Rainfall-Runoff-Inundation (RRI) Model Usage Guidelines

INDEX

1. Introduction

1.1. Purpose of hydraulic model applied to North Macedonia

1.1.1 Expected hydraulic model users and purpose of use

- CMC (Risk evaluation, Damage evaluation, Early warning)
- HMS (Hazard evaluation, Early warning)
- PENF (Evaluation of effect of forest conservation for flood control)

1.1.2 Objectives of using hydraulic model

- Flood hazard evaluation
- Flood risk evaluation
- Evaluation of effect of countermeasures (forest conservation, river facilities)
- Flood damage evaluation (assessment)
- Application to Crisis Management System
- Application to Early Warning System

1.2. Appropriate hydraulic models to meet the purpose

With considering the purpose of using hydraulic model, it is necessary to carry out the following analysis.

- To input time series data of rainfall causing a disaster.
- To calculate the amount of runoff from the basin to the river with taking into consideration rainfall and land use in the catchment.
- To compare the runoff amount and the cross section of the river, and to calculate the amount of flooding in the protected inland from the point where the river capacity is insufficient.
- To analyze the extent of inundation in the floodplain using time series of amount of flood.
- To output the calculation result (depth change, maximum depth, etc.).
- License free software will be used for hydraulic model development.

1.3. Selection of hydraulic model

Several hydraulic models that have been used in various parts of the world with free software are extracted. Operation System, necessary hardware specifications, required input / output data, existence of manual and usability were compared.

Models	HEC	RRI	iRIC
Run-off	HEC-HMS (Hydro Modeling System)	RRI (Rainfall-Runoff-Inundation)	SRM (Storage Routing Model)
Flood	HEC-RAS (River Analysis System)	RRI	—
Inundation	HEC-RAS	RRI	Nays2D Flood
Run-off model	Distributed parameter run-off model	Distributed parameter run-off model	Storage routing model
Hardware Requirements	Intel i3 or more Memory: 1GB/4GB Disk space: 120MB/1GB	Unknown (PC is available)	Unknown (PC is available)
Input data	【HEC-HMS】 Precipitation, Discharge, Stage, etc. Elevation-discharge relation, etc. Cross section Elevation, etc. 【HEC-RAS】 Geometric data (River system schematic, cross section, terrain model, culvert, etc.) Flow data (Result of HEC-HMS) Boundary conditions (Water level of downstream)	DEM Precipitation Watershed information (Land use, soil type, etc.) Cross section of river	【SRM】 Precipitation, Discharge Watershed information (Area, Model constants) Boundary conditions (Water level of downstream) 【Nays2D Flood】 DEM Precipitation (Option) Floodplain conditions (Roughness, road embankment, etc.)
Export GIS data	Available	Available	No function
Users	US, Asia, Europe	Japan, Asia	US, Asia, Japan
Remarks	【HEC-HMS】 Should select appropriate method from lots of choice →complicated and difficult ・Canopy method (4 available choices) ・Surface method (3 available choices) ・Loss method (12 available choices) ・Transform method (8 choices) ・Baseflow method (6 choices) ・Routing method (7 choices) ・Loss/gain method (3 choices)	Run-off and Inundation processes are analyzed integrally	Not necessary to prepare cross section
Difficulty of handling	Very difficult	Difficult	Relatively easy
Input data	Many	Ordinary	Ordinary
Result	A	AA	B

RRI (Rainfall-Runoff-Inundation) model is selected as hydraulic model to adopt to North Macedonia.

2. RRI model preparation (0_rri_4_2.exe)

2.1. Features of RRI model

The RRI model has the following features.

1) Runoff and inundation (river setting is important) processes are calculated in a unified manner.
2) Model created with grid (grid size is set arbitrarily for rainfall data, watershed model, river channel model, constants, etc.)
3) The calculation method in the soil differs between "the lateral subsurface flow" - dominant (for mountainous area) and "the vertical infiltration storage" - dominant (for flat area) depending on land use (the same constant can be set).
4) If the river model is not set appropriately, the discharge will change due to inundation.
5) Folder structure and the files to be placed are defined (calculation cannot be executed if the specified file does not exist).
6) The current model cannot calculate lateral flow when vertically infiltrated, and cannot calculate vertical flow when infiltrated laterally (unpermitted area = surface flow calculation unless vertically and laterally infiltrated).
7) Setting of river channel model is important for runoff and inundation calculation.
8) Since there is no initial loss (concave loss, trunk blockage, etc.), surface flow occurs even in small amount of rain.
9) If surface flow occurs, the discharge cannot be reduced except for the equivalent roughness coefficient (the equivalent roughness becomes larger).

2.2. Outline of RRI model

Outline of RRI model can be described as follows:

1) RRI (Rainfall - Runoff - Inundation) model is a two-dimensional model that can simultaneously simulate rainfall, runoff and flood inundation.
2) The model handles the slope model and the river channel model separately. A grid cell with a river channel assumes that both the slope model and the river channel model are located in the same grid cell
3) The river channel model is discretized as a single line along the grid cell center line of the slope model
4) Surface flow on the slope model is calculated using the 2D diffuse wave model, and the river channel model is calculated using the 1D diffuse wave model.
5) The slope model is divided into a mountainous area and a flatland area.

6) In the mountainous area, the mass balance formula (flow rate – flow cross sectional area relationship) is used in which both the unsaturated / saturated lateral flow and surface flow are taken into consideration.

7) On the other hand, in the flat area, the Green-Ampt model is used for the vertical seepage flow, and the surface flow is also calculated using the 2D diffuse wave flow.

8) Furthermore, it is possible to set the impervious zone (only the surface flow) when there is no side flow or vertical flow.

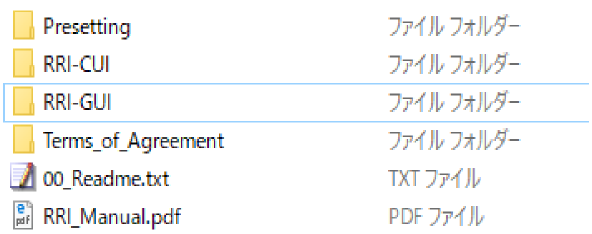
9) From the above, the calculation method is divided into three areas: 1) lateral seepage areas (expressed as mountainous areas), 2) vertical seepage areas (expressed as flat areas), and 3) non-permeable areas.

10) The flow interaction between the river channel model and the slope model is calculated based on different overflow equations depending on the water level and dike height conditions.

2.3. Overview of folder structure of RRI model

1) The RRI model downloaded here is the (RRI_1_4_2_3) version.

2) The downloaded version (RRI_1_4_2_3) of the RRI folder is structured as follows:



3) When using for the first time, use according to "2.4RRI model installation method".

4) There is a “Project” folder in “RRI-GUI”, so create your own project folder there.

2.4. How to install RRI model

<u>Step 1</u>: Copy “RRI” folder

1) Copy "RRI" folder from the USB memory and paste it under "C:¥" (The folders shown in "2.3Overview of folder structure of RRI model" will be created)

- Presetting: Library for running RRI model
- RRI-CUI: RRI model with command user interface (for advanced users)
- RRI-GUI: RRI-model with a graphical user interface

<u>Step 2</u>: Confirm your PC (32-bit or 64-bit)

1) Check if your PC is 32-bit or 64-bit

2) When using the RRI model, use software that matches the bit (32 or 64) of your PC.

Step 3: Install the library

1) The following files are in the Presetting folder

- Intel Fortran Redistributable Library Package (w_fcompxe_redist)
- Visual C++ redistributable package (vcredist)

2) Please click the following file according to your PC

- 64-bit machine: Install 'w_fcompxe_redist_intel64.msi' and 'vcredist_x64.exe'
- 32-bit machine: Install 'w_fcompxe_redist_ia32.msi' and 'vcredist_x86.exe'

3) If Intel Fortran is not installed on your PC, click on the following file

(The library required to run RRI programs compiled with Intel Fortran)

- 'RRI/RRI-CUI/etc/w-fcompxe/w_fcompxe_redist_intel64_2013.5.198.msi' (for 64 bit)
- 'RRI/RRI-CUI/etc/w-fcompxe/w_fcompxe_redist_ia32_2013.5.198.msi' (for 32 bit)

2.5. RRI model folder structure and important files

2.5.1 Folder structure

The RRI model folder has the following structure (can be added and cannot be reduced)

```
Root folder ("RRI_******")
  └ Subfolder ("Project" - Generally this name)
      └ Sub-subfolder (project name) *1
          ├ bound *2
          ├ init *3
          ├ out *4
          ├ rain *5
          ├ riv *6
          └ topo *7
```

*1: RRI_input.txt (control of the entire RRI calculation)

*2: Folder for the boundary condition (file structure unknown at this time)

*3: Set moisture value of each grid at the start of calculation

(Use of one-time data of OUT where calculation results are stored separately)

*4: Calculation result files are output

(If you don't delete all files before the calculation, the viewer may become unusable.)

*5: Folder for rain data and rain station Thiessen data

*6: Folder for river shape

*7: Folder for basin structure

2.5.2 Important files

1) Root folder (“RRI_******”)

- ‘RRI_BUILDER_v4-64.exe’ (for data creation)
- ‘RRI_VIEWER_64_v140.exe’ (for checking calculation results)

2) Subfolder (“Project”)

- No important files

3) Sub-subfolder (project name)

- ‘0_rri_1.4.2.exe’ (RRI model calculation)
- ‘rainThiessen.exe’ (RRI model rainfall creation)
- ‘RRI_input.txt’ (calculation control)
- ‘RainThiessen.txt’ (rainfall control)
- ‘time.dat’ (calculation start year/month/day/hour)

4) “bound” folder

-Unknown file format

5) “init” folder

- Operates if there is no file (starts with zero moisture in each grid)

6) “out” folder

-The calculation result is output (make empty before starting the calculation)

7) “rain” folder

- ‘rain.dat’ (rain)
- ‘rain_Map.txt’ (Thiessen map)

8) “riv” folder

- Operates if there is no file (river data created in advance)
- ‘depth.txt’
- ‘heigt.txt’
- ‘width.txt’

9) “topo” folder

- ‘dem.txt’
- ‘acc.txt’
- ‘dir.txt’

3. Basic knowledge of maps used in RRI model

3.1. Global geodetic system

- The global geodetic system can be applied to the entire earth within the geodetic system.
- The difference between them is quite small

Among them, typical geodetic systems are shown below.

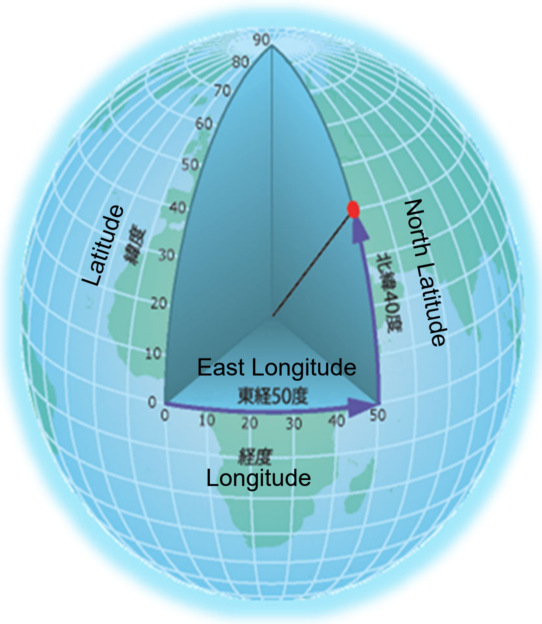
- US geodetic system: World Geodetic System 1984 (WGS84)
- International Terrestrial Reference System (ITRF) (ITRF94, etc.)

3.2. Coordinate system

- The agreement of the origin and coordinate unit for representing the position on the earth with coordinates is called "the coordinate system".
- Expressing coordinates according to this agreement makes it easy to overlay and express multiple GIS data
- Coordinate systems handled by GIS include 'geographic coordinate system', 'projected coordinate system', and 'vertical coordinate system'. Among them, geographic coordinate system and projected coordinate system will be explained.

■ Geographic coordinate system

- The geographic coordinate system is a coordinate system that expresses a 3D position on the earth in latitude and longitude.
- Latitude is 90 degrees each in the north-south direction with the equator at 0 degrees.
- Longitude is expressed up to 180 degrees in the east-west direction, with the meridian called the prime meridian being 0 degrees.
- Latitude is expressed as an angle in the geographic coordinate system with the center of gravity of the earth as the origin.
- The latitude represents the relationship between the “origin”, “equator plane”, and “target position” as an angle (40 degrees north latitude in the figure).
- Longitude expresses the relationship between the “origin”, “prime meridian plane”, and “target meridian plane” as an angle (50 degrees east longitude in the figure).

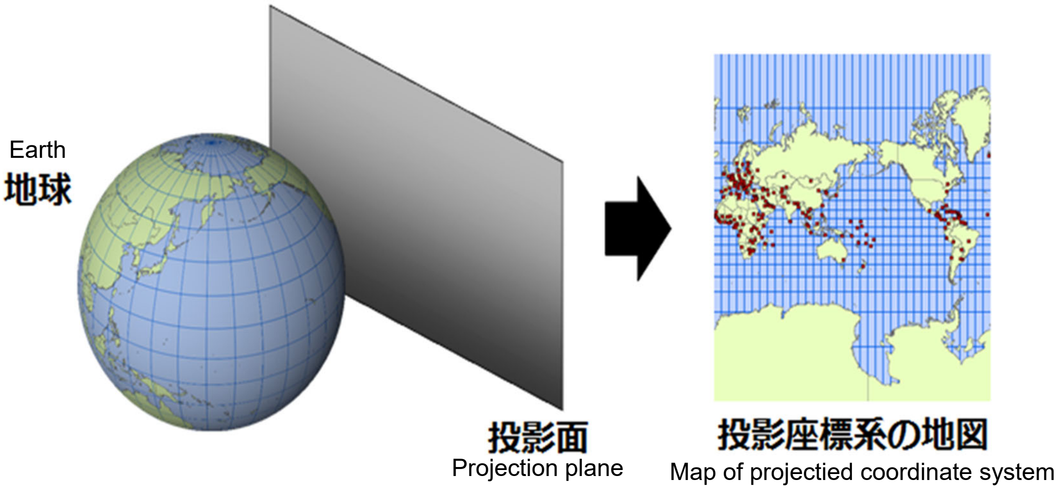


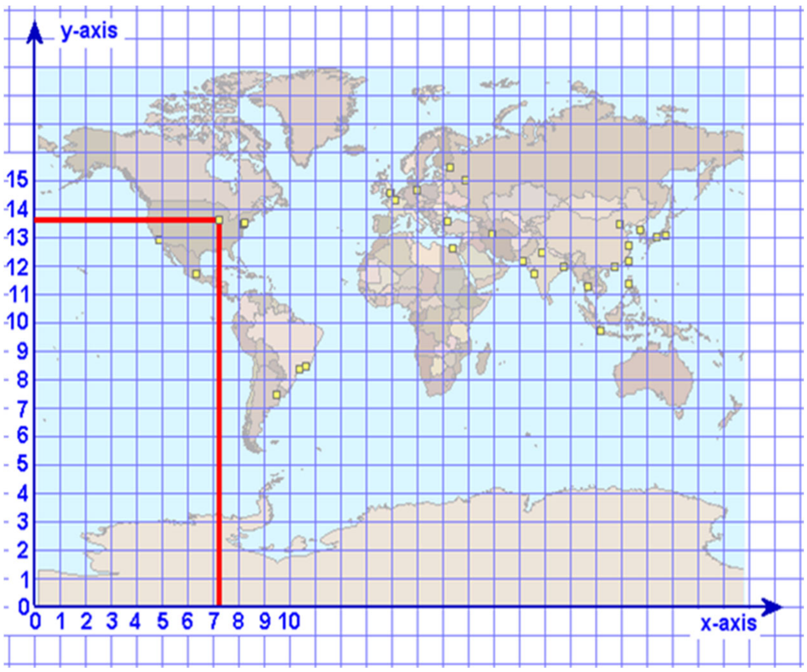
■Projection coordinate system

-The projected coordinate system is a coordinate system that projects the 3D Earth onto a 2D plane and expresses it in XY coordinates.

-The method of projecting in 2D is called map projection, and there are various projection coordinate systems depending on the projection method used and the origin to be set.

-The coordinates in the projected coordinate system are determined by the distance (meters, etc.) from the origin in the XY axis direction.

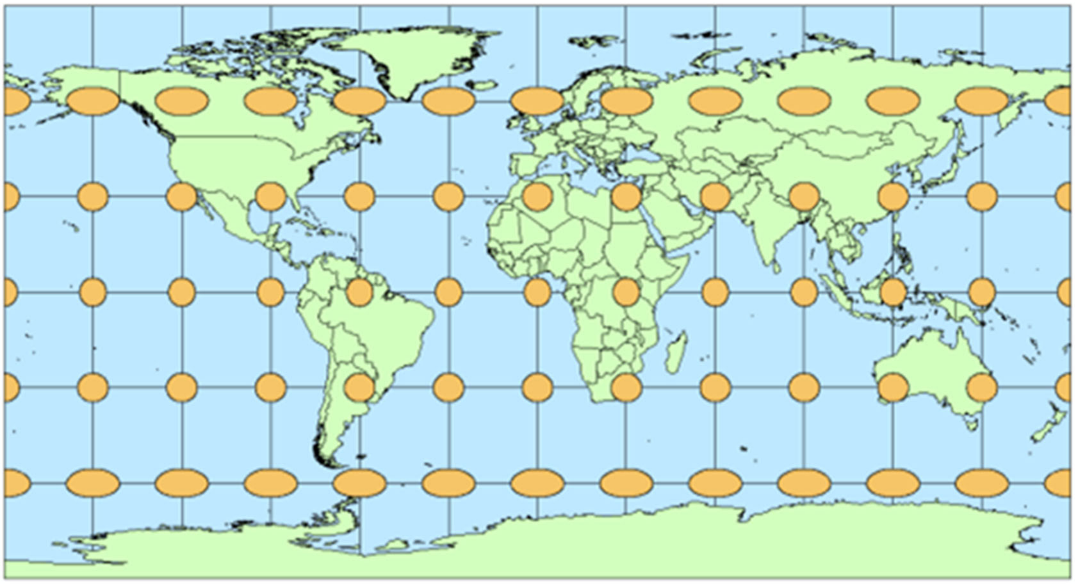




■ Characteristics of geographic coordinate system and projected coordinate system

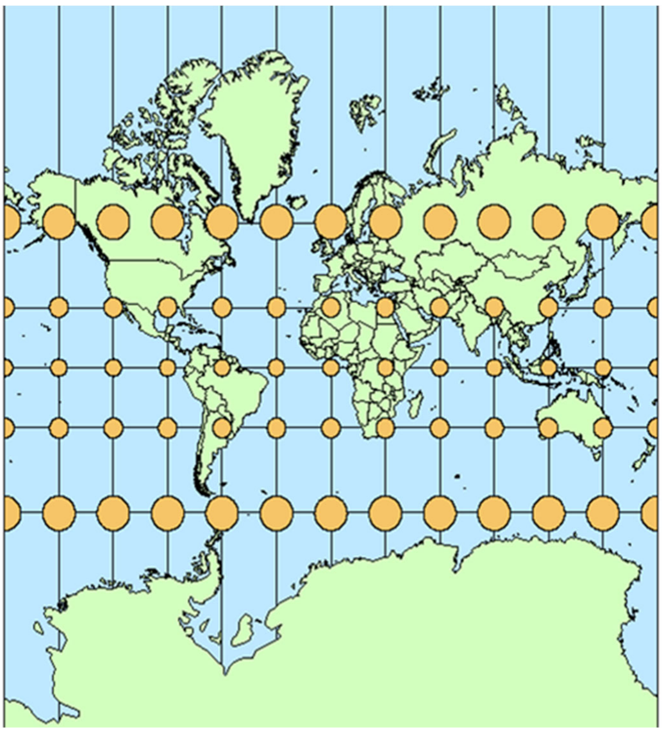
● Characteristics of geographic coordinate system

- The geographic coordinate system has the advantage that it can manage a wide range such as the whole country or the world as one data with a certain scale, but none of the distance, area, or angle is accurate when they are represented on a plane, because it is expressed in 3D angles.
- The following figure is a map in which a circle of the same size drawn on the Earth's surface is displayed in 2D in the geographic coordinate system.
- The shape changes to an ellipse depending on the region, and the size is different, so you can see that the area and angle etc. are not accurately expressed.



● Characteristics of projected coordinate system

- The projected coordinate system has the feature that it can accurately express either distance, area, or angle, depending on the projection method used.
- Therefore, the projected coordinate system is used for map representation with correct shape, drawing of figures, analysis by distance and area, etc.
- The following figure is a map of a circle of the same size drawn on the Earth's surface, projected using the Mercator projection, which is a type of regular projection (a projection that corrects the angle).
- In this example, it can be seen that the shape is still a circle in every region and the angle can be expressed correctly.
- However, the size of the circle varies depending on the region, and you can see that the area cannot be expressed correctly.
- Therefore, it is necessary to select a projection method that matches the element you want to accurately represent.

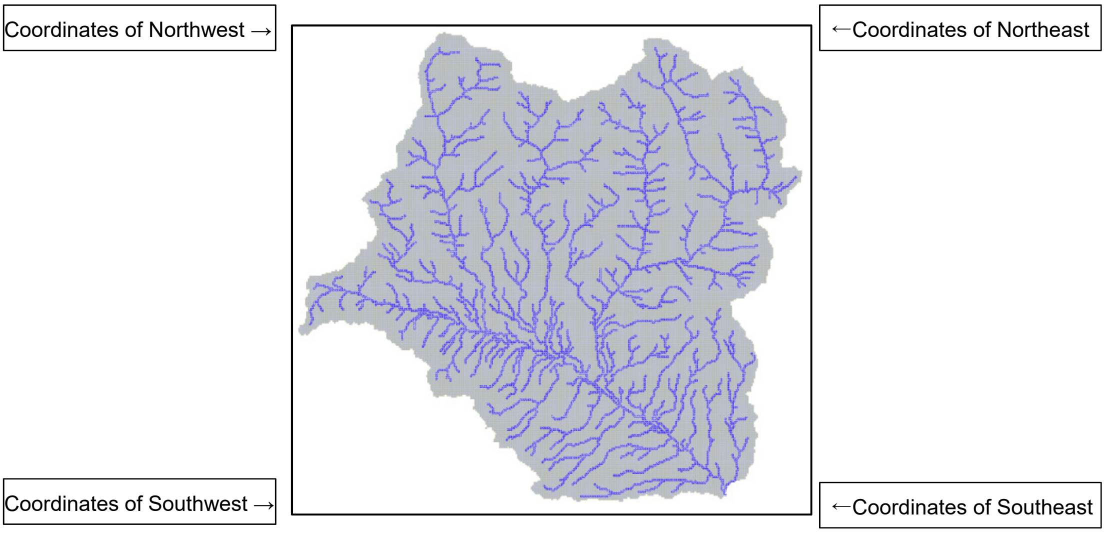


4. Basic data creation method of RRI model

4.1. Basin mesh data creation method

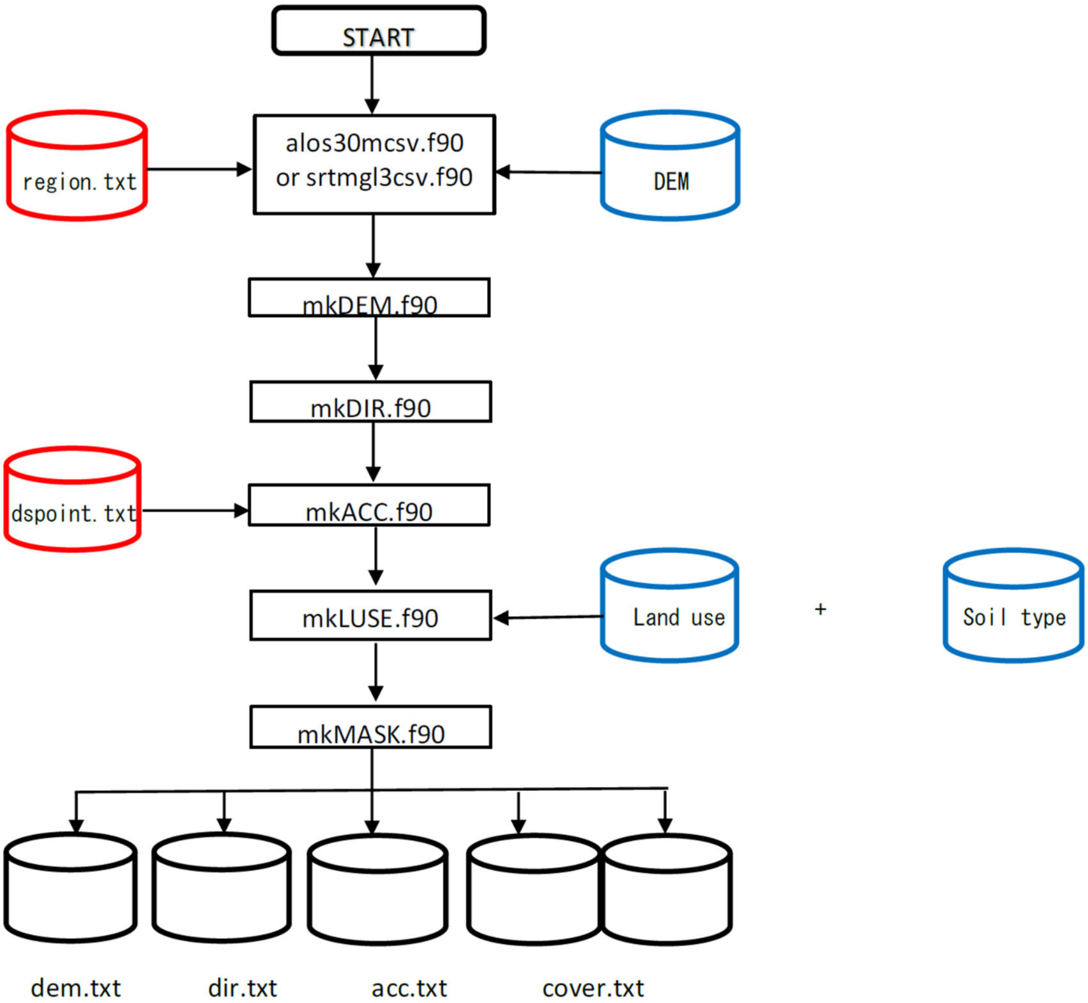
(1) Check river basin range (range of longitude and latitude)

- Confirm the target river basin area in the longitude and latitude by Googlemap etc.
- The range is rectangular and the coordinates of the four corners are calculated.
- The river basin map shown below is an example from North Macedonia.



(2) DEM in latitude and longitude creation flow

- The outline of creation of DEM in latitude and longitude is shown in the following figure.
- In the figure, red disk files represent files created by the user.
- Blue disk files represent public data available from the Internet.
- '*.f90' indicates the source code.



START
region. txt
alos30mcsv.f90
or srtmgl3csv.f90
DEM
mkDEM.f90
mkDIR.f90
dspoint. txt
mkACC.f90
mkLUSE.f90
Land use
+
Soil type
mkMASK.f90
dem.txt
dir.txt
acc.txt
cover.txt

(3) How to get DEM in latitude and longitude

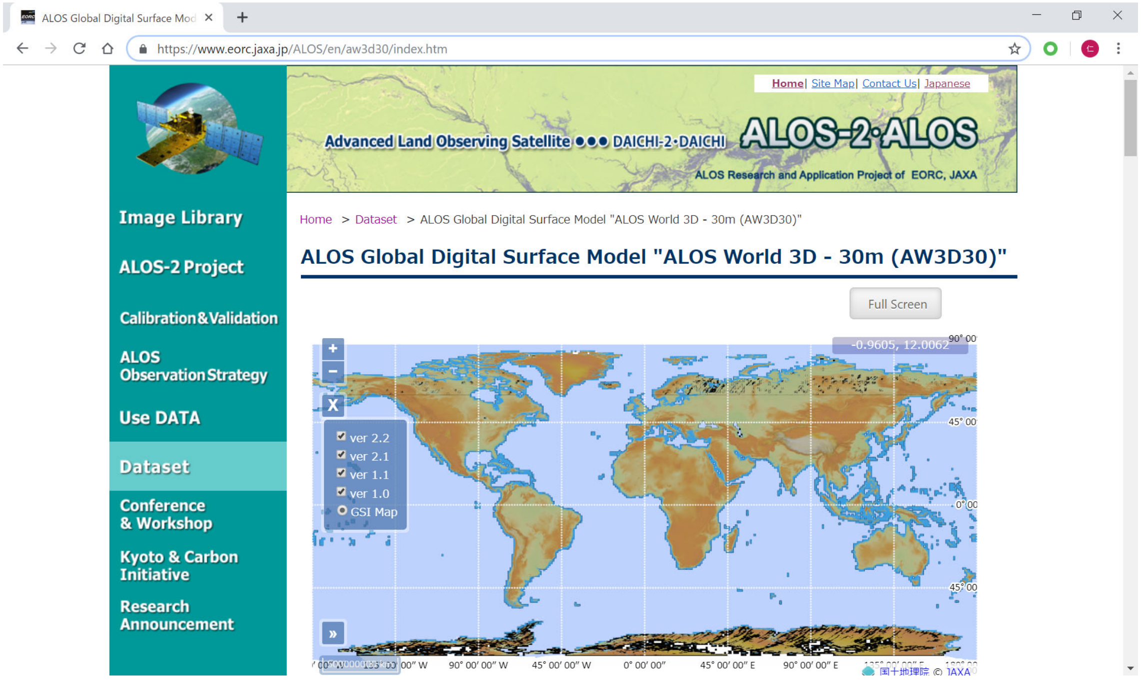
- There are two sources of DEM in latitude and longitude: "ALOS" and "HydroSHEDS"
- Here is how to get each.

(a) ALOS global numerical surface model (DEM)

● Data acquisition destination (1-second (about 30m) data)

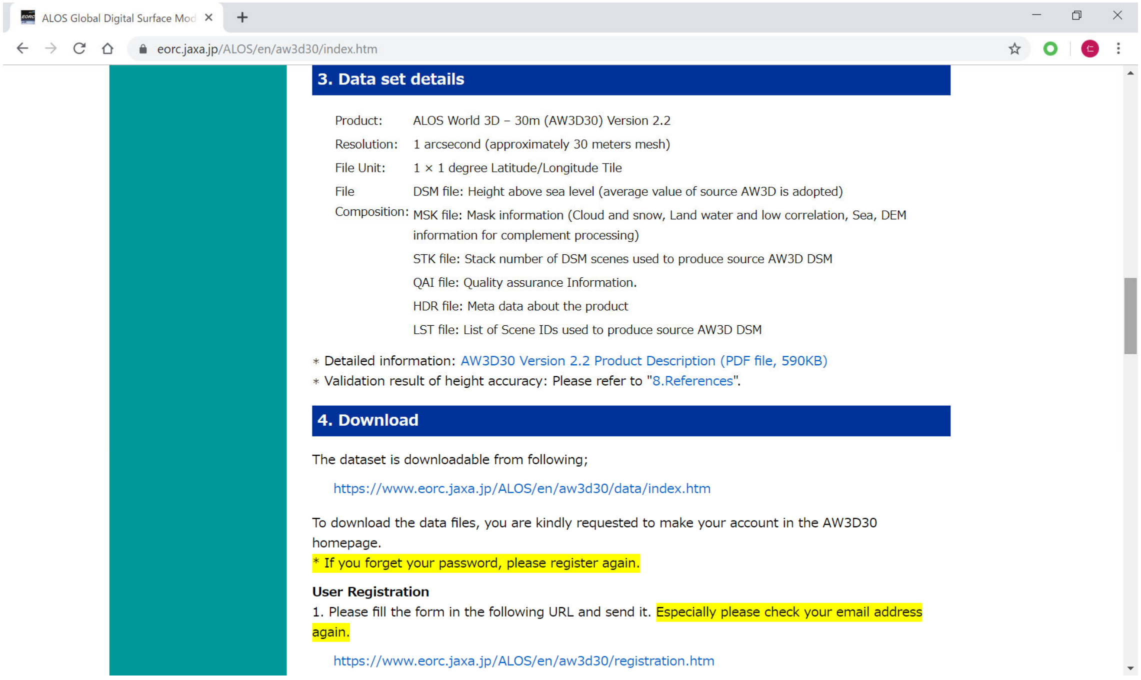
- Download 30m mesh DEM data from the following site.

https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm



● Data specifications / Download method

- DEM data specifications and download methods are as follows
- Download all data within the rectangular area (latitude and longitude) that covers the basin


ALOS Global Digital Surface Mod

eorc.jaxa.jp/ALOS/en/aw3d30/index.htm

3. Data set details

Product:	ALOS World 3D – 30m (AW3D30) Version 2.2
Resolution:	1 arcsecond (approximately 30 meters mesh)
File Unit:	1 × 1 degree Latitude/Longitude Tile
File Composition:	DSM file: Height above sea level (average value of source AW3D is adopted) MSK file: Mask information (Cloud and snow, Land water and low correlation, Sea, DEM information for complement processing) STK file: Stack number of DSM scenes used to produce source AW3D DSM QAI file: Quality assurance Information. HDR file: Meta data about the product LST file: List of Scene IDs used to produce source AW3D DSM

* Detailed information: AW3D30 Version 2.2 Product Description (PDF file, 590KB)
* Validation result of height accuracy: Please refer to "8.References".

4. Download

The dataset is downloadable from following;

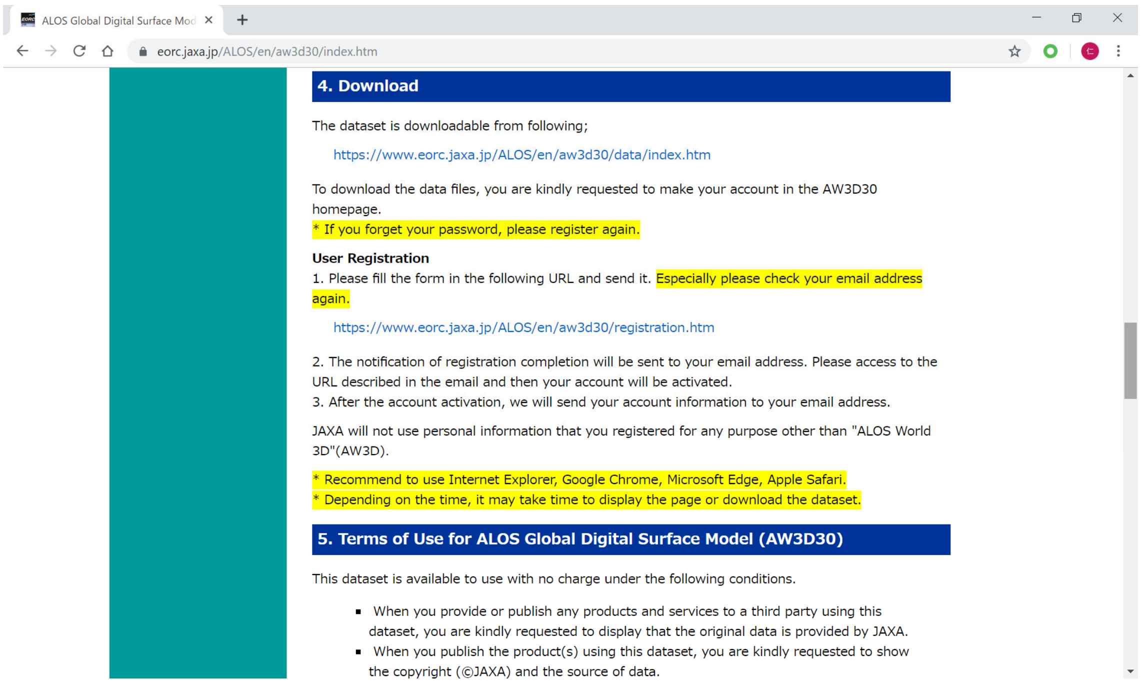
https://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm

To download the data files, you are kindly requested to make your account in the AW3D30 homepage.
* If you forget your password, please register again.

User Registration

1. Please fill the form in the following URL and send it. Especially please check your email address again.

https://www.eorc.jaxa.jp/ALOS/en/aw3d30/registration.htm


ALOS Global Digital Surface Mod

eorc.jaxa.jp/ALOS/en/aw3d30/index.htm

4. Download

The dataset is downloadable from following;

https://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm

To download the data files, you are kindly requested to make your account in the AW3D30 homepage.
* If you forget your password, please register again.

User Registration

1. Please fill the form in the following URL and send it. Especially please check your email address again.

https://www.eorc.jaxa.jp/ALOS/en/aw3d30/registration.htm

2. The notification of registration completion will be sent to your email address. Please access to the URL described in the email and then your account will be activated.
3. After the account activation, we will send your account information to your email address.

JAXA will not use personal information that you registered for any purpose other than "ALOS World 3D"(AW3D).

* Recommend to use Internet Explorer, Google Chrome, Microsoft Edge, Apple Safari.
* Depending on the time, it may take time to display the page or download the dataset.

5. Terms of Use for ALOS Global Digital Surface Model (AW3D30)

This dataset is available to use with no charge under the following conditions.

- When you provide or publish any products and services to a third party using this dataset, you are kindly requested to display that the original data is provided by JAXA.
- When you publish the product(s) using this dataset, you are kindly requested to show the copyright (©JAXA) and the source of data.

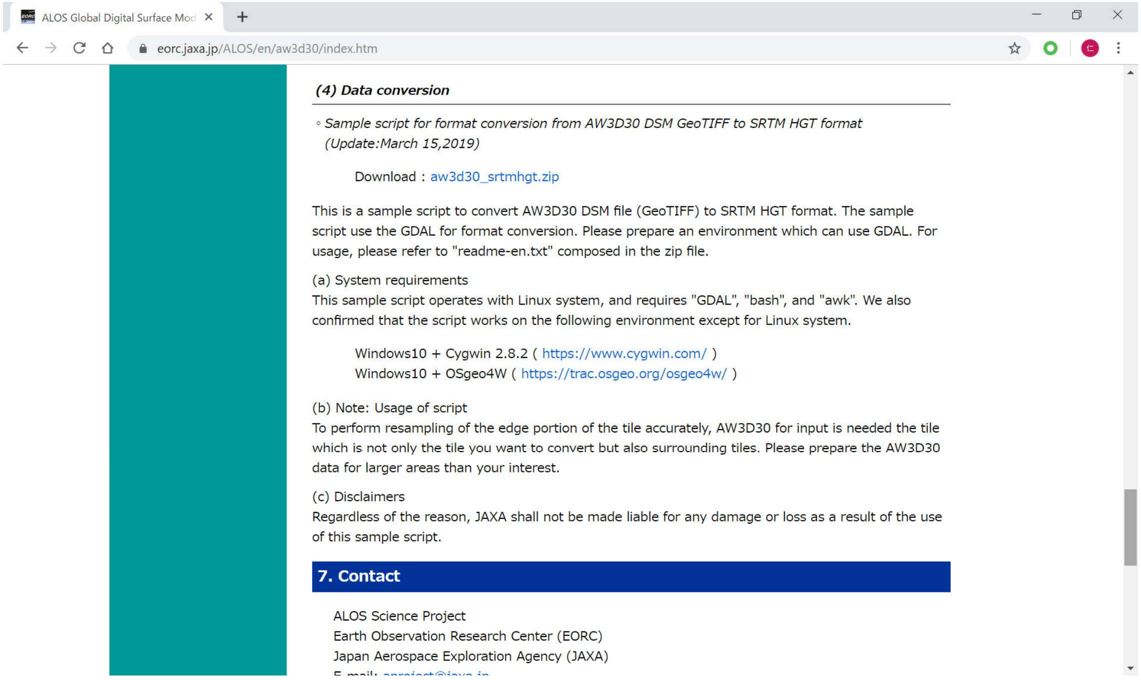
● Data conversion method

- Conversion is generally done on Linux and may be possible on Windows, but it will be quite difficult.

-Download 'aw3d30_srtmhgt.zip'.

- 'gdal' is required for data conversion and set as follows.

```
sudo apt install gdal-bin
```



● Data conversion execution

- Execution command: 'bash aw3d2strm.sh'

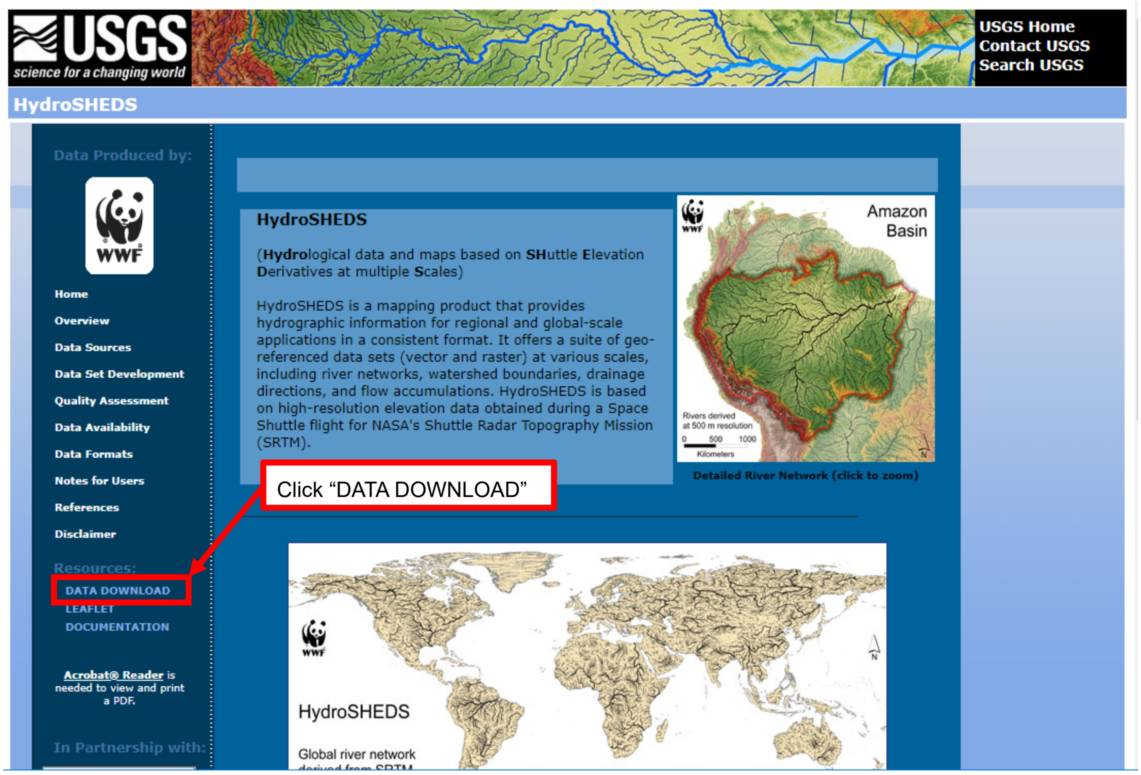
- Directory structure:

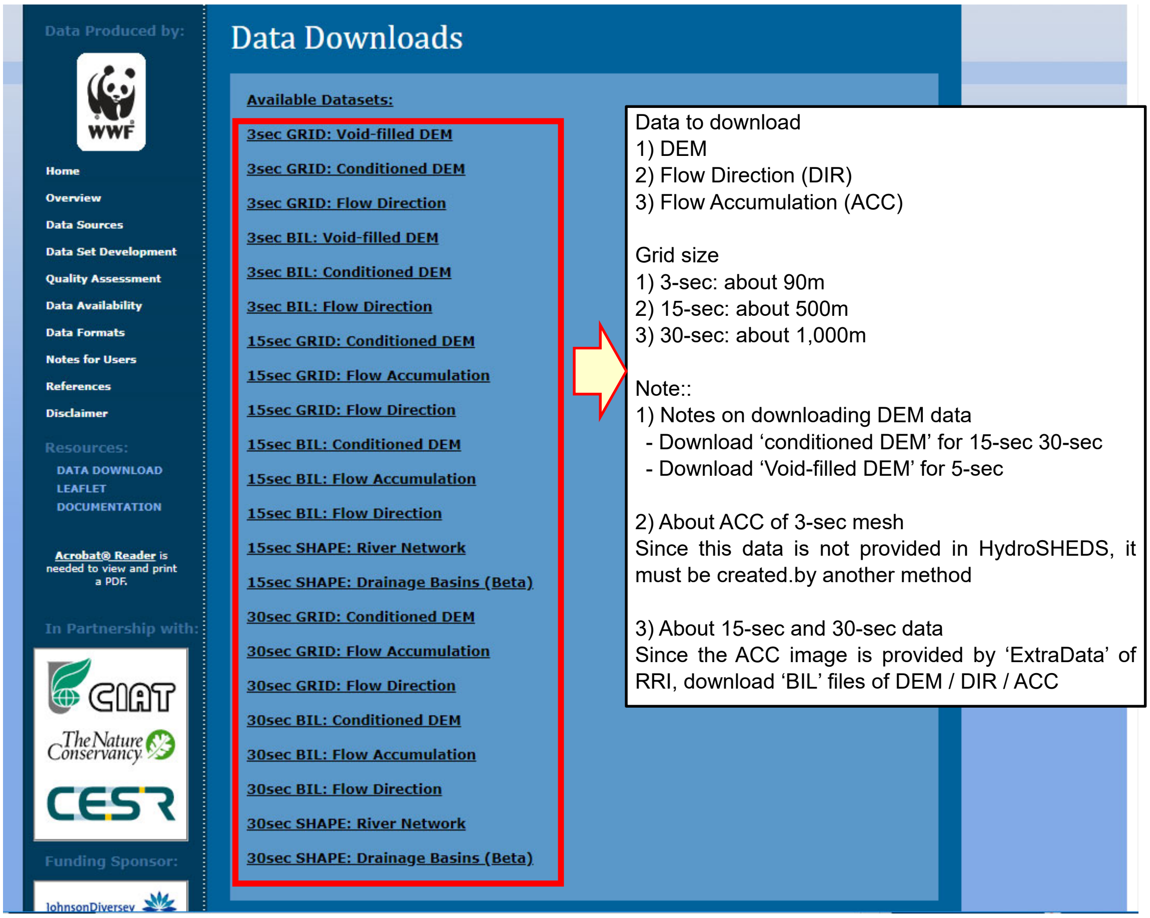
[[input]	N041E022_AVE_DSM.tif					
		Easting	Northing	bytes	bytes	integer*2 iheight(0:3600,0:3600)
[output]	N41E022.hgt	3601	3601	2	25,934,402	read(1) ((iheight(i,j),i=0,nx),j=0,ny)
	N41E022.hgt.aux.xml					
	aw3d2srtm.sh					

(b) HydroSHEDS data

- Download 3D, 15sec, 30sec grid DEM data from the following site.
  https://hydrosheds.cr.usgs.gov/index.php

- 15 sec / 30 sec grid DEM data is stored in the “RRI model” directory.



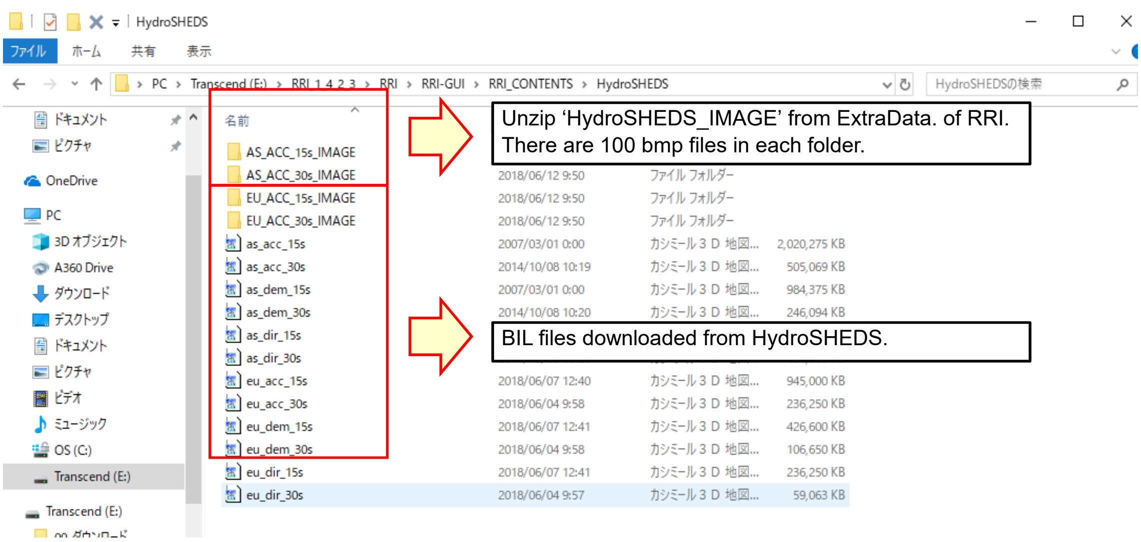


● Folders for extracting files and storing the extracted data

- Extract 'ExtraData' into the folder below.

"RRI-GUI ¥ RRI_CONTENTS ¥ HydroSHEDS"

- This will allow the GUI to select the outflow point and extract the basin.



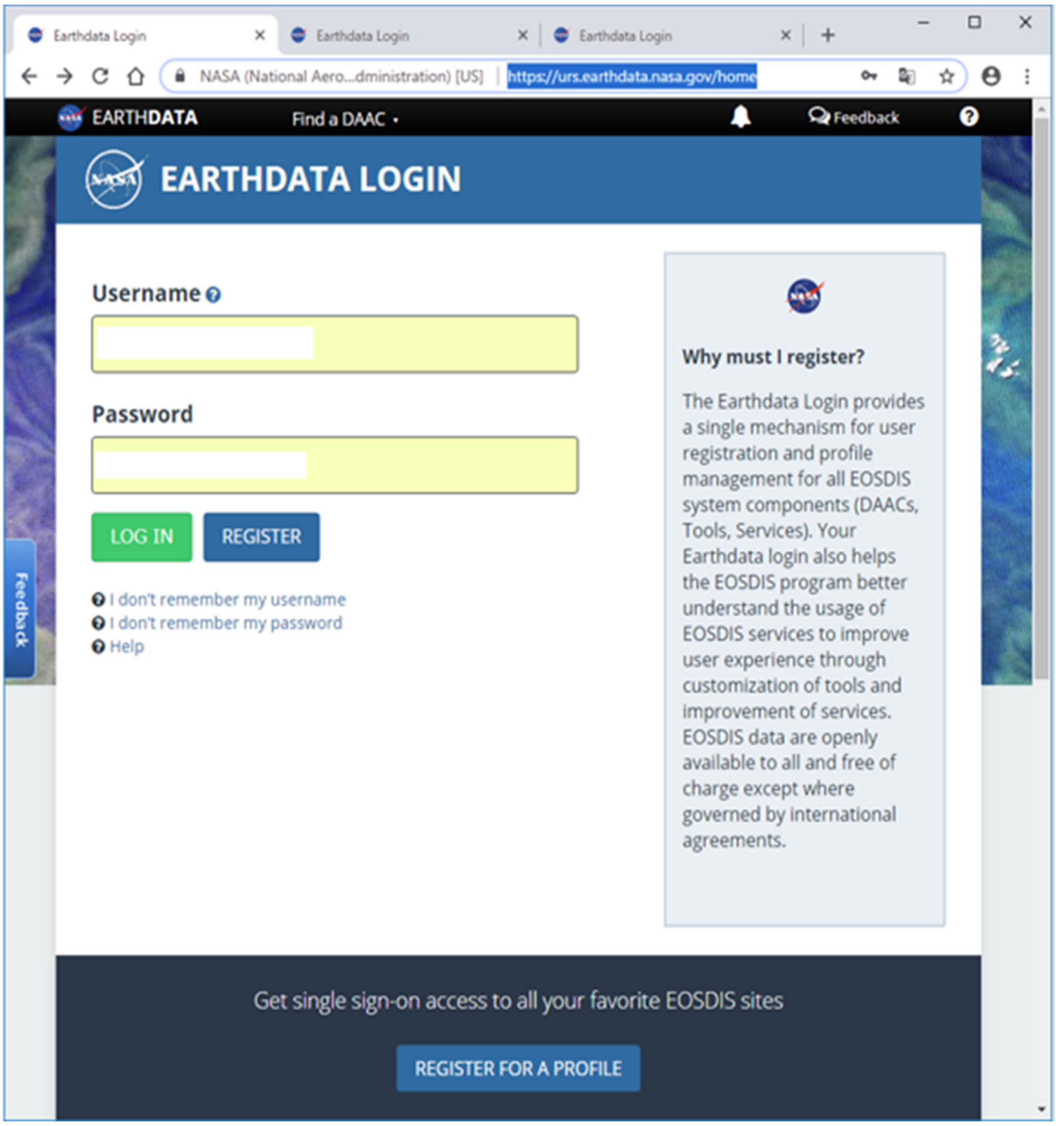
(c) Acquisition of geological and soil data from SRTM (Shuttle Radar Topography Mission Height)

● Login

- Log in to the following site to obtain geological and soil data.

    https://urs.earthdata.nasa.gov/home

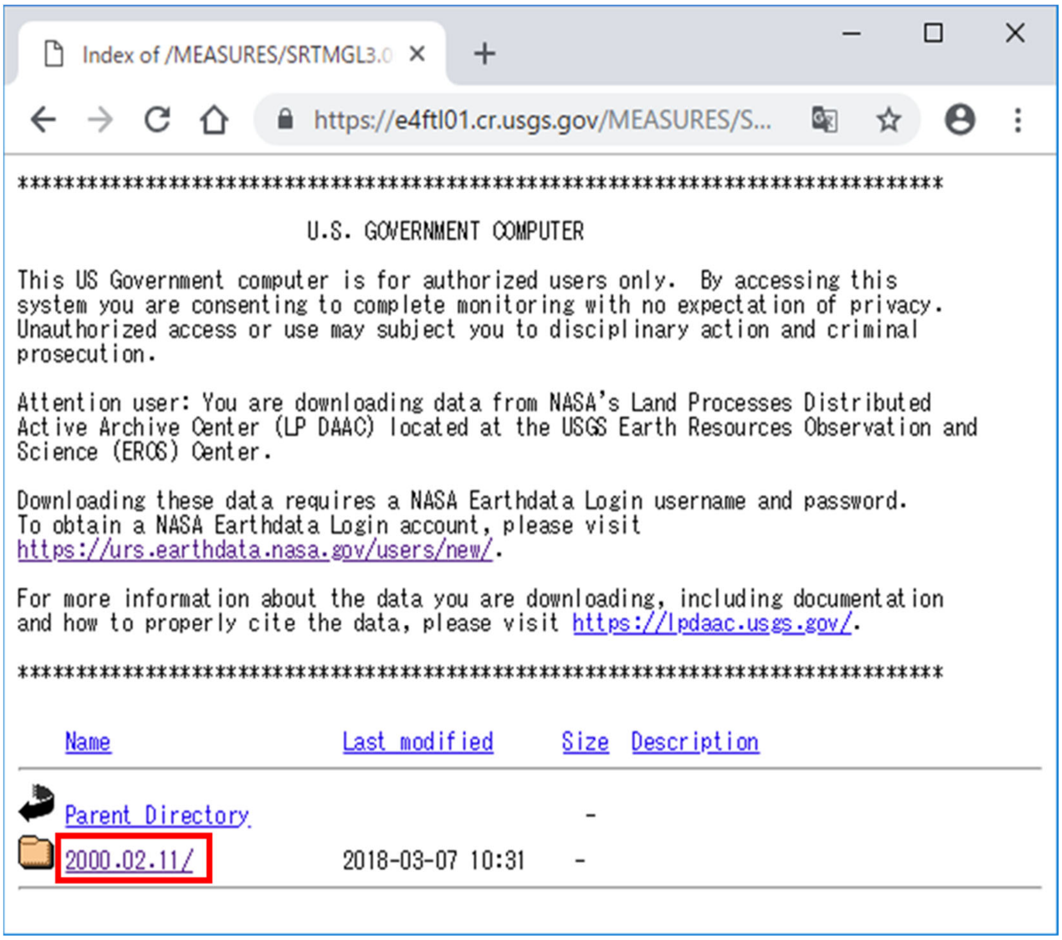
- Enter the pre-registered Username and Password.

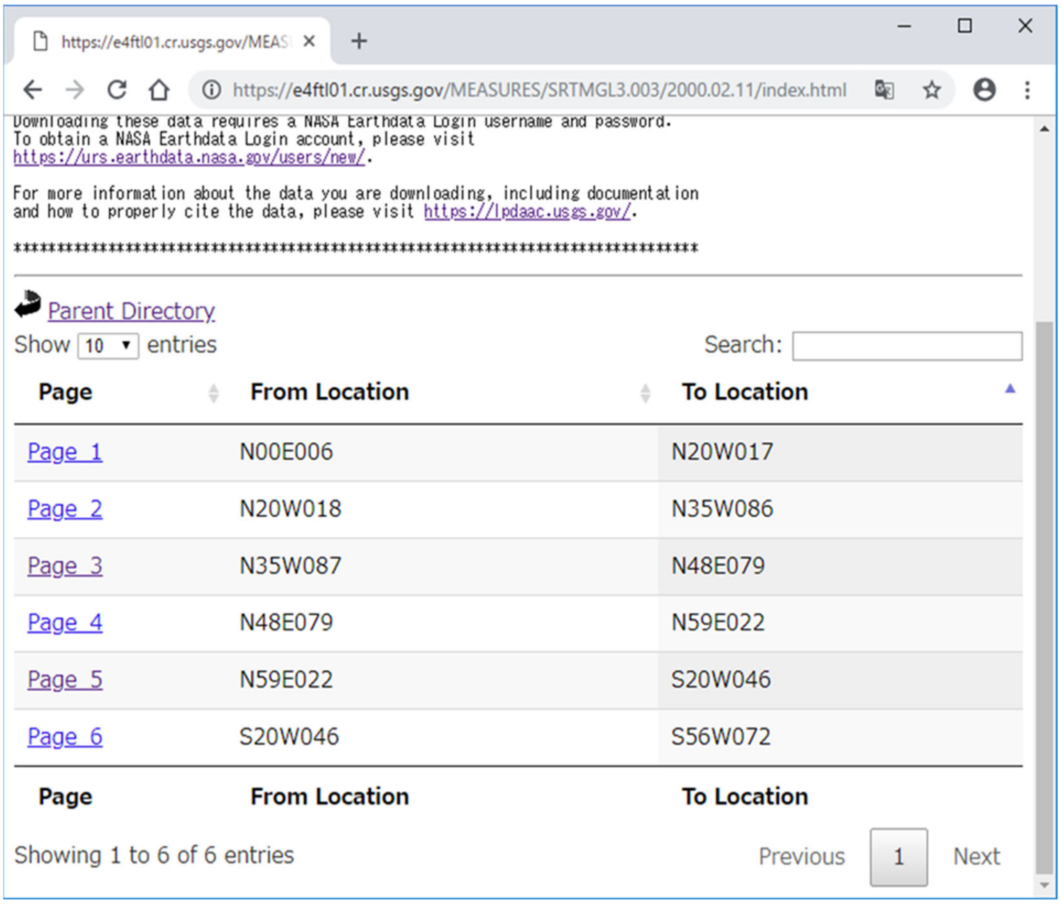


● Data acquisition

- After logging in, jump to the following URL.

https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL3.003/




https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL3.003/2000.02.11/index.html

Downloading these data requires a NASA Earthdata Login username and password.
To obtain a NASA Earthdata Login account, please visit
https://urs.earthdata.nasa.gov/users/new/.

For more information about the data you are downloading, including documentation
and how to properly cite the data, please visit https://lpdaac.usgs.gov/.

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Parent Directory

Show 10 entries Search:

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Page 1	N00E006	N20W017
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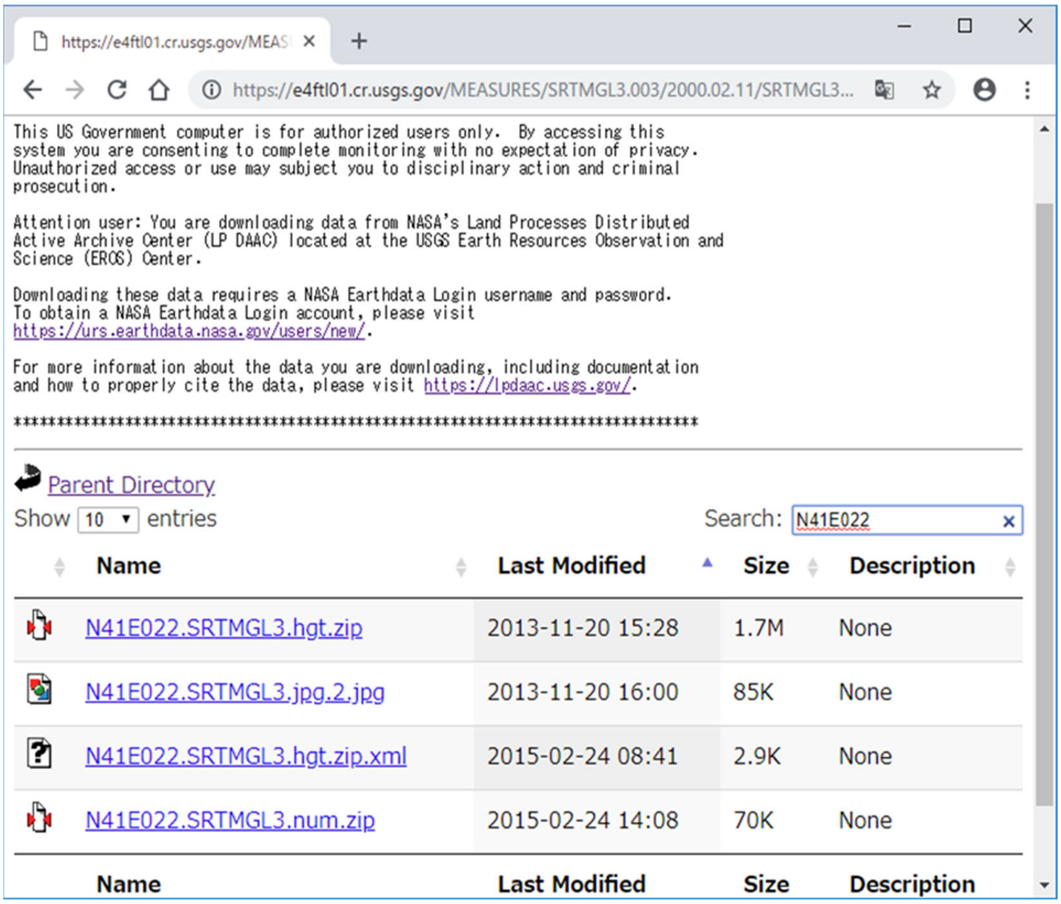
Page 4	N48E079	N59E022
Page 5	N59E022	S20W046
Page 6	S20W046	S56W072
Page	From Location	To Location

Showing 1 to 6 of 6 entries Previous 1 Next

- When you open the following page and after a while, the [Search] button on the right side of the screen will appear.
- For Macedonia (Radovish), enter N42E022 to search
- Then, the file name is displayed as in the following screen, so download it.

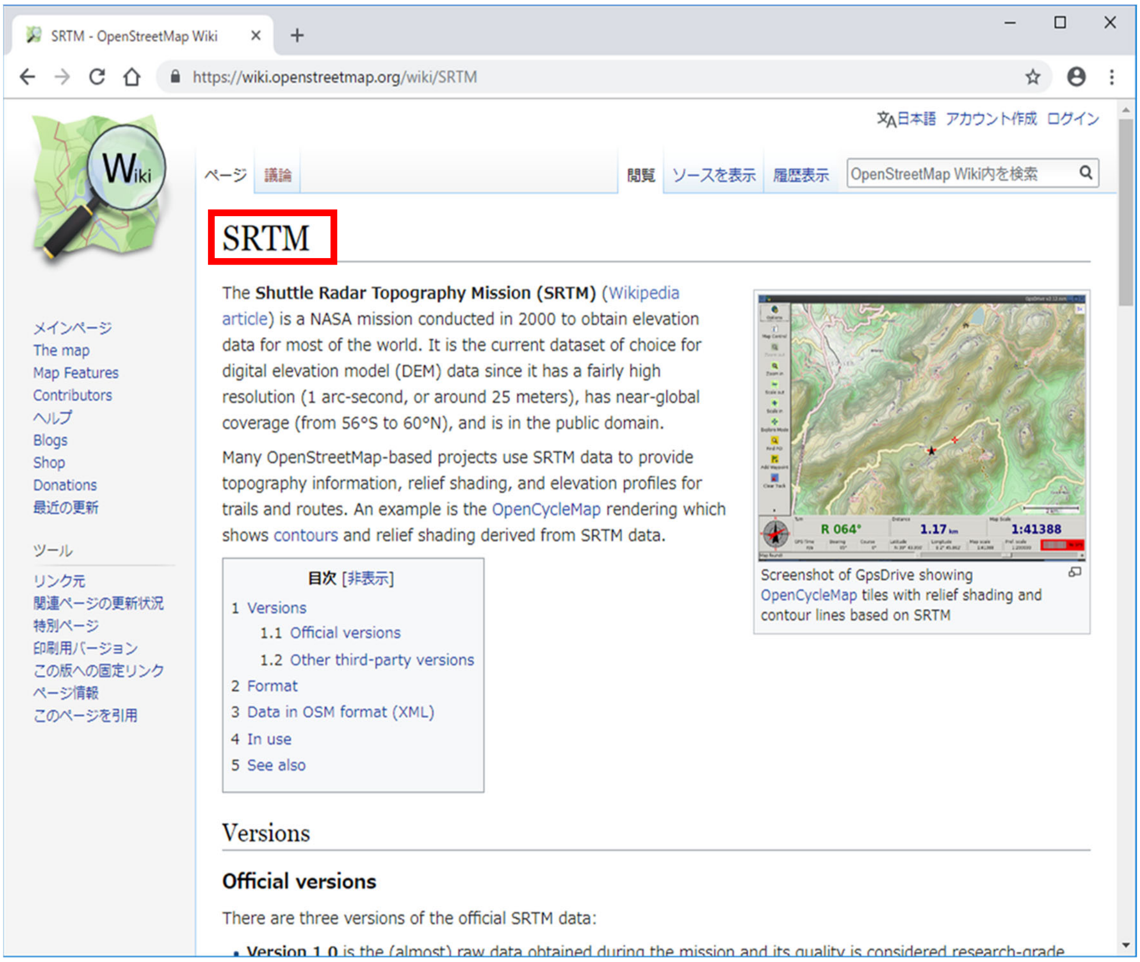


Note)
- If you are not signed in, you will be asked for username and password.
- You cannot download data without registration.

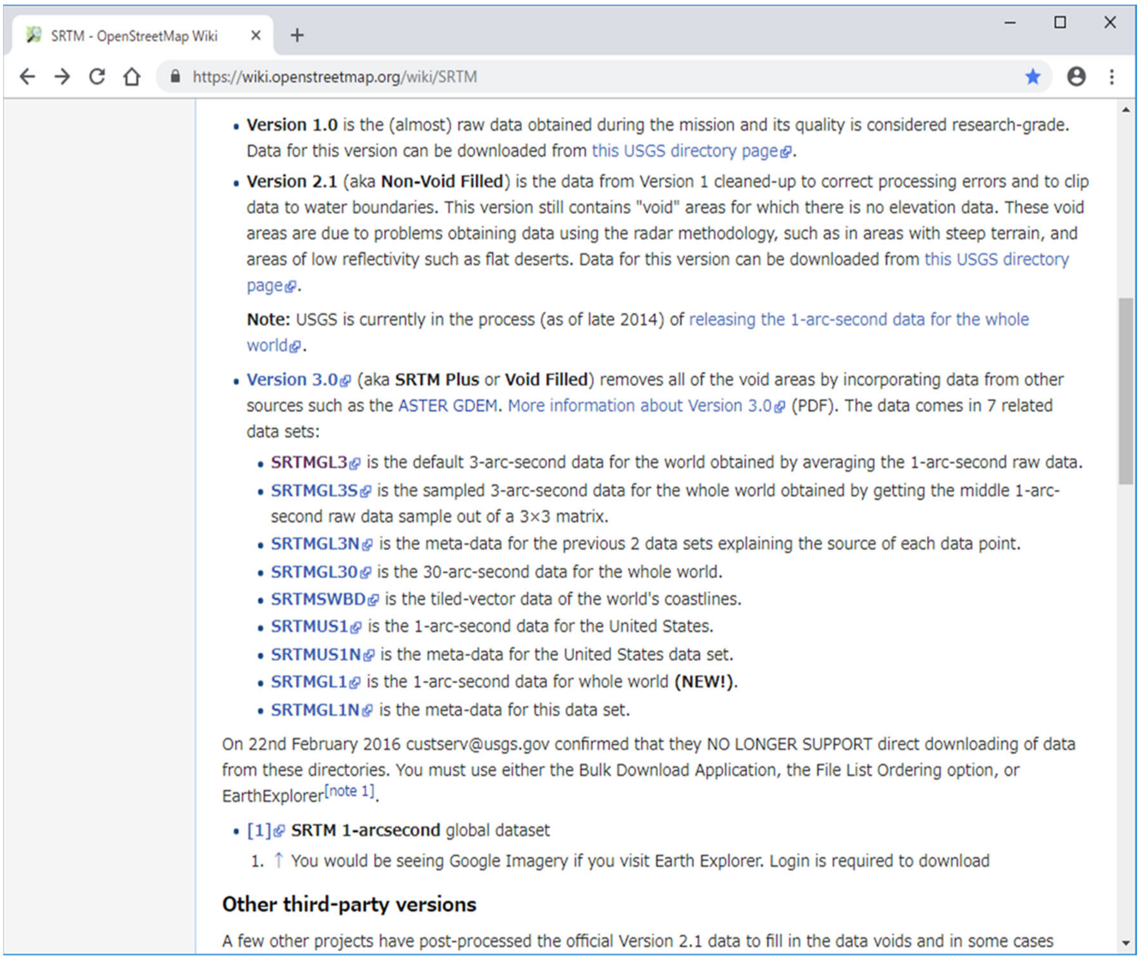
(d) Information about data structure, etc.

