Grid based Rainfall-runoff Model User's Manual

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History

The Grid-based Rainfall-Runoff Model (GRM) is a grid-based and physically based distributed rainfall-runoff model that was developed by the Korea Institute of Civil Engineering and Building Technology (KICT). The development history of the GRM is as follows.

- The GRM was first developed in 2008. It could simulate overland flow, channel flow, subsurface flow, and controlled flow by stream facilities. The model was developed as HyGIS-GRM, an add-on for Hydro Geographic Information System (HyGIS), and was operated as an extension menu under HyGIS.
- In 2010, the base flow simulation was added. Moreover, a real-time flow analysis module using real-time rainfall data was developed.
- In 2012, a multi-site calibration method for single watersheds was developed.
- In 2014, infiltration, subsurface flow, and base flow simulation methods were improved and the MW-GRM plug-in that could run on MapWindow GIS (v.4.8.8), an open source GIS, was developed. In addition, an optimization module using a model-independent parameter estimation tool (PEST) was developed.
- In 2015, the sensitivity of the calculation time step (dt) was improved. Moreover, the real-time flow analysis module was improved to allow simulations of the real-time flow control. A multi-site calibration method that allowed coupled analysis of multiple watershed systems was developed.
- In 2017, the GRM was separated from GIS and graphic user interfaces (GUIs) and was developed into an independent executable file. In addition, a parallel computation method using .NET and a method that could change the calculation time step (dt) during simulation were developed.

The GRM is continuously being developed by the KICT. A stability improvement of the model, addition of functions, and development of modeling softwares are currently in progress.

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1. Overview of the GRM

1.1 Model structure

The Grid-based Rainfall–Runoff Model (GRM) is a physically based distributed rainfall–runoff model used for simulating rainfall–runoff events. A kinematic wave model is used to analyze overland and channel flow and the Green–Ampt model is used to calculate infiltration. The finite volume method is used to discretize governing equations and the Newton–Raphson method is used to derive converging solutions for nonlinear terms (Choi, 2010).

Surface flow is divided into overland flow and channel flow, while direct runoff comprises overland flow and subsurface flow. Overland flow is caused by infiltration excess flow (Horton, 1933) and saturation excess flow (Dunne and Black, 1970). The infiltration process and subsurface flow are simulated in the soil water zones (Bras, 1990).

x is the flow direction, y is the direction perpendicular to the flow of horizontal components, and h is the water depth. Hydrological components flowing into a control volume consist of surface inflow from the upper part of the control volume, lateral inflow, and rainfall. Hydrological components flowing out of a control volume consist of surface outflow and infiltration. Here, infiltration contributes to subsurface outflow. This subsurface outflow becomes a lateral inflow of the downstream control volume if there is a stream. If the downstream cell is a saturated overland flow control volume, subsurface outflow contributes to overland inflow (Beven and Kirkby, 1979).

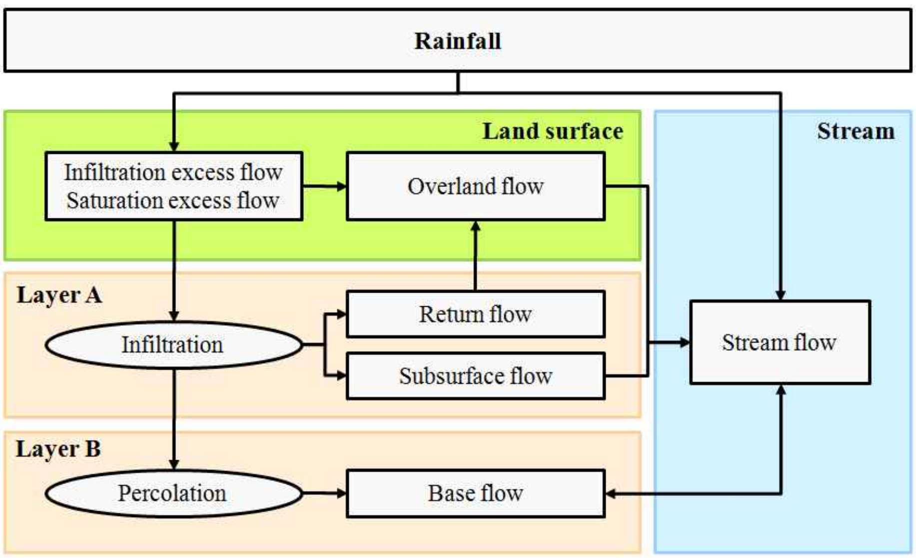


Fig. 1.1 Flow process of hydrological components

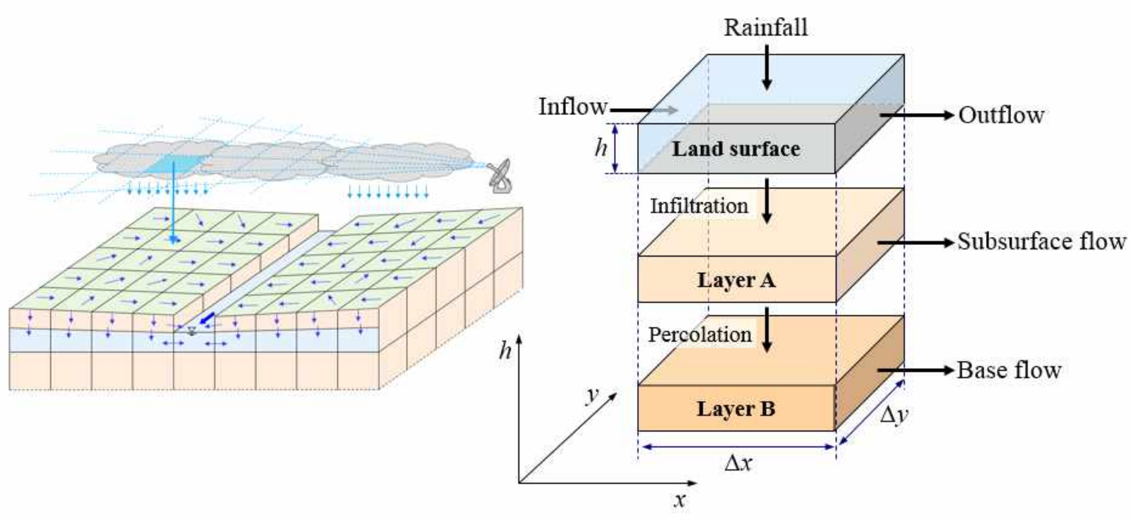


Fig. 1.2 Inflow and outflow of hydrological components within a control volume

1.2 Surface flow

Surface flow can be divided into overland flow and channel flow. A kinematic wave equation is used for flow analysis. The kinematic wave equation uses a combination of the continuity equation and momentum equation. Equation (1.2.1) is the continuity equation for overland flow and Eq. (1.2.2) is the equation for channel flow. In Eq. (1.2.2), effective rainfall for a channel is considered as the source term and the lateral inflow includes subsurface flow, base flow, and overland flow parts in channel flow cells (Choi, 2010). The momentum equation for the kinematic wave model is defined by Eq. (1.2.3).

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r - f + \frac{q_r}{\Delta y} \tag{1.2.1}$$

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = r\Delta y + q_L + q_{ss} + q_b \tag{1.2.2}$$

$$S_0 = S_f \tag{1.2.3}$$

Here, q is the flow per unit width (q = uh), u is the flow velocity in x direction, r is the rainfall intensity, f is the infiltration rate, q_r is the return flow, A is the cross-sectional flow area perpendicular to the x direction, Q is the flow, h is the water depth, q_L is the lateral inflow from overland flow, q_{ss} is the subsurface flow into the channel, q_b is the base flow, and t is the time.

From equation (1.2.3), the bed slope can be used instead of the friction slope to calculate the flow velocity with Manning's flow velocity equation. The water depths is used to approximate the hydraulic radius of overland flow with shallow water depths. An asymmetrical trapezoidal cross section can be applied to the hydraulic radius for channel routing.

$$u = \frac{R^{2/3} S_0^{1/2}}{n} \tag{1.2.4}$$

Here, n is the roughness coefficient and R is the hydraulic radius.

$$R = \frac{b_s \cdot h}{b_s + 2h} \approx h \tag{1.2.5}$$

Here, b_s is the control volume width for overland flow ($b_s \gg h$)

$$R = \frac{b + \frac{h^2}{2}\left(\frac{1}{SLB} + \frac{1}{SRB}\right)}{b + h \times \sqrt{1 + \frac{1}{SLB^2}} + h \times \sqrt{1 + \frac{1}{SRB^2}}} \tag{1.2.6}$$

Here, $SLB = h/bLB$, $SRB = h/bRB$, and b is the channel base width.

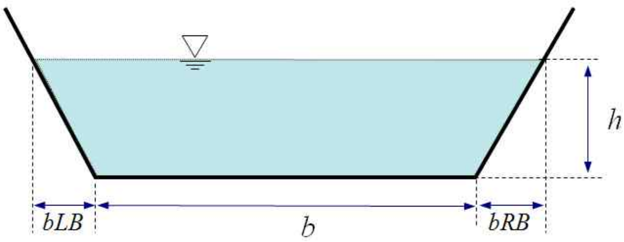


Fig. 1.3 Asymmetrical trapezoidal channel cross section

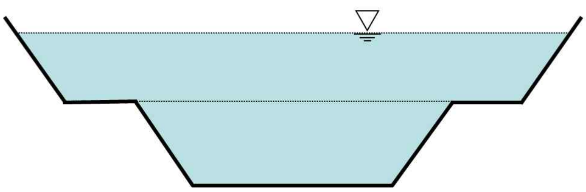


Fig. 1.4 Compound channel cross section

1.3 Infiltration

The GRM can simulate infiltration excess flow, which occurs when the rainfall intensity exceeds infiltration rate, and saturation excess flow, which occurs when soil is saturated. The Green–Ampt Model is used to calculate the infiltration. The Green–Ampt Model calculates cumulative infiltration, as shown in Eq. (1.3.1). The infiltration rate is then calculated with Eq. (1.3.2) using the cumulative infiltration.

$$F(t) = Kt + \Delta\theta\psi\ ln(1 + \frac{F(t)}{\Delta\theta\psi}) \tag{1.3.1}$$

$$f(t) = K\left(\frac{\psi\Delta\theta}{F(t)} + 1\right) \tag{1.3.2}$$

Here, $F(t)$ is the cumulative infiltration at time t, $f(t)$ is the infiltration rate at time t, $\Delta\theta$ is the change in the soil moisture content ($\Delta\theta = (1 - S_e)\theta_e$), S_e is the effective saturation ($S_e = (\theta - \theta_r)/(\eta - \theta_r)$), θ is the moisture content ($\theta_r \le \theta \le \eta$), θ_r is the residual moisture content ($\theta_r = \eta - \theta_e$), η is the porosity, θ_e is the effective porosity, ψ is the wetting front soil suction head, and K is the hydraulic conductivity.

1.4 Subsurface flow

Beven (1981) applied the kinematic wave model to simulate subsurface flow at saturated conditions. The subsurface flow from the kinematic wave model is based on the assumption that the hydraulic gradient is equal to the land surface gradient within a control volume. Equation (1.4.1) can be used to calculate the subsurface flow.

$$q_{ss} = KD_s \sin(S_a) \tag{1.4.1}$$

Here, q_{ss} is the subsurface flow, D_s is the saturated soil depth, and S_a is the land surface inclination angle.

The simulation of subsurface flow from the kinematic wave model with soil depth D is shown in the figure below (Choi, 2010). The GRM assumes the hydraulic gradient of subsurface flow within a control volume to be equal to the land surface gradient and simulates the subsurface flow for saturated soil depths. When the soil becomes saturated to a certain depth due to infiltration, subsurface flow contributes as a component of lateral flow into the channel flow. When the soil is completely saturated ($D_s = D$) within a control volume, local return flow and saturation excess flow contributing to overland flow (Dunne and Black, 1970) are simulated.

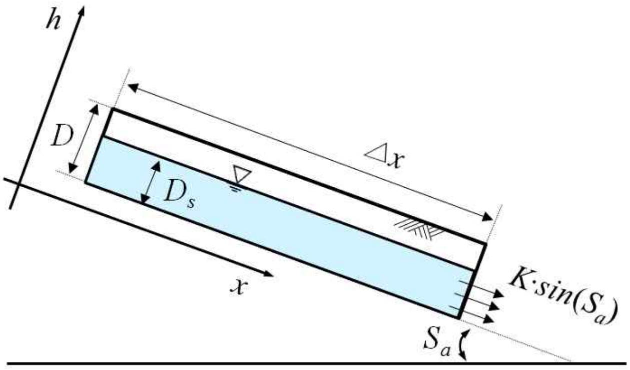


Fig. 1.5 Subsurface flow of a kinematic wave model

Sloan and Moore (1984) suggested the Simple Storage–Discharge Model based on the water budget to calculate flow in an arbitrary segment including completely saturated soil. Equation (1.4.2) shows the saturated excess flow and subsurface flow for completely saturated soil. Each component of the GRM is used to simulate the overland inflow and either lateral inflow or return flow at the downstream control volume. Particularly, when rainfall and runoff occur, the depth of the saturated soil varies. Thus the control volumes in which saturated excess flow and return flow simulated only for completely saturated soil are occurred also vary (Dunne and Black, 1970; Bras, 1990).

$$q_o = i_s L_s + q_s \tag{1.4.2}$$

Here, q_o is the flow per unit width at the downstream end of an arbitrary segment, L_s is the length of the land surface segment that is saturated up to the land surface, and i_s is the inflow perpendicular to the saturated water surface from an external area.

1.5 Base flow

The GRM divides soil into two layers. Simulations of the infiltration and subsurface flow are done for the upper layer A and the base flow is simulated for the lower layer B. When layer A is saturated, percolation occurs into layer B. Equation (1.5.1) is used to calculate the percolation depth.

$$p = K_{Bv} \times \Delta t \tag{1.5.1}$$

Here, K_{Bv} is the vertical hydraulic conductivity of layer B, p is the percolation during time Δt.

The horizontal flow in layer B can be calculated using Eq. (1.5.2) based on Darcy's law (Freeze and Cheery, 1979). Here, the head difference of segment Δx is assumed to be equal to the land surface slope when applying Eq. (1.5.3).

$$q_{Bh} = K_{Bh} D_B \frac{dz_B}{dx} \tag{1.5.2}$$

$$q_{Bh} = K_{Bh} D_B \sin(S_a) \tag{1.5.3}$$

Here, z_B is the water level of layer B, K_{Bh} is the horizontal hydraulic conductivity of layer B, D_B is the water depth of layer B, and q_{Bh} is the horizontal flow per unit width of layer B.

For the flow exchange between an unconfined aquifer and stream, the base flow into the channel is calculated with Eq. (1.5.4) when the water depth of the unconfined aquifer (h_B) is deeper than the water depth of the channel (h_{ch}). When the water depth of the channel is deeper than the water depth of the unconfined aquifer, Eq. (1.5.5) is used to calculate the flow from the channel into soil layer B.

$$q_b = K_{Bh} \frac{h_B - h_{ch}}{h_{ch}} b \qquad (\text{for} \quad h_B > h_{ch}) \tag{1.5.4}$$

$$q_b = K_{Bh} (h_B - h_{ch}) \qquad (\text{for} \quad h_B < h_{ch}) \tag{1.5.5}$$

Here, h_B is the water depth of the unconfined aquifer, h_{ch} is the water depth of the channel, b is the channel base width, and q_b is the base flow per unit length of the control volume.

