Runoff analysis using a distributed model

- Application of the GRM model -

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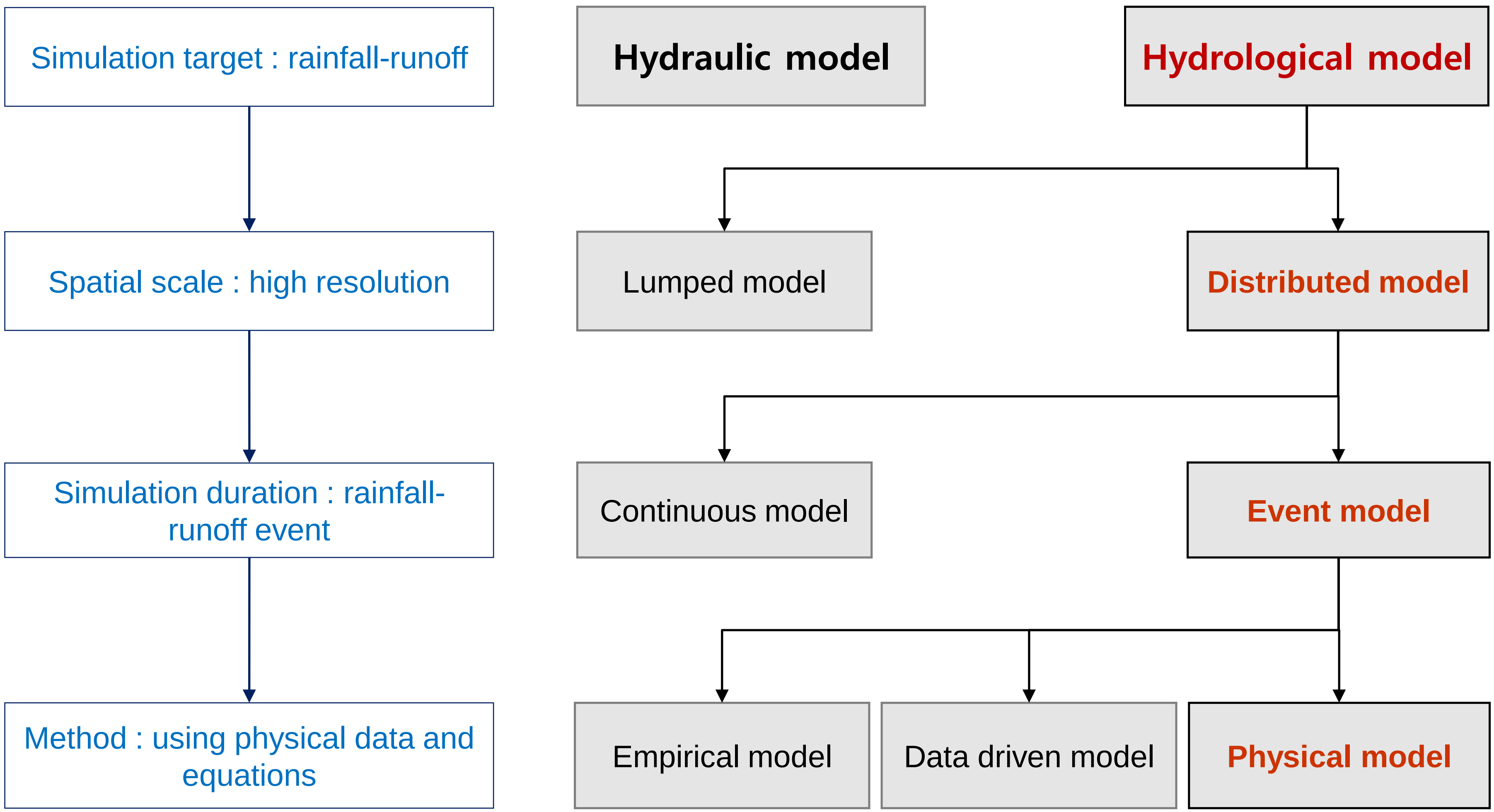
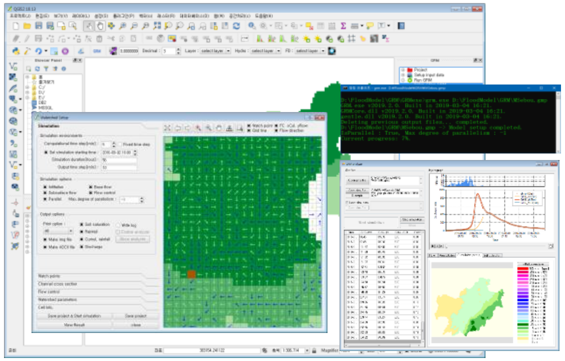
Introduction to the GRM model

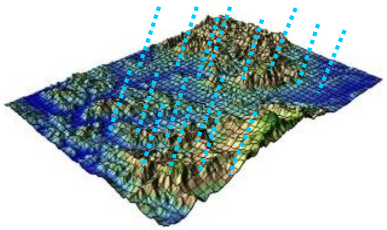
- **GRM (Grid based Rainfall-runoff Model)**

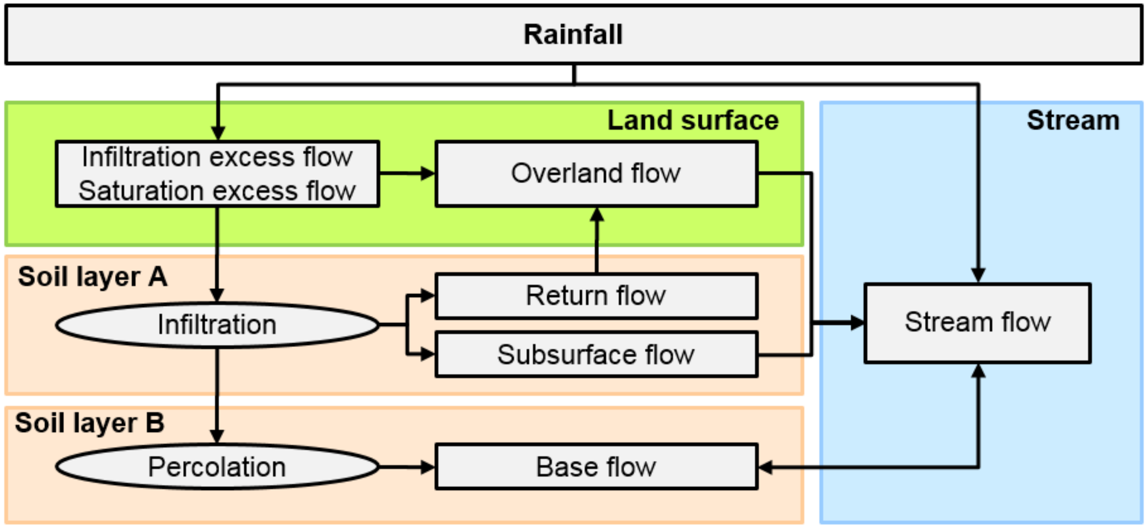


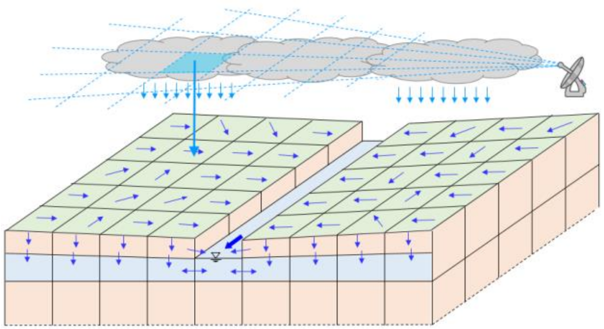
Introduction to the GRM model

- **GRM (Grid based Rainfall-runoff Model)**
  - Physically based 1-dimensional rainfall-runoff model developed by KICT in 2008
  - Kinematic wave model, Green-Ampt model
  - Calculate overland flow, channel flow, subsurface flow, baseflow
  - Flow control facilities effects (reservoir outflow, dam control, etc.)
  - https://github.com/floodmodel/GRM









Introduction to the GRM model

● Governing equations

➢ **Overland flow :** $\dfrac{\partial h}{\partial t}+\dfrac{\partial q}{\partial x}=r-f+\dfrac{q_r}{\Delta y}$