- Obtain above information from the following site.

  https://wiki.openstreetmap.org/wiki/SRTM



↓ scroll down



- **Version 1.0** is the (almost) raw data obtained during the mission and its quality is considered research-grade. Data for this version can be downloaded from this USGS directory page.
- **Version 2.1** (aka **Non-Void Filled**) is the data from Version 1 cleaned-up to correct processing errors and to clip data to water boundaries. This version still contains "void" areas for which there is no elevation data. These void areas are due to problems obtaining data using the radar methodology, such as in areas with steep terrain, and areas of low reflectivity such as flat deserts. Data for this version can be downloaded from this USGS directory page.

  Note: USGS is currently in the process (as of late 2014) of releasing the 1-arc-second data for the whole world.
- **Version 3.0** (aka **SRTM Plus** or **Void Filled**) removes all of the void areas by incorporating data from other sources such as the ASTER GDEM. More information about Version 3.0 (PDF). The data comes in 7 related data sets:
  - **SRTMGL3** is the default 3-arc-second data for the world obtained by averaging the 1-arc-second raw data.
  - **SRTMGL3S** is the sampled 3-arc-second data for the whole world obtained by getting the middle 1-arc-second raw data sample out of a 3×3 matrix.
  - **SRTMGL3N** is the meta-data for the previous 2 data sets explaining the source of each data point.
  - **SRTMGL30** is the 30-arc-second data for the whole world.
  - **SRTMSWBD** is the tiled-vector data of the world's coastlines.
  - **SRTMUS1** is the 1-arc-second data for the United States.
  - **SRTMUS1N** is the meta-data for the United States data set.
  - **SRTMGL1** is the 1-arc-second data for whole world **(NEW!)**.
  - **SRTMGL1N** is the meta-data for this data set.

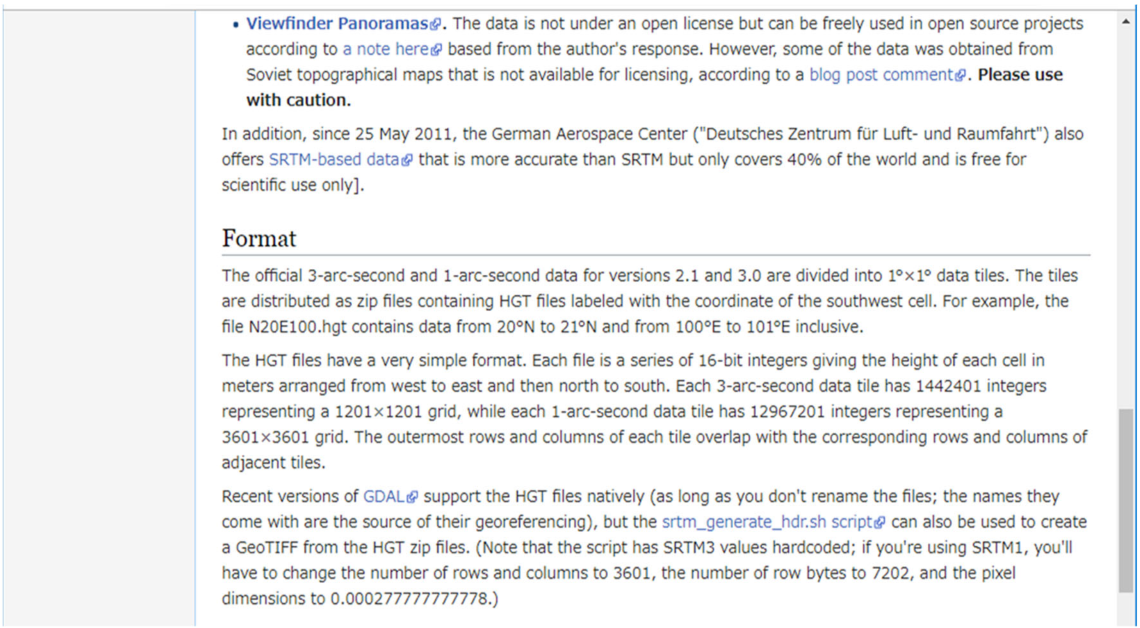
On 22nd February 2016 custserv@usgs.gov confirmed that they NO LONGER SUPPORT direct downloading of data from these directories. You must use either the Bulk Download Application, the File List Ordering option, or EarthExplorer[note 1].

- [1] **SRTM 1-arcsecond** global dataset

1. ↑ You would be seeing Google Imagery if you visit Earth Explorer. Login is required to download

Other third-party versions

A few other projects have post-processed the official Version 2.1 data to fill in the data voids and in some cases



- **Viewfinder Panoramas**. The data is not under an open license but can be freely used in open source projects according to a note here based from the author's response. However, some of the data was obtained from Soviet topographical maps that is not available for licensing, according to a blog post comment. **Please use with caution.**

In addition, since 25 May 2011, the German Aerospace Center ("Deutsches Zentrum für Luft- und Raumfahrt") also offers SRTM-based data that is more accurate than SRTM but only covers 40% of the world and is free for scientific use only].

Format

The official 3-arc-second and 1-arc-second data for versions 2.1 and 3.0 are divided into 1°×1° data tiles. The tiles are distributed as zip files containing HGT files labeled with the coordinate of the southwest cell. For example, the file N20E100.hgt contains data from 20°N to 21°N and from 100°E to 101°E inclusive.

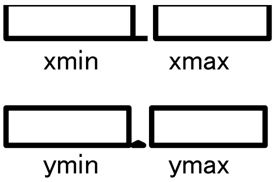
The HGT files have a very simple format. Each file is a series of 16-bit integers giving the height of each cell in meters arranged from west to east and then north to south. Each 3-arc-second data tile has 1442401 integers representing a 1201×1201 grid, while each 1-arc-second data tile has 12967201 integers representing a 3601×3601 grid. The outermost rows and columns of each tile overlap with the corresponding rows and columns of adjacent tiles.

Recent versions of GDAL support the HGT files natively (as long as you don't rename the files; the names they come with are the source of their georeferencing), but the srtm_generate_hdr.sh script can also be used to create a GeoTIFF from the HGT zip files. (Note that the script has SRTM3 values hardcoded; if you're using SRTM1, you'll have to change the number of rows and columns to 3601, the number of row bytes to 7202, and the pixel dimensions to 0.000277777777778.)

■ Data structure

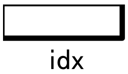
● Data specification of user created file (region.txt)

1) ‘region.txt’: To specify analysis range

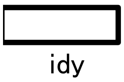


xmin: West end longitude (deg) of analysis range
xmax: East longitude (deg) of analysis range
ymin: Southern latitude (deg) of analysis range
ymax: North latitude of the analysis range (deg)

2) dspoint: To identify downstream grid number



idx: Grid number in the east-west direction at the downstream end of the river



idy: Grid number in the east-west direction at the downstream end of the river

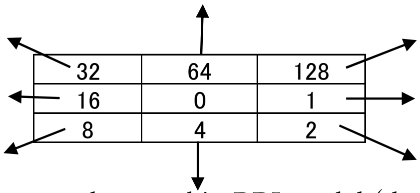


Fig. Flow direction number used in RRI model (described in ‘dir.txt’)

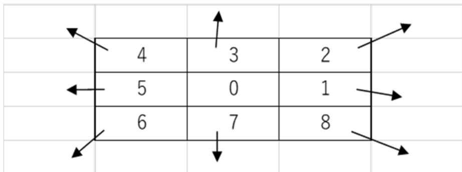


Fig. Flow direction number for explanation in the figure below
(RRI model uses the number in the figure above)

idx and idy are determined using the temporary file ‘dir_tmp.txt’ according to the procedure shown below.

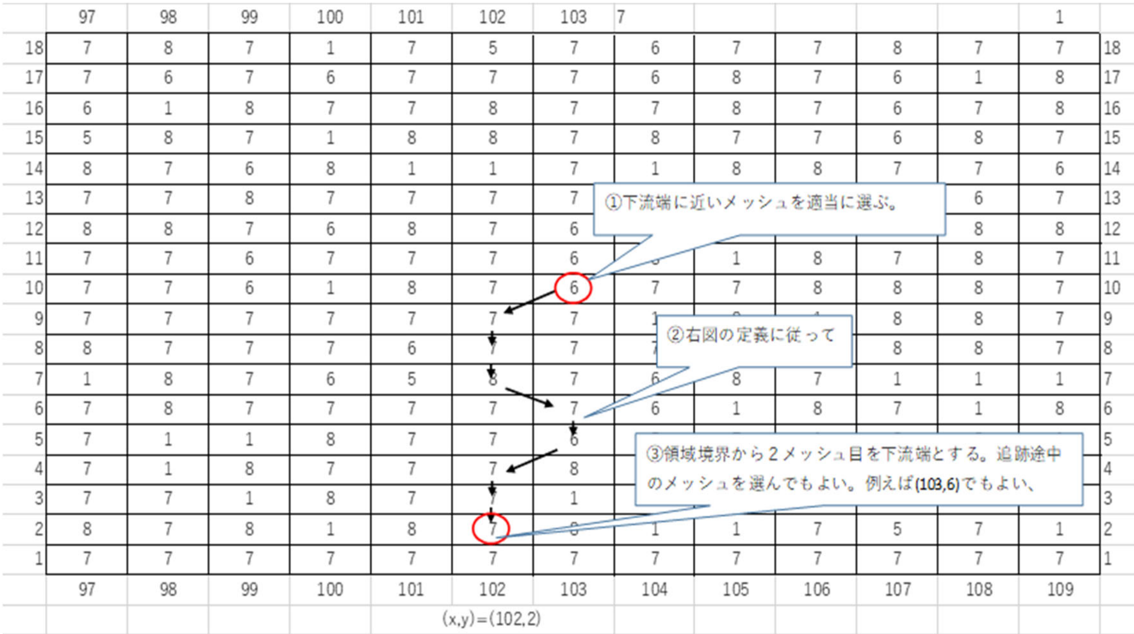


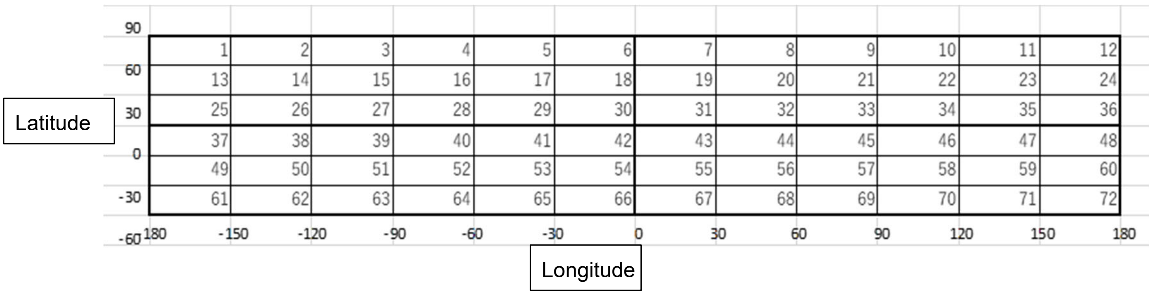
Fig. Search method for downstream grid of the river

■ Land use / vegetation data

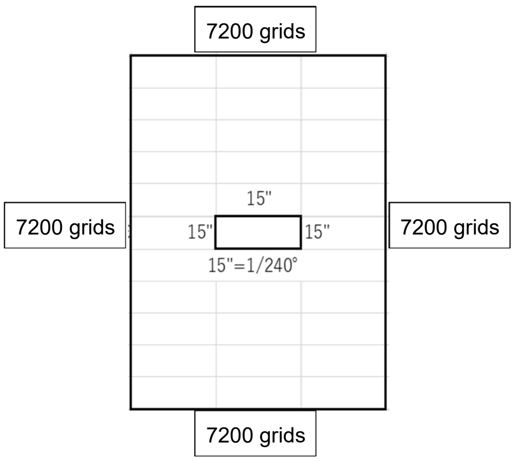
● Use USGS land cover (GLCNMO)

Although this data is available on the Internet, use data prepared by RRI.

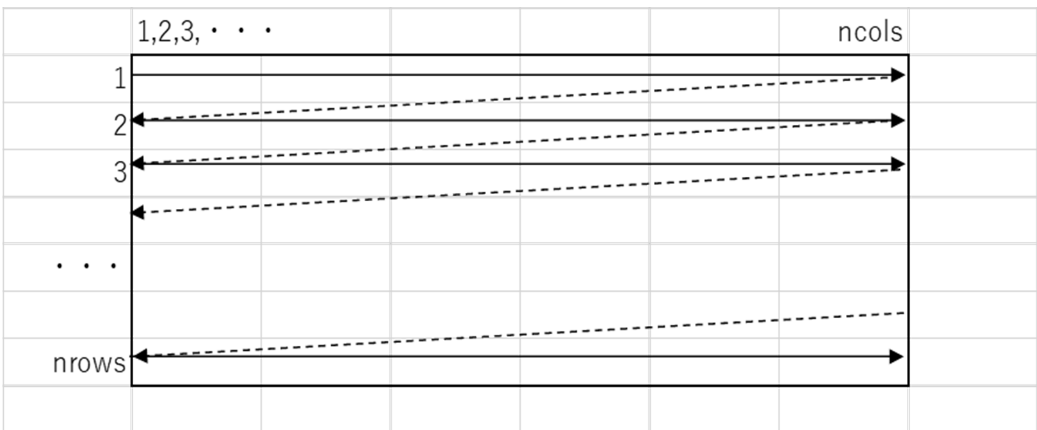
(1) File number



(2) Grid size



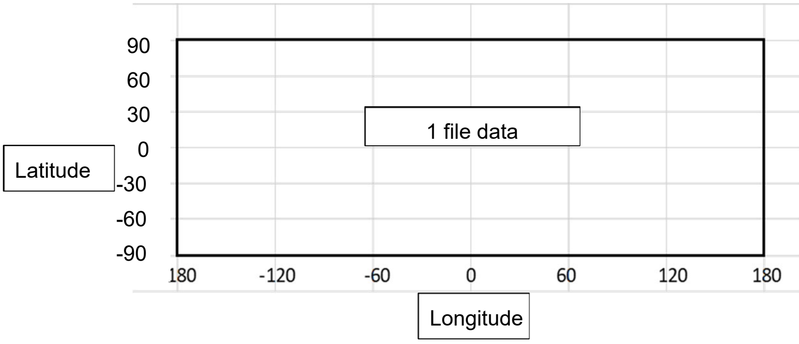
(3) Order of data



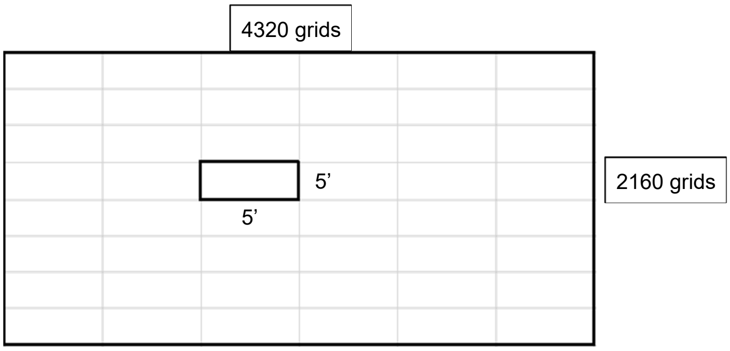
■ Soil and geological data (FAO soil data)

● Use FAO_CODE_DATA.csv prepared by RRI.

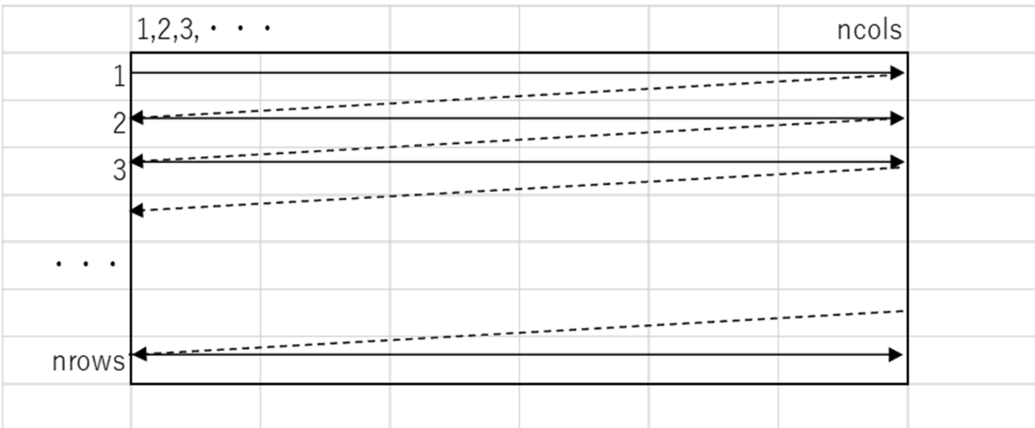
(1) File



(2) Grid size



(3) Order of data



(4) Table of the code

Code	Vertical sa	Effective p	Saction at	Lateral sa	Unsaturat	Beta	Class name
1	6.54E-05	0.417	0.0495	6.54E-01	0.02	4	Sand
2	1.66E-05	0.401	0.0613	1.66E-01	0.035	4	Loamy sand
3	6.00E-06	0.412	0.1101	6.00E-02	0.041	4	Sandy loam
4	3.67E-06	0.434	0.0889	3.67E-02	0.027	4	Loam
5	1.89E-06	0.486	0.1668	1.89E-02	0.015	4	Silt loam
6	1.36E-06	0.408	0.198	1.36E-02	0.042	4	Silt
7	8.33E-07	0.33	0.2185	8.33E-03	0.068	4	Sandy clay loam
8	5.56E-07	0.309	0.2088	5.56E-03	0.075	4	Clay loam
9	5.56E-07	0.432	0.273	5.56E-03	0.04	4	Silty clay loam
10	3.33E-07	0.321	0.239	3.33E-03	0.109	4	Sandy clay
11	2.78E-07	0.423	0.2922	2.78E-03	0.056	4	Silty clay
12	1.67E-07	0.385	0.3163	1.67E-03	0.09	4	Clay

■ Execute data conversion for RRI

(1) For ALOS30m

```
cd (1a)ALOS¥(1)ALOS30m_N42E022_on_Linux
gfortran alos30mcsv.f90
a.exe

cd ../../(2)mkDEM
gfortran mkDEM.f90
a.exe

cd ../(3)mkDIR
gfortran mkDIR.f90
a.exe

cd ../(4)mkACC
gfortran mkACC.f90
a.exe

cd ../(5)mkLUSE
gfortran mkLUSE.f90
a.exe

cd ../(6)mkMASK
gfortran mkMASK.f90
a.exe

cd ..
```

(2) For SRTM3

```
cd (1b)SRTM¥(1)SRTMGL3_N41E022_on_Linux
gfortran srtmgl32csv.f90
a.exe

cd ../../(2)mkDEM
gfortran mkDEM.f90
a.exe

cd ../(3)mkDIR
gfortran mkDIR.f90
a.exe

cd ../(4)mkACC
gfortran mkACC.f90
a.exe

cd ../(5)mkLUSE
gfortran mkLUSE.f90
a.exe

cd ../(6)mkMASK
gfortran mkMASK.f90
a.exe

cd ..
```

■ File structure of RRI data conversion program

```
mytools ──┬─(1a)ALOS ──── (1)ALOS30mN42E022 ──── alos30mcsv.f90
          │        Pre-processing to create RRI DEM from SRTM3 DEM
          ├─(1b)SRTM ──── (1)SRTMGL3_N41E022 ──── srtmgl3csv.f90
          │        Pre-processing to create RRI DEM from SRTM3 DEM
          ├─(2)mkDEM ──── mkDEM.f90      DEM creation for RRI
          ├─(3)mkDIR ──── mkDIR.f90      DIR creation for RRI
          ├─(4)mkACC ──── mkACC.f90      ACC creation for RRI
          ├─(5)mkLUSE ─── mkLUSE.f90     LUSE, LSOIL creation for RRI
          ├─(6)mkMASK ─── mkMASK.f90
          │               Mask dem.txt, dir.txt, acc.txt, cover.txt, soil.txt
          └─data    Storage folder for input, output, and temporary files
```

4.2. River mesh data creation method

4.2.1 Number of river certified meshes (riv_thresh) setting

- In 'RRI_input.txt' (calculation control), which is the most important file of the RRI model, it is necessary to identify where the river begins from the flow direction line.
- In the RRI model, the river is downstream from the point where the number of grids exceeds the certified number of grids, and it is described as "riv_thresh" in 'RRI_input.txt'.
- For this reason, the certified number of "riv_thresh" (line 38 of 'RRI_input.txt': described in L38) differs depending on the grid size.

4.2.2 How to create a file of rectangular cross section of the river

- In the RRI model, the existence of rivers is determined from the number of upstream grids (basin area) of the flow direction line.
- In the RRI model, the river width and height can be obtained by regime theory in places where there is no river measurement data.
- In the current RRI model, it is not possible to define multi-section rivers by regime theory.

■ Setting of river width (regime theory)

- In order to use the RRI model, it is necessary to set the river width for all river sections.
- Since all river width data can hardly be obtained, set using the following regime equation.
- In the RRI model, the river width can be set to all river grids by entering regime constants.
- The theoretical formula of the RRI model is a formula for finding the width of a river close to a natural river.
- Therefore, as a preparation for setting the river width, apply the following formula at a point where the river width is known, and then determine the constant to be adopted.

Formula1: $B=5.0A^{0.35}$ (RRI)

Formula2: $B=5.3A^{0.5}$ (Sakamoto)

Formula3: $B=8.4A^{0.5}$ (Harada)

Here, B: River Width (m)

A: Basin area (km^2)

■ Setting of river height (HWL-riverbed height: regime theory)

- In order to use the RRI model, it is necessary to set the river height for all river sections.
- Since all river height data is hardly available, set it using the following regime equation.
- In the RRI model, the river height can be set to all river grids by entering regime constants.

- The theoretical formula of the RRI model is a formula for finding the river height close to a natural river.
- Therefore, as a preparation for setting the river height, apply the following formula at a point where the river height is known, and then determine the constant to be adopted.

Formula1: $H=0.95A^{0.2}$ (RRI)

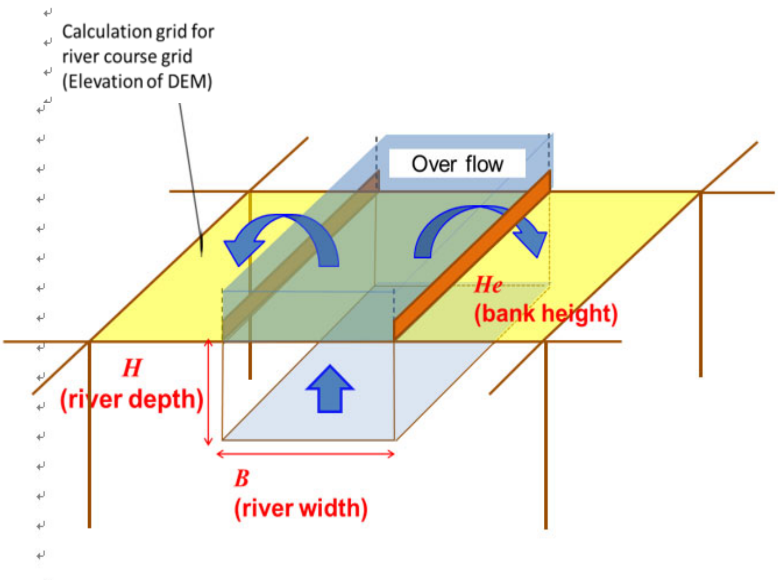
Formula2: $H=1.65A^{0.21}$ (Sakamoto)

Here, H: River height (HWL-riverbed height) (m)

A: Basin area (km^2)

■ Concept of river parameter of RRI model

- The river parameter created by the RRI model regime theory is composed of river height, river width, and bank height.



■ Margin height (= bank height-ground height (or HWL)) setting (Only a fixed value can be set with the current RRI model)

- In the current RRI model, the margin cannot be set for each grid, so a constant value should be set to all sections.
- Margin (constant value) = Bank height-Ground height (or HWL)

4.2.3 How to create general cross section file

- Use the file format below for complex river cross sections rather than rectangular ones.

■ Correction and addition of 'RRI_input.txt'

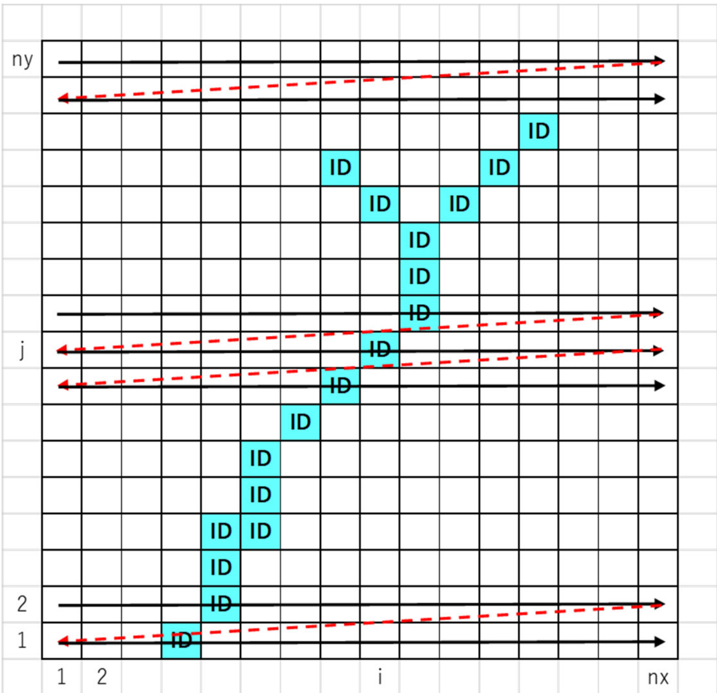
- To change the format from rectangular cross section to general section, modify or add 'RRI_input.txt' as shown below.

L83	1	Set '1' when inputting a general river cross section.
L84	./riv/sec_map.txt	A file that associates mesh number (I,J) with river cross section ID
L85	./riv/section/sec_	Common part of file name to input general river cross section

■ Create river location file (file name: './riv/sec_map.txt')

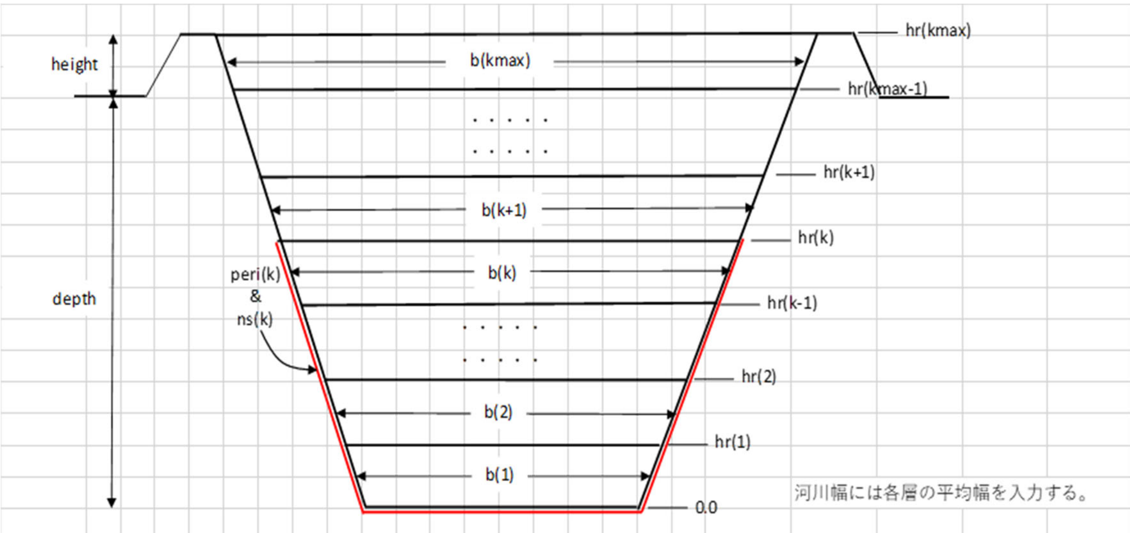
- ID: General river channel ID (1 to 999999)

Note) ID is preferably a serial number.

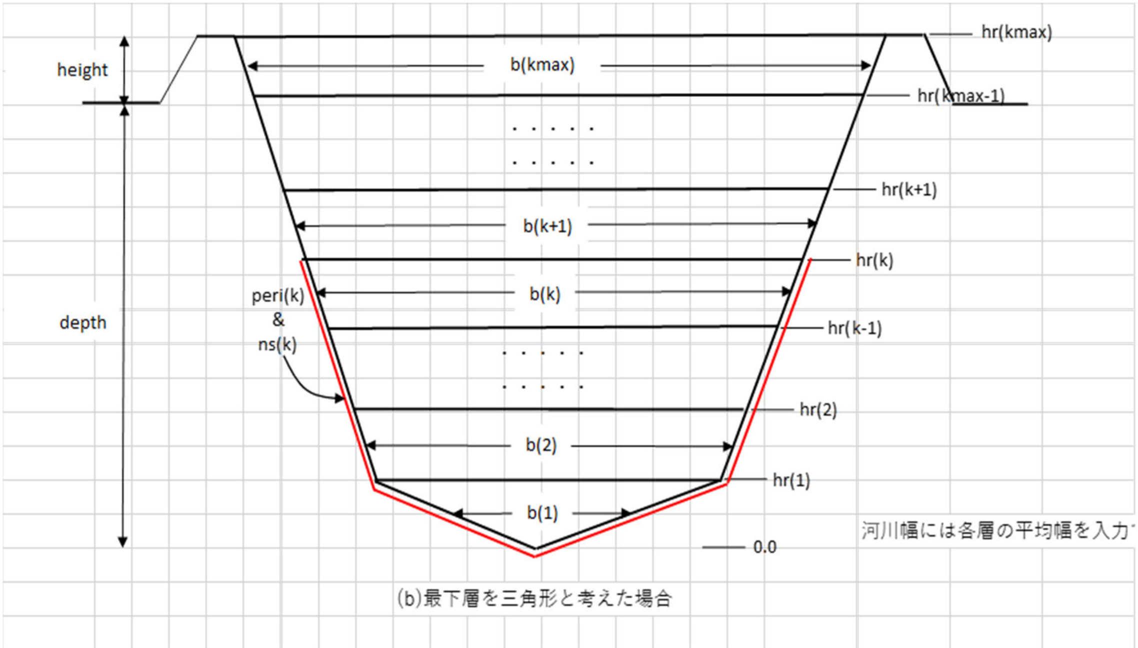


■ Create river cross section shape file (file name: './riv/section/sec_######.txt')

	######：一般河道断面ID(000001～999999)					character*6 ID		
1行目	kmax	␣	depth	␣	height			kmax:各一般河道断面の分割数
2行目	hr(1)	␣	peri(1)	␣	b(1)	␣	ns(1)	Kmax:全一般河道断面の分割数の最大値
3行目	hr(2)	␣	peri(2)	␣	b(2)	␣	ns(2)	depth:地盤面から河床までの深さ[m]
	・・・・・・・・・・・・・・・・・・・・・							height:地盤面から堤防天端までの高さ[m]
	・・・・・・・・・・・・・・・・・・・・・							hr(k):河床からの高さ[m]
	・・・・・・・・・・・・・・・・・・・・・							peri(k):潤辺長[m]
k行目	hr(k)	␣	peri(k)	␣	b(k)	␣	ns(k)	b(k):河道幅[m]（各層の平均幅）
	・・・・・・・・・・・・・・・・・・・・・							ns(k):合成粗度係数
	・・・・・・・・・・・・・・・・・・・・・							注）データの区切りは１つ以上の空白（␣）
	・・・・・・・・・・・・・・・・・・・・・							
kmax行目	hr(kmax)	␣	peri(kmax)	␣	b(kmax)	␣	ns(kmax)	



(a)最下層を台形と考えた場合



4.3. Rainfall mesh data creation method

- Rainfall data includes point data (ground rainfall) and surface data (radar rainfall).
- Here, how to create point data (ground rainfall) is shown below.

4.3.1 Point data (rainfall) creation method

■ Correction and addition of rainThiessen.txt

● Example of 'rainThiessen.txt'

rain/Temp_Gage.csv		・Location where rain data is stored (ex.Temp_Gage.csv)
rain/rain.dat		
rain/rain_Map.txt		
ncols	420	
nrows	360	
xllcorner	22.35042	Note) Set the range to cover the entire basin
yllcorner	41.49958	Note) Set the range to cover the entire basin
cellsize	0.00083	

● Contents of 'rainThiessen.txt'

- 1st line: Rainfall observation data file name (e.g., 'Temp_Gage.csv')
- 2nd line: Rainfall data by time series mesh (e.g., 'rain.dat')
- 3rd line: Nearest observatory code file of each grid (e.g., 'rain_Map.txt')
- 4th line: Number of grids in east-west direction

- 5th line: Number of grids in north-south direction
- 6th line: Longitude of southwest end of analysis area [deg]
- 7th line: Latitude of southwest end of analysis area [deg]
- 8th line: Grid size [deg]

■ Create rain data (e.g., 'Temp_Gage.csv')

- Rainfall data is described sequentially in the column for each station.

example 'Temp_Gage.csv'

		St.1	St.2	St.3	
Number of stations	3				
Longitude [deg]	lon	135.23	134.33	132.59	
Latitude [deg]	lat	45.67	46.33	47.21	
Time1 (seconds)	0	0.0	0.0	0.0	Rain(1)
Time2 (seconds)	3600	12.0	1.0	4.0	Rain(2)
Time3 (seconds)	7200	15.0	3.0	10.0	Rain(3)
･･･	･･･	･･･	･･･	･･･	
･･･	･･･	･･･	･･･	･･･	
･･･	･･･	･･･	･･･	･･･	
TimeN (seconds)	86400	2.0	4.0	5.0	Rain(N)

4.3.2 Creating initial precipitation data for calculation (used in init)

- If the calculation starts with no water in both the underground of the grid and the river, zero discharge will continue. In order to avoid this situation, it is necessary to put the data file of the initial precipitation condition in 'init'.
- An example of initial precipitation data is shown below. Create it in the same way.

Time(s)	Rain(mm)	Time(s)	Rain(mm)	Time(s)	Rain(mm)	Time(s)	Rain(mm)
0	0	61200	0	122400.0	0.0	183600.0	0
3600	4	64800	0	126000.0	0.0	187200.0	2
7200	4	68400	0	129600.0	0.0	190800.0	2
10800	4	72000	0	133200.0	0.0	194400.0	2
14400	4	75600	0	136800.0	0.0	198000.0	2
18000	4	79200	0	140400.0	0.0	201600.0	2
21600	4	82800	0	144000.0	0.0	205200.0	2
25200	4	86400	0	147600.0	0.0	208800.0	2
28800	4	90000	0	151200.0	0.0	212400.0	2
32400	4	93600	0	154800.0	0.0	216000.0	2
36000	4	97200	0	158400.0	0.0	219600.0	2
39600	0	100800	0	162000.0	0.0	223200.0	0
43200	0	104400	0	165600.0	0.0	226800.0	0
46800	0	108000	0	169200.0	0.0	230400.0	0
50400	0	111600	0	172800.0	0.0	234000.0	0
54000	0	115200	0	176400.0	0.0	237600.0	0
57600	0	118800	0	180000.0	0.0	241200.0	0

4.3.3 Executing precipitation data creation

- Place necessary files in the following folders and click 'rainThiessen_xxx.exe' to create rain data.
- Precipitation data files (rain.dat, rain_Map.txt) are created in the 'rain' folder.

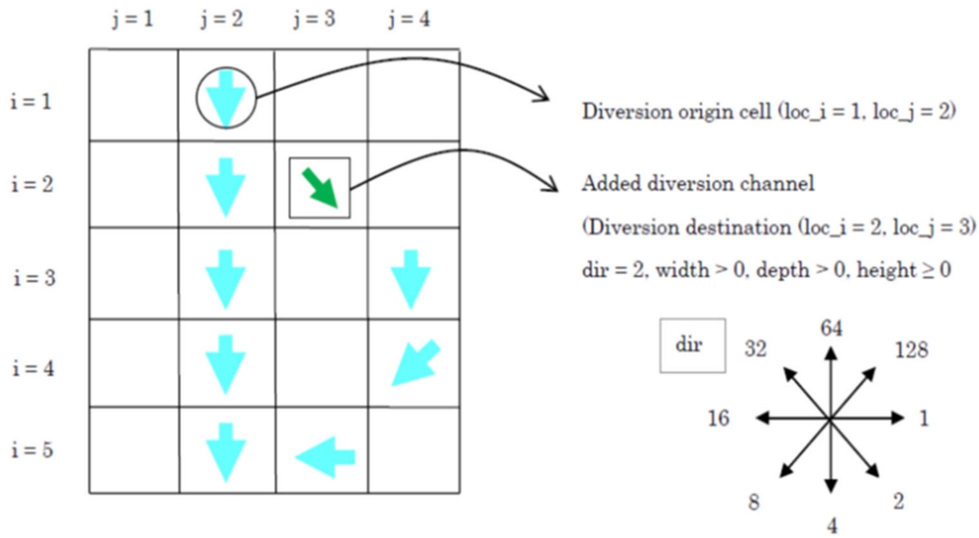
Root folder ("RRI_******")
  └ Subfolder ("Project" - Generally this name)
    └ Sub-subfolder (project name)
      | 'rainThiessen_xxx.exe' ←Click!
      | 'rainThiessen.txt'
      └ rain
        e.g., 'model_rain.csv' (file name can be freely assigned)
          ⇒ 'rain.dat' and 'rain_Map.txt' are created

Example of 'Model_rain.csv'

5	obs001	obs002	obs003	obs004	obs005
lat	41.511795	41.5118	41.511795	41.5	41.5
lon	22.363609	22.38771	22.4118042	22.4	22.5
0	0	0	0	0.0	0.0
3600	1.0	1.0	5.0	3.0	2.0
7200	3.0	2.0	4.0	6.0	8.0
10800	0.0	0.0	0.0	0.0	0.0
14400	0.0	0.0	0.0	0.0	0.0
18000	2.0	2.0	5.0	1.0	4.0

4.4. How to create a diversion data file

- The diversion data file format is shown below.
- Check the diversion origin cell (loc_i_org, loc_j_org) and the diversion destination cell (loc_i_dest, loc_j_dest).
- Both cells of the diversion origin and diversion destination must be specified in the river grid cell. (Able to warp to non-adjacent points)
- The parameter "div_rate" specifies the diversion ratio from the diversion source river to the diversion destination river.



div_sample.txt

```
1    2    2    3    0.2
```

loc_i_org	loc_j_org	loc_i_dest	loc_j_dest	div_rate

4.5. How to create a dumb data file

The file format is shown below.

```
2
Bhumibol    166    71    5800000000    150
Sirikit     135    166   3510000000    500
```

dam_sample.txt

dam names, loc_i_dam, loc_j_dam, storage volume [m³], constant discharge [m³/s]

Number of dams (2)
Dam1) name, eastward location, northward location, maximum volume, maximum discharge
Dam2) name, eastward location, northward location, maximum volume, maximum discharge

4.6. Evapotranspiration data file creation method

- The evapotranspiration data file format is shown below.
- The input format of evapotranspiration data file is the same as that for precipitation.
- The grid cell size and time step of the evapotranspiration cell can be set arbitrarily.
- For example, to set a constant rate of evapotranspiration, the following input file (e.g., 'evp_4mm.txt') with a value of 0.166667 mm/h corresponding to the evapotranspiration amount of 4 mm/day can be prepared.

```
0 1 1
0.166667
10000000 1 1
0.166667
```

evp_4mm.txt

Start time
Evapotranspiration of start time
End time
Evapotranspiration of end time

- To read the evapotranspiration data file, set flag '1' to L71 and specify the input file name.
- Coordinates of southwest corner ('xllcorner' and 'yllcorner') and grid size (both x and y directions) must also be set to L73-L75.

```
L71 | 1
L72 | ./infile/lowerindus/evp_4mm.txt
L73 | 66.0d0              # xllcorner_evp
L74 | 23.0d0              # yllcorner_evp
L75 | 1000.d0 1000.d0     # cellsize_rain
```

RRI_Input.txt

xllcorner_evp, yllcorner_evp cellsize_rain (x, y) are specified in RRI_Input.txt

4.7. How to create data by GUI

4.8. Boundary condition data file creation method

- In the boundary condition data file, set the boundary condition of the downstream water level and upstream discharge (vary in time series).

4.8.1 Folder to place

- The boundary condition file is placed in the 'bound' folder.

Root folder ("RRI_******")
　└ Subfolder ("Project" - Generally this name)
　　　└ Sub-subfolder (project name)
　　　　　└ bound

4.8.2 Types of boundary condition files

- The boundary condition file can be set to the following files described in "6.1Control file configuration (RRI_Input.txt)".

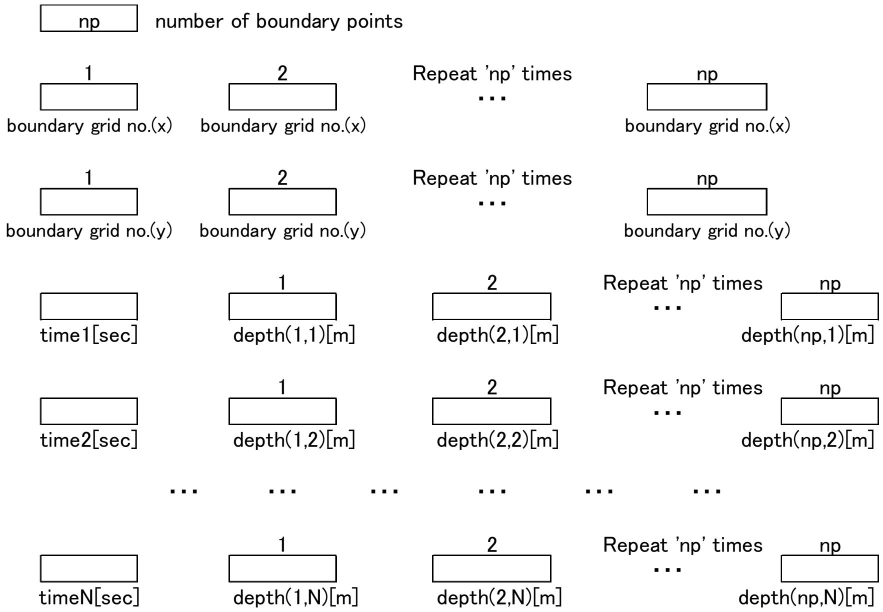
Control input	L57; Water depth boundary condition (optional): Water depth boundary not set=0, 1D data format=1, 2D data format=2
hs_bound.txt	L58; Slope: L57=0→No slope boundary set, L57=1→1D boundary time series file, L57=2→2D boundary time series file
hr_bound.txt	L59; River: L57=0→No river boundary set, L57=1→1D boundary time series file, L57=2→2D boundary time series file

Control input	L61; Flow boundary condition (optional): Flow boundary not set=0, 1D data format=1, 2D data format=2
qs_bound.txt	L62; Slope: L61=0→No slope boundary set, L61=1→1D boundary time series file, L61=2→2D boundary time series file
qr_bound.txt	L63; River: L61=0→No river boundary set, L61=1→1D boundary time series file, L61=2→2D boundary time series file

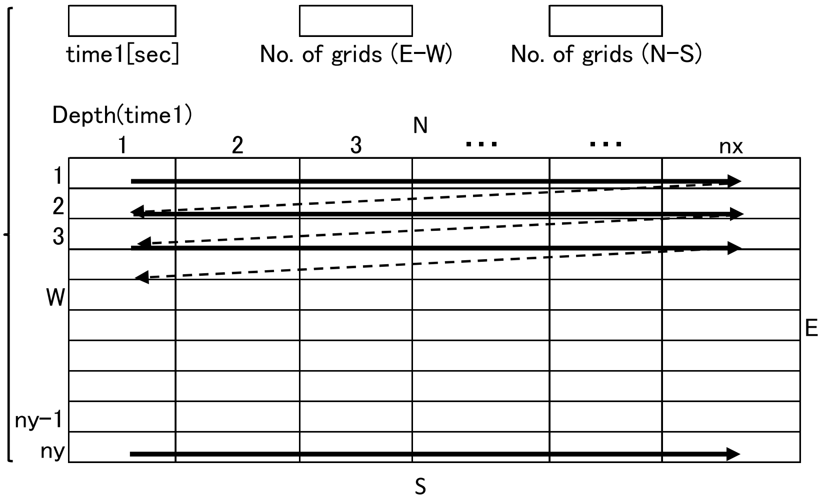
4.8.3 Structure of depth boundary condition file

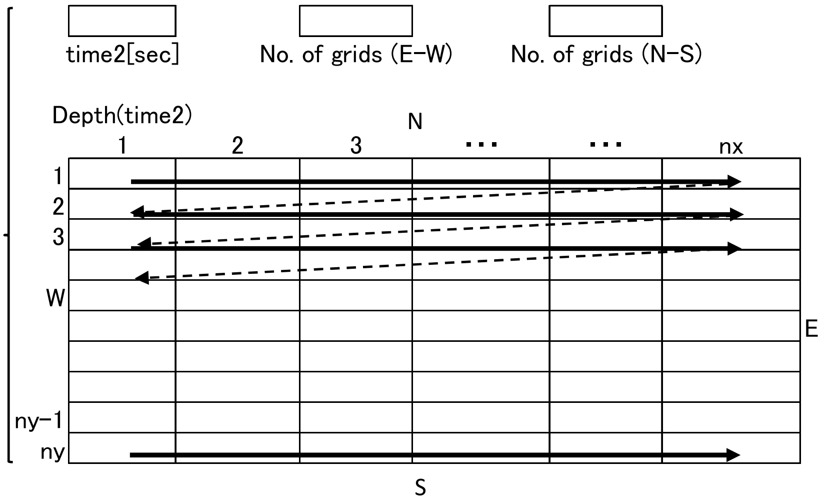
- This condition file gives time series water depth at the boundary

[Slope 1-dimension (bound_slo_wlev_switch =1)]

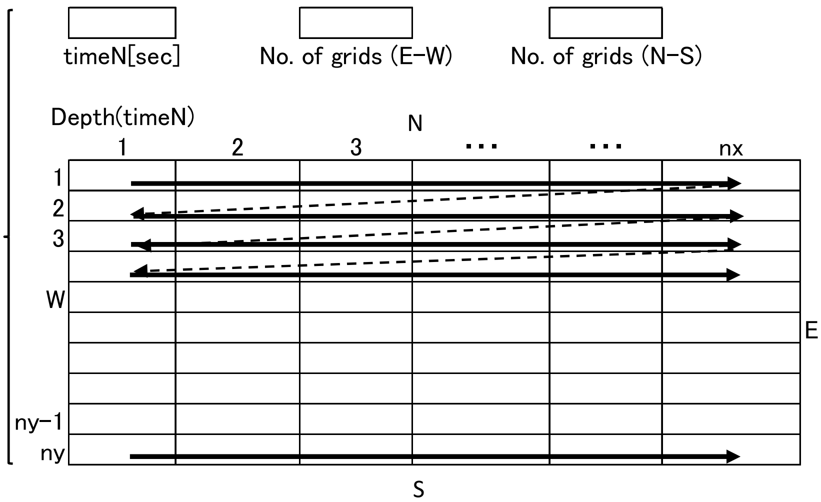


[Slope 2-dimension (bound_slo_wlev_switch =2)]





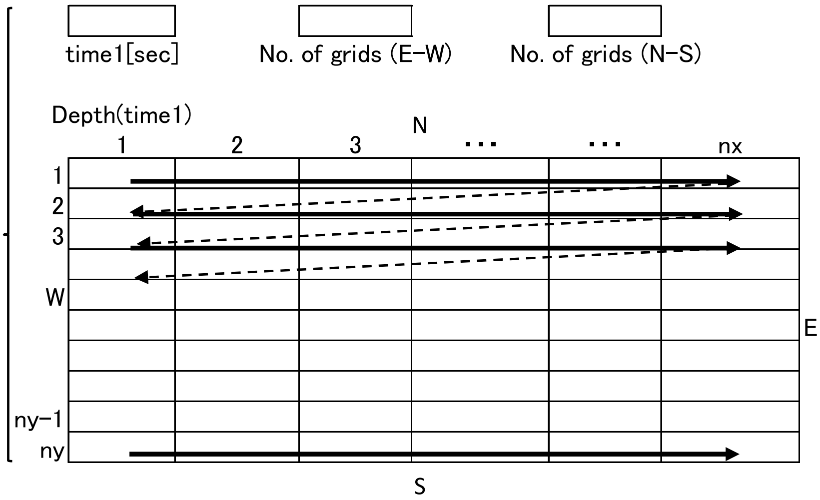
Repeat ・・・ ・・・ ・・・ ・・・

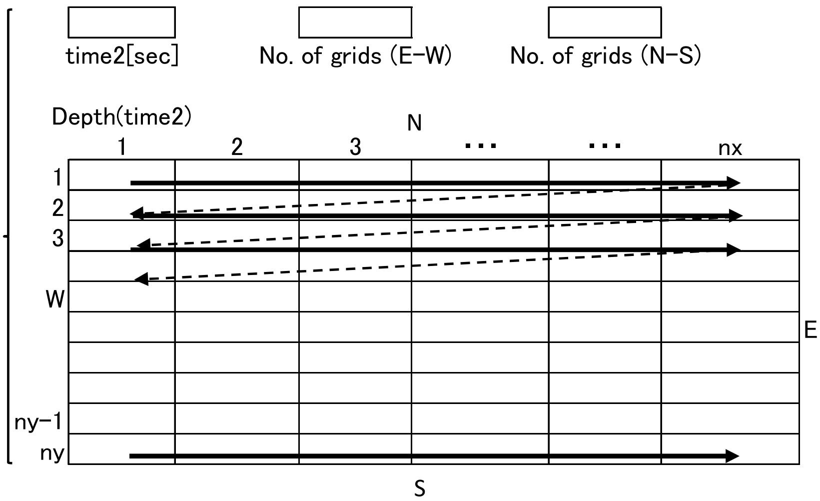


[River 1-Dimension (bound_riv_wlev_switch =1)]

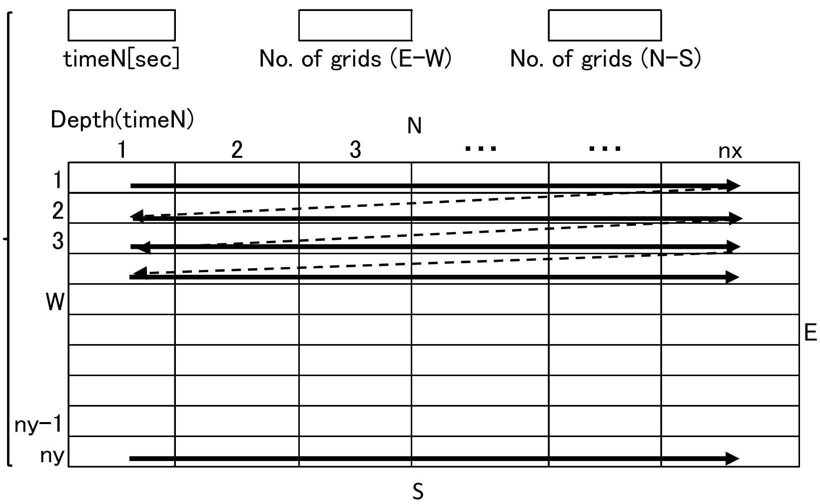
np	number of boundary points				
1	2	Repeat 'np' times ・・・	np		
boundary grid no.(x)	boundary grid no.(x)		boundary grid no.(x)		
1	2	Repeat 'np' times ・・・	np		
boundary grid no.(y)	boundary grid no.(y)		boundary grid no.(y)		
	1	2	Repeat 'np' times ・・・	np	
time1[sec]	depth(1,1)[m]	depth(2,1)[m]		depth(np,1)[m]	
	1	2	Repeat 'np' times ・・・	np	
time2[sec]	depth(1,2)[m]	depth(2,2)[m]		depth(np,2)[m]	
・・・	・・・	・・・	・・・	・・・	・・・
	1	2	Repeat 'np' times ・・・	np	
timeN[sec]	depth(1,N)[m]	depth(2,N)[m]		depth(np,N)[m]	

[River 2-Dimension (bound_riv_wlev_switch =2)]





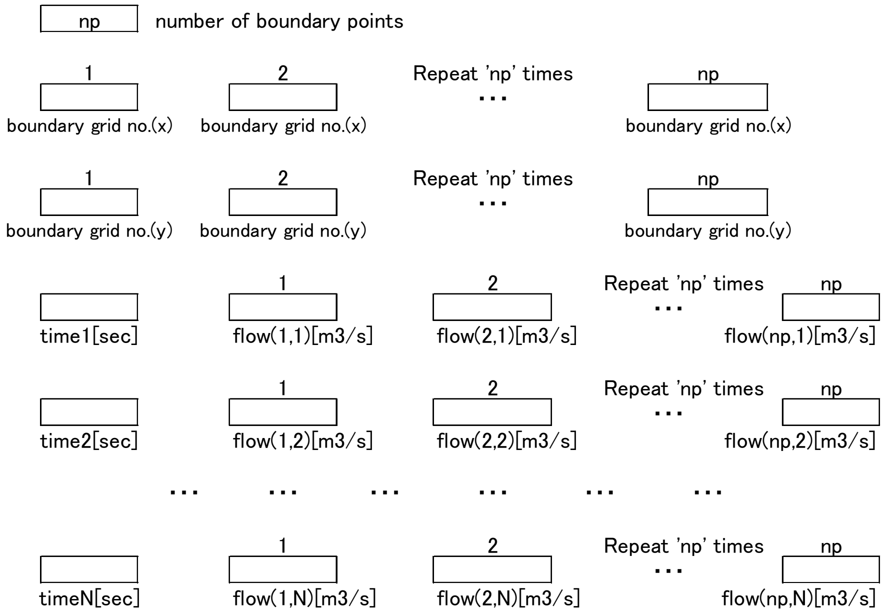
Repeat ・・・ ・・・ ・・・ ・・・



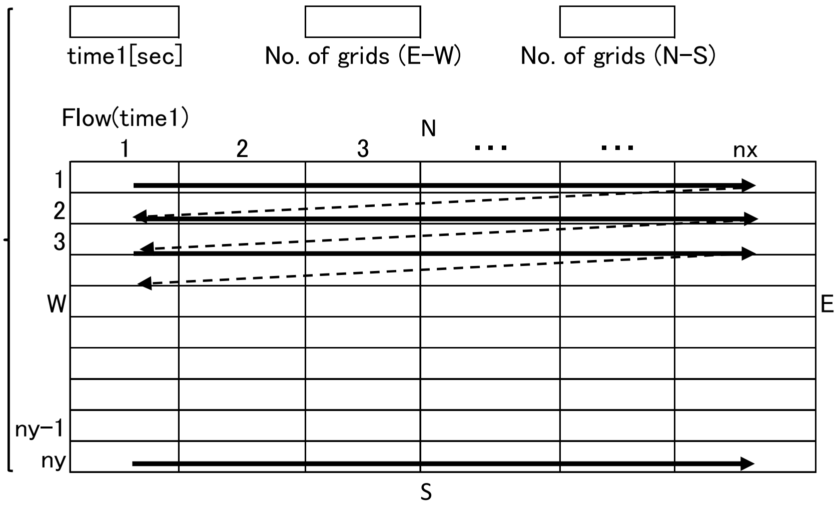
4.8.4 Structure of flow boundary condition file

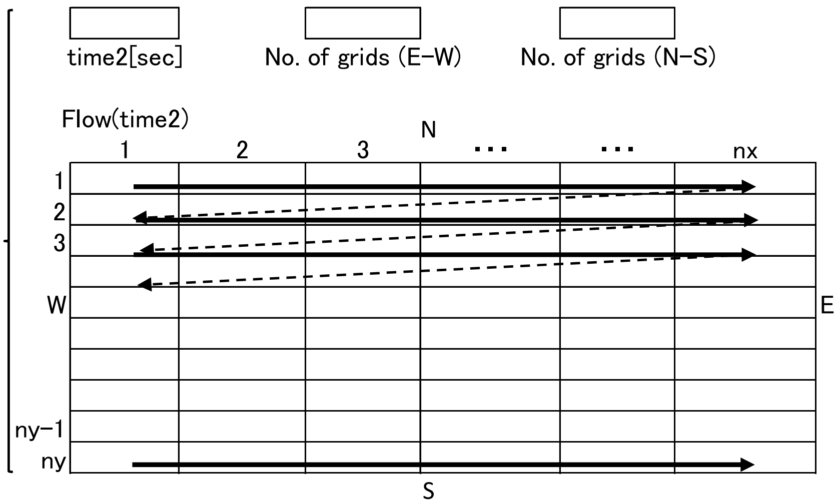
- This condition file gives time series flow at the boundary

[Slope 1-dimension (bound_slo_disc_switch =1)]

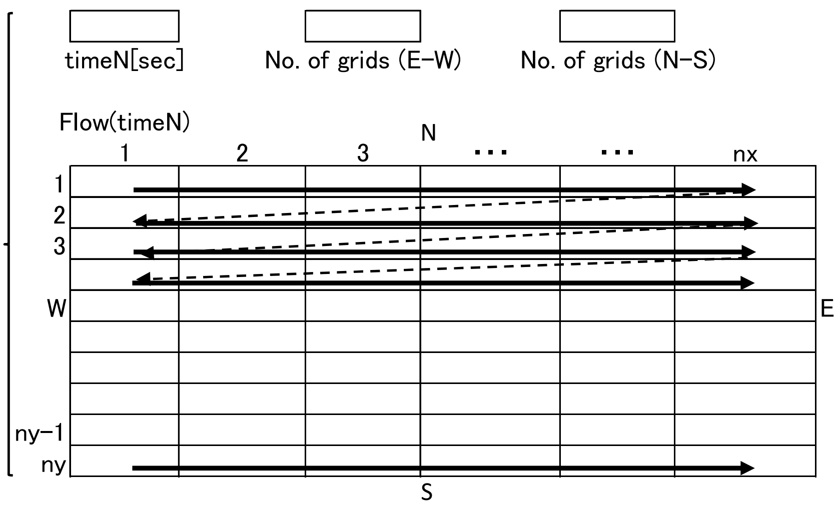


[Slope 2-dimension (bound_slo_disc_switch =2)]





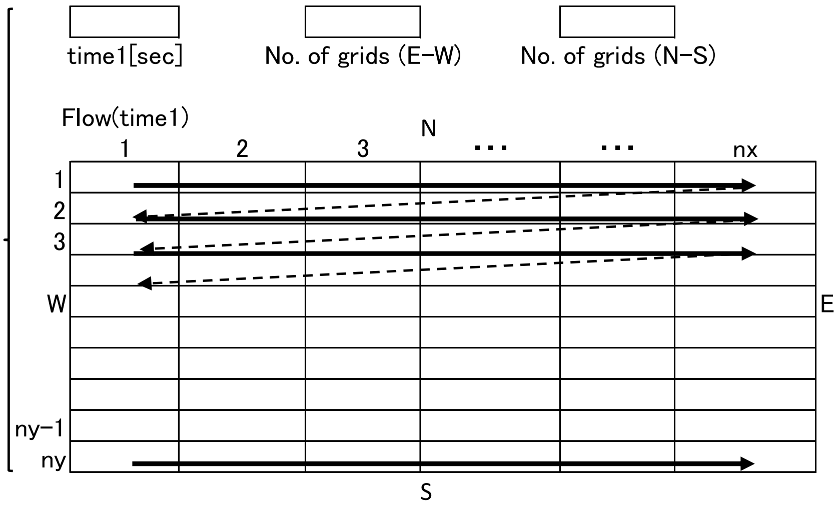
Repeat ・・・ ・・・ ・・・ ・・・

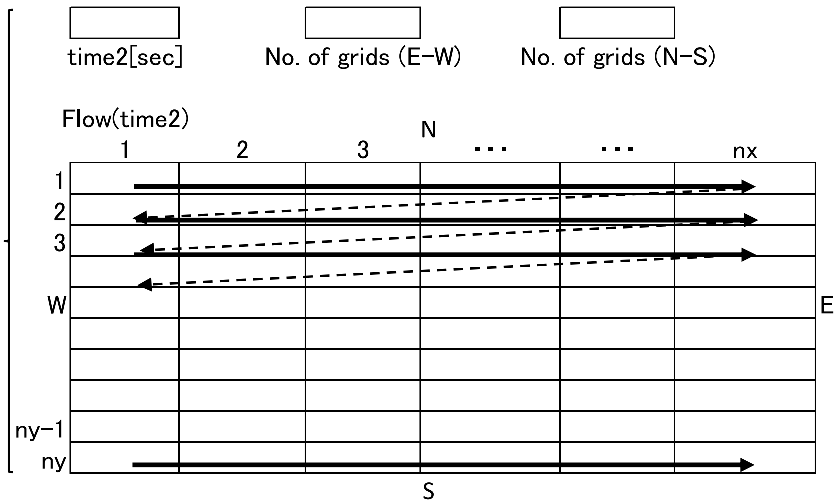


[River 1-dimension (bound_riv_disc_switch =1)]

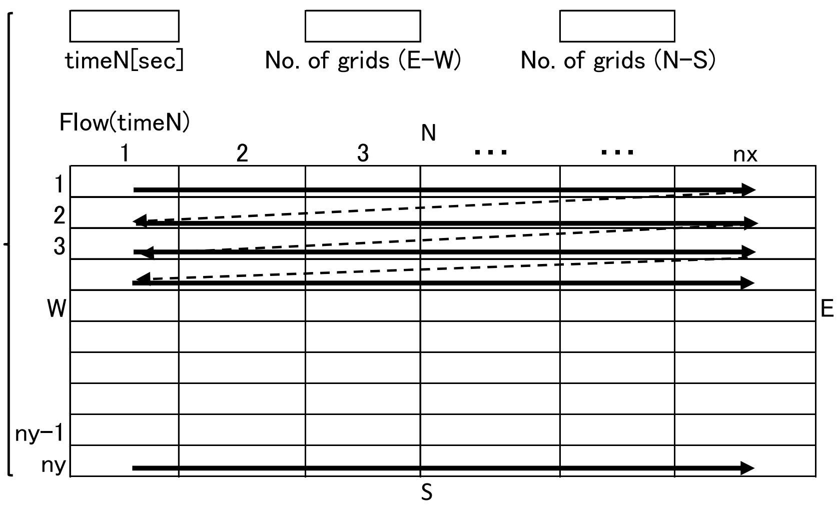
np	number of boundary points			
1	2	Repeat 'np' times ・・・	np	
boundary grid no.(x)	boundary grid no.(x)		boundary grid no.(x)	
1	2	Repeat 'np' times ・・・	np	
boundary grid no.(y)	boundary grid no.(y)		boundary grid no.(y)	
	1	2	Repeat 'np' times ・・・	np
time1[sec]	flow(1,1)[m3/s]	flow(2,1)[m3/s]		flow(np,1)[m3/s]
	1	2	Repeat 'np' times ・・・	np
time2[sec]	flow(1,2)[m3/s]	flow(2,2)[m3/s]		flow(np,2)[m3/s]
・・・	・・・	・・・	・・・	・・・ ・・・
	1	2	Repeat 'np' times ・・・	np
timeN[sec]	flow(1,N)[m3/s]	flow(2,N)[m3/s]		flow(np,N)[m3/s]

[River 2-dimension (bound_riv_disc_switch =2)]





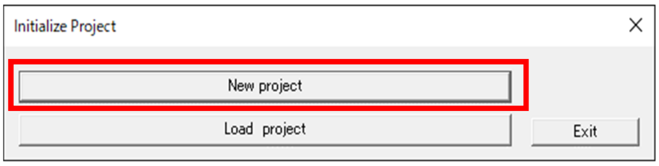
Repeat ・・・ ・・・ ・・・ ・・・



5. Checking data with GUI (RRI_BUILDER_v4-64.exe)

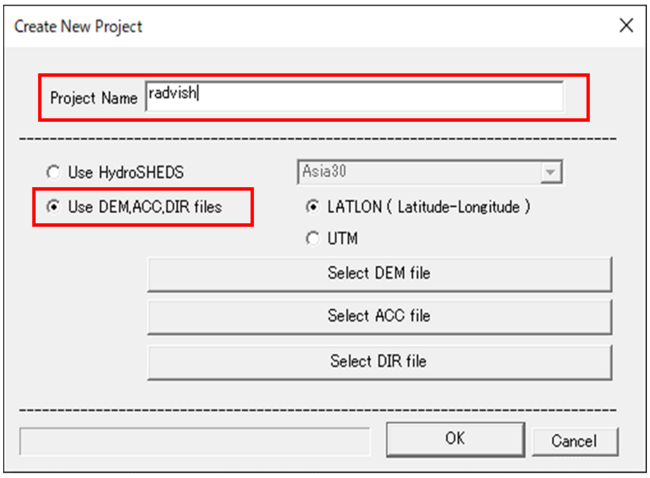
5.1. Start and select "RRI_BUILDER_v4-64.exe"

- When 'RRI_BUILDER_v4-64.exe' is launched, the following dialog is displayed.
- Select [New project].



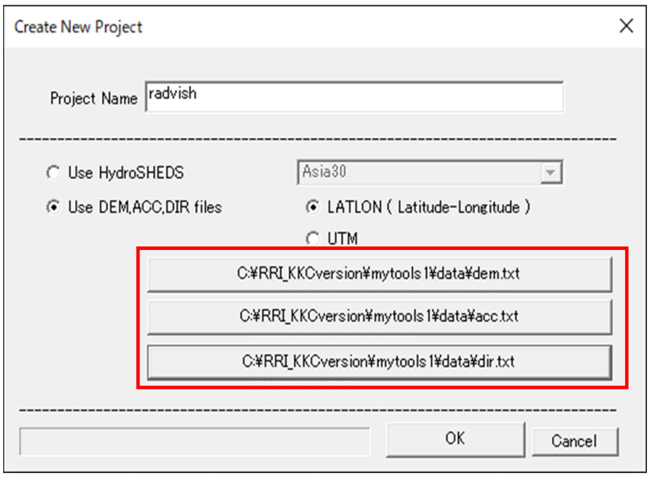
5.2. Input and select project name

- Enter the Project Name. (e.g., "radvish")
- Select [Use DEM, ACC, DIR files].



5.3. Designation of folder name for basic data

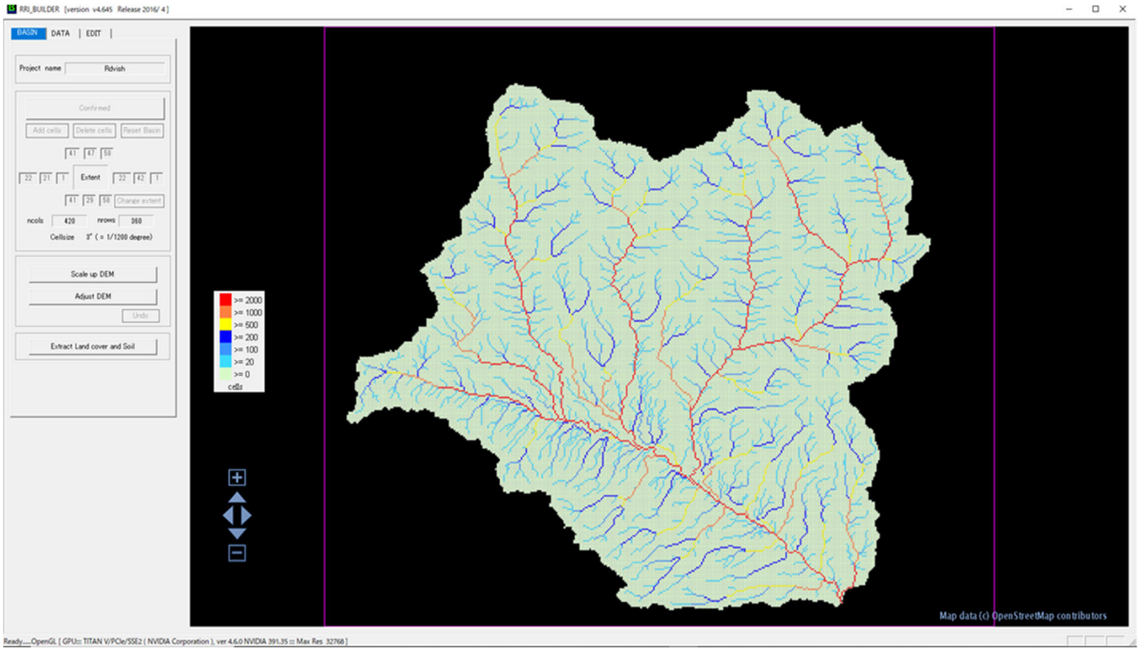
- Specify the folder name and file name of DEM, ACC, and DIR data, and click [OK] button.