1.6 Discretization of governing equations

The GRM uses the finite volume method for the discretization of governing equations. The definition of a control volume for such a process is shown in the following figure. The control volume number is indicated with subscript i, the central point of the control volume with p, the control volume surface in the upstream direction ($-x$ direction) from the inflow into the control volume with w, and the control volume surface in the downstream direction (x direction) with outflow with e (Patankar, 1980).

Equations (1.6.1) and (1.6.2) show the discretization of equations from integrating the continuity equations for overland flow and channel flow analyses with respect to x and t for CV_i. Converging solutions for nonlinear terms are found from the Newton–Raphson iteration method (Choi, 2010). When overland flow and channel flow must be simulated together from one grid, the difference between the length in direction y (Δy) and the channel base width (b) is applied to Δy_i which is used for overland flow analysis in Eq. (1.6.1).

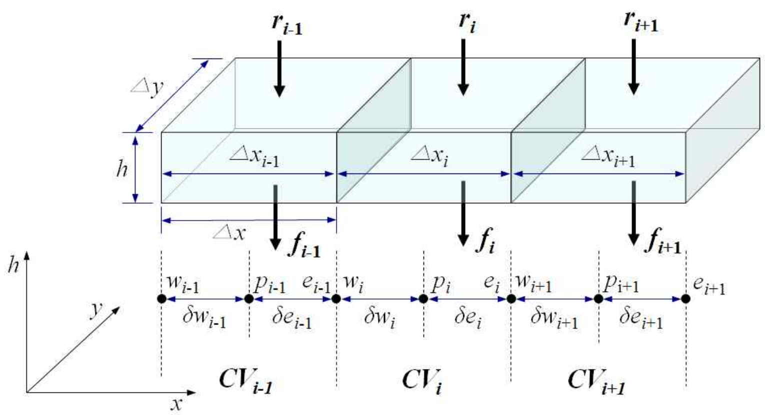


Fig. 1.6 Definition of the control volume for discretization

$$h_{ip}^{j+1} = h_{ip}^{j} - \alpha(\overline{u})_{ie}^{j+1} h_{ie}^{j+1} \frac{\Delta t}{\Delta x_i} + \alpha(\overline{u})_{iw}^{j+1} h_{iw}^{j+1} \frac{\Delta t}{\Delta x_i} - (1-\alpha)\left\{(\overline{u})_{ie}^{j} h_{ie}^{j} - (\overline{u})_{iw}^{j} h_{iw}^{j}\right\} \frac{\Delta t}{\Delta x_i}$$
$$+ \left\{\alpha S_i^{j+1} + (1-\alpha) S_i^{j}\right\} \Delta t \qquad (1.6.1)$$

Here, S_i is the source term ($S_i = r_i - f_i + \frac{q_{ri}}{\Delta y_i}$), $\Delta y_i = \Delta y - b_i$, and b_i is the channel base width defined for the control volume CV_i.

$$A_{ip}^{j+1} = A_{ip}^{j} - \alpha(\overline{u})_{ie}^{j+1} A_{ie}^{j+1} \frac{\Delta t}{\Delta x_i} + \alpha(\overline{u})_{iw}^{j+1} A_{iw}^{j+1} \frac{\Delta t}{\Delta x_i} - (1-\alpha)\left\{(\overline{u})_{ie}^{j} A_{ie}^{j} - (\overline{u})_{iw}^{j} A_{iw}^{j}\right\} \frac{\Delta t}{\Delta x_i}$$
$$+ \left\{\alpha S_i^{j+1} + (1-\alpha) S_i^{j}\right\} \Delta t \qquad (1.6.2)$$

Here, S_i is the source term ($S_i = r_i \Delta y_i + q_{Li} + q_{ssi} + q_{bi}$).

An arbitrary control volume which have channel properties is divided into two cases according to the channel base width and grid cell size (shown in the following figures): the case of the channel base width being smaller than the grid cell size and the case of the channel base width being equal to or larger than the grid cell size. When the channel base width is smaller than the grid cell size, all the hydrological components for overland flow and channel flow are simulated with respect to the corresponding control volume. However, when the channel base width is equal to or larger than the grid cell size, only channel flow is simulated.

Here, rainfall at the corresponding control volume either occurs within the channel base width or outside of it. The rainfall occurring within the channel base width contributes to the direct runoff of the stream and the rainfall outside the channel is needed infiltration analysis as it is done for the overland flow control volume.

Consequently, Δy_i in Eq. (1.6.2) for channel flow analysis must be the same as the grid cell size in direction y ($\Delta y_i = \Delta y$) when the channel base width is equal to or larger than the grid cell size. And when the channel base width is smaller than the grid cell size, the channel base width should be applied ($\Delta y_i = b_i$).

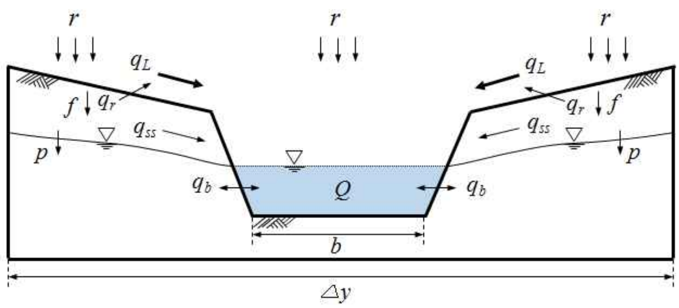


Fig. 1.7 Channel cell with channel base width is smaller than the cell size

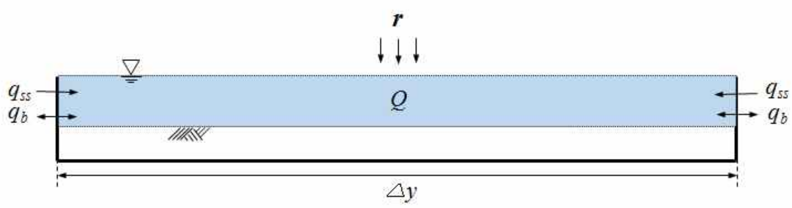


Fig. 1.8 Channel cell with channel base width is equal to or larger than the cell size

1.7 Flow control

The GRM can not only simulate natural flow, such as direct runoff from rainfall, but also reflects the changes of artificial flow conditions occurring within a watershed to runoff simulations using a flow control module. The flow conditions that can be simulated with the flow control module are “Reservoir outflow,” “Inlet,” “Reservoir operation,” “Sink flow,” and “Source flow.”

The flow control technique can be applied to all grids with channel flow and overland flow properties. Moreover, multiple flow control conditions can be simultaneously applied to a single watershed to reflect the direct runoff from rainfall and changes of various flow conditions that occur during runoff simulations (KICT, 2011b).

1.7.1 Reservoir outflow

The “Reservoir outflow” function simulates runoff by dividing a watershed into upstream and downstream with respect to grids selected as the reservoir; it does not consider the reservoir operation rule. The discharge from the control volume selected as the reservoir is set using an observed hydrograph of the reservoir entered by the user (Eq. (1.7.1)). The runoff simulation of the control volume located in the immediate downstream of the reservoir is performed by including the reservoir outflow in the upstream boundary conditions.

$$q_{ie} = q_o \tag{1.7.1}$$

Here, q_{ie} is the outflow per unit width from the control volume i selected as the reservoir and q_o is the outflow per unit width calculated from the observed discharge hydrograph of the reservoir.

1.7.2 Inlet

Upstream and downstream are distinguished based on the grid selected as the inlet. This is identical to the “Reservoir outflow” that simulates flow by dividing a watershed based on a particular grid. However, the “Inlet” does not simulate the upstream of inlet grid. Moreover, it does not consider the reservoir operation rule. When a runoff hydrograph for the inlet grid is given, the outflow of inlet grid is calculated with the method shown in Eq. (1.7.1). And data is applied as the upstream boundary condition for the downstream cell of the inlet.

This "Inlet" function excludes the upstream area of a dam and reservoir from simulation area when observed runoff hydrographs of a dam or reservoir are available for large watersheds that include dams and reservoirs. It only simulates the downstream areas and thus allows the reduction of the scope of required spatial data and hydrological time series data. In grid-based distributed models, the number of grids comprising a watershed is reduced when the simulation area decreases. It can reduce the model run time. Moreover, applying equal model run times allows using small-sized grids. This can reduce uncertainties in gridded topographical and hydrological data due to issues with the scales of grid sizes.

1.7.3 Reservoir operation

The "Reservoir operation" function can reflect the effects of storage in a reservoir and reservoir operation in flow simulations. The GRM can produce dynamic simulations for the initial storage, maximum storage, maximum storage ratio, constant discharge, and Reservoir Operation Method (ROM) from the relations of water level-storage and water level-discharge. For such simulations, reservoir data and the ROM are required, as shown in the following table.

Table 1.1 Reservoir conditions for applying the "Reservoir operation" function (Choi, 2010).

Classification		Description
Specifica-tions	Initial Storage	Initial storage of the reservoir
	Maximum Storage	Maximum storage of the reservoir
	Maximum Storage Ratio	Available ratio of the maximum storage
ROM	Automatic ROM	Reservoir discharge does not occur until the maximum possible storage is reached. When the maximum possible storage is reached, all flow into the reservoir is discharged.
	Rigid ROM	If the reservoir storage is less than the set discharge, all of it is discharged. If the reservoir storage is more than the set discharge, set constant flow is discharged until the storage exceeds the maximum possible storage; in that case, all inflow to the reservoir is discharged.
	Constant Discharge	A constant flow is discharged for a specific amount of time regardless of reservoir capacity
	Storage–Discharge Relationship	The storage–discharge, water level–storage, or water level–discharge relationships are used to calculate the storage and discharge (only supported in source code level).

1.7.4 Sink flow / source flow

"Sink flow" simulates the condition of partially omitting flow that was simulated in an arbitrary grid. "Source flow" simulates flow by reflecting flow conditions that were added to the flow simulated in an arbitrary grid. The discharge, either omitted or added due to "Sink flow" and "Source flow," is given by hydrographs and is applied as source term when simulating overland flow and channel flow. "Sink flow" or "Source flow" can simultaneously used with the "Reservoir operation" function for channel grid cells; based on this, the reservoir operation can also be simulated.

1.8 Calculation time step

The GRM can either use the same calculation time step (Δt) for the entire simulation process or different calculation time steps according to calculated flow. The first case applies the same calculation time step set by the user repeatedly for the entire simulation process. The second case uses the Courant–Friedrichs–Lewy (CFL) condition to change the calculation time step for each calculation step. The CFL condition is defined by the equation below.

$$\Delta t \leq \frac{\Delta x}{u_{\max}} \tag{1.8.1}$$

Here, $u_{\max}$ is the maximum flow among all grids calculated at time t and Δt is the calculation time step for time $t+\Delta t$.

2. Model parameters

The GRM analyzes the rainfall–runoff relationship physically and consequently physical parameters assigned to each grid are used. Theoretically, physical parameters selected based on the watershed boundaries, stream network, soil, and land cover should be omitted from the list of parameters estimated by the user. However, they can become parameters to be estimated depending on the limitations of governing equations and issues with data creation and scale.

The GRM considers the initial soil saturation ratio, minimum channel slope, channel roughness coefficient, and dry stream order as parameters to be estimated by users and not as fixed parameters reflecting physical properties. Moreover, each parameter selected according to the soil and land cover properties can be calibrated by uniform ratio using the parameter calibration coefficient.

Table 2.2 Input data and parameters for the GRM

Model input data	Selected parameters
Watershed	Control volume number, cell size, flow analysis area
Flow direction	Upstream/downstream control volume, flow relationship, calculation order
Flow accumulation	
Slope	Slope, Minimum land surface slope, minimum channel bed slope
Stream network	Minimum channel base width, stream control volume, stream order, dry stream order, channel roughness coefficient
Land cover map	Land surface roughness coefficient, impervious ratio
Soil map	Green–Ampt parameters, effective soil depth
Rainfall	Rainfall, initial saturation ratio
Discharge	Initial discharge

2.1 Soil parameters

The GRM uses the Green–Ampt model to simulate the infiltration process. The Green–Ampt model parameters according to the soil properties for the simulation of infiltration excess flow and the soil depth for saturation excess flow and subsurface flow must be selected.

Calculating the infiltration using the Green–Ampt model requires the physical soil properties such as porosity, effective porosity, wetting front suction head, and hydraulic conductivity. Such soil properties can be obtained by measuring the soil moisture content (Brakensiek et al., 1981). Rawls et al. (1983) analyzed approximately 5,000 soil samples across the U.S. and suggested average values for the Green–Ampt model parameters according to the soil texture (Table 2.3) (Rawls et al., 1983; Chow et al., 1988). All parameters used to derive the effective saturation of the soil for the Green–Ampt model, except for the initial moisture content (θ), are defined by the values already set according to the soil texture. Moreover, each parameter can be estimated during the flow simulation process. The initial moisture content (θ) can be derived from measurement or parameter estimation and can vary depending on the hydrological conditions of a watershed such as antecedent rainfall.

※ Typical soil map applicable in Korea is detailed soil map (Kim, 1998). The detailed soil map is based on a detailed soil survey focused on Korea. It categorizes Korean soil into 'soil series' and further according to 'soil type' and 'soil phase'. It also includes the physical properties of the smallest unit, the 'soil phase'. The parameters of the Green–Ampt model are set according to the soil texture. The detailed soil map categorizes the 'soil type' in the same manner as soil texture. Moreover, the soil depths of Korean soil required for the calculation of the saturation excess flow are categorized with respect to the 'soil series' of the detailed soil map. The range of each soil depth category was defined based on the results of a soil survey project and is shown in table 2.4 (National Institute of Agricultural Science and Technology, 1992).

The hydraulic conductivity (K) shown in the table 2.3 indicates the saturated hydraulic conductivity. Bouwer (1996) and Ralws et al. (1983) reported that the hydraulic conductivity of unsaturated soil has ½ the value of that in saturated soil and also various studies on the selection of the hydraulic conductivity of unsaturated soil are currently performed. The GRM uses the hydraulic conductivity to calculate the infiltration, percolation, subsurface flow, and base flow. The GRM uses the following empirical equation to calculate the hydraulic conductivity (K_u) of unsaturated soil; K_u is reduced by multiplying a coefficient (a) and the current soil saturation ratio with the saturated hydraulic conductivity. Here, reduction coefficient a has an empirical range of 0.15 – 0.3. The GRM sets the default value to 0.2.

$$K_u = aK_s r_s \tag{2.1.1}$$

Here, K_u is the hydraulic conductivity of unsaturated soil, a is the coefficient (default value of 0.2), K_s is the saturated hydraulic conductivity, and r_s is the soil saturation ratio.