➢ **Channel flow :** $\dfrac{\partial A}{\partial t}+\dfrac{\partial Q}{\partial x}=r\Delta y+q_L+q_{ss}+q_b$

➢ **Manning's eq. :** $u=\dfrac{R^{2/3}S_0^{1/2}}{n}$

➢ **Infiltration :** $F(t)=Kt+\Delta\theta\psi\ ln\left(1+\dfrac{F(t)}{\Delta\theta\psi}\right)$ $\quad f(t)=K\left(\dfrac{\psi\Delta\theta}{F(t)}+1\right)$

➢ **Subsurface flow :** $q_{ss}=KD_s\sin(S_a)$

➢ **Percolation :** $p=K_{Bv}\times\Delta t$

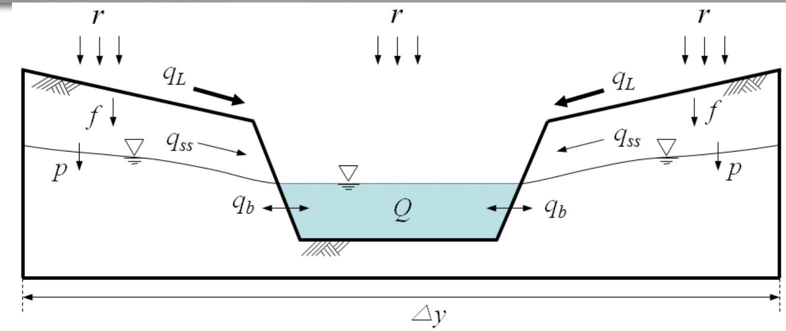
➢ **Lateral flow in soil layer B**

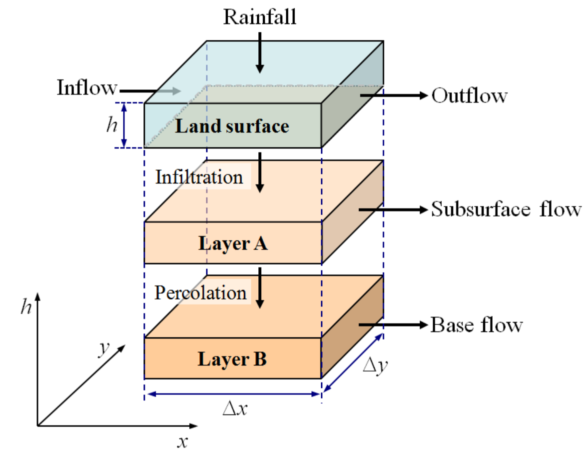
$$q_{Bh}=K_{Bh}D_B\frac{dz_B}{dx}=K_{Bh}D_B\sin(S_a)$$

➢ **Baseflow :**

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

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



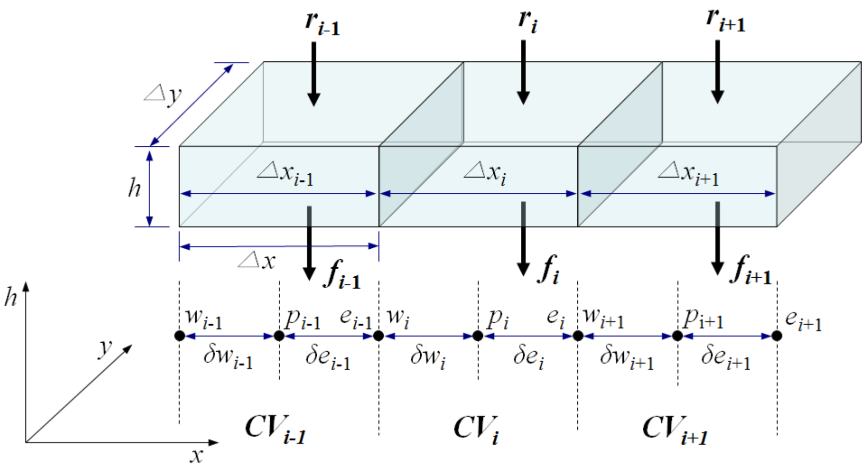


q : 단위 폭당 유량($q=uh$), u : x 방향 유속, r : 강우강도,
f : 침투율, q_r : 복귀류, A : x 방향에 직각인 흐름 단면적,
Q : 유량, h : 수심, q_L : 측방유입, q_{ss} : 지표하 유출,
q_b : 기저유출, t : 시간

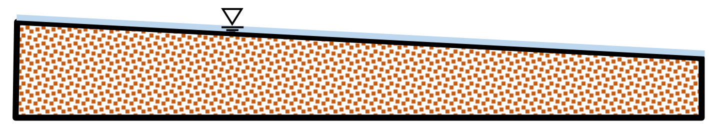
K_{Bv} : B 층에서의 연직 투수계수, p : 침누량
z_B : B 층의 수위, K_{Bh} : B 층의 횡방향 투수계수,
D_B : B 층의 수심, q_{Bh} : B 층의 단위폭당 횡방향 유량,
h_B : 비피압대수층의 수심, h_{ch} : 하도 수심, b : 하폭

Introduction to the GRM model

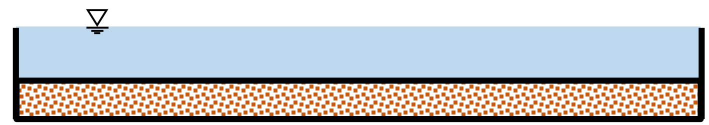
- **Numerical solutions**



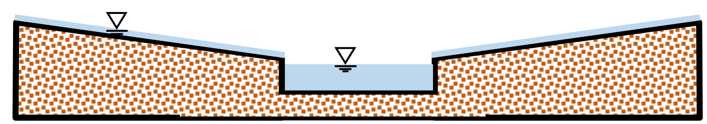
➢ **Control volume types**



<Overland flow>



<Channel flow>



<Channel and overland flows>

➢ **Overland flow**

$$h_{ip}^{j+1} = h_{ip}^{j} - \alpha(\bar{u})_{ie}^{j+1} h_{ie}^{j+1}\frac{\Delta t}{\Delta x_i} + \alpha(\bar{u})_{iw}^{j+1} h_{iw}^{j+1}\frac{\Delta t}{\Delta x_i}$$

$$-(1-\alpha)\left\{(\bar{u})_{ie}^{j} h_{ie}^{j} - (\bar{u})_{iw}^{j} h_{iw}^{j}\right\}\frac{\Delta t}{\Delta x_i} + \left\{\alpha S_i^{j+1} + (1-\alpha)S_i^{j}\right\}\Delta t \qquad S_i = r_i - f_i + \frac{q_{ri}}{\Delta y_i}$$

➢ **Channel flow**

$$A_{ip}^{j+1} = A_{ip}^{j} - \alpha(\bar{u})_{ie}^{j+1} A_{ie}^{j+1}\frac{\Delta t}{\Delta x_i} + \alpha(\bar{u})_{iw}^{j+1} A_{iw}^{j+1}\frac{\Delta t}{\Delta x_i}$$

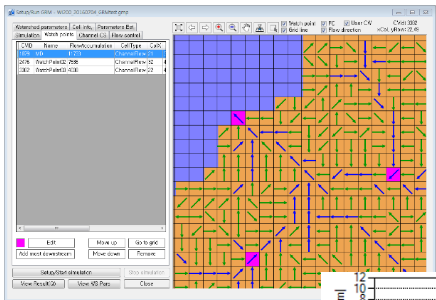
$$-(1-\alpha)\left\{(\bar{u})_{ie}^{j} A_{ie}^{j} - (\bar{u})_{iw}^{j} A_{iw}^{j}\right\}\frac{\Delta t}{\Delta x_i} + \left\{\alpha S_i^{j+1} + (1-\alpha)S_i^{j}\right\}\Delta t \qquad S_i = r_i\Delta y_i + q_{Li} + q_{ssi} + q_{bi}$$

Introduction to the GRM model

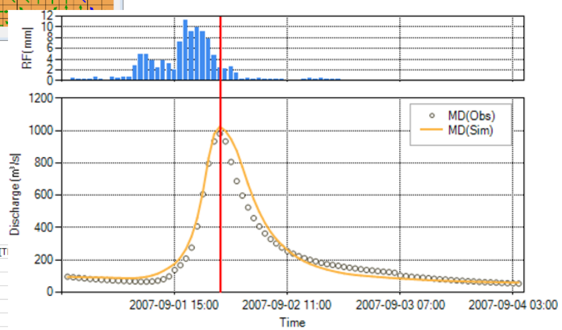
- **Input data and corresponding model parameters**