5.4. Checking data (Basin and runoff line, “DEM”, “ACC”, “DIR”, Land use data)

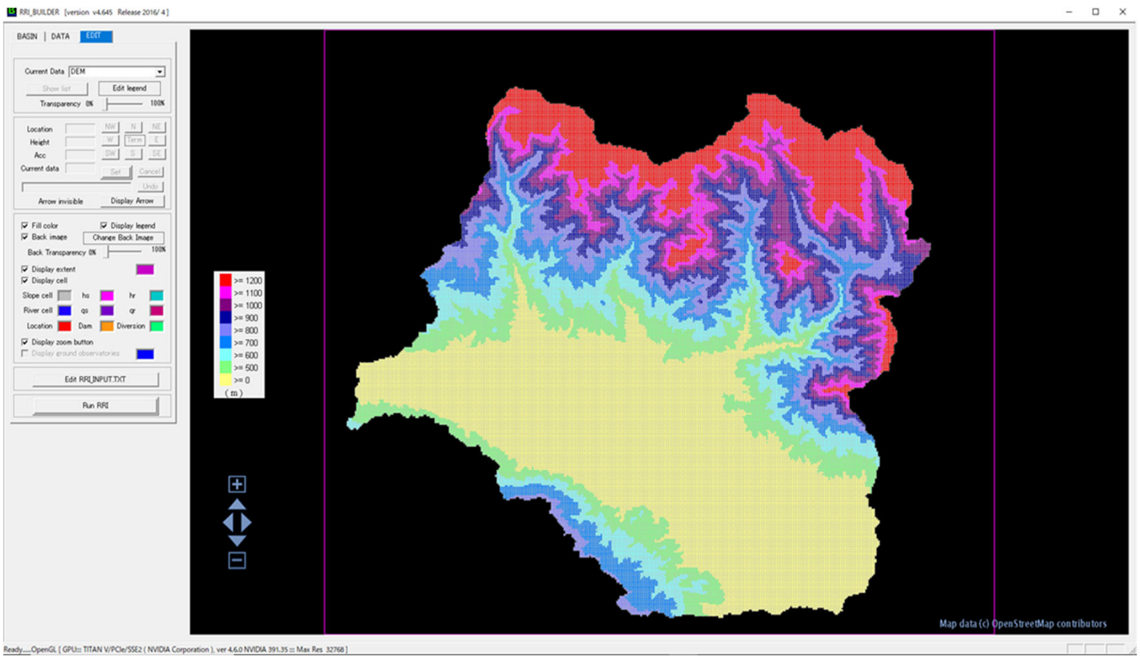
●Basin and stream line

- Select the [BASIN] tag and check the basin and stream line.



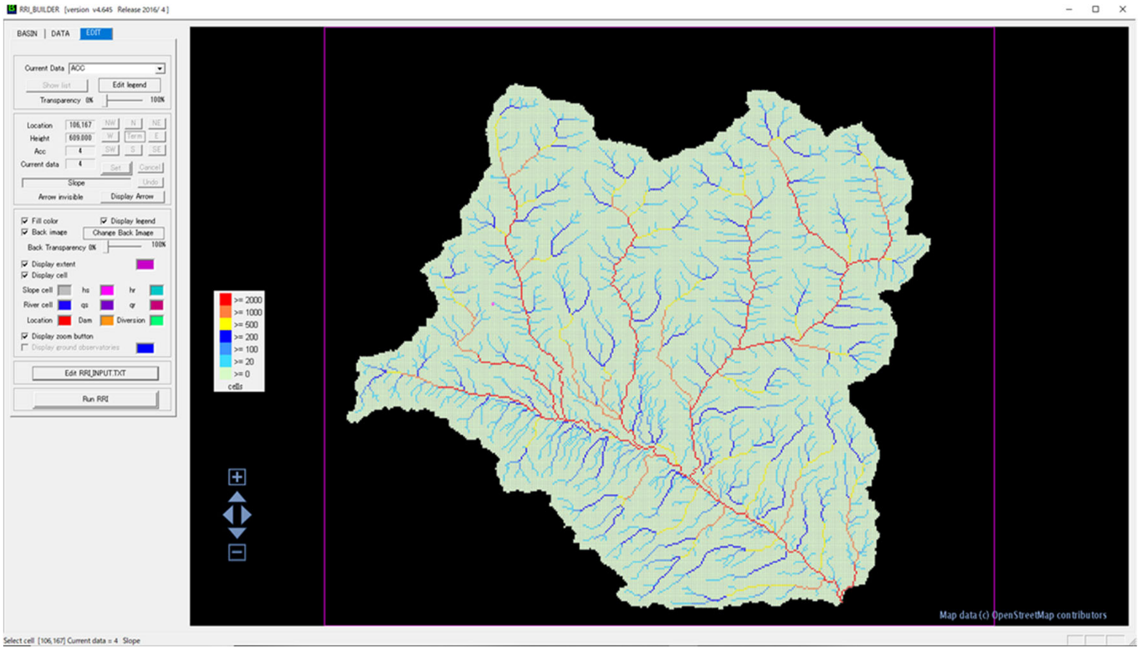
●DEM

- Select the [EDIT] tag and select DEM in the “Current Data” column.
- Confirm node and data where DEM is displayed as follows



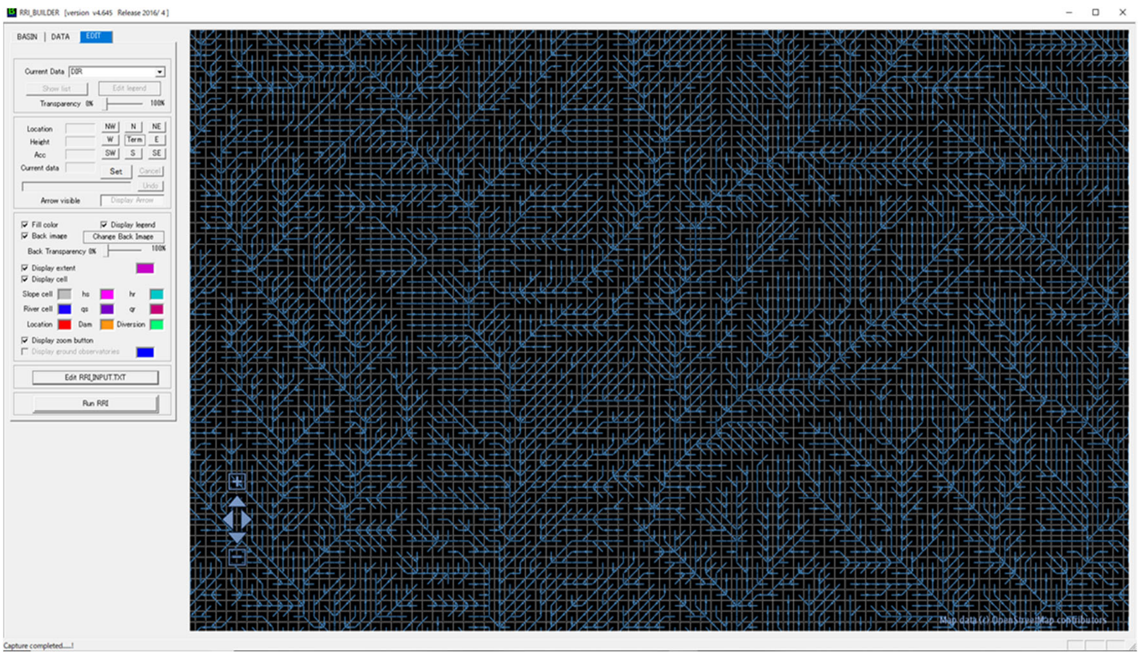
●ACC

- When select ‘ACC’ in the “Current Data” column, ACC is displayed as shown below.
- Check the ACC data.



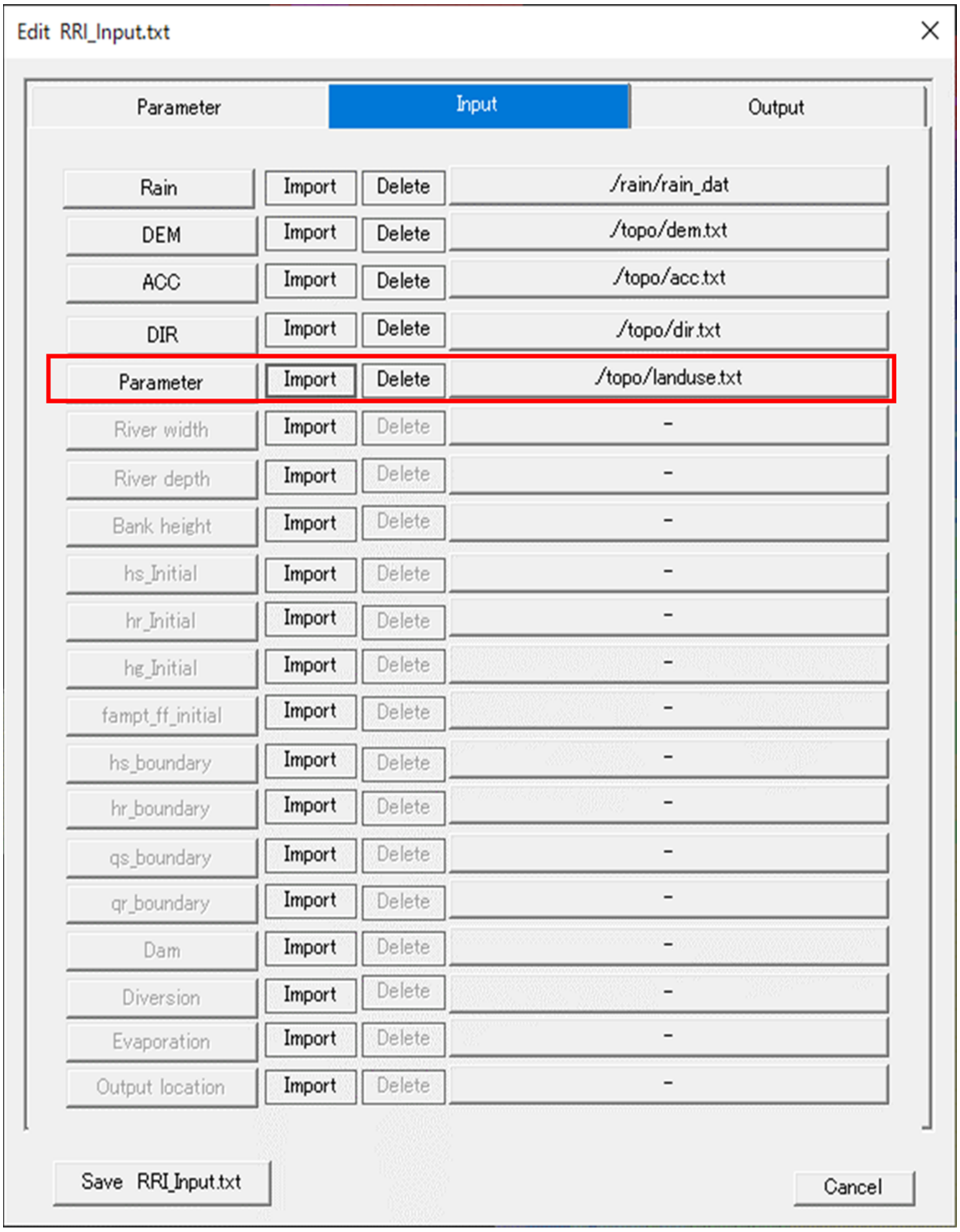
●DIR

- Select ‘DIR’ in the “Current Data” column.
- The arrow indicating the flow direction is not displayed in the small scale map, so enlarge the view as shown below and check the DIR data.

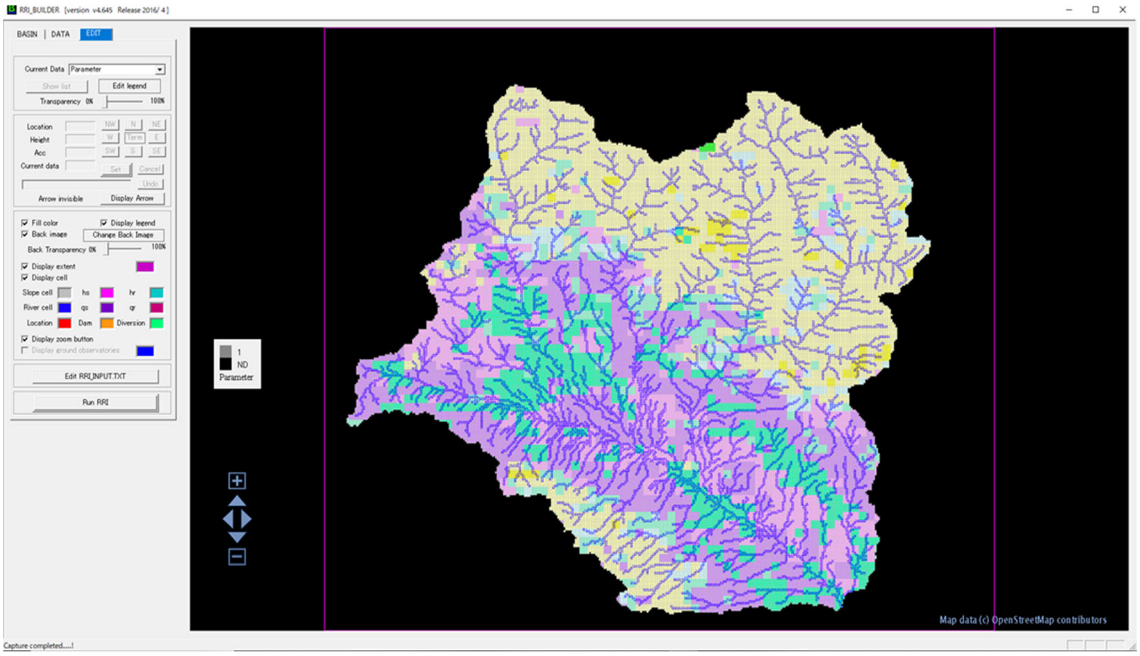


●Land use

- Copy the created ‘landuse.txt’ to the [Project]-[radovish]-[topo] folder.
- Press the [Edit RRI_INPUT.TXT] button, select the [Input] tag, and set the land use data in the [parameter] field.



- When select parameter in the Current Data column, the land use distribution is displayed as shown below, so check the data.

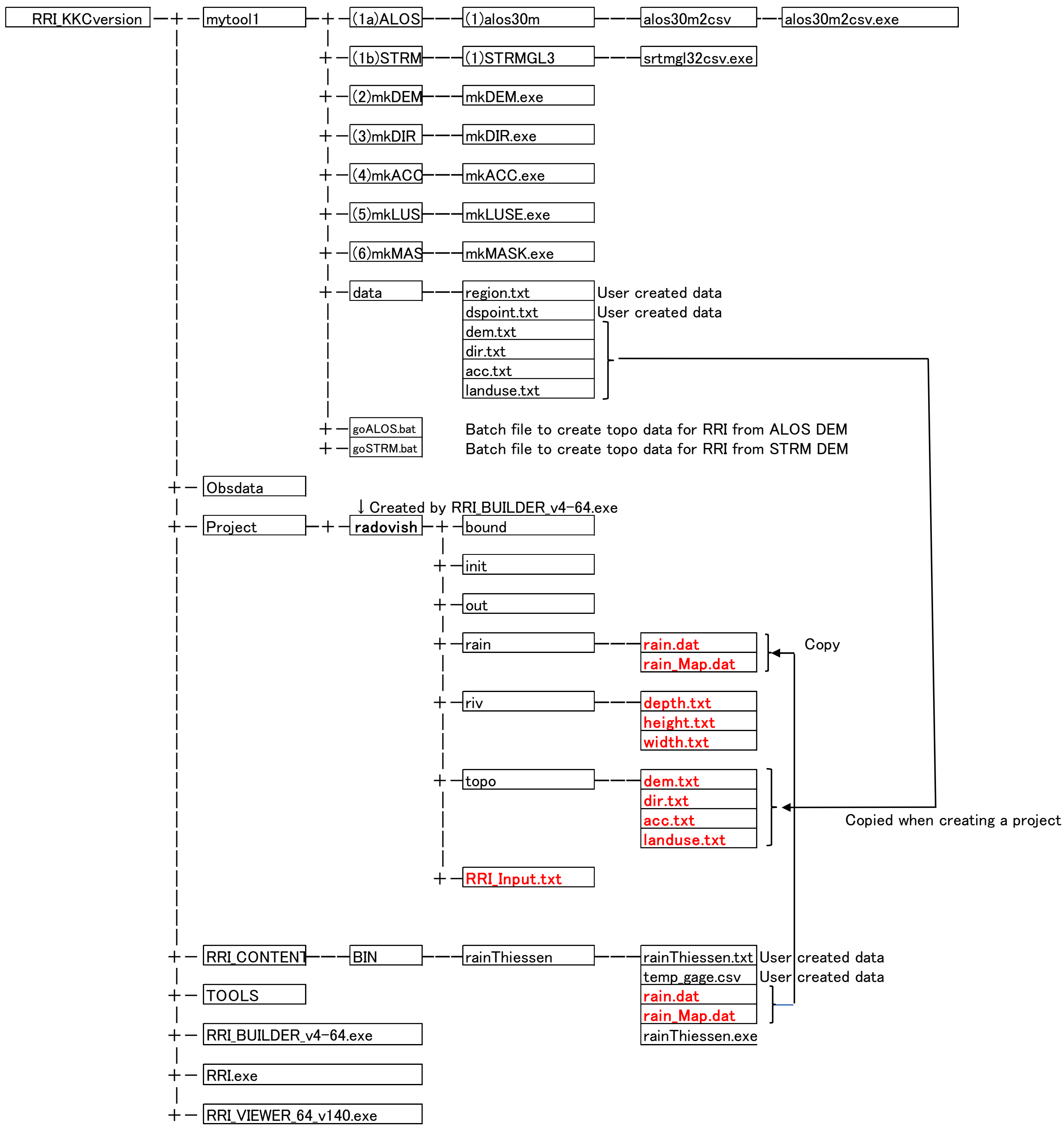


5.5. Copying precipitation data

- Copy 'rain.dat' and 'rain_Map.dat' created by 'rainThiessen.exe' to [Project]-[radovish]-[rain] folder

5.6. Checking folder configuration

- The following is a summary of all folders.
- Check the folder and the files (red bold) that should be in it.



6. RRI model control file (RRI_Input.txt)

6.1. Control file configuration (RRI_Input.txt)

- The control file of the RRI model is configured as shown below.
- The "#"comment is only allowed for numeric lines like L8-L16, but it is not allowed for lines with characters such as L3 to L6.

- L3 to L6: Input file path (rain, dem, acc, dir)
- L1 to L16: Southwest coordinates and precipitation data resolution

RRI_Input.txt

```
L1   RRI_Input_Format_Ver1_4_2
L2
L3   ./rain/rain.dat
L4   ./topo/adem.txt
L5   ./topo/acc.txt
L6   ./topo/adir.txt
L7
L8   0                        # utm(1) or latlon(0)
L9   1                        # 4-direction (0), 8-direction(1)
L10  360                      # lasth [hour]
L11  600                      # dt [sec]
L12  60                       # dt_riv [sec]
L13  96                       # outnum [-]
L14  110.2d0                  # xllcorner_rain
L15  -8.3d0                   # yllcorner_rain
L16  0.00833333d0 0.00833333d0    # cellsize_rain
L17
```

L1 : Version of the control file format
L2 : Project name
L3 : Specifies the path to an input rainfall file
L4 : Specify the paths to input adjust dem file
L5 : Specify the paths to input acc file
L6 : Specify the paths to input adjust dir file
L8 : Topographic and rainfall data coordinate system (UTM (1) or Lat Lon(0)
L9 : Simulating with 4- (0) or 8-direction (1) by the two dimensional model [default : 1]
L10: Simulation period [hour]
L11: Simulation time step [sec], [default : 600 sec]
L12: Simulation time step for river [sec], [default : 60 sec]
L13: Number of output files
L14 ～L16 : South west coordinate and resolution of rainfall data

- L25, L26: Green-Ampt infiltration model parameters
- L28 to L30: lateral subsurface and surface model parameters

L18	0.03d0	# ns_river	RRI_Input.txt
L19	1	# num_of_landuse	
L20	1	# diffusion(1) or kinematic(0)	
L21	0.4d0	# ns_slope	
L22	1.0d0	# soildepth	
L23	0.475d0	# gammaa	
L24			
L25	0.d0	# kv (m/s)	
L26	0.3163d0	# Sf (m)	
L27			
L28	0.0d0	# ka (m/s)	
L29	0.0d0	# gammam (-)	
L30	0.0d0	# beta (-)	
L31			

L18: River roughness coefficient (Describe to L82 when changing from river to river)
L19: Number of land use types
(L20-31 data requires this L19 number set
→ L20 and below are described side by side and the number of L19 in parallel)
L20: diffusion (1) or kinematic (0) [default: 1]
L21: Ground surface equivalent roughness coefficient
L22: Soil thickness [m]
L23: Saturation effective porosity [%/100]
L25: Green-Ampt infiltration model parameter (kv): Vertical saturated hydraulic conductivity [m/s]
L26: Green-Ampt infiltration model parameter (sf): Wet front suction pressure [m]
L28: Lateral saturated hydraulic conductivity [m/s]
L29: Unsaturated effective porosity [%/100]
L30: Reverse ratio of unsaturated / saturated

-L38 to L44: River channel shape setting by equation (regime theory)

-L46 to L49: river channel shape setting by file (option)

L38	100	# riv_thresh	RRI_Input.txt
L39	5.0d0	# width_param_c	
L40	0.35d0	# width_param_s	
L41	0.95d0	# depth_param_c	
L42	0.20d0	# depth_param_s	
L43	0.d0	# height_param	
L44	20	# height_limit_param	
L45			
L46	0		
L47	./riv/width.txt		
L48	./riv/depth.txt		
L49	./riv/height.txt		
L50			

L38: Threshold of definition of “river”
(This number is the number of meshes where the river channel is generated, so the river channel changes from about 0.5 km to 1.0 km depending on mesh size)
L39: River width constant (C_w)
L40: River width constant (S_w)
L41: River height constant (C_d)
L42: River height constant (S_d)
L43: Constant of the river margin
L44: Set number of meshes for river margin (set downstream from this number of meshes)
L46: River channel shape set by regime theory = 0, River channel shape set by file = 1
L47: River width data file location folder when L46 = 1
L48: River height (= ground height or HWL-river bed height) data file location folder when L46 = 1
L49: River margin (Bank height-Ground height or HWL) data file location folder when L46 = 1

regime theory

$$width = c_w A^{S_w}$$

$$depth = c_d A^{S_d}$$

- L51-L55: Initial water depth condition setting (optional)
- L57 to L59: Depth boundary condition setting (optional)
- L61 to L63: Drainage boundary condition setting (optional)

RRI_Input.txt

```
L51  0 0 0 0
L52  ./init/hs_init_dummy.out
L53  ./init/hr_init_dummy.out
L54  ./init/hg_init_dummy.out
L55  ./init/gamptff_init_dummy.out
L56
L57  0 0
L58  ./bound/hs_bound.txt
L59  ./bound/hr_bound.txt
L60
L61  0 0
L62  ./bound/qs_bound.txt
L63  ./bound/qr_bound.txt
L64
```

L51: Initial water depth condition (initial value) setting (option)
(Initial condition not set = 0, Initial condition set = 1 (initial condition file required L52 to L55))
L52: Slope (surface) initial depth file (hs)
L53: River channel initial depth file (hr)
L54: Slope (underground) initial depth file (hg)
L55: Green-Ampt cumulative depth initial depth file (gamptff)

L57: Water depth boundary condition (optional); Water depth boundary not set = 0, 1D data format = 1, 2D data format = 2
L58: Slope (ground surface); L57=0 → No slope boundary set, L57=1 → 1D boundary position time series file, L57=2 → 2D boundary position time series file
L59: River; L57=0 → No river boundary set, L57=1 → 1D boundary position time series file, L57=2 → 2D boundary position time series file

L61: Flow boundary condition (optional); No flow boundary set = 0, 1D data format = 1, 2D data format = 2
L62: Slope (ground surface); L61=0 → No flow boundary set, L61=1 → 1D position time series file, L61=2 → 2D boundary position time series file
L63: River; L61=0 → No river boundary set, L61=1 → 1D position time series file, L61=2 → 2D position time series file

- L65 to L66: Land use setting (optional)
- L68 to L69: Dam condition setting (option)
- L71 to L72: River diversion setting (optional)
- L74 to L78: Evapotranspiration setting (option)
- L80 to L81: River extension setting (optional)
- L83 to L84: River section setting (optional)

RRI_Input.txt

```
L65 0
L66 ./topo/landuse.txt
L67
L68 0
L69 ./dam.txt
L70
L71 0
L72 ./div.txt
L73
L74 0
L75 ./infile/PET.txt
L76 110.2d0                  # xllcorner_evp
L77 -8.3d0                   # yllcorner_evp
L78 0.00833333d0 0.00833333d0     # cellsize_rain
L79
L80 0
L81 ./riv/length.txt
L82
L83 0
L84 ./riv/sec_map.txt
L85 ./riv/section/sec_
L86
```

L65: Land use setting (option)
  Without multiple parameter set = 0, Multiple parameter set = 1 (Land use file required L66)
L66: Land use file path
L68: Dam operation condition setting (option)
  No dam operation set = 0, Dam operation set = 1 (dam operation file required L69)
L69: Dumb operation file (see dam_sample.txt)
L71: River diversion condition setting (option)
  River channel diversion not set = 0, River channel diversion set = 1 (requires river diversion file L72)
L72: River diversion file (div.txt, origin cell, destination cell, diversion ratio set (see div_sample.txt)
L74: Evapotranspiration setting (option); Evapotranspiration is not set = 0
L75: Evapotranspiration file path
L76: Southern coordinates of evapotranspiration data (xllcorner_rain)
L77: Western coordinate of evapotranspiration data (yllcorner_rain)
L78: Resolution of cell size of evapotranspiration data (cellsize_rain)
L80: River extension setting (optional); River channel extension not set = 0, River channel extension set = 1 (river channel extension file required L81)
L81: River extension file path
L83: River arbitrary section setting (optional); River channel arbitrary section set not set = 0, River channel arbitrary section set = 1 (file required L84, L85)
L84: River arbitrary section map file path
L85: River arbitrary section shape file path (see section.txt)

- L87 to L97: Output file setting
- L99 to L100: Hydrograph output setting (optional)

RRI_Input.txt

```
L87  | 1 1 0 1 0 0 0 0 0 1
L88  | ./out/hs_
L89  | ./out/hr_
L90  | ./out/hg_
L91  | ./out/qr_
L92  | ./out/qu_
L93  | ./out/qv_
L94  | ./out/gu_
L95  | ./out/gv_
L96  | ./out/gampt_ff_
L97  | ./out/storage.dat
L98  |
L99  | 1
L100 | ./location.txt
```

L87: Simulation result output; Not output = 0, Output = 1 (file folder specified below)
L88: Slope (ground surface) depth file path
L89: River channel depth file path
L90: Slope groundwater depth file path
L91: River channel flow file path
L92: Slope underground runoff file path in the x direction
L93: Slope underground runoff file path in the y direction
L94: X-direction (Green-ampt) flat ground runoff file path
L95: Y-direction (Green-ampt) flat ground runoff file path
L96: Green-Ampt Cumulative Depth File Path
L97: Water balance check file path

L99: Simulation hydrograph output (option); Not output = 0, Output = 1 (file designation below)
L100: Output file name

6.2. Example of control file

- Example of ‘RRI_Input.txt’

```
RRI_Input_Format_Ver1_4_2
usune
./rain/rain.dat
./topo/dem.txt
./topo/acc.txt
./topo/dir.txt

1    # utm(1) or latlon(0)
1    # 4-direction (0), 8-direction(1)
336    # lasth(hour)                ←    Total calculation time (hours)
30    # dt(second)                 ←    Conditions to stabilize calculation with 50m grid
3    # dt_riv                      ←    Conditions to stabilize calculation with 50m grid
336    # outnum [-]                 ←    Total number of calculation results (time)
-74425.00000   # xllcorner_rain
64975.000000    # yllcorner_rain
50.0 50.0    # cellsize_rain

4.000d-2     # ns_river
32    # num_of_landuse
1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1   # diffusion(1) orr kinematic(0)    ←    Constant: Necessary for each land use, vegetation, geology, topographic gradient, etc.
2.00d0  0.400d0  0.300d0  0.300d0  0.800d0  0.300d0  0.010d0  0.300d0  0.005d0  0.300d0  0.001d0  0.300d0  0.300d0  0.001d0  0.001d0  0.200d0  2.00d0  0.500d0  0.400d0  0.400d0  0.900d0  0.500d0  0.030d0  0.400d0  0.010d0  0.400d0  0.001d0  0.400d0  0.400d0  0.001d0  0.001d0  0.300d0  # ns_slope
1.000d0  0.900d0  0.800d0  0.800d0  1.200d0  0.900d0  0.100d0  0.800d0  0.010d0  0.800d0  0.100d0  0.800d0  0.800d0  0.100d0  0.100d0  0.800d0  0.900d0  0.800d0  0.600d0  0.600d0  1.000d0  0.700d0  0.150d0  0.600d0  0.015d0  0.600d0  0.080d0  0.600d0  0.600d0  0.080d0  0.080d0  0.700d0  # soildepth
0.500d0  0.600d0  0.500d0  0.500d0  0.700d0  0.400d0  0.150d0  0.500d0  0.100d0  0.600d0  0.400d0  0.500d0  0.500d0  0.500d0  0.500d0  0.600d0  0.500d0  0.600d0  0.500d0  0.500d0  0.700d0  0.400d0  0.150d0  0.500d0  0.100d0  0.600d0  0.400d0  0.500d0  0.500d0  0.500d0  0.500d0  0.600d0  # gammaa

6.00d-5  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  1.00d-5  0.00d0  5.00d-6  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  # ksv
1.00d-1  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  3.00d-1  0.00d0  0.50d-1  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  0.00d0  # faif

0.00d0  1.20d-3  2.40d-4  2.40d-4  5.00d-3  0.70d-3  0.00d0  2.40d-4  0.00d0  0.85d-3  0.00d0  2.40d-4  2.40d-4  0.00d0  0.00d0  0.60d-2  0.50d-3  1.50d-3  3.00d-4  3.00d-4  6.00d-3  0.90d-3  2.50d-4  3.00d-4  1.25d-5  1.00d-3  0.00d0  3.00d-4  3.00d-4  0.00d0  0.00d0  0.70d-2  # ka
0.00d0  0.150d0  0.125d0  0.125d0  0.175d0  0.100d0  0.00d0  1.25d-1  0.00d0  0.150d0  0.00d0  0.125d0  0.125d0  0.00d0  0.00d0  0.150d0  0.125d0  0.150d0  0.125d0  0.125d0  0.175d0  0.100d0  0.038d0  0.125d0  0.025d0  0.150d0  0.00d0  0.125d0  0.125d0  0.00d0  0.00d0  0.150d0  # gammam
0.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  0.00d0  4.00d0  0.00d0  4.00d0  0.00d0  4.00d0  4.00d0  0.00d0  0.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  4.00d0  0.00d0  4.00d0  4.00d0  0.00d0  0.00d0  4.00d0  # beta

0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0  0.000d0    # kgv
4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1  4.000d-1    # gammag
5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4  5.000d-4    # tg
3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2  3.000d-2    # fpg
5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1  5.000d-1    # init_cond_gw

100.0      # riv_thresh
8.40d0      # width_param_c (2.5)
5.00d-1      # width_param_s (0.4)
1.45d0      # depth_param_c (0.1)
2.50d-1      # depth_param_s (0.4)
1.20d0      # height_param
100.0      # height_limit_param

          0
./riv/width.txt
./riv/depth.txt
./riv/height.txt

1  1  1  1                    ←    Use this set if you want the calculation result to be the initial condition of the calculation.
./init/hs_init.out
./init/hr_init.out
./init/hg_init.out
./init/gamptff_init.out

0  0
./bound/hs_wlev_bound.txt
./bound/hr_wlev_bound.txt

0  0
./bound/qs_bound.txt
./bound/qr_bound.txt

          1
./topo/landuse.txt

          0
./damcnt.txt

          0
./div.txt

          0
./rain/Evp.dat
100.000000      # xllcorner_evp
10.000000       # yllcorner_evp
0.0083333333  0.0083333333      # cellsize

          0
./riv/length.txt

          0
./riv/sec_map.txt
./riv/section/sec_

1  1  1  1  0  0  0  0  1  1      ←    Use this set if you want the calculation result to be the initial condition of the calculation.
./out/hs_
./out/hr_
./out/hg_
./out/qr_
./out/qu_
./out/qv_
./out/gu_
./out/gv_
./out/gampt_ff_
./out/storage.dat

          0
./location.txt
```

6.3. Example of parameter setting

- As an example, a constant was set according to the land use / vegetation (the number of this division condition is required in ‘landuse.txt’ in the “topo” folder).

Row number	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Broadleaf Deciduous Forest	Broadleaf Evergreen Forest	Needleleaf Deciduous Forest	Needleleaf Evergreen Forest	Mixed Forest	Tree Open	Shrub	Herbaceous	Herbaceous with Sparse Tree/Shrub	Sparse vegetation	Cropland	Paddy field	Cropland / Other Vegetation Mosaic	Mangrove	Wetland	Bare area, consolidated (gravel, rock)	Bare area, unconsolidated (sand)	Urban	Snow / Ice	Water bodies
L21	ns_slope	2.000d−1	2.000d−1	2.000d−1	2.000d−1	2.000d−1	5.000d−2	1.000d−1	5.000d−2	5.000d−2	5.000d−2	5.000d−2	1.000d−1	5.000d−2	1.000d−2	1.000d−2	1.000d−2	1.000d−2	5.000d−2	1.000d−2	1.000d−2
L22	soildepth	1.500d−1	1.500d−1	1.500d−1	1.500d−1	1.500d−1	1.500d−1	1.500d−1	1.500d−1	1.500d−1	1.500d−1	4.000d−1	5.000d−1	4.000d−1	1.000d−1	1.000d−1	5.000d−2	5.000d−2	1.000d−1	1.000d−1	1.000d−1
L23	gammaa	4.500d−1	4.500d−1	4.500d−1	4.500d−1	4.500d−1	4.000d−1	4.500d−1	4.500d−1	4.500d−1	4.500d−1	6.000d−1	5.000d−1	6.000d−1	2.000d−1	2.000d−1	4.000d−1	4.000d−1	1.500d−1	2.000d−1	2.000d−1
L25	ksv	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	6.000d−5	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	1.000d−6	0.000d0	0.000d0
L26	faif	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	1.000d−1	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	3.000d−1	0.000d0	0.000d0
L28	ka	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	1.000d−2	1.000d−2	1.000d−2	2.000d−2	0.000d0	2.000d−2	0.000d0	0.000d0	7.000d−3	7.000d−3	0.000d0	0.000d0	0.000d0
L29	gammam	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	5.000d−2	3.000d−2	0.000d0	3.000d−2	0.000d0	0.000d0	2.000d−2	2.000d−2	0.000d0	0.000d0	0.000d0
L30	beta	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	0.000d0	6.000d0	0.000d0	0.000d0	6.000d0	6.000d0	0.000d0	0.000d0	0.000d0
L32	kgv	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0
L33	gammag	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1	4.000d−1
L34	tg	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4	5.000d−4
L35	fpg	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2	3.000d−2
L36	init_cond_gw	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1	5.000d−1

6.4. Example of “landuse.txt”

- An example of 'landuse.txt' is shown below.

```
ncols          443
nrows           550
xllcorner       -74425.0000000000
yllcorner        64975.0000000000
celsize            50.0000000000
NODATA_value        -9
 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9  -9 -9 -9 -9 -9 -9
-9 -9 -9 -9 21 21 21 21 21 21 21 -9 -9 -9 -9 -9 21 21 21 21  5 21 21 21 21 21 21 21 21 21 21
```

7. RRI model execution (0_rri_4_2.exe)

7.1. Check of folder configuration

- Check folder structure and existence of files before running RRI model
- Delete the OUT file before executing the RRI model

folder structure			Role	Necessary files in the folder				
RRI_root folder			Root folder	RRI_BUILDER_v4-64.exe	RRI_VIEWER_64_v140.exe			
Project_subfolder			Unchanged					
	sub-subfolder			0_rri_1_4_2.exe	rainThiessen.exe	rainThiessen.txt	RRI_Input.txt	time.dat
Executable without this file	→	bound	boundary condition	hs_bound.txt	hr_bound.txt	qs_bound.txt	qr_bound.txt	
Executable without this file	→	init	Calculation initial condition	gamptff_init.out	hg_init.out	hr_init.out	hs_init.out	
Overwrite past data	→	out	Calculation result	Delete past data and calculate	Use this calculation result for 'init'			
Infeasible without this file	→	rain	rainfall	rain.dat	rain_Map.txt			
Executable without this file	→	riv	River model	depth.txt	height.txt	width.txt		
Infeasible without this file	→	topo	Basin model	acc.txt	dem.txt	dir.txt	landuse.txt	

7.1.1 "bound" folder

- Boundary condition file
- Description about "bound" of 'RRI_Input.txt' file

Line	Required description	Explanation
L57	0 0	0=L58 no file, 1=L58 file exists (same for L59)
L58	./bound/hs_wlev_bound.txt	
L59	./bound/hr_wlev_bound.txt	
L61	0 0	0=L62 no file, 1=L62 file exists (same for L63)
L62	./bound/qs_bound.txt	
L63	./bound/qr_bound.txt	

7.1.2 "init" folder

- Data file is required when calculation is started from the water level condition at any time using the calculation result file of 'out'.
- Change the following file name output to 'out' folder, and use it in 'init' folder.
- Use the file created in the 'out' folder at the time when the water level and the discharge became almost constant.
- When the RRI model is calculated for the first time, the amount of water in each grid is zero, so there will be no runoff for several hours. In order to avoid this, use the rainfall data shown in "4.3.2 Creating initial precipitation data for calculation" and enter 'init' folder.

File written to 'out' folder		File name to use in 'init' folder
gampt_ff_******.out	⇒	gamptff_init.out
hg_******.out	⇒	hg_init.out
hr_******.out	⇒	hr_init.out
hs_******.out	⇒	hs_init.out

Note: ****** is the calculation time

7.1.3 “out” folder

- Calculation result is output to “out” folder.

- The data output to “out” folder is specified by the simulation result output flag of L87 (no output =0, output =1)

Files output to the 'out' folder	Role of each file data
gampt_ff_******.out	Green-Ampt cumulative water depth file
hg_******.out	Slope groundwater depth file
hr_******.out	River depth file
hs_******.out	Slope (ground surface) depth file
qr_******.out	River flow file

7.1.4 “rain” folder

- Make sure to put the rain data used for the calculation in this folder

Files to put in the 'rain' folder	Role of each file data
rain.dat	File listing time series rainfall of each grid
rain_Map.txt	File defining the coordinate of each grid

7.1.5 “riv” folder

- Put river model data to be used for calculation (not necessary when calculating by regime theory)

Files to put in the 'riv' folder	Role of each file data
depth.txt	River height (= ground height-bed height) of each grid
height.txt	Margin (= bank height-ground height) of each grid
width.txt	River width of each grid

7.1.6 “topo” folder

- Make sure to put the basin data used for the calculation in this folder

Files to put in the 'topo' folder	Role of each file data
acc.txt	Cumulative flow file
gem.txt	Elevation file
dir.txt	Downstream file
landuse.txt	Land use file

7.1.7 Project_Sub-subfolder

- Make sure to put the project data used for the calculation in this folder

Files to put in the Sub-subfolder	Role of each file data
0_rri_1_4_2.exe	RRI model execution file (exe)
RRI_Input.txt	RRI model input file (control)
time.dat	RRI model calculation start time file

7.2. Execution of RRI model

- For RRI model calculation, place the necessary files in the following folders and click '0_rri_1_4_2.exe'.
- Files such as river water level and river flow are created in the "out" folder.

```
Root folder ("RRI_GUI")
  └ Subfolder ("Project" - Generally this name)
      └ Sub-subfolder (project name)
          ├ bound
          |    ・0_rri_1_4_2.exe      ←click!
          |    ・RRI_Input.txt
          |    ・time.dat
          ├ init
          ├ out
          |    ・hg_******.out
          |    ・gampt_ff_******.out
          |    ・hr_******.out
          |    ・hs_******.out
          |    ・qr_******.out       ,etc. are created
          ├ rain
          ├ riv
          └ topo
```

7.3. Created folders and files

- By setting to ‘RRI_input.txt’, files are created and output to ‘out’ folder.
- The simulation result output is created by setting “No output =0” and “Output =1” to L87 for each file below.

Output file	Role of each file data
hs_******.out	Slope (ground surface) water depth file
hr_******.out	River water depth file
hg_******.out	Slope groundwater depth file
qr_******.out	River flow file
qu_******.out	x-direction slope underground runoff file
qv_******.out	y-direction slope underground runoff file
gu_******.out	x-direction (green-Ampt) groundwater runoff file (plane)
gv_******.out	y-direction (green-Ampt) groundwater runoff file (plane)
gampt_ff_******.out	Green-Ampt cumulative water depth file
storage.dat	Water balance check file

8. Display of calculation results (RRI_VIEWER_64_V140.exe)

8.1. Role of the viewer

- ‘RRI_VIEWER.exe’ can check the following items:

1. Flooded water depth (2D)
2. Inundation depth time series (points)
3. River water depth (2D)
4. River discharge (2D)
5. River hydrograph (points)
6. River water level profile
7. Inundation depth profile

8.2. Starting the viewer

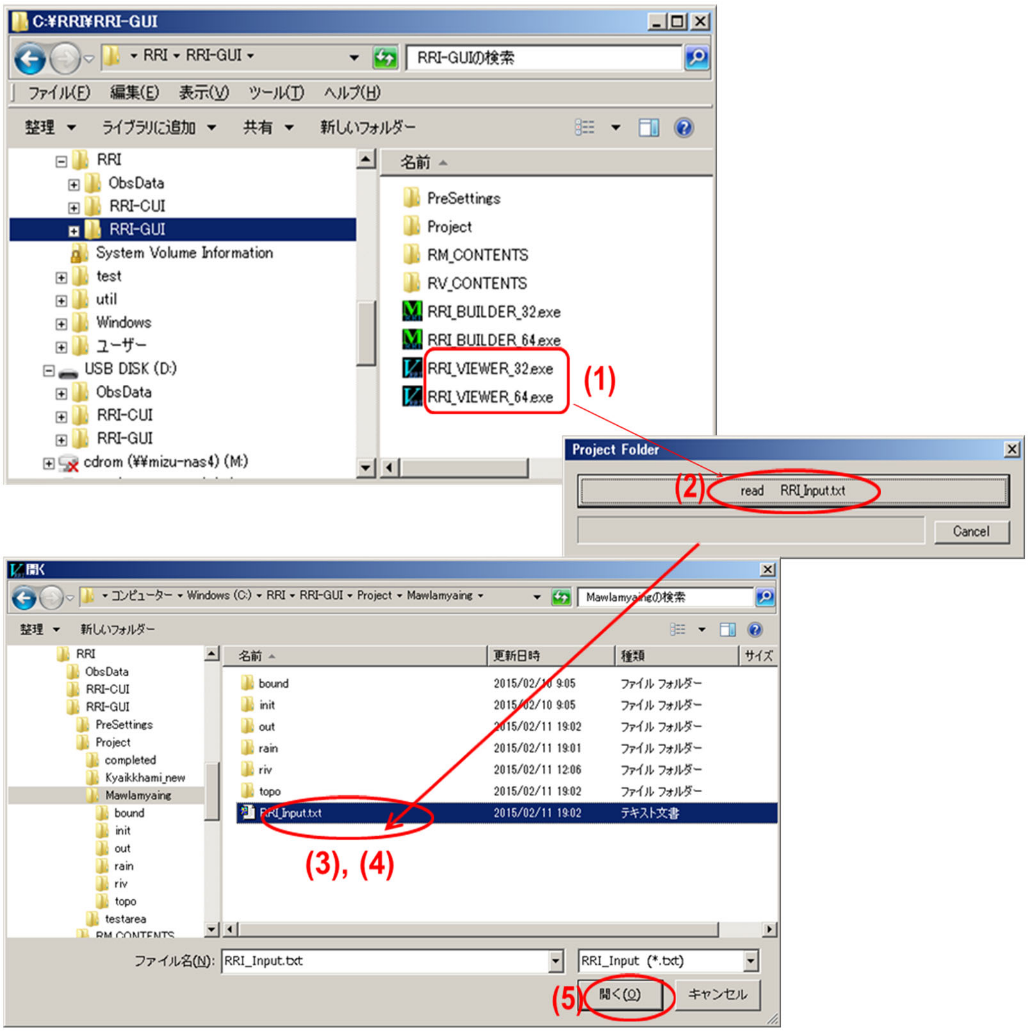
(1) Double Click “RRI_VIEWER_32.exe” or “RRI_VIEWER_64.exe”

(2) Click “read RRI_Input.txt”

(3) Go to C:¥RRI¥RRI-GUI¥Project¥*** (e.g., ‘radovish’)

(4) Select ‘RRI_input.txt’

(5) Click “Open”



8.3. Confirmation of calculation results and flood depth (animation)

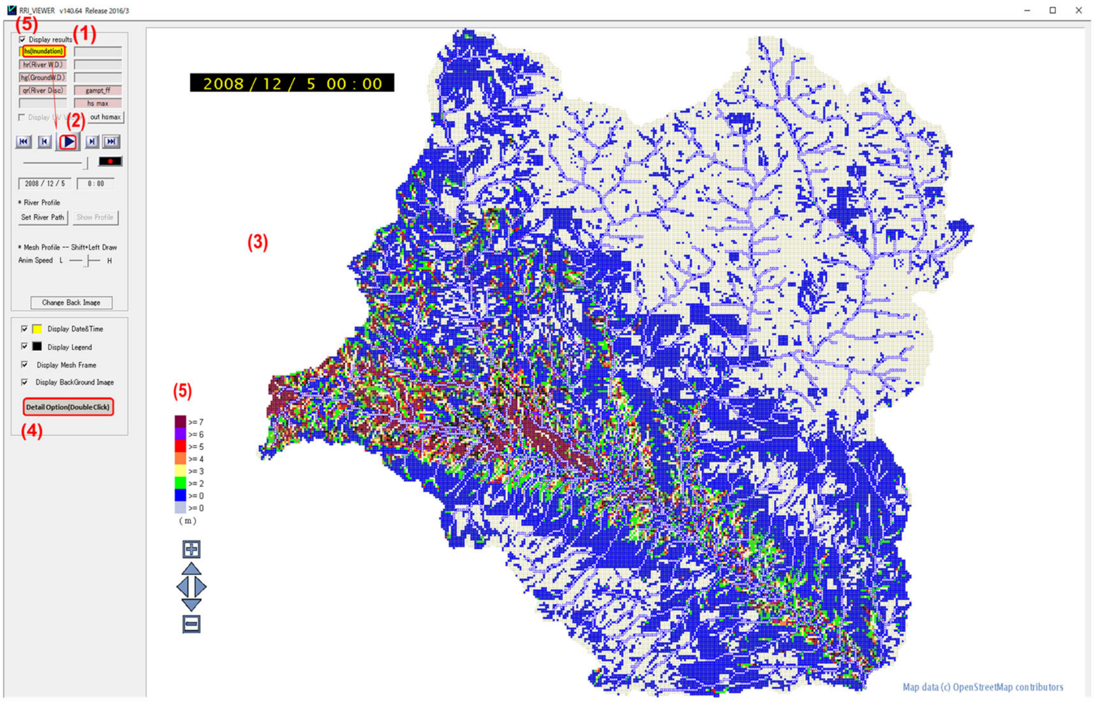
(1) Click hs (inundation)

(2) Click animation button

(3) Check the results in animation

(4) Double Click to Open “Model Display Options” window

(5) Change color legend if necessary



8.4. Export of time series discharge (hydrograph)

- Display the hydrograph at any point using the following procedure.

(1) Display flow direction map: ‘qampt_ff_******.out’ is read and “hs” (inundation depth) is displayed

(2) Display discharge data: Switch to “qr (River Disc)” (threshold of index can be changed with “Detail Option”).

(3) Click the discharge output point: Double-clicking on the desired location (discharge output point) on the basin drainage map (the map can be expanded with “+”) to display the hydrograph.

(4) Output hydrograph: Click “Export (csv)” on the upper right of Hydro diagram to export hydrograph (t-q data) file (csv).

8.5. Comparison of discharge record and calculated result with “Excel”

(1) Read the csv data created in the above work into Excel.

(2) Load also actual flow data into Excel.

(3) Verify accuracy by graphing both of the above.

9. Availability in future (methods or examples)

9.1. Making contents of MKFFIS

9.1.1 Making contents of MKFFIS for Radovish River

- Input: output of RRI model calculation in Radovish (different probability of rainfall)
- Output: maximum inundation depth (geotiff), hourly (0h-48h) inundation depth (geotiff)

Note: It is depend on decision of CMC if the output will be uploaded on MKFFIS with considering the limitation of model.

9.1.2 Making contents of MKFFIS for any river basin

- Input: output of RRI model calculation in the target river basin (different probability of rainfall)
- Output: maximum inundation depth (geotiff), hourly (0h-48h) inundation depth (geotiff) (different probability of rainfall)

9.2. Flood risk evaluation

Using GIS, flood risk valuation will be possible.

- Input: output of RRI model calculation, census data (houses, population, etc.)
- Output: amount of exposure (inundated houses, affected population, etc.)

9.3. Evaluation of effect of countermeasures

9.3.1 Utilization of RRI model for evaluation of effect of countermeasures

- Input: DEM(with countermeasures), Land use(with countermeasures), Precipitation
- Output: inundated area, inundation depth, inundation duration
- Output2: difference between results before and after countermeasure

9.3.2 Issues and proposal for utilization

- Issues

Reflection of effect of countermeasures (forest conservation, river facilities) to the model is necessary.

- Proposal of measures

Forest conservation effect should be reflected to land use data of RRI model.

River facilities should be reflected to river data (width, depth, height of dikes) of RRI model.

Large embankment should be reflected to DEM of RRI model.

9.4. Flood damage evaluation

Using GIS, flood damage valuation will be possible.

- Input: output of RRI model calculation, population, asset data (house assets, industrial assets, crops, etc.), damage curve (relation formula of inundation depth and damage)
- Output: amount of damage (Number of casualties, house damage, industry damage, crop damage, etc.)

9.5. Application to Crisis Management System

9.5.1 Utilization of RRI model for application to crisis management system

- Input: DEM, Land use, precipitation scenarios (e.g., Past largest rainfall, rainfall probabilities (e.g., 0.5%, 1%, 2%), etc.)
- Output: inundated area, inundation depth, inundation duration

9.5.2 Issues and proposal for utilization

- Issues

  Practical scenario is necessary to make the system effective.

- Proposal of measures

  Consider evacuation order issuance criteria (precipitation, discharge) in consideration of appropriate scenarios (e.g., past largest rainfall scenario, several rainfall probabilities (e.g., 0.5%, 1%, 2%) scenario, etc.).

9.6. Application to Early Warning System

9.6.1 Utilization of RRI model for application to early warning system

- Input: DEM, Land use, precipitation scenarios (e.g., Past largest rainfall, rainfall probabilities (e.g., 0.5%, 1%, 2%), etc.)
- Output: inundated area, inundation depth, inundation duration

9.6.2 Issues and proposal for utilization

- Issues

  Automatic collection (system) of meteorological and hydrological data is necessary.

  Immediate calculation is necessary.

  Forecasted precipitation is necessary.

- Proposal of measures

  Construct a collection system of observation data.

  Introduce a dedicated workstation with high computation speed.

Utilize grid time series rainfall forecast based on radar rainfall observation etc.

Disclaimer:
The author is not responsible for any damages or malfunctions caused by the use of software listed in this guideline and the included files.

Crisis Management Center
Japan International Cooperation Agency

Project on capacity building for Ecosystem based Disaster Risk Reduction(Eco-DRR)
through sustainable forest management

RRI model Training

～Case study in Radovish Model, and PC setting～

Dr. Keishi KUDO
Personnel of hydraulic model/Eco-DRR

30/Sep/2019

Outline

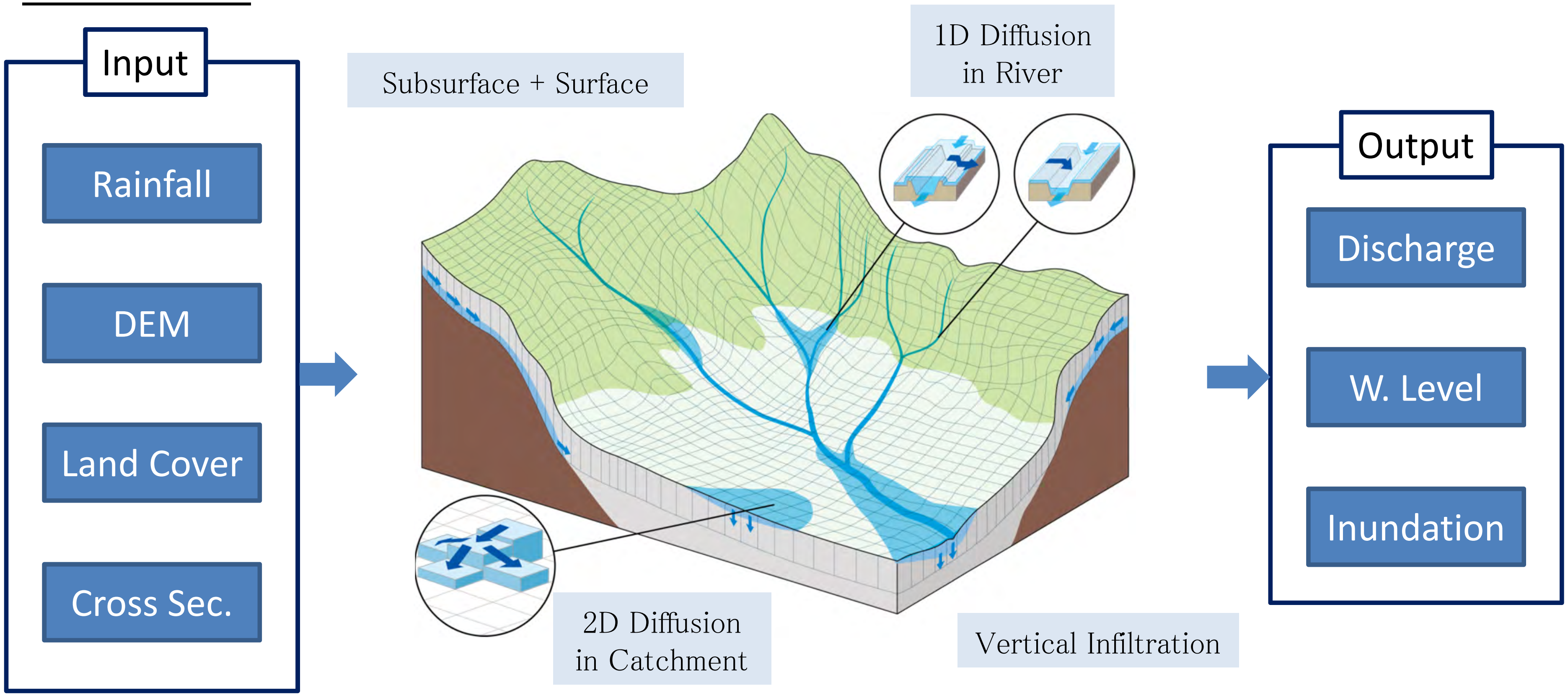
Today outline is below.

1. **Introduction**
2. **Outline of RRI model(Radovish model)**
3. **PC setting**
   a) vc_redist.x64.exe
   d) w_fcompxe_redist_intel64.msi
   c) mingw-w64-install.exe(for gfortran)
4. **Outline of Training on next day**

1-1) Rainfall-Runoff-Inundation model

★Outline of RRI model Based on the explanatory materials by ICHARM*, Japan

Structures



- Two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously
- The model deals with slopes and river channels separately
- At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell

1-1) Rainfall-Runoff-Inundation model

★Outline of RRI model Based on the explanatory materials by ICHARM*, Japan

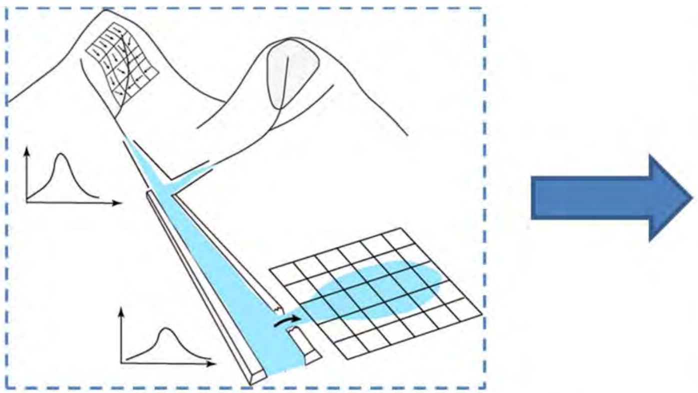
Features

1) Integration for versatile topography: The RRI model analyzes river channels one-dimensionally and land area two-dimensionally. It is applicable to basins including mountains and plains.

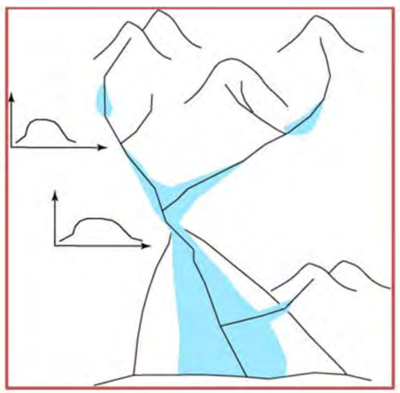
2) Fast, stable numerical algorithm: In the project of International Center for Water Hazard and Risk Management (ICHARM), it had been capable of simulating rainfall-runoff-inundation for a period of five months in the Chao Phraya River basin (160,000 km2) within two hours.

3) Analysis with complex hydrological processes : It can simulate lateral subsurface flows in mountainous areas, vertical infiltration flows in plain areas, structures such as levees, dams and diversion channels.

4) Tools for emergency-response modeling : Complete with tools and manuals for effective use of satellite rainfall and topological information.



Conventional Applications of flood models



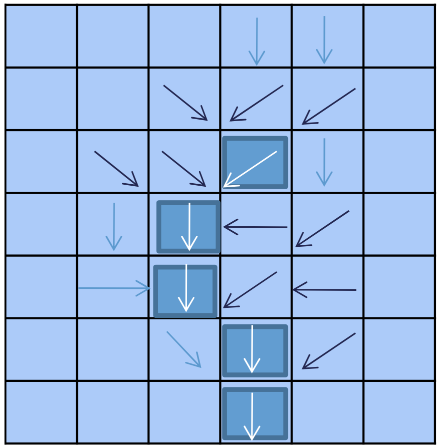
RRI Model Application

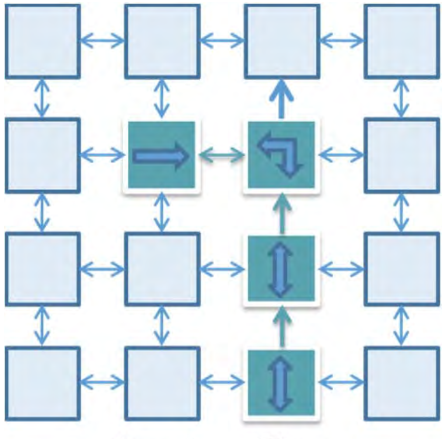
1-1) Rainfall-Runoff-Inundation model

★Outline of RRI model Based on the explanatory materials by ICHARM*, Japan

Main difference between typical distributed Rainfall-Runoff models and RRI?

Distributed R-R Model (1D kinematic(or similar))	RRI model (2D Diffusive)
Flow directions **are fixed** based on topography.	Flow directions **change** based on **water levels**.





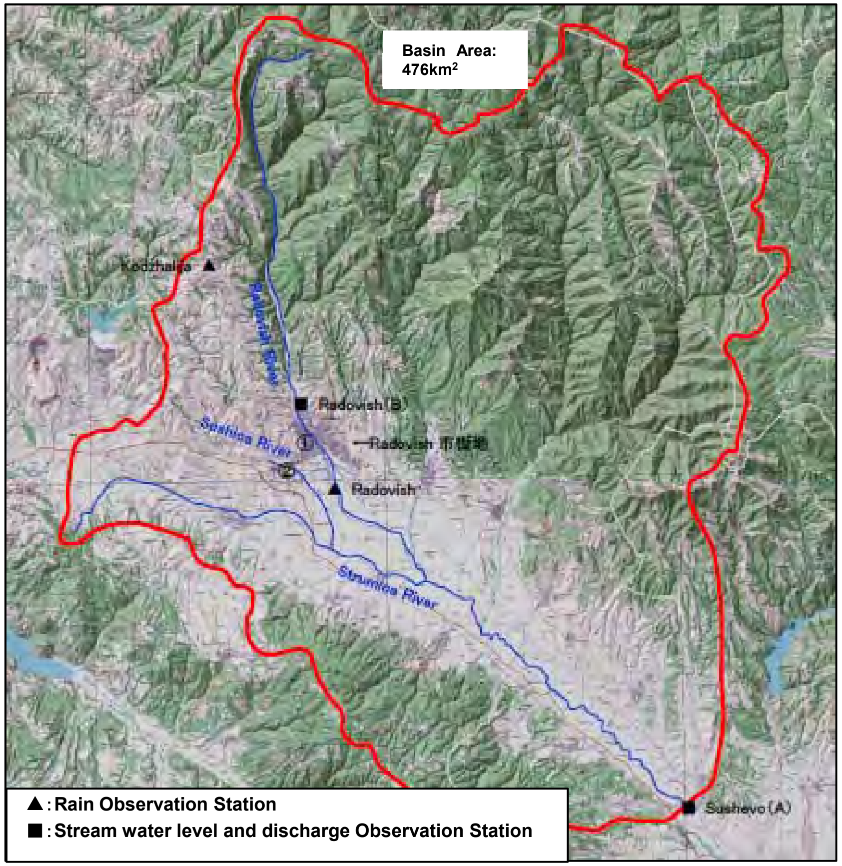
- Distributed R-R Model needs separately the flood model for estimation of the inundation area.
- RRI model is capable of simulating rainfall-runoff and flood inundation simultaneously.

(2) Outline of RRI model(Radovish model)

2-1) Introduction

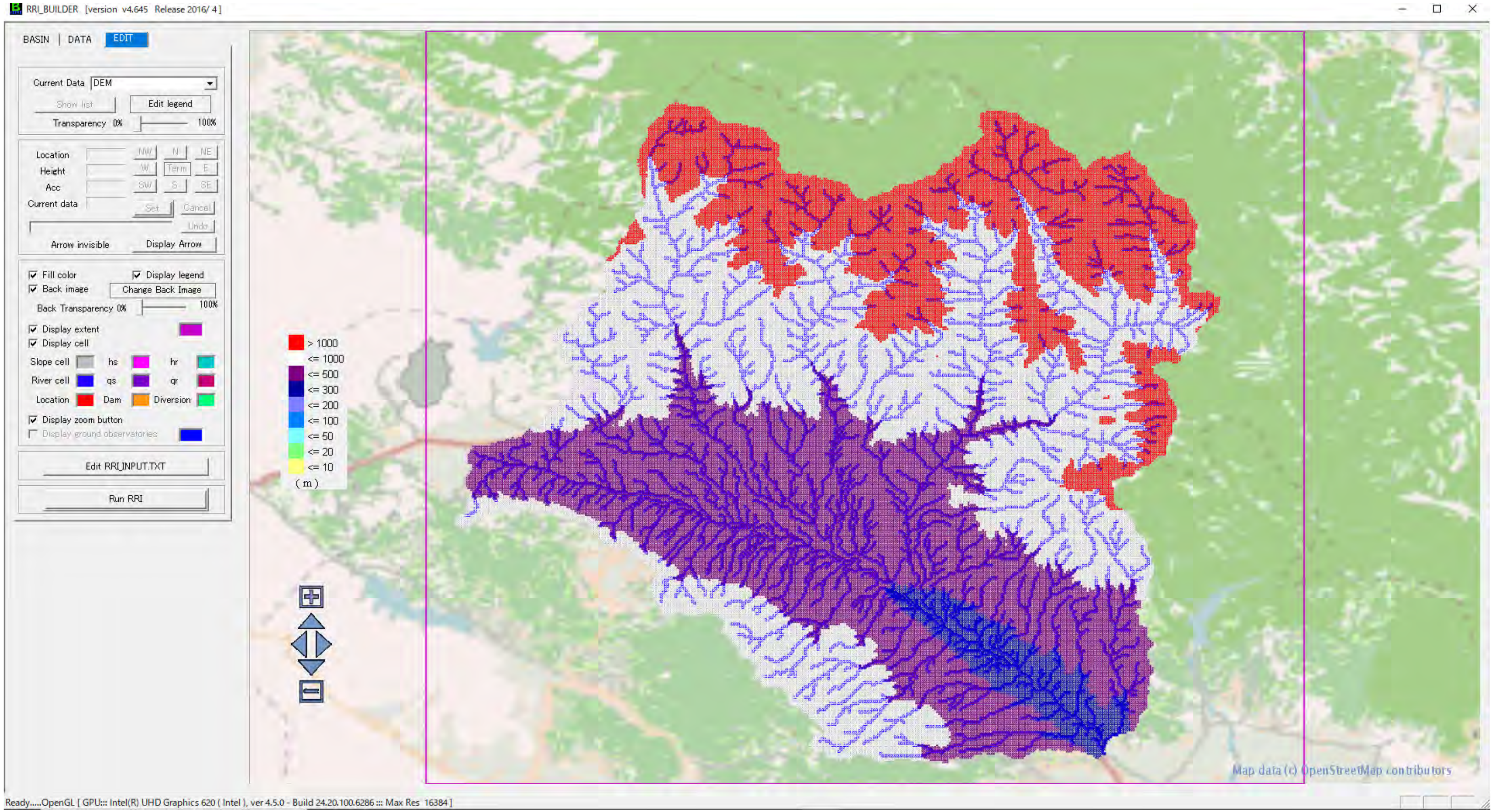
★Basic condition of model development in the Radovish river basin

Content		General description
Code		Rainfall-Runoff-Inundation model (RRI model)
Software		RRI Model
Modeling region		41.50～41.80N、23.35～22.70E Number of grids： 420×360 (Including Strumica River basin upstream of Sushevo)
Basin area		476 km²
Grid size		3-sec grid (≒90m)
Analysis period		2008/12/4 4:00～2008/12/6 3:00 total 48h
Input data	Elevation Data (DEM)	SRTM(=Shuttle Radar Topography Mission Height) 3-sec grid (≒90m)
	Flow Direction Data (DIR)	ditto
	Accumulative Flow Data (ACC)	Ditto
	Land Cover Data	USGS data
	Soil type Data	FAO data
	Rainfall	1% probability rainfall with rainfall intensity formula from Blinkov and Jagev (2004)
River setting	River width	Estimated from water catchment area (㎢)
	River depth	Ditto
	Bank height	No setting (since there is not remarkable dike)



2-2) Input data

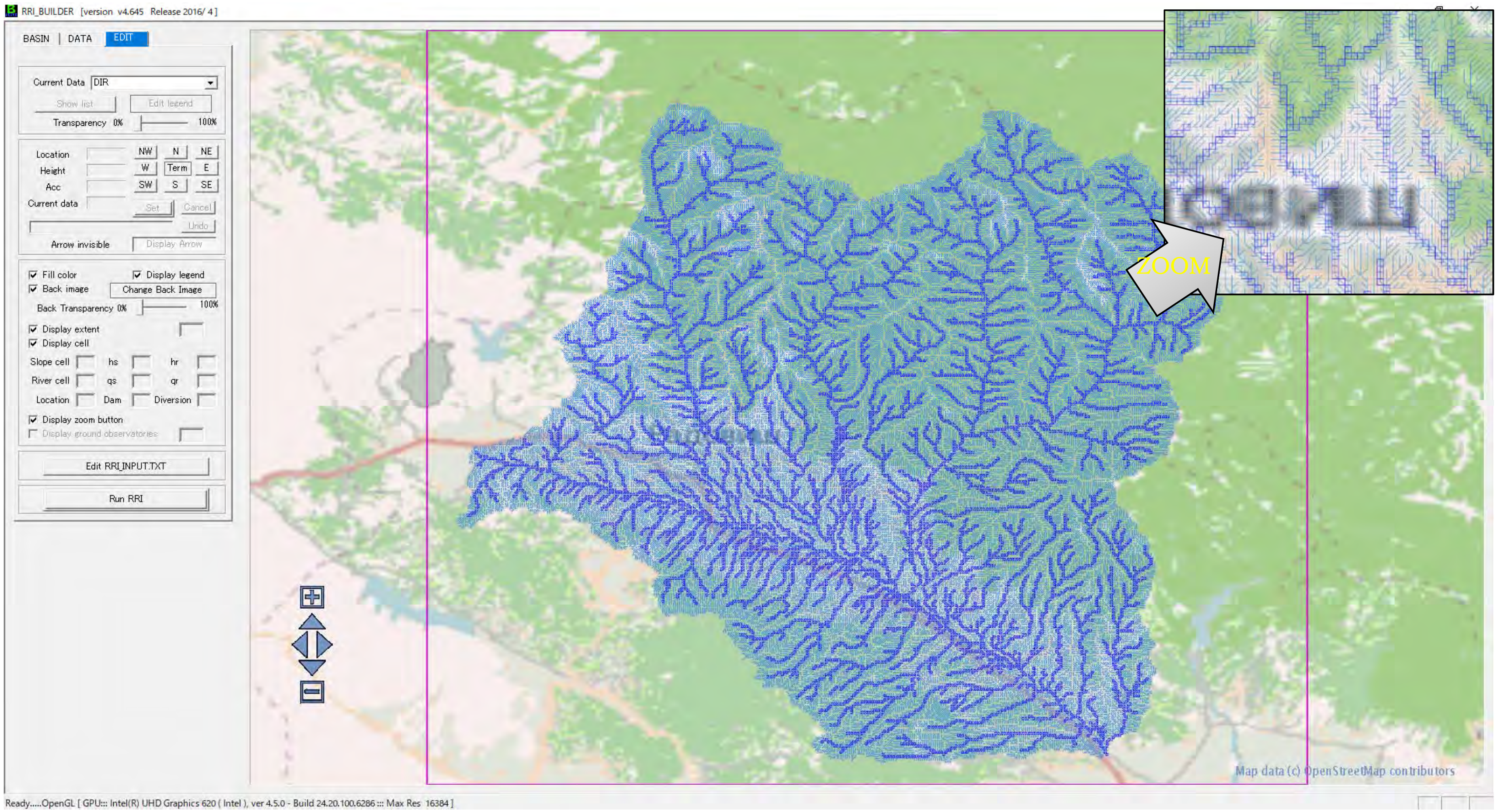
★Digital-Elevation-Model(DEM)



※Digital Elevation model (DEM) was prepared by using SRTM 3sec grid DEM

2-2) Input data

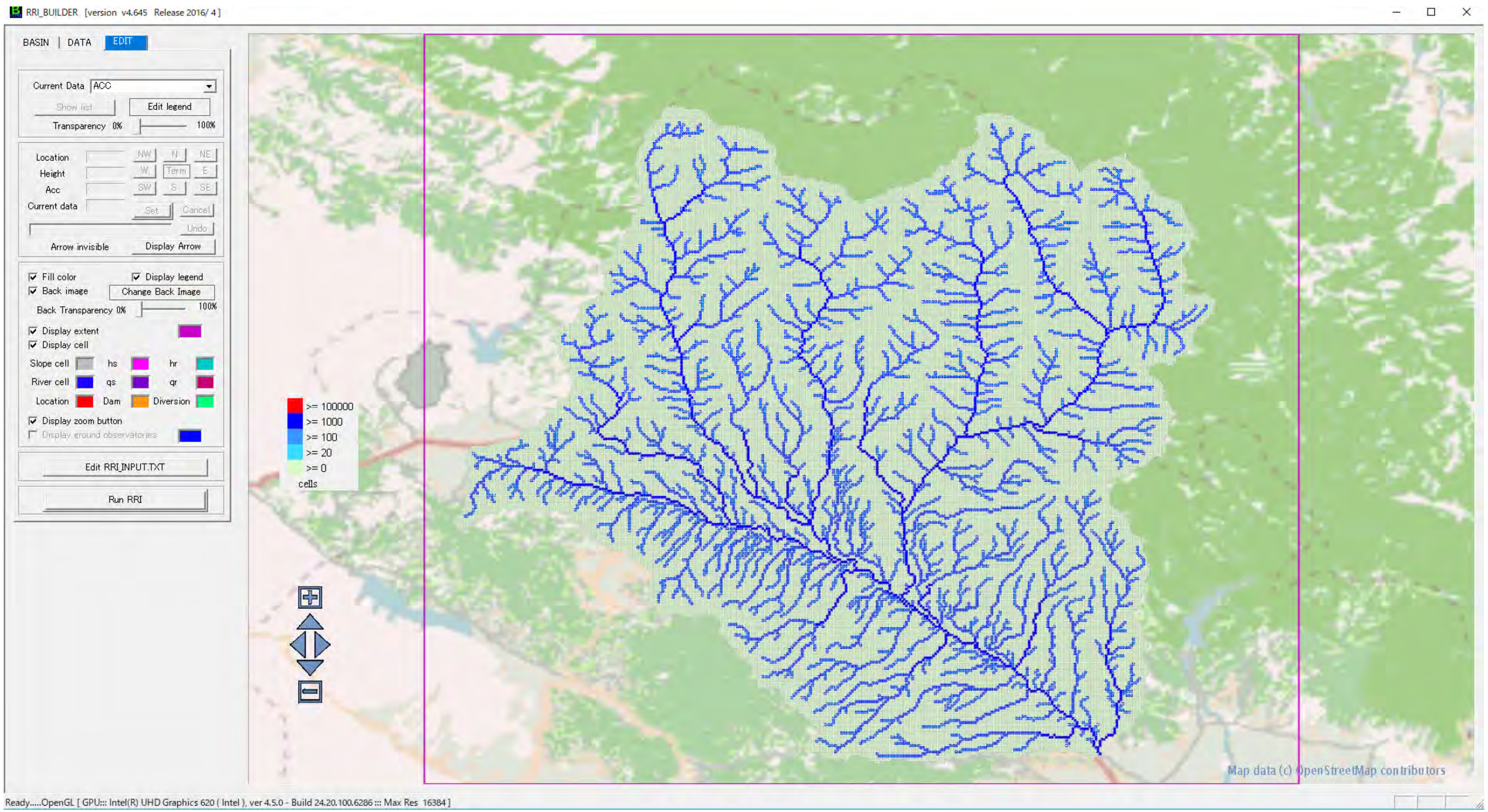
★Flow Direction model(DIR)



※Flow direction model (DIR) was prepared from DEM

2-2) Input data

★Accumulative Flow model(ACC)



※Accumulative Flow (ACC) model was prepared by using DEM and DIR.