Table 2.3 Green–Ampt model parameters according to the soil texture

Soil Texture	Porosity (η)	Effective porosity (θ_e)	Residual moisture content ($\theta_r = \eta - \theta_e$)	Wetting front soil suction head ($\lvert \psi_f \rvert$)[cm]	Hydraulic conduct. (K) [cm/hr]
Sand	0.437 (0.374-0.5)	0.417 (0.354-0.479)	0.02	4.95 (0.97-25.35)	11.78
Loamy sand	0.437 (0.363-0.505)	0.401 (0.329-0.472)	0.036	6.13 (1.35-27.93)	2.99
Sandy loam	0.453 (0.351-0.554)	0.412 (0.283-0.54)	0.041	11.01 (2.67-45.46)	1.09
Loam	0.463 (0.375-0.55)	0.434 (0.334-0.533)	0.029	8.89 (1.33-59.37)	0.34
Silt loam	0.501 (0.42-0.581)	0.486 (0.394-0.577)	0.015	16.68 (2.92-95.38)	0.65
Sandy clay loam	0.398 (0.332-0.463)	0.33 (0.235-0.424)	0.068	21.85 (4.42-108.1)	0.15
Clay loam	0.464 (0.409-0.518)	0.309 (0.279-0.5)	0.155	20.88 (4.79-91.9)	0.1
Silty clay loam	0.471 (0.418-0.523)	0.432 (0.347-0.516)	0.039	27.3 (5.67-131.49)	0.1
Sandy clay	0.43 (0.37-0.489)	0.321 (0.207-0.434)	0.109	23.9 (4.08-140.1)	0.06
Silty clay	0.479 (0.425-0.532)	0.423 (0.334-0.511)	0.056	29.22 (6.13-139.3)	0.05
Clay	0.475 (0.427-0.522)	0.385 (0.269-0.5)	0.09	31.63 (6.39-156.4)	0.03

Table 2.4 Classification of the soil depth for soil series

Soil depth classification	Soil depth (cm)	
	USDA*	Detailed soil map
Very shallow	0 - 10	0 - 20
Shallow	10 - 30	20 - 50
Moderately deep or Moderately shallow	35 - 50	50 - 100
Deep	50 - 60	100 - 150
Very Deep	> 60	> 150

* USDA: United States Department of Agriculture

2.2 Land cover parameters

The land cover of watersheds have influence on determining the roughness coefficient and impervious ratio to calculate overland flow. The GRM uses roughness coefficients suggested by Engmand (1986) and Vieux (2004), as shown in the table below, to simulating overland flow from rainfall.

Table 2.5 Roughness coefficients according to land cover properties

7 Classifications of land cover (Ministry of Environment, Korea)		Roughness coefficient
Code	Attributes	
100	Urban/dry area	0.015
200	Agricultural area	0.035
300	Forest	0.1
400	Grass	0.15
500	Wetland	0.07
600	Bare	0.02
700	Water	0.03

"Impermeable areas of overland" refers to areas without infiltration through soil, even with rainfall. Sagong (2003) classified land cover as permeable or impermeable using IKONOS satellite images with a spatial resolution of 1 m (Table 2.4). This classification system was applied to Anyang City in Korea to calculate impervious ratios for different land usage. The GRM uses impervious ratios from the study results by Sagong (2003) that correspond to the 7 classifications of land cover attributes by the Ministry of Environment (Table 2.5). Table 2.5 shows impervious ratios ranging from 0 – 1. When the ratio is "1," grids with corresponding land cover properties are determined as impermeable areas. Moreover, because soil of water and wetlands is always saturated, it is assumed that infiltration from rainfall does not occur and the impervious ratio is set as "1."

Table 2.6 Classification of land cover according to the permeability (Sagong, 2003)

Permeable area	Impermeable area
Vegetation	Paved road
Cultivated land	Concrete structure
Vinyl greenhouse	Apartment
Stream	Detached house
Bare land	Town house
Other grassland	Buildings other than houses
Railway	Factory

Table 2.7 Impervious ratios according to land cover map properties (Sagong, 2003)

Land cover map attributes	Land usage type (Sagong, 2003)	Impervious ratio	
		Range of values	Mean
Urban/dry area	Commercial area	0.641-0.947	0.853
Agricultural area	Rice paddy	0.107-0.456	0.391
	Field	0.053-0.504	
	Vinyl greenhouse	0.422-0.842	
Forest	Greenbelt area, non-urban area, forest	0.001-0.05	0.025
Grass	Grassland	0.14-0.86	0.44
Wetland	-	-	1
Bare	Bare land	0.12-0.81	0.442
Water	-	-	1

2.3 Channel base width

The channel base width is a parameter to simulate the channel flow. The GRM can simulate asymmetrical trapezoidal compound cross sections. Here, the channel base width is applied to calculate cross-sectional flow areas of channels. Streams in watersheds have irregular compound cross sections and channel base widths; entering such varying channel shapes for every stream grid is very difficult. Therefore, objective parameters must be used when entering channel base widths for flood flow simulations to obtain consistent simulation results for all stream grids. In the GRM model, either the flow accumulation from grids or the design channel base width equation can be used.

2.3.1 Method using flow accumulation

The flow accumulation from watershed grids increases as it approaches downstream grids. The channel base width is typically larger in the downstream than upstream. A method using flow accumulation reflects these trends to set the channel base width proportional to flow accumulation. Here, the channel base width for an arbitrary control volume (CV_i) can be calculated using Eq. (2.3.1). The grid at the most downstream of a watershed shows maximum flow accumulation. The channel base width calculated with Eq. (2.3.1) takes a maximum value for the most downstream grid. This value decreases as it approaches grids upstream. When the channel base width is defined based on Eq. (2.3.1), the measured channel base width from the most downstream location can be applied and used to define the channel base width for upstream grids with the consistent method (Choi, 2010).

$$b_i = \frac{FA_i \times b_{max}}{FA_{max}} \tag{2.3.1}$$

Here, b_i is the channel base width for CV_i, FA_{max} is the flow accumulation for the most downstream control volume, FA_i is the flow accumulation for CV_i, and b_{max} is the channel base width for the most downstream control volume.

2.3.2 Method using the design channel width equation

The Ministry of Construction and Transportation (2005) recommends an empirical equation that adopts topographical properties, such as slope and watershed area, to select the design channel base widths according to design floods when designing channels. Equation (2.3.2) is used for southern regions (Honam and Youngnam regions, Korea) and Eq. (2.3.3) is used for central regions (Gyeonggi, Gangwon, Chungnam, and

Chungbuk provinces, Korea).

$$B = 1.698 \frac{A_w^{0.318}}{S_0^{0.5}} \tag{2.3.2}$$

$$B = 1.303 \frac{A_w^{0.318}}{S_0^{0.5}} \tag{2.3.3}$$

Here, A_w is the watershed area (km^2), and S_0 is the channel bed slope.

The watershed area of each grid is used as the watershed area (A_w) to calculate the channel base width for each grid applying the design channel base width equation. The watershed area of each grid is calculated using the equation below, by multiplying the flow accumulation of the corresponding grid and grid area. The slope of each grid selected in the slope layer (input data for the model) can be used as the channel bed slope (S_0).

$$A_{wi} = (FA_i + 1) \times (\Delta y)^2 \tag{2.3.4}$$

Here, A_{wi} is the watershed area of an arbitrary control volume.

2.4 Initial saturation ratio

Initial saturation ratio is a parameter used to calculate infiltration and maximum possible infiltration and shows the soil saturation ratio at the time of runoff simulation. The initial saturation ratio is estimated within the range of "0 – 1" during the calibration process of the model and can approach 1 with increasing antecedent rainfall. If there is a soil saturation ratio raster data, it can be applied to flow simulation instead of estimating initial soil saturation ratio parameter.

2.5 Minimum slope

The kinematic wave model uses the land surface slope as friction slope to calculate the flow velocity. The flat area calibration process of a DEM entails a very small elevation modification to minimize changes in the original DEM. Therefore, the surface slope of areas that went through flat area processing can take very small values. When such miniscule surface slopes are applied to the kinematic wave model, the calculated flow velocity and discharge can be close to "0." Various studies were performed to determine minimum values that can be applied to the kinematic wave model as surface slopes (Ponce et al., 1978; Woolhiser and Liggett, 1967); the values mostly ranged from 0.0001–0.01. Moreover, Henderson (1966) and ASCE (1996) suggested that the kinematic wave model was appropriate for streams with a bed slope of 0.002 (10 ft/mi) or more when analyzing flood waves.

Minimum slopes of the channel and overland flow are parameters estimated by users to apply the slope layer including grids with very small slope values that resulted from flat area calibration of a DEM to the kinematic wave model. The minimum slope is part of the flow calculations for flood routing and thus affects discharge and flood wave arrival times. Consequently, it must be estimated by considering the watershed and stream properties and DEM properties applied during flow simulation.

2.6 Channel roughness coefficient

The roughness coefficient of a channel can vary depending on the channel shape, ground composition materials, vegetation, and degree of management (Chow, 1959). Chow (1959) combined existing studies on the roughness coefficient selection for channels to suggest roughness coefficients for various channel conditions. Among these roughness coefficients, those for natural streams are shown in Table 2.6. Chaudhry (1993) suggested roughness coefficients for "clean, straight, full stage, no rifts, or deep pools," "bottom: gravel, cobbles, and few boulders," and "bottom: cobbles with large boulders" for natural streams. However, for actual flow simulations, it is appropriate to estimate roughness coefficients considering the channel conditions that can reflect the properties of a watershed within the range of roughness coefficient for each channel condition.

Table 2.8 Roughness coefficients for natural rivers (Chow, 1959)

Classification		Roughness Coefficient		
		Minimum	Typical	Maximum
Streams on plain	Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
	Same as above, but more stones and weeds	0.030	0.035	0.040
	Clean, winding, some pools and shoals	0.033	0.040	0.045
	Same as above, but some weeds and stones(Ⓐ)	0.035	0.045	0.050
	Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
	Same as Ⓐ, but more stones	0.045	0.050	0.060
	Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
	Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage	Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
	Bottom: cobbles with large boulders	0.040	0.050	0.070

2.7 Dry stream order

The GRM simulates under the condition that all rainfall occurring within a channel base width contributes to direct flow. Therefore, when a stream network entered into the river raster data is dense, large direct runoff can be simulated, even from small amounts of rainfall. However, when the antecedent rainfall is small in natural streams, their upstream tributaries can be dry streams and infiltration may occur first.

To take into account early infiltration at dry streams during flow analysis, the GRM uses the dry stream order. When the entered stream network is dense, the dry stream order can be entered by considering antecedent rainfall and stream flow. The direct runoff of dry streams is calculated with the same method used for overland flow. The dry stream order is estimated within the range of “0 to maximum stream order.” To apply the dry stream order during flow analysis, stream order data must be entered into the stream network raster data. Hydrological GIS S/W, such as HyGIS, uses the stream order as grid cell value when creating a stream network raster data. The maximum stream order can also be identified based on the entered stream network raster data.

2.8 Parameter calibration coefficients

In the case of calibrating roughness coefficients and parameters of the Green–Ampt model set from land cover and soil properties with a certain ratio, a calibration coefficient corresponding to each parameter can be applied. The parameter calibration coefficient is a value applied to each parameter of the entire grid to be simulated. When 1 is entered, the corresponding parameter takes the value initially set in the flow simulations.

2.9 Parameter estimation

A physically based model assumes that parameters set according to spatial data from field surveys represent true values. Therefore, parameters which are difficult to set observed values for every cell and have relatively high uncertainties and high sensitivities such as initial saturation, channel minimum slope, channel roughness coefficient, permeability, and soil depth, are estimated by users.

The GRM simulates rainfall-runoff events. Consequently, the model calibration mainly reproduces observed hydrographs for peak discharge, peak time, and total discharge. Moreover, the overall trend of the calculated hydrograph can be considered to determine how well it reproduces the trend of the observed hydrograph. The typical trial-and-error method and any other optimization techniques can be used for model calibration.

Goodness-of-fit evaluation of a model can be performed using various objective functions such as relative errors of peak discharge, peak time, and the total discharge and root-mean-square error (RMSE), normalized RMSE (nRMSE), mean absolute percentage error (MAPE), correlation coefficient (CC), and Nash–Sutcliffe model efficiency (ME) of time series data.

3. Multi-site calibration

Most distributed models are set up with uniform grid sizes for single watersheds. Moreover, flow simulations are carried out using one parameter group that was set for each grid. Here, when one parameter group is used for flow simulations of a watershed that is comprised of many subwatersheds with varying runoff properties (Ajami et al., 2004), the physical and hydrological properties of the subwatersheds cannot be reflected properly in the model.

Distributed models have the advantage of easily obtaining flow simulation results from arbitrary sites within a watershed divided by grids (Beven and O'Connell, 1982). To improve the reliability of the flow analysis results for arbitrary cells which are not calibration sites, the model should be set up securing physical and hydrological similarities between the watershed of a cell to get simulation results and the calibrated watershed (Pilgrim, 1983; Dawson et al., 2006). The most intuitive method to secure physical and hydrological similarities between the model calibration watershed and the watershed outputting flow analysis results is to establish the model such that model calibration is possible at a point close to the point of the flow analysis output (Ajami et al., 2004; Merz, R. and Blöschl, 2004; Young, 2006). This requires the calibration of models for multiple sites (multi-site calibration) within a watershed.

The multi-site calibration method can be divided into a method for a single watershed system and a method that connects multiple subwatersheds. If verifiable stream gauges exist within a watershed, the watershed can be divided into subwatersheds according to the gauges. The single watershed multi-site calibration method calibrates a model collectively using the corresponding observed flow for subwatershed areas that were divided according to stream gauges within a watershed. All subwatersheds have a uniform grid size, which restricts applications of varying resolutions for each subwatershed. However, the advantage is the simple model calibration for multiple sites within one watershed.

The multi-site calibration method of connecting subwatersheds connects the flow analysis results from each watershed using the flow control module of the GRM. This method can improve the flow analysis results for an entire area consisting of multiple watersheds. Here, each subwatershed is an independent watershed system and thus different resolutions can be applied and data suitable for the properties of each subwatershed can be applied separately. Therefore, the properties of each subwatershed are reflected as much as possible. Moreover, flow analysis for each subwatershed is carried out by an independent process, which allows parallel computation through separated processes and consequently reduces the calculation time required for an entire watershed. In a typical hydrological event simulation, the multi-site calibration method of connecting subwatersheds takes the entire time series of flow analysis results and applies it to the flow control module of a different watershed. However, a real-time flow analysis system using real-time analysis modules of the GRM (GRM Real Time) requires real-time input of rainfall and flow control data and flow analysis is performed through dynamic connection of each subwatershed.

3.1 Single watershed multi-site calibration

The multi-site calibration method for single watersheds is used to set up a model with a single watershed system with uniform grid size. Moreover, it is used to collectively calibrate a model with respect to numerous stream gauges existing within a watershed. Parameters are set for each subwatershed using watershed raster data divided into subwatersheds and the model is calibrated according to each subwatershed. The basic principle of the multi-site calibration module is the application of the parameter set of an arbitrary watershed to the entire upstream area. If there is no subwatershed upstream with parameters set by user, a single parameter group is applied (Choi et al., 2012).

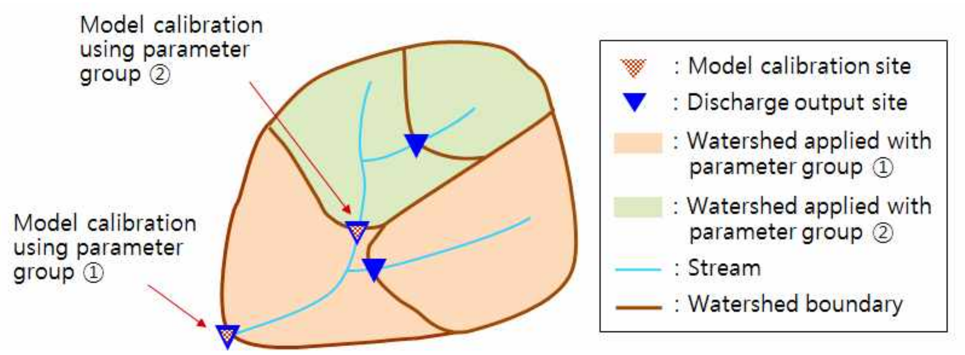


Fig. 3.1 Application method of the single watershed multi-site calibration

Table 3.1 Parameters of the GRM subject to multi-site calibration

Classification	Parameter subject to multi-site calibration	Abbreviation
Topographic	Minimum land surface slope	MinSlopeOF
	Minimum channel bed slope	MinSlopeChBed
	Minimum channel base width	MinChBaseWidth
	Channel roughness coefficient	ChRoughness
	Dry stream order	DryStreamOrder
Land Cover and Soil	Land surface roughness coefficient calibration coefficient	CalCoefLCRoughness
	Porosity calibration coefficient	CalCoefPorosity
	Wetting front soil suction head calibration coefficient	CalCoefWFSuctionHead
	Hydraulic conductivity calibration Coefficient	CalCoefHydraulicK
	Soil depth calibration coefficient	CalCoefSoilDepth
Hydrological conditions	Initial saturation ratio	IniSaturation
	Initial flow	IniFlow

The GRM uses project files in xml format to save the environment and parameters of a modelling project. Multi-site calibration data are saved as a subwatershed parameter table ("SubWatershedSettings") in an xml project file. A subwatershed parameter table takes the subwatershed number as the key code, has parameters entered according to subwatersheds, and can reuse previously saved parameters of each subwatershed through the open project command.