Original data	Input data	Format	Required	Parameters(user defined parameters)
DEM	Watershed	ASCII raster	O	Define simulation area Set control volume number, size, etc.
	Flow direction Flow accumulation	ASCII raster	O	1D grid flow network, calculation order
	Slope	ASCII raster	O	Slope, (minimum land surface slope, minimum channel bed slope)
	Stream	ASCII raster	Optional (recommended to use)	Define stream flow cell, (minimum channel bed width, most downstream channel width, channel roughness coefficient, dry stream order)
Channel width		ASCII raster	Optional	Channel width for each stream cell
Initial soil saturation ratio		ASCII raster	Optional	Initial soil saturation ratio for each cell
Initial stream flow		ASCII raster	Optional	Initial stream flow for each stream cell
Land cover map	Land cover	ASCII raster	Optional	Land cover roughness coefficient, impervious ratio, (calibration coefficient)
Soil map	Soil texture	ASCII raster	Optional	Green-Ampt model infiltration parameters, (calibration coefficient)
	Soil depth	ASCII raster	Optional	Effective soil depth, (calibration coefficient)
Rainfall gauge, radar, satellite	Rainfall(distributed rainfall field or mean areal rainfall)	ASCII raster Text	O	Rainfall
Discharge	Observed discharge	Text	Optional	Flow control discharge, (Initial stream flow)

- **Model outputs**
  - **Hydrological time series at watch points**
    - **- Discharge, soil saturation ratio, etc.**



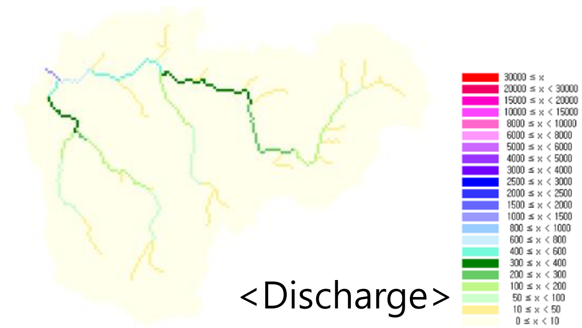
<Watch points>



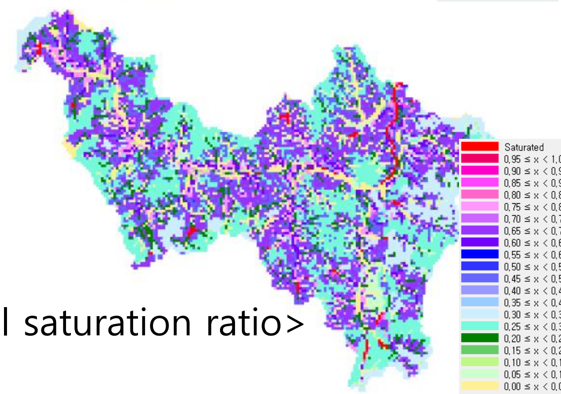
Date_Time	[Cheungmi]	[T								
2011-06-29 10:00	24.59268									
2011-06-29 10:10	24.58917									
2011-06-29 10:20	24.58876									
2011-06-29 10:30	2.46E+01									
2011-06-29 10:40	2.46E+01									
2011-06-29 10:50	2.47E+01	[illegible]	[illegible]	0.12	234	1	[illegible]	0	0	
2011-06-29 11:00	2.47E+01	1.08E-01	2.00E-05	0.18	312	1	0.18	0	0	
2011-06-29 11:10	2.47E+01	1.25E-01	3.00E-05	0.35	234	1	0.354	0	0	
2011-06-29 11:20	24.90103	1.41E-01	0.0001	1.06	234	2	1.061999942	0	0	
2011-06-29 11:30	24.99353	1.58E-01	0.00011	0.56	312	2	0.558	0	0	
2011-06-29 11:40	2.50E+01	1.69E-01	9.00E-05	0.24	218	2	0.237	0	0	
2011-06-29 11:50	2.51E+01	1.78E-01	7.00E-05	0.12	234	2	0.116999998	0	0	
2011-06-29 12:00	2.52E+01	1.88E-01	8.00E-05	0.41	312	3	0.411	0	0	
2011-06-29 12:10	2.53E+01	1.95E-01	8.00E-05	0.36	234	3	0.363	0	0	
2011-06-29 12:20	2.54E+01	2.01E-01	9.00E-05	0.4	250	3	0.404999984	0	0	
2011-06-29 12:30	2.55E+01	2.06E-01	8.00E-05	0.22	312	4	0.216	0	0	
2011-06-29 12:40	2.57E+01	2.10E-01	0.0001	0.57	218	4	0.567	0	0	
2011-06-29 12:50	25.807	2.14E-01	0.0001	0.4	234	4	0.404999984	0	0	
2011-06-29 13:00	26.10286	2.18E-01	0.00016	1.1	312	4	1.098	0	0	
2011-06-29 13:10	26.44873	2.23E-01	0.00027	1.49	250	5	1.488	0	0	
2011-06-29 13:20	26.87397	0.22812	0.00039	1.82	250	5	1.817999928	0	0	
2011-06-29 13:30	27.24726	0.23128	0.0003	0.93	328	5	0.933	0	0	
2011-06-29 13:40	27.48931	2.32E-01	0.00021	0.3	250	5	0.3	0	0	
2011-06-29 13:50	27.71608	2.32E-01	0.00014	0.05	250	6	0.054000001	0	0	
2011-06-29 14:00	2.81E+01	2.32E-01	9.00E-05	0.08	296	6	0.078	0	0	
2011-06-29 14:10	2.84E+01	2.32E-01	7.00E-05	0.16	250	6	0.156	0	0	
2011-06-29 14:20	2.87E+01	2.32E-01	5.00E-05	0	234	6	0	0	0	
2011-06-29 14:30	29.35775	2.33E-01	0.00011	1.03	343	7	1.029	0	0	
2011-06-29 14:40	2.98E+01	2.33E-01	0.0001	0.25	234	7	0.249	0	0	
2011-06-29 14:50	3.03E+01	2.34E-01	9.00E-05	0.3	234	7	0.297000021	0	0	
2011-06-29 15:00	31.29472	2.36E-01	0.00017	1.29	328	8	1.29	0	0	
2011-06-29 15:10	32.25723	0.24156	0.00032	1.83	234	8	1.833	0	0	

<Time series data at watch points>

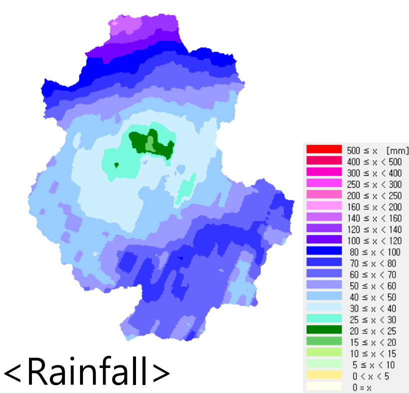
- **Hydrological time series for all cells**