2-3) Model condition setting

★Setting of river width and depth

Empirical equations

For the estimation,
the following empirical equations can be used to represent river width and depths for each river grid-cell.

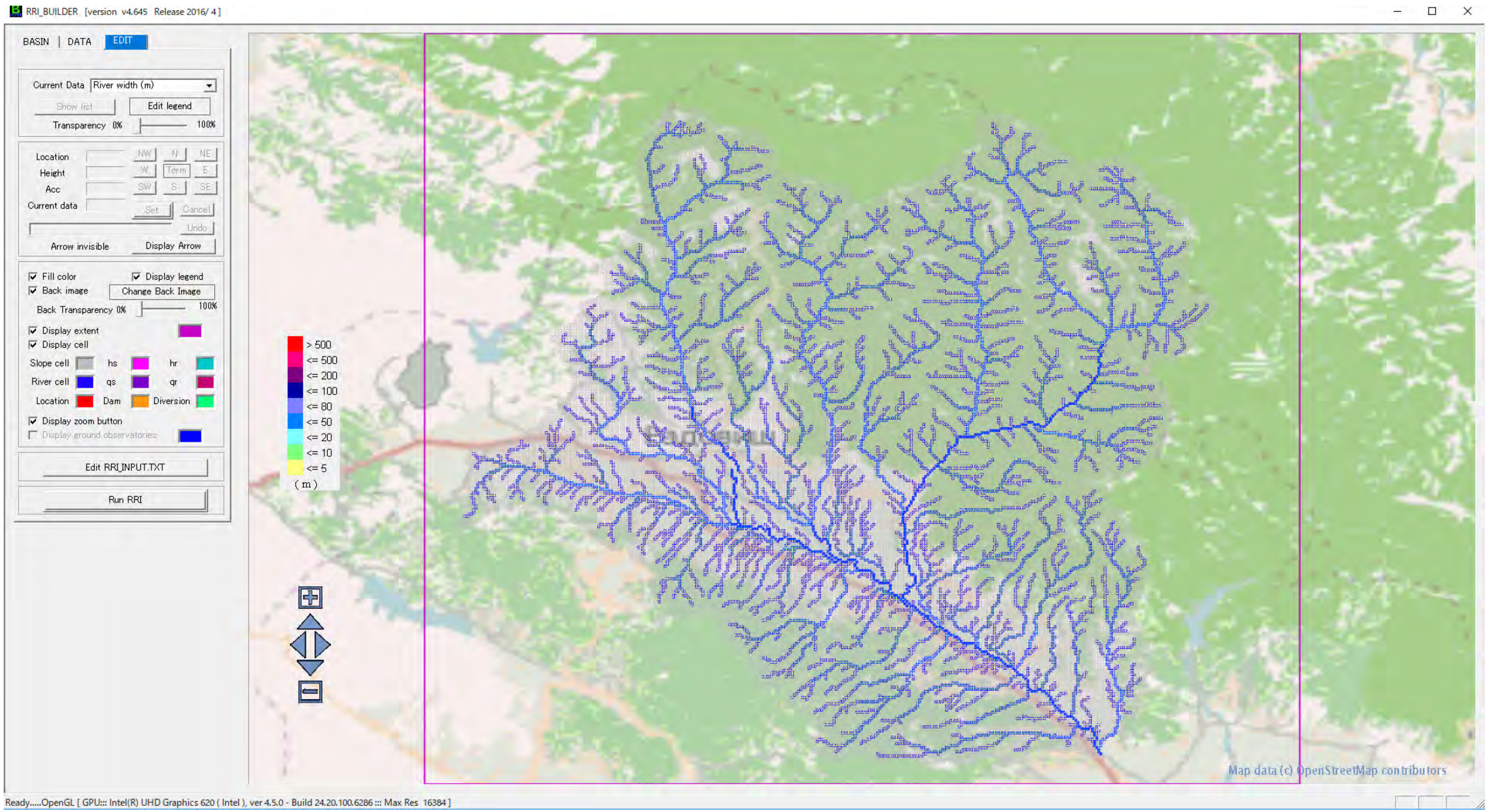
$$width = c_w A^{s_w}$$

$$depth = c_d A^{s_d}$$

where *A* is the upstream catchment area in [km^2] for each river grid-cell.
Note that the units of width and depth are in [m].

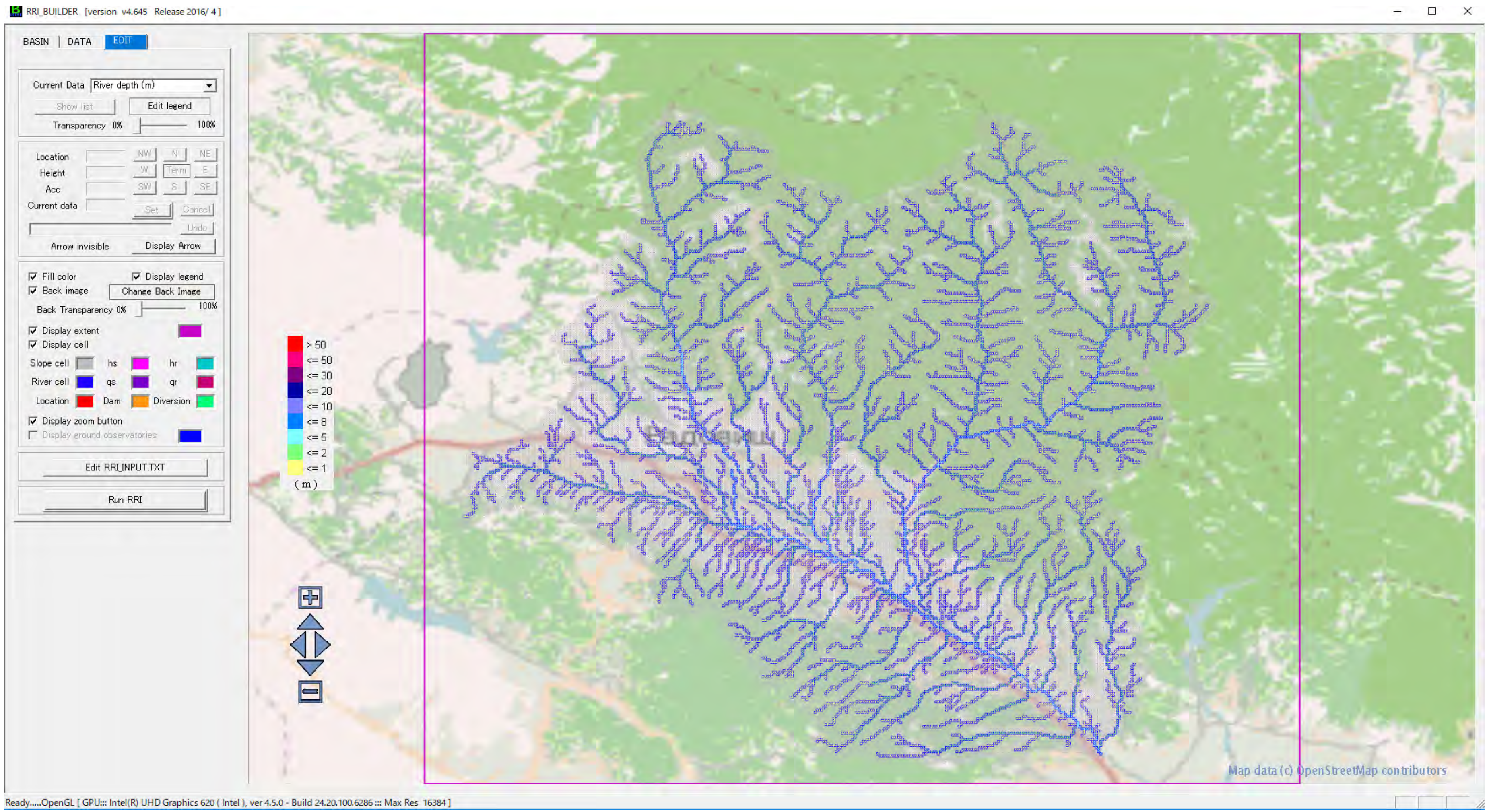
2-3) Model condition setting

★River width



2-3) Model condition setting

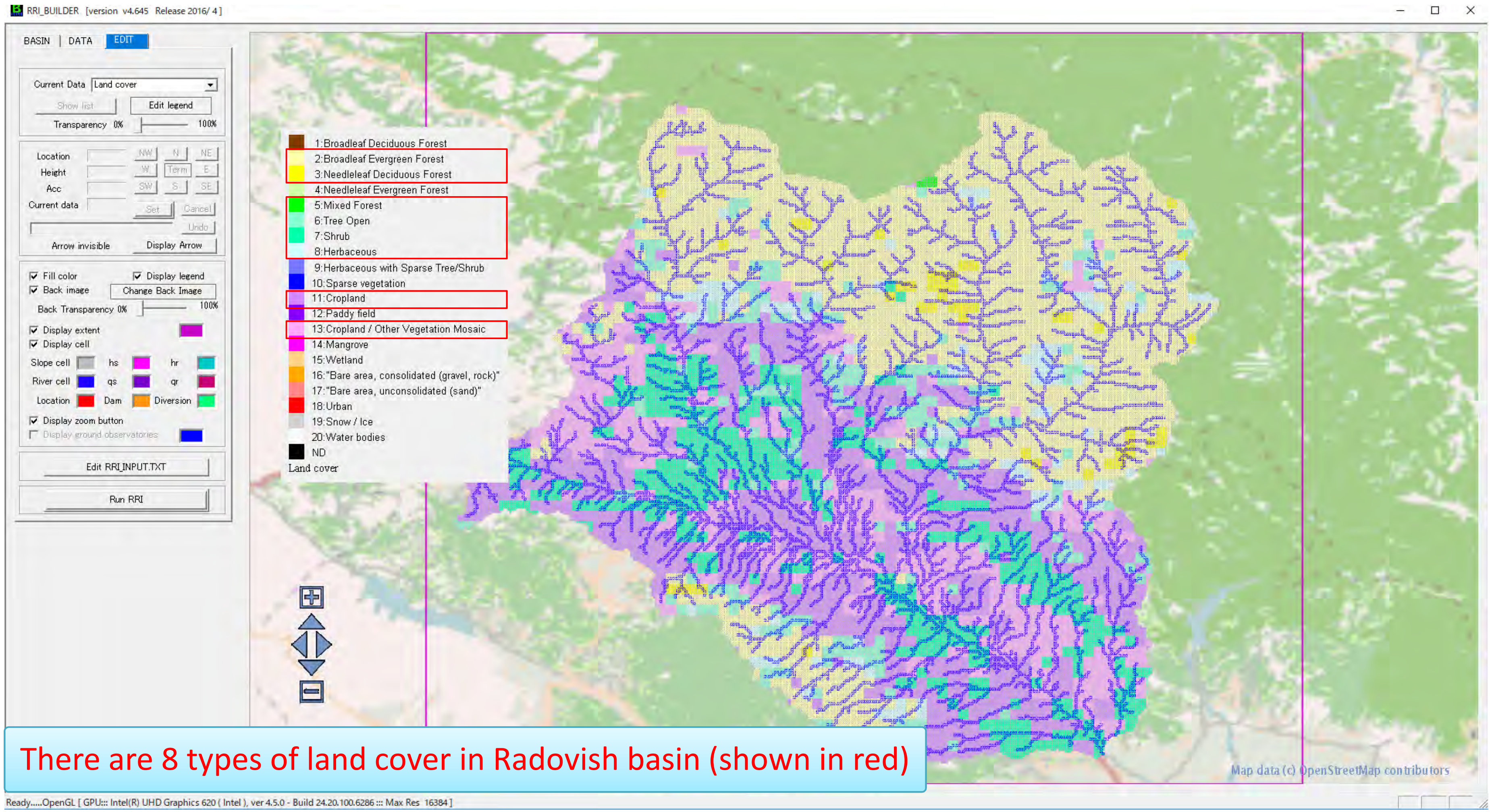
★River depth



(2) Outline of RRI model(Radovish model)

2-3) Model condition setting

★Land cover



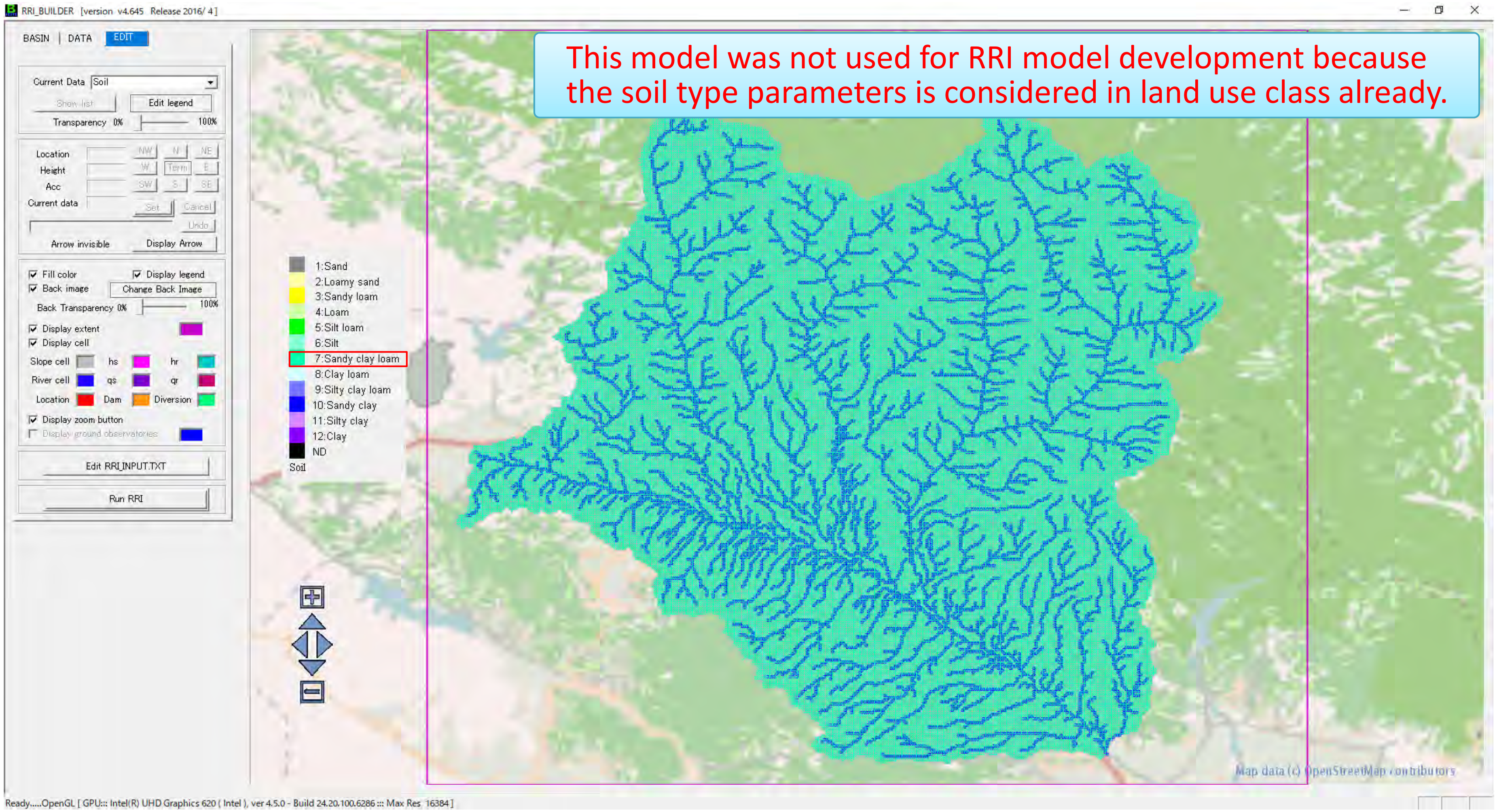
There are 8 types of land cover in Radovish basin (shown in red)

※Land cover model was prepared from USGS data

(2) Outline of RRI model(Radovish model)

2-3) Model condition setting

★Soil type



※Soil type model was prepared by FAO data.

2-3) Model condition setting

★Setting parameter

No.	2	3	5	6	7	8	11	13
Land use	Evergreen broadleaf	Evergreen conifer	Mixed forest	Vacant land	Shrub	Herbaceous plant	Farmland	Other
Equivalent Roughness	0.200	0.200	0.200	0.050	0.100	0.050	0.050	0.050
Thickness of soil (m)	0.150	0.150	0.150	0.150	0.150	0.150	0.400	0.400
Effective porosity (%)	0.450	0.450	0.450	0.400	0.450	0.450	0.600	0.600
Vertical saturated hydraulic conductivity (m/s)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wet front suction pressure (m)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Side saturation hydraulic conductivity (m/s)	0.010	0.010	0.010	0.010	0.010	0.002	0.005	0.005
Unsaturated porosity (%)	0.050	0.050	0.050	0.050	0.050	0.050	0.030	0.030
Inverse ratio of unsaturation / saturation	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000

※Parameter was set using land cover

・With this parameter, RRI model can express discharge observation records in Japanese river basin using real precipitation records.
・Based on this, parameters had been adjusted so that the flood of Radovish could be calculated appropriately.

2-4) Preparation of Rainfall model

★Flood event

The significant flood events in the past were shown in below Table.

No.	Date (Month/Year)	Precipitation	Discharge	Remarks
1	Mar./1962	39.2mm/day @Stip 45.5mm/day @Strumica	210m^3/s @Sushevo	Maximum flow at Sushevo 1961-2008
2	Nov./2004	45.0mm/day @Stip 40.7mm/day @Strumica	148m^3/s @Sushevo	Maximum flow at Sushevo in 2000s
3	Dec./2008	14mm/day @Stip	17.9m^3/s @Sushevo 40.7m^3/s @Novo Selo	The biggest flood in recent years in the city of Radovish
		1% probability * @Radovish Basin	159.49m^3/s * @Radovish River	
4	Jan./2015	9.2mm/day @Stip	No record	Water level photos and videos of the Radovish River exist

*) Blinkov and Lazareva (2016)

[Flood event in Dec./2008]


Radovish city

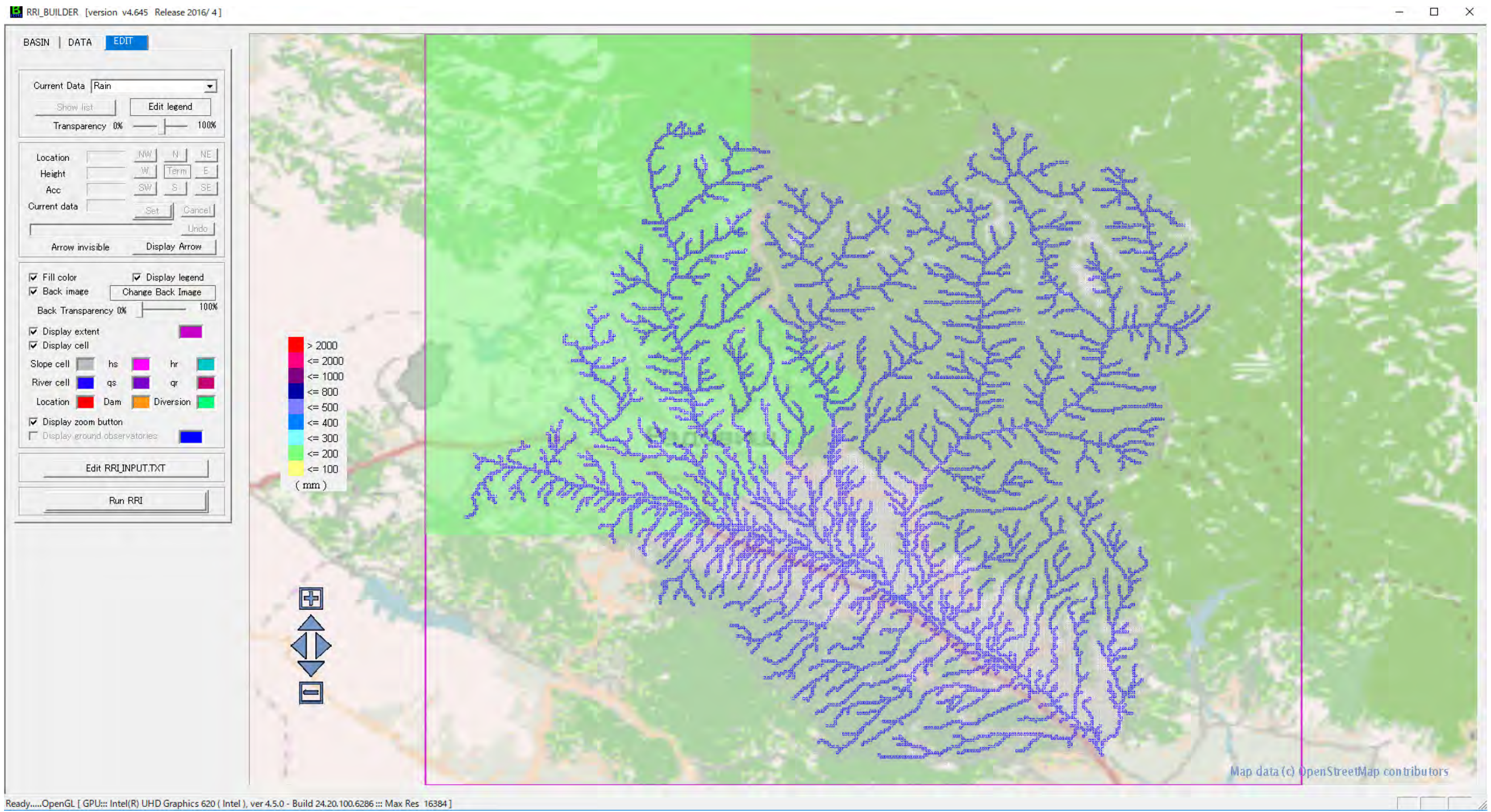

Overflow in the bridge (The Sushica river)

(2) Outline of RRI model(Radovish model)

2-4) Preparation of Rainfall model

★Input Rainfall model

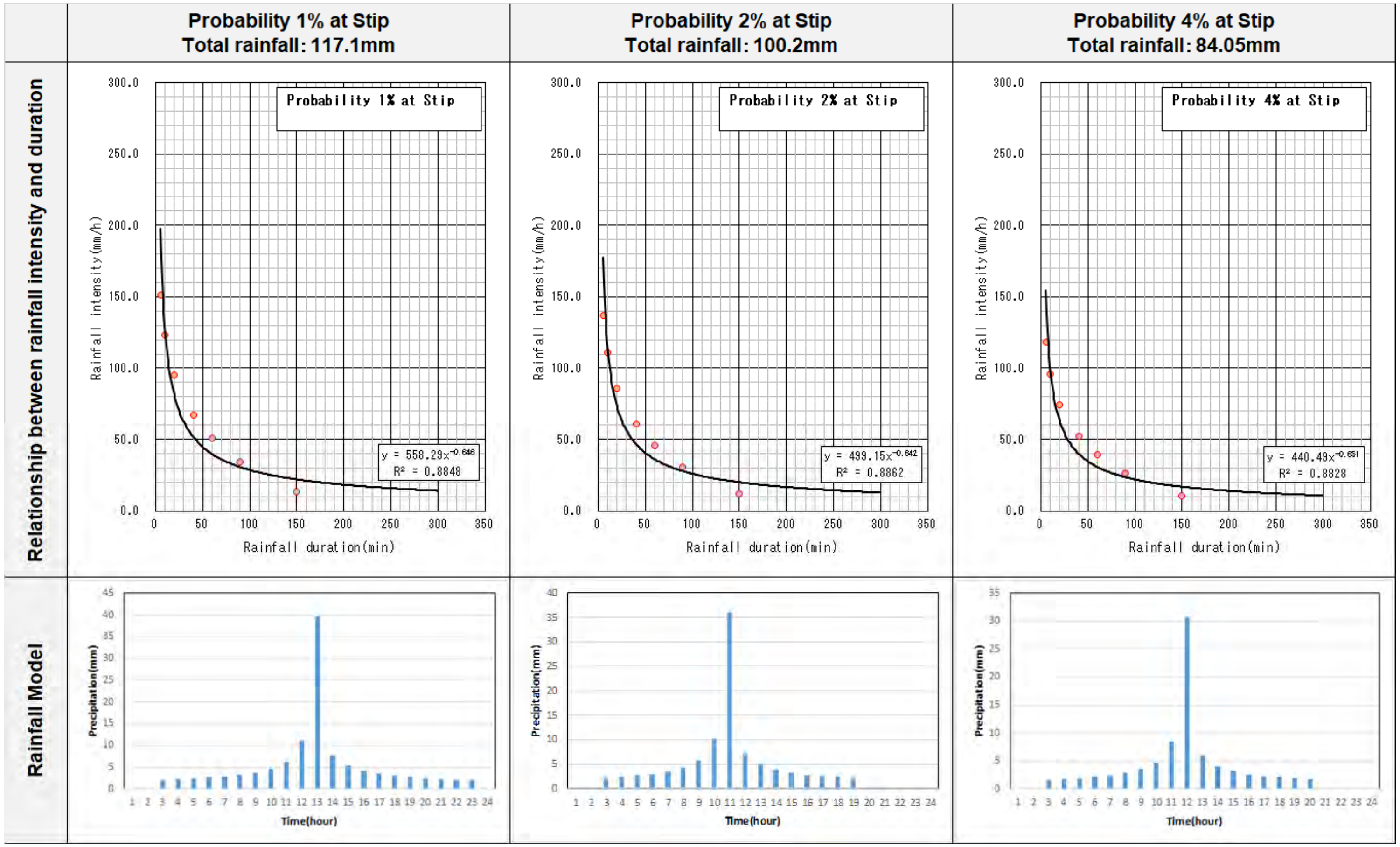
- Observed records of precipitation and discharge do not correspond well
- Heavy rainfall may occurs in specific
- The rainfall area was defined only around Radovish River basin as shown in below figure (Green hatch)



2-4) Preparation of Rainfall model

★Input Rainfall model(Estimation of precipitation amount)

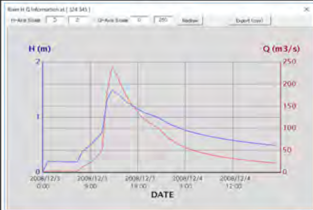
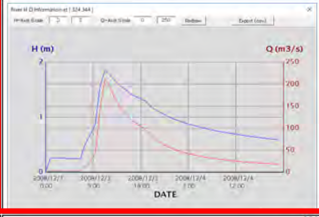
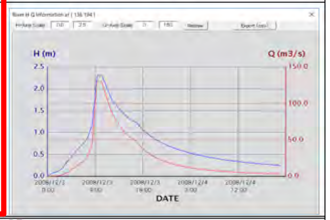
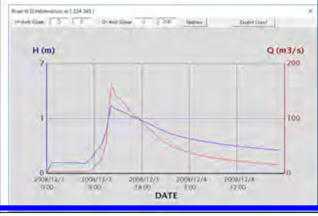
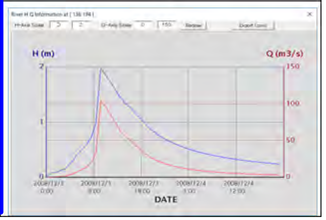
- Relationship between rainfall intensity and duration in probability at Stip was estimated from formula by Blinkov and Jagev (2004)
- Total rainfall of 1%, 2% and 4% probability were calculated using probability precipitation program from annual daily maximum precipitation in Stip

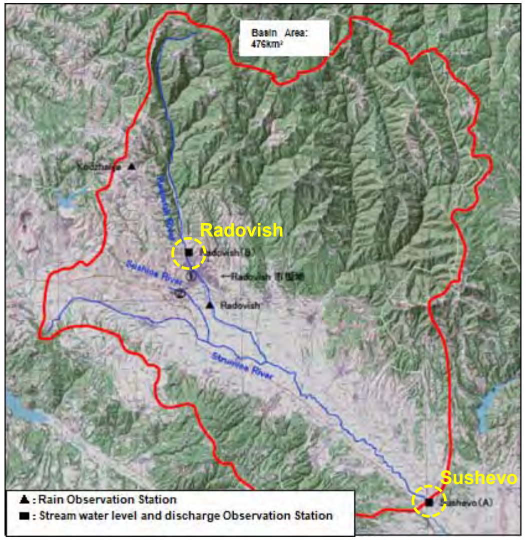


(2) Outline of RRI model(Radovish model)

2-5) RRI Results and Verification

★Results

Probability	W=100 (probabilty 1%)	
Site	Sushevo	Radovish
Discharge (m3/s)	240	150
H and Q		
Probability	W=50 (probability 2%)	
Discharge (m3/s)	210	130
H and Q		
Probability	W=25 (probability 4%)	
Discharge (m3/s)	150	105
H and Q		

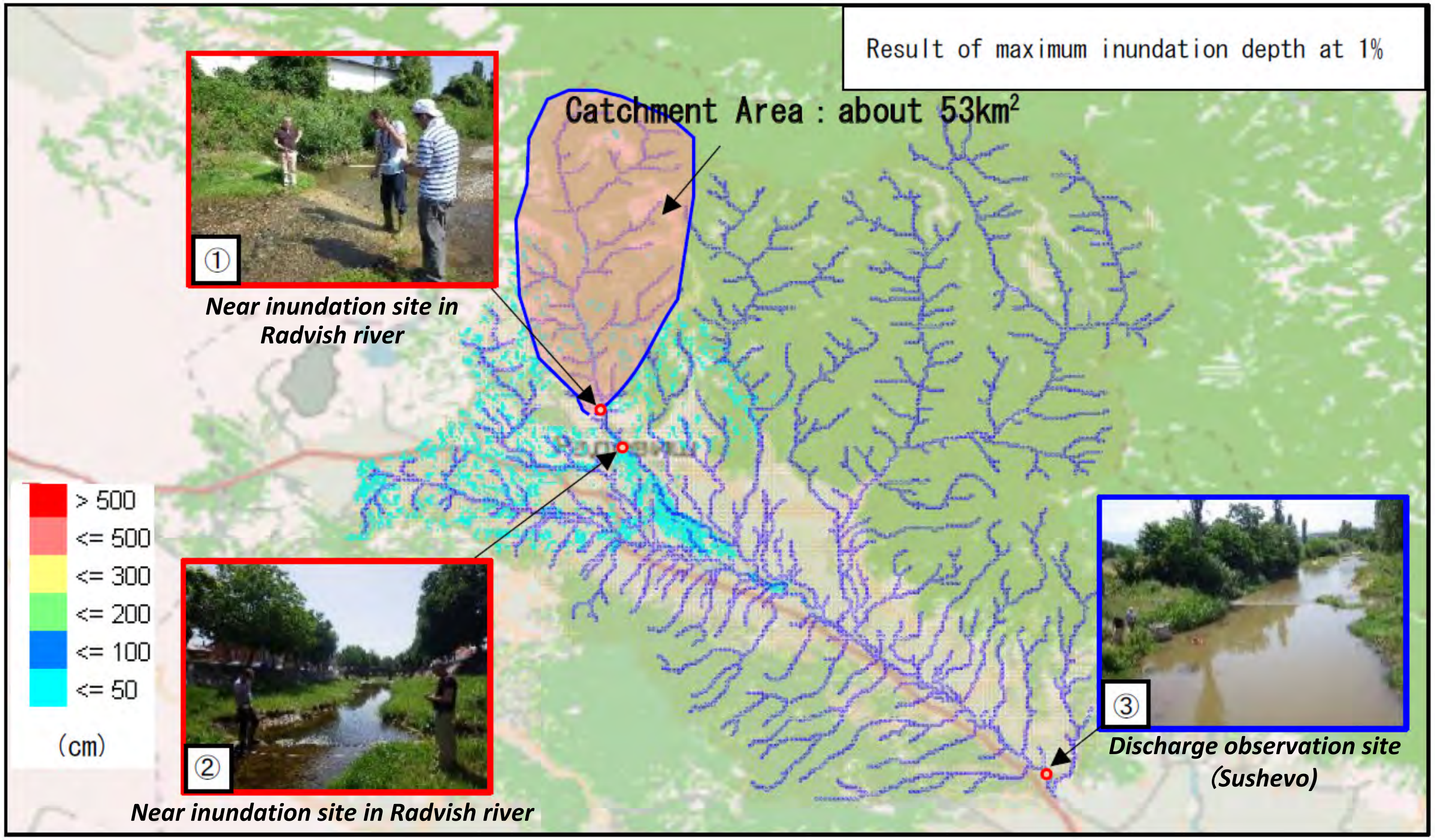


Rainfall	Discharge	Date	Discharge model	consistency
1% (Blinkov)	1%=159.5m³/s @radovish river by Blinkov	2008.12	~150m³/s @radovish in W=1/100	○
39.2mm/day@Stip 45.5mm/day@Strumica	210m³/s @Sushevo	1962.3	~210m³/s @Sushevo in W=1/50	○
45.0mm/day@Stip 40.7mm/day@Strumica	148m³/s @Sushevo	2004.11	~150m³/s @Sushevo in W=1/25	○
9.2mm/day@Stip	No record	2015.1	~100m³/s @radovish in W=1/25	?

- Green square shown is consistent with the discharge 159.49m3/s at Radovish in Dec. 2008 flood(Blinkov and Lazareva (2016))
- Red square shown is the result of RRI model calculation with 2% probability rainfall and consistent with the discharge at Sushevo on Mar. 1962(largest discharge during about 50 years'observation)
- Blue square shown is similar to the discharge at Sushevo on Nov. 2004

2-5) RRI Results and Verification

★Verification(Stream discharge)



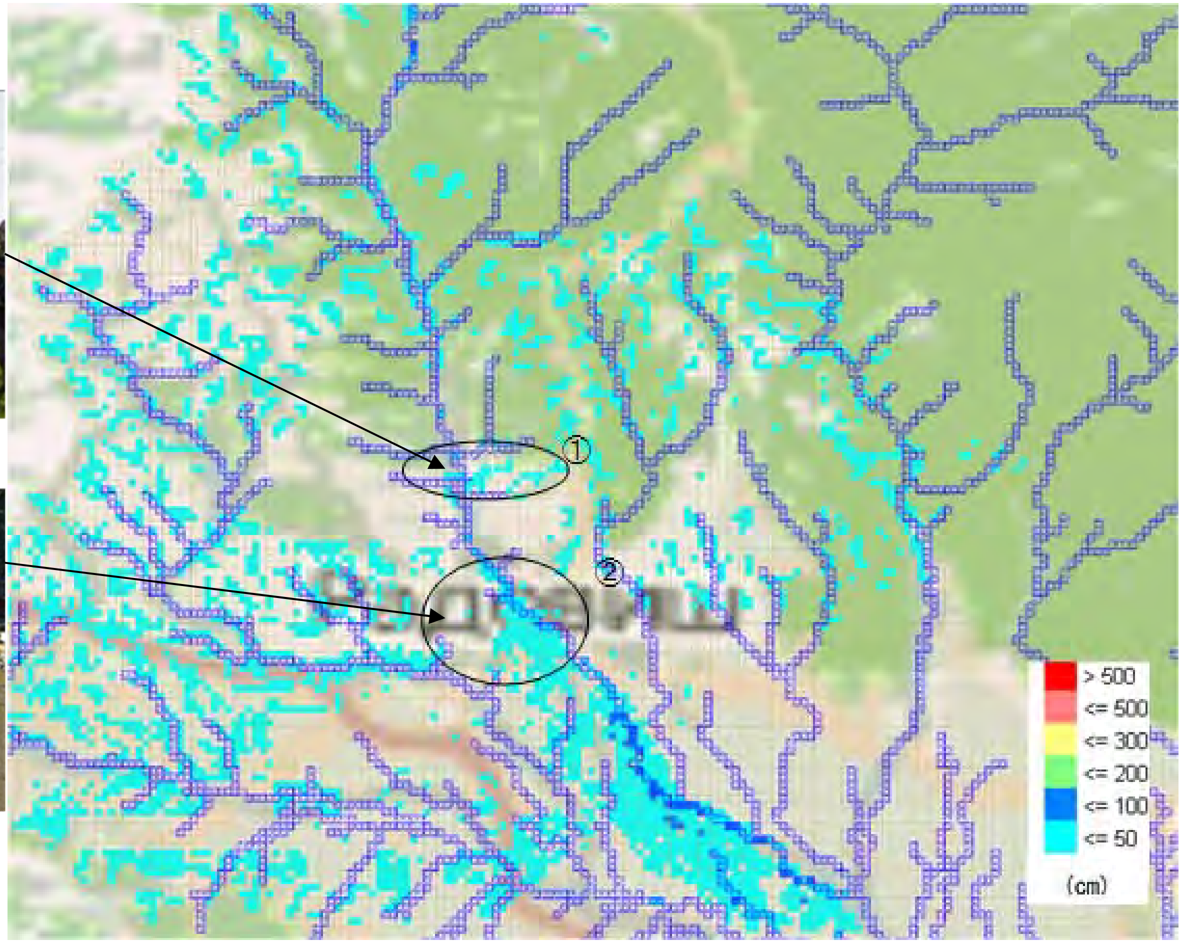
- Blinkov and Lazareva (2016) reported that catchment area of Radovish River is 54.38km2.
- Catchment area upper than the flooded area in Radovish of Dec. 2008 flood is about 53km2, and it close reported by Blinkov and Lazareva (2016).
- Moreover, discharge obtained from RRI is consistent well with that estimated by Blinkov and Lazareva (2016).

2-5) RRI Results and Verification

★Verification(Inundation area)

Interview(2019/6/13)

Photo(2008/12/4)



- From the interview conducted on 13 June 2019 to local resident about Dec. 2008 flood in Radovish, flood reached to the field next to the house on the left bank of the Radovish River (①).
- As a result, it was confirmed that the inundation area shown in above circle and photos shown below are the same area at 4 December 2008.

(3) PC Setting

3-1) Copy all folder and file

①Copy “USB” and paste it under “Desktop”

- **ExtraData :**

  HydroSHEDS_IMAGE(DEM,ACC,DIR), Images(Map), obsdata(precipitation), Parameter

- **QGIS :**

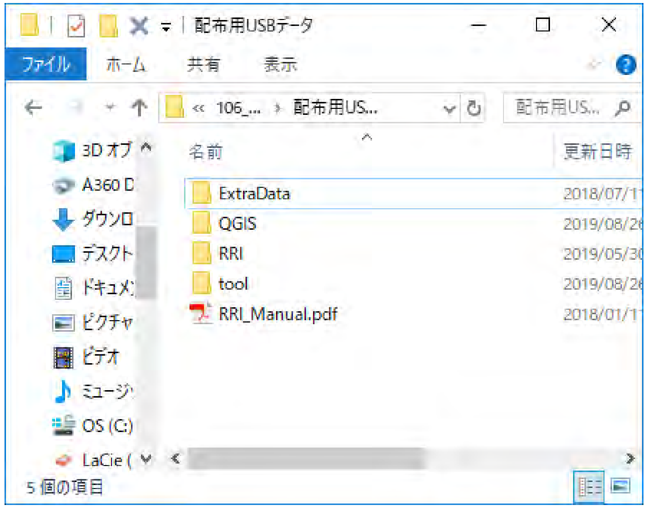
  Install file ※In this lecture, does not use.

- **RRI :**

  Presetting, RRI-CUI, RRI-GUI, Teams_of_Agreement

- **tool :**

  Creating program of topography data



3-1) Copy all folder and file

②Copy “RRI” folder from USB and paste it under “C:¥”

- **Presetting :**

  mingw-w64-install.exe etc

- **RRI-CUI :**

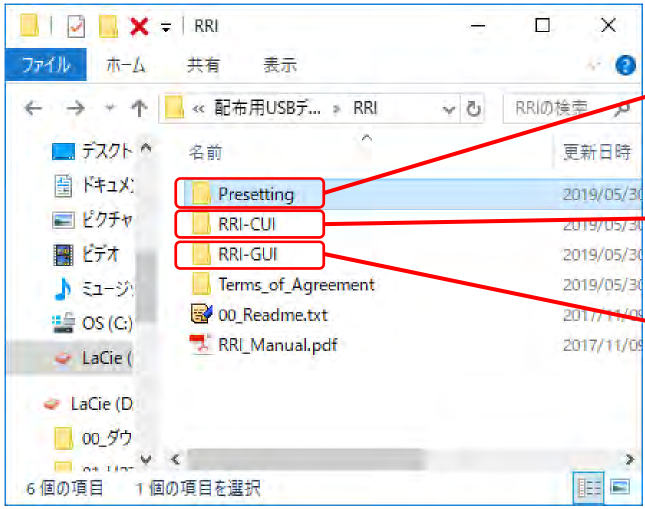
  RRI-Model with Command User Interface (Advanced)

- **RRI-GUI :**

  RRI-Model with Graphical User Interface)

In this lecture

- **Terms_of_Agreement**



- vc_redist.x64.exe
- w_fcompxe_redist_intel64.msi

etc

RRI-Model with Command Prompt
(For advanced user)

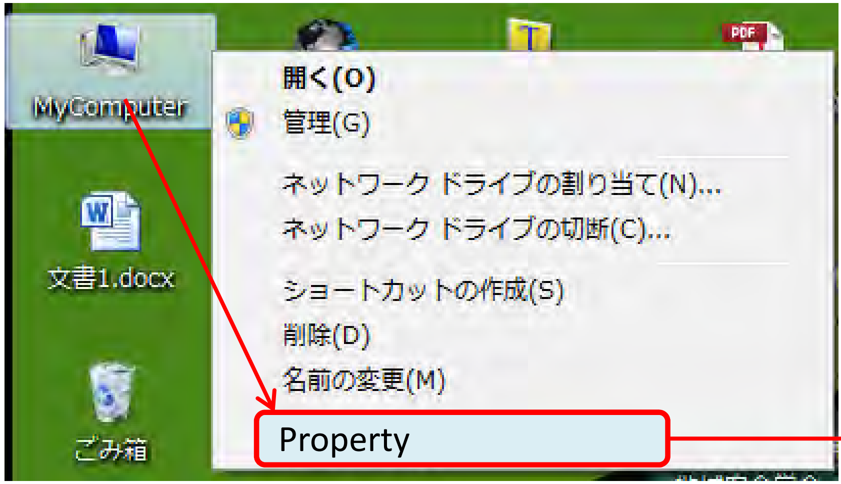
RRI-Model with GUI
(Graphical User Interface)

(3) PC Setting

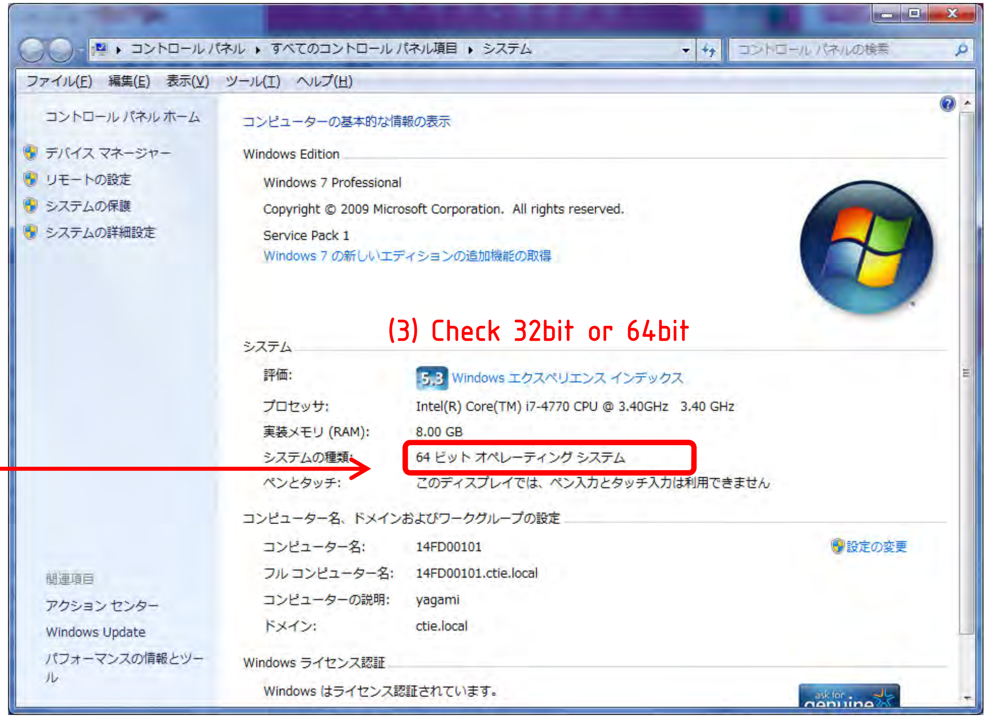
3-2) Install libraries

①Check your PC: 32bit or 64 bit?

(1) Right Click on My Computer



(2) Select "property "

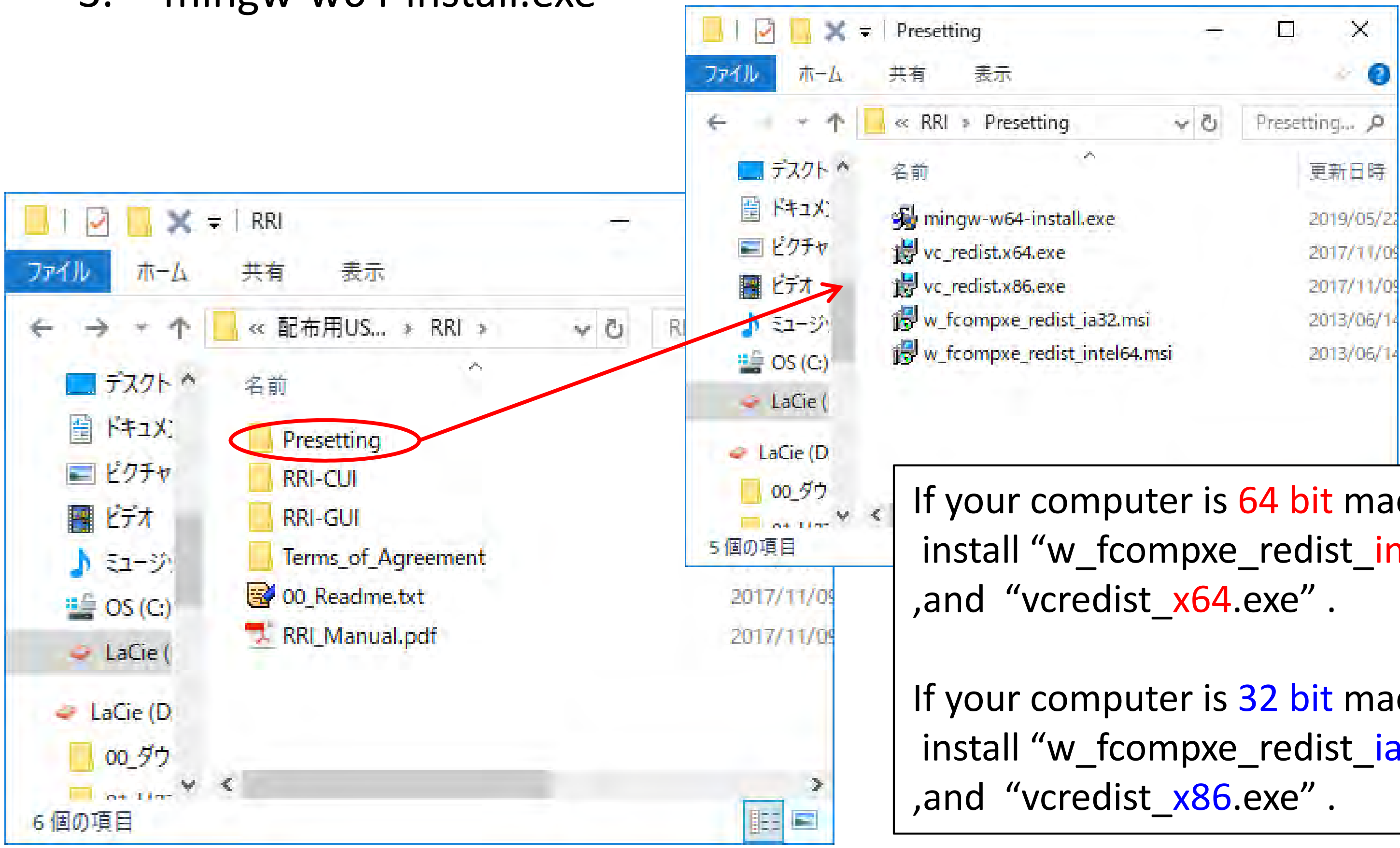


3-2) Install libraries

②Install libraries

Before execute RRI-GUI, install three programs saved in “presetting” folder.

1. Intel Fortran Redistributable Library Packages (w_fcompxe_redist)
2. Visual C++ Redistributable Packages (vcredist)
3. mingw-w64-install.exe



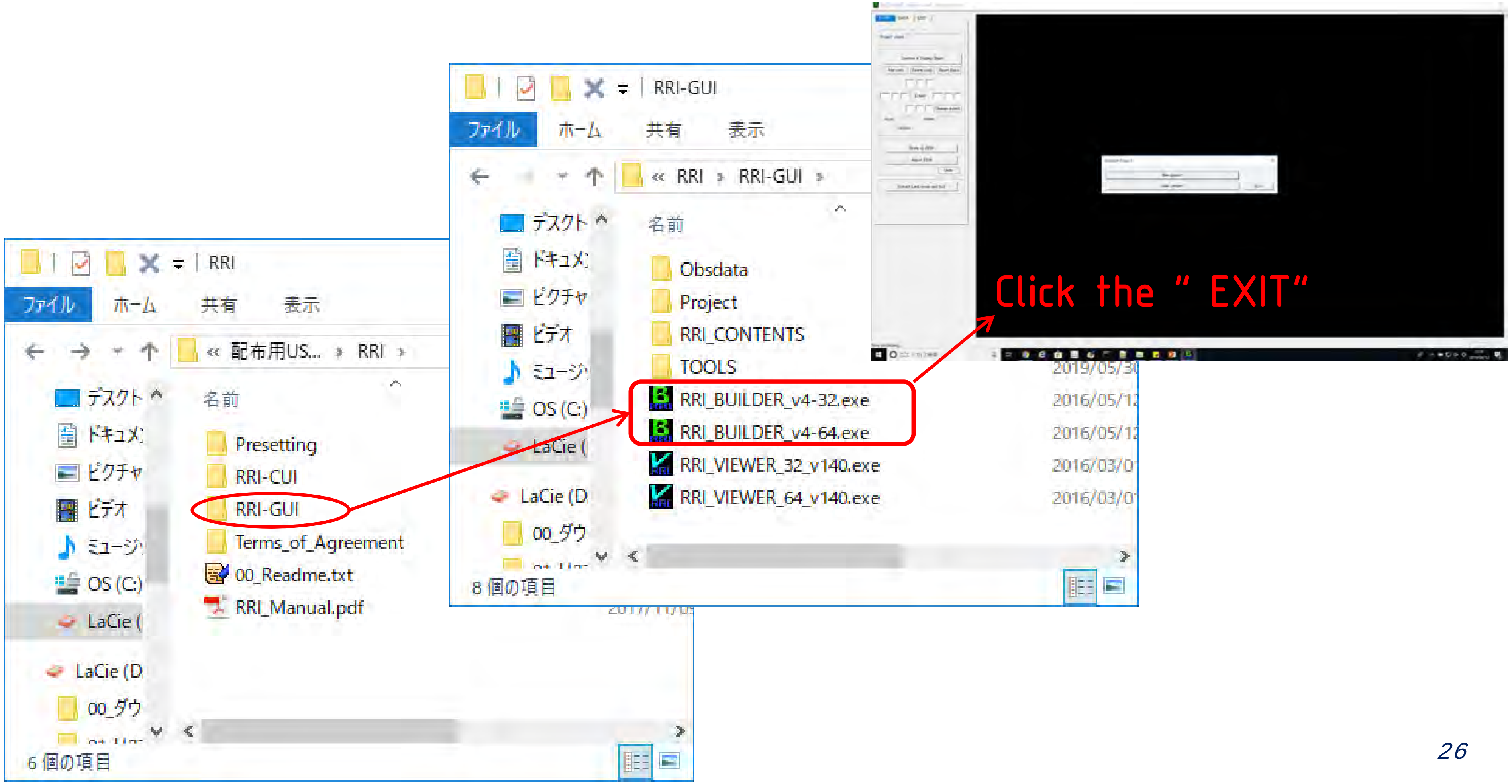
If your computer is 64 bit machine,
install “w_fcompxe_redist_intel64.msi”
,and “vcredist_x64.exe” .

If your computer is 32 bit machine,
install “w_fcompxe_redist_ia32.msi”
,and “vcredist_x86.exe” .

(3) PC Setting

3-3) Execute RRI_Builder.exe

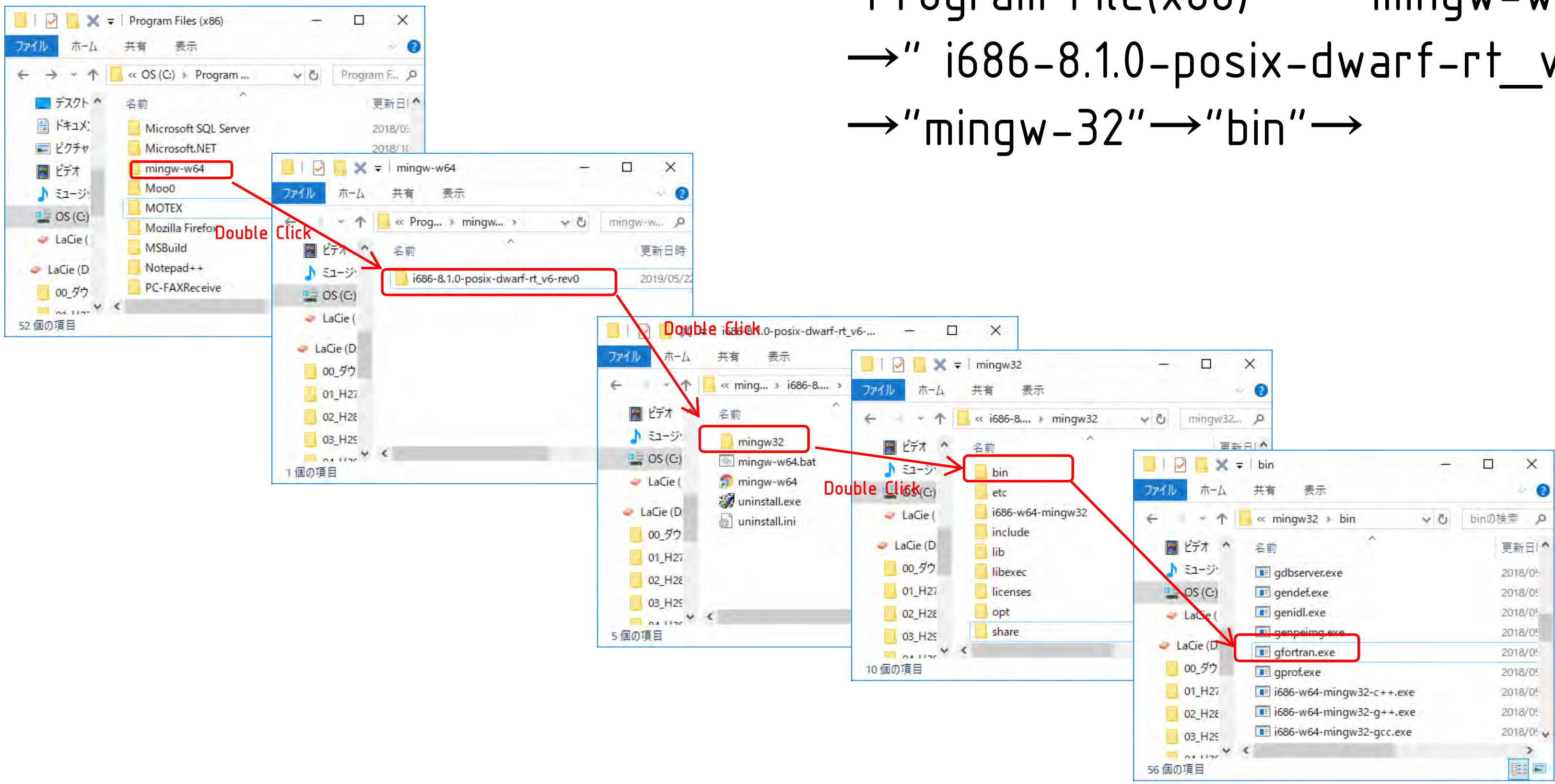
- Execute RRI_BUILDER_32.exe for 32bit machine or
  RRI_BUILDER_64.exe for 64 bit machine.



3-4) Add a path to

①Check installed the “mingw-w64”

"Program File(x86)"→" mingw-w64"
→" i686-8.1.0-posix-dwarf-rt_v6-rev0"
→"mingw-32"→"bin"→



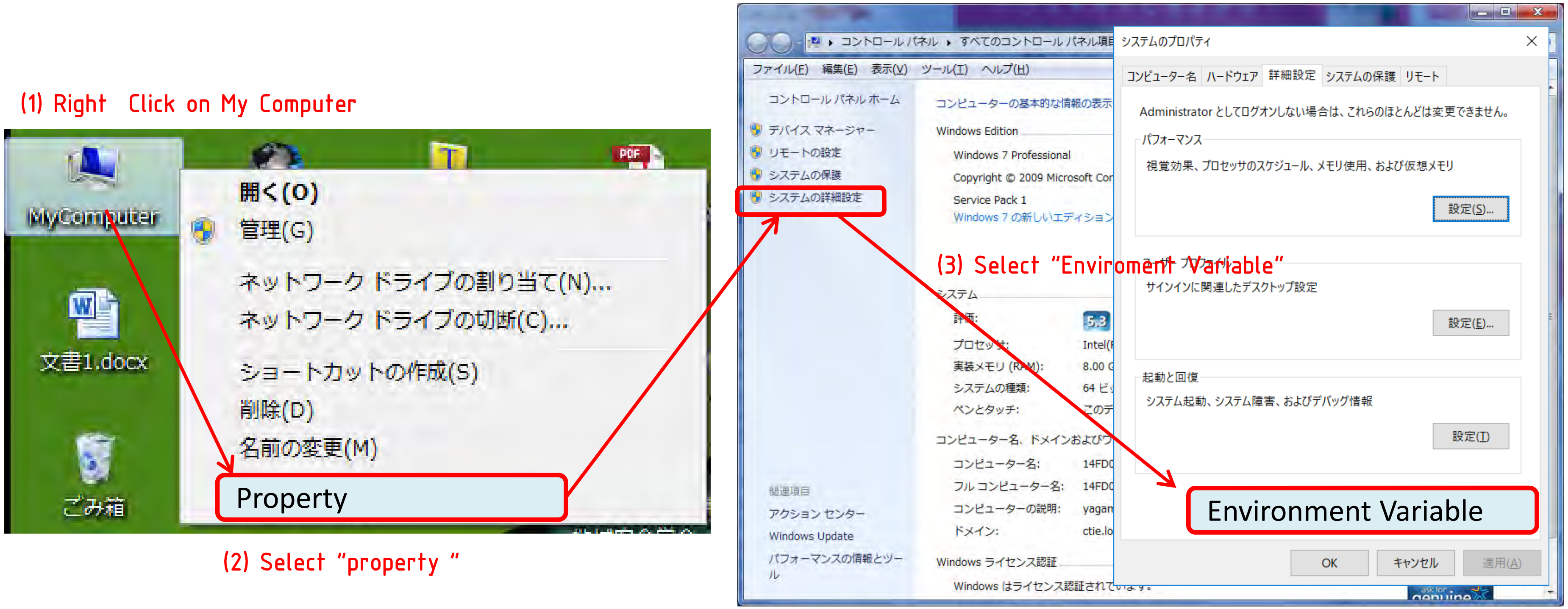
Confirmation of "gfortran.exe"

3-4) Add a path to “mingw-w64”

②Add a path

Add a path to “mingw-w64” with the following steps.

1. Select Computer from the Start menu
2. Choose System Properties from the context menu
3. Click on Environment Variable, under User’s Variables, find PATH, and click to edit it
4. In the Edit windows, modify PATH by adding “C:¥Program Files (x86)¥mingw-w64¥i686-8.1.0-posix-dwarf-rt_v6-rev0¥mingw32¥bin”



(3) Outline of Training on next day

Tomorrow outline is below.

1. **Explanation of target area**
2. **Exercise of data creation**
   a) dem data and dem adjustment
   d) dir data ※Flow Direction
   c) ACC data ※Flow Accumulation
   d) landuse and soil data
   e) River settings
   f) Rainfall data with Thiessen Polygon method
3. **Outline of Training on next day**

Rainfall-Runoff-Inundation (RRI) Model

ver. 1.4.2

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Rainfall-Runoff-Inundation Model User’s Manual

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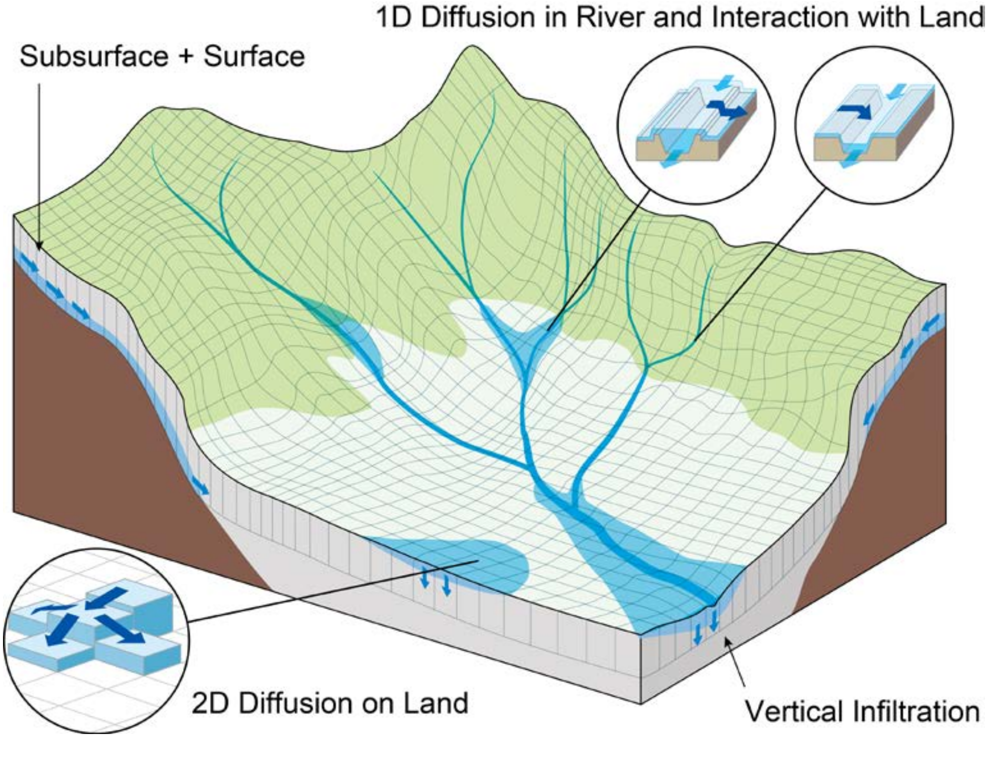
1. Outline of Rainfall-Runoff-Inundation (RRI) Model

1.1 Model Structure Overview

Rainfall-Runoff-Inundation (RRI) model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012, Sayama et al., 2015a, Sayama et al., 2015b). The model deals with slopes and river channels separately. At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell. The channel is discretized as a single line along its centerline of the overlying slope grid cell. The flow on the slope grid cells is calculated with the 2D diffusive wave model, while the channel flow is calculated with the 1D diffusive wave model. For better representations of rainfall-runoff-inundation processes, the RRI model simulates also lateral subsurface flow, vertical infiltration flow and surface flow. The lateral subsurface flow, which is typically more important in mountainous regions, is treated in terms of the discharge-hydraulic gradient relationship, which takes into account both saturated subsurface and surface flows. On the other hand, the vertical infiltration flow is estimated by using the Green-Ampt model. The flow interaction between the river channel and slope is estimated based on different overflowing formulae, depending on water-level and levee-height conditions.