3.2 Subwatersheds connecting multi-site calibration

To obtain reliable flow analysis using a physical model for watersheds with various hydrological properties and watershed areas, models suitable for each watershed property must be established. Runoff analysis using a distributed model usually builds a model for one watershed with uniform grid size and uses the one parameter group. However, when single-sized grids are used to build a model and a single parameter group is used to calibrate a model for multiple subwatersheds with various hydrological properties, the physical and hydrological properties of subwatersheds are not properly reflected. Therefore, different watershed systems must be established according to different watershed properties and a modeling technique that can integrate each watershed is required.

The subwatersheds connecting multi-site calibration method builds models for each subwatershed using the flow control module of the GRM. Moreover, the flow analysis results for each subwatershed can be connected to perform flow analysis of the entire watershed. Here, flow analysis results from the upstream of a watershed are transferred to a subwatershed downstream using the inlet function of the flow control module (Korea Institute of Civil Engineering and Building Technology, 2015). To execute flow analysis dynamically for each watershed using the subwatersheds connecting multi-site calibration method, the real-time analysis module of the GRM (GRM RT) is used. The GRM RT not only enters rainfall data but also input data of the flow control module, such as dam discharge, in real-time for flow analysis. Therefore, the downstream of a watershed receives simulation results from the upstream in real-time and dynamic simulation can be obtained for the entire watershed. The description of GRM RT is included in the GRM RT section in this user manual.

Models with different grid sizes can be created using the subwatersheds connecting multi-site calibration and reflecting properties of different subwatersheds. Therefore, the model calibration for each subwatershed can be optimized and the flow analysis results for arbitrary sites within watersheds can be improved compared with the flow analysis results from calibrating only the site at the lowest end of a stream in a single watershed system. However, it is inconvenient because the input data for each watershed must be established separately and model calibration must be performed with individual processes according to the watersheds. Such model calibration is very complex and requires great efforts to maintain a dependable operation of the modeling system and stable analyses of flow preservation between subwatersheds and of flood routing problems.

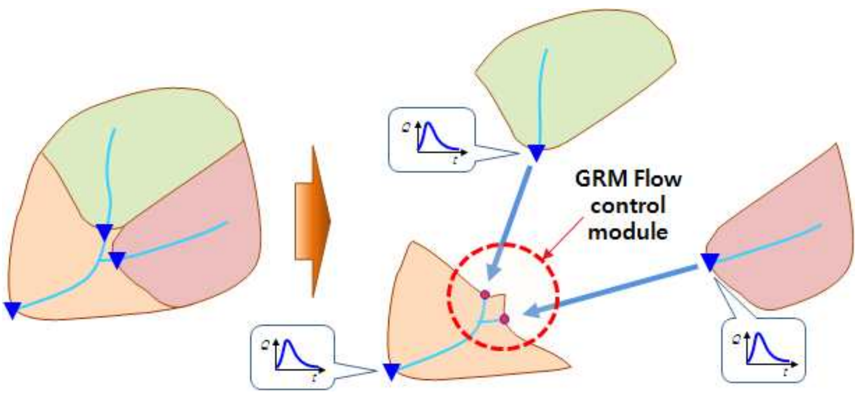


Fig. 3.2 Conceptual diagram of the subwatersheds connecting multi-site calibration

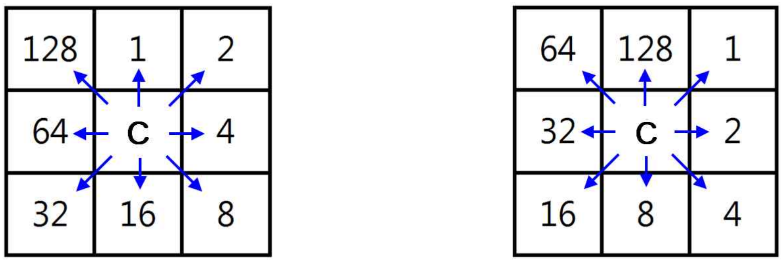
4. Input data

The GRM is executed in project units. Project file of the GRM have .gmp extension and is saved in xml format. The input data required to run the GRM, simulation environment, and parameters are saved in GRM project file. The GRM uses topographical and spatial data established based on a DEM, soil and land cover maps, and rainfall raster file as input data. The watershed, slope, flow direction, flow accumulation, stream network files generated in DEM analyses can be created using the GIS tool, which can also produce hydrological spatial data. The general S/W that includes hydrological spatial data-creating tools based on DEM analyses, such as HyGIS and ArcGIS, can be used for the GIS tool, which creates input data. The GRM uses a ASCII raster format. Thus, data of various formats created using the GIS tool can be converted to ASCII format and applied to the model.

Table 4.1 Input data for the GRM

Classification	Data	Format	Applicable Original Data	Note
Topography	Watershed boundary Slope Flow direction Flow accumulation Stream Channel width	ASCII	DEM (digital topography map, Remote Sensing (RS) images)	Stream network and channel base width data are optional
Land Cover	Land cover map	ASCII	Land cover map RS image	The GRM parameters of 7 classifications of land cover are given as reference values
Soil	Soil texture Soil depth	ASCII	Detailed soil map Global soil data	
Hydrological	Rainfall	ASCII Text	Observed Estimated	Raster format time-series and time series of mean rainfall are optional
	Discharge	Text ASCII	Observed Estimated	Text data is a value for a grid and ASCII data is the value for all the stream grids. Text and ASCII are optional.
	Soil saturation ratio	ASCII	Observed Estimated	Instead of initial saturation ratio parameter text value, ASCII data for all grids in a watershed can be used. (optional)

The flow direction data used by the GRM is unidirectional, created with the D8 method. The flow direction is determined based on the value in the flow direction raster data (flow direction index). The selections of the 1 o'clock position as 1 (northeast, NE) or 12 o'clock position as 1 (north, N) both are applicable in the GRM. When the flow direction data is created from DEM data, the index corresponding the flow direction can be different according to the GIS S/W and thus caution must be needed when applying the flow direction data.



(a) Index starting at 12 o'clock　　(b) Index starting at 1 o'clock

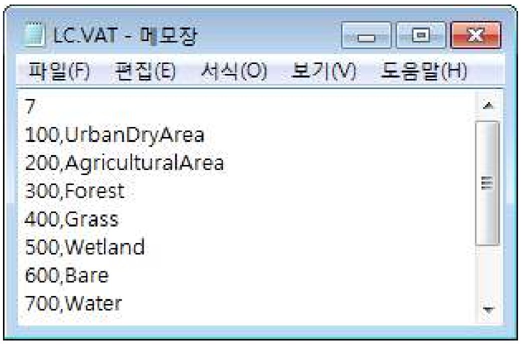
Fig 4.1 Flow direction index

4.1 Spatial data

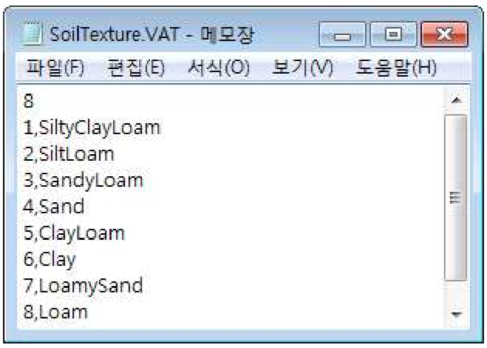
The GRM uses raster data in ASCII format as input data; the raster data required to run the GRM is shown in the table below. The values of raster files for land cover, soil texture, and soil depth are entered in numbers. Therefore, a response between the numbers in each raster file and the properties to be used for actual flow analysis is required. The GRM uses a Value Attribute Table (VAT) text file for this response. The VAT files can be manually created by users with a text editor or automatically created using GIS software. The model parameters related to land cover and soil are saved in the GRM static database (i.e., C:₩GRM₩GRMStaticDB.xml), which can be used to set the parameter default values for each property.

Table 4.2 Spatial input data for the GRM

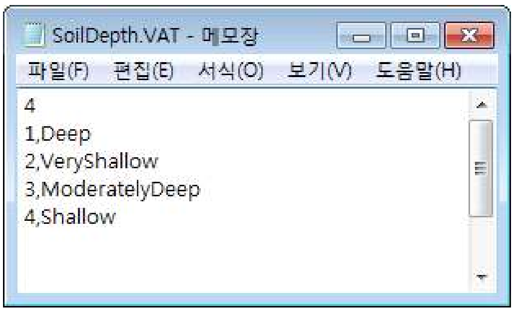
Data	Definition	Data type
Watershed	Raster file with distinguished watershed boundaries	Integer
Slope	Steepest slope data assigned to each grid	Double
Flow direction	Unidirectional flow direction according to the D8 method	Integer
Flow accumulation	Flow accumulation	Integer
Stream	Stream network	Integer
Channel width	Channel base width data for the same location as the stream network grid	Single
Soil texture	Soil texture	Integer
Soil depth	Soil depth	Integer
Land cover	Land cover	Integer



(a) Land Cover VAT File



(b) Soil Texture VAT File



(c) Soil Depth VAT File

Fig. 4.2 Examples of VAT files using notepad

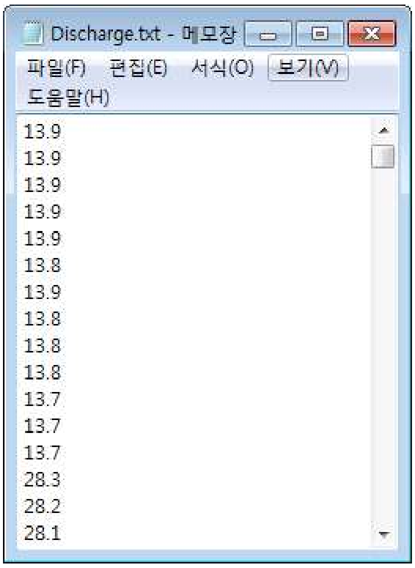
4.2 Hydrological data

The mean areal rainfall of a watershed and spatially distributed rainfall raster files can be selected and applied for the GRM. The distributed rainfall raster file can be either created from spatial interpolation of point rainfall observed at a rainfall gauge or spatially distributed rainfall data such as radar or numerical prediction data. Rainfall and flow data are saved as text files. Here, the mean areal rainfall and discharge are saved as time series (text). When the grid-based distributed rainfall ASCII raster file is used, a list of rainfall time series files (ACIII files) is saved.

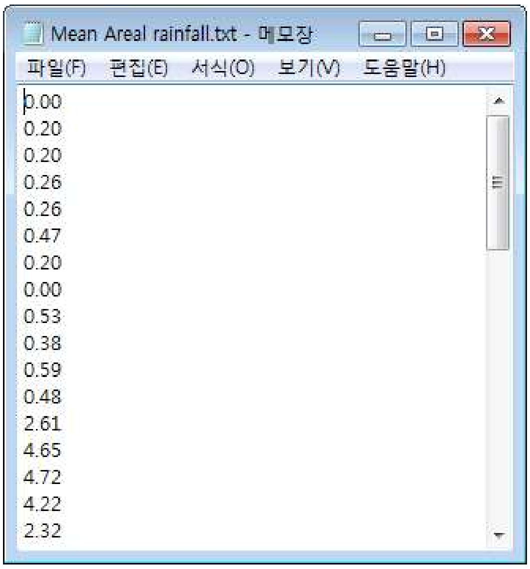
When there is a soil saturation ratio raster data from observation or estimation, the data save as ASCII format can be applied. If this data is used, initial soil saturation ratio parameter is not estimated during runoff simulation.

Table 4.3 Hydrological input data for the GRM

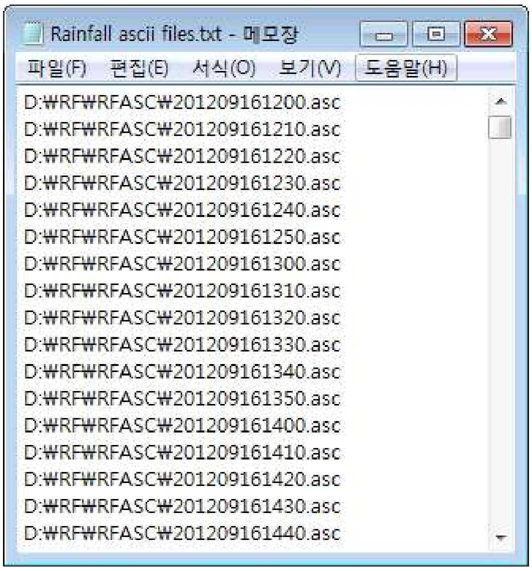
Data	Definition	Data type
Rainfall	Mean areal rainfall of a watershed (mm), text file	Single
	Grid-based distributed rainfall (mm), ASCII file	
Discharge	Observed flow (CMS)	Single
	Simulated flow (CMS)	
Soil saturation ratio	Soil saturation ratio saved as ASCII format for all grids in a watershed	Single



(a) Discharge input file



(b) Mean areal rainfall input file



(c) ASCII raster rainfall input file

Fig. 4.3 Examples of hydrologic input data files

4.3 GRM project file

The GRM runs using project file (.gmp). Running the GRM on a console window requires setting the gmp file as the switch.

(i.e., D:₩grm.exe "projectFilePahAndName.gmp")

The gmp file is saved in xml format. The tables, contents of tables, field names and description for each table, and settings for each field included in the gmp files are shown in the following table. Users can create gmp file with a text editor; however, it is difficult to intuitively determine certain parameters (control volume ID, maximum flow accumulation, grid location, etc.). Thus, it is convenient to automatically create gmp files using GUI S/W (MapWindow plug-in, QGIS plug-in, etc.) of the GRM.