<Discharge>



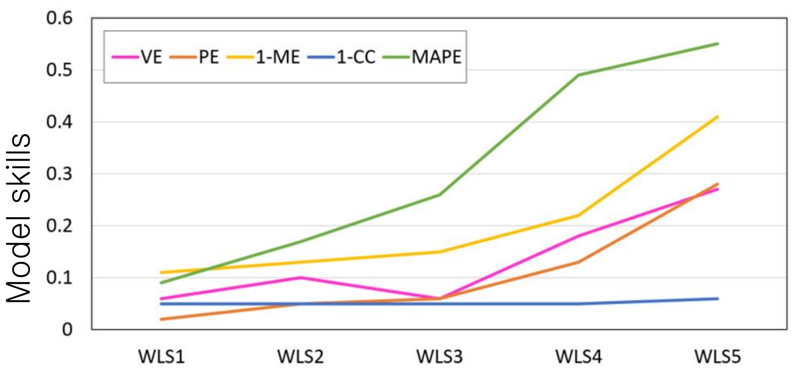
<Soil saturation ratio>



<Rainfall>

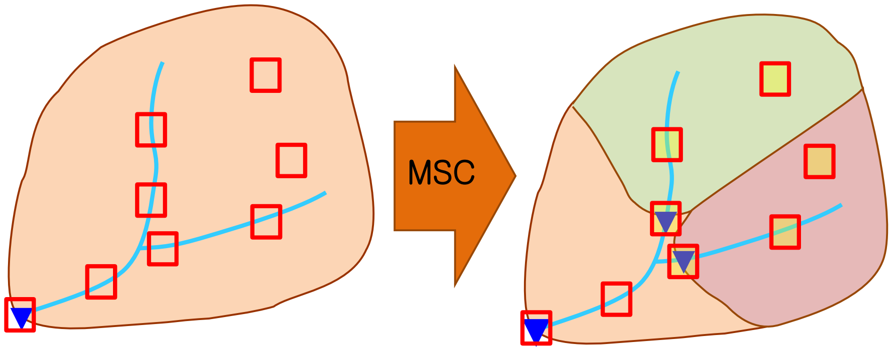
Introduction to the GRM model

- **(In a large watershed) How to improve the accuracies of inner grids simulation results ?**
  - Improve the accuracy of high resolution input data (by using radar rainfall, detail field survey data, etc. Scale problem must be considered)
  - Improve the accuracy of observed data (for model input, calibration, validation, etc.)
  - Multi-site calibration (MSC)



Points away from calibration point

- WLS1: calibration point
- WLS5: the farthest point form WLS1



▼: Model calibration point

□: The points of modelling results will be printed out

□: Modelling results can be improved by MSC

Introduction to the GRM model

- **(In a large watershed) How to reduce model run time ?**

➢ **(Parallelism)** Adopt parallel vs. serial calculation algorithm

- CPU or GPU, using a machine vs. multiple machines

➢ **(Model construction)** Simulate a large watershed with a model vs. divide into sub-watersheds and simultaneous running for each sub-watershed model

➢ **(Computational resources)** Apply high performance computational resources

- High performance workstation, cluster computing system, PC, etc.
- Windows vs. Linux

➢ **(Assessment)** Assessment of parallelism, model construction, and computational resources for target system is needed

Introduction to the GRM model

- **GRM modules**

User

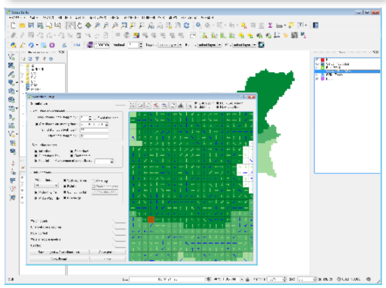
↓

Prepare GRM input data ↔ **GIS S/W**

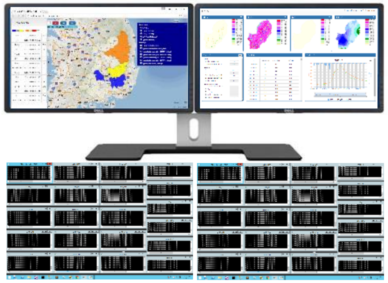
- HyGIS, ArcGIS, QGIS, Drainage tools, etc.
- Topographic analysis using DEM
- Make geographic input raster files
- Analyze and manage GIS data

↓

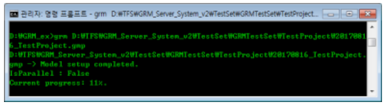
QGIS-GRM GUI



Real time flood analysis system

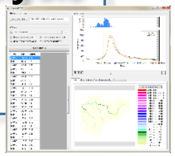


Console GRM.exe



Applications…

GRMAnalyzer
Optimization
Sensitive analysis
·
·
·



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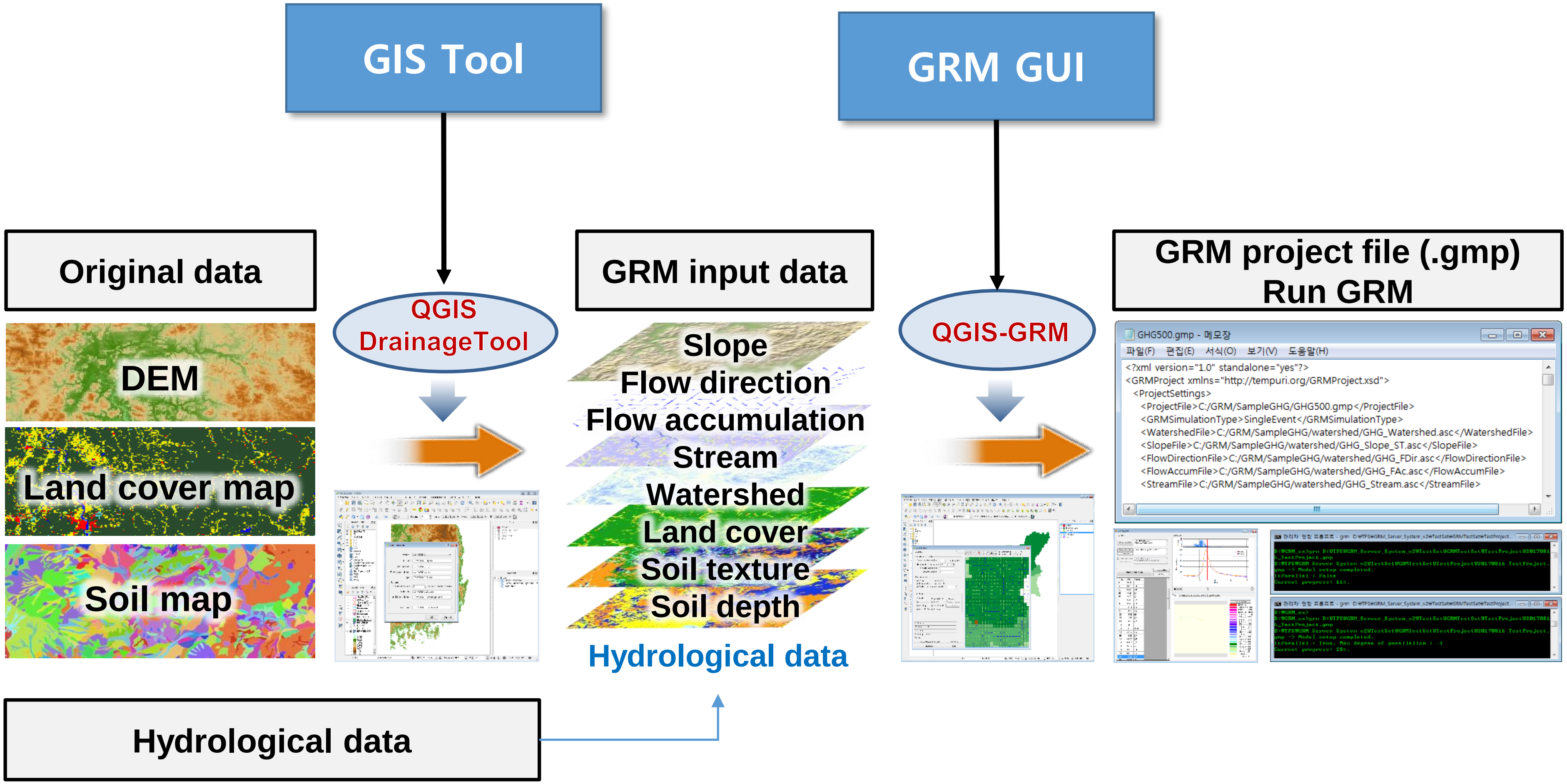
GRMCore Library

