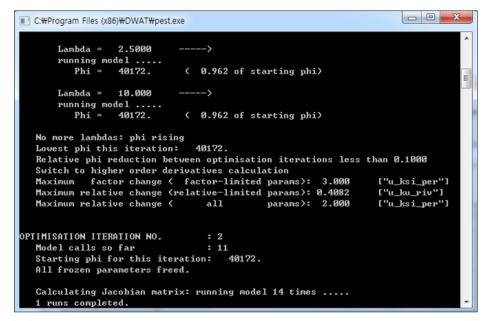


Figure 5.44 Model iterative process

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.

ile Home	Share	View															^
to Quick Copy	Dacte	从 Cut ₩ Copy path Paste shortcut		Copy to V	X Delete	■ Rename	New folder	Pasy Easy		Properties	 → Open ▼ → Edit → History 	Sele	ct nor				
Cli	pboard			Org	anize			New		0	pen	S	elect				
· · · •	> Th	is PC → Local Disk	(D:) > ne	w >	pangyo_	gis → C	alibration					~ č		Search	Calibratio	n	,
												— •	V		<u>п</u> 🗙		
			~									<u> </u>		•		· •	_
Ouick access	^	Name					ate modi	fied	Туре		Size						
Desktop	*	cal_01.cnd				1	2/5/2017	7:59 PM	CND Fil	e	5	KB					
-		Cal_01.drf				1	2/5/2017	7:59 PM	DRF File	2	480	KB					
Downloads		Cal_01.ins				1	2/5/2017	7:40 PM	INS File		136	KB					
🔮 Documents	*	📄 cal_01.jac				1	2/5/2017	7:59 PM	JAC File	2	143	KB					
Pictures	*	📄 cal_01.jco				1	2/5/2017	7:59 PM	JCO File	2	416	KB					
01_Boryeong		📄 cal_01.jst				1	2/5/2017	7:57 PM	JST File		276	KB					
pangyo_gis		📄 cal_01.mtt				1	2/5/2017	7:59 PM	MTT Fil	le	4	KB					
Videos		📄 cal_01.par				1	2/5/2017	7:59 PM	PAR File	2	1	KB					
다운로드		🚺 Cal_01.pst				1	2/5/2017	7:40 PM		k Data File	228	KB					
		cal_01.rec					2/5/2017		REC File	2	1,402						
🕋 OneDrive		📄 cal_01.rei					2/5/2017		REI File		873						
💷 This PC		cal_01.res					2/5/2017		RES File		1,600						
3D Objects		cal_01.rst					2/5/2017		RST File			KB					
- · ·		cal_01.sen					2/5/2017		SEN File			KB					
Desktop		cal_01.seo					2/5/2017		SEO File	-	753						
Documents	~	📑 Cal_01.tpl				1	2/5/2017	7:40 PM	TPL File	2	2	KB					

Figure 5.45 Optimal parameters

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

🥘 cal_01.par - Note	epad				-	\times
<u>F</u> ile <u>E</u> dit F <u>o</u> rmat	<u>V</u> iew <u>H</u> elp					
single point						^
u_soil_th	1000.00000000000	1.000000	0.00000	00		
u_theta_s	0.4000000000000000	1.000000	0.0000	00		
u_ks_per	6.084334100000000E-05	1.000000	0.000	0000		
u_ksi_per	5.675284100000000E-02	1.000000	0.000	000		
u_riv_th	100.2290737000000	1.000000	0.00000	0		
u_ku_riv	1.000000000000000E-02	1.000000	0.000	000		
u_aqf_s	1.486168120000000E-02	1.000000	0.000	000		
						\sim
<						>
		Windo	ows (CRLF)	Ln 1, Col 1	100%	

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.