Table 4.4 Descriptions of the tables in the GRM project xml file

Table name	Description	Required
ProjectSettings	Environment settings, input files, and global parameters to run the model	Required
SubWatershedSettings	Parameters set for each subwatershed	Required
WatchPoints	Grid information subjected to output selected by user	Required
FlowControlGrid	Grids subjected to flow control selected by user, flow control type, data properties, reservoir specifications, and ROM data	Required
GreenAmptParameter	Soil texture data properties and Green–Ampt parameters values applied to flow simulations	Required
SoilDepth	Soil depth data properties and soil depth values applied to flow simulations	Required
LandCover	Land cover data properties and roughness coefficient and impervious ratio applied to flow simulations	Required

Table 4.5 ProjectSettings table

Field name	Description	Data type	Required
ProjectFile	gmp file path and name	String	Required
GRMStaticDB	GRM Static DB file path and name	String	Required
GRMSimulationType	Modeling type (SingleEvent or RealTme)	String	Required
WatershedFile	Watershed ASCII file path and name	String	Required
SlopeFile	Slope ASCII file path and name	String	Required
FlowDirectionFile	Flow direction ASCII file path and name	String	Required
FlowAccumFile	Flow accumulation ASCII file path and name	String	Required
StreamFile	Stream ASCII file path and name	String	Required
ChannelWidthFile	Channel base width ASCII file path and name	String	Optional
LandCoverDataType	Land cover data type (File or Constant)	String	Required
LandCoverFile	Land cover ASCII file path and name, only used when 'File' is selected for LandCoverDataType	String	Optional
LandCoverVATFile	Land cover ASCII file VAT file path and name, only used if 'File' is selected for LandCoverDataType	String	Optional
ConstantRoughness-Coeff	Land cover roughness coefficient, only used if 'Constant' is selected for LandCoverDataType	Single	Optional
ConstantImpervious-Ratio	Impervious ratio, only used if 'Constant' is selected for LandCoverDataType	Single	Optional
SoilTextureDataType	Soil texture data type (File or Constant)	String	Required
SoilTextureFile	Soil texture ASCII file path and name, only used if 'File' is selected for SoilTextureDataType	String	Optional
SoilTextureVATFile	Soil texture ASCII file VAT file path and name, only used if 'File' is selected for SoilTextureDataType	String	Optional
ConstantSoilPorosity	Soil porosity, only used if 'Constant' is selected for SoilTextureDataType	Single	Optional
ConstantSoilEffPorosity	Effective soil porosity, only used if 'Constant' is selected for SoilTextureDataType	Single	Optional
ConstantSoilWetting-FrontSuctionHead	Wetting front soil suction head, only used if 'Constant' is selected for SoilTextureDataType	Single	Optional
ConstantSoilHydraulic-Conductivity	Hydraulic conductivity, only used if 'Constant' is selected for SoilTextureDataType	Single	Optional

<ProjectSettings table (continued)>

Field name	Description	Data type	Required
SoilDepthDataType	Soil depth data type (File or Constant)	String	Required
SoilDepthFile	Soil depth ASCII file path and name, only used when 'File' is selected for SoilDepthDataType	String	Optional
SoilDepthVATFile	Soil depth ASCII file VAT file path and name, only used when 'File' is selected for SoilDepthDataType	String	Optional
ConstantSoilDepth	Soil depth, only used when 'Constant' is selected for SoilDepthDataType	Single	Optional
InitialSoilSaturation-RatioFile	Initial soil saturation ratio ASCII file path and name	Single	Optional
InitialChannelFlowFile	Initial stream flow ASCII file path and name. Values are set only for stream cell.	Single	Optional
RainfallDataType	Rainfall data type (TextFileMAP or TextFileASCgrid)	String	Required
RainfallInterval	Rainfall data time interval (min)	Integer	Required
RainfallStartsFrom	Rainfall data start time, only used when time is selected (i.e., 2012-09-16 12:00 LST)	String	Optional
RainfallEndsAt	Rainfall data end time, only used when time is selected (i.e., 2012-09-16 12:00 LST)	String	Optional
RainfallDuration	Rainfall data duration (min)	Integer	Required
RainfallDataFile	Rainfall data file path and name	String	Required
FlowDirectionType	Flow direction data type (StartsFromNE or StartsFromN)	String	Required
GridCellSize	Grid cell size (m)	Integer	Required
IsParallel	Parallel computation (true or false), 'false' is applied when it is not set	Boolean	Optional
SimulStartingTime	Simulation start time, only used when time is selected (i.e., 2012-09-16 12:00 LST)	String	Optional
SimulEndingTime	Simulation end time, only used when time is selected (i.e., 2012-09-18 12:00 LST)	String	Optional
ComputationalTimeStep	Computational time step (min)	Integer	Required
IsFixedTimeStep	Fixed calculation time step used (true or false), 'true' is applied when nothing is selected	Boolean	Optional
SimulationDuration	Simulation duration (h)	Integer	Required
OutputTimeStep	Output time step (min)	Integer	Required
SimulateInfiltration	Infiltration simulation (true or false)	Boolean	Required
SimulateSubsurface-Flow	Subsurface flow simulation (true or false)	Boolean	Required

<ProjectSettings table (continued)>

Field name	Description	Data type	Required
SimulateBaseFlow	Base flow simulation (true or false)	Boolean	Required
SimulateFlowControl	Flow control simulation (true or false)	Boolean	Required
WatchPointCount	Number of watch points	Integer	Required
CrossSectionType	Channel cross section type (CSSingle or CSCompound)	Single	Required
SingleCSChannel-WidthType	Channel base width calculation method (CWGeneration or CWEquation)	String	Required
ChannelWidthEQc	Coefficient of the channel base width equation, only used if 'CWEquation' is selected for SingleCSChannelWidthType	Single	Optional
ChannelWidthEQd	Coefficient of the channel base width equation, only used if 'CWEquation' is selected for SingleCSChannelWidthType	Single	Optional
ChannelWidthEQe	Coefficient of the channel base width equation, only used if 'CWEquation' is selected for SingleCSChannelWidthType	Single	Optional
ChannelWidthMost-DownStream	Channel base width at the lowest downstream end of stream, only used if 'CSCompound' is selected for CrossSectionType	Single	Optional
LowerRegionHeight	Low-water area height of compound cross section, only used if 'CSCompound' is selected for CrossSectionType	Single	Optional
LowerRegionBaseWidth	Channel base width of low-water area of compound cross section, only used if 'CSCompound' is selected for CrossSectionType	Single	Optional
UpperRegionBaseWidth	Channel base width of high-water area of compound cross section, only used if 'CSCompound' is selected for CrossSectionType	Single	Optional
CompoundCSIniFlow-Depth	Initial flow depth at compound cross section, only used if 'CSCompound' is selected for CrossSectionType	Single	Optional
CompoundCSChannel-WidthLimit	Range of the channel base width limit applicable to channel compound cross section (Single cross section is applied for stream sections with a channel base width smaller than this limit), only used if 'CSCompound' is selected for CrossSectionType	Single	Optional
BankSideSlopeRight	Right bank slope	Single	Required
BankSideSlopeLeft	Left bank slope	Single	Required
FlowAccumulationMax	Maximum flow accumulation	Integer	Required

<ProjectSettings Table (continued)>

Field name	Description	Data type	Required
MakeIMGFile	Raster image file creation (true or false)	Boolean	Required
MakeASCFile	ASCII raster file creattion (true or false)	Boolean	Required
MakeSoilSaturation-DistFile	Write soil saturation distribution file (true or false) (either MakeIMGFile or MakeASCFile must be true for it to be applied)	Boolean	Required
MakeRfDistFile	Write rainfall distribution file (true or false) (either MakeIMGFile or MakeASCFile must be true for it to be applied)	Boolean	Required
MakeRFaccDistFile	Write flow accumulation distribution file (true or false) (either MakeIMGFile or MakeASCFile must be true for it to be applied)	Boolean	Required
MakeFlowDistFile	Write flow distribution file (true or false) (either MakeIMGFile or MakeASCFile must be true for it to be applied)	Boolean	Required
MakeOutput-DischargeOnly	Wite only discharge value from simulation results (true or false)	Boolean	Required
AboutThisProject	Project description entered by user	String	Optional
AboutWatershed	Watershed description entered by user	String	Optional
AboutLandCoverMap	Land cover map description entered by user	String	Optional
AboutSoilMap	Soil texture map description entered by user	String	Optional
AboutSoilDepthMap	Soil depth map description entered by user	String	Optional
AboutRainfall	Rainfall data description entered by user	String	Optional
ProjectSavedTime	"Project saved" time, automatically saved by the S/W	String	Optional
ComputerName	Computer name, automatically saved by the S/W	String	Optional
ComputerUserName	Computer user name, automatically saved by the S/W	String	Optional
GRMVersion	Version of used GRM, automatically saved by the S/W	String	Optional

Table 4.6 SubWatershedSettings table

Field name	Description	Data type	Required
ID	Watershed number Integer greater than 0 is entered as a watershed identifier	Integer	Required
IniSaturation	Initial saturation parameter, if soil saturation ratio ASCII file is applied, this parameter is not used	Single	Required
MinSlopeOF	Parameter of minimum bed slope condition for overland flow	Single	Required
MinSlopeChBed	Parameter of minimum bed slope condition for channel flow	Single	Required
MinChBaseWidth	Minimum channel base width parameter	Single	Required
ChRoughness	Channel roughness coefficient parameter	Single	Required
DryStreamOrder	Dry stream order condition parameter; the stream order is entered; in case of entering 0, the dry stream order is not applied	Integer	Required
IniFlow	Initial flow parameter, the flow observed at the simulation start time at the lowest stream end of a watershed is entered; if initial stream flow ASCII file is applied, this parameter is not used	Single	Required
CalCoefLCRough-ness	Roughness coefficient calibration parameter selected according to land cover	Single	Required
CalCoefPorosity	Soil porosity calibration parameter	Single	Required
CalCoefWFSuction-Head	Wetting front soil suction head calibration parameter	Single	Required
CalCoefHydraulicK	Soil hydraulic conductivity calibration parameter	Single	Required
CalCoefSoilDepth	Soil depth calibration parameter	Single	Required
UserSet	If parameters of the current watershed were selected by the user or not (true or false)	Boolean	Required

Table 4.7 WatchPoints table

Field name	Description	Data type	Required
CVID	ID of WatchPoint grid control volume, ID is assigned starting from the top left grid of the watershed and increasing x (column) numbers first followed by y (row) numbers, CVID starts from 1 and its maximum value is the number of grids within a watershed (grids with values greater than 0 in the watershed file)	Integer	Required
Name	Watch point name	String	Required
FlowAccu-mulation	Flow accumulation	Integer	Required
CellType	Flow type (1 chosen from OverlandFlow, ChannelFlow, and ChannelNOverlandFlow)	String	Required
ColX	Watch point grid column number, numbering starts from top left corner (0,0)	Integer	Required
RowY	Watch point grid row number, numbering starts from top left corner (0,0)	Integer	Required

Table 4.8 FlowControlGrid table

Field name	Description	Data type	Required
CVID	Control volume number for FlowControlGrid, entered with the same method as for CVID in the WatchPoints table	Integer	Required
ColX	Column number for FlowControlGrid, entered with the same method as for ColX in the WatchPoints table	Integer	Required
RowY	Row number for FlowControlGrid, entered with the same method as Row Y in the WatchPoints table	Integer	Required
Name	Name of FlowControlGrid	String	Required
ControlType	Flow control type (1 chosen from ReservoirOutflow, Inlet, SinkFlow, SourceFlow, and ReservoirOperation)	String	Required
DT	Flow data time interval (min)	Integer	Required
FlowDataFile	Flow data file path and name, "ReservoirOperation" is entered when ControlType is ReservoirOperation	String	Required

<FlowControlGrid table (continued)>

Field name	Description	Data type	Required
IniStorage	Reservoir initial storage, only used when ControlType is ReservoirOperation	Single	Optional
MaxStorage	Reservoir maximum storage, only used when ControlType is ReservoirOperation	Single	Optional
MaxStorageR	Reservoir maximum available storage ratio, only used when ControlType is ReservoirOperation	Single	Optional
ROType	Reservoir operation type (1 chosen from AutoROM, RigidROM, ConstantQ, and SDEqation)	String	Optional
ROConstQ	Constant discharge value (CMS), applied when ROType is ConstantQ	Single	Optional
ROConstQDur-ation	Constant discharge duration (h), applied when ROType is ConstantQ	Integer	Optional
ROSDEqA	Storage–discharge relationship coefficient, applied when ROType is SDEqation, relationship eq. must be entered in source code when establishing a flood analysis system	Single	Optional
ROSDEqB	Storage–discharge relationship coefficient, applied when ROType is SDEqation, relationship eq. must be entered in source code when establishing a flood analysis system	Single	Optional
ROSDEqC	Storage–discharge relationship coefficient, applied when ROType is SDEqation, relationship eq. must be entered in source code when establishing a flood analysis system	Single	Optional
ROSDEqD	Storage–discharge relationship coefficient, applied when ROType is SDEqation, relationship eq. must be entered in source code when establishing a flood analysis system	Single	Optional
ROSDEqE	Storage–discharge relationship coefficient, applied when ROType is SDEqation, relationship eq. must be entered in source code when establishing a flood analysis system	Single	Optional
ROSDEqF	Storage–discharge relationship coefficient, applied when ROType is SDEqation, relationship eq. must be entered in source code when establishing a flood analysis system	Single	Optional

Table 4.9 GreenAmptParameter table

Field name	Description	Data type	Required
GridValue	Grid value in soil texture raster file	Integer	Required
USERSoil	Name of soil texture attribute selected by user	String	Required
GRMCode	Soil texture code (refer to "SoilTextureCode" field value in GreenAmptSoilParameter table of the static DB)	String	Required
GRMTextureE	Soil texture English name (refer to "SoilTextureE" field value in GreenAmptSoilParameter table of the static DB)	String	Required
GRMTextureK	Soil texture Korean name (refer to "SoilTextureK" field value in GreenAmptSoilParameter table of the static DB)	String	Required
Porosity	Porosity	Single	Required
EffectivePorosity	Effective porosity	Single	Required
WFSoilSuctionHead	Wetting front soil suction head	Single	Required
HydraulicConduc-tivity	Hydraulic conductivity	Single	Required

Table 4.10 SoilDepth table

Field name	Description	Data type	Required
GridValue	Grid value in the soil depth raster file	Integer	Required
UserDepthClass	Soil depth attributey name selected by user	String	Required
GRMDepthCode	Soil depth code (refer to "SoilDepthCode" field value in the SoilDepthParameter table of the static DB)	String	Required
SoilDepthClassE	Soil depth English name (refer to "SoilDepthClassE" field value in the SoilDepthParameter table of the static DB)	String	Required
SoilDepthClassK	Soil depth Korean name (refer to "SoilDepthClassK" field value in the SoilDepthParameter table of the static DB)	String	Required
SoilDepth	Soil depth value	Single	Required

Table 4.11 LandCover table

Field name	Description	Data type	Required
GridValue	Grid value in land cover raster file	Integer	Required
UserLandCover	Land cover attribute name selected by user	String	Required
GRMLandCover-Code	Land cover code (refer to "LandCoverCode" field value in the LandCoverParameter table of the static DB)	String	Required
GRMLandCoverE	Land cover English name (refer to "LandCoverE" field value in the LandCoverParameter table of the static DB)	String	Required
GRMLandCoverK	Land cover Korean name (refer to "LandCoverK" field value in the LandCoverParameter table of the static DB)	String	Required
RoughnessCoeff-icient	Roughness coefficient	Single	Required
ImperviousRatio	Impervious ratio	Single	Required

4.4 GRM Static database

The GRM static database saves the default reference values for soil and land cover parameters used in the GRM model in xml format. Default values for soil and land cover parameters can be selected using the GRM Static database when a GRM project file (.gmp) is created. Table descriptions and specifications for each table of the GRM static database are shown below.