How to use the GRM model

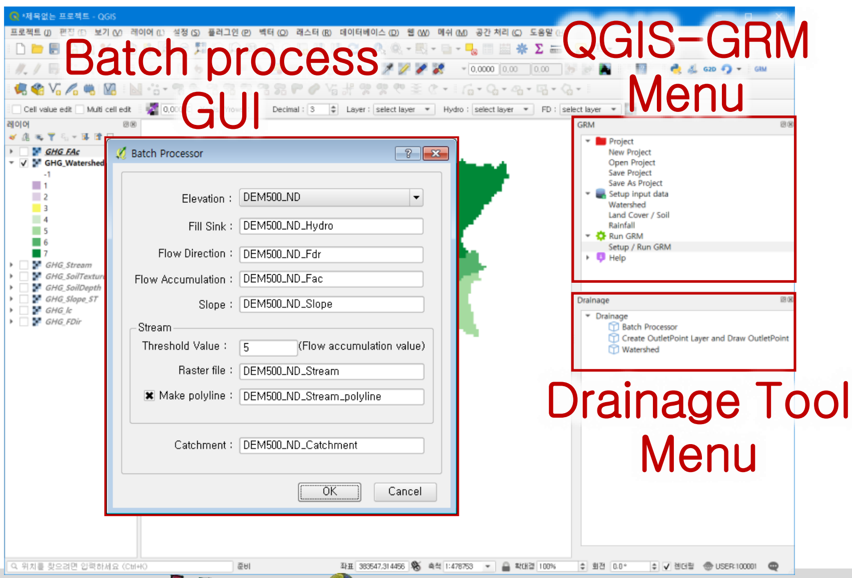
- **Application process**

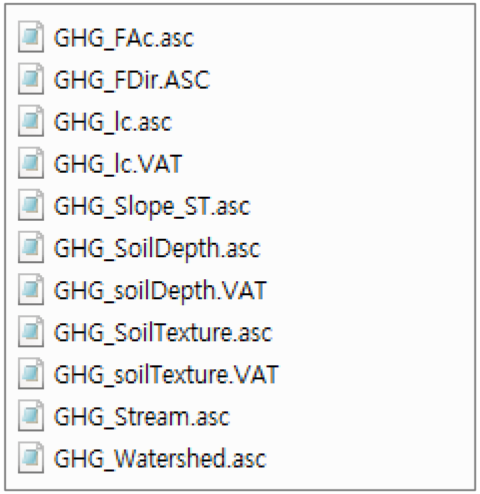


How to use the GRM model

- **QGIS Drainage Tool**

  - DEM processing using TauDEM (http://hydrology.usu.edu/taudem/taudem5/index.html) and GDAL (https://www.gdal.org)
  - Making hydrological topographic data
    - flow direction (D8, combined gradient), flow accumulation, slope (Steepest), stream, watershed
  - Making the GRM model input files (ASCII raster files)





How to use the GRM model

- **The GRM model project file (~.gmp)**
  - Text xml format with the extension of ‘.gmp’.
  - Includes input file info., modeling options, the model parameters, etc.
  - Text editor or QGIS-GRM GUI can be used to make a project file


```xml
<?xml version="1.0" standalone="yes"?>
<GRMProject xmlns="http://tempuri.org/GRMProject.xsd">
  <ProjectSettings>
    <ProjectFile />
    <GRMSimulationType>SingleEvent</GRMSimulationType>
    <DomainFile>C:/GRM/SampleGHG/watershed/GHG_Watershed.asc</DomainFile>
    <SlopeFile>C:/GRM/SampleGHG/watershed/GHG_Slope_ST.asc</SlopeFile>
    <FlowDirectionFile>C:/GRM/SampleGHG/watershed/GHG_FDir.asc</FlowDirectionFile>
    <FlowAccumFile>C:/GRM/SampleGHG/watershed/GHG_FAc.asc</FlowAccumFile>
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    <ConstantImperviousRatio />
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    <MakeIMGFile>false</MakeIMGFile>
    <MakeASCFile>false</MakeASCFile>
    <MakeSoilSaturationDistFile>true</MakeSoilSaturationDistFile>
    <MakeRfDistFile>true</MakeRfDistFile>
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    <WriteLog>false</WriteLog>
```

How to use the GRM model

GRM model project file (~.gmp)

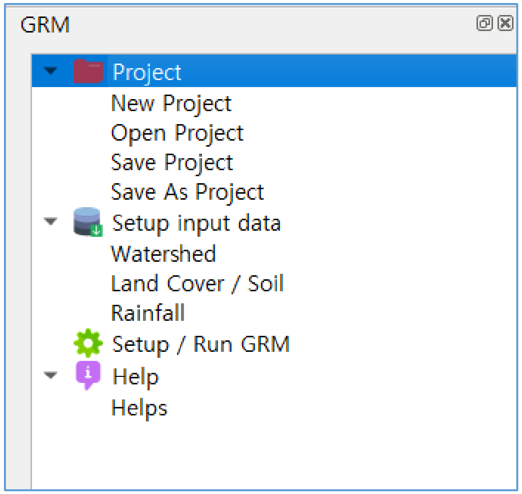
- **Make GRM model project file using QGIS-GRM plug-in**

- **In QGIS**

1. Run QGIS and add watershed, slope, flow direction, flow accumulation, stream, land cover, soil texture, and soil depth ASC raster files to QGIS map.
2. Run QGIS-GRM plug-in

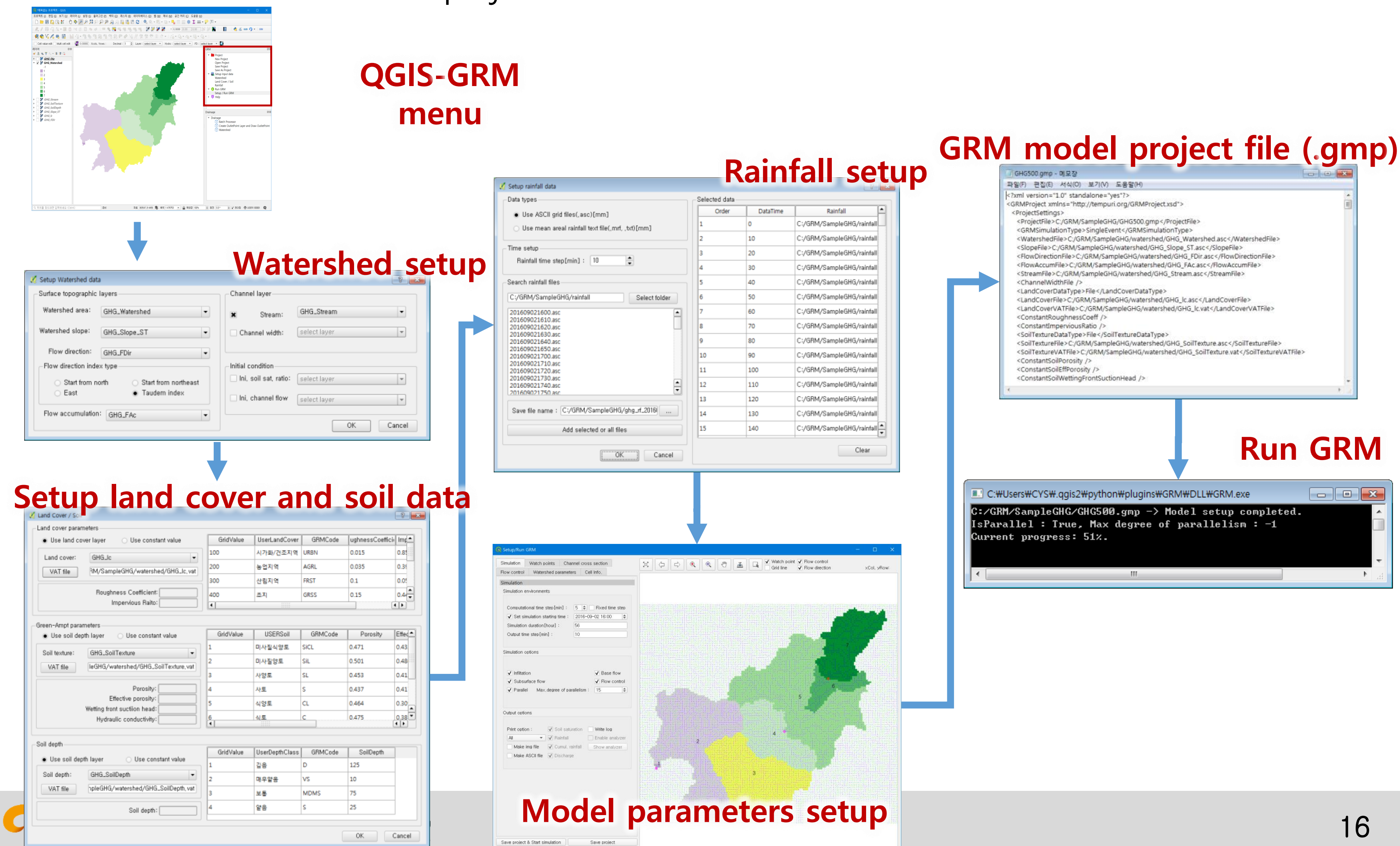
- **In QGIS-GRM plug-in**

1. Click Project > New project
2. Click Project > Save project
3. Click Setup input data > Watershed
4. Click Setup input data > Land Cover / Soil
5. Click Setup input data > Rainfall
6. Click Run GRM > Setup / Run GRM
7. Click Project > Save project