ode	Catchment 1	Output field F	ilow_Total(mm)	Convert cms to mm(Observe
ame bservatio		_gis₩Calibration₩Cal_02 _gis₩Calibration₩Observed_2	017	
		 ~ 2008-01-01 	Calibrate Term 2007-01-0	▼ Observed data 1 ▼ 2007-12-31 ▼
Paramete	er Result Table G	araph Scatter		
	Date	Simulated	Observed	_
5261	2007/08/08 04	0.202	0.200	
5262	2007/08/08 05	0.199	0.197	
5263	2007/08/08 06	0.212	0.220	
5264	2007/08/08 07	1.672	1.779	
5265	2007/08/08 08	3.047	3.197	
5266	2007/08/08 09	1.944	1.926	
5267	2007/08/08 10	1.481	1.383	
5268	2007/08/08 11	1.147	1.020	
5269	2007/08/08 12	1.068	0.947	
5270	2007/08/08 13	0.998	0.887	
5271	2007/08/08 14	0.938	0.835	
5272	2007/08/08 15	0.897	0.819	
5273	2007/08/08 16	0.848	0.762	
5274	2007/08/08 17	0.807	0.726	
5275	2007/08/08 18	0.767	0.693	
5276	2007/08/08 19	0.731	0.664	
5277	2007/08/08 20	0.698	0.637	
5278	2007/08/08 21	0.668	0.612	
5279	2007/08/08 22	0.640	0.589	

Figure 5.47 Time series result after calibration

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

	D: Wnew Wpan	gyo_gis₩Calibrati	on₩Cal_02			
oservation	D:\mew\meypan	gyo_gis₩Calibrati	on₩Observed_20	117 Table	•	Observed data
nulate Tern	n 2006-01-01	▼ ~ 2008-0	1-01 👻	Calibrate Term	2007-01-01 💌	~ 2007-12-31 -
Parameter	Result Table	Graph Scatte	r]			
				-		
3						
2.8						- Simulated
2.4						- Observed
2.2				_		
2						
1.8						
1.6						
1.4						1
1		-				
			1 11			
0.8						
0.8						
0.6 0.4						
0.6			LIM			

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.

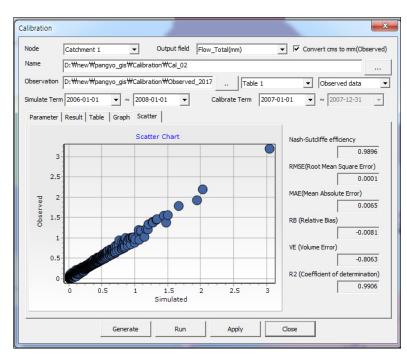


Figure 5.49 Statistical results after calibration

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.

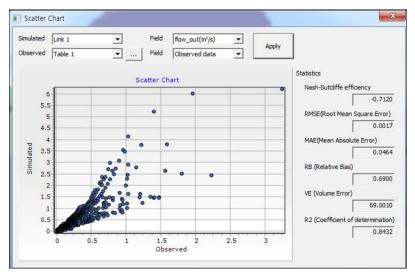


Figure 5.50 Statistical results before calibration

Appendix : BASIC THEORIES of DWAT

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.

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

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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)

Classification of ground surfaces	Overview	Corresponding module		
Impervious zone	Roofs or roads	Impervious zone module		
Pervious zone	Infiltration zones for land use such as forests, grasslands, urban green belts	Pervious zone modul		
Rice paddy	Rice paddies have special soil and runoff processes			

Table 1.1 Classification of ground surface in DWAT model

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. subcatchments are principally divided into regions close to rivers (discharge area) and outer regions (recharging area), see Figure 1.1).

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Figure 1.1 Catchment delineation in DWAT model

A-3 Modeling of Water Cycle Processes

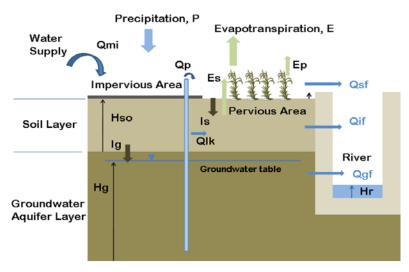
The water cycle processes in DWAT were considered both of pervious and impervious zone. In each zone, the infiltration, evapotranspiration and the movement of groundwater were simulated. DWAT has one soil layer and unconfined aquifer layer in vertically. The intake from aquifer is also considered.