Table 4.12 Table Definitions for a GRM Static xml file

Table name	Description
GreenAmptSoilParameter	Green–Ampt parameter values according to soil texture
SoilDepthParameter	Soil depth according to soil depth classification
LandCoverParameter	Roughness coefficient and impervious ratio according to land cover properties, land cover properties categorized into 7 are set as default values

Table 4.13 GreenAmptSoilParameter table

Field name	Description	Data type
SoilTextureE	Soil texture, English name	String
SoilTextureK	Soil texture, Korean name	String
SoilTextureCode	Soil texture code	String
PorosityMin	Minimum porosity	Single
PorosityMax	Maximum porosity	Single
PorosityDefault	Default porosity	Single
EffectivePorosityMin	Minimum effective porosity	Single
EffectivePorosityMax	Maximum effective porosity	Single
EffectivePorosityDefault	Default effective porosity	Single
ResidualMoistureContent	Residual moisture content	Single
WFSoilSuctionHeadMin	Minimum wetting front soil suction head	Single
WFSoilSuctionHeadMax	Maximum wetting front soil suction head	Single
WFSoilSuctionHeadDefault	Default wetting front soil suction head	Single
HydraulicConductivity	Hydraulic conductivity	Single

Table 4.14 SoilDepthParameter table

Field name	Description	Data type
SoilDepthCode	Soil depth code	String
SoilDepthClassE	Soil depth classification, English name	String
SoilDepthClassK	Soil depth classification, Korean name	String
SoilDepthMin	Minimum soil depth	Single
SoilDepthMax	Maximum soil depth	Single
SoilDepthDefault	Default soil depth	Single

Table 4.15 LandCoverParameter table

Field name	Description	Data type
LandCoverE	Land cover, English name	String
LandCoverK	Land cover, Korean name	String
LandCoverCode	Land cover code	String
RoughnessCoefficient	Roughness coefficient	Single
ImperviousRatio	Impervious ratio	Single

5. Output data

All hydrologic components of the GRM are calculated from every grid existing within a watershed and the user selects a grid cell for the calculation output, which becomes the 'watch point'. Calculations from a grid cell set as the watch point are saved as a text file if GRMSSimulationType is set as SingleEvent in ProjectSettings of the project file (gmp). If GRMSimulationType is set as RealTime, they are saved as a text file and database (SQL, etc.). And simulation results for all grids within a watershed can be saved as ASCII raster file and image (png) file (by using MakeIMGFile and MakeASCFile options in gmp file).

The calculation results mainly include discharge data. The water depth should not be calculated from a hydrologic model, such as the GRM, but from a hydraulic stream model or the water level–discharge relationship equation. The calculation result files created for each watch point include various results such as flow and saturation.

Table 5.1 GRM simulation output file

Simulation Type	Output File	Content
SingleEvent	*[Project name]*Discharge.out	Flow calculation results, mean rainfall for the watershed, and used calculation time for every watch point
	*[Project name]*FCData.out	Flow control discharge data for every flow control grid (only outputted if the flow control is simulated)
	*[Project name]*FCStorage.out	Reservoir storage for every watch point (only saved when the flow control is simulated and ROM is applied)
	*[Project name]*RFUpMean.out	Mean upstream rainfall for every watch point
	*[Project name]*WP_-[*watchpoint name]*.out	All calculation results outputted by a corresponding watch point (file created for every watch point)
RealTme	*[Project name]*RealTime_-[*watchpoint name]*.out	Upstream watershed mean rainfall and discharge from corresponding watch points
	Saved in DB	Upstream watershed mean rainfall and discharge from corresponding watch points
ASCII file		Distributions of discharge, soil saturation ratio, incremental rainfall, and cumulative rainfall are saved in ASCII files
Image file		Distributions of discharge, soil saturation ratio, incremental rainfall, and cumulative rainfall are saved in png files

6. GRM-PEST

The GRM provides a module that can calibrate a model by automatically coupling the GRM with PEST, a universal parameter estimation model (Doherty, 2010). The GRM-PEST can automatically create and run PEST input files through a modelling S/W that includes a GUI to run the GRM. Information on PEST input and output files and theoretical details can be found in the PEST model manual (Doherty, 2010) and a manual for GRM-PEST can be found in the GRM modeling software user manual.

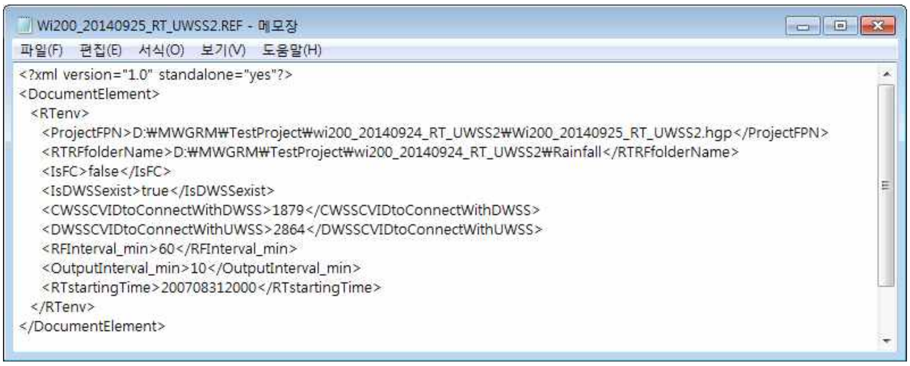
7. GRM Real Time

The GRM RT (Real Time) module is provided by API to establish a real-time flow analysis system. Real-time flow analysis uses distributed rainfall data created from real-time radar or watershed mean rainfall data collected in real time. Using distributed rainfall data requires clipping and resampling areas that correspond to topographical data of the targeted watershed with the same grid size and region.

Environmental parameters for real-time flow analysis are saved in xml text file (.REF). The REF file includes data on watershed system components and initial environmental conditions for flow simulations such as data on flow analysis project file (gmp), subwatersheds connected to the downstream (when multi-site calibration of connecting subwatersheds is used), real time flow control data, etc.

Table 7.1 File (.REF) structure for real-time flow analysis settings

File name	Field name	Description
[Project name].REF (xml)	ProjectFPN	Name and path of the GRM project file (gmp) of the current watershed
	RTRFfolderName	Real-time rainfall data receiving folder path
	IsFC	Whether FlowControlGrid is included or not
	IsDWSSexist	Whether subwatershed connected to the downstream exists or not
	CWSSCVIDtoConnectWithDWSS	Control volume ID (CVID) of the current watershed grid that is to be connected with the downstream subwatershed
	DWSSCVIDtoConnectWithUWSS	Control volume ID (CVID) of a downstream subwatershed grid that is to be connected with the current watershed
	RFInterval_min	Rainfall data time interval (min)
	OutputInterval_min	Output time interval (min)
	RTstartingTime	Real-time modeling start time (yyyymmddhhmm)


Wi200_20140925_RT_UWSS2.REF - 메모장
파일(F) 편집(E) 서식(O) 보기(V) 도움말(H)

```
<?xml version="1.0" standalone="yes"?>
<DocumentElement>
  <RTenv>
    <ProjectFPN>D:₩MWGRM₩TestProject₩wi200_20140924_RT_UWSS2₩Wi200_20140925_RT_UWSS2.hgp</ProjectFPN>
    <RTRFfolderName>D:₩MWGRM₩TestProject₩wi200_20140924_RT_UWSS2₩Rainfall</RTRFfolderName>
    <IsFC>false</IsFC>
    <IsDWSSexist>true</IsDWSSexist>
    <CWSSCVIDtoConnectWithDWSS>1879</CWSSCVIDtoConnectWithDWSS>
    <DWSSCVIDtoConnectWithUWSS>2864</DWSSCVIDtoConnectWithUWSS>
    <RFInterval_min>60</RFInterval_min>
    <OutputInterval_min>10</OutputInterval_min>
    <RTstartingTime>200708312000</RTstartingTime>
  </RTenv>
</DocumentElement>
```

Fig. 7.1 Example of a REF file

The GRMCore.dll is used to recreate the GRM RT in an application system. The GRMCore.dll recreates the GRM RT and provides the user API to run it as shown in the table below.

Table 7.2 API provided by GRMRTStarter

Class	Function
cRTStarter	New(fpn_REF As String) Instancing an object using the REF file - fpn_REF : REF file path and name
	SetUpAndStartGRMRT() Real-time flow analysis starts
	StopRTsimulation() Real-time flow analysis ends
	UpdateWSPars(ByVal wsid As Integer, iniSat As Single, minSlopeChannel As Single, roughnessChannel As Single, soilHydraulicCond As Single, applyIniFlow As Boolean, Optional iniFlow As Single = 0) As Boolean Memory updates for GRM parameters - wsid : subwatershed ID - iniSat : initial saturation - minSlopeChannel : minimum channel bed slope - roughnessChannel : channel roughness coefficient - soilHydraulicCond : soil hydraulic conductivity - applyIniFlow : whether or not initial flow was selected - iniFlow : initial flow (CMS)
	SaveParsToProjectFile() Save parameters in the GRM project file (.gmp)

Appendix

A. Example of a GRM project file (with one watershed and one watch point)

```xml
<?xml version="1.0" standalone="yes"?>
<GRMProject xmlns="http://tempuri.org/GRMProject.xsd">
    <ProjectSettings>
    <ProjectFile>C:₩GRM₩Sample₩SampleProject.gmp</ProjectFile>
    <GRMStaticDB>C:₩GRM₩GRMStaticdb.xml</GRMStaticDB>
    <GRMSimulationType>SingleEvent</GRMSimulationType>
    <WatershedFile>C:₩GRM₩Sample₩Data₩WiWatershed.asc</WatershedFile>
    <SlopeFile>C:₩GRM₩Sample₩Data₩Wi_Slope_ST.asc</SlopeFile>
    <FlowDirectionFile>C:₩GRM₩Sample₩Data₩WiFDir.asc</FlowDirectionFile>
    <FlowAccumFile>C:₩GRM₩Sample₩Data₩WiFAc.asc</FlowAccumFile>
    <StreamFile>C:₩GRM₩Sample₩Data₩WiStream6.asc</StreamFile>
    <ChannelWidthFile />
    <LandCoverDataType>File</LandCoverDataType>
    <LandCoverFile>C:₩GRM₩Sample₩Data₩wilc200.asc</LandCoverFile>
    <LandCoverVATFile>C:₩GRM₩Sample₩Data₩wilc200.vat</LandCoverVATFile>
    <SoilTextureDataType>File</SoilTextureDataType>
    <SoilTextureFile>C:₩GRM₩Sample₩Data₩wistext200.asc</SoilTextureFile>
    <SoilTextureVATFile>C:₩GRM₩Sample₩Data₩wistext200.vat</SoilTextureVATFile>
    <SoilDepthDataType>File</SoilDepthDataType>
    <SoilDepthFile>C:₩GRM₩Sample₩Data₩wisdepth200.asc</SoilDepthFile>
    <SoilDepthVATFile>C:₩GRM₩Sample₩Data₩wisdepth200.vat</SoilDepthVATFile>
    <RainfallDataType>TextFileMAP</RainfallDataType>
    <RainfallInterval>60</RainfallInterval>
    <RainfallDuration>3000</RainfallDuration>
    <RainfallDataFile>C:₩GRM₩Sample₩Data₩RF_MAP.txt</RainfallDataFile>
    <FlowDirectionType>StartsFromNE</FlowDirectionType>
    <GridCellSize>200</GridCellSize>
    <IsParallel>true</IsParallel>
    <ComputationalTimeStep>5</ComputationalTimeStep>
    <IsFixedTimeStep>true</IsFixedTimeStep>
    <SimulationDuration>80</SimulationDuration>
    <OutputTimeStep>60</OutputTimeStep>
    <SimulateInfiltration>true</SimulateInfiltration>
    <SimulateSubsurfaceFlow>true</SimulateSubsurfaceFlow>
    <SimulateBaseFlow>true</SimulateBaseFlow>
    <SimulateFlowControl>false</SimulateFlowControl>
    <WatchPointCount>1</WatchPointCount>
    <CrossSectionType>CSSingle</CrossSectionType>
    <SingleCSChannelWidthType>CWEquation</SingleCSChannelWidthType>
```

```xml
    <ChannelWidthEQc>1.698</ChannelWidthEQc>
    <ChannelWidthEQd>0.318</ChannelWidthEQd>
    <ChannelWidthEQe>0.5</ChannelWidthEQe>
    <ChannelWidthMostDownStream>260</ChannelWidthMostDownStream>
    <LowerRegionHeight>0</LowerRegionHeight>
    <LowerRegionBaseWidth>0</LowerRegionBaseWidth>
    <UpperRegionBaseWidth>0</UpperRegionBaseWidth>
    <CompoundCSIniFlowDepth>0</CompoundCSIniFlowDepth>
    <CompoundCSChannelWidthLimit>0</CompoundCSChannelWidthLimit>
    <BankSideSlopeRight>1.5</BankSideSlopeRight>
    <BankSideSlopeLeft>1.5</BankSideSlopeLeft>
    <FlowAccumulationMax>11733</FlowAccumulationMax>
    <MakeIMGFile>false</MakeIMGFile>
    <MakeASCFile>false</MakeASCFile>
    <MakeSoilSaturationDistFile>true</MakeSoilSaturationDistFile>
    <MakeRfDistFile>true</MakeRfDistFile>
    <MakeRFaccDistFile>true</MakeRFaccDistFile>
    <MakeFlowDistFile>true</MakeFlowDistFile>
    <MakeOutputDischargeOnly>false</MakeOutputDischargeOnly>
    <ProjectSavedTime>2016-12-20  18:12</ProjectSavedTime>
    <ComputerName>CYS-PC</ComputerName>
    <ComputerUserName />
    <GRMVersion>2017</GRMVersion>
  </ProjectSettings>
  <SubWatershedSettings>
    <ID>1</ID>
    <IniSaturation>0.96</IniSaturation>
    <MinSlopeOF>0.0001</MinSlopeOF>
    <MinSlopeChBed>0.0005</MinSlopeChBed>
    <MinChBaseWidth>30</MinChBaseWidth>
    <ChRoughness>0.045</ChRoughness>
    <DryStreamOrder>0</DryStreamOrder>
    <IniFlow>94.8</IniFlow>
    <CalCoefLCRoughness>1</CalCoefLCRoughness>
    <CalCoefPorosity>1</CalCoefPorosity>
    <CalCoefWFSuctionHead>1</CalCoefWFSuctionHead>
    <CalCoefHydraulicK>1.3</CalCoefHydraulicK>
    <CalCoefSoilDepth>1</CalCoefSoilDepth>
    <UserSet>true</UserSet>
  </SubWatershedSettings>
  <WatchPoints>
    <CVID>1879</CVID>
    <Name>MD</Name>
    <FlowAccumulation>11733</FlowAccumulation>
    <CellType>ChannelFlow</CellType>
    <ColX>21</ColX>
```

```
    <RowY>39</RowY>
  </WatchPoints>
  <GreenAmptParameter>
    <GridValue>1</GridValue>
    <USERSoil>미사질식양토 </USERSoil>
    <GRMCode>SiCL</GRMCode>
    <GRMTextureE>SiltyClayLoam</GRMTextureE>
    <GRMTextureK>미사질식양토</GRMTextureK>
    <Porosity>0.471</Porosity>
    <EffectivePorosity>0.432</EffectivePorosity>
    <WFSoilSuctionHead>27.3</WFSoilSuctionHead>
    <HydraulicConductivity>0.1</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>2</GridValue>
    <USERSoil>미사질양토</USERSoil>
    <GRMCode>SiL</GRMCode>
    <GRMTextureE>SiltLoam</GRMTextureE>
    <GRMTextureK>미사질양토</GRMTextureK>
    <Porosity>0.501</Porosity>
    <EffectivePorosity>0.486</EffectivePorosity>
    <WFSoilSuctionHead>16.68</WFSoilSuctionHead>
    <HydraulicConductivity>0.65</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>3</GridValue>
    <USERSoil>사양토</USERSoil>
    <GRMCode>SL</GRMCode>
    <GRMTextureE>SandyLoam</GRMTextureE>
    <GRMTextureK>사양토</GRMTextureK>
    <Porosity>0.453</Porosity>
    <EffectivePorosity>0.412</EffectivePorosity>
    <WFSoilSuctionHead>11.01</WFSoilSuctionHead>
    <HydraulicConductivity>1.09</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>4</GridValue>
    <USERSoil>사토</USERSoil>
    <GRMCode>S</GRMCode>
    <GRMTextureE>Sand</GRMTextureE>
    <GRMTextureK>사토</GRMTextureK>
    <Porosity>0.437</Porosity>
    <EffectivePorosity>0.417</EffectivePorosity>
    <WFSoilSuctionHead>4.95</WFSoilSuctionHead>
    <HydraulicConductivity>11.78</HydraulicConductivity>
  </GreenAmptParameter>
```

```
<GreenAmptParameter>
  <GridValue>5</GridValue>
  <USERSoil>식토</USERSoil>
  <GRMCode>C</GRMCode>
  <GRMTextureE>Clay</GRMTextureE>
  <GRMTextureK>식토</GRMTextureK>
  <Porosity>0.475</Porosity>
  <EffectivePorosity>0.385</EffectivePorosity>
  <WFSoilSuctionHead>31.63</WFSoilSuctionHead>
  <HydraulicConductivity>0.03</HydraulicConductivity>
</GreenAmptParameter>
<GreenAmptParameter>
  <GridValue>6</GridValue>
  <USERSoil>양질사토</USERSoil>
  <GRMCode>LS</GRMCode>
  <GRMTextureE>LoamySand</GRMTextureE>
  <GRMTextureK>양질사토</GRMTextureK>
  <Porosity>0.437</Porosity>
  <EffectivePorosity>0.401</EffectivePorosity>
  <WFSoilSuctionHead>6.13</WFSoilSuctionHead>
  <HydraulicConductivity>2.99</HydraulicConductivity>
</GreenAmptParameter>
<GreenAmptParameter>
  <GridValue>7</GridValue>
  <USERSoil>양토</USERSoil>
  <GRMCode>L</GRMCode>
  <GRMTextureE>Loam</GRMTextureE>
  <GRMTextureK>양토</GRMTextureK>
  <Porosity>0.463</Porosity>
  <EffectivePorosity>0.434</EffectivePorosity>
  <WFSoilSuctionHead>8.89</WFSoilSuctionHead>
  <HydraulicConductivity>0.34</HydraulicConductivity>
</GreenAmptParameter>
<LandCover>
  <GridValue>1</GridValue>
  <UserLandCover>수역</UserLandCover>
  <GRMLandCoverCode>WATR</GRMLandCoverCode>
  <GRMLandCoverE>Water</GRMLandCoverE>
  <GRMLandCoverK>수역</GRMLandCoverK>
  <RoughnessCoefficient>0.03</RoughnessCoefficient>
  <ImperviousRatio>1</ImperviousRatio>
</LandCover>
<LandCover>
  <GridValue>2</GridValue>
  <UserLandCover>시가화/건조지역</UserLandCover>
  <GRMLandCoverCode>URBN</GRMLandCoverCode>
```

```
    <GRMLandCoverE>Urban</GRMLandCoverE>
    <GRMLandCoverK>시가화/건조지역</GRMLandCoverK>
    <RoughnessCoefficient>0.015</RoughnessCoefficient>
    <ImperviousRatio>0.853</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>3</GridValue>
    <UserLandCover>나지</UserLandCover>
    <GRMLandCoverCode>BARE</GRMLandCoverCode>
    <GRMLandCoverE>Bare</GRMLandCoverE>
    <GRMLandCoverK>나지</GRMLandCoverK>
    <RoughnessCoefficient>0.02</RoughnessCoefficient>
    <ImperviousRatio>0.442</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>4</GridValue>
    <UserLandCover>습지</UserLandCover>
    <GRMLandCoverCode>WTLD</GRMLandCoverCode>
    <GRMLandCoverE>Wetland</GRMLandCoverE>
    <GRMLandCoverK>습지</GRMLandCoverK>
    <RoughnessCoefficient>0.07</RoughnessCoefficient>
    <ImperviousRatio>1</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>5</GridValue>
    <UserLandCover>초지</UserLandCover>
    <GRMLandCoverCode>GRSS</GRMLandCoverCode>
    <GRMLandCoverE>Grass</GRMLandCoverE>
    <GRMLandCoverK>초지</GRMLandCoverK>
    <RoughnessCoefficient>0.15</RoughnessCoefficient>
    <ImperviousRatio>0.44</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>6</GridValue>
    <UserLandCover>산림지역</UserLandCover>
    <GRMLandCoverCode>FRST</GRMLandCoverCode>
    <GRMLandCoverE>Forest</GRMLandCoverE>
    <GRMLandCoverK>산림지역</GRMLandCoverK>
    <RoughnessCoefficient>0.1</RoughnessCoefficient>
    <ImperviousRatio>0.05</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>7</GridValue>
    <UserLandCover>농업지역</UserLandCover>
    <GRMLandCoverCode>AGRL</GRMLandCoverCode>
    <GRMLandCoverE>Agricultural Area</GRMLandCoverE>
```

```
      <GRMLandCoverK>농업지역</GRMLandCoverK>
      <RoughnessCoefficient>0.035</RoughnessCoefficient>
      <ImperviousRatio>0.391</ImperviousRatio>
    </LandCover>
    <SoilDepth>
      <GridValue>1</GridValue>
      <UserDepthClass>얕음</UserDepthClass>
      <GRMDepthCode>S</GRMDepthCode>
      <SoilDepthClassE>Shallow</SoilDepthClassE>
      <SoilDepthClassK>얕음</SoilDepthClassK>
      <SoilDepth>25</SoilDepth>
    </SoilDepth>
    <SoilDepth>
      <GridValue>2</GridValue>
      <UserDepthClass>보통</UserDepthClass>
      <GRMDepthCode>MDMS</GRMDepthCode>
      <SoilDepthClassE>ModeratelyDeepOrModeratelyShallow</SoilDepthClassE>
      <SoilDepthClassK>보통</SoilDepthClassK>
      <SoilDepth>75</SoilDepth>
    </SoilDepth>
    <SoilDepth>
      <GridValue>3</GridValue>
      <UserDepthClass>깊음</UserDepthClass>
      <GRMDepthCode>D</GRMDepthCode>
      <SoilDepthClassE>Deep</SoilDepthClassE>
      <SoilDepthClassK>깊음</SoilDepthClassK>
      <SoilDepth>125</SoilDepth>
    </SoilDepth>
    <SoilDepth>
      <GridValue>4</GridValue>
      <UserDepthClass>매우얕음</UserDepthClass>
      <GRMDepthCode>VS</GRMDepthCode>
      <SoilDepthClassE>VeryShallow</SoilDepthClassE>
      <SoilDepthClassK>매우얕음</SoilDepthClassK>
      <SoilDepth>10</SoilDepth>
    </SoilDepth>
  </GRMProject>
```