How to use the GRM model

- **GRM model GUI : QGIS-GRM**
  - Used to make a GRM project file

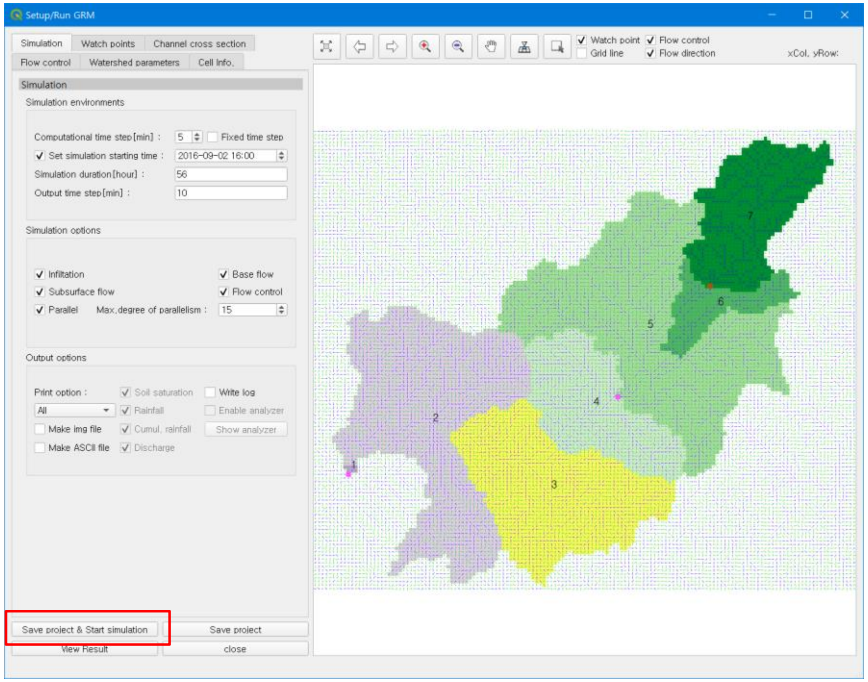


How to use the GRM model

- **Run the GRM model**

  ➢ **Using QGIS-GRM GUI**

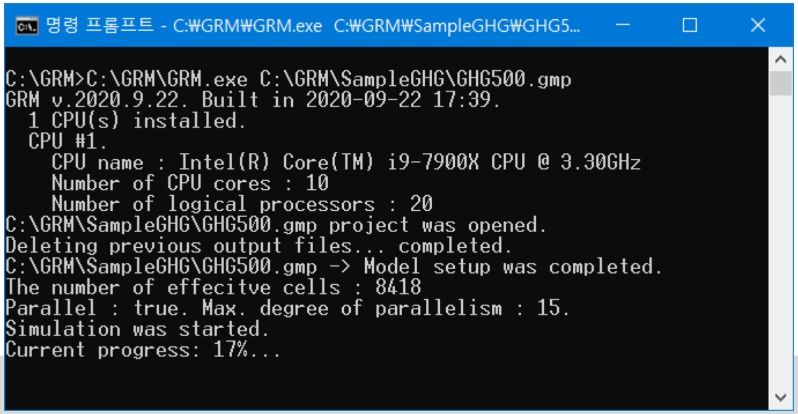
  - Click “Save project & start simulation” button on GUI



  ➢ **Using GRM.exe in console window**

  - Run GRM.exe using a project file argument in console window
  - Execute [“GRM.exe file path and name” “Project file(gmp) path and name with file extension(.gmp)”]
  - Example

    C:₩GRM₩GRM.exe C:₩GRM₩SampleGHG₩GHG500.gmp



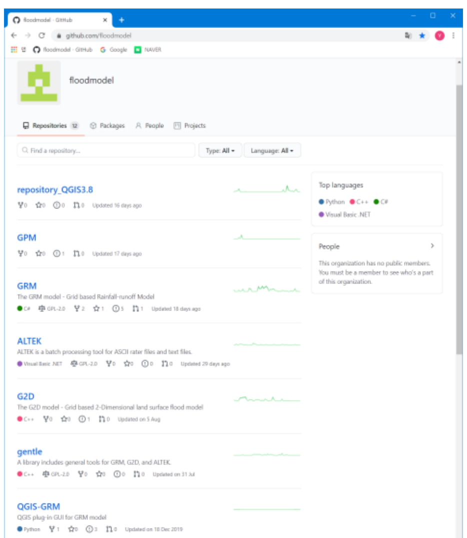
How to use the GRM model

● How to get the softwares

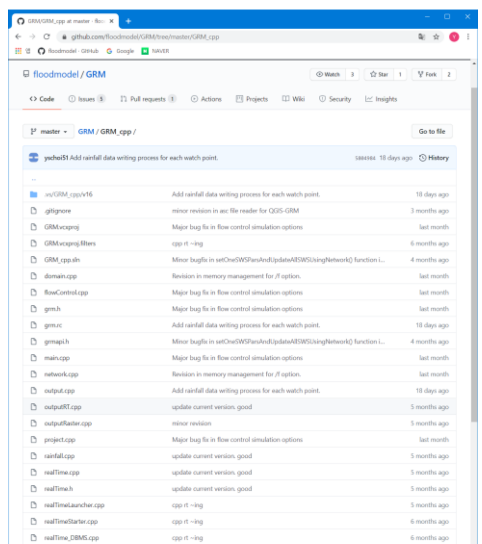
- ➢ Softwares : GRM, QGIS-GRM plug-in, Drainage Tool plug-in, etc.
- ➢ Contents : Source codes, executable files(dll, exe), manuals, sample data, etc.
- ➢ Searching web site

  - Search Google (https://www.google.com) or GitHub (https://github.com/) using “github grm”, “floodmodel grm”, “floodmodel qgis-grm”, “floodmodel drainage”
- ➢ QGIS plug-in repository location (QGIS 3.8.X)

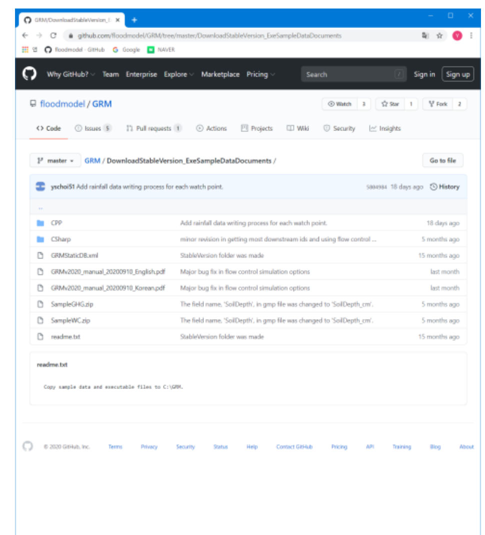
  - https://github.com/floodmodel/repository_QGIS3.8/tree/master/QGIS_GRM
    Download the latest version of QGIS-GRM, unzip the file and copy unzipped folder to “C:₩Users₩[user name]₩AppData₩Roaming₩QGIS₩QGIS3₩profiles₩default₩python₩plugins”
  - https://raw.githubusercontent.com/floodmodel/repository_QGIS3.8/master/plugins.xml