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:



Pervious/Impervious Area

Fig. 1.2 Schematic diagram of water movement in catchment block

$$\frac{dS_{imp}}{dt} = P - D_{imp} - E_{imp} \tag{1.1}$$

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.

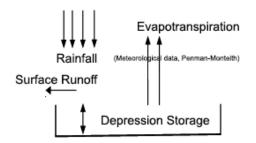


Figure 1.3 Concept of the impervious zone model

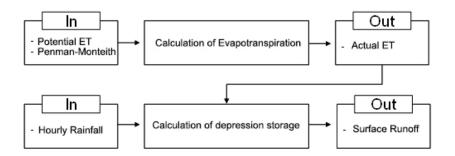


Figure 1.4 Flow chart of the calculation in the impervious zone model and the relationship between inputs and outputs

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:

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

$$\frac{dS_2}{dt} = P - E_2 - R - U_z + P_{a1}$$
(1.3)

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

where,

- S₁: storage in depressions (mm/hr)
- S₂: storage in soil layer (mm/hr)
- Sg : storage in groundwater layer (mm/hr)
- D_s : surface runoff (mm/hr)
- E₁: evaporation from depressions (mm/hr)
- E2: 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)
- Us : the amount of water recovered on the ground surface (mm/hr)
- Dg : 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.)
- Pa2 : 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.)

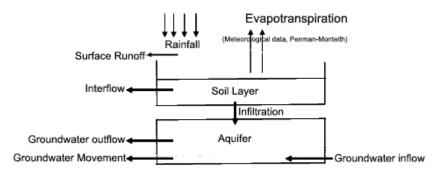


Figure 1.5 Concept of the pervious zone model

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

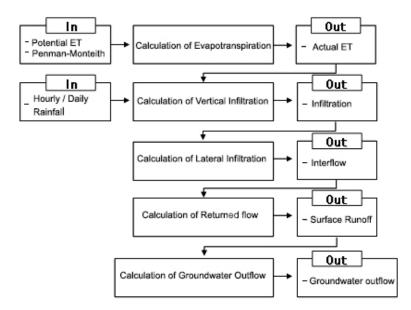


Figure 1.6 Flow chart of calculation in pervious zone model and the relationship between

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.

$$k_{\mathbf{r}}(\theta) = \left(\frac{\theta - \theta_{\mathbf{r}}}{\theta_{\mathbf{s}} - \theta_{\mathbf{r}}}\right)^{n} \tag{1.5}$$

$$k = K_{0} k_{r} (\theta)$$
 (vertical direction) (1.6)

$$k = K_{0I} k_r(\theta)$$
 (lateral direction) (1.7)

where,

k: unsaturated hydraulic conductivity[cm/s]

 $k_{\tau}(\theta)$: relative hydraulic conductivity

 K_0 : vertical saturated hydraulic conductivity[cm/s]

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 $K_{\mathfrak{A}}$: horizontal(slope direction) hydraulic saturated hydraulic conductivity[cm/s]

- * : Mualem's coefficient
- θ : current volumetric soil moisture[cm³/cm³]
- θ_* : saturated soil moisture[cm³/cm³]
- θ_r : residual soil moisture[cm³/cm³]

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 ΔT (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(= Δ 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.

$$R = \int_{T}^{T+\Delta T} K_{0} \cdot k_{r}(\theta) dt$$
(1.8)

where,

K₀ : saturated hydraulic conductivity (m/hr)

 $K_r(\theta)$: relative hydraulic conductivity

 θ : current volumetric soil moisture

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.

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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($=\Delta T/10$), 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.

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

where,

KoI : saturated hydraulic conductivity in slope directions (m/hr)

 $K_r(\theta)$: relative hydraulic conductivity

s : slope degree of downslope (dimensionless)

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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.