B. Example of a discharge output file (with one watch point)

Project name : 20170105_TestProject.gmp 2017-02-13 19:42 by GRM2017
Output data : Discharge[CMS]

DataTime	[MD]	Rainfall_Mean	FromStarting[sec]
0	94.20855	0	0
1	94.0425	0.2	0
2	94.428	0.2	0
3	95.26047	0.26	0
4	96.03966	0.26	0
5	96.43736	0.47	0
6	96.11489	0.2	1
7	95.18248	0	1
8	94.23956	0.53	1
9	93.73375	0.38	1
10	94.06026	0.59	1
11	94.83338	0.48	1
12	96.09375	2.61	2
13	97.88503	4.65	2
14	100.0421	4.72	2
15	102.9258	4.22	2
16	106.4718	2.32	2
17	112.0597	3.58	2
18	121.7061	3.32	2
19	138.5302	2.05	3
20	163.9824	7.77	3
21	197.7056	10.4	3
22	257.3974	8.92	3
23	389.864	9.7	3
24	627.8921	8.65	3
25	840.0349	7.32	4
26	966.605	4.41	4
27	984.8084	1.38	4
28	938.363	2.03	4
29	854.1904	2.7	4
30	753.0909	1.54	4
31	655.4438	0.16	5
32	570.9659	0.46	5
33	500.7943	0.12	5
34	441.0729	0.21	5
35	387.7297	0.15	5
36	341.2569	0.33	5
37	302.5433	0.33	5
38	271.0864	0.08	6

....

....

....

....