<Softwares>



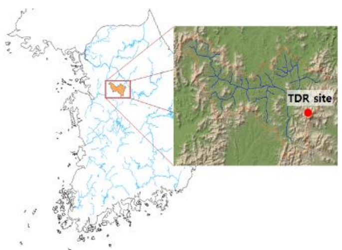
<Source codes>

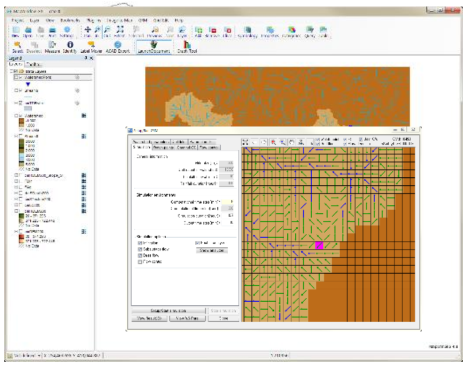


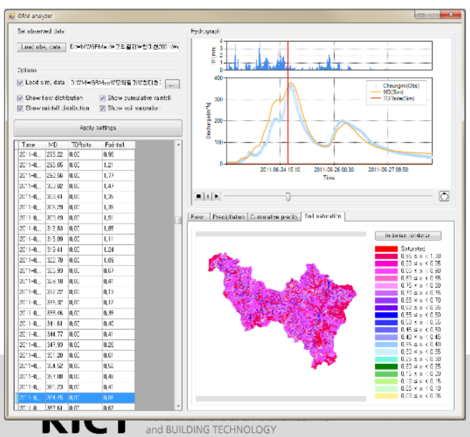
<Executable files, sample data>

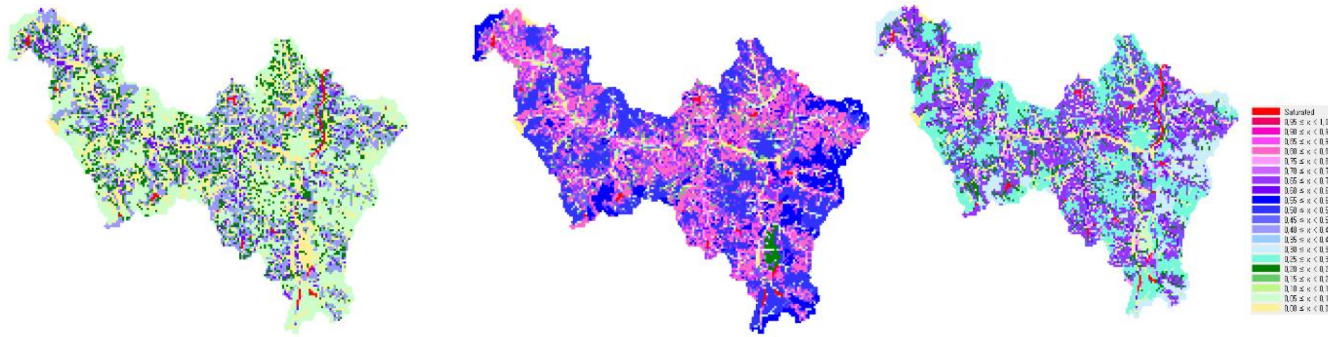
Applications

- **Simulation of stream discharge and soil saturation during flood events**
  - Study area : Cheongmi-cheon (Riv.) IHP (International Hydrology Program) test bed
  - Soil water content observation using TDR

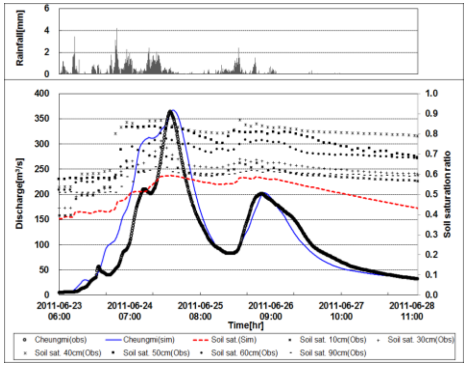








< Initial soil saturation ratio distribution – auto estimation >



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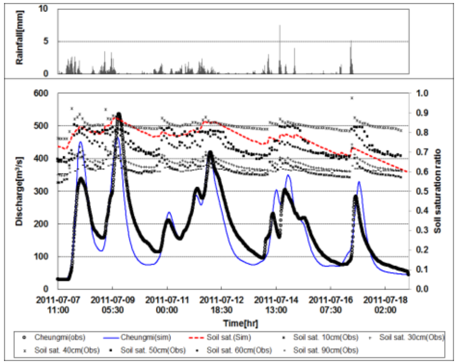

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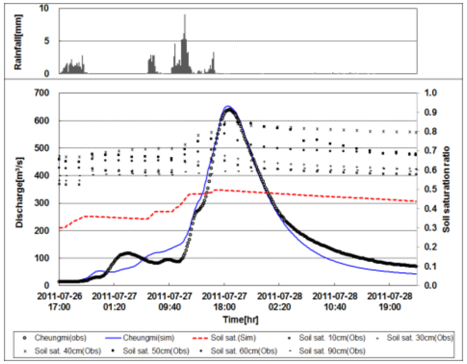
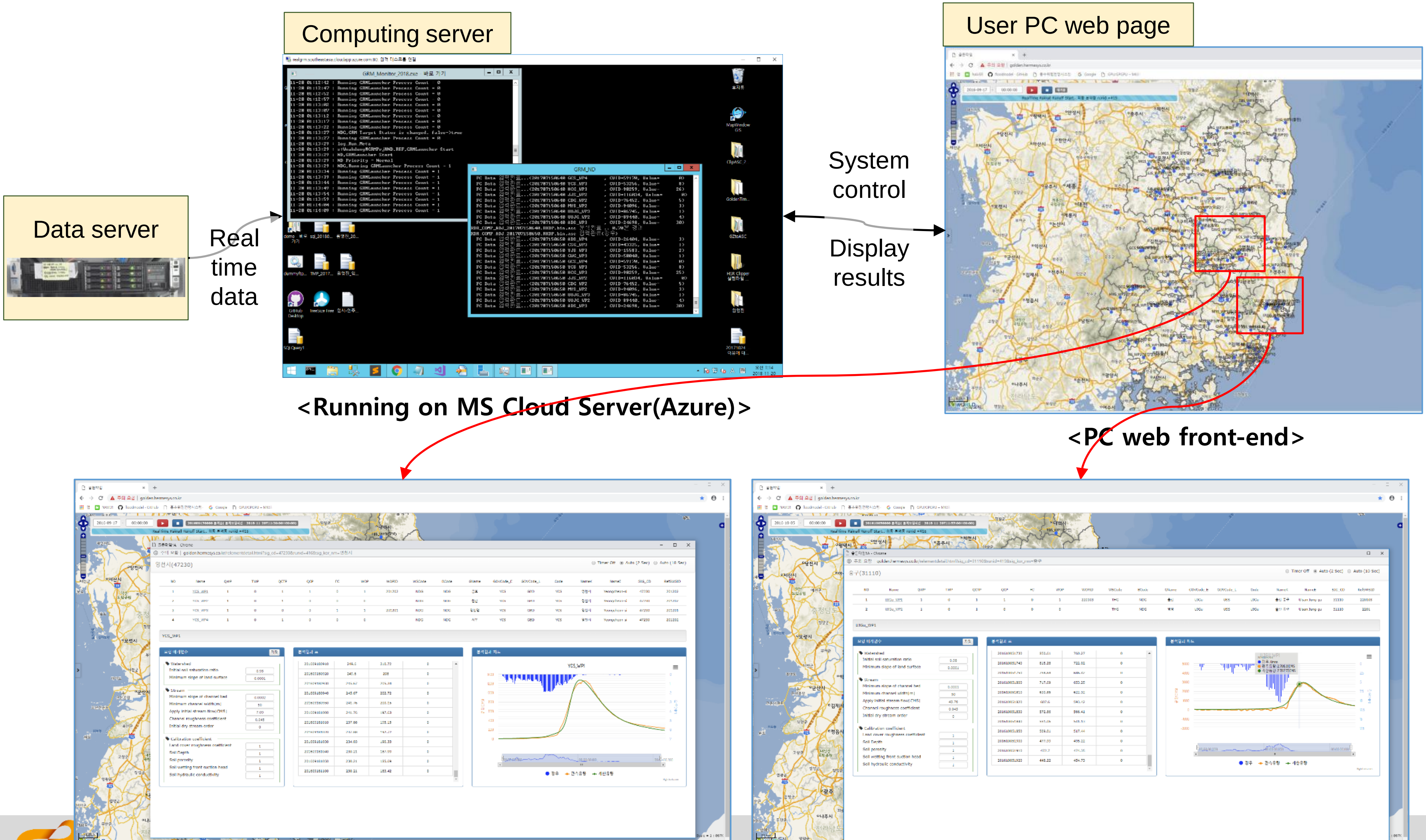