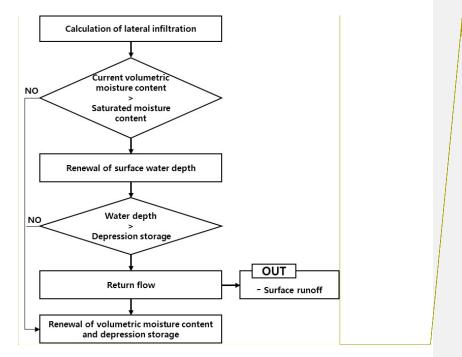


Figure 1.7 Flow chart of the calculation of return flows

2) Green & Ampt method

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

$$f_{\varphi} = K_{g} \frac{L+S}{L} \tag{1.10}$$

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.

$$F(t) = L(\theta_s - \theta_i) = L \times IMD \tag{1.11}$$

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 θ s is equivalent to porosity of soil.

$$f_{\mathfrak{p}}(t) = K_{\mathfrak{s}}(1 + S \times IMD/F(t)) \tag{1.12}$$

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

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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.

$$f_{\psi} = f_{c} + (f_{o} - f_{c})e^{-kt}$$
(1.14)

where,

- fp: infiltration capacity at time t (mm/hr)
- f₀: 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.

$$F = \int_{0}^{T} f_{v} dt = \int_{0}^{T} f_{c} dt + \int_{0}^{T} (f_{o} - f_{c}) e^{-kt} dt$$

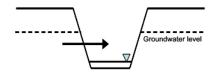
= $f_{c} T + \frac{1}{k} (f_{o} - f_{c}) (1 - e^{-kt})$ (1.15)

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

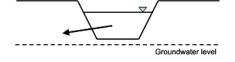
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A-3-3 Groundwater

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

$$Q_{a} = k_0 A_{bad} \tag{1.16}$$

$$Q_{d} = k_0 \frac{h - H_{risbed}}{b_{bed}} A_{bed}$$
(1.17)

where,

 Q_d : inflow into the river or recharges from the river (m³/s)

k₀ : saturated hydraulic conductivity of riverbed material (m/s)

A_{bed} : seepage area (m²)

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)

(m³/s)

K₀ : saturated hydraulic conductivity of aquifer (m/hr)

∂h

 ∂x : slope of groundwater level, hydraulic gradient (dimensionless)

 ℓ : conjuncted length between divided catchments (m)

T : average aquifer thickness in the catchment (m)

...

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

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where,

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

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

- A : catchment area (m²)
- 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.

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

where,

 λ : latent heat energy (MJm-2d-1)

E: depth of evaporation rate (mm/d)

△: slope of saturated vapour pressure-temperature curve de/dT (kPa/°C)

H set: net radiation (MJm-2d-1)

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

p w: air density (kg/m³)

^C^s: specific heat at a certain pressure (MJkg-2d-1)

 \mathcal{e}^{σ} : saturated steam pressure at height z (kPa)

 e_a : steam pressure at height z (kPa)

 \forall : the psychrometric constant (kPa/°C)

r^{*c*}: vegetation coverage resistance (s/m)

*r*₄: 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.

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

 $T_{\mathcal{T}\!a} = k \, \bullet \, E_{\mathcal{T}}$

(1.21)

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

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.

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

where:

 $R_{\rm A}$: mean extra-terrestrial radiation [mm/day], which is a function of the latitude

(Figure 1.9)

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TD : temperature difference = maximum temperature - minimum temperature [$^{\circ}$ C].

TC : mean air temperature [$^{\circ}$ C].