C. Example of a GRM project file (with multiple watersheds and multiple watch points)


```xml
<?xml version="1.0" standalone="yes"?>
<GRMProject xmlns="http://tempuri.org/GRMProject.xsd">
  <ProjectSettings>
    <ProjectFile>D:₩GRM₩TestProject₩gd_20170109.gmp</ProjectFile>
    <GRMStaticDB>C:₩GRM₩GRMStaticDB.xml</GRMStaticDB>
    <GRMSimulationType>SingleEvent</GRMSimulationType>
    <SimulStartingTime>2012-09-16 12:00</SimulStartingTime>
    <SimulEndingTime>2012-09-18 12:00</SimulEndingTime>
    <WatershedFile>D:₩GRM₩DataGD500₩GD500_Watershed.asc</WatershedFile>
    <SlopeFile>D:₩GRM₩DataGD500₩GD500_Slope_ST.asc</SlopeFile>
    <FlowDirectionFile>D:₩GRM₩DataGD500₩GD500_FDir.asc</FlowDirectionFile>
    <FlowAccumFile>D:₩GRM₩DataGD500₩GD500_FAc.asc</FlowAccumFile>
    <StreamFile>D:₩GRM₩DataGD500₩GD500_Stream3.asc</StreamFile>
    <ChannelWidthFile />
    <LandCoverDataType>File</LandCoverDataType>
    <LandCoverFile>D:₩GRM₩DataGD500₩GD500_LC.asc</LandCoverFile>
    <LandCoverVATFile>D:₩GRM₩DataGD500₩GD500_LC.vat</LandCoverVATFile>
    <SoilTextureDataType>File</SoilTextureDataType>
    <SoilTextureFile>D:₩GRM₩DataGD500₩GD500_STexture.asc</SoilTextureFile>
    <SoilTextureVATFile>D:₩GRM₩DataGD500₩GD500_STexture.vat</SoilTextureVATFile>
    <SoilDepthDataType>File</SoilDepthDataType>
    <SoilDepthFile>D:₩GRM₩DataGD500₩GD500_SDepth.asc</SoilDepthFile>
    <SoilDepthVATFile>D:₩GRM₩DataGD500₩GD500_SDepth.vat</SoilDepthVATFile>
    <RainfallDataType>TextFileASCgrid</RainfallDataType>
    <RainfallInterval>10</RainfallInterval>
    <RainfallStartsFrom>2012-09-16 12:00</RainfallStartsFrom>
    <RainfallEndsAt>2012-09-18 23:50</RainfallEndsAt>
    <RainfallDuration>3600</RainfallDuration>
    <RainfallDataFile>D:₩GRM₩DataGD500₩RF₩RF_gd500_201209161200.txt</RainfallDataFile>
    <GridCellSize>500</GridCellSize>
    <IsParallel>false</IsParallel>
    <ComputationalTimeStep>5</ComputationalTimeStep>
    <IsFixedTimeStep>true</IsFixedTimeStep>
    <SimulationDuration>48</SimulationDuration>
    <OutputTimeStep>10</OutputTimeStep>
    <SimulateInfiltration>true</SimulateInfiltration>
    <SimulateSubsurfaceFlow>true</SimulateSubsurfaceFlow>
    <SimulateBaseFlow>true</SimulateBaseFlow>
    <SimulateFlowControl>true</SimulateFlowControl>
    <WatchPointCount>4</WatchPointCount>
```

```
    <CrossSectionType>CSSingle</CrossSectionType>
    <SingleCSChannelWidthType>CWEquation</SingleCSChannelWidthType>
    <ChannelWidthEQc>1.698</ChannelWidthEQc>
    <ChannelWidthEQd>0.318</ChannelWidthEQd>
    <ChannelWidthEQe>0.5</ChannelWidthEQe>
    <LowerRegionHeight>0</LowerRegionHeight>
    <LowerRegionBaseWidth>0</LowerRegionBaseWidth>
    <UpperRegionBaseWidth>0</UpperRegionBaseWidth>
    <CompoundCSIniFlowDepth>0</CompoundCSIniFlowDepth>
    <CompoundCSChannelWidthLimit>0</CompoundCSChannelWidthLimit>
    <BankSideSlopeRight>1.5</BankSideSlopeRight>
    <BankSideSlopeLeft>1.5</BankSideSlopeLeft>
    <FlowAccumulationMax>17765</FlowAccumulationMax>
    <MakeIMGFile>false</MakeIMGFile>
    <MakeASCFile>false</MakeASCFile>
    <MakeSoilSaturationDistFile>false</MakeSoilSaturationDistFile>
    <MakeRfDistFile>false</MakeRfDistFile>
    <MakeRFaccDistFile>false</MakeRFaccDistFile>
    <MakeFlowDistFile>false</MakeFlowDistFile>
    <ProjectSavedTime>2017-05-30 12:20</ProjectSavedTime>
    <ComputerName>CYS-PC</ComputerName>
    <ComputerUserName />
    <GRMVersion>2017</GRMVersion>
  </ProjectSettings>
  <SubWatershedSettings>
    <ID>1</ID>
    <IniSaturation>1</IniSaturation>
    <MinSlopeOF>0.0001</MinSlopeOF>
    <MinSlopeChBed>0.0002</MinSlopeChBed>
    <MinChBaseWidth>50</MinChBaseWidth>
    <ChRoughness>0.055</ChRoughness>
    <DryStreamOrder>0</DryStreamOrder>
    <IniFlow>350</IniFlow>
    <CalCoefLCRoughness>1</CalCoefLCRoughness>
    <CalCoefPorosity>1</CalCoefPorosity>
    <CalCoefWFSuctionHead>1</CalCoefWFSuctionHead>
    <CalCoefHydraulicK>2</CalCoefHydraulicK>
    <CalCoefSoilDepth>1</CalCoefSoilDepth>
    <UserSet>true</UserSet>
  </SubWatershedSettings>
  <WatchPoints>
    <CVID>1018</CVID>
    <Name>gd_md</Name>
```

```xml
    <FlowAccumulation>17765</FlowAccumulation>
    <CellType>ChannelFlow</CellType>
    <ColX>12</ColX>
    <RowY>51</RowY>
  </WatchPoints>
  <WatchPoints>
    <CVID>1557</CVID>
    <Name>gd_gd</Name>
    <FlowAccumulation>16841</FlowAccumulation>
    <CellType>ChannelFlow</CellType>
    <ColX>39</ColX>
    <RowY>57</RowY>
  </WatchPoints>
  <WatchPoints>
    <CVID>1074</CVID>
    <Name>gd_add</Name>
    <FlowAccumulation>6401</FlowAccumulation>
    <CellType>ChannelFlow</CellType>
    <ColX>90</ColX>
    <RowY>51</RowY>
  </WatchPoints>
  <WatchPoints>
    <CVID>1534</CVID>
    <Name>gd_ihd</Name>
    <FlowAccumulation>5349</FlowAccumulation>
    <CellType>ChannelFlow</CellType>
    <ColX>108</ColX>
    <RowY>56</RowY>
  </WatchPoints>
  <FlowControlGrid>
    <CVID>1074</CVID>
    <ColX>90</ColX>
    <RowY>51</RowY>
    <Name>gd_fc_add</Name>
    <ControlType>Inlet</ControlType>
    <DT>10</DT>
    <FlowDataFile>D:₩GRM₩DataGD500₩FCdata₩gd_fc_add_201209161200.txt</FlowDataFile>
  </FlowControlGrid>
  <FlowControlGrid>
    <CVID>1534</CVID>
    <ColX>108</ColX>
    <RowY>56</RowY>
    <Name>gd_fc_ihd</Name>
```

```
    <ControlType>Inlet</ControlType>
    <DT>10</DT>
    <FlowDataFile>D:₩GRM₩DataGD500₩FCdata₩gd_fc_ihd_201209161200.txt</FlowDataFile>
  </FlowControlGrid>
  <GreenAmptParameter>
    <GridValue>1</GridValue>
    <USERSoil>미사질식양토</USERSoil>
    <GRMCode>SiCL</GRMCode>
    <GRMTextureE>SiltyClayLoam</GRMTextureE>
    <GRMTextureK>미사질식양토</GRMTextureK>
    <Porosity>0.471</Porosity>
    <EffectivePorosity>0.432</EffectivePorosity>
    <WFSoilSuctionHead>27.3</WFSoilSuctionHead>
    <HydraulicConductivity>0.1</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>2</GridValue>
    <USERSoil>미사질양토</USERSoil>
    <GRMCode>SiL</GRMCode>
    <GRMTextureE>SiltLoam</GRMTextureE>
    <GRMTextureK>미사질양토</GRMTextureK>
    <Porosity>0.501</Porosity>
    <EffectivePorosity>0.486</EffectivePorosity>
    <WFSoilSuctionHead>16.68</WFSoilSuctionHead>
    <HydraulicConductivity>0.65</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>3</GridValue>
    <USERSoil>사양토</USERSoil>
    <GRMCode>SL</GRMCode>
    <GRMTextureE>SandyLoam</GRMTextureE>
    <GRMTextureK>사양토</GRMTextureK>
    <Porosity>0.453</Porosity>
    <EffectivePorosity>0.412</EffectivePorosity>
    <WFSoilSuctionHead>11.01</WFSoilSuctionHead>
    <HydraulicConductivity>1.09</HydraulicConductivity>
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  <GreenAmptParameter>
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    <GRMCode>S</GRMCode>
    <GRMTextureE>Sand</GRMTextureE>
    <GRMTextureK>사토</GRMTextureK>
```

```
    <Porosity>0.437</Porosity>
    <EffectivePorosity>0.417</EffectivePorosity>
    <WFSoilSuctionHead>4.95</WFSoilSuctionHead>
    <HydraulicConductivity>11.78</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>5</GridValue>
    <USERSoil>식양토</USERSoil>
    <GRMCode>CL</GRMCode>
    <GRMTextureE>ClayLoam</GRMTextureE>
    <GRMTextureK>식양토</GRMTextureK>
    <Porosity>0.464</Porosity>
    <EffectivePorosity>0.309</EffectivePorosity>
    <WFSoilSuctionHead>20.88</WFSoilSuctionHead>
    <HydraulicConductivity>0.1</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>6</GridValue>
    <USERSoil>식토</USERSoil>
    <GRMCode>C</GRMCode>
    <GRMTextureE>Clay</GRMTextureE>
    <GRMTextureK>식토</GRMTextureK>
    <Porosity>0.475</Porosity>
    <EffectivePorosity>0.385</EffectivePorosity>
    <WFSoilSuctionHead>31.63</WFSoilSuctionHead>
    <HydraulicConductivity>0.03</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>7</GridValue>
    <USERSoil>양질사토</USERSoil>
    <GRMCode>LS</GRMCode>
    <GRMTextureE>LoamySand</GRMTextureE>
    <GRMTextureK>양질사토</GRMTextureK>
    <Porosity>0.437</Porosity>
    <EffectivePorosity>0.401</EffectivePorosity>
    <WFSoilSuctionHead>6.13</WFSoilSuctionHead>
    <HydraulicConductivity>2.99</HydraulicConductivity>
  </GreenAmptParameter>
  <GreenAmptParameter>
    <GridValue>8</GridValue>
    <USERSoil>양토</USERSoil>
    <GRMCode>L</GRMCode>
    <GRMTextureE>Loam</GRMTextureE>
```

```
    <GRMTextureK>양토</GRMTextureK>
    <Porosity>0.463</Porosity>
    <EffectivePorosity>0.434</EffectivePorosity>
    <WFSoilSuctionHead>8.89</WFSoilSuctionHead>
    <HydraulicConductivity>0.34</HydraulicConductivity>
  </GreenAmptParameter>
  <LandCover>
    <GridValue>100</GridValue>
    <UserLandCover>시가화/건조지역</UserLandCover>
    <GRMLandCoverCode>URBN</GRMLandCoverCode>
    <GRMLandCoverE>Urban</GRMLandCoverE>
    <GRMLandCoverK>시가화/건조지역</GRMLandCoverK>
    <RoughnessCoefficient>0.015</RoughnessCoefficient>
    <ImperviousRatio>0.853</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>200</GridValue>
    <UserLandCover>농업지역</UserLandCover>
    <GRMLandCoverCode>AGRL</GRMLandCoverCode>
    <GRMLandCoverE>Agricultural Area</GRMLandCoverE>
    <GRMLandCoverK>농업지역</GRMLandCoverK>
    <RoughnessCoefficient>0.035</RoughnessCoefficient>
    <ImperviousRatio>0.391</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>300</GridValue>
    <UserLandCover>산림지역</UserLandCover>
    <GRMLandCoverCode>FRST</GRMLandCoverCode>
    <GRMLandCoverE>Forest</GRMLandCoverE>
    <GRMLandCoverK>산림지역</GRMLandCoverK>
    <RoughnessCoefficient>0.1</RoughnessCoefficient>
    <ImperviousRatio>0.05</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>400</GridValue>
    <UserLandCover>초지</UserLandCover>
    <GRMLandCoverCode>GRSS</GRMLandCoverCode>
    <GRMLandCoverE>Grass</GRMLandCoverE>
    <GRMLandCoverK>초지</GRMLandCoverK>
    <RoughnessCoefficient>0.15</RoughnessCoefficient>
    <ImperviousRatio>0.44</ImperviousRatio>
  </LandCover>
  <LandCover>
```

```xml
    <GridValue>500</GridValue>
    <UserLandCover>습지</UserLandCover>
    <GRMLandCoverCode>WTLD</GRMLandCoverCode>
    <GRMLandCoverE>Wetland</GRMLandCoverE>
    <GRMLandCoverK>습지</GRMLandCoverK>
    <RoughnessCoefficient>0.07</RoughnessCoefficient>
    <ImperviousRatio>1</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>600</GridValue>
    <UserLandCover>나지</UserLandCover>
    <GRMLandCoverCode>BARE</GRMLandCoverCode>
    <GRMLandCoverE>Bare</GRMLandCoverE>
    <GRMLandCoverK>나지</GRMLandCoverK>
    <RoughnessCoefficient>0.02</RoughnessCoefficient>
    <ImperviousRatio>0.442</ImperviousRatio>
  </LandCover>
  <LandCover>
    <GridValue>700</GridValue>
    <UserLandCover>수역</UserLandCover>
    <GRMLandCoverCode>WATR</GRMLandCoverCode>
    <GRMLandCoverE>Water</GRMLandCoverE>
    <GRMLandCoverK>수역</GRMLandCoverK>
    <RoughnessCoefficient>0.03</RoughnessCoefficient>
    <ImperviousRatio>1</ImperviousRatio>
  </LandCover>
  <SoilDepth>
    <GridValue>1</GridValue>
    <UserDepthClass>깊음</UserDepthClass>
    <GRMDepthCode>D</GRMDepthCode>
    <SoilDepthClassE>Deep</SoilDepthClassE>
    <SoilDepthClassK>깊음</SoilDepthClassK>
    <SoilDepth>125</SoilDepth>
  </SoilDepth>
  <SoilDepth>
    <GridValue>2</GridValue>
    <UserDepthClass>매우얕음</UserDepthClass>
    <GRMDepthCode>VS</GRMDepthCode>
    <SoilDepthClassE>VeryShallow</SoilDepthClassE>
    <SoilDepthClassK>매우얕음</SoilDepthClassK>
    <SoilDepth>10</SoilDepth>
  </SoilDepth>
  <SoilDepth>
```

```
      &lt;GridValue&gt;3&lt;/GridValue&gt;
      &lt;UserDepthClass&gt;보통&lt;/UserDepthClass&gt;
      &lt;GRMDepthCode&gt;MDMS&lt;/GRMDepthCode&gt;
      &lt;SoilDepthClassE&gt;ModeratelyDeepOrModeratelyShallow&lt;/SoilDepthClassE&gt;
      &lt;SoilDepthClassK&gt;보통&lt;/SoilDepthClassK&gt;
      &lt;SoilDepth&gt;75&lt;/SoilDepth&gt;
   &lt;/SoilDepth&gt;
   &lt;SoilDepth&gt;
      &lt;GridValue&gt;4&lt;/GridValue&gt;
      &lt;UserDepthClass&gt;얕음&lt;/UserDepthClass&gt;
      &lt;GRMDepthCode&gt;S&lt;/GRMDepthCode&gt;
      &lt;SoilDepthClassE&gt;Shallow&lt;/SoilDepthClassE&gt;
      &lt;SoilDepthClassK&gt;얕음&lt;/SoilDepthClassK&gt;
      &lt;SoilDepth&gt;25&lt;/SoilDepth&gt;
   &lt;/SoilDepth&gt;
&lt;/GRMProject&gt;
```

D. Example of a discharge output file (with multiple watch points)

Project name : gd_20170109.gmp 2017-06-08 13:26 by GRMexe
Output data : Discharge[CMS]

DataTime	[gd_md]	[gd_gd]	[gd_add]	[gd_ihd]	Rainfall_Mean	FromStarting [sec]
2012-09-16 12:00	350.4516	332.0119	13.9	262.2	0.46	0
2012-09-16 12:10	350.8403	332.3075	13.9	260	0.49	0
2012-09-16 12:20	351.2209	332.7836	13.9	260	0.45	0
2012-09-16 12:30	351.6313	333.4045	13.9	260	0.39	0
2012-09-16 12:40	352.1013	334.1719	13.9	260	0.39	0
2012-09-16 12:50	352.5387	335.0735	13.8	260	0.44	0
2012-09-16 13:00	352.8278	335.8903	13.9	260	0.45	0
2012-09-16 13:10	353.4478	336.9601	13.8	260	0.44	0
2012-09-16 13:20	354.0913	337.8145	13.8	260	0.36	0
2012-09-16 13:30	354.7765	338.7128	13.8	260	0.3	0
2012-09-16 13:40	355.2483	339.7681	13.7	260	0.28	0
2012-09-16 13:50	355.8333	340.7002	13.7	260	0.22	0
2012-09-16 14:00	356.552	341.6407	13.7	259.9	0.19	0
2012-09-16 14:10	357.1193	342.532	28.3	259.9	0.23	0
2012-09-16 14:20	357.7554	343.4671	28.2	259.9	0.25	0
2012-09-16 14:30	358.4831	344.3747	28.1	259.9	0.28	0
2012-09-16 14:40	359.1673	345.3325	27.9	259.9	0.42	0
2012-09-16 14:50	359.7625	346.6602	27.9	259.9	0.42	0
2012-09-16 15:00	360.4977	347.5413	27.9	257.8	0.41	0
2012-09-16 15:10	361.184	348.4242	27.8	261.7	0.28	0
2012-09-16 15:20	361.905	349.1802	27.7	261.7	0.28	0
2012-09-16 15:30	362.6127	349.8822	27.6	261.7	0.4	1
2012-09-16 15:40	363.3061	350.6813	27.5	261.7	0.47	1
2012-09-16 15:50	364.4876	351.5355	27.5	261.9	0.6	1
2012-09-16 16:00	365.57	352.4438	27.9	261.9	0.75	1
2012-09-16 16:10	366.5452	353.3953	27.9	262	0.57	1
2012-09-16 16:20	367.4208	354.4072	27.8	262	0.48	1
2012-09-16 16:30	368.6237	355.1749	27.7	262.1	0.51	1
2012-09-16 16:40	369.5866	355.9764	27.6	262.1	0.68	1
2012-09-16 16:50	370.6096	357.6233	27.4	262.1	0.67	1
2012-09-16 17:00	371.6232	359.0224	27.4	262.2	0.46	1
2012-09-16 17:10	372.8139	359.9545	27.3	262.3	0.39	1
2012-09-16 17:20	374.2094	360.7924	25.9	262.5	0.37	1
2012-09-16 17:30	375.5147	361.4733	27.3	262.5	0.36	1
2012-09-16 17:40	376.8022	362.3229	25.8	262.6	0.37	1
2012-09-16 17:50	378.3651	363.1553	25.8	262.6	0.39	1
2012-09-16 18:00	379.8471	364.1845	27	262.7	0.42	1
2012-09-16 18:10	381.4146	365.2714	27	262.9	0.42	1
2012-09-16 18:20	382.8731	366.3638	27.2	263	0.36	1

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E. Execution environment setting

The GRM only runs on the .NET framework 4.0 version or higher. If the .NET framework is not installed on the PC, the following steps can be taken for installation.

https://www.microsoft.com/net/download/framework

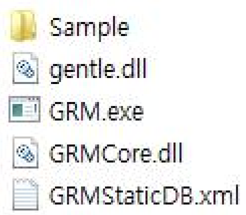
(install .net framework 4.0)

** if a version of .NET framework 4.0 or higher is not installed, an error occurs when running the GRM (error related to .NET framework version); therefore, a proper version must be installed when this running error of the GRM occurs.

F. Executable file and sample data

The GRM does not require a software installation process because it simply copies the dll and exe files to be used. In the case of allocating the GRM executable file in "C:₩GRM," the folder structure is as shown below. The "C:₩GRM" folder contains the executable file for the GRM (GRM.exe) and dll; the GRM.exe and two dlls (gentle.dll and GRMCore.dll) must be in the same folder for it to run. The GRMCore.dll contains key functions of the GRM and the gentle.dll contains functions of universal tools.

The 'Sample' folder contains sample projects and data to run the GRM. The paths of input files in the sample project file (C:₩GRM₩Sample₩SampleProject.gmp) are set for the case of 'C:₩GRM₩Sample'. Therefore, when the sample project is in the other folder, the paths in the gmp file have to be changed.



<Files of the GRM>

G. How to Run the GRM

To run the GRM, either the menu in a modeling S/W can be used or the user can manually run it in a console window. This manual describes how to run the model using a console window.

1. Input of spatial data, VAT file, and hydrological time-series data is required.

2. A text editor is used to create a gmp file.

3. In the console window, the gmp file is entered as the switch to run GRM.exe.

For example,

The execute statement when the GRM.exe file is in the 'C:₩GRM' folder and the SampleProject.gmp file is in the C:₩GRM₩Sample folder is as follows:

C:₩GRM>GRM.exe C:₩GRM₩Sample₩SampleProject.gmp

If there is space in the project file name or path, quotation marks "" are used to enclose it for input.

C:₩GRM>GRM.exe "C:₩GRM₩Sample₩Sample Project.gmp"

When the GRM.exe and gmp files are in the same folder, the project file path does not have to be entered. Thus, the following example shows how to run it when the GRM.exe and gmp files are in the C:₩GRM folder.

C:₩GRM>GRM.exe SampleProject.gmp

When running it by entering "/b folder path," the GRM can run at once for all gmp files in the corresponding folder.

C:₩GRM>GRM.exe /b C:₩GRM₩Sample

When "/bd folder path" is entered, the GRM can run at once for all gmp files in the corresponding folder and all files with simulation results, except for the discharge file (*discharge.out), are deleted.

C:₩GRM>GRM.exe /bd C:₩GRM₩Sample

"/?" can be entered to seek help.

C:₩GRM>GRM.exe /?

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