Schematic diagram of Rainfall-Runoff-Inundation (RRI) Model

Model Features

1) RRI is a 2D model simulating for rainfall-runoff and flood inundation simultaneously.
2) It simulates flows on land and in river and their interactions at a river basin scale.
3) It simulates lateral subsurface flow in mountainous areas and infiltration in flat areas.

1.2 Governing Equations of RRI Model

A method to calculate lateral flows on slope grid-cells is characterized as "a storage cell-based inundation model" (e.g. Hunter et al. 2007). The model equations are derived based on the following mass balance equation (1) and momentum equation (2) for gradually varied unsteady flow.

$$\frac{\partial h}{\partial t}+\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}=r-f \quad (1)$$

$$\frac{\partial q_x}{\partial t}+\frac{\partial u q_x}{\partial x}+\frac{\partial v q_x}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{\tau_x}{\rho_w} \quad (2)$$

$$\frac{\partial q_y}{\partial t}+\frac{\partial u q_y}{\partial x}+\frac{\partial v q_y}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{\tau_y}{\rho_w} \quad (3)$$

where h is the height of water from the local surface, q_x and q_y are the unit width discharges in x and y directions, u and v are the flow velocities in x and y directions, r is the rainfall intensity, f is the infiltration rate, H is the height of water from the datum, ρ_w is the density of water, g is the gravitational acceleration, and τ_x and τ_y are the shear stresses in x and y directions. The second terms of the right side of (2) and (3) are calculated with the Manning's equation.

$$\frac{\tau_x}{\rho_w}=\frac{gn^2u\sqrt{u^2+v^2}}{h^{1/3}} \quad (4)$$

$$\frac{\tau_y}{\rho_w}=\frac{gn^2v\sqrt{u^2+v^2}}{h^{1/3}} \quad (5)$$

where n is the Manning's roughness parameter.

Under the diffusion wave approximation, inertia terms (the left side terms of (2) and (3)) are neglected. Moreover, by separating x and y directions (i.e. ignoring v and u terms in equations (2) and (3) respectively), the following equations are derived:

$$q_x=-\frac{1}{n}h^{5/3}\sqrt{\left|\frac{\partial H}{\partial x}\right|}\,\mathrm{sgn}\left(\frac{\partial H}{\partial x}\right) \quad (6)$$

$$q_y = -\frac{1}{n} h^{5/3} \sqrt{\left|\frac{\partial H}{\partial y}\right|} \operatorname{sgn}\left(\frac{\partial H}{\partial y}\right) \quad (7)$$

where sgn is the signum function.

The RRI model spatially discretizes mass balance equation (1) as follows:

$$\frac{dh^{i,j}}{dt} + \frac{q_x^{i,j-1} - q_x^{i,j}}{\Delta x} + \frac{q_y^{i-1,j} - q_y^{i,j}}{\Delta y} = r^{i,j} - f^{i,j} \quad (8)$$

where $q_x^{i,j}$, $q_y^{i,j}$ are x and y direction discharges from a grid cell at (i, j).

By combining the equations of (6), (7) and (8), water depths and discharges are calculated at each grid cell for each time step. One important difference between the RRI model and other inundation models is that the former uses different forms of the discharge-hydraulic gradient relationship, so that it can simulate both surface and subsurface flows with the same algorithm. The RRI model replaces the equations (6) and (7) with the following equations of (9) and (10), which were originally conceptualized by Ishihara and Takasao (1962) and formulated with a single variable by Takasao and Shiiba (1976, 1988) based on kinematic wave approximations. The first equations in (9) and (10) ($h \le d_a$) describe the saturated subsurface flow based on the Darcy law, while the second equations ($d_a \le h$) describe the combination of the saturated subsurface flow and the surface flow. Note that for the kinematic wave model, the hydraulic gradient is assumed to be equal to the topographic slope, whereas the RRI model assumes the water surface slope as the hydraulic gradient.

$$q_x = \begin{cases} -k_a h \dfrac{\partial H}{\partial x}, & (h \le d_a) \\ -\dfrac{1}{n}(h - d_a)^{5/3} \sqrt{\left|\dfrac{\partial H}{\partial x}\right|} \operatorname{sgn}\left(\dfrac{\partial H}{\partial x}\right) - k_a h \dfrac{\partial H}{\partial x}, & (d_a < h) \end{cases} \quad (9)$$

$$q_y = \begin{cases} -k_a h \dfrac{\partial H}{\partial y}, & (h \le d_a) \\ -\dfrac{1}{n}(h - d_a)^{5/3} \sqrt{\left|\dfrac{\partial H}{\partial y}\right|} \operatorname{sgn}\left(\dfrac{\partial H}{\partial y}\right) - k_a h \dfrac{\partial H}{\partial y}, & (d_a < h) \end{cases} \quad (10)$$

where k_a is the lateral saturated hydraulic conductivity and d_a is the soil depth times the effective porosity.

Equations (11) and (12) can be also used to simulate the effect of unsaturated, saturated subsurface flow and surface flow with the single variable of h (Tachikawa et al. 2004, Sayama and McDonnell 2009 for English).

$$q_x = \begin{cases} -k_m d_m \left(\frac{h}{d_m}\right)^{\beta} \frac{\partial H}{\partial x}, & (h \le d_m) \\ -k_a (h-d_m) \frac{\partial H}{\partial x} - k_m d_m \frac{\partial H}{\partial x}, & (d_m < h \le d_a) \\ -\frac{1}{n}(h-d_a)^{5/3} \sqrt{\left|\frac{\partial H}{\partial x}\right|} \operatorname{sgn}\left(\frac{\partial H}{\partial x}\right) - k_a (h-d_m)\frac{\partial H}{\partial x} - k_m d_m \frac{\partial H}{\partial x}, & (d_a < h) \end{cases} \quad (11)$$

$$q_y = \begin{cases} -k_m d_m \left(\frac{h}{d_m}\right)^{\beta} \frac{\partial H}{\partial y}, & (h \le d_m) \\ -k_a (h-d_m) \frac{\partial H}{\partial y} - k_m d_m \frac{\partial H}{\partial y}, & (d_m < h \le d_a) \\ -\frac{1}{n}(h-d_a)^{5/3} \sqrt{\left|\frac{\partial H}{\partial y}\right|} \operatorname{sgn}\left(\frac{\partial H}{\partial y}\right) - k_a (h-d_m)\frac{\partial H}{\partial y} - k_m d_m \frac{\partial H}{\partial y}, & (d_a < h) \end{cases} \quad (12)$$

Note that to assure the continuity of the discharge change when $h = d_m$, the lateral hydraulic conductivity in unsaturated zone (k_m) can be computed by $k_m = k_a / \beta$, so that k_m is no longer the model parameter.

These stage-discharge relationship equations were originally developed to be applied to humid forest areas with a high permeable soil layer, where a lateral subsurface flow is the dominant runoff generation mechanism. On the other hand, for relatively flat areas, the vertical infiltration process during the first period of rainfall has more impact on large-scale flooding; therefore, the vertical infiltration can be treated as loss for event-based simulation. Here we calculate infiltration loss f with the Green-Ampt infiltration model (Raws et al., 1992).

$$f = k_v \left[1 + \frac{(\phi - \theta_i) S_f}{F} \right] \quad (13)$$

where k_v is the vertical saturated hydraulic conductivity, ϕ is the soil porosity, θ_i is the initial water volume content, S_f is the suction at the vertical wetting front and F is the cumulative infiltration depth.

Typically for mountainous areas where lateral subsurface flow and saturated excess overland flow dominate, the equations (9) and (10) (or (11) and (12)) can be used with setting f equals to be zero. (Note that the equations (9) and (10) (or (11) and (12)) implicitly assume that the vertical infiltration rate within the soil is infinity.) On the other hand, for plain areas where infiltration excess overland flow dominates, the surface flow equations (6) and (7) can be used with the consideration of vertical infiltration by equation (13). If the vertical infiltration f is set to be non-zero and the lateral subsurface equations are used instead of the surface flow equation, the lateral subsurface water is infiltrated to bedrock by the rate of f.

As one can see from the equations, the parameter values of k_a, k_m and k_v decide which equations to be used; i.e. (6) and (7) are used when k_a and k_m are zero, (9) and (10) are used when k_m is zero, and (13) is inactivated when k_v is zero.

1.3 One-dimensional River Routing Model

A one-dimensional diffusive wave model is applied to river grid cells. The geometry is assumed to be rectangle, whose shapes are defined by width W, depth D and embankment height H_e. When detailed geometry information is not available, the width and depth are approximated by the following function of upstream contributing area A [km^2].

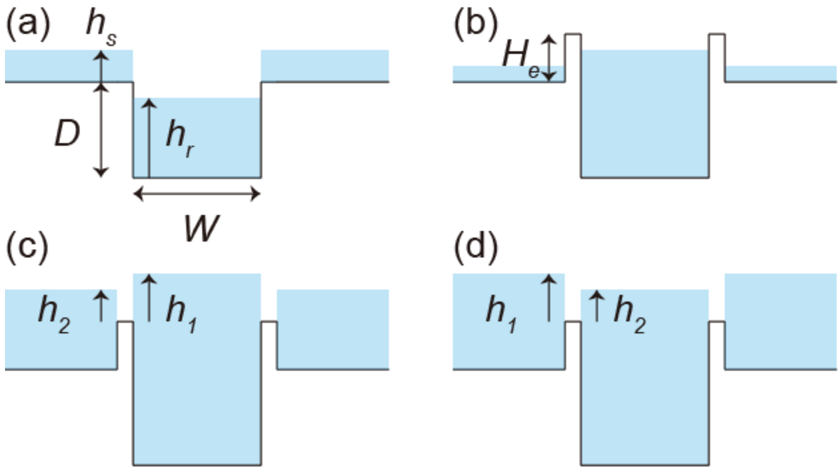
$$W = C_W A^{S_W} \quad (14)$$

$$D = C_D A^{S_D} \quad (15)$$

where C_W, S_W, C_D and S_D are geometry parameters. Here the units of W and D are meters.

1.4 River and Slope Water Exchange

Water exchange between a slope grid cell and an overlying river grid cell is calculated at each time step depending on the relationship among the levels of slope water, river water, levee crown and ground. The figure below shows four different conditions. For each condition, different overtopping formulae are applied to calculate the unit length discharge from slope to river (q_{sr}) or from river to slope (q_{rs}), which are then multiplied by the length of the river vector at each grid cell to calculate the total exchange flow rate (Iwasa and Inoue, 1982).



(a) When the river water level is lower than the ground level, q_{sr} is calculated by the following step fall formula.

$$q_{sr} = \mu_1 h_s \sqrt{g h_s} \quad (16)$$

where μ_1 is the constant coefficient (=$(2/3)^{3/2}$), and h_s is the water depth on a slope cell. As far as the river water level is lower than the ground level, the same equation is used even for the case with levees so that the slope water can flow into the river.

(b) When the river water level is higher than the ground level and both the river and slope water levels are lower than the levee height, no water exchange is assumed between the slope and river.

(c) When the river water level is higher than the levee crown and the slope water level, the following formula is used to calculate overtopping flow q_{rs} from river to slope.

$$q_{rs} = \begin{cases} \mu_2 h_1 \sqrt{2 g h_1} & h_2 / h_1 \le 2/3 \\ \mu_3 h_2 \sqrt{2g(h_1 - h_2)} & h_2 / h_1 > 2/3 \end{cases} \quad (17)$$

where μ_2 and μ_3 are the constant coefficients (=0.35, 0.91), and h_1 is the difference between the river water level and the levee crown.

(d) When the slope water level is higher than the levee height and the river water level, the same formula as (17) is used to calculate overtopping flow q_{sr} from slope to river. In this case, h_1 is the elevation difference between the slope and the river, and h_2 is the elevation difference between the river and the levee crown.

1.5 Numerical Scheme

To solve equations (8), (9) and (10), the fifth-order Runge-Kutta method with adaptive

time-step control is applied. This method solves an ordinary differential equation by the general fifth-order Runge-Kutta formula and estimates its error by an embedded forth-order formula to control the time-step (Cash and Karp 1990, Press et al. 1992).
The general form of the fifth-order Runge-Kutta formula is

$$
\begin{aligned}
k_1 &= \Delta t f\left(t, h_t\right) \\
k_2 &= \Delta t f\left(t + a_2 \Delta t, h_t + b_{21} k_1\right) \\
&\cdots \\
k_6 &= \Delta t f\left(t + a_6 \Delta t, h_t + b_{61} k_1 + \cdots b_{65} k_5\right) \\
h_{t+1} &= h_t + c_1 k_1 + c_2 k_2 + c_3 k_3 + c_4 k_4 + c_5 k_5 + c_6 k_6 + O\left(\Delta t^6\right)
\end{aligned} \quad (18)
$$

while the embedded forth-order formula (Cash and Karp 1990) is

$$h^*_{t+1} = h_t + c^*_1 k_1 + c^*_2 k_2 + c^*_3 k_3 + c^*_4 k_4 + c^*_5 k_5 + c^*_6 k_6 + O\left(\Delta_t^{\ 5}\right) \quad (19)$$

By subtracting h_{t+1} minus h^*_{t+1}, the error can be estimated by using k_1 to k_6 as follows,

$$\delta \equiv h_{t+1} - h^*_t = \sum_{i=1}^{6} \left(c_i - c^*_i\right) k_i \quad (20)$$

The constant values (a_i, b_{ij}, c_i, c_i^*) used in this study are the ones introduced by Cash and Karp (1990). If δ exceeds a desired accuracy δ_d, h_{t+1} is recalculated with a smaller time step (Δt_{post}).

$$\Delta t_{post} = \max\left(0.9\Delta t \left|\frac{\delta_d}{\delta}\right|^{0.25}, 0.5\Delta t\right) \quad (21)$$

As described above, the RRI model calculates slopes, rivers and slope-river interactions. Model users specify the time step for slope-river interaction Δt, which is also used as an initial time step for slope calculations. Since river calculations usually require smaller time steps because of higher water velocities and depths, the model allows river calculations to proceed independently with different time steps until the next river-slope calculation time step. The initial time step for river calculation (Δt_r) can be also specified by model users as the common divisor of Δt. In this study, $\delta_d = 0.01$, $\Delta t = 600$ sec. and $\Delta t_r = 60$ sec. were used.

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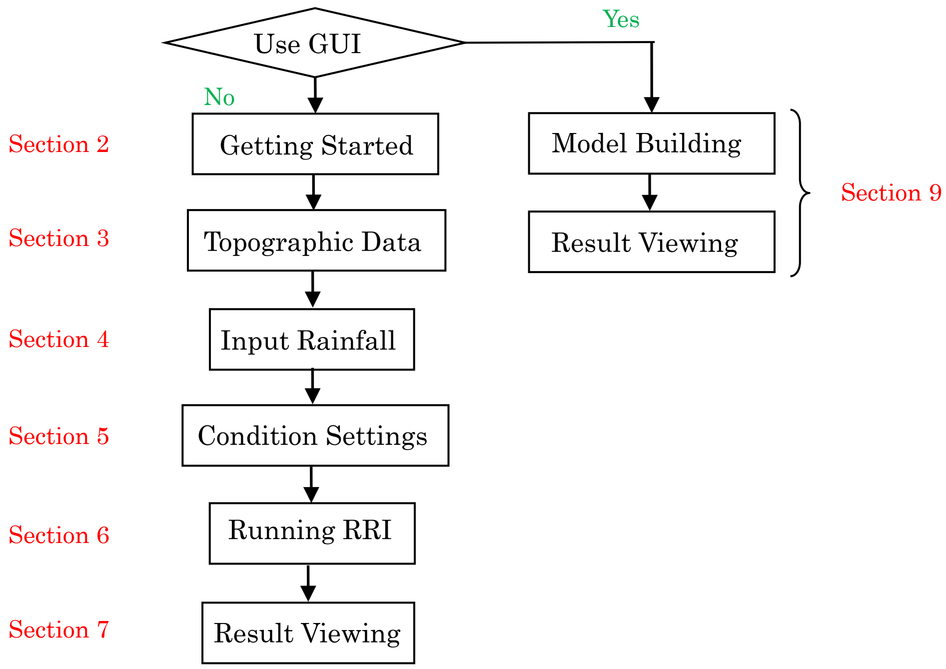
2. Getting Started

RRI model and related tools were originally developed with Fortran 90 computer language. The model has been operated on Command User Interface (CUI) such as Command Prompt on Windows. Since 2014, RRI-Graphical User Interface (GUI) has been also developed to support users for efficient model building and result visualization.

For non-experts in hydrologic modeling, it is recommended to use RRI-GUI to begin with by referring to Section 9 to learn the basic steps with RRI-GUI.

Refer to Section 2 (i.e. this following chapter) on the tutorial of RRI-CUI, followed by more detail descriptions in Sections 3 to 7. Section 8 shows an application example including some advanced model settings.

If you use RRI-GUI not RRI-CUI, you can skip the following steps. Go directly to Section 9.



There are essentially five steps to conduct RRI Model simulation.

1. Preparing topography data (Section 3)
2. Preparing input rainfall data (Section 4)
3. Preparing model condition files with parameter settings (Section 5)
4. Executing RRI Model. (Section 6)
5. Plotting output data (Section 7)

Among the five steps, only the essence of step 4 and 5 are described here with sample data of the Solo River Basin (in 30 sec resolution) in Indonesia.

2.1 Preparation for the use of RRI-CUI

1) Unzip "RRI_1.4.2.zip" and move it under a working directory (e.g. C:\).

2) Add a path to RRI-CUI folder with the following steps (e.g. for Windows 7)

1. Select Computer from the Start menu
2. Choose System Properties from the context menu
3. Click Advanced system settings → Advanced tab
4. Click on Environment Variables, under User's Variables, find **PATH**, and click to edit it. If you do not have the item PATH, you may select to add a new variable and add PATH as the name.
5. In the Edit windows, modify **PATH** by adding ";C:/RRI/RRI-CUI/bin/" (for 64 bit) or ";C:/RRI/RRI-CUI/bin32/" (for 32 bit) at the end of line.

   Note: do not delete existing PATH settings. Only add the above item to the existing line. Also do not forget to add ";" to separate it from the existing path folders.
6. Click OK and close Command Prompt windows if opened.

3) If your computer has no Intel Fortran installed, run
RRI/RRI-CUI/etc/w-fcompxe/w_fcompxe_redist_intel64_2013.5.198.msi (for 64 bit) or
RRI/RRI-CUI/etc/w-fcompxe/w_fcompxe_redist_ia32_2013.5.198.msi (for 32 bit),
which installs necessary library files to execute RRI programs compiled by Intel Fortran.

4) Open Command Prompt by Start → All Programs → Accessories → Command Prompt
(If your computer has Intel Fortran installed, you may also operate it from Start → All Programs → Intel(R) Software Development Tools → Intel(R) Fortran Compiler ** → Fortran Build Environment for Applications running on …)

2.2 Run RRI Model

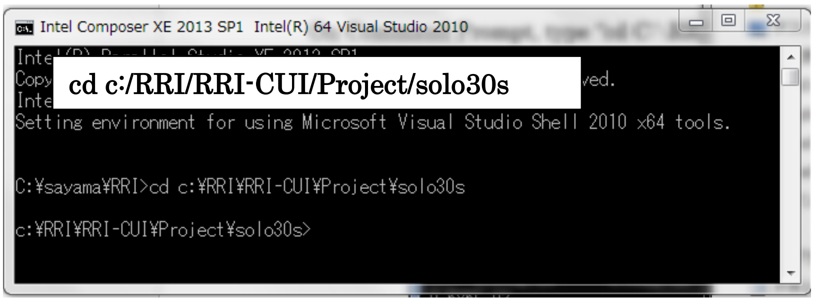
Open "RRI_Input.txt" under "RRI-CUI/Project/solo30s" with a text editor and look inside the file. This is a control file used by RRI Model. By editing the RRI_Input.txt file, you change the simulation settings.

RRI_Input.txt

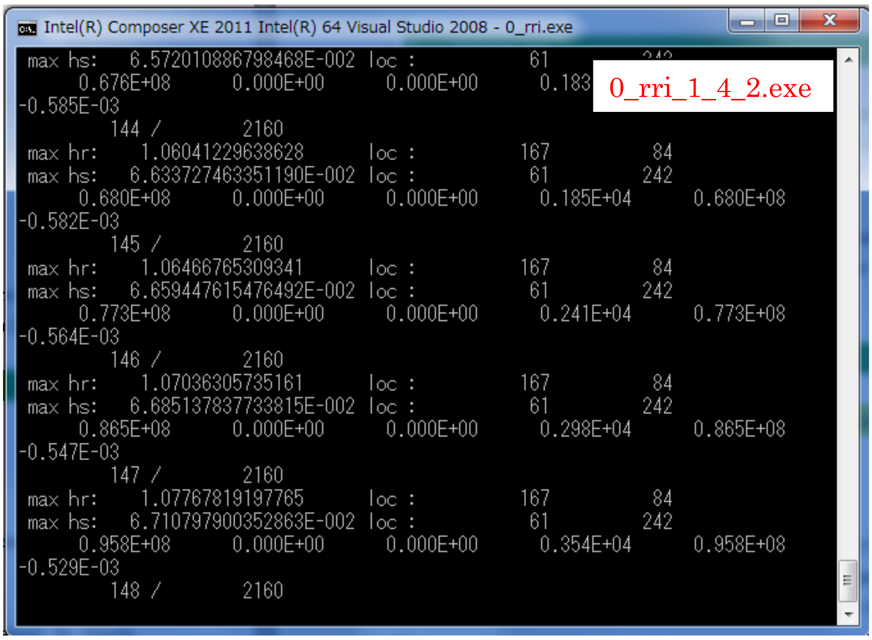
```
RRI_Input_Format_Ver1_4_2

./rain/rain.dat
./topo/adem.txt
./topo/acc.txt
./topo/adir.txt

0                # utm(1) or latlon(0)
1                # 4-direction (0), 8-direction(1)
360              # lasth [hour]
600              # dt [sec]
```

For example, L3 specifies the path to an input rainfall file and L4 – L6 specify the paths to input topography files (adem, acc, and adir).

Open Command Prompt and type in "cd C:/RRI/RRI-GUI/Project/solo30s/" to change the current directly.



Type in "0_rri_1_4_2.exe" and enter to execute RRI Model with RRI_Input.txt.



Confirm the output files are successfully created inside the directory of "RRI/RRI-CUI/Project/solo30s/out/". Note that "**hr_000001.out**" represents the spatial distribution of **river water depths [m]** at the output time step 1. "**hs_000001.out**" and "**qr_000001.out**" represent those of **slope water depths [m]** and **river discharge [m³/s]**, respectively.

2.3 Post Analysis

2.3.1 Visualize Inundation Depth (./out/hs_***.out) with GNUPLOT

Run a GNUPLOT installation program "RRI-CUI/etc/gp466-win32-setup.exe" and install it onto your PC. If the installation is successful, "gnuplot" folder is appeared under All Programs of windows. Choose "gnuplot 4.6" to run GNUPLOT.

Open "RRI-CUI/Model/hs.plt" with a text editor. It is a GNUPLOT script file to convert from the simulation outputs (e.g. ./out/hs_***.out) to gif files to visualize inundation depth distributions.

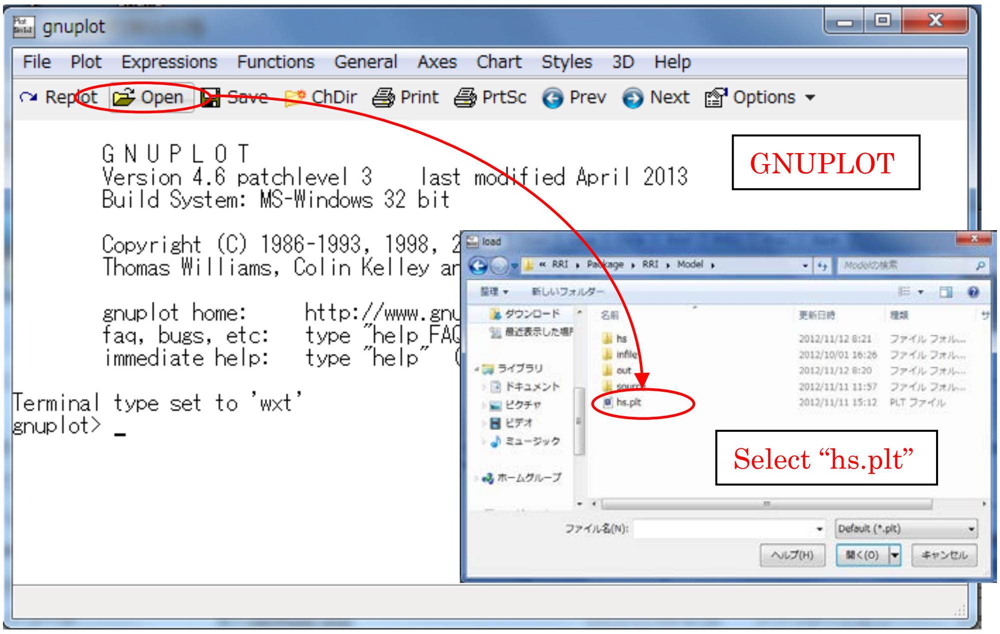
hs_plt.txt

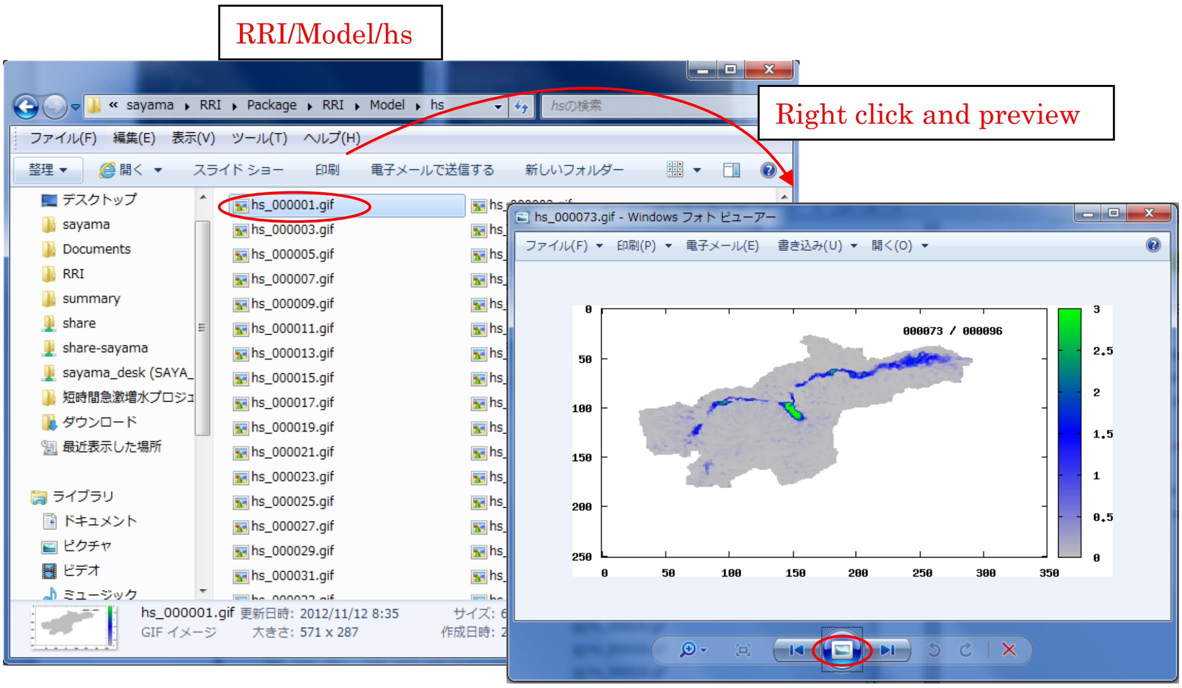
```
reset

set terminal gif medium size 672, 408 crop

set pm3d map
set palette defined (0.0 "gray", 1.5 "blue", 3 "green")

set xrange [0:]
set yrange [:] reverse
set zrange [0:] reverse

#set xrange [180:200]
#set yrange [435:455] reverse

set cbrange[0.:3]
set zrange[0.0:]

set output "./hs/hs_000001.gif"
splot "./out/hs_000001.out" matrix t "000001 / 000096"

set output "./hs/hs_000002.gif"
splot "./out/hs_000002.out" matrix t "000002 / 000096"

set output "./hs/hs_000003.gif"
splot "./out/hs_000003.out" matrix t "000003 / 000096"
```

From RRI output (hs_***.out) to gif

Select "Open" on GNUPLOT Toolbar and open "RRI-CUI/Project/solo30s/hs.plt", which is a script file to create gif files from the RRI output (see above figure).

Look at "RRI-CUI/Project/solo30s/hs" directory, where gif files are newly created. Check the created gif files by preview.





2.3.2 Compute hydrograph

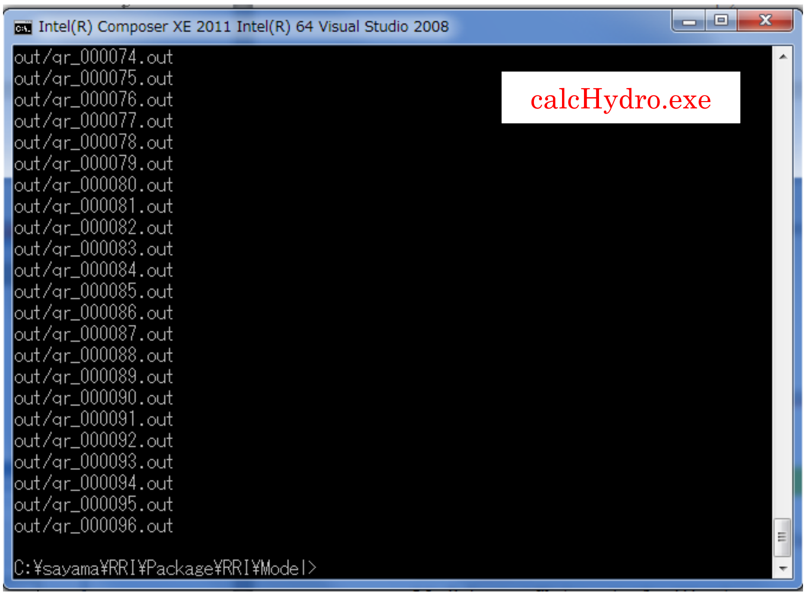
Look at "RRI/RRI-CUI/Project/solo30s/calcHydro.txt" (see "./etc/calcHydro/00_readme.txt" for more details)

L1 : [In] location file (e.g. ./location.txt)

L2 : [In] RRI output file (e.g. ./out/qr_***.txt)

L3 : [Out] hydrograph file (e.g. ./disc_Cepu.txt)

On Command Prompt with current folder at "./Project/solo30s/", type in "calcHydro.exe" to compute time series data from RRI output files.



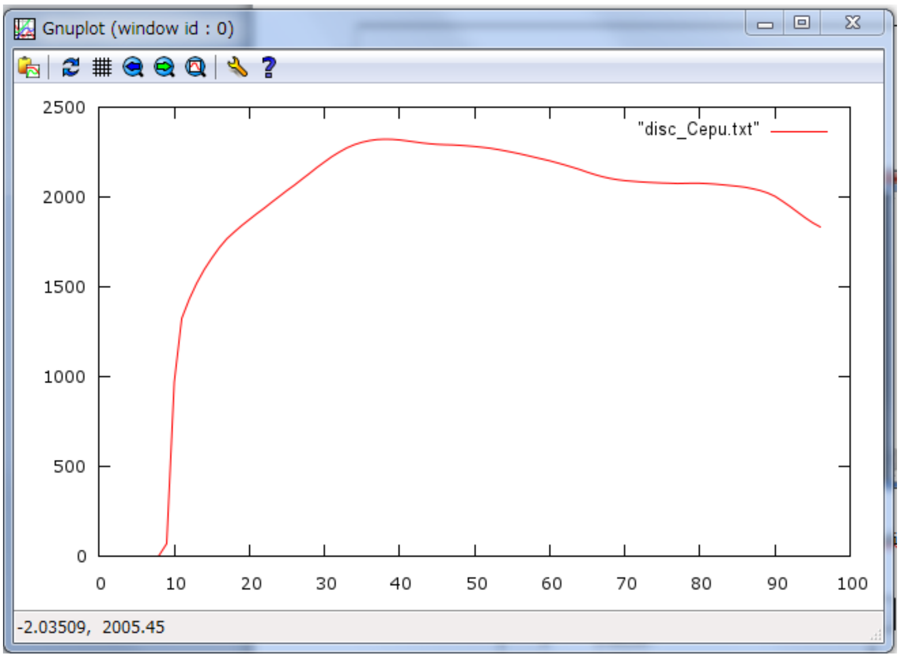
Confirm that a hydrograph file named "disc_Cepu.txt" is created.

disc_cepu.txt

1	0.00789
2	0.04591
3	0.08256
4	0.10557
5	0.12529
6	0.14543
7	0.24838
8	0.56375
9	69.88281
10	967.36834
11	1322.37727
12	1429.53330
13	1518.85970
.....	......

Visualize the created hydrograph file (e.g. "./infile/solo30s/disc_Cepu.txt") by GNUPLOT.

From GNUPLOT screen, open and select "hydro.plt", which is a GNUPLOT script file to plot hydrograph from the "disc_Cepu.txt".



2.3.3 Compute and visualize peak inundation depths

Look at "./Project/solo30s/calcPeak.txt" (see "./etc/calcPeak/00_readme.txt" for more details) and edit the file if necessary.

L1 : [in] dem file (e.g. ./topo/adem.txt)

L2 : [in] output file without numbers or extension (e.g. ./out/hs_)

L3 : [in] the number of output files (e.g. 96)

L4 : [out] output peak inundation depth file (e.g. ./hpeak.txt)

On Command Prompt with current folder at "RRI/Project/solo30s/", type in "calcPeak.exe" to compute peak inundation depth.

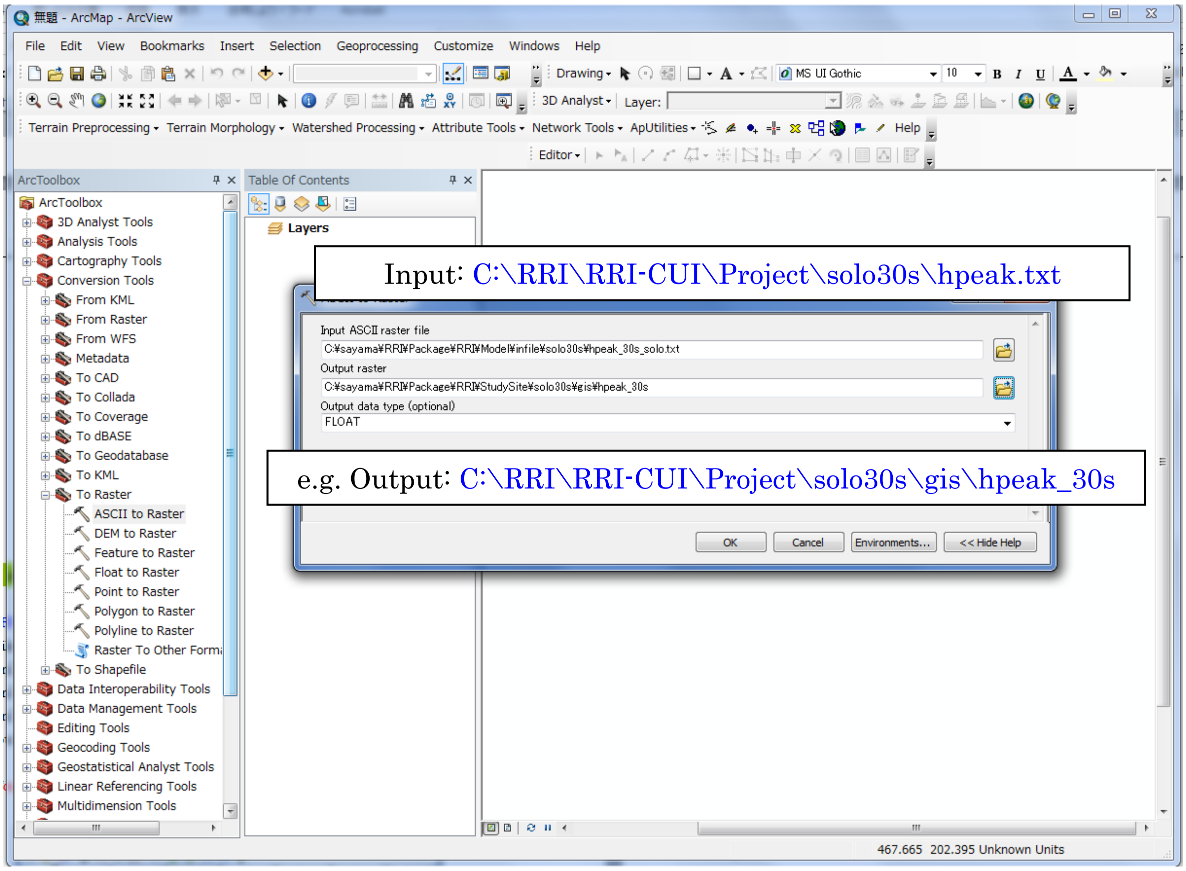
```
ncols         336
nrows          204
xllcorner     110.2
yllcorner     -8.3
cellsize      0.00833333333333
NODATA_value  -9999
 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
```

hpeak.txt

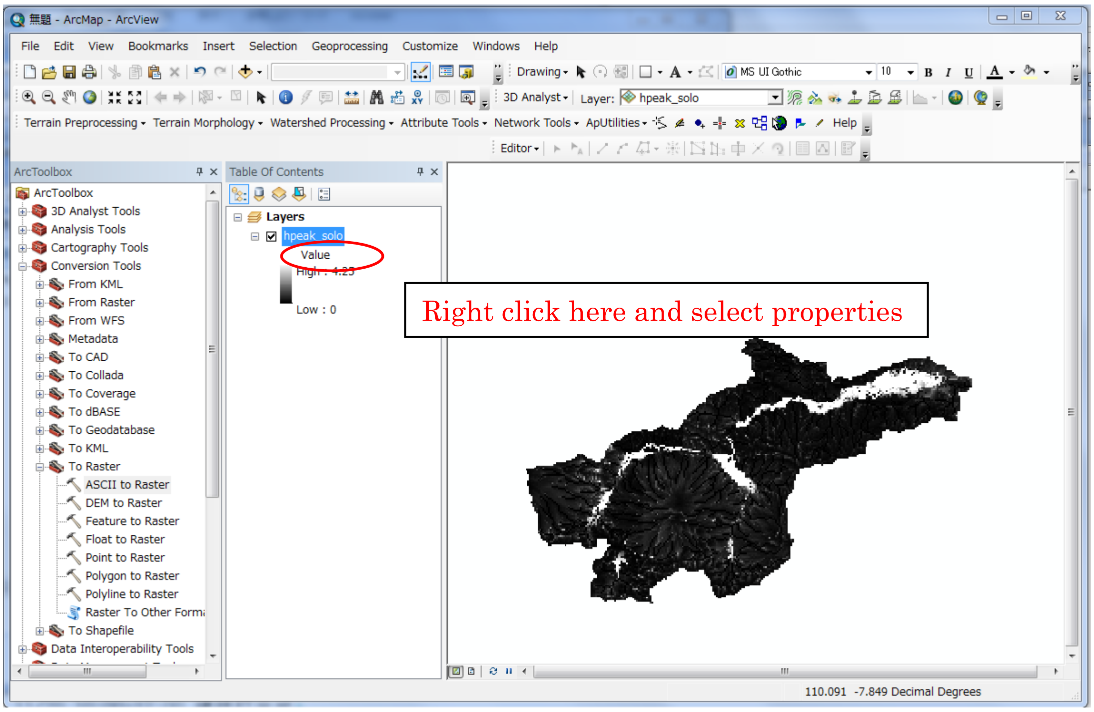
Visualize created “hpeak.txt” on ArcGIS by converting it from ASCII to Raster.

1) Start ArcGIS (Skip the following procedure if ArcGIS softwre is inaccessible. Consider the use of GRASS GIS by following the instruction in 3.3)

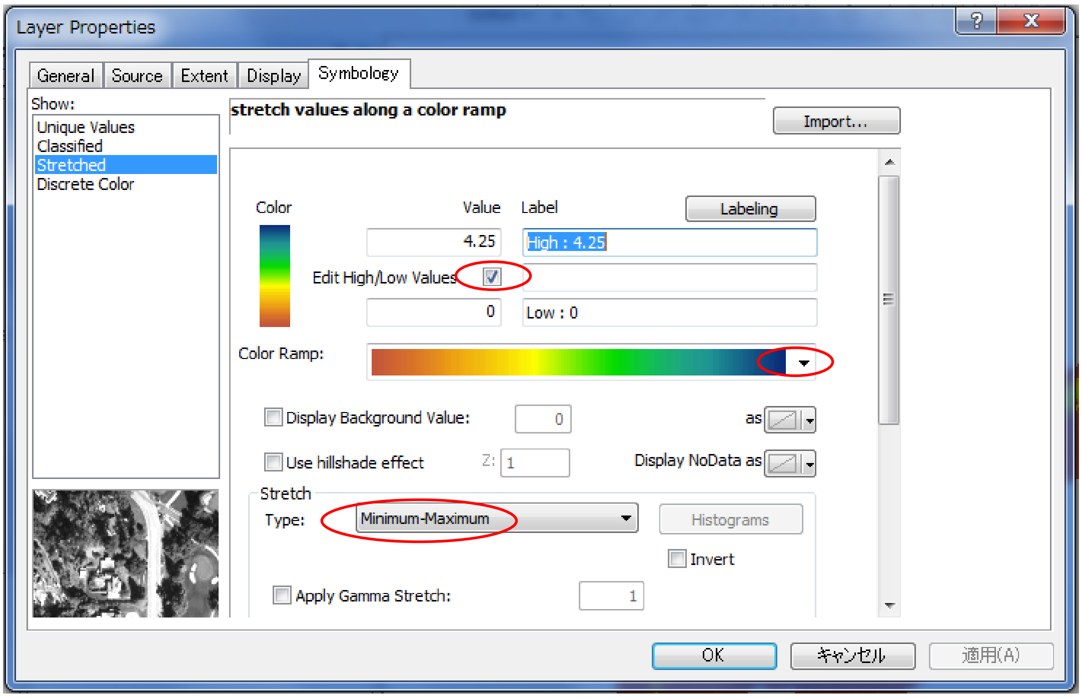
2) From ArcToolbox → [Conversion Tools] → [To Raster] → [ASCII to Raster]



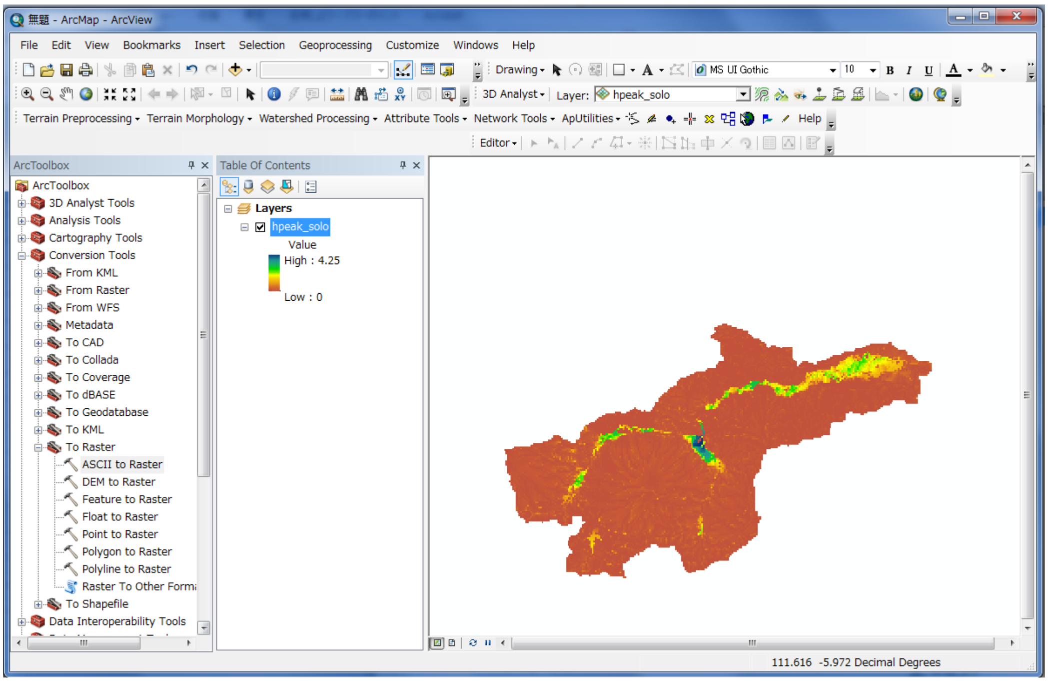
3) For the input data, select “hpeak.txt”. For the output raster, a user may use “RRI/StudySite/solo30s/gis/hpeak_30s”.



4) Right click “hpeak_30s” and select properties to change the layer color setting.



5) On the layer property, change the stretch type to “Minimum-Maximum” and change Color Ramp if necessary. By checking “Edit High/Low Values”, you can change the max and min value range of the stretching.


無題 - ArcMap - ArcView
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
Terrain Preprocessing Terrain Morphology Watershed Processing Attribute Tools Network Tools ApUtilities Help
3D Analyst
Layer: hpeak_solo
ArcToolbox
3D Analyst Tools
Analysis Tools
Cartography Tools
Conversion Tools
From KML
From Raster
From WFS
Metadata
To CAD
To Collada
To Coverage
To dBASE
To Geodatabase
To KML
To Raster
ASCII to Raster
DEM to Raster
Feature to Raster
Float to Raster
Point to Raster
Polygon to Raster
Polyline to Raster
Raster To Other Form
To Shapefile
Data Interoperability Tools
Table Of Contents
Layers
hpeak_solo
Value
High : 4.25
Low : 0
111.616 -5.972 Decimal Degrees

3. Preparing Input Topography Data

This section shows the method to prepare topography data input to the RRI Model. The topography data can be prepared by a user or downloaded from the website of USGS HydroSHEDS, which is a global scale dataset offered by the United States Geological Survey (USGS). The dataset includes elevation, flow direction and flow accumulation.

From the downloaded topographic dataset, a user must clip out the target river basin and save them as ESRI/ASCII format files. Then using a program included in RRI Model package, one adjusts the original DEM and flow direction data to be suitable for the RRI simulation. The following chart shows the procedure descried in this section. In the previous section, the 30 second resolution of the Solo River Basin data was used, whereas this section presents how to prepare the topographic data in 15 second.

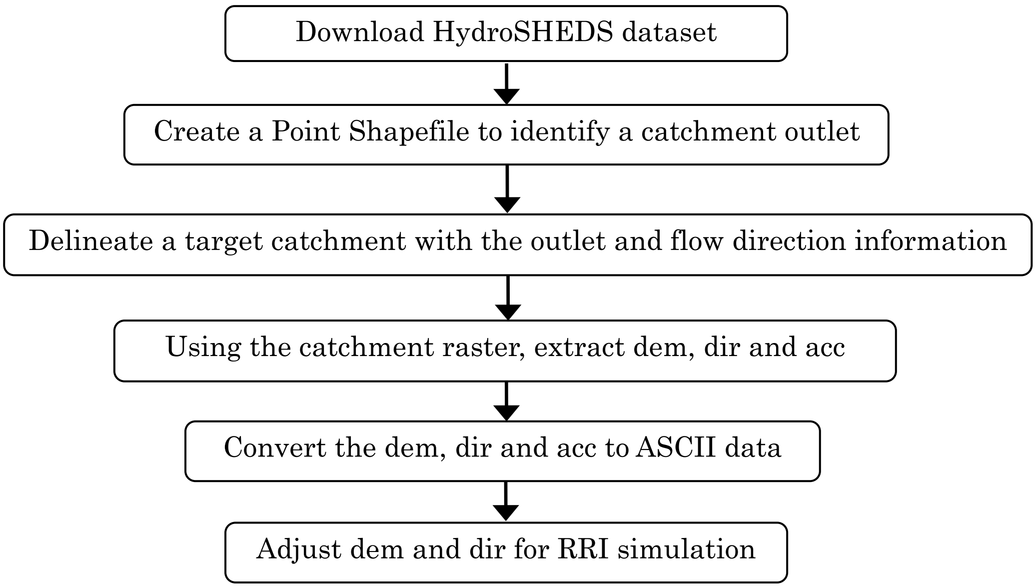
Create a New Project Folder

When you prepare a new input topographic data, create a new project folder:

Copy "newProject" folder including all the files and folders inside and save it with a new project name under "RRI-CUI/Project/".

Note: In the package, "RRI-CUI /Project/solo15s" is prepared in advance for the tutorial.

The flow of the procedure is as follows.



3.1 Downloading HydroSHEDS Data

The following three types of topography data must be downloaded from HydroSHEDS website for RRI simulation.

1) Elevation data

3 arc-second (about 90 m), 15 arc-second (about 500 m), and 30 arc-second (about 1,000 m) are available.

2) Flow direction data

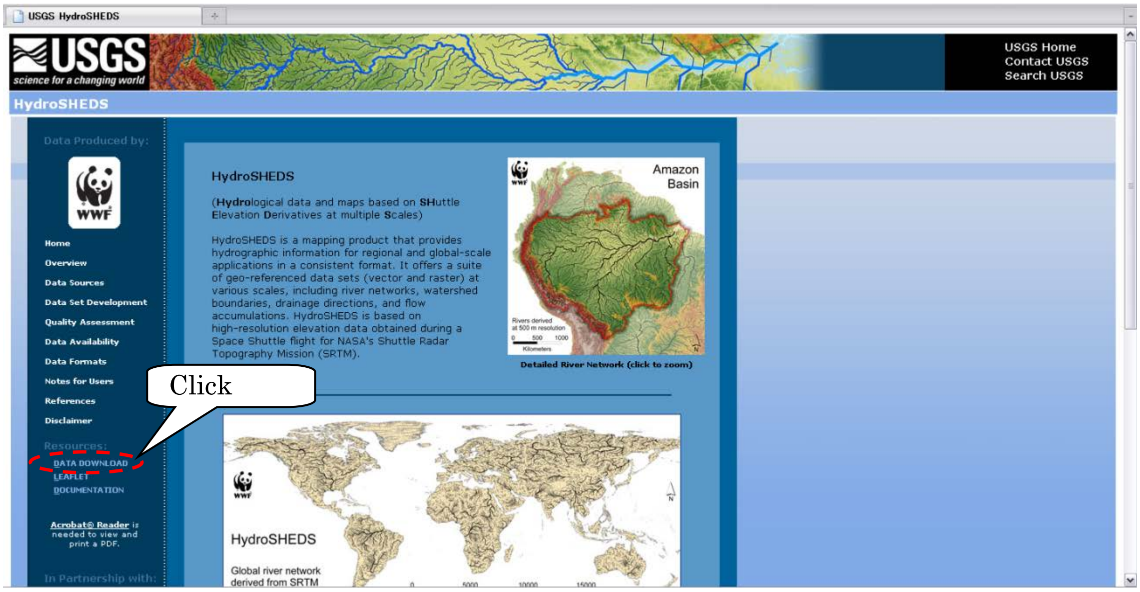
3 arc-second, 15 arc-second, and 30 arc-second are available.

3) Flow accumulation data

Only 15 arc-second and 30 arc-second are available. For 3 arc-second resolution, a user must prepare a flow accumulation by using a GIS function [Spatial Analyst] → [Hydrology] → [Flow Accumulation].

※ For detailed specifications of HydroSHEDS, refer to HydroSHEDS Technical Documentation packaged with the downloaded data.

① Access USGS HydroSHEDS website (http://hydrosheds.cr.usgs.gov/index.php) from a web browser and then select and click the DATADOWNLOAD button on the lower left.



② Select “15sec GRID: Conditioned DEM” and download “as_dem_15s_grid.zip” (207 MB) for Asian region with 15 sec grid-size. NOTE that for 3 sec, choose “Void-filled DEM”. For 15 sec and 30 sec, only “Conditioned DEM” is available, but in fact they are the same as previously named as “Void-filled DEM” (i.e. DEM along rivers are **not** deepened).

③ Select also “15 sec GRID: Flow Accumulation” and “15 sec Flow Direction” to download “as_acc_15s_grid.zip” (132 MB) and “as_dir_15s_grid.zip” (64 MB) as well.

④ Unzip the three types of topography data downloaded.

※Folder naming rule

“Continental range” _ ”Data type” _ “resolution”

e.g.) as_acc_15s → Asia catchment area data 15 sec

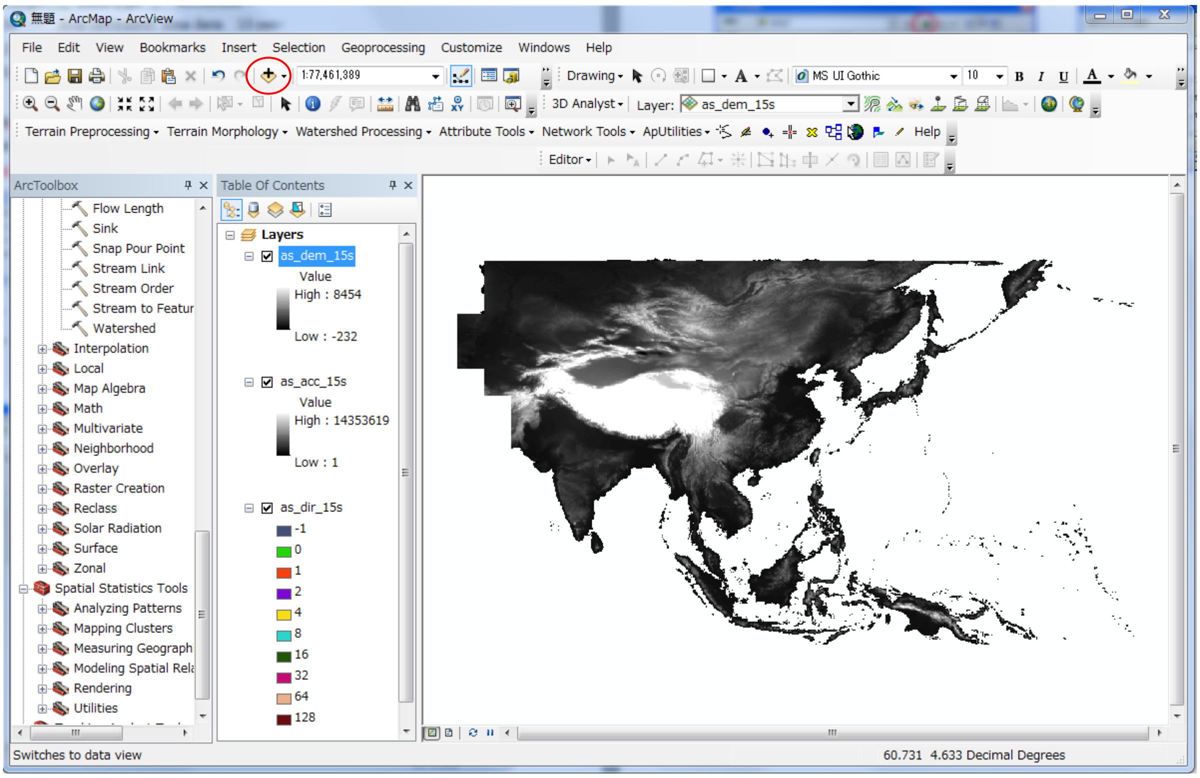
as_dem_15s → Asia digital elevation data 15 sec

as_dir_15s → Asia flow direction data 15 sec

3.2 Delineating HydroSHEDS Data using ArcGIS

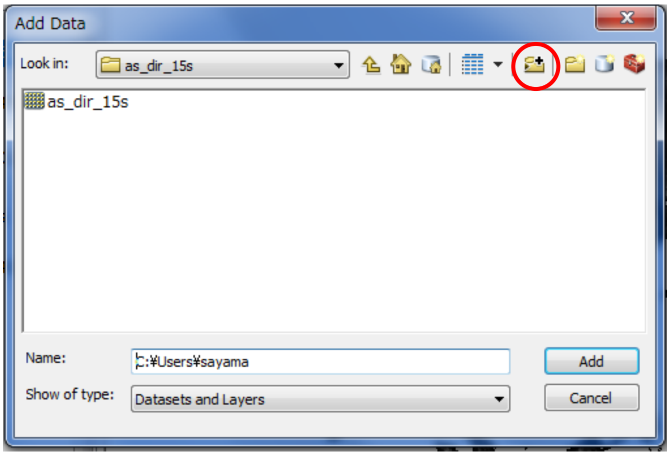
(If ArcGIS is inaccessible, skip this section and go to 3.3 to use free GLASS GIS)

① Start ArcMap, and read in the unzipped files by selecting [File]>[Add Data]. (Or use icon of “Add Data” on the standard tool bar). Perform the same operation for all the three types (dem, dir, acc) of topography data.

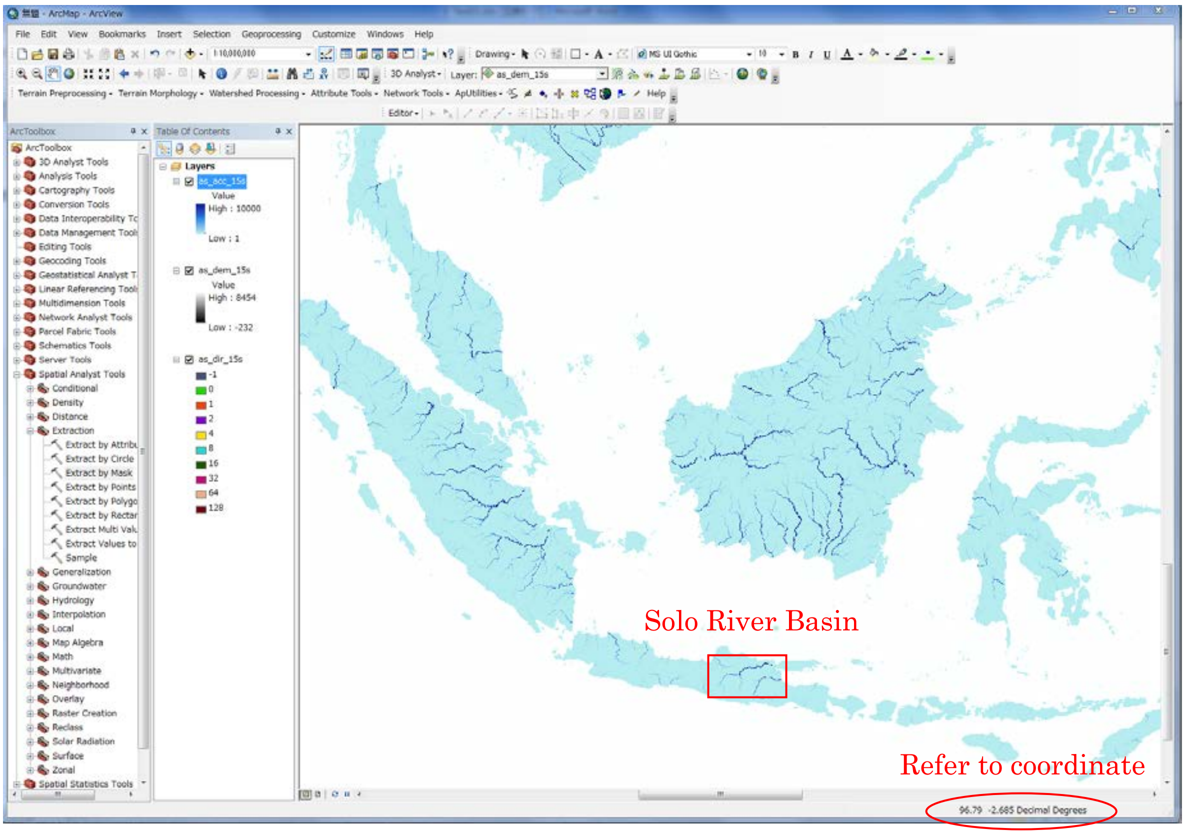


※Selecting the folder to connect

If the folder you need to connect is not displayed in the window, click “Connect to Folder” to connect to the working folder.



③ Display the flow accumulation data (i.e. as_acc_15s) on top screen (change the color range to show river network clearly). Then find your target river and decide the rectangular range, which covers all upstream contributing area. (At this stage, the following rectangle range should be just written down on your notebook and no operation is necessary with GIS.)



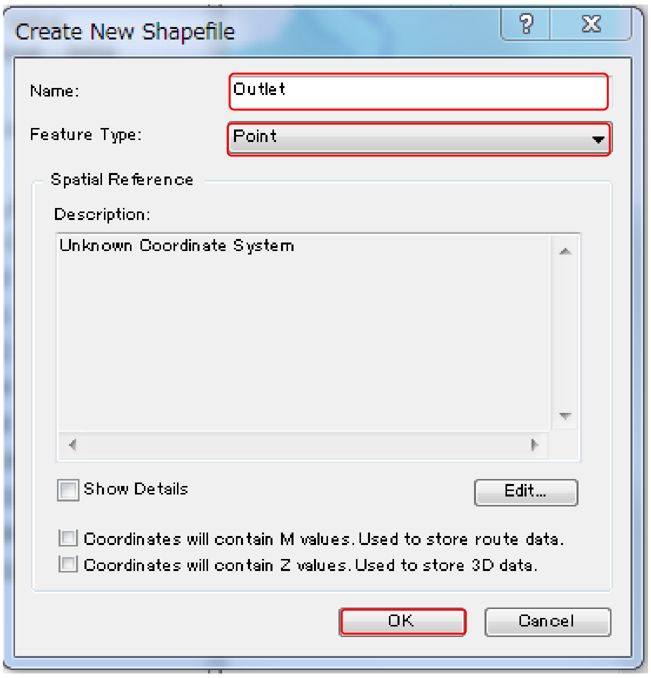
-6.6

110.2 e.g.) Solo River 113.0

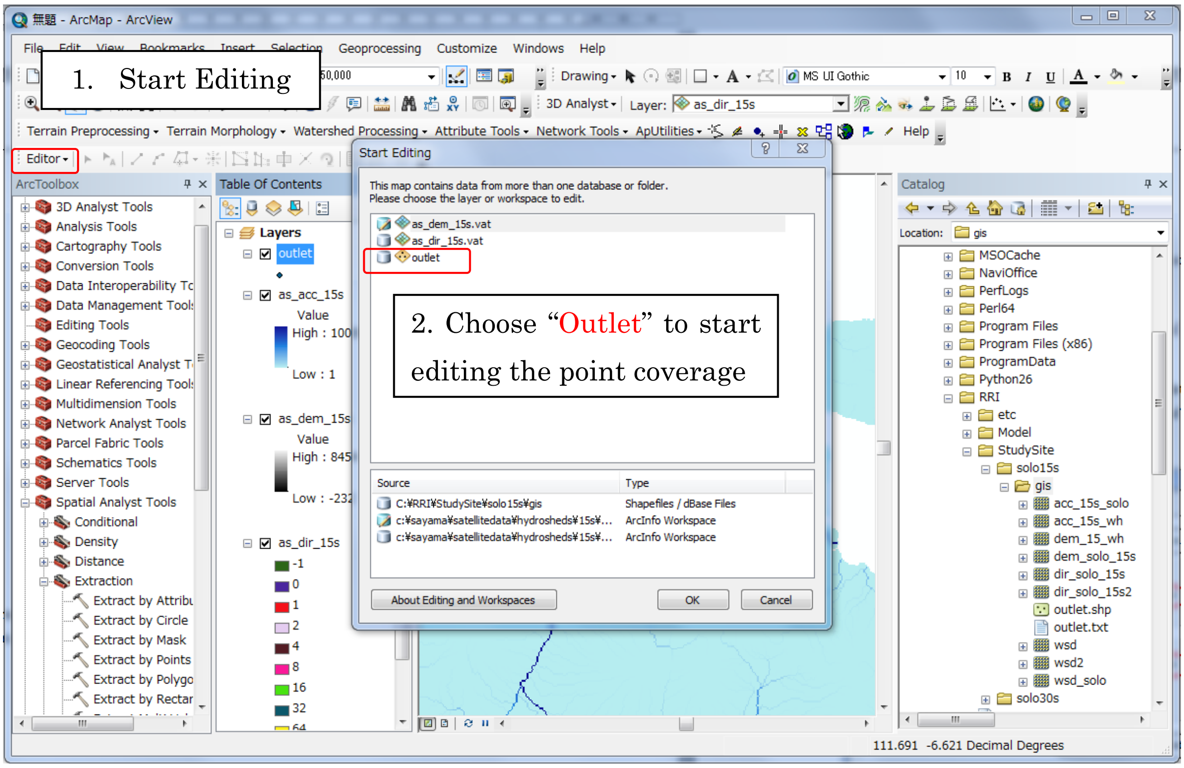
-8.3

(The range should be written down on your notebook.)

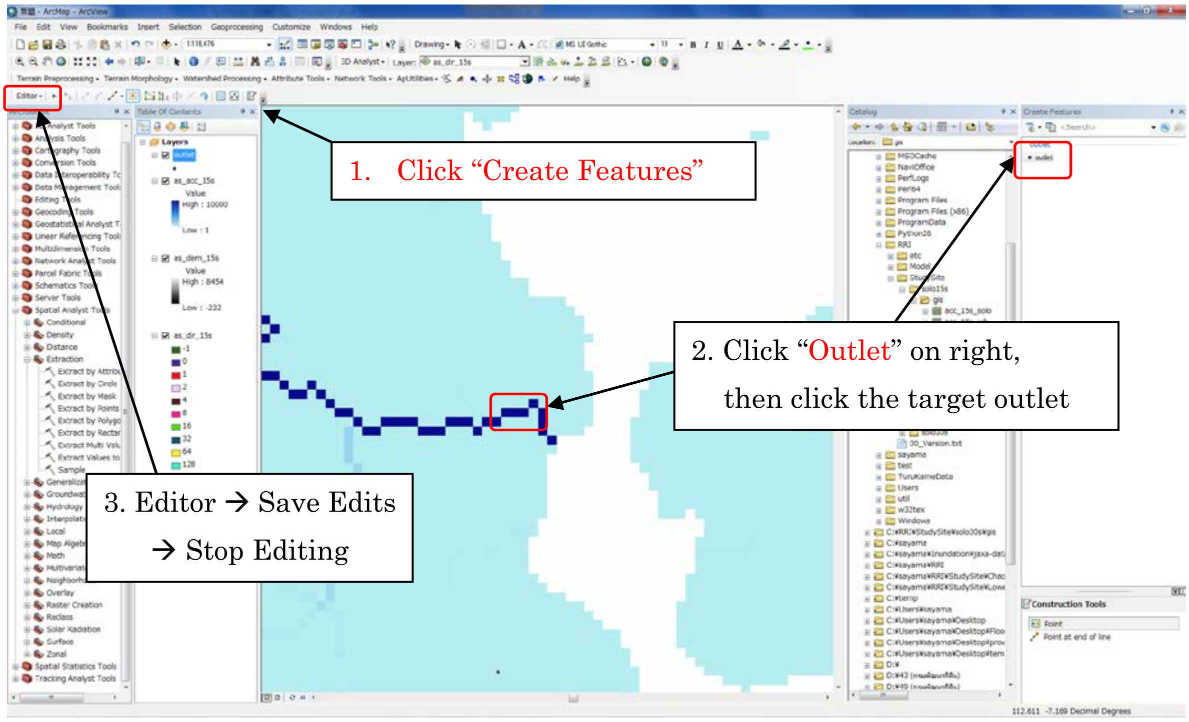
④ Show arc catalog (from the main menu, [Windows] → [Catalog]).
On the arc catalog, "Folder Connections" to a working folder (e.g. RRI/Project/solo15s/gis/) and right click to choose New → Shapefile to create a point Shapefile (e.g. Outlet).



⑤ From the main menu [Customize] → [Toolbars] → [Editor]
On the Editor, choose [Start Editing], then Choose "Outlet" (the new Shapefile) to start editting.