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	Sep	Oct	Nov	De
4.3	6.6	9.4 1 9.8 1 10.2 1 10.6 1 11.0 1	3.0 3.3 3.7	15.9 16.0 16.1	17.2 17.2 17.2	16.5 16.6 16.6	14.3 14.5 14.7	11.2 11.5 11.9	7.8 8.3 8.7	5.0 5.5 6.0	3.7 4.3 4.7	48 46 44	17.6 17.7 17.8	14.9 15.1 15.3	11.2	7.0 7.5 7.9 8.4 8.8	4.7 5.2 5.7	3.5	4.0	6.0 6.5 6.9	9.3 9.7 10.2	$13.2 \\ 13.4$	16.6	18 18 18
6.9	9.0 9.4 9.8	11.4 11.8 12.1 12.4 12.4 12.8	4.5	16.4	17.2 17.2 17.1	16.7 16.7 16.8	15.3 15.4 15.5	12.8 13.1 13.4	10.0 10.6 10.8	7.5 8.0 8.5	6.1	40 38 36 34 32	17.9 17.9 17.8	15.8 16.0 16.1	12.8 13.2 13.5	9.2 9.6 10.1 10.5 10.9	7.1 7.5 8.0	5.8 6.3 6.8	6.3 6.8 7.2	8.3 8.8 9.2	11.4 11.7 12.0	14.6	17.0 17.0 17.1	18 18 18
).3).8	11.1 11.5 11.9	13.1 1 13.4 1 13.7 1 13.9 1 14.2 1	5.3	16.5 16.4 16.4	16.8 16.7 16.6	16.7 16.6 16.5	15.7 15.7 15.8	14.1 14.3 14.5	12.0 12.3 12.6	9.9 10.3 10.7	8.8 9.3 9.7	30 28 26 24 22	17.7	16.4	14.3 14.4 14.6	$ \begin{array}{r} 11.3 \\ 11.6 \\ 12.0 \\ 12.3 \\ 12.6 \\ \end{array} $	9.3 9.7 10.2	8.2 8.7 9.1	8.6 9.1 9.5	10.4 10.9 11.2	13.0 13.2 13.4	15.4 15.5 15.6	17.2 17.2 17.1	1
1.6	13.0 13.3 13.6	14.4 1 14.6 1 14.7 1 14.9 1 15.1 1	5.6	16.1 16.0 15.8	16.1 15.9 15.7	16.1 15.9 15.7	15.8 15.7 15.7	14.9 15.0 15.1	13.6 13.9 14.1	12.0 12.4 12.8	11.1 11.6 12.0	18 16	17.1 16.9 16.7 16.6	16.5 16.4 16.4 16.3	15.1 15.2 15.3 15.4	13.0 13.2 13.5 13.7 14.0	11.4 11.7 12.1 12.5	10.4 10.8 11.2 11.6	10.8 11.2 11.6 12.0	12.3 12.6 12.9 13.2	14.1 14.3 14.5 14.7	15.8 15.8 15.8 15.8	16.8 16.7 16.5 16.4	
3.6 3.9 4.3 4.7	14.5 14.8 15.0 15.3	15.3 15.3 15.4 15.5 15.6 15.6	15.6 15.4 15.5 15.3	15.3 15.1 14.9 14.6	15.0 14.7 14.4 14.2	15.1 14.9 14.6 14.3	15.4 15.2 15.1 14.9	15.3 15.3 15.3 15.3	14.8 15.0 15.1 15.3	13.9 14.2 14.5 14.8	13.3 13.7 14.1 14.4	6 4 2	16.1 15.8 15.5	16.1 16.0 15.8 15.7	15.5 15.6 15.6	14.2 14.4 14.7 14.9 15.1 15.3	13.1 13.4 13.8 14.1	12.4 12.8 13.2 13.5	12.7 13.1 13.4 13.7	13.7 14.0 14.3 14.5	14.9 15.0 15.1 15.2	15.8 15.7 15.6 15.5	16.0 15.8 15.5 15.3	

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.