<Event 3>

<Soil saturation ratio and discharge hydrographs>

Applications

- **Real time rainfall-runoff analysis system**

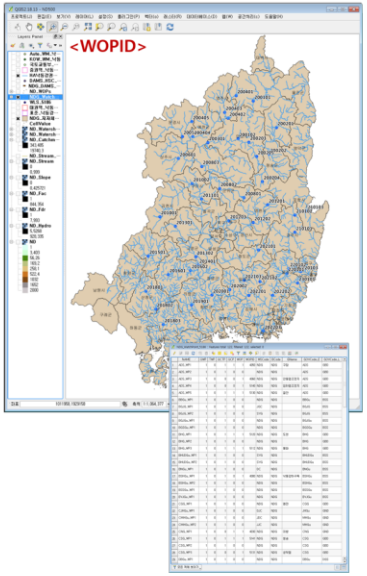


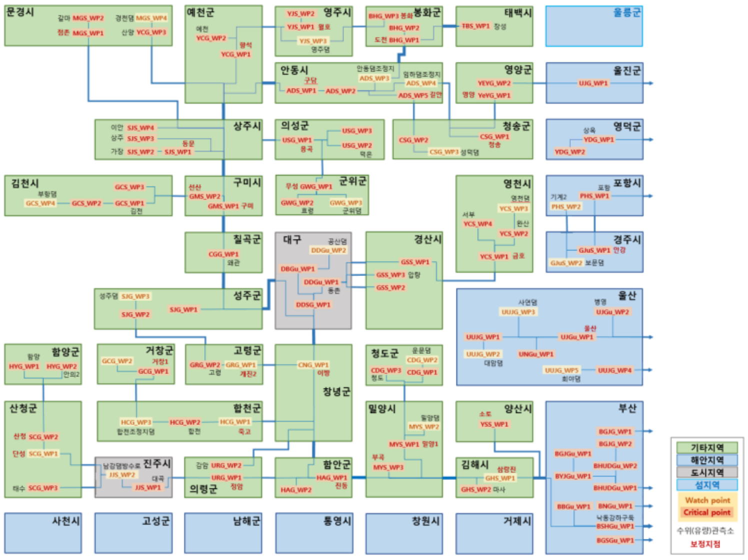
<Running on MS Cloud Server(Azure)>

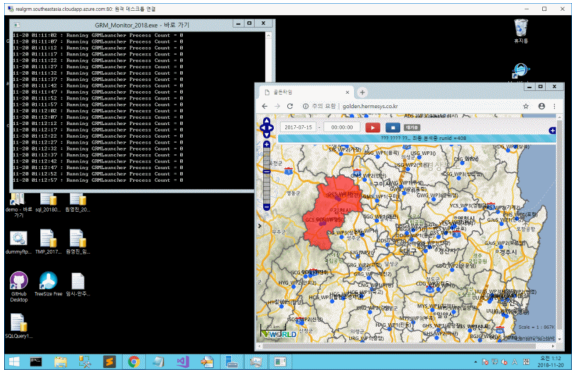
<PC web front-end>

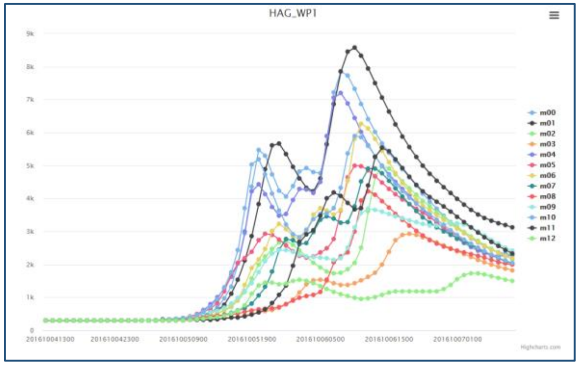
Applications

- **Application of ensemble precipitation data**
  - 기상청 앙상블 강우자료를 이용한 홍수위험전망 정보 생산
  - 500m X 500m 해상도로 전국 GRM 모델 구축
  - 13개 강우 자료 다발을 이용해서 GRM 모델 실행 후 하천 유량에 의한 전국 행정구역별 홍수위험을 판단할 수 있는 시스템 구축(진행 중)



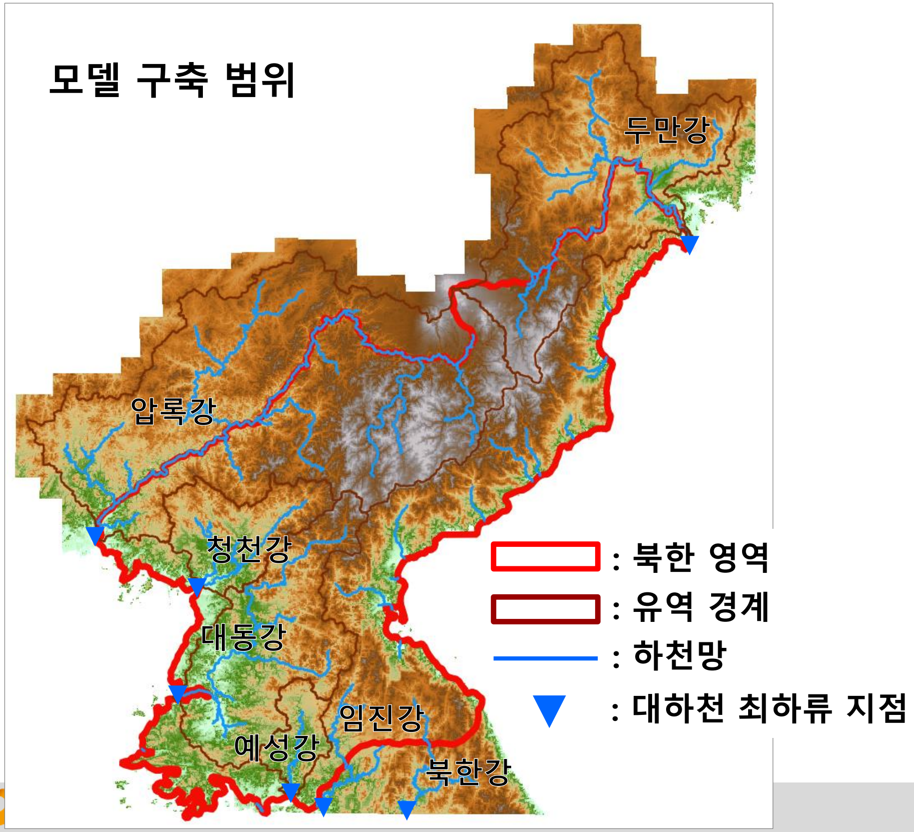


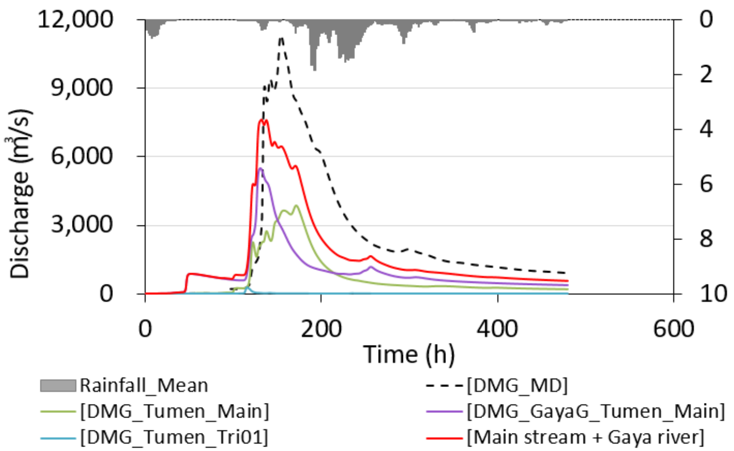




Application of the GRM to North Korea

- 북한 지역 전체에 대해서 홍수 유출 해석 모델 구축
- 목적 : 북한 지역에 홍수 발생시에 신속하게 홍수량 산정 -> 산정된 홍수량을 **침수 모의에 적용**
  (분포형 유출 모형을 적용함으로써 모의 영역 **임의 지점에서 유출량 산정 가능**)
- 공간해상도 : 500m × 500m
- 유출 해석 범위 : 북한 전역, 중국과 러시아 지역 중 압록강 유역과 두만강 유역이 포함된 영역





Thank you…