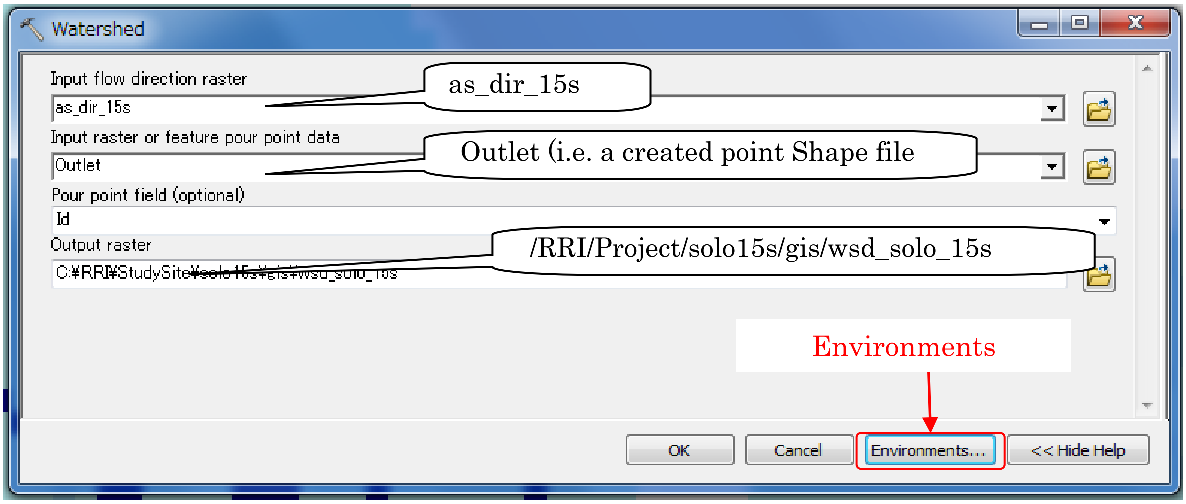


Clicking "Outlet", so that you can bring a point to indicate the target outlet.
After editting the outlet point, go to the editor menu to save and stop editing.

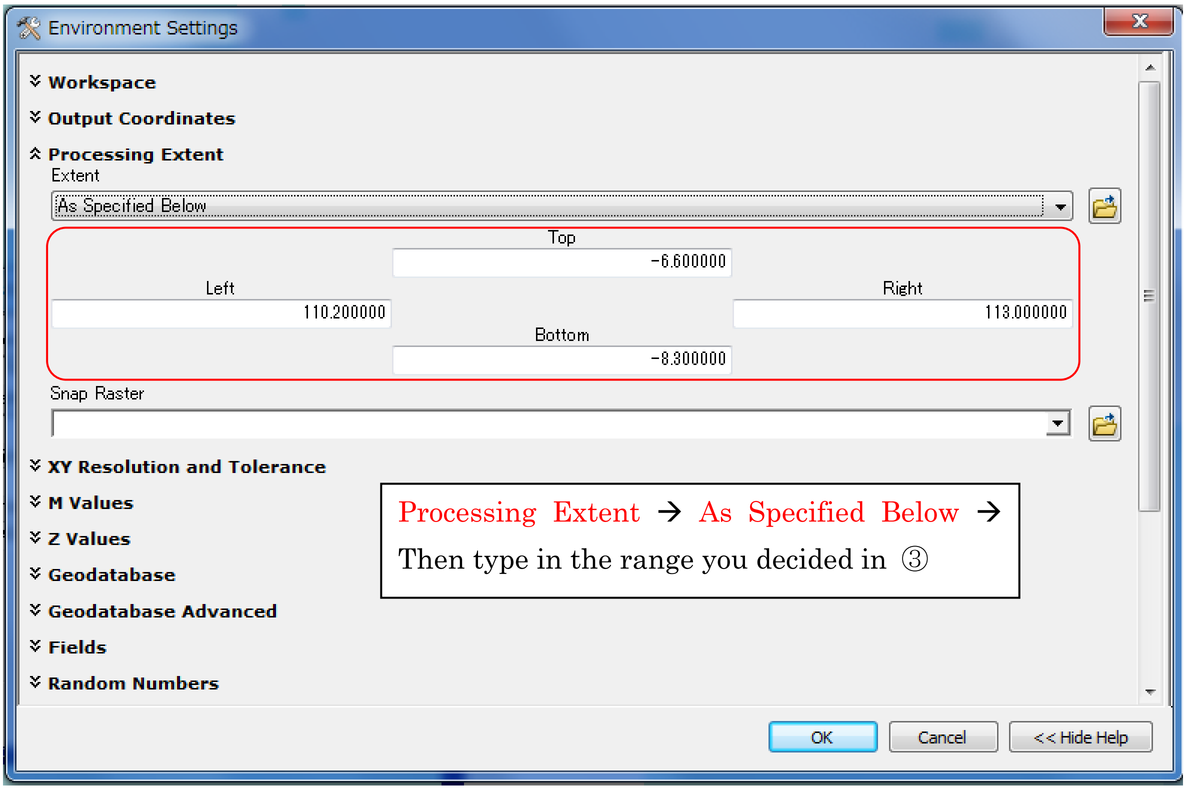


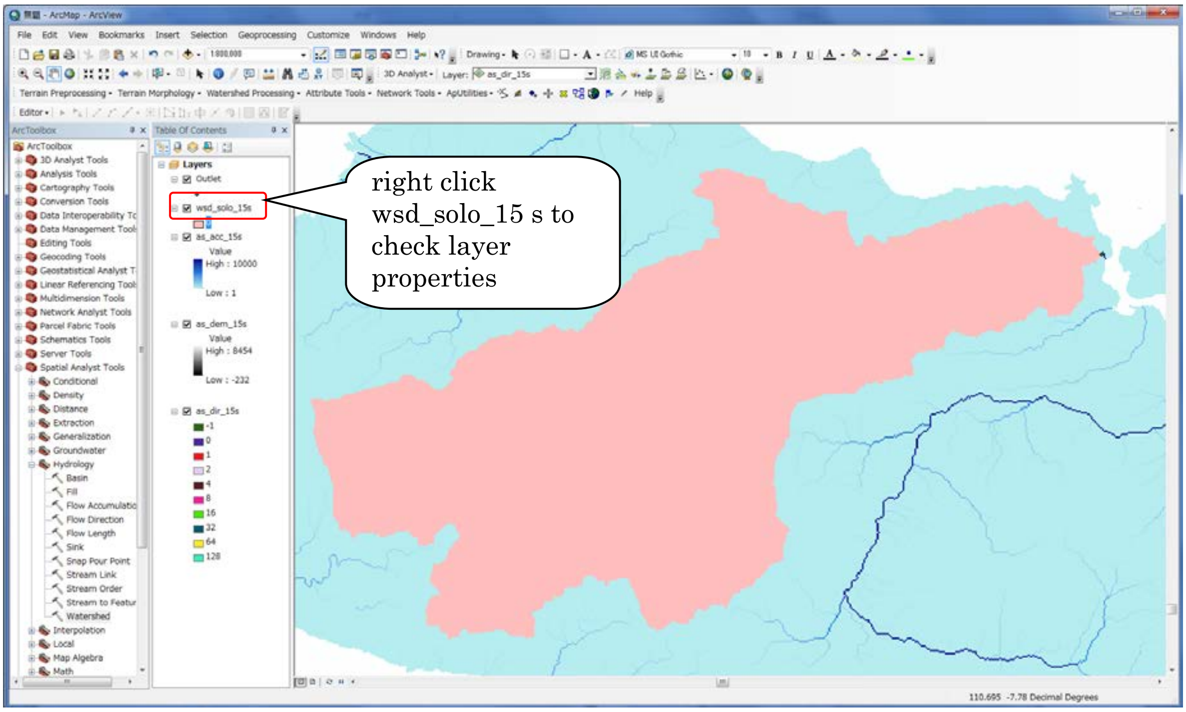
⑥ Using [ArcToolbox] → [Spatial Analyst Tools] → [Hydrology] → [Watershed], delineate a watershed with the defined outlet.

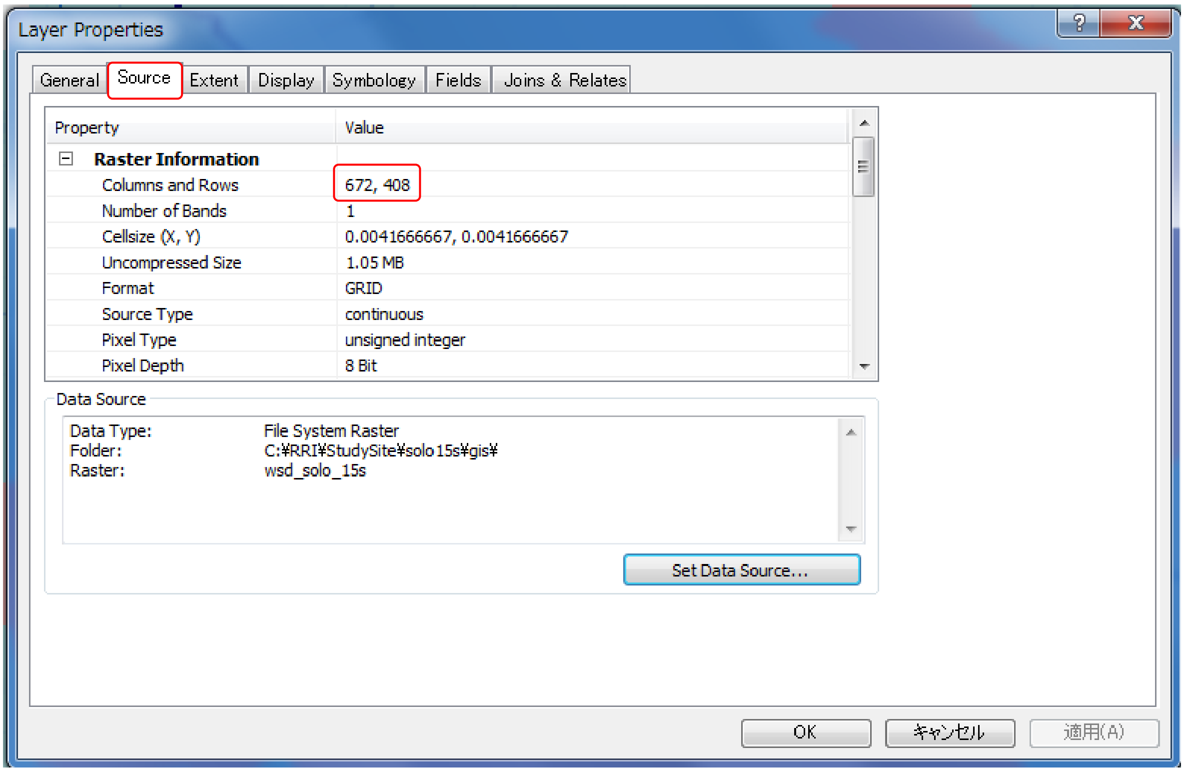
(IMPORTANT) To use [Spatial Analyst Tools] on ArcGIS, you must have the extension and activate it by choosing [Cusomize] → [Extentions] → add a check for [Spatial Analyst].



(IMPORTANT) Analysis range must be specified from the "environment" as below;

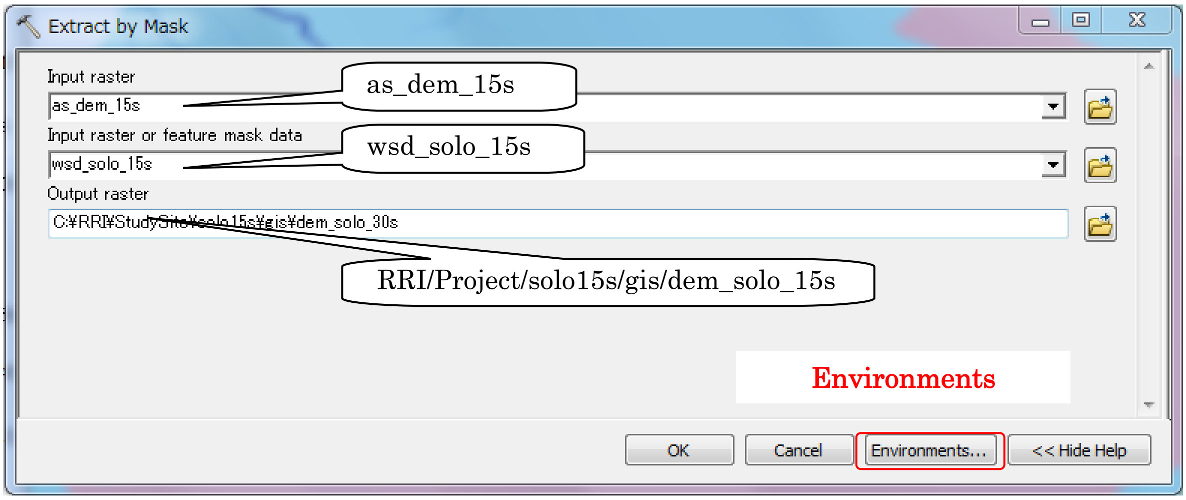


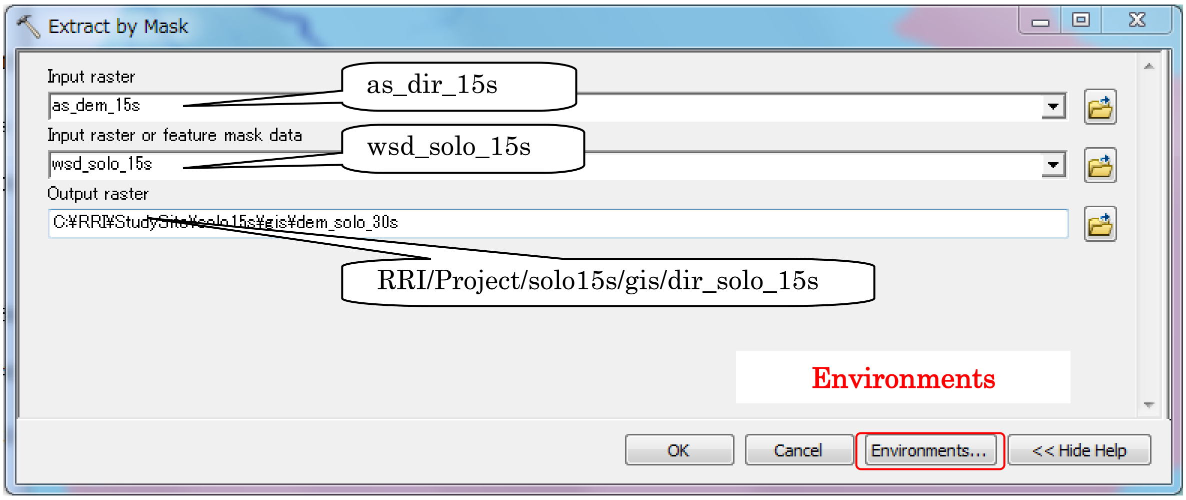


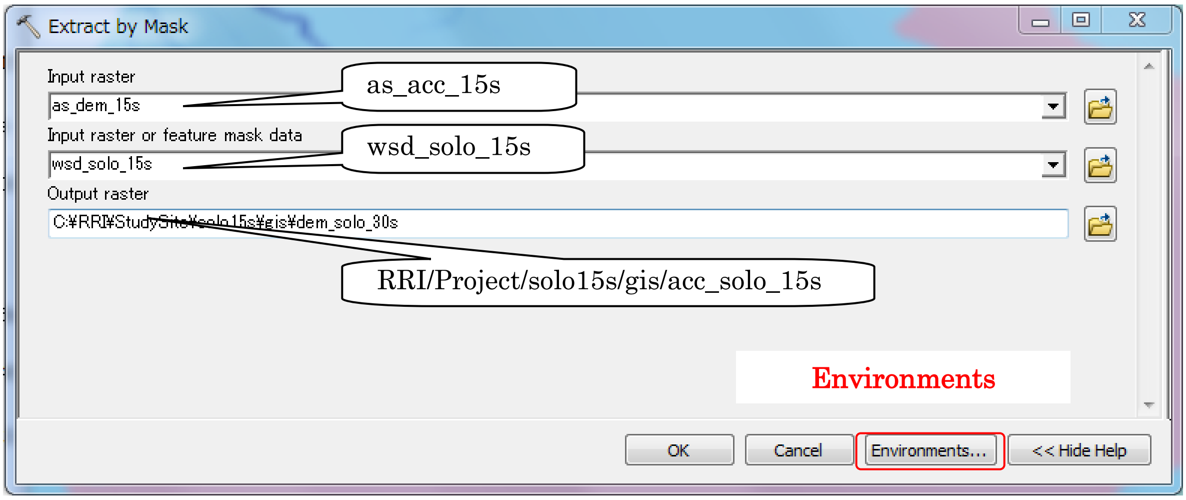


⑦ Right click the created watershed raster (e.g. wsd_solo_15s) and check layer properties. Under the "Source" tab, you can check "Columns and Rows". This will be the number of columns and rows for the topographic data used by RRI Model. If it exceeds more than 1000, using coarser resolution data is recommended to use.

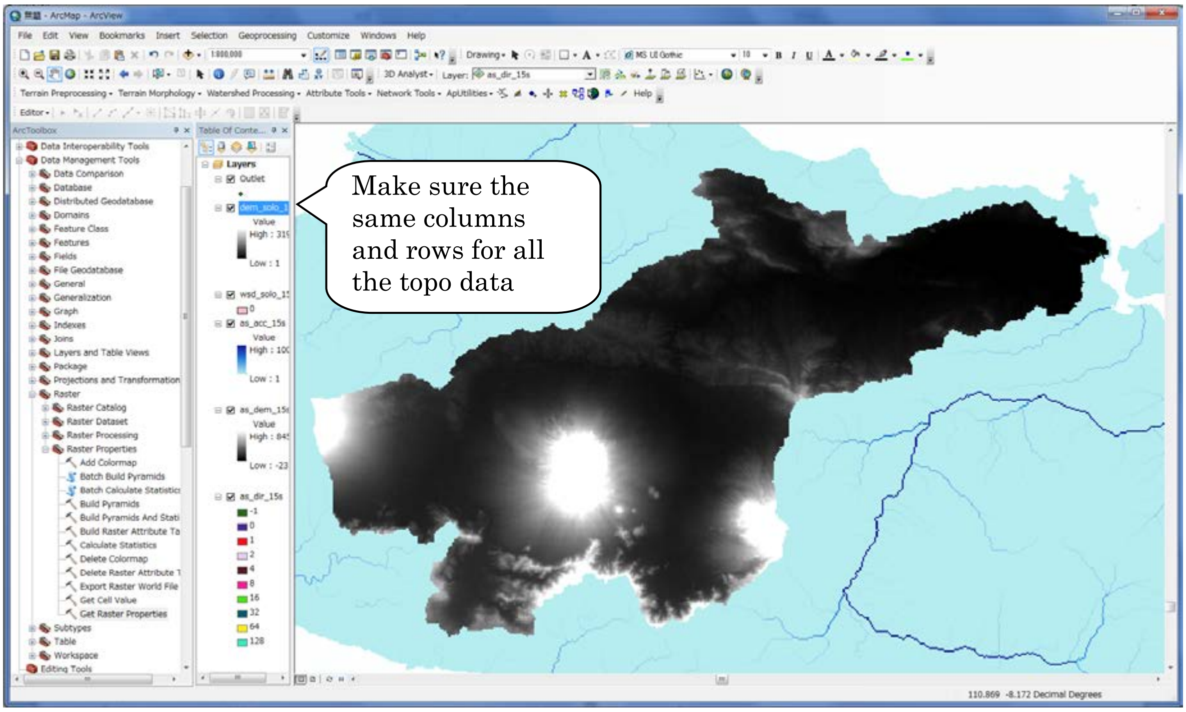
⑧ [Spatial Analyst Tools] → [Extraction] → [Extract by Mask], prepare dem (elevation), acc (flow accumulation) and dir (flow direction) masked by the delineated watershed.







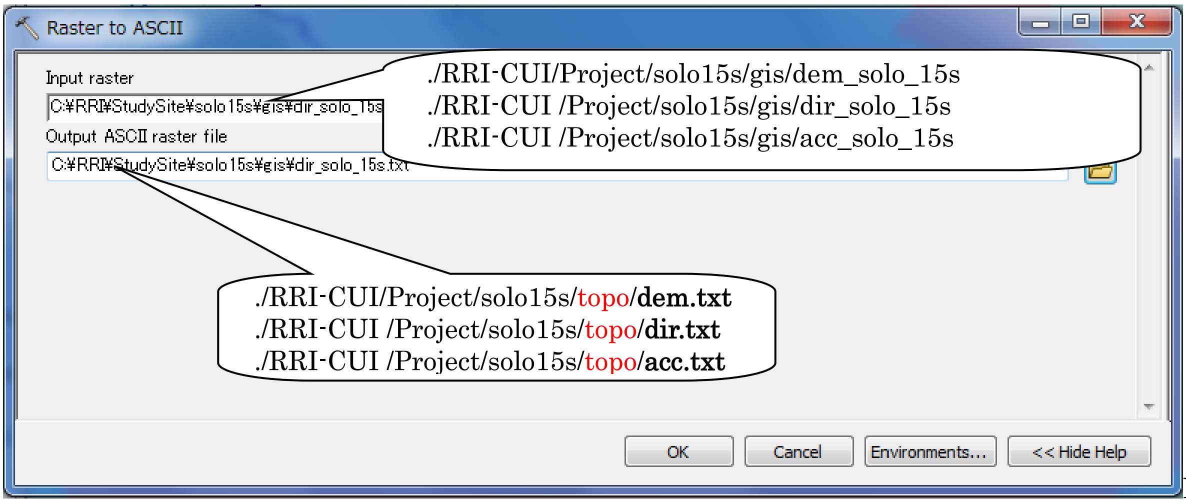
(IMPORTANT) Analysis range must be specified from the “environment” the same as above.



The above figure is the example of dem. The dir and acc must be also extracted in a same way.

⑨ Convert all the processed data (i.e. dem, dir, and acc) from ArcGIS Raster to ASCII, which are input data files for RRI Model. Using [Conversion tool] → [Conversion from Raster] → [Raster to ASCII], perform conversion from raster to ASCII for all the three types of topography data.

The output files should be named as "**dem.txt**", "**dir.txt**" and "**acc.txt**" to be saved under "topo" folder in your project folder (e.g. "./RRI-CUI/Project/solo15s/topo/").



The created ASCII data have the following format. Make sure once again all the three datasets have the same numbers in "ncols" and "nrows".

```
ncols         673
nrows          409
xllcorner     110.2
yllcorner     -8.3
cellsize      0.004166666667
NODATA_value  -9999
 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
```

dir.txt

In the RRI model, the following three data must be prepared on the ASCII data format.

- DEM data (dem)
- Flow accumulation data (acc)
- Flow direction data (dir)

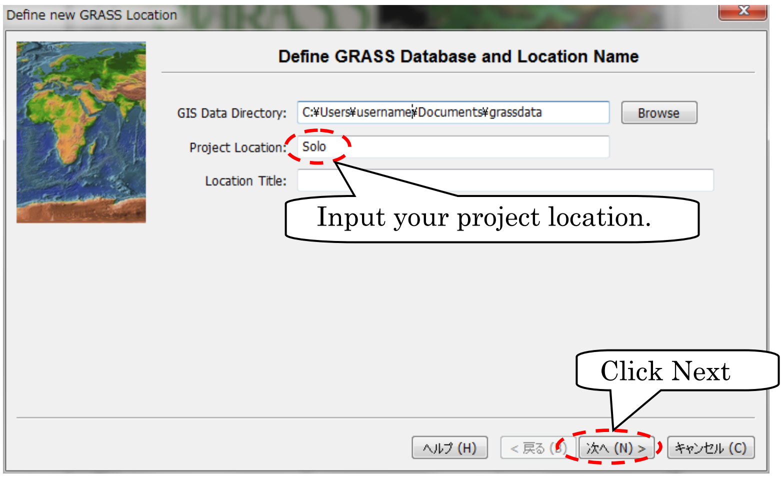
3.3 Delineating HydroSHEDS Data using GLASS GIS (optional)

(If the HydroSHEDS data delineation is completed with ArcGIS, skip this section.)

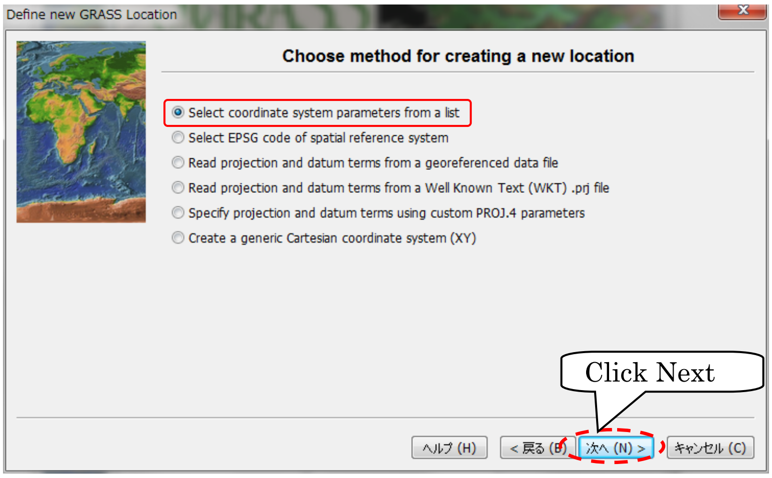
① Install the latest GRASS GIS (Latest GRASS in December 2013 is ver 6.4.3.) (GRASS website: http://grass.osgeo.org/).

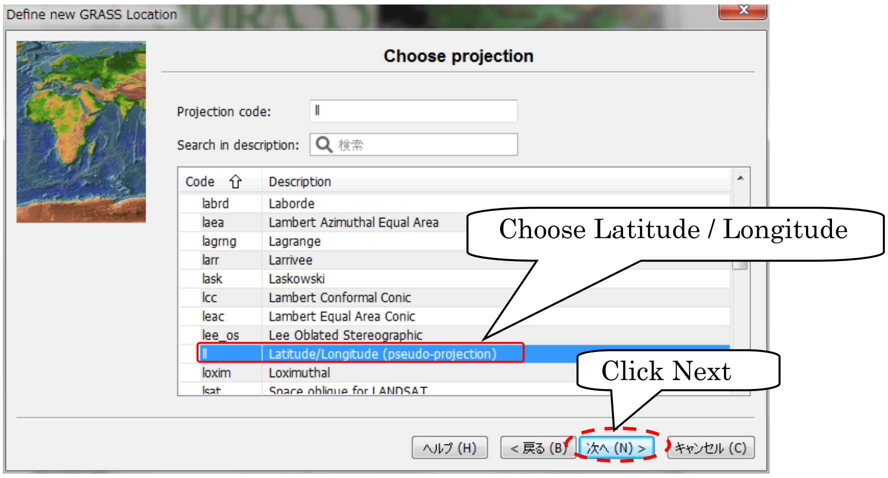
② Start GRASS GIS GUI, and click "Location wizard".

③ Input your location name (e.g. Solo) and Click next.

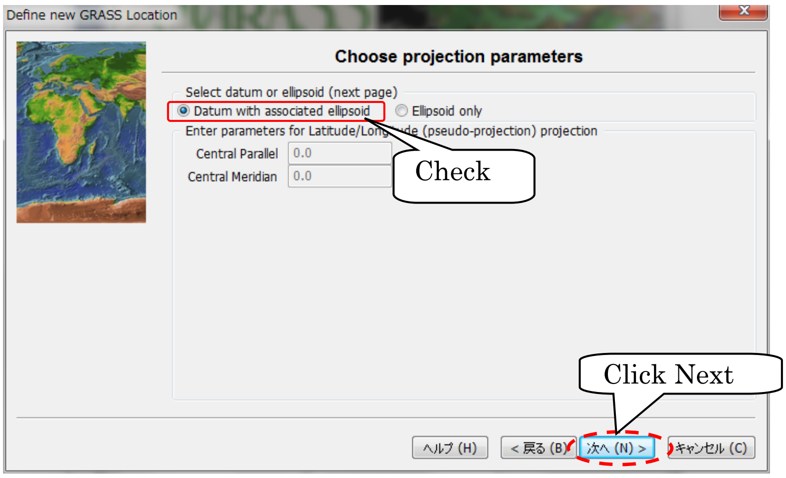


④ Select "Select coordinate system parameters from a list" and "Latitude/longitude (Pseudo-projection)" as a projection.

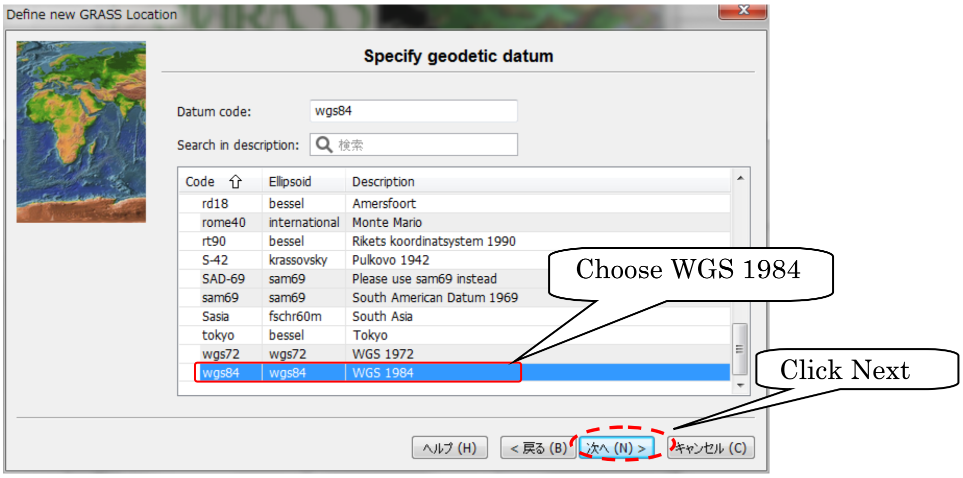




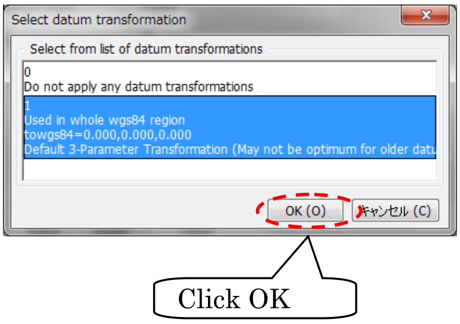
⑤ Check “Datum with associated ellipsoid” and click “NEXT“.



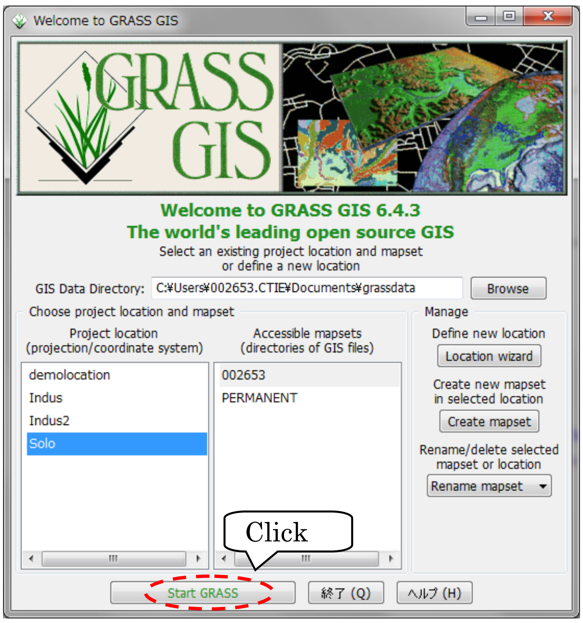
⑥ Select “WGS 1984” and as a geodetic datum and click “NEXT”.



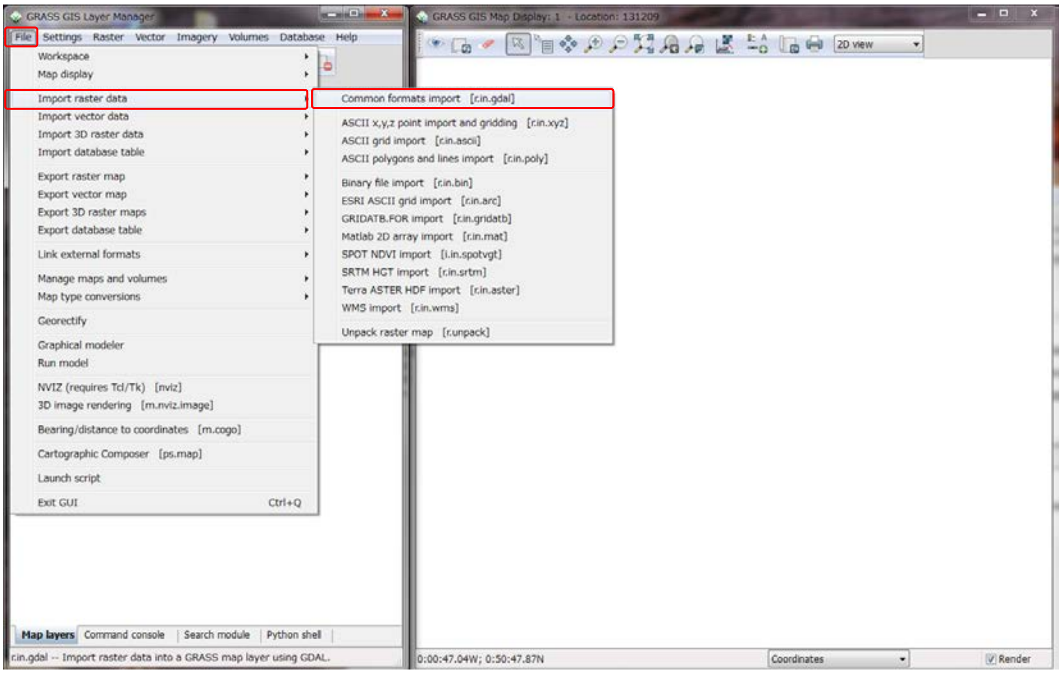
⑦ Click “OK” on “Select datum transformation” window and click “FINISH” on Summary window. (Select “Cancel” for default resolution setting).



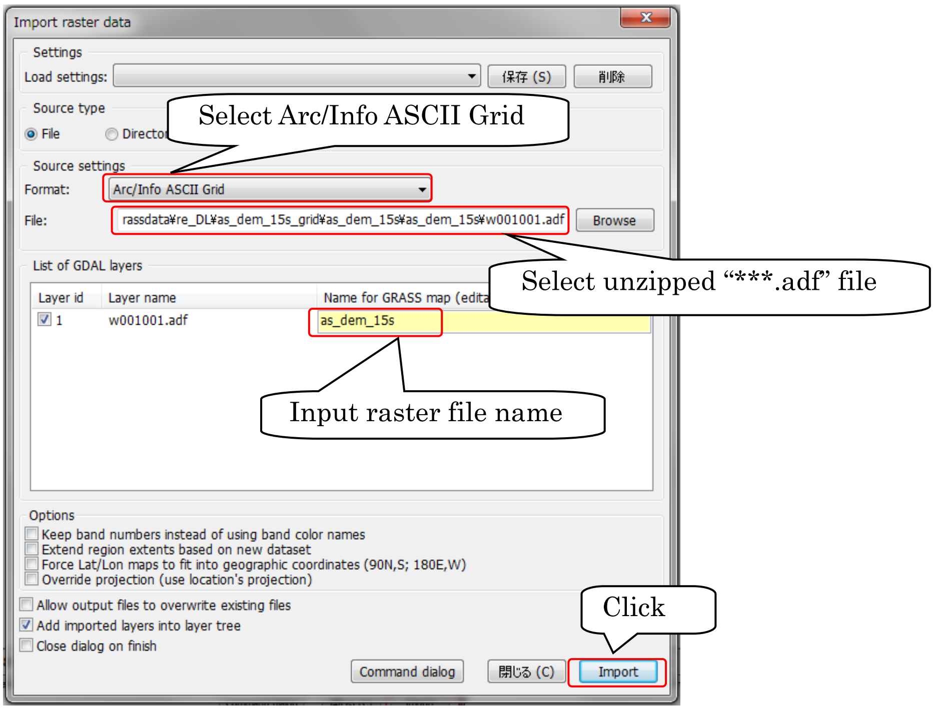
⑧ Click “Start GRASS” to start GRASS GIS.



⑨ Read in the unzipped files by selecting [File]>[Import raster data] >[Common formats import].

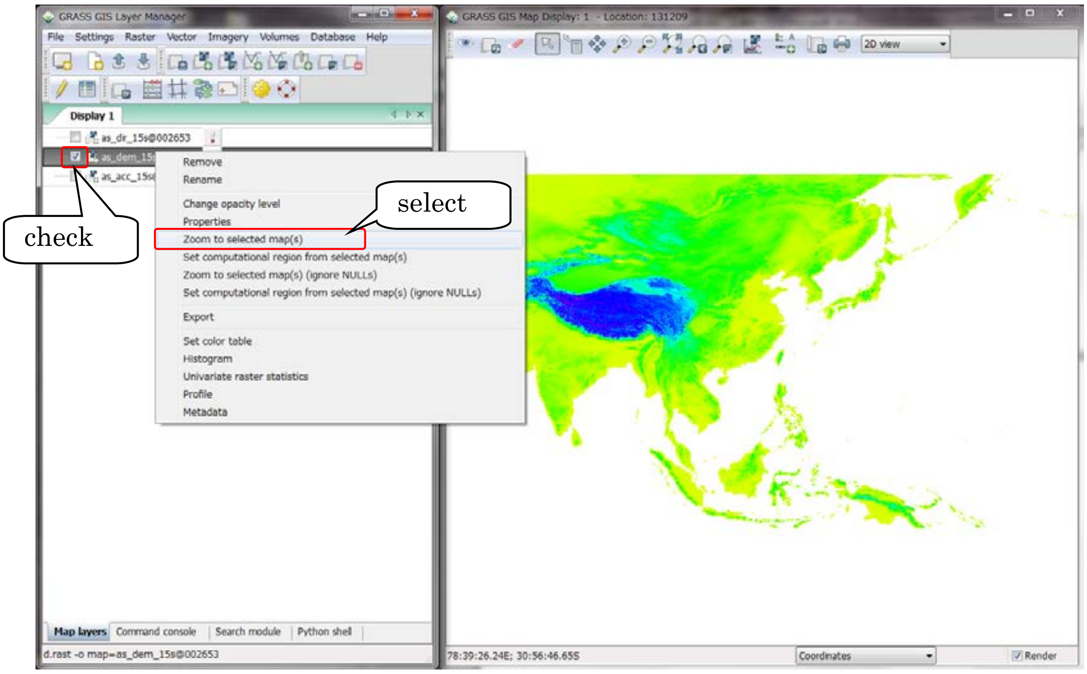


⑩ Select "Arc/Info ASCII Grid" from the "Format" list and select unzipped HydroSHEDS raster file name (e.g. w001001.adf for dem). Input "Name for GRASS map (editable)" as "as_dem_15s" for example and click Import.

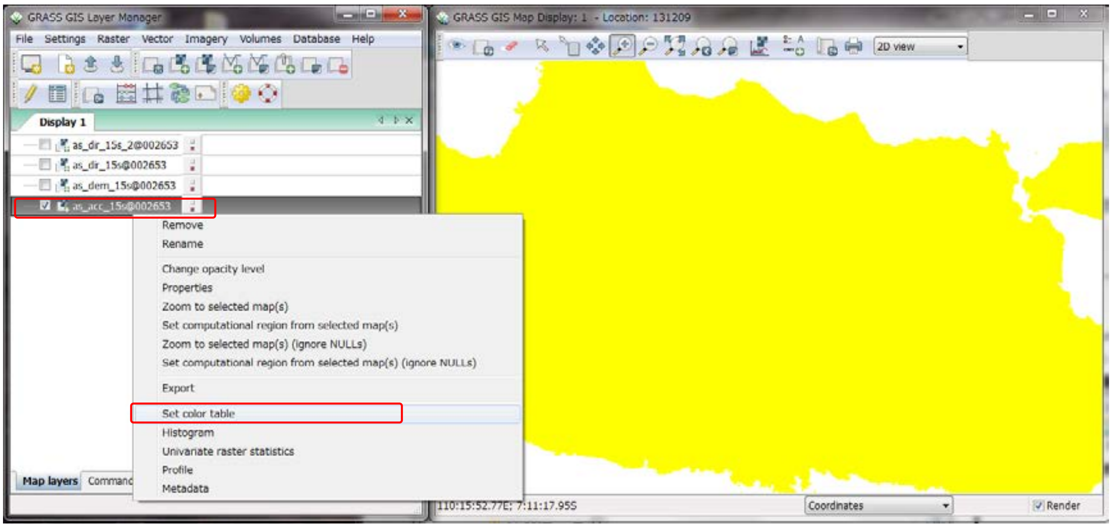


⑪ Perform the same operation for all the three types (dem, dir, acc) of topography data.

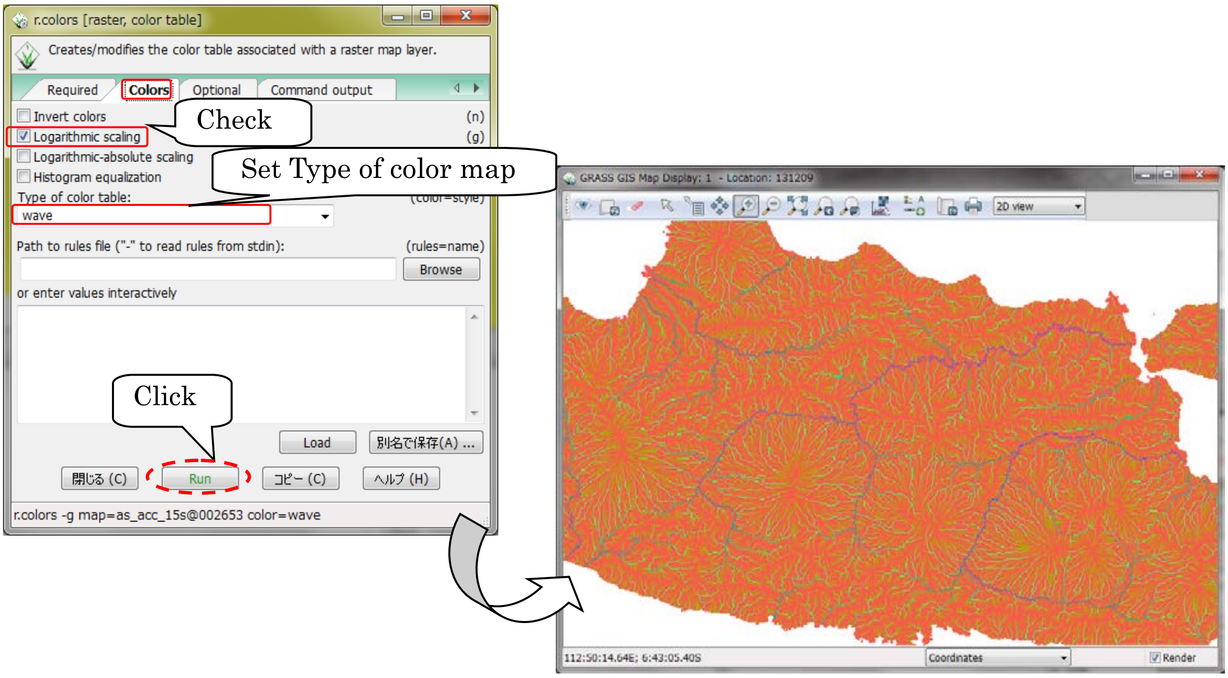
⑫ After importing three types of topography data, check the layer and right click on it and "select zoom to selected map(s)", then the raster file will be displayed in the window. (the following figure shows the example of "dem" display)



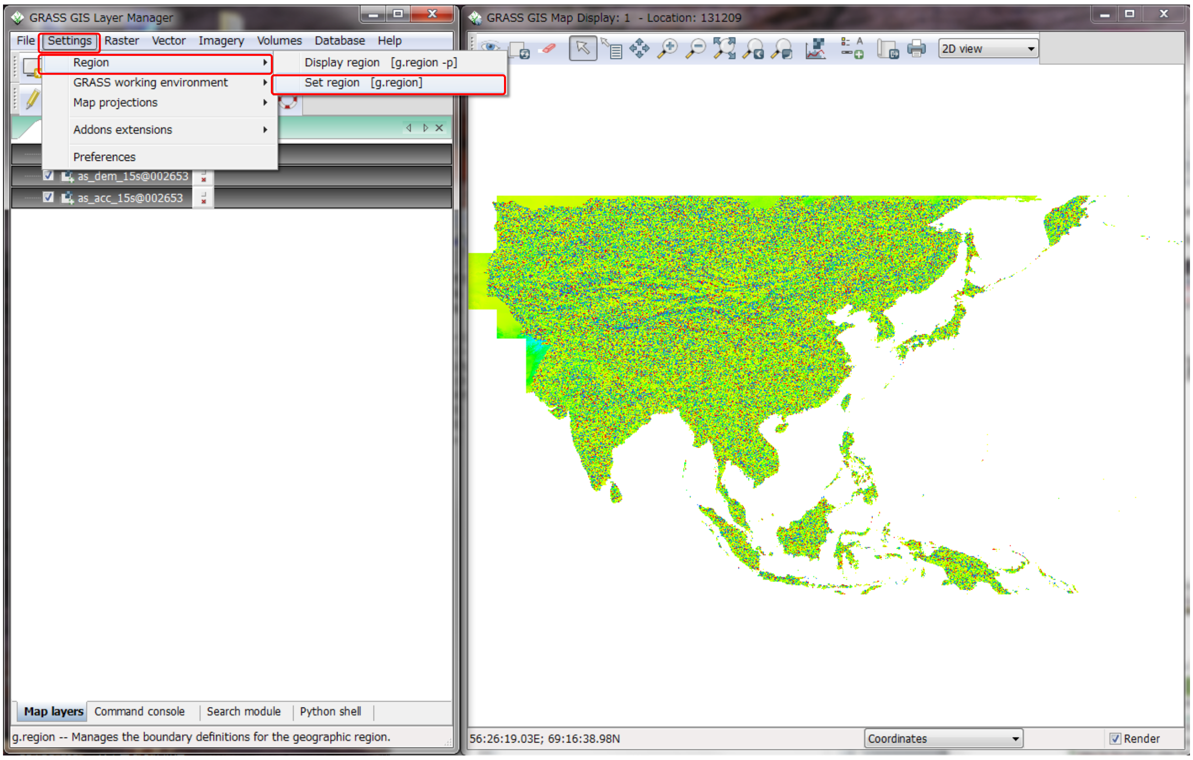
To show the flow accumulation (acc) clearly, right-click the filename of "acc" and select "Set color table".



⑬ Check "Logarithmic scaling" on "Colors" tab and select "Type of color map". User can select color table from several color tables. Following figure shows the example selecting "wave" as "Type of color table".

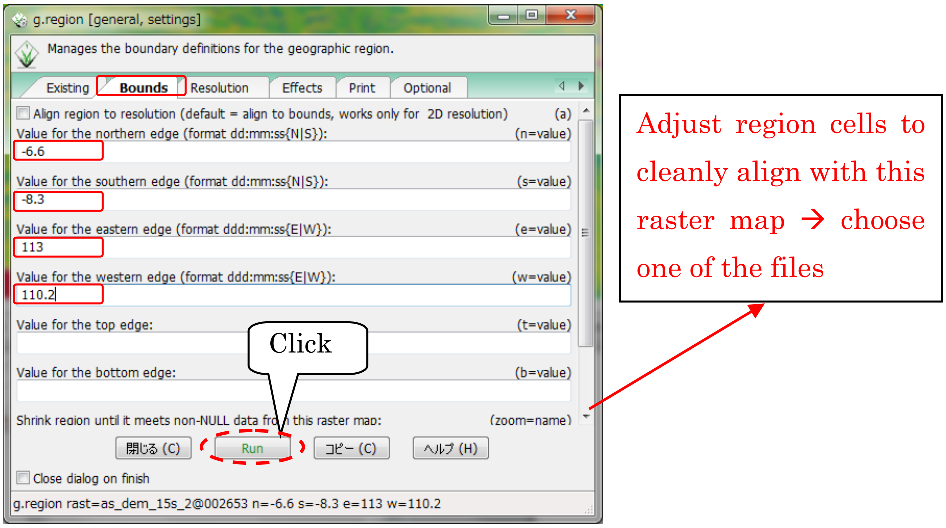


⑭ To set the delineation range, select [Settings]＞[Region]＞[Set Region].

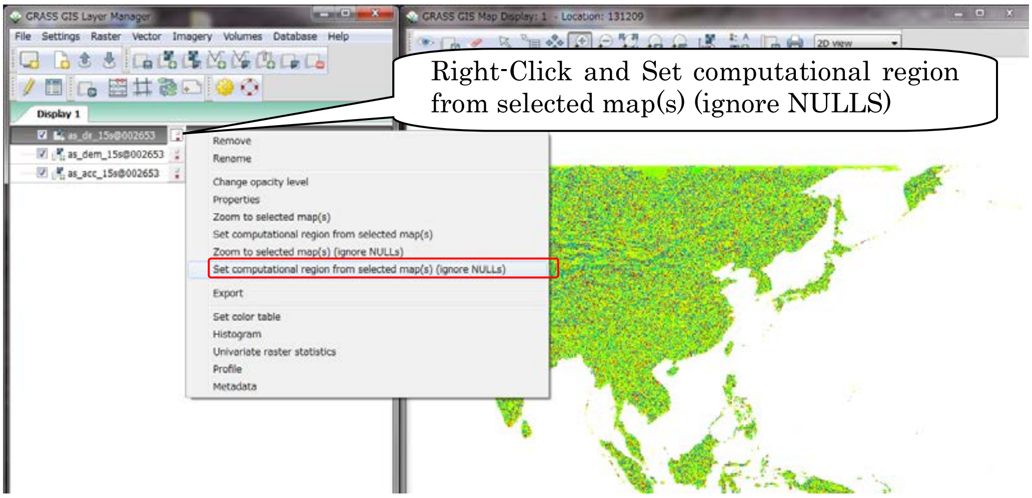


⑮ Input values for edges of the target area (coordinates) and set a file for adjusting region cells to cleanly align with a raster map, then click “Run”.

(To decide your target area, display the flow accumulation data (i.e. as_acc_15s) on top screen to find your target river. The set rectangle range must cover all upstream contributing area.)

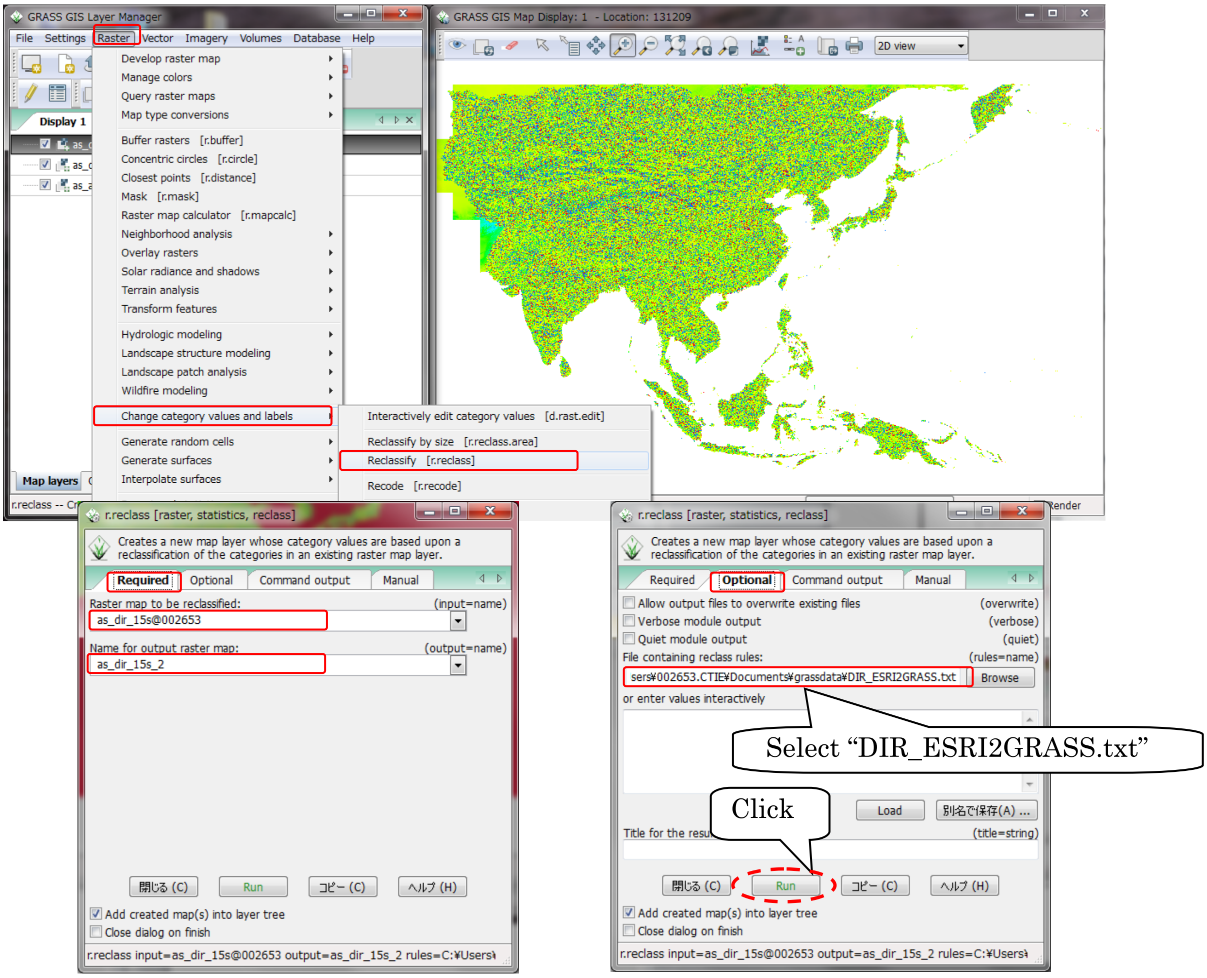


⑯ Right-click the filename of "dir" file and select "Set computational region from selected map(s) (ignore NULLS)". Perform the same operation for all the three types (dem, acc and dir) of topography data.

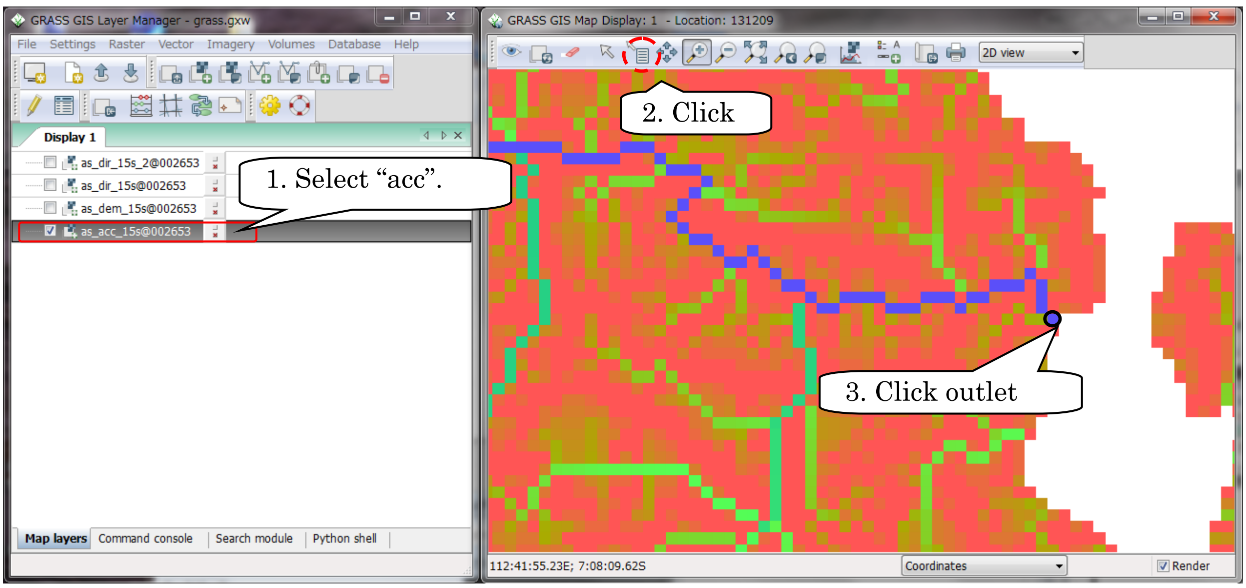


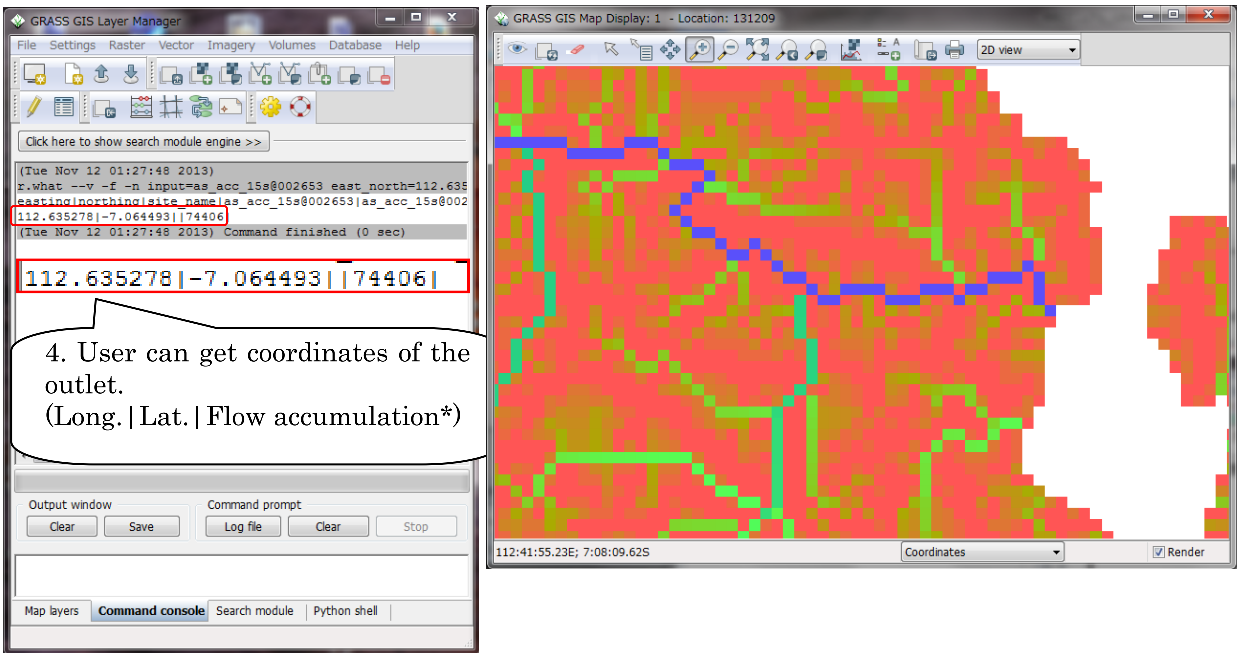
⑰ Only for flow direction, change category values (definition of river flow direction in DIR file), from ESRI type (1, 2, 4, 8, 16, 32, 64, 128) to GRASS type (1, 2, 3, 4, 5, 6, 7, 8).

Select [Raster] > [Change category values and labels] > [reclassify]: Select "DIR_ESRI2GRASS.txt", prepared in package (/RRI/etc), as "File containing reclass rules"

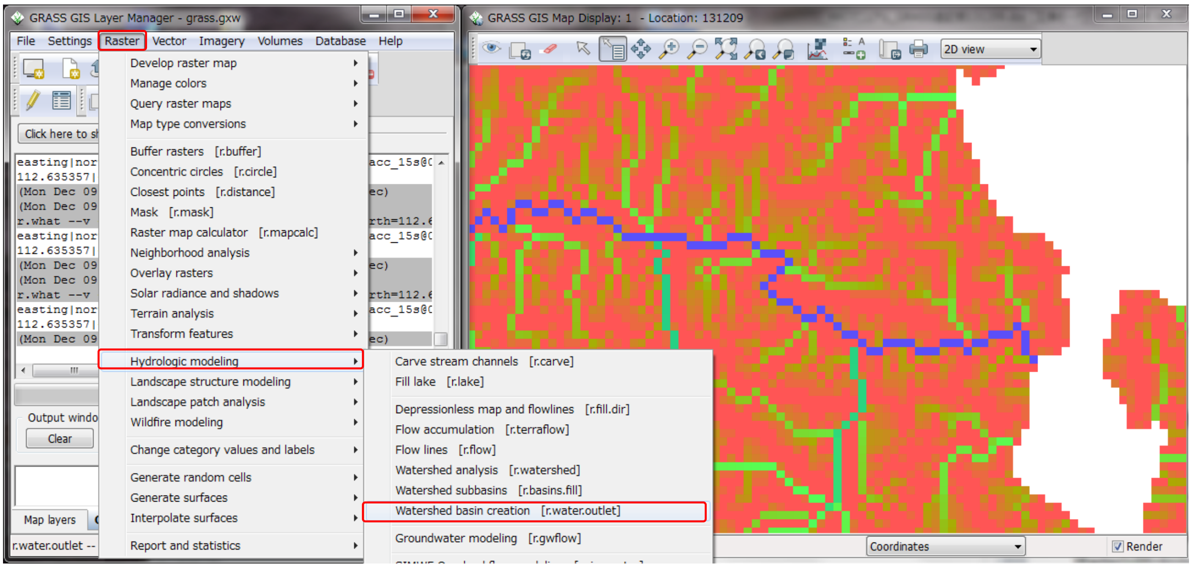


⑱ User needs to know the coordinates of the outlet (long./lat.) of target river basin to clip. Select “acc” file and perform 1, 2, 3 and 4 as shown in following figures.



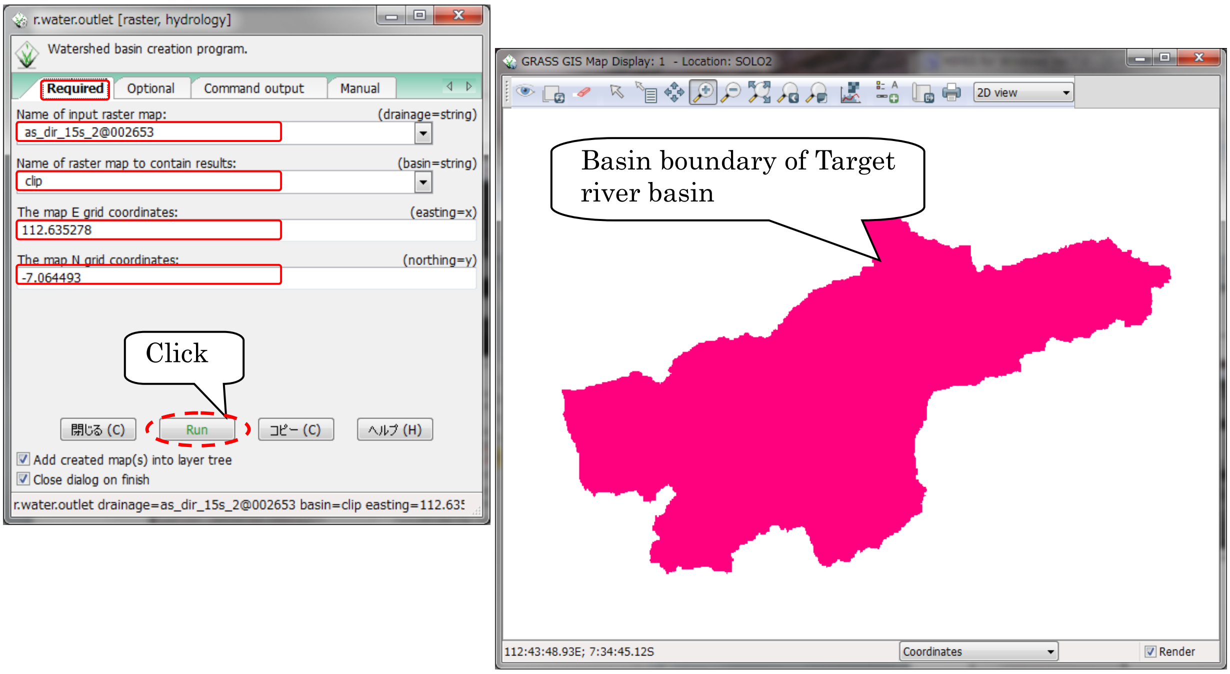


⑲ To create basin boundary, select the outlet of target river basin.
[Raster]>[Hydrologic modeling]>[Watershed basin creation (r.water.outlet)]



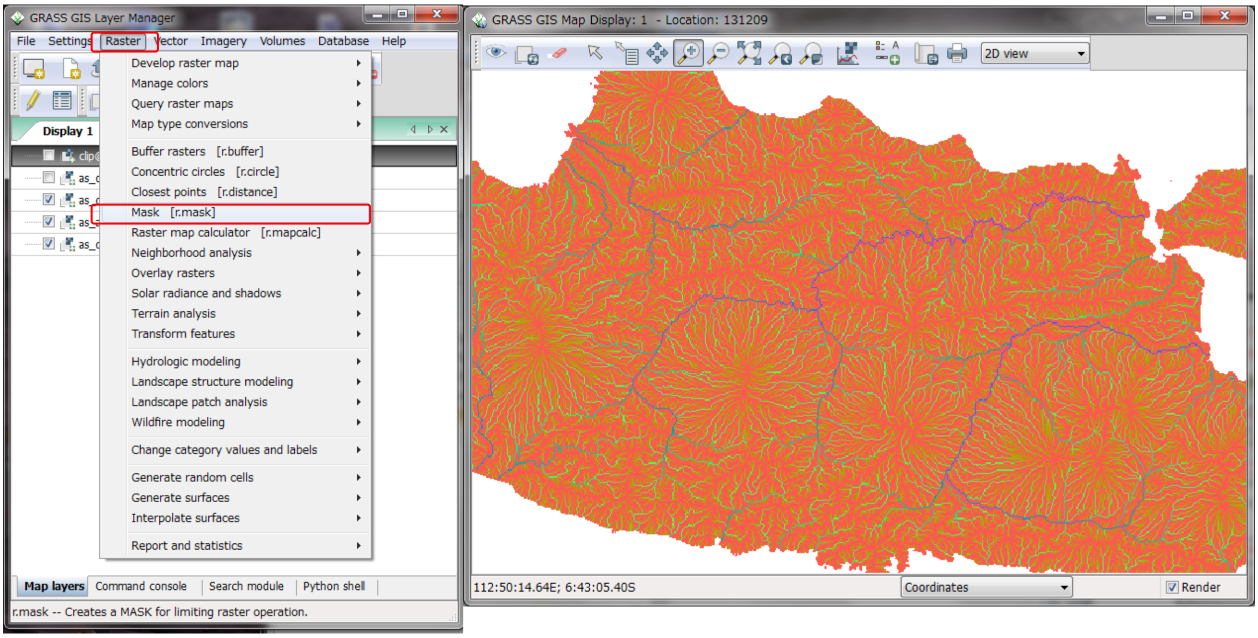
⑳ Select layer of "dir" file as "Name of input raster map" and input layer name of basin boundary data in "Name of raster map to contain results".

㉑ Input x-coordinate(long.) of the outlet in "The map E gird coordinates" and input y-coordinate(lat.) of the outlet in "The map N grid coordinates" and click "Run". Then, basin boundary layer of target river basin will be shown.

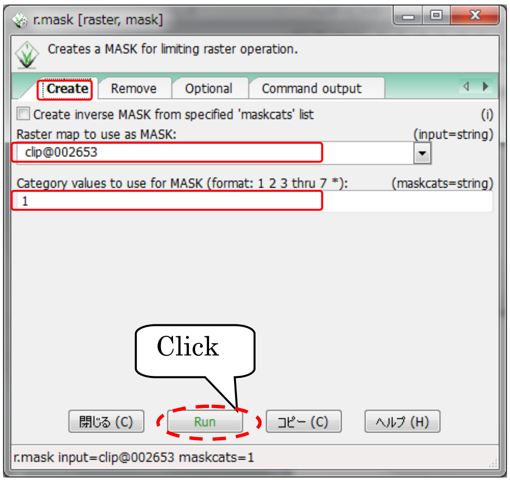


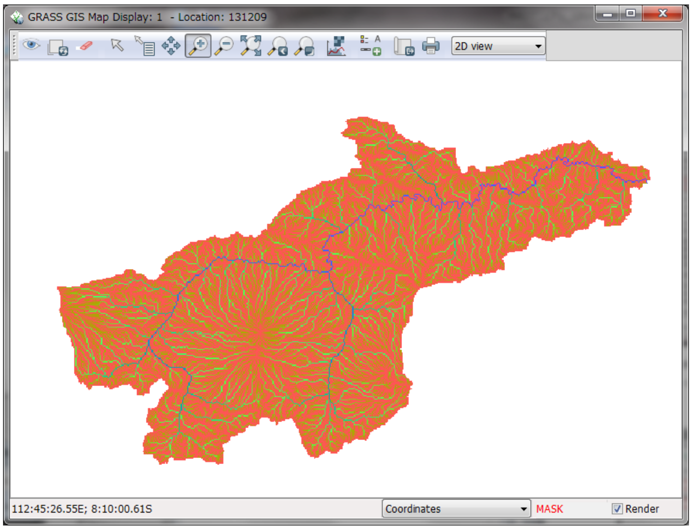
㉒ Clip target river basin by using basin boundary layer.