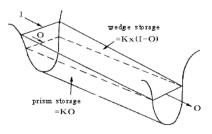


Figure 1.10 concept of wedge storage and prism storage

$$S = KO + Kx (I - O) = K [xI + (1 - x)O]$$
(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 ($0 \le x \le 0.5$), 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 ($0 \le x \le 0.3$ 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:

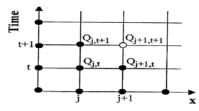


Figure 1.11 Dispersion of Muskingum-Cunge model variables on the x-t plane

$$Q_{s+1}^{n+1} = G_0 \ Q_s^{n+1} + C_1 Q_s^n + C_2 Q_{s+1}^n + C_3 Q_L$$
(1.24)

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

$$C_2 = \frac{K - Kx - 0.5 \Delta t}{K - Kx + 0.5 \Delta t} | C_3 = \frac{K - Kx - 0.5 \Delta t}{K - Kx + 0.5 \Delta t} |$$
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$$\frac{\Delta t}{K(1 - x)} < 0.5$$

where,

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C₀, C₁, C₂, C₃ : 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.

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

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

where,

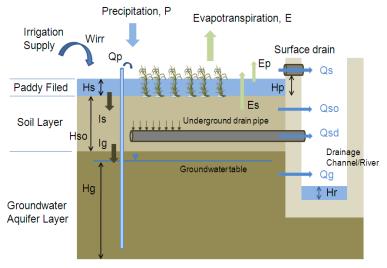
- B : channel width (m)
- y: water depth (m)
- S_o : riverbed slope
- A: flow cross-sectional area (m²)
- q : lateral inflows (m³/s)

 $^{(2)}$, 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.

A-3-6 Paddy



Paddy Area

Fig 1.12 Concept of rice paddy fields

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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:

$$Q_s = \alpha_0 \sqrt{(H_s - H_p)} \quad (H_s > H_p)$$

$$Q_s = 0 \quad (H_s \le H_p) \quad (1.27)$$

where,

- Q_s: discharge from surface (m³/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:

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

where,

Q_{sd}: discharge through underground culvert(m³/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<mark>-3-7 Wetland</mark>

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.

$$\frac{dS_{\omega}}{dt} = Q_{\omega} - Q_{\omega dis} - Q_{\omega ouf} + R - E$$
(1.29)

where,

Sw : storage in wetland (m^3)

Qw : inflow into wetland (m³/s)

Qwdis : outflow from wetland (m³/s)

Qwovf : overflow from wetland (m³/s)

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

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

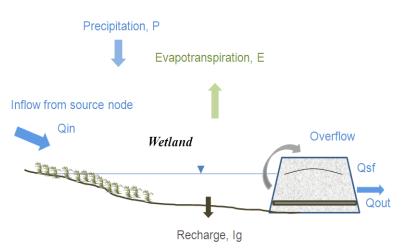


Fig 1.13 Concept of wetland

A-3-8 Reservoir

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.

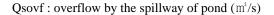
$$\frac{dS_s}{dt} = Q_s - Q_{dis} - Q_{souf} + R - E$$
(1.30)

where,

Ss : storage of pond (m³) Qs : inflow into pond (m³/s) Qdis : outflow from pond (m³/s)

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- R : rainfall onto the surface of pond (mm)
- E : evaporation from surface of pond (mm)

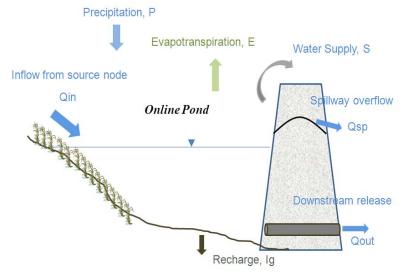


Fig 1.14 Concept of reservoir

A-3-9 Recycle and Import

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.

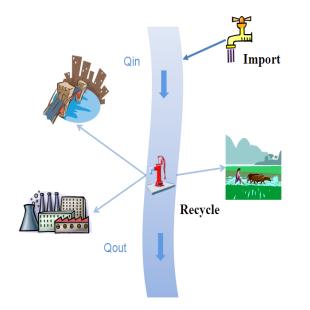


Fig 1.15 Concept of recycle and import

Comment [j45]: Review 25

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