[Raster]>[Mask(r.mask)]



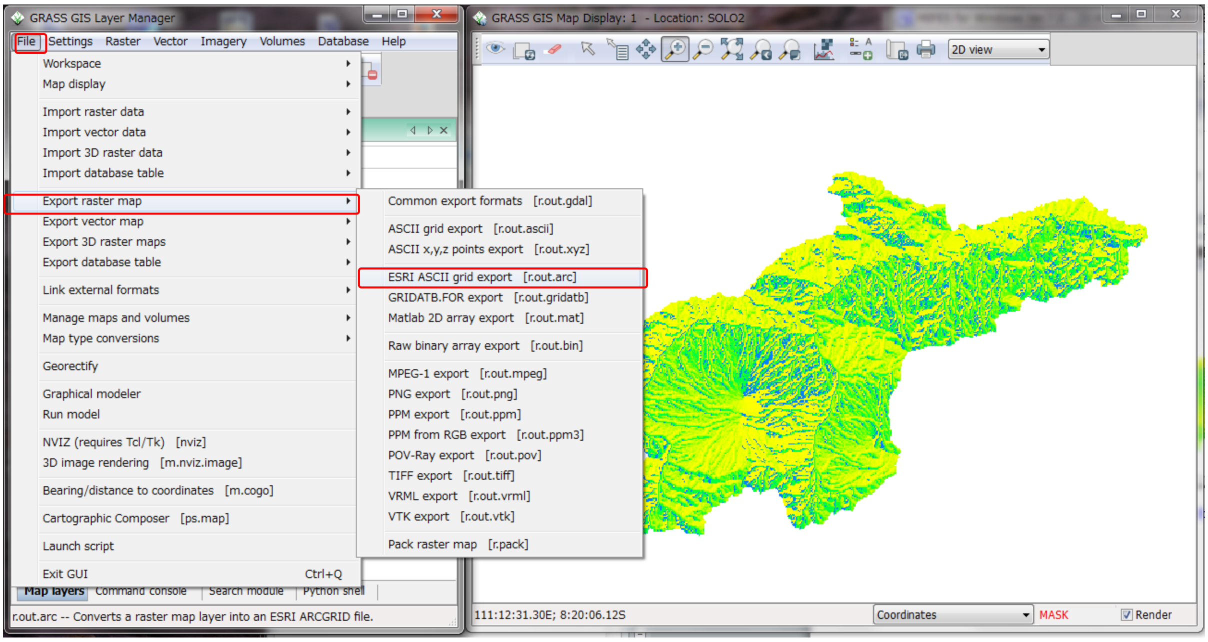
㉓ Select basin boundary layer as “Raster map to use as MASK” and input “1” in “Category values to use for MASK” on “Create” tab and click “Run”. Then, clipped target river basin will be shown.





㉔ Export the three layer data (dem, dir, acc).

[File]>[Export raster map]> >[ESRI ASCII grid export]



㉕ Select three layer data (dem, dir, acc) and input output file name in "Name for output ARC-GRID map" and click "Run".

㉖ Perform the same operation for all the three layers (dem, dir, acc).

3.4 Upscaling the spatial resolutions of DEM, DIR and ACC (optional)

If a user needs to upscale the resolutions of the topography files (dem, dir and acc), one can use a program called "scaleUp.exe". By specifying a multiple factor for upscaling the resolution, the program outputs new dem, dir and acc based on the original topography files. For example, if the spatial resolutions of the topography files are 30 sec and the specified multiple factor is 3, the program creates the topography files having 90 sec (30s x 3). The following shows the procedure to use the program.

① Copy "scaleUp.txt" file from "RRI-CUI/etc/scaleUp/" and save it under your project folder (e.g. RRI-CUI/Project/solo30s/)

```
./topo/dem.txt
./topo/dir.txt
./topo/acc.txt
3
./topo/dem_90s.txt
./topo/dir_90s.txt
./topo/acco_90s.txt
```

scaleUp.txt
input files (lines 1–3)
multiple factor for upscaling (line 4)
output files (lines 5–7)

② Type in "scaleUp.exe" and return to execute scaleUp.exe program and find the created three sets of the topographic data indicated in L5, L6 and L7 in scaleUp.txt

3.5 DEM Data Adjustment

There are some hollows in the original HydroSHEDS elevation data. Some of them represent actual topographic features, while some of them are caused due to the intrinsic characteristics of DEM. For example, deep and narrow valley, in which a river flows, may be blocked by surrounding topography because of the DEM resolution. In that case, the simulated water depths and river discharges with the original DEM are unrealistic.

Therefore, the following DEM adjustment is always recommended to avoid the unrealistic hollows in the original DEM. The provided program called demAdjust2 (demAdjust2.exe) follows the flow direction of HydroSHEDS and remove all the negative slope along the flow direction by carving and lifting the original DEM.

The algorithm of demAdjust2 is as follows;

1. Based on the flow direction, demAdjust2 finds upstream cells (i.e. cells with no inflow).
2. Among the detected upstream cells, searching order is determined from the total length of the flow paths from each upstream cell to its most downstream cell.
3. Following the above decided order, demAdjust2 adjusts elevations based on the following procedures.

1) The negative elevation is set to be zero.

2) Lifting: If a single cell is extremely low (likely as a noise error) compared to its upstream and downstream cells, the cell's elevation will be replaced by the same elevation as the upstream cell. The parameter "lift" is used as the threshold to detect sudden drop and its default value is set to be 500 m.

3) Carving: If the elevation suddenly increases along the flow direction, the cell's elevation will be replaced by the same elevation as the upstream cell. The parameter "carve" is used as the threshold to detect the sudden increase and its default value is 5 m.

4) Lifting and Carving: By searching from the most upstream, it finds a cell whose downstream elevation is higher than that cell (point L). By searching from point L toward downstream, it finds a cell whose downstream is lower than that cell (point H). The point L is lifted and point H is carved by the parameter "increment", whose default is 0.01 m.

The demAdjust2 program conducts each of the above procedure repeatedly for each flow path ways from all the detected upstream cells until all negative slopes are removed. Note that the above procedure does not change flow direction.

Edit demAdjust2.txt if necessary and run demAdjustment2 program by typing in "demAdjustment2.exe" on Command Prompt under the project folder (e.g. solo15s or solo30s).

> The process is necessary even if a user would like to use original dem data. "demAdjust2" program modifies not only "dem" data but also flow direction data "dir". The modified "dir" (named as "adir") has flow direction equals to zero at outlet cells. This operation must be done and "adir" always must be used for RRI simulation. Also note that there is no correction for "acc", so use the original "acc" regardless the demAdjust2 procedure.

Read the adjusted dem and dir data to ArcGIS to visualize the data.

Select [ArcToolBox] > [Conversion tool] > [Conversion from raster] > [ASCII→Raster].

"adem", "adir", "acc" are the three important topography data for the RRI simulation.

4. Preparing Input Rainfall Data

This section explains the method to prepare rainfall data for RRI Model. A user can prepare the data by any method as far as it follows a specified data format. Currently three program sets are prepared for processing:

1) gauged rainfall with Thiessen polygon interpolation (/etc/rainThiessen),

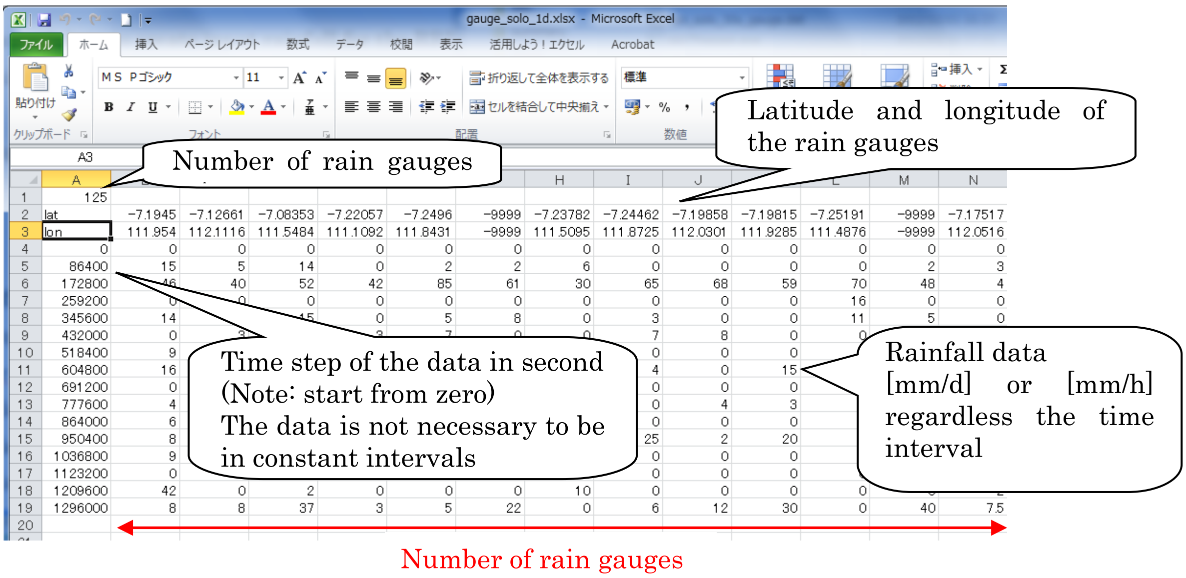
2) GSMaP satellite based rainfall (/etc/GSMaP) and

3) 3B42RT (/etc/3B42RT) satellite based rainfall.

4.1 Prepare Input Rainfall Data from Gauged Rainfall Records

To use ground gauged data for creating input rainfall for the RRI simulation, one can use rainThiessen.exe (./RRI-CUI/etc/rainThiessen/rainThiessen.f90) program.

① First, prepare rain gauge data in Excel (e.g. /solo30s/rain/gauge_solo_1d.xlsx).



Set any negative value (e.g. -999) for missing data, not to be used for the interpolation.

② Select all cells having values, and copy and paste on a text editor. Then save it as txt file (e.g. gauge_1d.txt)

③ Edit the input file "rainThiessen.txt" as follows.

```
./rain/gauge_1d.txt
24
./rain/rain.dat
./rain/gauge_map.txt
ncols    336
nrows 204
xll 110.2
yll -8.3
cellsize 0.0083333333333333
```

1D rainfall data prepared above

Divide parameter
set 1 if the input rain data is in [mm/h],
set 24 if it is in [mm/d]

Output file names
L3 : output rainfall (i.e. input for RRI) [mm/h]
L4 : output map file (to check the spatial distribution of rain gauges)

Coordinate specifications of the output rainfall file. One can copy and paste the header of a topographic file (i.e. dem).

However any coordinates values and cellsize can be specified as far as the same coordinate is set in “RRI_Input.txt” and the range covers an entire domain. See the detail in Section 8.2.

④ On command prompt under the project file (e.g. RRI/Project/solo30s/), type in “rainThiessen.exe” to execute the program.

⑤ Confirm an input rainfall file for RRI Model (e.g. “rain.dat”) is newly created.

4.2 Prepare Input Rainfall Data from GSMaP

GSMaP products were updated on September 2014. Now the products include GSMaP_NRT (realtime), GSMaP_MVK (standard ver.5 or ver.6) and GSMaP_Gauge (gauge composite). Refer to the following website for the latest information and the registration to download the data. (http://sharaku.eorc.jaxa.jp/GSMaP/index.htm)

4.2.1 Download GSMaP Data

① First, create “gsmap” folder under your project folder (e.g. solo30s).

② Under “gsmap” folder, create “infile” and “cutfile” folders.

③ Download all GSMaP rainfall data you would like to proceed and save them in “infile”.

4.2.2 Calculate Rainfall Data Range for a Target Catchment

To calculate the range for the data delineation, calc_area_gsmap.exe can be used. Before executing calc_area_gsmap.exe, copy /etc/GSMaP/calc_area_gsmap.txt and paste it under the created “gsmap” folder.

In the copied “calc_area.txt”, specify “horizontal_resolution [d]” and “temporal_resolution [h]” of original GSMaP product you will use. Also specify “ncols” to “cellsize” based on the target catchment, whose parameters can be obtained from the headers of topographic files of “dem”, “acc” or “dir”.

Note: The holizontal resolution of GSMaP product is either 0.1 [deg] or 0.25 [deg], and the temporal resolution is either 1 [h] or 24 [h].

(In case of 0.1 deg → xul = 0.05, yul = 59.95; 0.25 → xul = 0.125, yul = 59.875).

Running calc_area_gsmap.exe creates a file named “out_by_calc_area_gsmap.txt”.

out_by_calc_area_by_gsmap.txt

```
horizontal_resolution [d] :   0.1000000
temporal_resolution [h]   :           1

xll     :     110.2000
yll     :     -8.300000
xur     :     113.0000
yur     :     -6.600000

xll_rain        :    110.1250
yll_rain        :   -8.375000
xur_rain        :    113.1250
yur_rain        :   -6.375000

jleft   :     440
ibottom :     273
jright  :     452
itop    :     265

xllcorner_rain (raster)   :     110.0000
yllcorner_rain (raster)   :    -8.500000
cellsize_rain             :    0.2500000
```

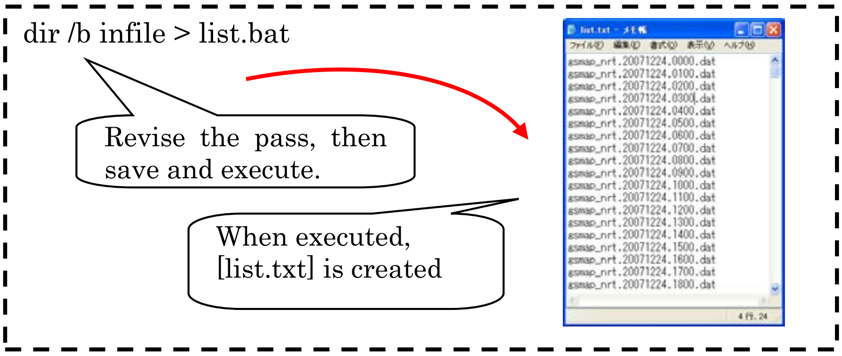
Information that is necessary to delineate GSMaP (jleft, ibottom, iright, itop)

Rainfall location information to be specified in the RRI_Input.txt (xllcorner, yllcorner, cellsize)

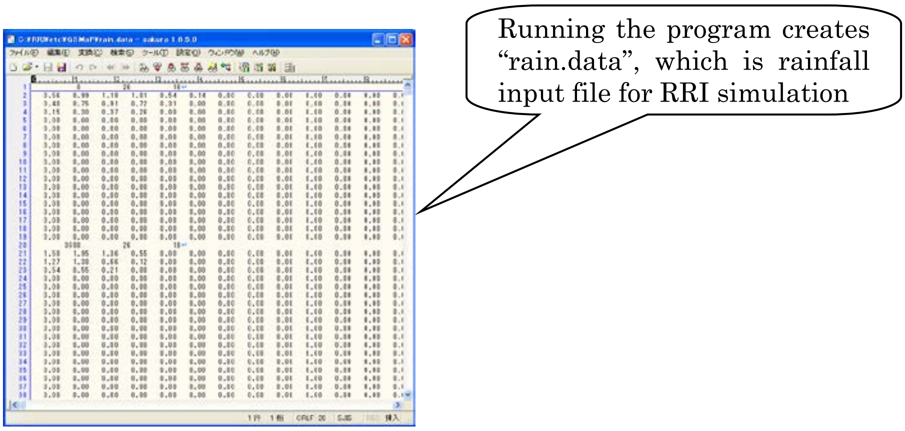
4.2.3 Delineating GSMaP Data for Target Area

④ Unzip all the downloaded files (a linux user may use “gunzip *”, otherwise please find an appropriate program to unzip “.dat.gz” files)

⑤ Copy “/etc/GSMaP/makeList.bat” under “gsmap” folder and execute it to list up all the unziped files as "list.txt”



⑥ Type in “read_gsmap.exe” on command prompt at “gsmap”.



4.3 Prepare Input Rainfall Data from 3B42RT

4.3.1 Download 3B42RT Data

① Access the following FTP site for downloading 3B42RT data
ftp://trmmopen.gsfc.nasa.gov/pub/merged

② Download "3B42RT.20*****.7R2.bin.gz" files from the FTP site and save them under ./etc/3B42RT/read/infile/

4.3.2 Calculate Rainfall Data Range for a Target Catchment

To calculate the suitable range for the delineation, /etc/3B42RT/calc_area.f90 program can be used. See details in 4.2.2, the same process is used for GSMaP data extraction.

4.3.3 Delineating 3B42RT Data for Target Area

① The following process uses “bash script”. Windows users may install “clink” program to run bash scripts (*.sh) on windows command prompt. The “clink” program can be downloaded from: http://code.google.com/p/clink/

② To calculate the suitable range for the delineation, /etc/3B42RT/calc_area.f90 program can be used. See details in 4.2.2 because the same process is applied also to GSMaP data extraction.

③ Execute "bash unzip.sh" in /etc/3B42RT/read/ to unzip the downloaded files under ./etc/3B42RT/read/infile.

④ Edit "read_rt_file.sh" file to set extraction range in L4 to L7 (jleft, ibottom, jright, itop) suggested by calc_area.f90.

⑤ Execute "bash read_rt_file.sh" to extract data

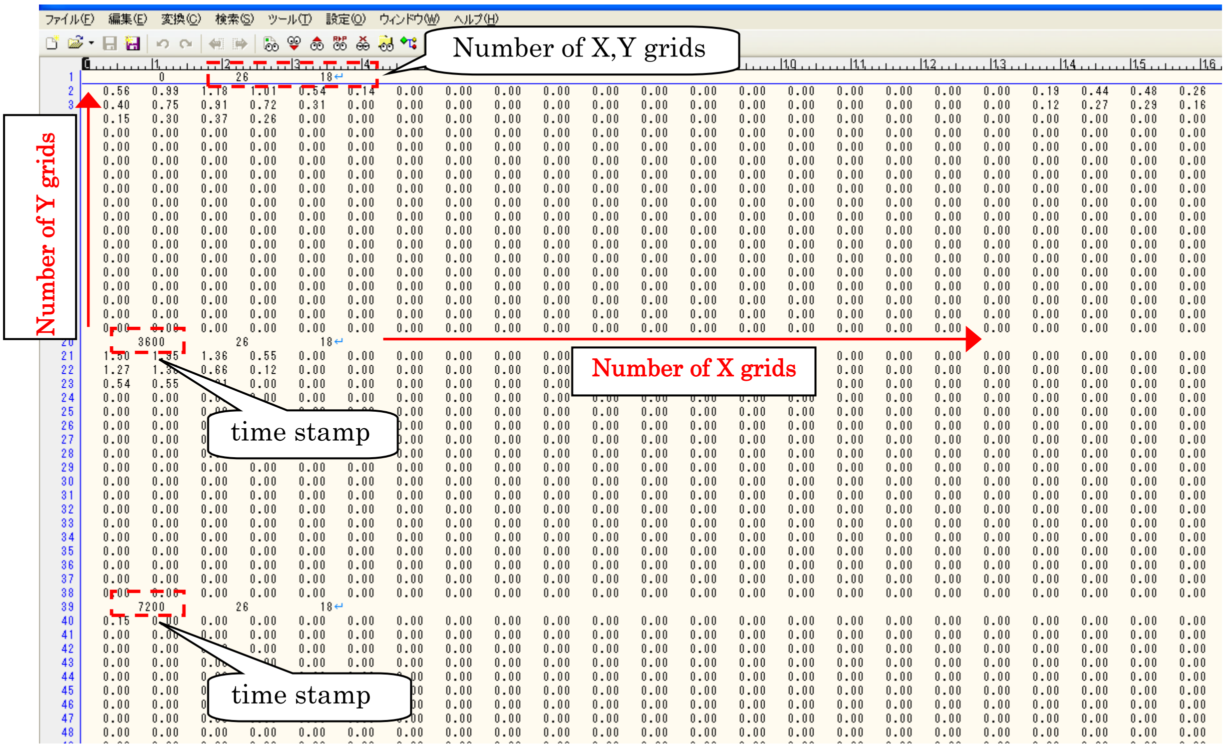
Note: the extract does not run if the same output files already exist

⑥ Edit "combine.sh" by setting the extraction range in L4 to L7 (jleft, ibottom, jright, itop) suggested by "out_by_calc_area.txt", and set output file name on L9. Also edit L14, L17 and L20 to indicate which year, month and day of the data should be processed.

⑦ Execute "bash ./combine.sh" to combine all rainfall files to create the RRI input, so that the rainfall file, which can be read by the RRI program, will be created.

4.4 Format of Input Rainfall Data for RRI Model

Here is the format of the input rainfall data used for RRI Model. By specifying the cell size, xll_corner and yll_corner of the rainfall data into a control file of RRI model (i.e. “RRI_Input.txt”), the model can overlay the rainfall distribution even if the ranges and the resolutions are different from topographic data as far as the rainfall data covers all the simulation extent.



※ The input unit of rainfall must be always **mm/hr** regardless the data interval.
※ The time interval is not necessary to be constant.
※ Rainfall between 3600 and 7200 is written under the time stamp of 7200
(just like rain gauge data).

【RRI_Input.txt】・・・Control file of the RRI Model

RRI_Input.txt

```
RRI_Input_Format_Ver1_4_2

./rain/rain.dat
./topo/adem.txt
./topo/acc.txt
./topo/adir.txt

0                # utm(1) or latlon(0)
1                # 4-direction (0), 8-direction(1)
360              # lasth
600              # dt
60               # dt_riv
96               # outnum
110.2d0          # xllcorner_rain
-8.3d0           # yllcorner_rain
0.00833333d0 0.00833333d0     # cellsize_rain
```

Coordinates and grid size of the south-west end of the rainfall data range

4.5 Calculation of Catchment Average Rainfall

To calculate catchment average rainfall from the input rainfall data, a user can use "rainBasin.exe" program. To run the program, "rainBasin.txt" must be prepared in the following way.

rainBasin.txt

```
./rain/rain.dat
./topo/adem.txt
110.2d0
-8.3d0
0.00833333d0 0.00833333d0
./rain/rain_hyeto.txt
./rain/rain_dist.txt
./rain/rain_cum.txt
```

L1 : [in] rainfall file (RRI format) [mm/h]

L2 : [in] catchment mask file (e.g. dem file)

L3 : [in] rainfall xll corner

L4 : [in] rainfall yll corner

L5 : [in] rainfall cellsize (x, y)

L6 : [out] hyetograph [mm/h]

L7 : [out] total rainfall distribution map [mm]

L8 : [out] cumulative rainfall [mm]

On command prompt, type in "rainBasin.exe" to create three output files identified in L6, L7 and L8 to show hyetograph, total rainfall distribution map and cumulative rainfall, respectively.

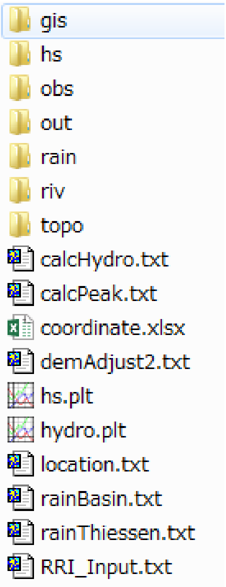
Note: To calculate average rainfall over a sub-catchment, one can replace the file indicated in L2. First, one can use GIS to delineate the sub-catchment and convert the mask into ASCII GIS format. For areas having pixel values greater than -10 will be considered as a sub-catchment area.

5. Conditions Setting for RRI Simulation

5.1 Folder Configuration

The following shows the folder configuration inside ./RRI-CUI/Project/solo30s

[./**RRI-CUI/Project/solo30s**]



Folders-

topo : Stores following sets of topographic data
- Digital elevation model (dem.txt)
- Adjusted digital elevation model (adem.txt)
- Flow accumulation (acc.txt)
- Flow direction (dir.txt)
- Adjusted flow direction (adir.txt)
- (optional) Land use data (landuse.txt)

rain : Stores following sets of input rainfall data
- Rainfall data (rain.dat)
- (optional) Evapotranspiration data (PET.txt)

out : Stores simulation results for each output time step
- hr_ : River water depth [m]
- hs_ : Slope water depth [m]
- qr_ : River discharge [m^3/s]
- qu_ : Slope discharge for x direction [m^3/s]
- qv_ : Slope discharge for y direction [m^3/s]
- gampt_ff : Green-Ampt cumulative water depth [m]
- storage.dat : water balance checking file

hs : Stores figures of inundation depths (hs) by gnuplot

gis : Stores GIS related data

obs: Stores observation related data

riv: Stores river section related data

【Control files】
- RRI_Input.txt : RRI model control file for 0_rri_1_4_2.exe
- demAdjust2.txt : demAdjustment program (demAdjust2.exe) [pre-processing]
- rainThiessen.txt : Rainfall processing program (rainThiessen.exe) [pre-processing]
- calcHydro.txt : Hydrograph calculation program (calcHydro.exe) [post-processing]
- calcPeak.txt : Peak inundation depth calculation program (calcPeak.exe) [post-processing]
- rainBasin.txt : Rainfall analysis program (rainBasin.exe) [post-processing]

【Input Files Other Programs and Files】
- hydro.plt : gnuplot script to draw hydrograph
- hs.plt : gnuplot script to create inundation depths figures (prepared by /etc/prepHsPlt)
- ciirdubate.xlsx: excel file to covert from (i, j) to (x, y) or (x, y) to (i, j)
- location.txt : Location list to draw hydrographs

5.2 RRI Model Control File (RRI_Input.txt)

RRI_Input.txt

```
L1   RRI_Input_Format_Ver1_4_2
L2
L3   ./rain/rain.dat
L4   ./topo/adem.txt
L5   ./topo/acc.txt
L6   ./topo/adir.txt
L7
L8   0                     # utm(1) or latlon(0)
L9   1                     # 4-direction (0), 8-direction(1)
L10  360                   # lasth [hour]
L11  600                   # dt [sec]
L12  60                    # dt_riv [sec]
L13  96                    # outnum [-]
L14  110.2d0               # xllcorner_rain
L15  -8.3d0                # yllcorner_rain
L16  0.00833333d0 0.00833333d0     # cellsize_rain
L17
```

Note that #comment is allowed only for lines with numbers like L8 to L16, but it is not allowed for lines with characters like L3 to L6.

L1 : Version of the control file format.

This version has to be compatible with the RRI program version. When RRI Model version is updated, user may be requested to modify this control file to be suitable for the updated version.

L3 – L6 : Paths of the input files (rainfall, dem, acc, dir)

Note that adjusted direction file having zero at the outlet must be read in the flow direction column. This adjustment (for dem and dir) can be implemented through the process of demAdjust2.

L8 : Topographic and rainfall data coordinate system (UTM (1) or Lat Lon(0))

L9 : Simulating with 4- (0) or 8-direction (1) by the two dimensional model [default : 1]

L10 : Simulation period [hour]

L11 : Simulation time step [sec], [default : 600 sec]

L12 : Simulation time step for river [sec], [default : 60 sec]

The above time steps are just initial setting. The adaptive Runge-Kutta algorithm used for RRI simulation may shorten the time steps if necessary.

L13 : Number of output files

Simulation period specified above is equally divided for simulation output.

L14 – L16 : South west coordinate and resolution of rainfall data

Number of col and row are written in the rainfall data.

RRI_Input.txt

```
L18  0.03d0       # ns_river
L19  1            # num_of_landuse
L20  1            # diffusion(1) or kinematic(0)
L21  0.4d0        # ns_slope
L22  1.0d0        # soildepth
L23  0.475d0      # gammaa
L24
L25  0.d0         # kv (m/s)
L26  0.3163d0     # Sf (m)
L27
L28  0.0d0        # ka (m/s)
L29  0.0d0        # gammam (-)
L30  0.0d0        # beta (-)
L31
```

L18 : Manning's roughness in river channel

L19 : Number of landuse

Parameter sets specified below should correspond to the number of landuse specified here. For example, if there are three landuse types in a catchment, write three different parameter sets. Prepare also the landuse map which has numbers from one to three, so that the parameter sets described below will be assigned to each landuse grid cell. First column parameters are assigned to landuse type "1" in the landuse map.

L20 : diffusion (1) or kinematic (0) [default : 1]

The default mode of RRI model uses diffusion wave equations. However, by setting zero here, RRI model can use kinematic wave approximation.

L21 : Manning's roughness on slope cells

L22 : Soil depths [m]

L23 : Effective porosity [-]

L25, L26 : Green-Ampt infiltration model parameters

Set ksv = 0 for inactivating Green-Ampt infiltration model.

"ksv" : vertical saturated hydraulic conductivity [m/s], "faif" is the suction at the wetting front defined by S_f.

Note: In the previous versions of RRI Model, "delta" and "infilt_limit" parameters were used. The parameter "delta" is now replaced by "gamma" to represent soil porosity minus initial water volume content ($\phi - \theta_i$). The "infilt_limit" parameter is computed within the RRI program by multiplying "soildepth" and "gamma" to estimate the maximum cumulative infiltration depths in meter. Once the cumulative infiltration depths reaches to this maximum depths, no more infiltration happens at the grid-cells.

L28 – L30 : lateral subsurface and surface model parameters

L28 and L30 are options to consider unsaturated and saturated subsurface flow and surface flow in lateral direction. "kv" is lateral saturated hydraulic conductivity (which is typically two or three orders high compared with the vertical hydraulic conductivity set for Green-Ampt model. To start with, set zero for "dm" to inactivate the option to consider unsaturated subsurface flow. Setting zero makes no saturated subsurface flow consideration. See 8.7 for the details of the parameter settings.

Note: In the previous version of RRI Model, a parameter "da" was used to represent maximum water depth in saturated subsurface flow. Now this is calculated as "soil depth" times "gammaa" within the program.

L32 – L36

Set "ksg = 0.d0" to avoid deep groundwater component, whose algorithm is under development and not completed at RRI ver1.4.2. L33-L36 become inactive with ksg = 0.d0.

L38 – L44 : River channel geometry setting by equations

$$width = c_w A^{s_w}$$

$$depth = c_d A^{s_d}$$

The above equations are used as default settings for river channel widths and depths.
Note that A in the equations is the upstream catchment area [km^2] for each river grid-cell.

L46 – L49 : River channel geometry setting by files (optional)

If one would like to set width, depth and embankment height from files instead of the above equations, set 1 in L46 and prepare the files in ESRI/ASCII format.

```
L38  100              # riv_thresh
L39  5.0d0            # width_param_c
L40  0.35d0           # width_param_s
L41  0.95d0           # depth_param_c
L42  0.20d0           # depth_param_s
L43  0.d0             # height_param
L44  20               # height_limit_param
L45
L46  0
L47  ./riv/width.txt
L48  ./riv/depth.txt
L49  ./riv/height.txt
L50
```

RRI_Input.txt

L51 – L55 : Initial water depth on slope, river, groundwater and GA Model cumulative by files (optional)

If one would like to set initial water depths on slope and river for each grid cell, set 1 in L51 and prepare the initial condition distribution files specified in L52, L53, L54 and L55. Note that the format of the files is the same as RRI model output.

```
L51  0 0 0 0
L52  ./init/hs_init_dummy.out
L53  ./init/hr_init_dummy.out
L54  ./init/hg_init_dummy.out
L55  ./init/gamptff_init_dummy.out
L56
L57  0 0
L58  ./bound/hs_bound.txt
L59  ./bound/hr_bound.txt
L60
L61  0 0
L62  ./bound/qs_bound.txt
L63  ./bound/qr_bound.txt
L64
```

RRI_Input.txt

L57 – L59 : Water depths boundary conditions (optional)

L57 : Slope water depths boundary conditions, L58 : River water depths boundary conditions

See Section 8 for the format of the boundary condition files. Use flag 1 for one-dimensional data format (i.e. time series data at specific boundary condition locations). Use flag 2 in case the boundary condition files are prepared in two-dimensional data format, whose number of grid-cells must be the same as the topographic data including dem, dir, and acc. In both cases, time stamps in the boundary condition can vary within the file.

L61 – L63 : Water discharge boundary conditions (optional)

(Same as L57 – L59)

RRI_Input.txt

```
L65  0
L66  ./topo/landuse.txt
L67
L68  0
L69  ./dam.txt
L70
L71  0
L72  ./div.txt
L73
L74  0
L75  ./infile/PET.txt
L76  110.2d0                    # xllcorner_evp
L77  -8.3d0                     # yllcorner_evp
L78  0.00833333d0 0.00833333d0      # cellsize_rain
L79
L80  0
L81  ./riv/length.txt
L82
L83  0
L84  ./riv/sec_map.txt
L85  ./riv/section/sec_
L86
```

L65 – L66 : Landuse setting (optional)

If one would like to use multiple parameter sets for different grid-cells, set 1 in L65 and read landuse file specified in L66.

L68 – L69 : Dam condition setting (optional)

RRI model simulates the effect of dam reservoir operations based on simple rule. Refer to the source code "RRI_Dam.f90" for details. (See also 8.11)

L71 – L72 : River diversion setting (optional)

River channel diversion setting (See also 8.10)

L74 – L78 : Evapotranspiration setting (optional)

Prepare ET file and specify the path on L75. The format of ET file is the same as rainfall. The resolution and xll and yll corners can be different from the rainfall file as far as it covers all the simulation domain.

L80 – L81 : River length setting (optional) : newly added option to set arbitrary the length of river channel for each river grid cell (under preparation for more detail on this option).

L83 – L85 : River cross section settings (optional) : newly added option to set arbitrary cross section information for each river grid cell (under preparation for more detail on this option).

RRI_Input.txt

```
L87  | 1 1 0 1 0 0 0 0 0 1
L88  | ./out/hs_
L89  | ./out/hr_
L90  | ./out/hg_
L91  | ./out/qr_
L92  | ./out/qu_
L93  | ./out/qv_
L94  | ./out/gu_
L95  | ./out/gv_
L96  | ./out/gampt_ff_
L97  | ./out/storage.dat
L98  |
L99  | 1
L100 |  ./location.txt
```

L87 – L97 : Output file settings

Change the settings of L87 to “1” to output different sets of simulation results listed in the same order between L88 and L97

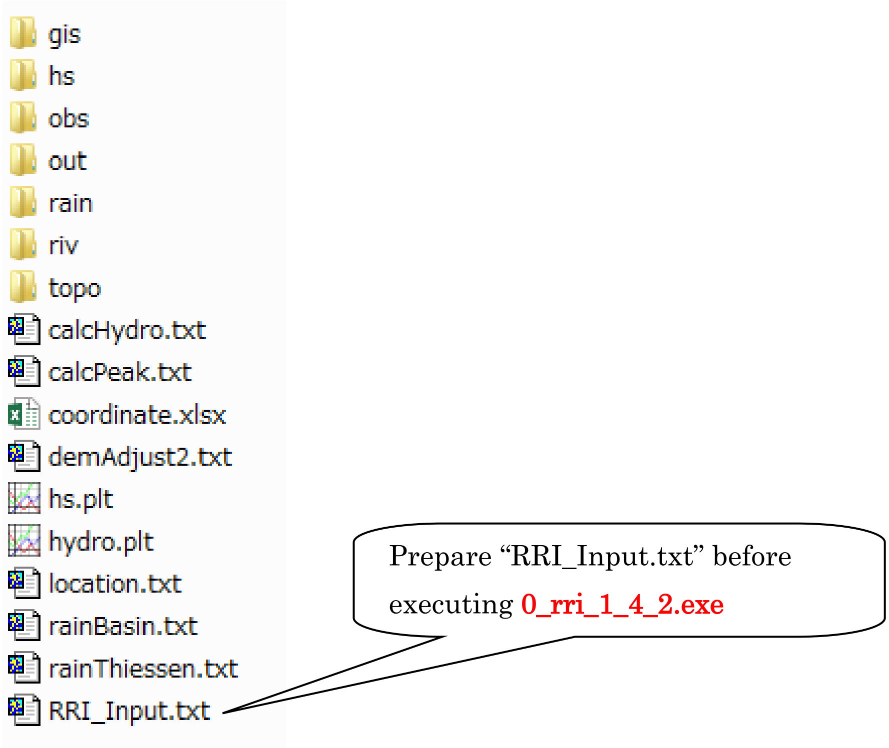
L99 – L100 : Output hydrographs at specified locations (Optional)

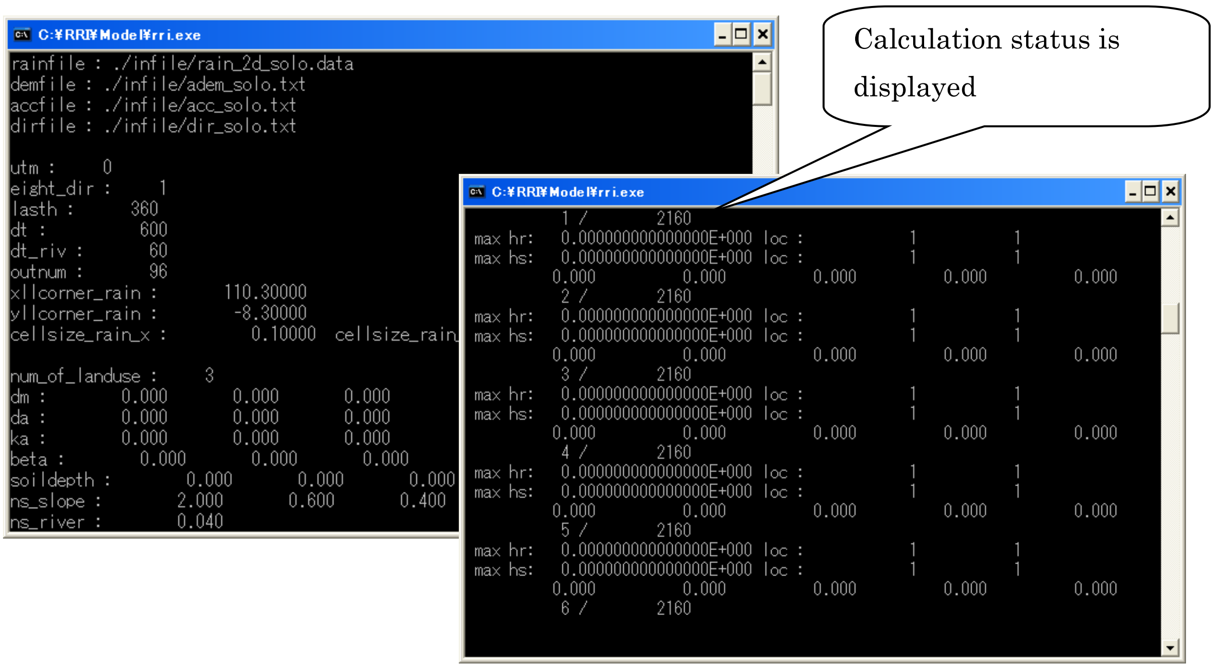
Set 1 in L99 to read the location file and output hydrographs at the specified locations.

6. Running RRI Model

① Prepare “RRI_Input.txt” under your project folder (e.g. “./RRI-CUI/Project/solo30s)”

② Move current folder to your project folder and type in “0_rri_1_4_2.exe” and return.



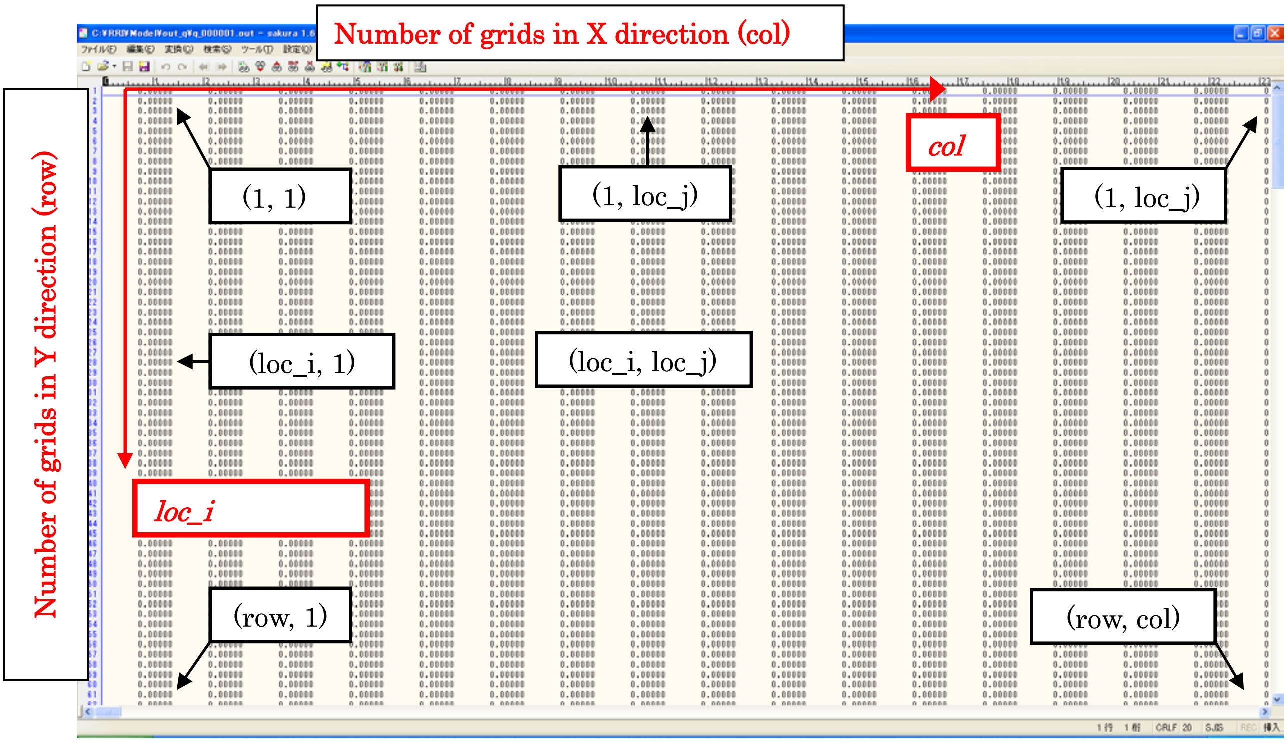


7. Visualize Output Data

This section explains how to visualize RRI Model output.

7.1 Format of the Output Files

Each output file contains water depths on slope (hs_) and on river (hr_) and river discharges (qr_) on river at a particular time step. The units of the output are [m] for water depths and [m^3/s] for discharge.



※The numbers of rows and columns are the same as those of the topographic data.

Note that for each type of model output, the number of the files is defined in RRI_Input.txt (L13 : outnum). The simulation period is equally divided by "outnum" and the number assigned to each output file represents the output time stamp.

7.2 Visualize Inundation Depth with GNUPLOT

GNUPLOT can be used to illustrate flood inundation depth distributions. Inside the project folder, the GNUPLOT script named "hs.plt" is included. To change the settings, one can edit "hs.plt" directly or create another "hs.plt" by using a Fortran program named "prepHsPlt.f90" saved in "RRI/etc/prepHsPlt".

① Edit “hs.plt” file to change the configurations.

```
reset

set terminal gif medium size 672, 408 crop

set pm3d map
set palette defined (0.0 "gray", 1.5 "blue", 3 "green")

set xrange [0:]
set yrange [:] reverse
set zrange [0:] reverse

#set xrange [180:200]
#set yrange [435:455] reverse

set cbrange[0.:3]
set zrange[0.0:]

set output "./hs/hs_000001.gif"
splot "./out/hs_000001.out" matrix t "000001 / 000096"

set output "./hs/hs_000002.gif"
splot "./out/hs_000002.out" matrix t "000002 / 000096"

set output "./hs/hs_000003.gif"
splot "./out/hs_000003.out" matrix t "000003 / 000096"
```

hs_plt.txt

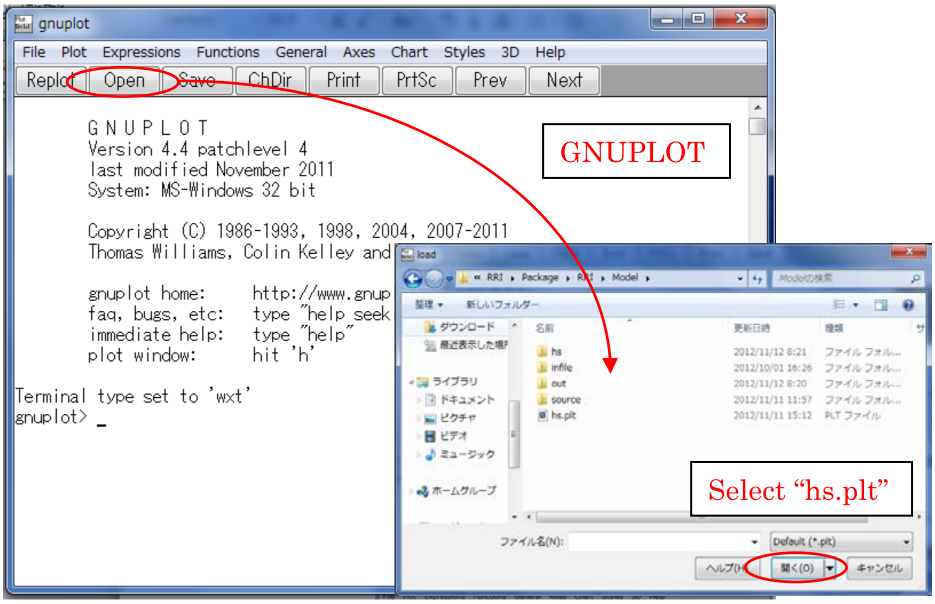
The size of output GIF file, X and Y direction. Use the same X and Y ratio as DEM’s col and row.

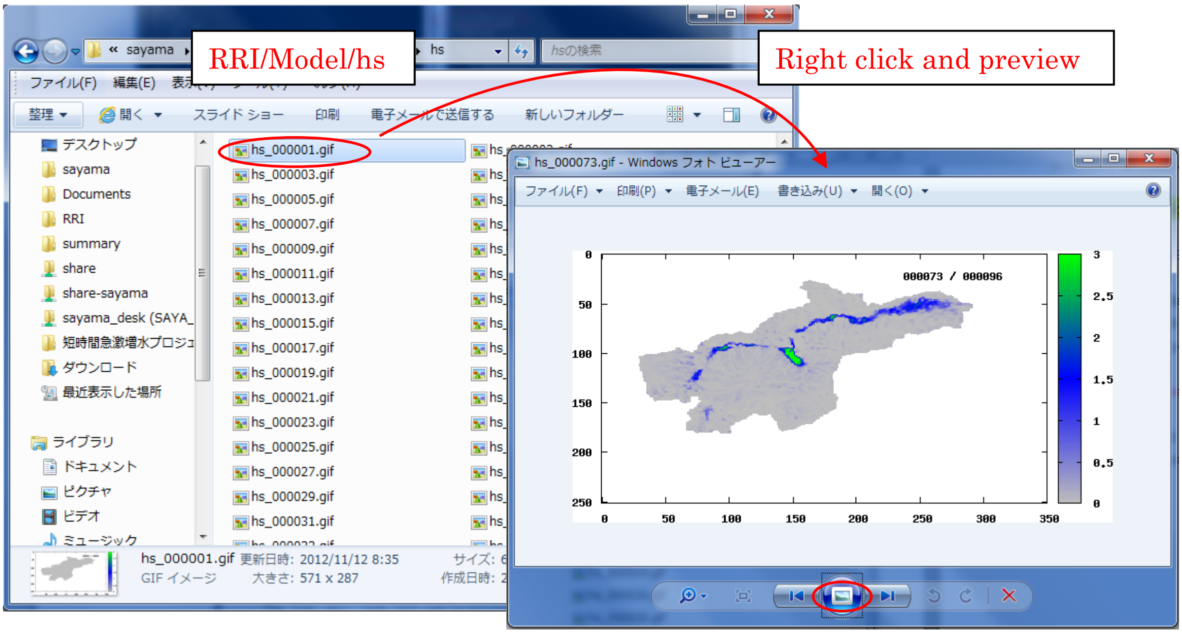
Color pattern settings

Color range

From RRI output (hs_***.out) to gif

② Start GNUPLOT program by clicking “/RRI-CUI/etc/gnuplot/binary/wgnuplot.exe”
Then open and select “hs.plt” script file.





7.3 Hydrographs at Specific Locations

A Fortran program named “calcHydro.exe” can be used to generate hydrographs by picking up values from “out/qr_***.txt” at specified locations.

① Edit “RRI/Model/calcHydro.txt” (see more details “RRI-CUI/etc/calcHydro/00_readme.txt”)

L1 : [In] location file (e.g. ./infile/solo30s/location_solo_30s.txt)

L2 : [In] RRI output file (e.g. ./out/qr_)

L3 : [Out] hydrograph file (e.g. ./infile/solo30s/disc_)

calcHydro.txt

```
./infile/solo30s/location_solo_30s.txt
out/qr_
./infile/solo30s/disc_
```

location_30s_solo.txt

```
Cepu 68 167
(list all target locations)
```

② Run “calcHydro.exe”. (Execute “makePostProcess.bat” in advance to compile.)

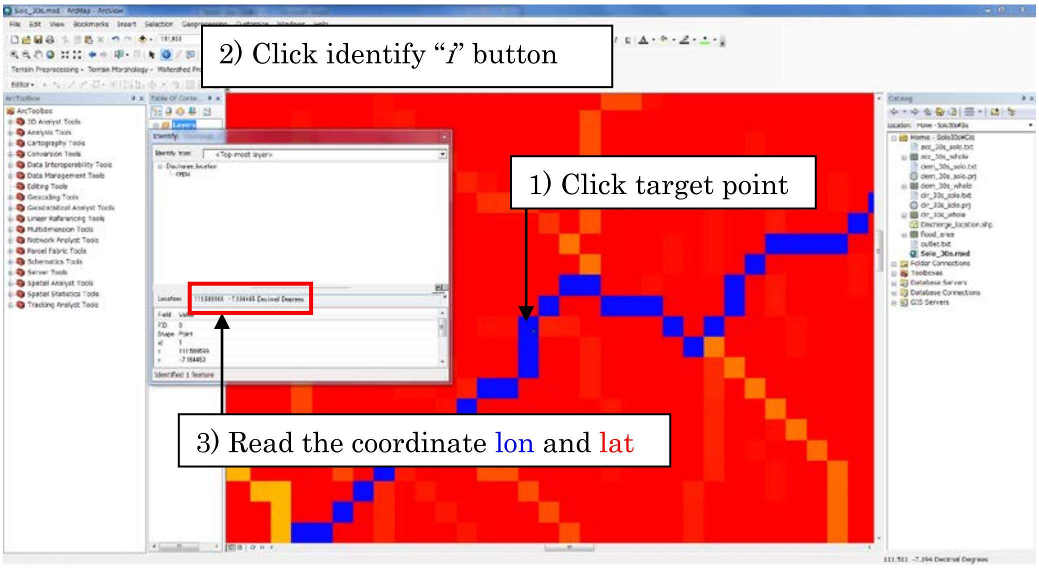
③ Check the created files specified in L3 of “calcHydro.txt”. (e.g. ./infile/solo30s/disc_)

④ From GNUPLOT screen, open and select “hydrograph.plt”, which is a GNUPLOT script file to plot hydrographs. Any other plotting software, such as Excel, can be also used to draw hydrographs from created files (e.g. ./infile/solo30s/disc_Cepu.txt).

In the location file (e.g. ./infile/solo30s/location_solo_30s.txt), one can list all target points, which you want to calculate hydrographs. Write the "*name of location*" and "loc_i" (y-direction) and "loc_j" (x-direction)
Note that "loc_i" is the row (y-direction from top) and "loc_j" is the col (x-direction from left).

To identify the observation points in mesh coordinate (loc_i, loc_j), one can use "/RRI/etc/coordinate.xlsx" to calculate based on the coordinate in latitude(y) and longitude(x).

① Find the latitude (y) and longitude (x) of the observation point using ArcGIS.



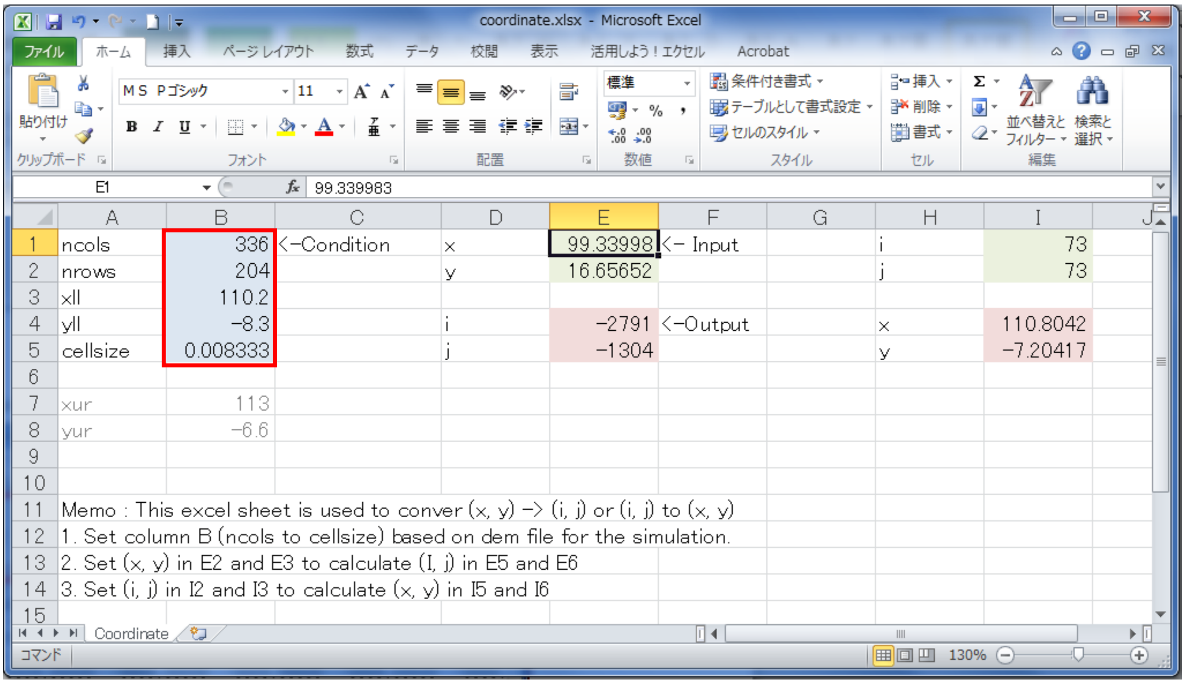
(Displaying "acc" on top to make sure the selected point is on a river grid cell.)

② Open one of the topographic data (i.e. dem, dir, or acc)

acc_solo_30s.txt

```
ncols          336
nrows           204
xllcorner      110.2
yllcorner      -8.3
cellsize       0.00833333333333
NODATA_value   -9999
 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
-9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999 -9999
```

③ Read the header part (red box in the above figure) of the topographic data and copy the same information in the Excel file (i.e. /RRI-CUI/etc/coordinate.xlsx).



④ Type x and y (or lon and lat) coordinate of the target point, then the calculated mesh coordinate (loc_i, loc_j) appears in (E4, E5).

("coordinate.xlsx" can be used also to convert from (loc_i, loc_j) to (lon, lat).

7.4 Visualize Peak Inundation Depths

Fortran program named "calcPeak.exe" can be used to compute the maximum flood depths based on RRI Model output ("out/hs_*.out"). See 2.2.3 the procedure more in detail.

① Edit "RRI/Model/calcPeak.txt" file after RRI model execution.
In "calcPeak.txt", L1 sets the path of dem file, L2 sets the RRI model output file to calculate the peak, and L3 sets the number of output files. L4 defines the output file of calcPeak program. See details the readme file of "/etc/calcPeak".

② Execute "calcPeak.exe". (Execute "makePostProcess.bat" if the executable file does not exist.)

③ Check the created files specified in L4 of "calcPeak.txt".

④ The obtained peak water data follows ESRI/ASCII format that can be visualized with ArcGIS.

7.5 Visualize Inundation Depths with Google Earth (Optional)

7.5.1 Preparing KML File

By using “RRI/etc/makeKML.f90”, a kml file (e.g. “runoff.kml”) can be prepared.
User needs to edit “RRI/etc/Kml_input.txt”.

Kml_input.txt

```
2007   12   24    0    0                : Start time (Year Month Day Hour Min ( UTC ))
  96                                    : Number of gif files( ＝ "outnum" of RRI_Input.txt )
 3.75                                   : Timestep (hourly) ( ≒ "lasth / outnum" of RRI_Input.txt )
./infile/solo/adem_30s_solo.txt         : Dem file name (for lat,lon)
./runoff.kml                            : Output file name
```

“Time step” needs to be input as “hourly” data.
This “Time step” should be “lasth” / ”outnum” input in ”RRI_Input.dat”.

When it is executed, “runoff.kml” is output.

runoff.kml

```
<Folder>
 <GroundOverlay>
  <TimeSpan>
   <begin>2007-12-24T00:00Z</begin>
   <end>2007-12-24T03:45Z</end>
  </TimeSpan>
  <Icon>
    <href>hs_kml/hs_000001.gif</href>
  </Icon>
  <LatLonBox>
   <north>   -6.60000</north>
   <south>   -8.30000</south>
   <east> 113.00000</east>
   <west> 110.20000</west>
  </LatLonBox>
 </GroundOverlay>
…
```

※ The output of “runoff.kml” reads gif files created in the folder of “hs_kml”.

7.5.2 Preparing GIF Files with GNUPLOT

The method of plotting “hs_kml.plt” using “gnuplot” is shown below.

① Prepare a gnuplot file (e.g. “RRI/Model/hs_kml.plt”), which can be essentially the same as hs.plt explained above. However, the gnuplot script file used here (i.e. hs_kml.plt) must have some additional statements in the blue box in the following figure. The statements delete unnecessary axis and legends to be appropriately overlay on Google Earth.

hs_kml.plt

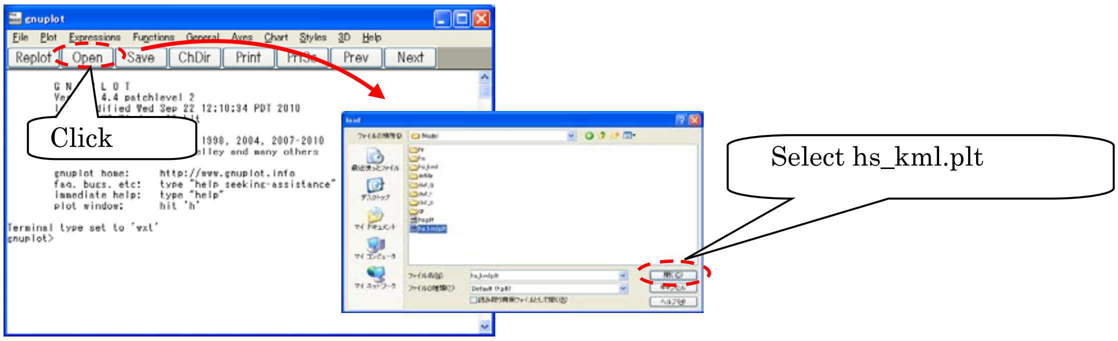
```
reset

set terminal gif medium size 672, 408 crop

set lmargin 0
set bmargin 0
set rmargin 0
set tmargin 0
set notics
set nokey
unset colorbox

set pm3d map
set palette defined (0.0 "gray", 1.5 "blue", 3 "green")

set xrange [0:]
set yrange [:] reverse
set zrange [0:] reverse

#set xrange [180:200]
#set yrange [435:455] reverse

set cbrange[0.:3]
set zrange[0.0:]

set output "./hs_kml/hs_000001.gif"
splot "./out/hs_000001.out" matrix t "000001 / 000096"
…
```

modify (672, 408): Designate size so that the aspect ratio of size and ratio of number of meshes match.

add (set lmargin 0 … unset colorbox): This part must be added to the original hs.plt file.

modify (/hs_kml/): The folder name, “hs_kml” should be input here.

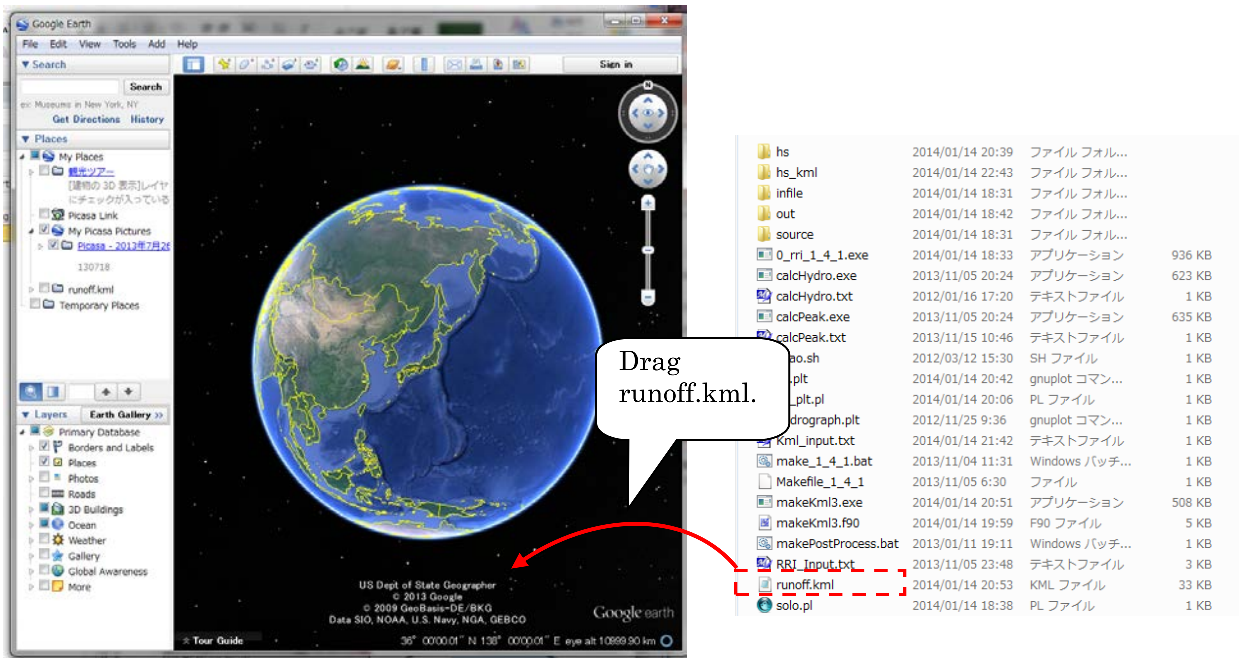
② Start “GNUPLOT” and run “RRI/Model/ hs_kml.plt”.

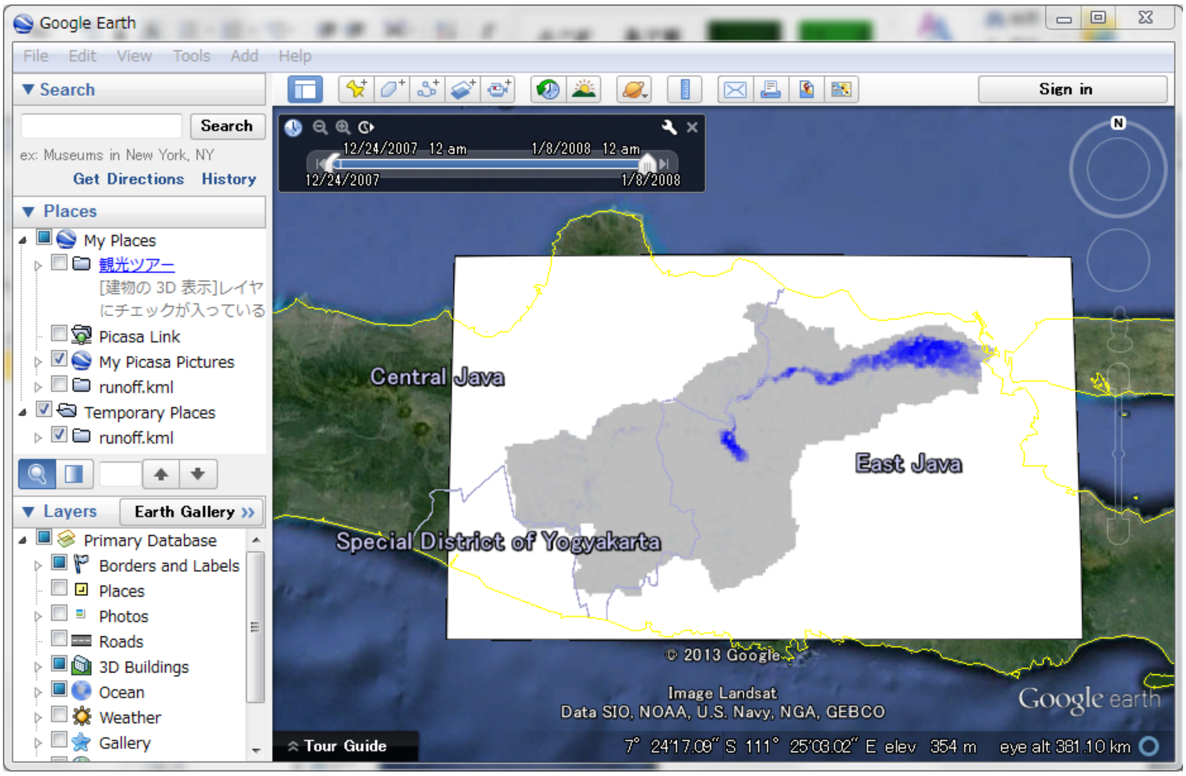


③ An image file is prepared in the “RRI/Model/hs_kml” folder. (Note that a new folder hs_kml must be created in advance.)

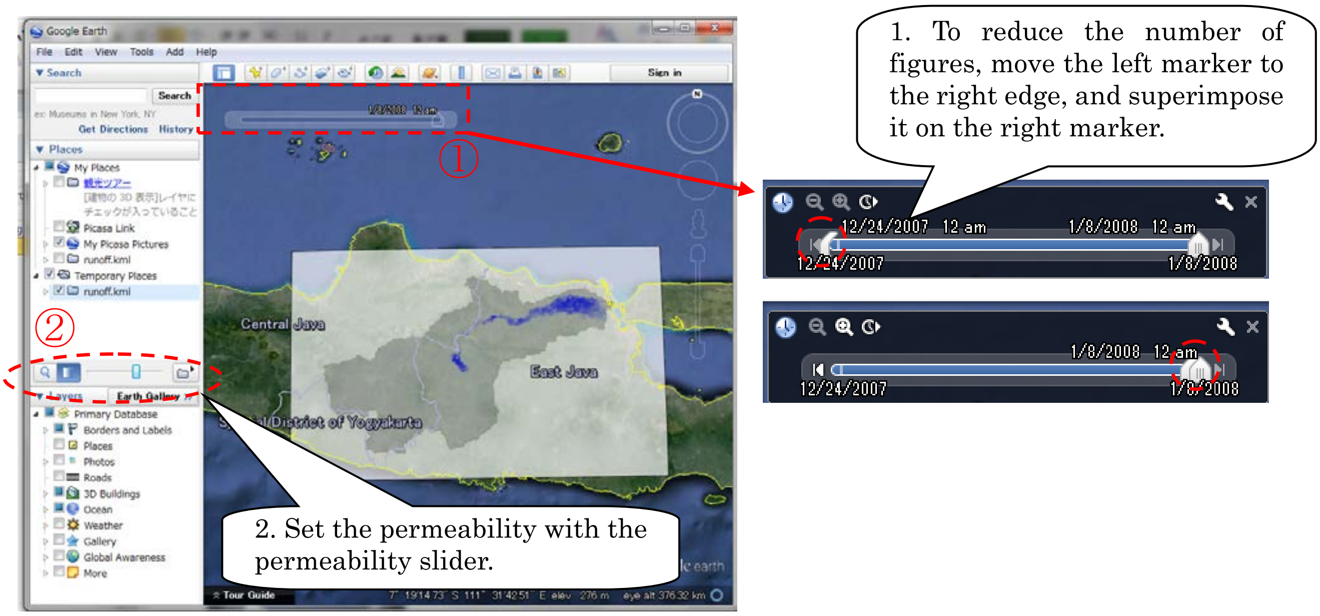
7.5.3 Visualize GIF files with Google Earth

① Start Google Earth and drag “/RRI/Model/runoff.kml”.



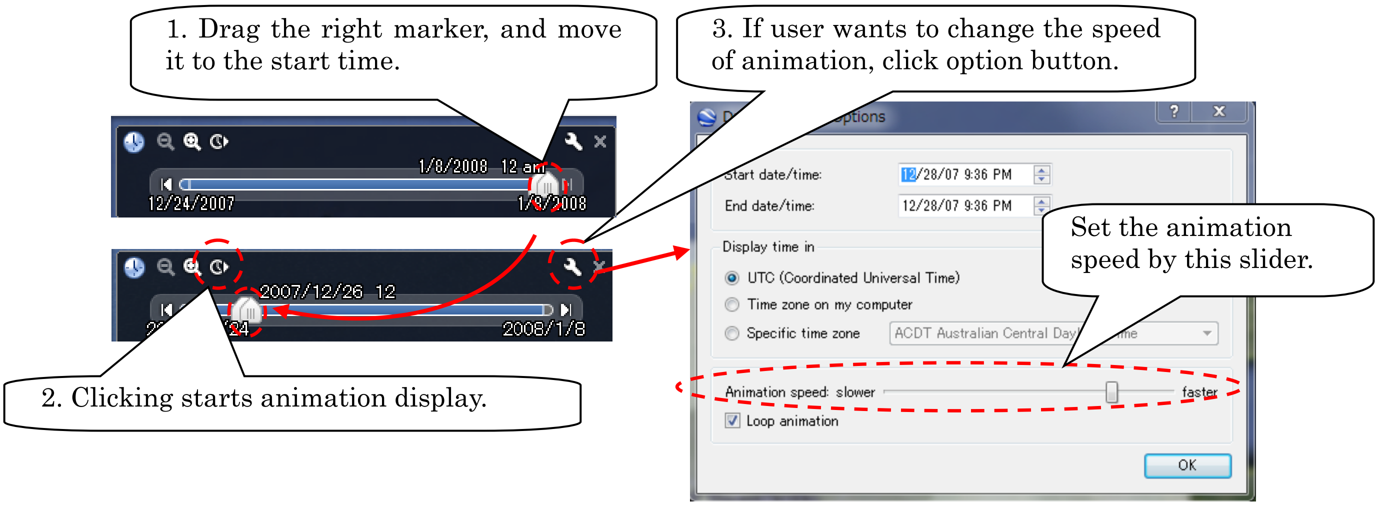


② Designate the number of figures to display at once and their transparency.



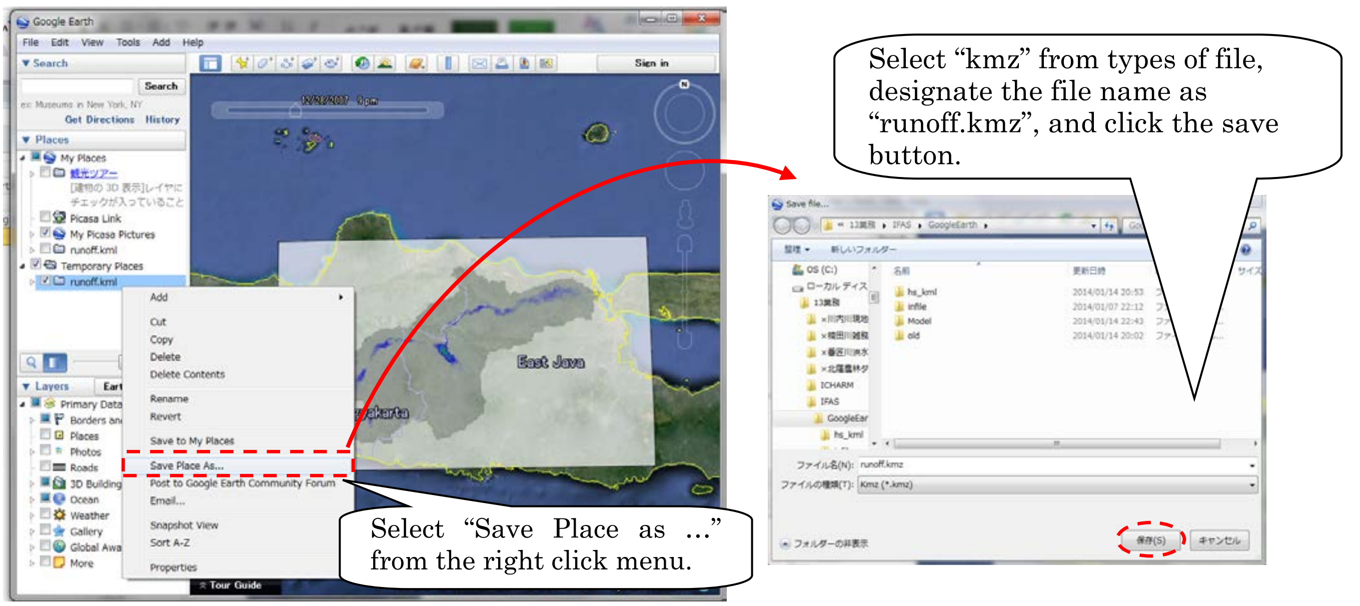
※ On time slider: The right marker represents the present time, while the left marker is used for the number of figures to overlay. Figures in the period between two markers are displayed.

③ Execute animation.



※ <note>. During the animation, two markers should be moved at the same time.
If user can't move the left marker, stop the animation and fit the left marker to the position of right marker and restart the animation.

④ Save the results with kmz file, so that it can be distributed to other users without gif files.



7.6 Visualize Results with Tecplot (Optional)

7.6.1 Preparing input File of Tecplot

calcTecplot.txt

```
2007 12 24 00                    # start time
360                              # lasth [hour]
96                               # outnum [-]

./Model/infile/solo30s/rain_solo_30s_gauge.dat
./Model/infile/solo30s/adem_30s_solo.txt

110.2d0             # xllcorner_rain
-8.3d0              # yllcorner_rain
0.00833333d0 0.00833333d0     # cellsize_rain

1 1 0 1 1 1 0 0 0 1
./Model/out/hs_
./Model/out/hr_
./Model/out/hg_
./Model/out/qr_
./Model/out/qu_
./Model/out/qv_
./Model/out/gu_
./Model/out/gv_
./Model/out/gampt_ff_

./calcTecplot_out.dat

TITLE        = "Internally created data set"
VARIABLES = "X"
"Y"
"DEM (m)"
"Rainfall (mm/h)"
"Water depth hs (m)"
"Water depth hr (m)"
"Water depth hg (m)"
"River discharge qr (m3/s)"
"Slope discharge qu (m3/s)"
"Slope discharge qv (m3/s)"
"Ground discharge gu (m3/s) "
"Ground discharge gv (m3/s)"
"g-ampt (m)"

ZONE T="Contour T ="
STRANDID=1, SOLUTIONTIME=
I=336, J=204, K=1, ZONETYPE=Ordered
DATAPACKING=POINT
DT=(SINGLE SINGLE SINGLE SINGLE SINGLE SINGLE SINGLE SINGLE SINGLE
SINGLE SINGLE SINGLE SINGLE)
```

: Year, Month, Day, Hour

: calculation time (l.10)

: output file number (l.13)

: Rainfall file (l.3)

: Dem file (l.4)

grid data of Rainfall (from l.14 to l.16)

Output file from RRI (from l.87 to l.96)

User needs to edit these lines in "calcTecplot.txt". All the lines except for the first line (start time) can be copied from "RRI_Input.txt" to be compatible with simulation setting.

Output file name for Tecplot (use "dat" for the extention)

All data outside the red border are header information, which is not necessary to be modified.

"VARIABLES =" …" shows the variables to be displayed on Tecplot. Edit this if necessary.

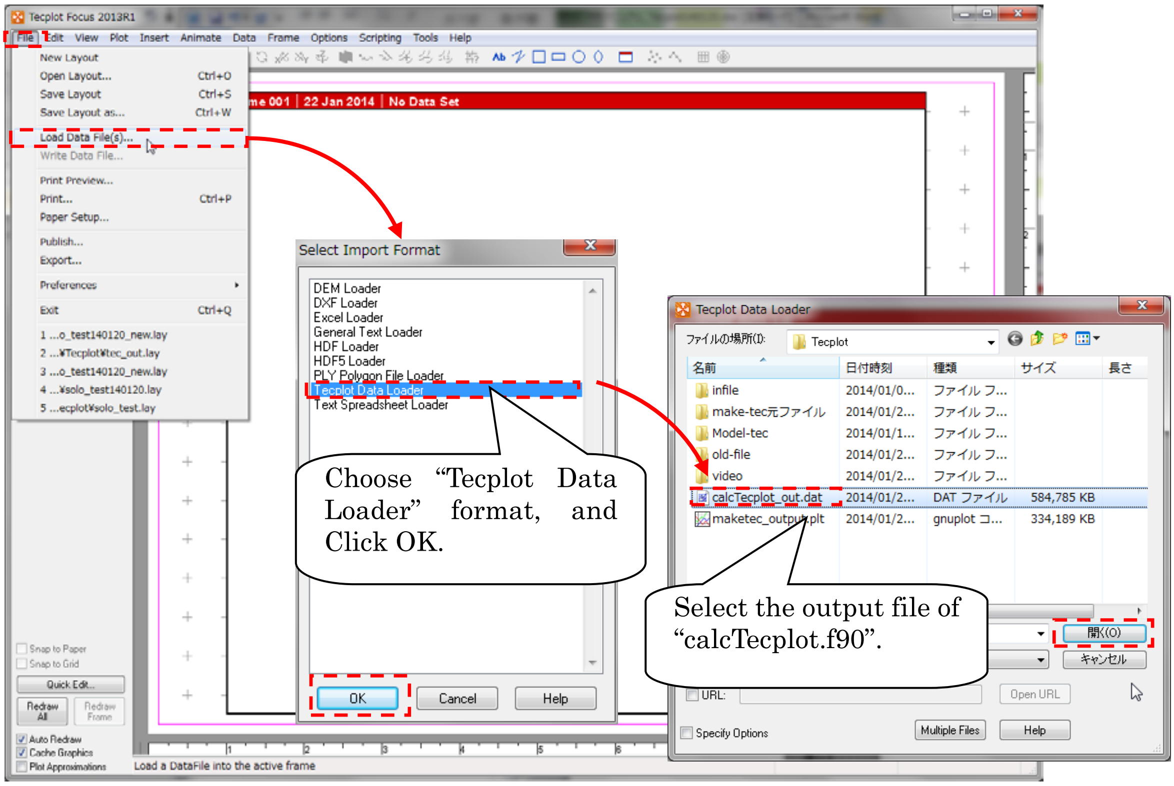
Use "RRI/etc/calcTecplot.f90" to prepare an input file for Tecplot (e.g. "calcTecplot_out.dat"). Prior to running calcTecplot.exe, edit "RRI/etc/calcTecplot.txt", which sets the condition for generating the input file.

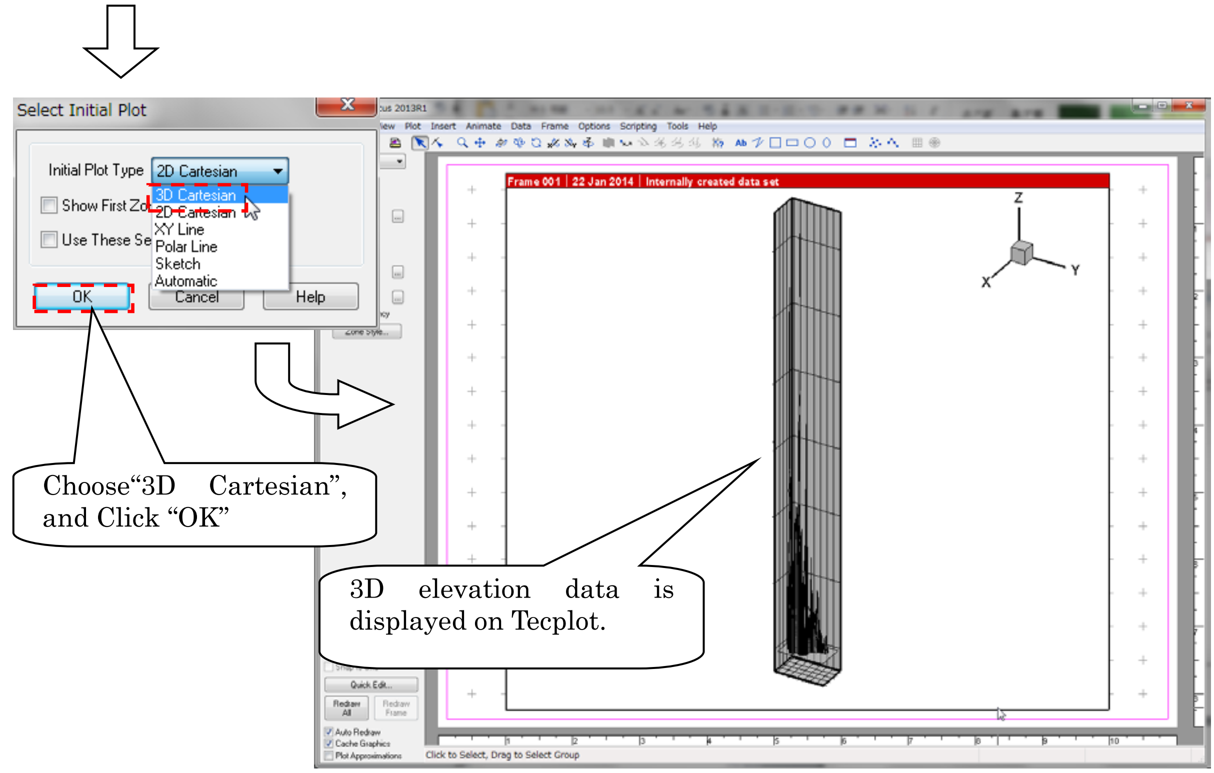
7.6.2 Displaying on Tecplot

① Start Tecplot, and load data file.

[File] > [Load Data file(s)] > [Tecplot Data Loader] > [calcTecplot_out.dat]

It takes several minutes to load the data file.



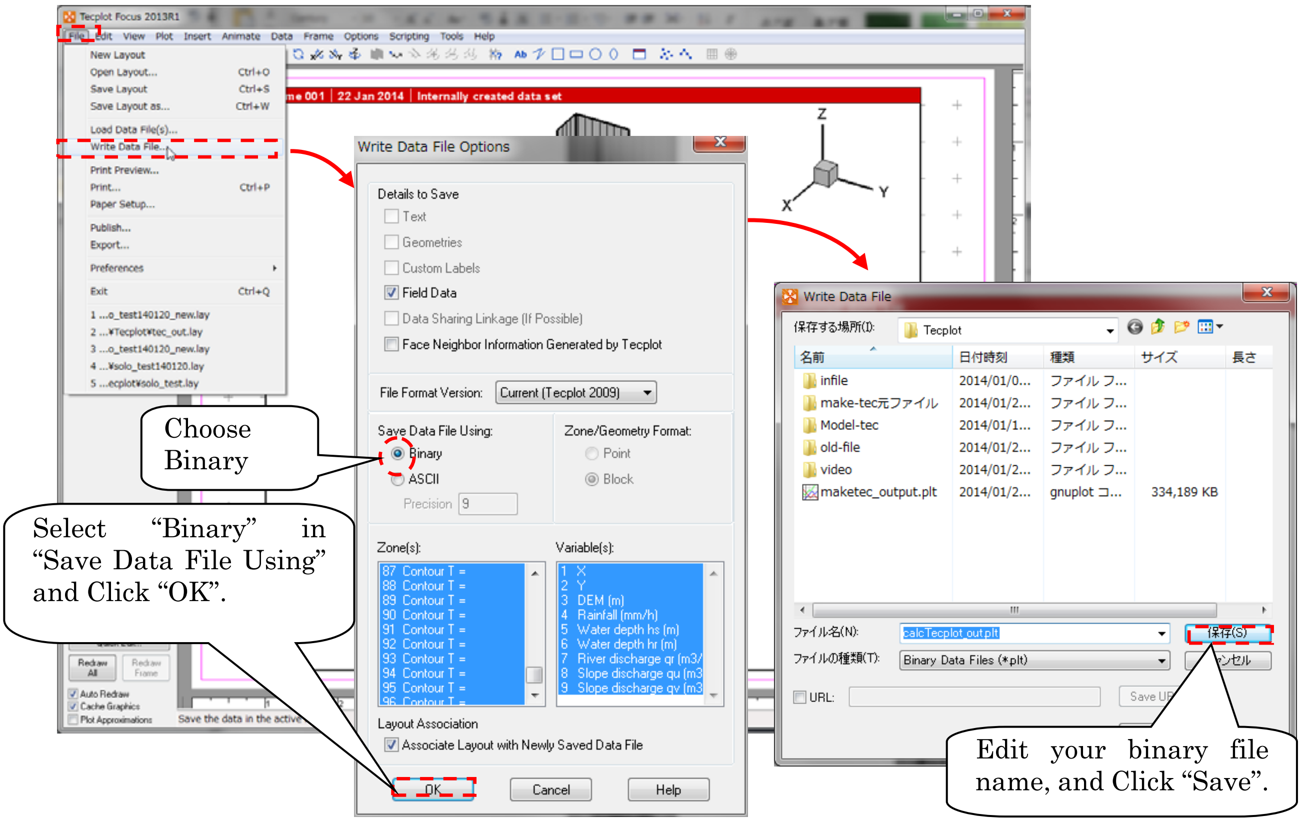


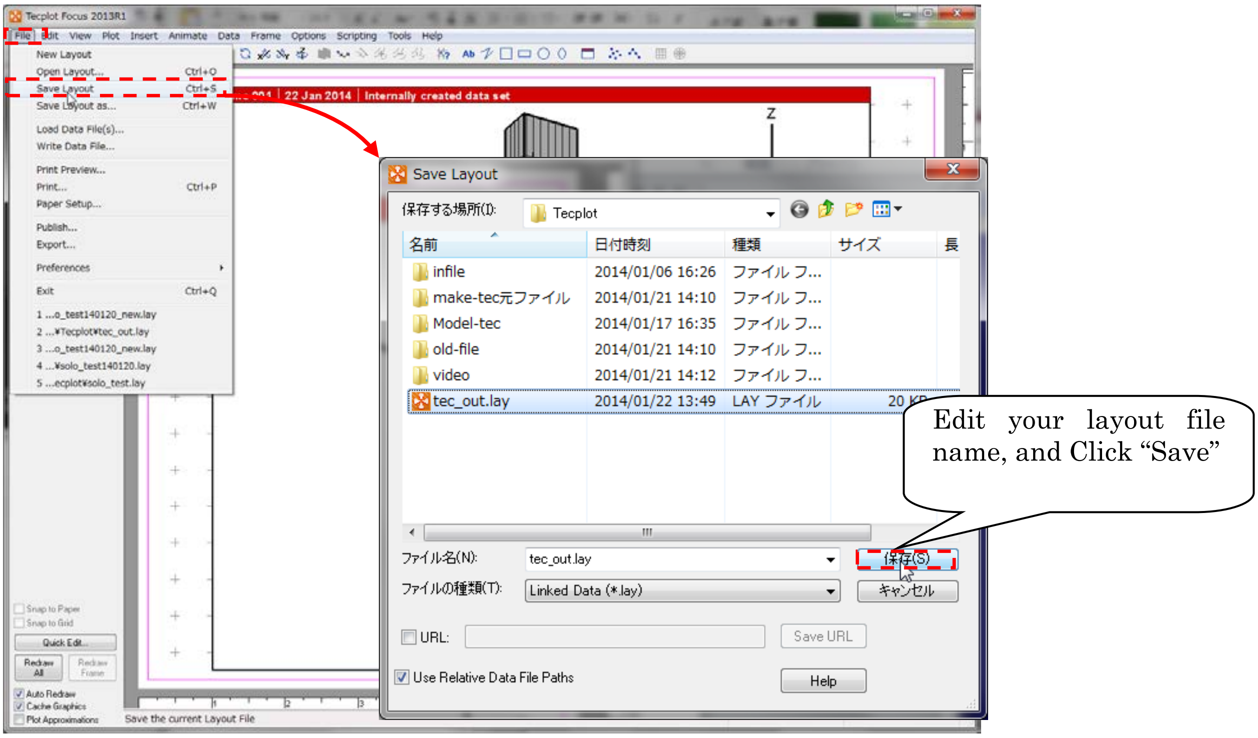
② Write data file (changing input data to binary data), and also save as layout file.

[File] > [Write Data file…]

[File] > [Save Layout] ..

By Making the binary data (*.plt), user can reduce the amount of time to reload layout file. User needs longer time to reload without the binary file.

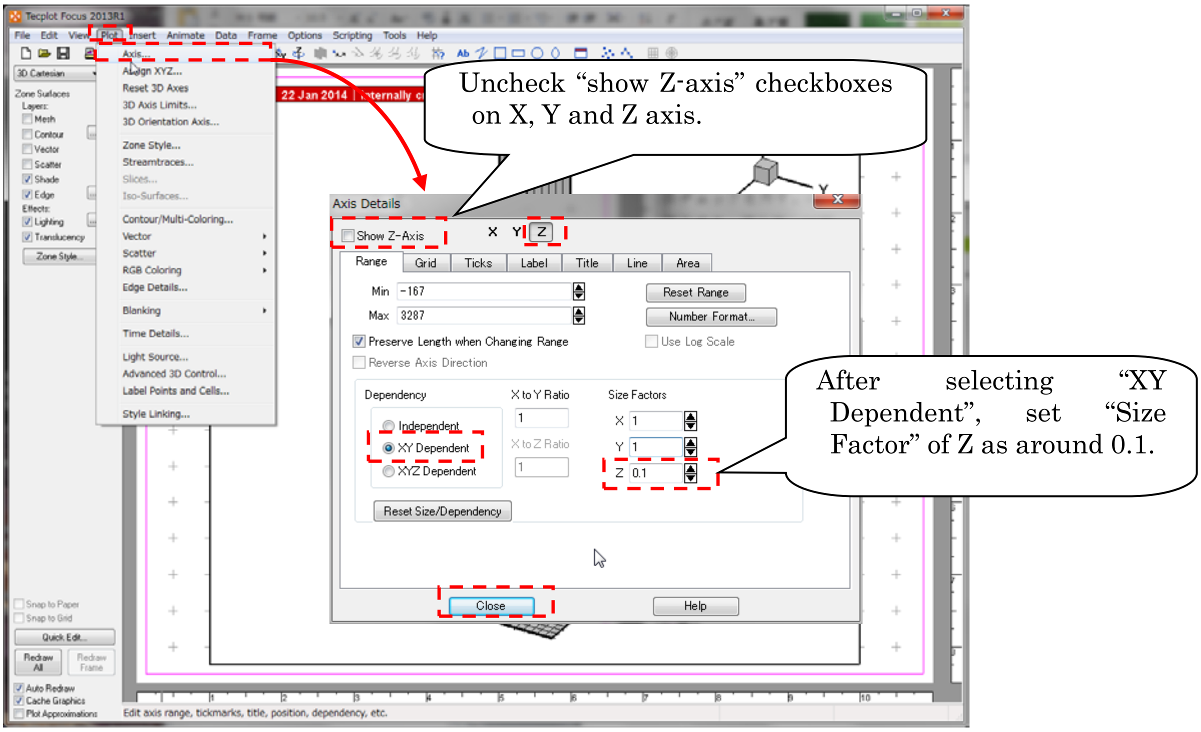




7.6.3 Edit display options on Tecplot

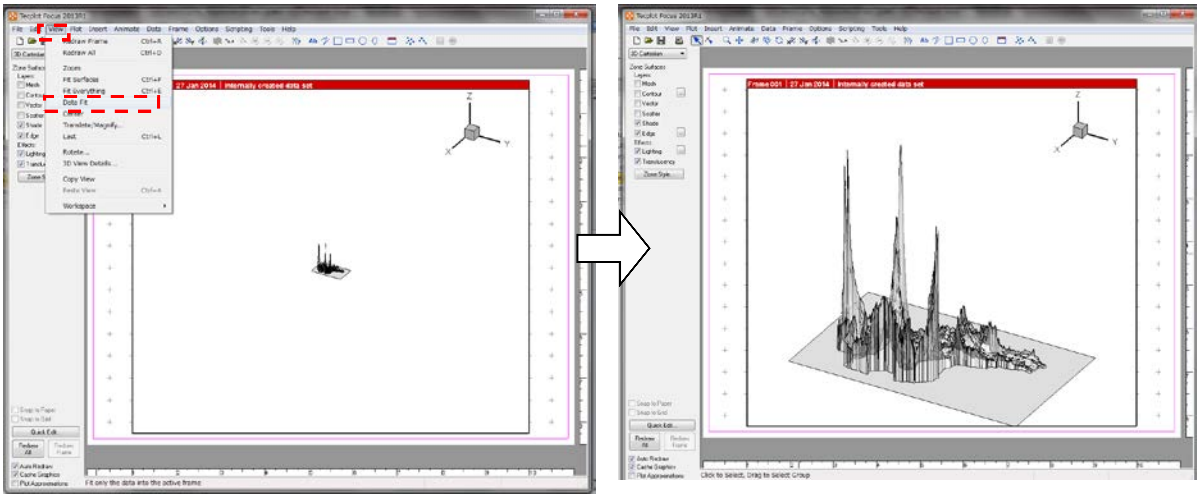
① Edit the ratio of XYZ and hide the axes.

[Plot] > [Axis …] Select "XY Dependent" in Dependency on "Z" tab and input Size Factors in Z (following example shows the Size Factors Z is set to 0.1). Uncheck "Show X(Y,orZ)-axis" on X, Y and Z tab to hide the axis.



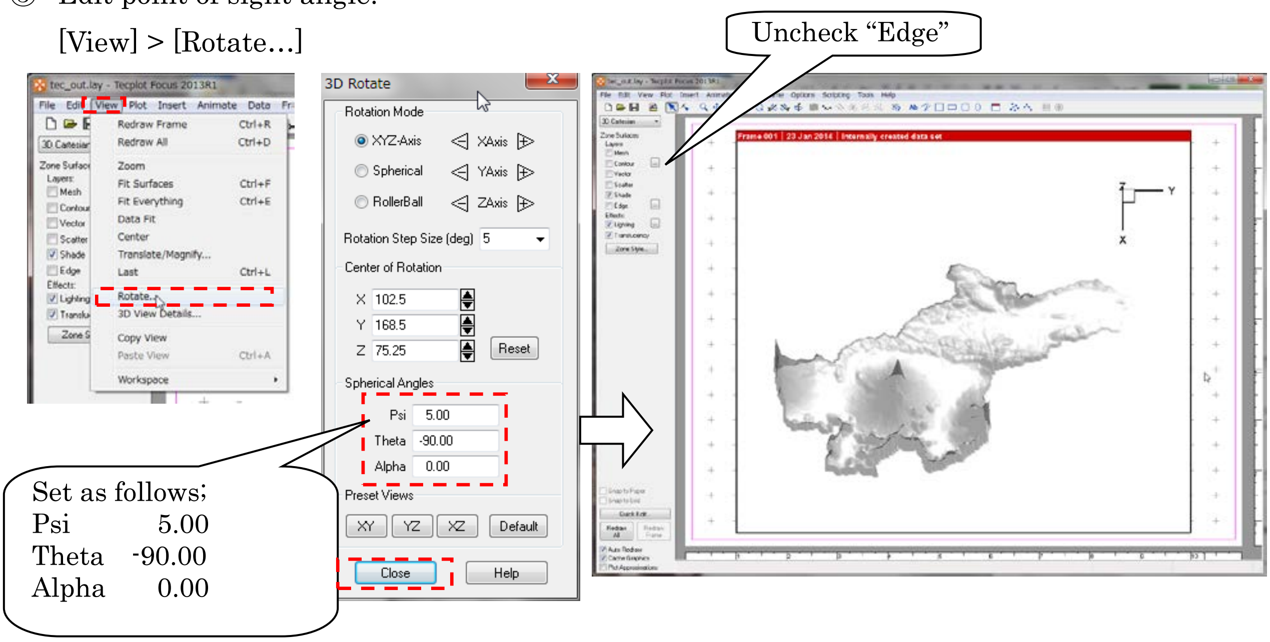
② Fit the data display range to the target range.

[View] > [Data fit]



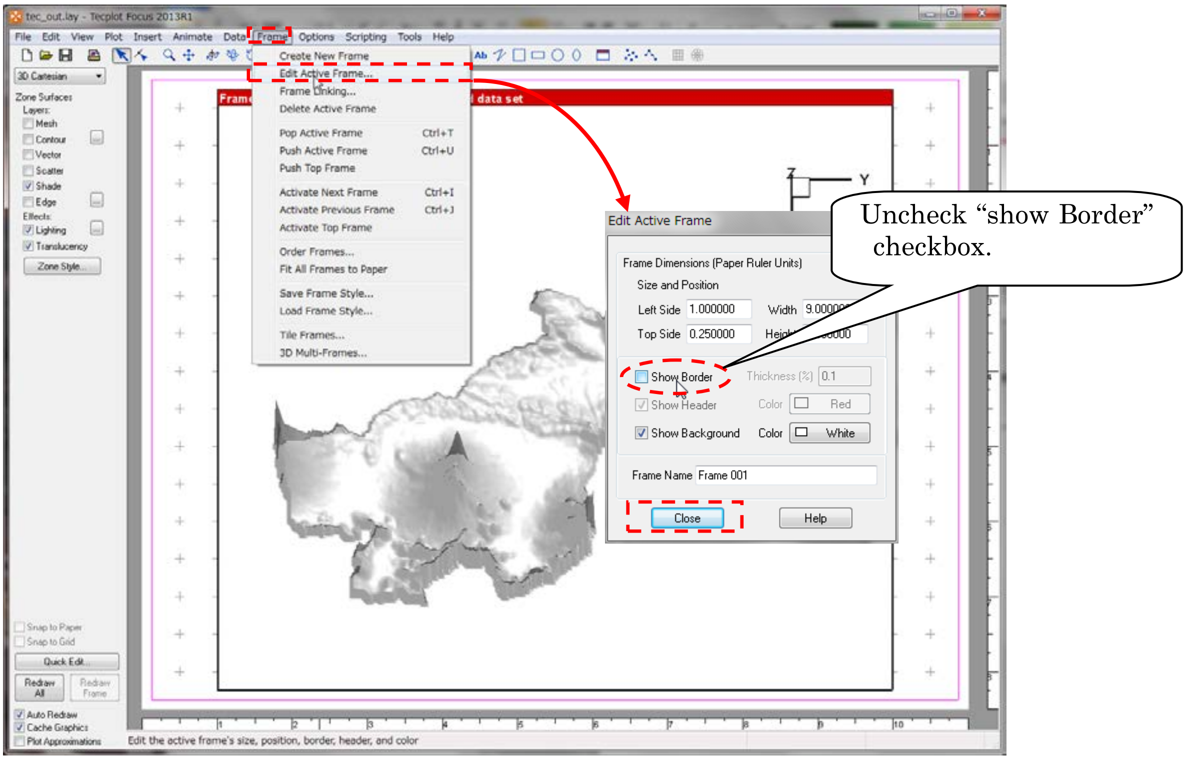
③ Edit point of sight angle.

[View] > [Rotate…]



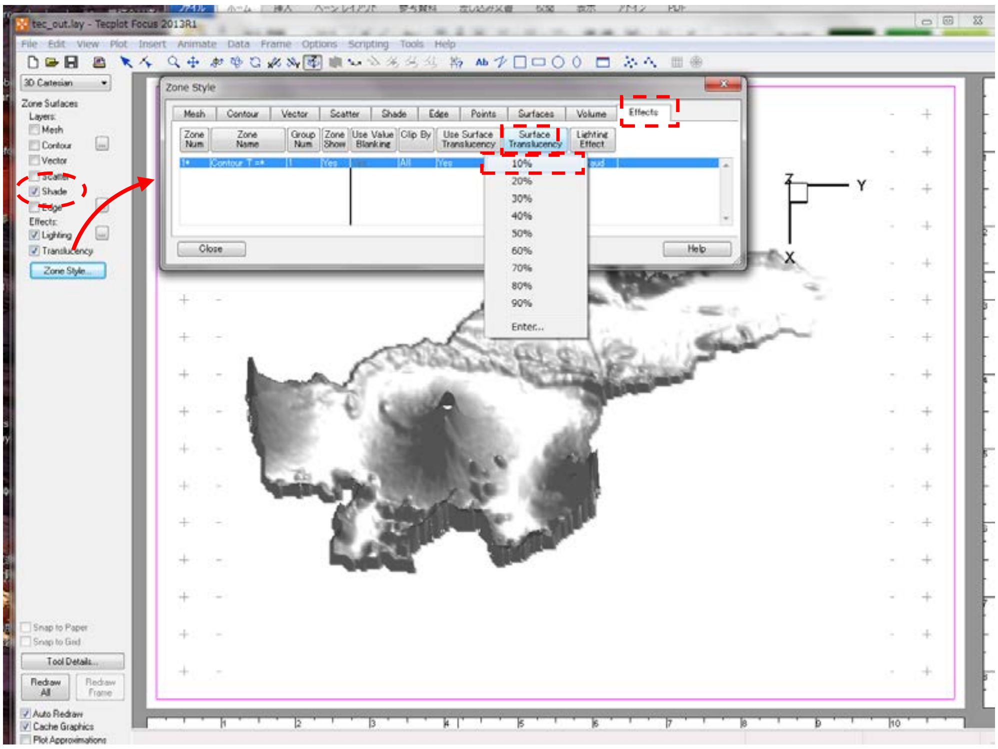
④ Delete unnecessary frame

[Frame] > [Edit Active Frame…]



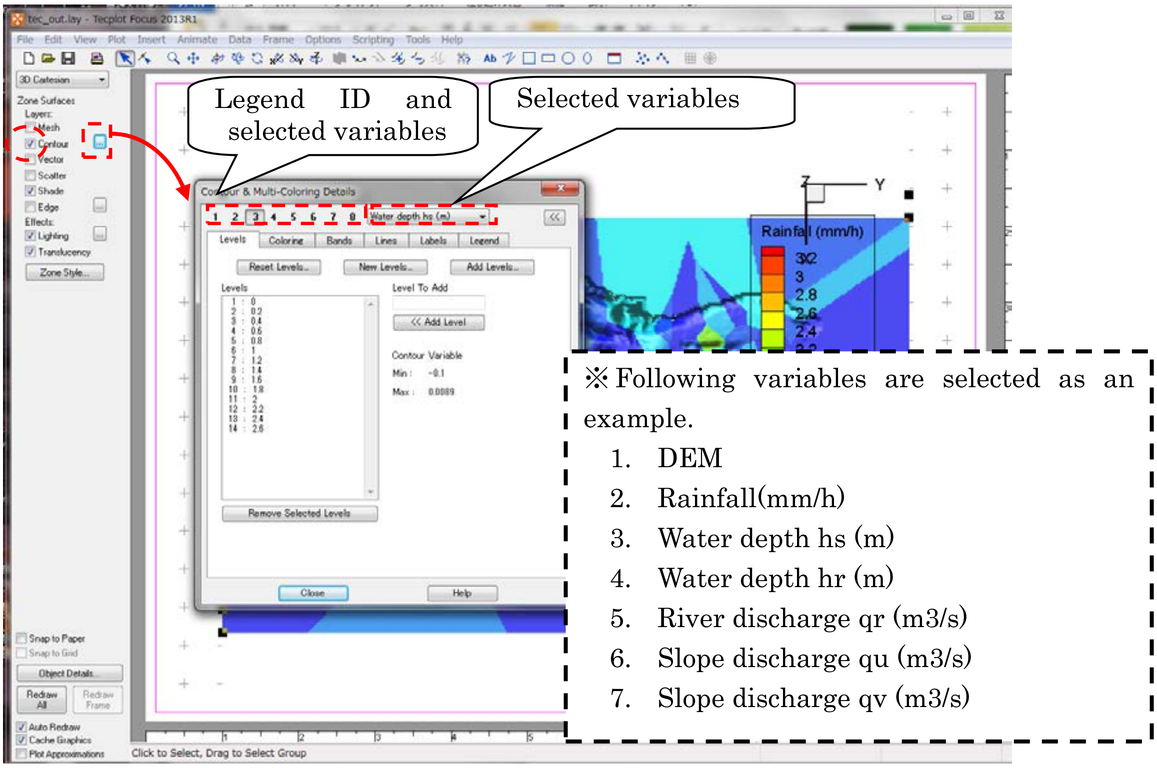
⑤ Edit translucency of shade

Click "Zone Style" and edit the value of "Surface Translucency" on "Effects Tab" to change the translucency of shade (e.g. 10%).

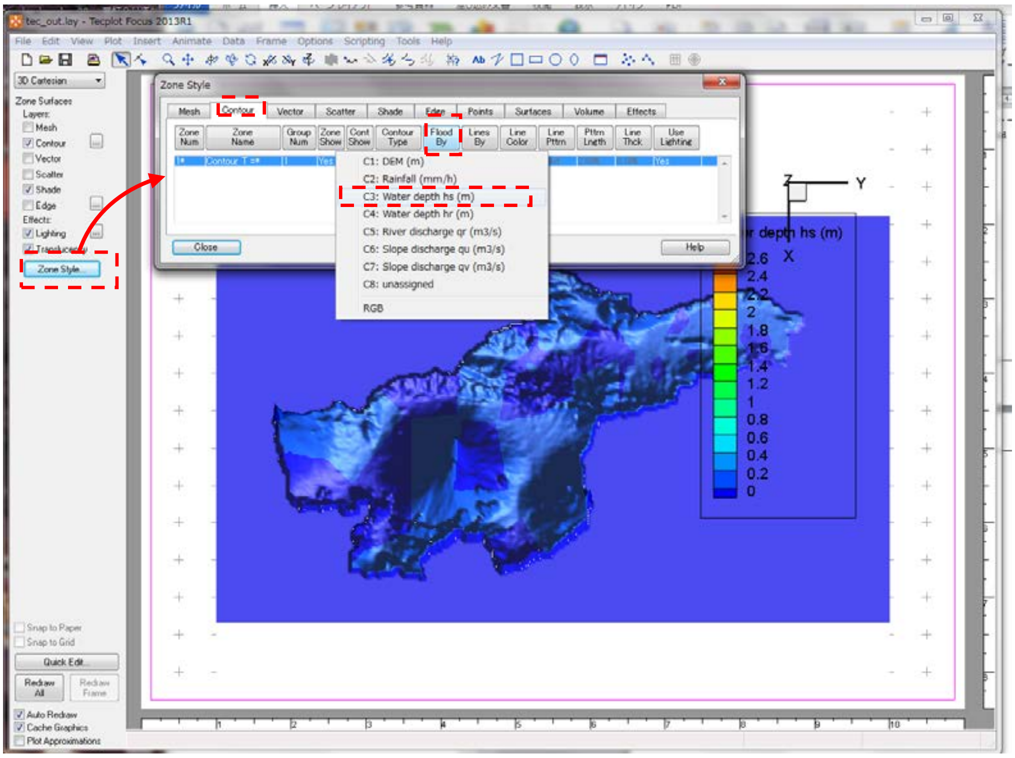


7.6.4 Draw contour figure on Tecplot

① Select variables to draw contour. User can select variables up to eight variables. The legends of variables are automatically set. The method to edit them is described in ③.

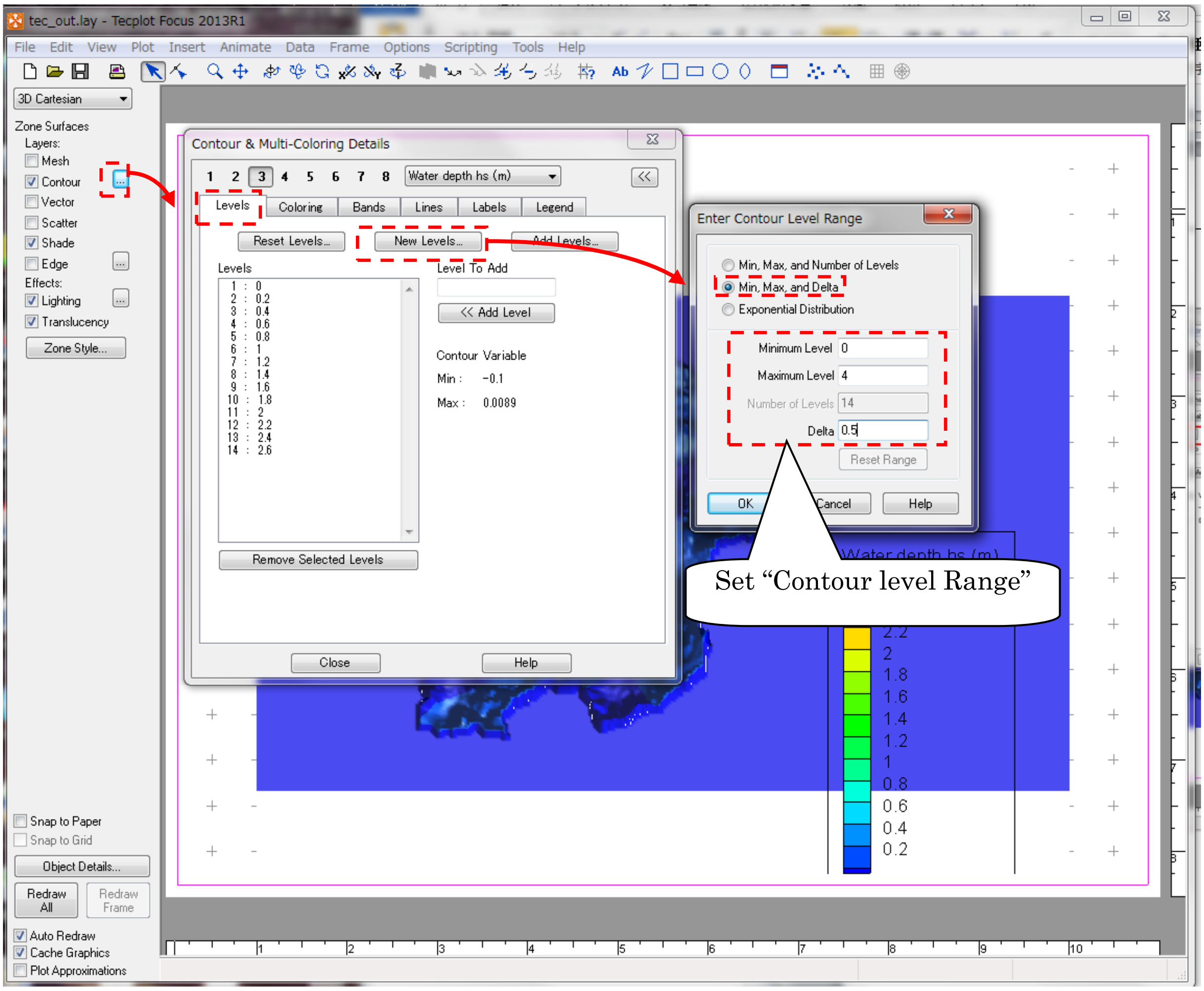


② Select variable to display. User can select variable from variables identified in ①. Click “Zone Style” and edit “Flood By” on “Contour” tab to edit target variable and its legend. ”Water depth hs (m)” is selected in the following figure as an example.

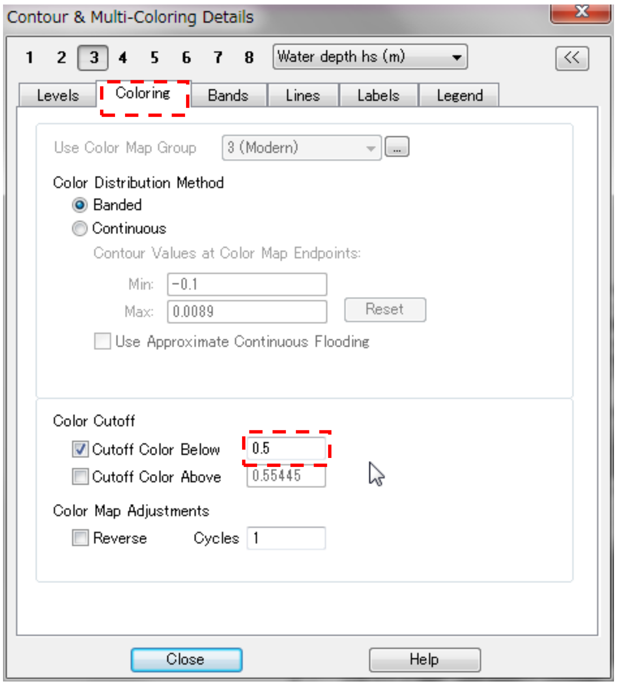


③ Edit legend.

User can edit color legend of contour as follows;

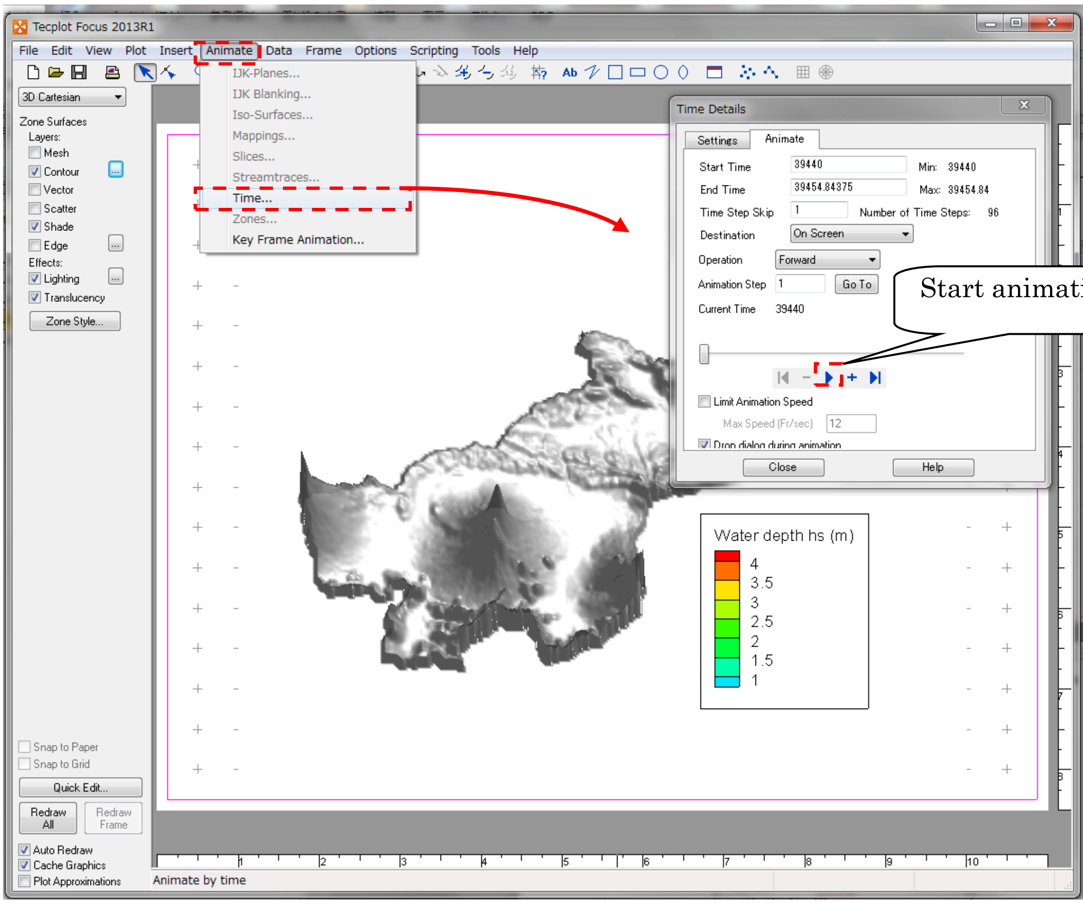


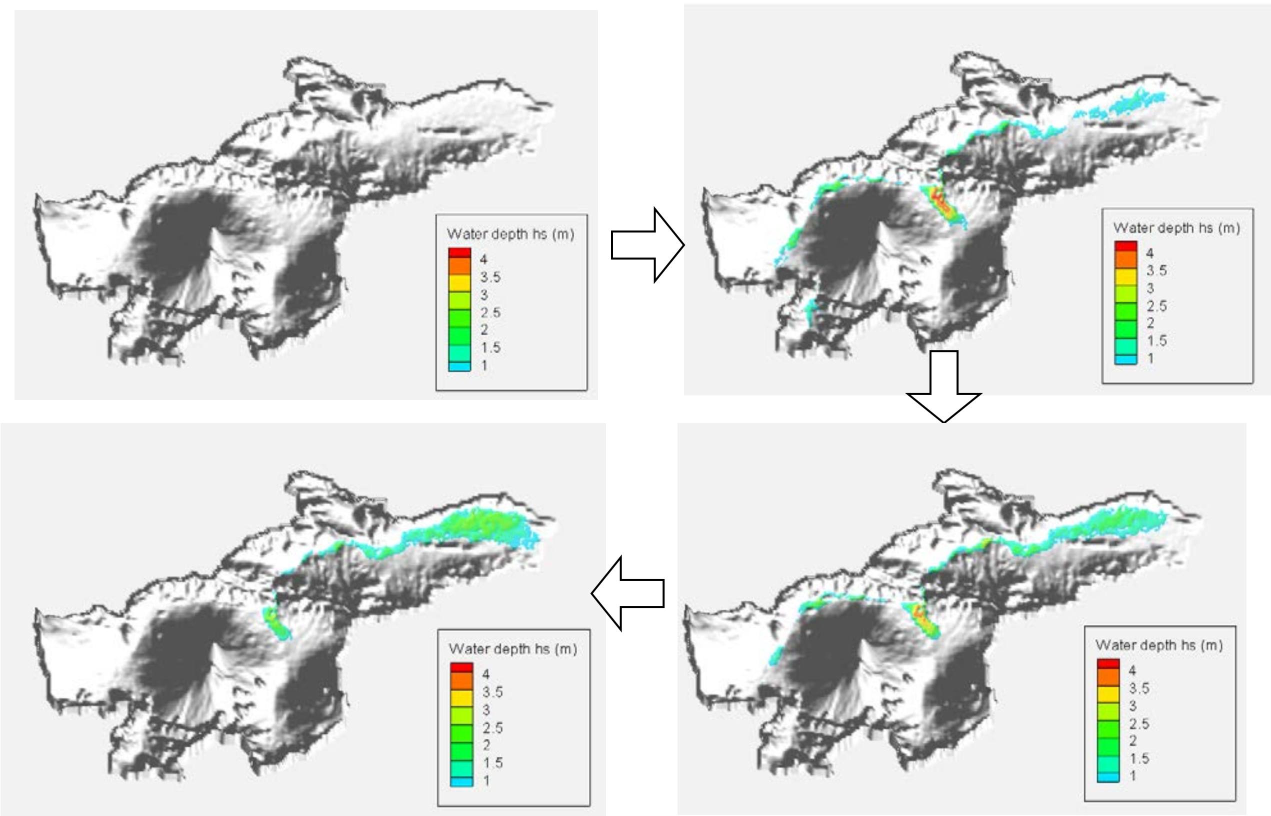
④ User also can edit “cut off” to display upper and lower color limits. Color up to 0.5m is cut in the following figure as an example.



⑤ User can check the time series of the contour figure.

[Animate] > [Time…]



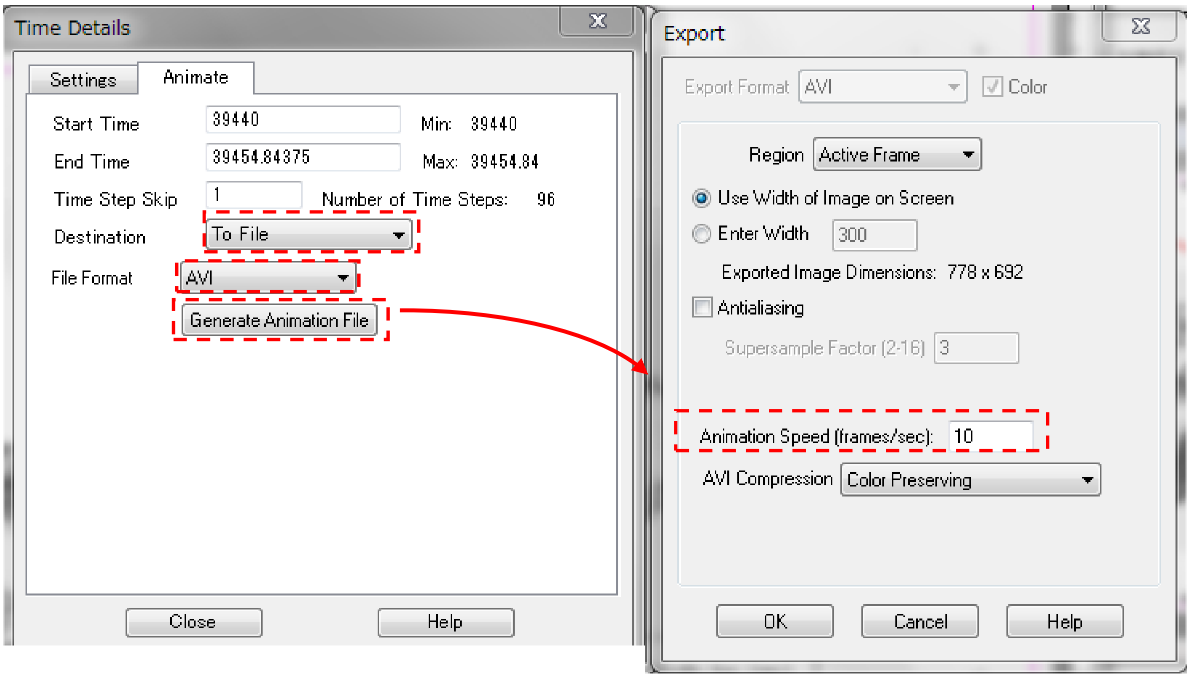


⑥ Export animation file

User can export animation file.

[Animate] > [Time...]

Select "To File" in "Destination" and "AVI" in "File Format" on "Animates" tab in "Time Details". If user needs to edit animation speed, click "Generate Animation File" and edit "Animation Speed" if necessary.



7.6.5 Supplement of display

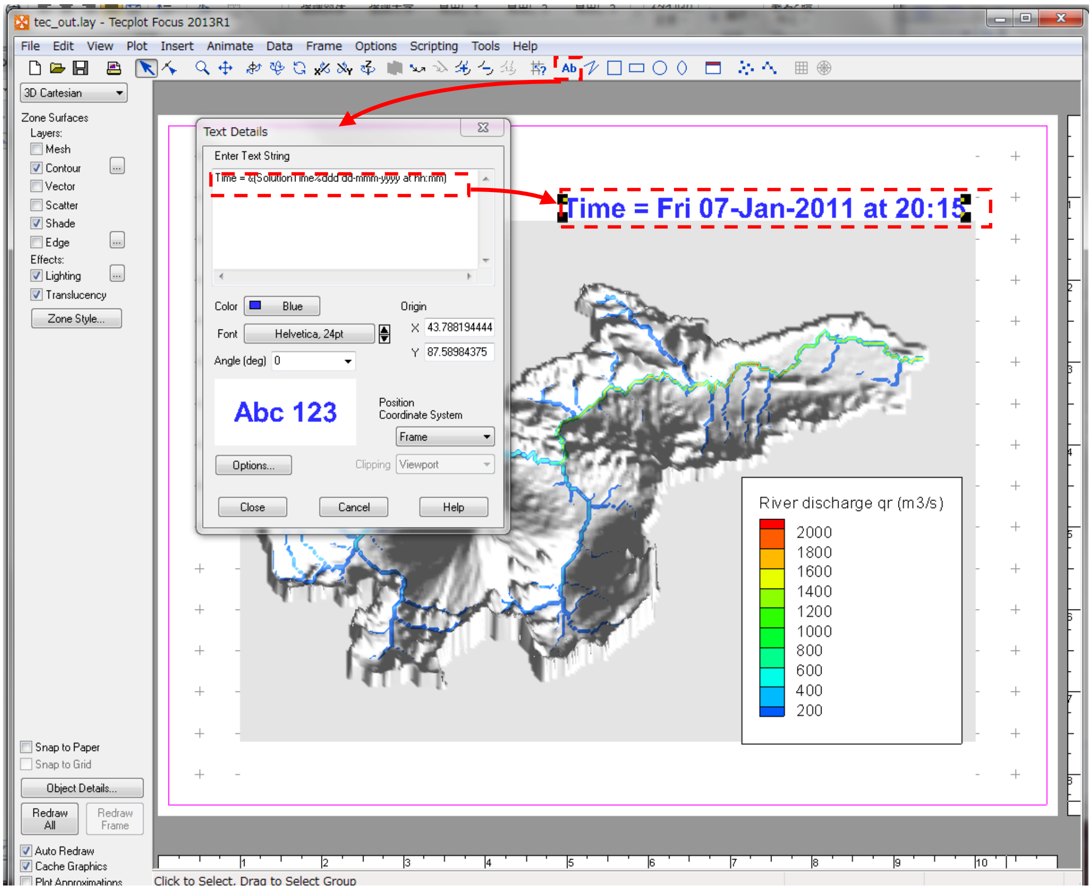
① Display timestamp information on animation

If user needs to display timestamp information on the contour figure, add textbox and input as follows;

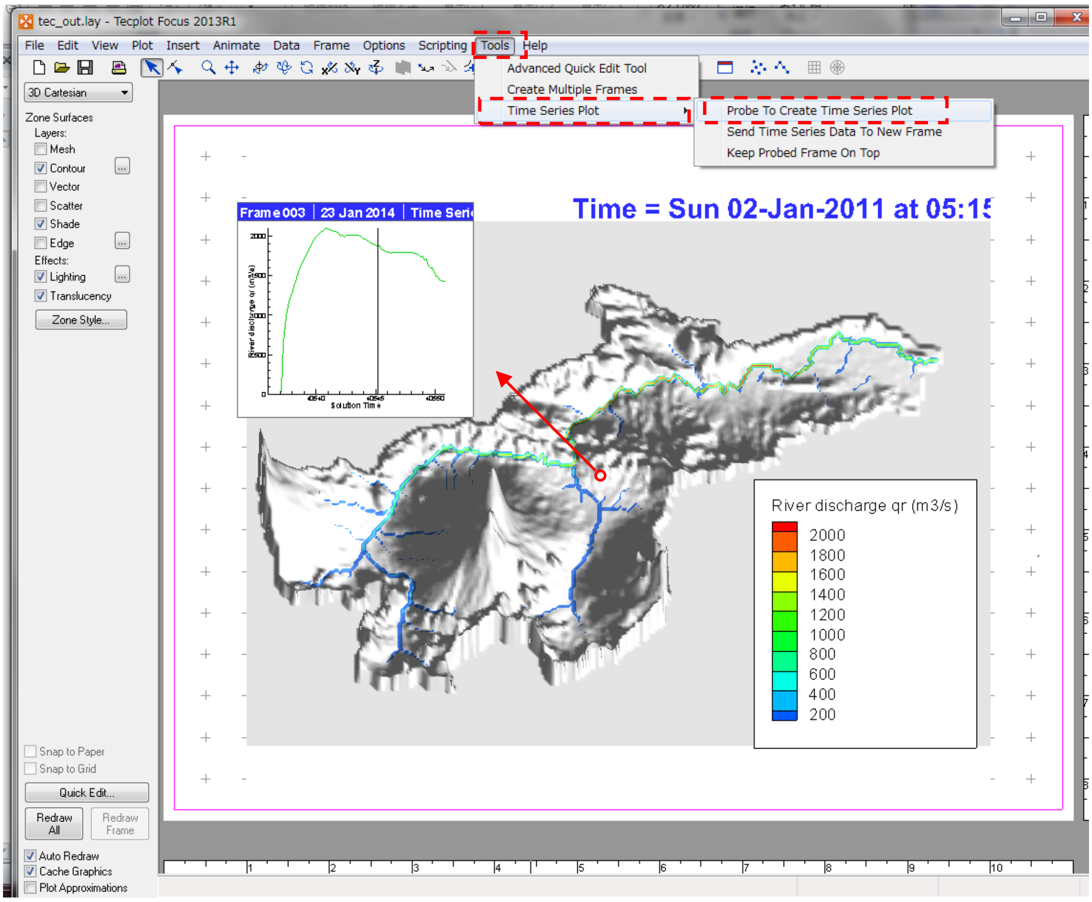
Time = &(SolutionTime%ddd dd-mmm-yyyy at hh:mm)

② Display time series graph on plane view.

Select [Tools] > [Time Series Plot] > [Probe To Create Time Series Plot] and identify the position by left click with the pointer "+" to display the time-series. Note that the variable selected as "Flood By" will be shown on the time series graph. Hence user needs to change the setting of Zone Style and "Flood By" to display different time-series (e.g. qr).



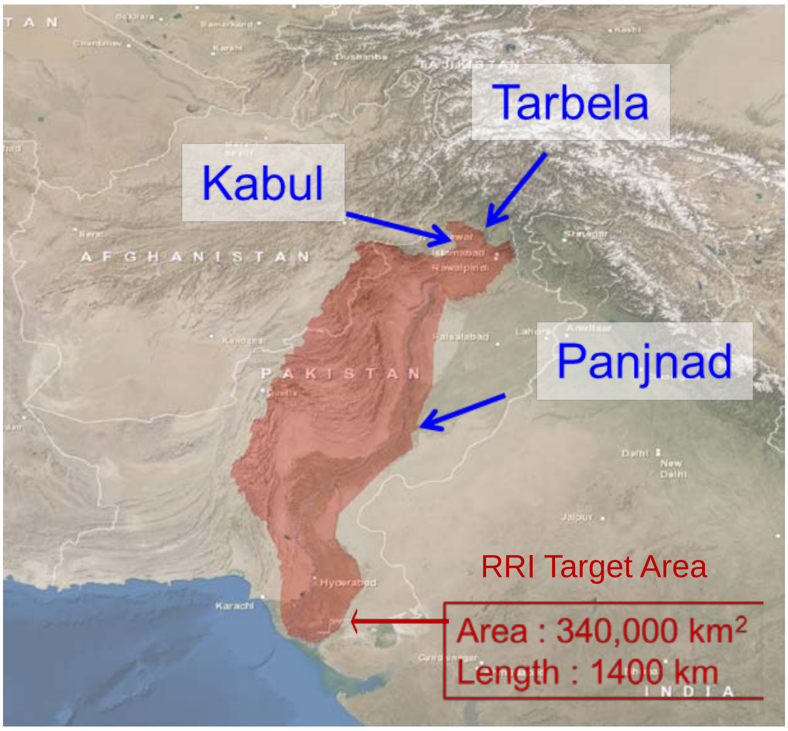
tec_out.lay - Tecplot Focus 2013R1
File Edit View Plot Insert Animate Data Frame Options Scripting Tools Help
Text Details
Enter Text String
Time = &(SolutionTime%ddd dd-mmm-yyyy at hh:mm)
Color Blue
Font Helvetica, 24pt
Angle (deg) 0
Origin
X 43.788194444
Y 87.58984375
Abc 123
Position Coordinate System
Frame
Options...
Clipping Viewport
Close Cancel Help
Time = Fri 07-Jan-2011 at 20:15
River discharge qr (m3/s)
2000
1800
1600
1400
1200
1000
800
600
400
200
Click to Select. Drag to Select Group



tec_out.lay - Tecplot Focus 2013R1
File Edit View Plot Insert Animate Data Frame Options Scripting Tools Help
Advanced Quick Edit Tool
Create Multiple Frames
Time Series Plot
Probe To Create Time Series Plot
Send Time Series Data To New Frame
Keep Probed Frame On Top
Frame003 | 23 Jan 2014 | Time Seri
Time = Sun 02-Jan-2011 at 05:15
River discharge qr (m3/s)
2000
1800
1600
1400
1200
1000
800
600
400
200

8. Application Example

This section presents the application of RRI Model to the lower Indus River basin. The target area is below Tarbela dam, Kabul and Panjdnad points as indicated below. The simulation domain is about 340,000 km^2 and the river length is about 1,400 km. In this example, the river discharge boundary conditions are prepared based on observed discharge records during 2010 floods to force the model with rainfall records.

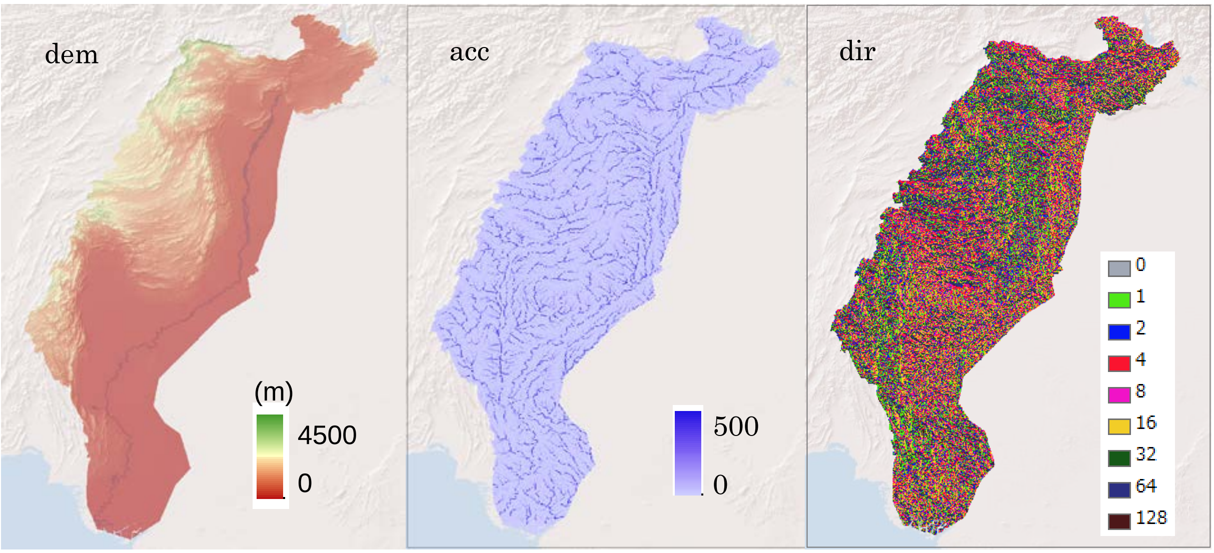


A polygon covering the simulation target (the red mask in the above figure) was prepared first. The flow direction data in HydroSHEDS (30sec) was used to identify the entire Indus River basin. Then the upstream areas above Tarbela, Kabul and Panjnad were removed from the entire Indus River basin.

The background image of the above figure can be obtained from the following site (http://goto.arcgisonline.com/maps/World_Imagery) and used in ArcGIS.

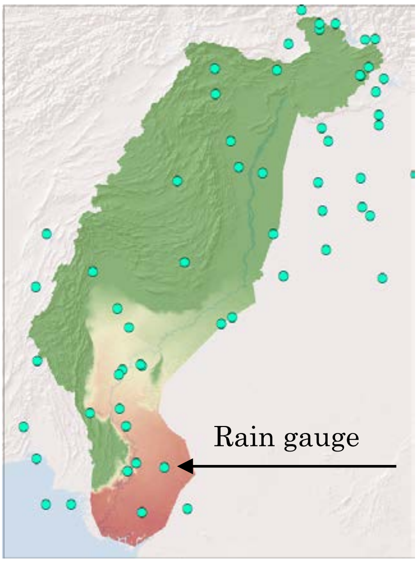
8.1 On Input Topography

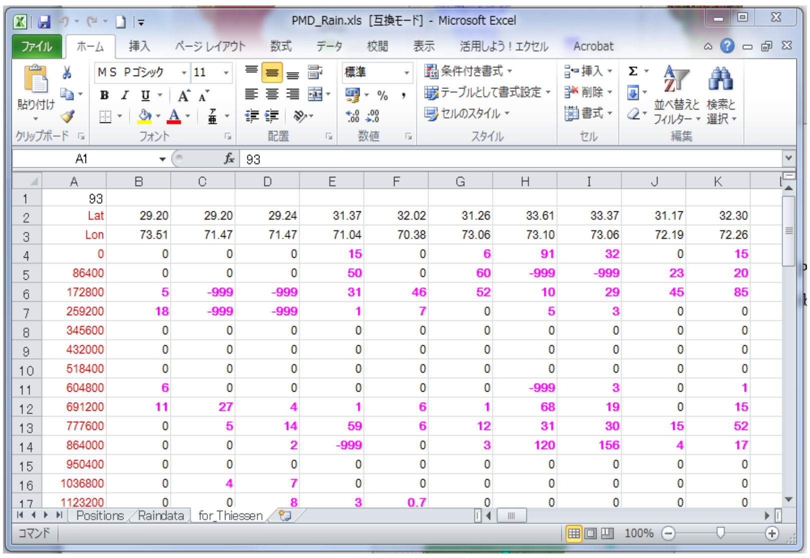
By using the catchment polygon, dem, acc and dir datasets were clipped for the catchment area. The function embedded in ArcGIS ([Spatial Analyst Tools] → [Conditional] → [Con]) was used to mask the target area out of the regional datasets of HydroSHEDS (30 second resolution). Then "demAdjust2" program was used to adjust dem and dir to create adem and adir.



8.2 On Input Rainfall

Ground gauged rainfall records provided by Pakistan Meteorological Department (PMD) were used for the simulation. The green dots in the left figure below show their spatial distribution. The below right figure is the formatted ground gauged rainfall data with the latitude and longitude information. Total 93 data was used to create spatially distributed rainfall data.



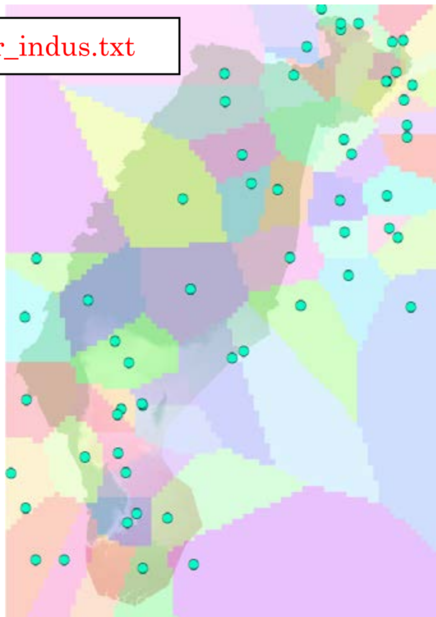


	A	B	C	D	E	F	G	H	I	J	K
1	93										
2	Lat	29.20	29.20	29.24	31.37	32.02	31.26	33.61	33.37	31.17	32.30
3	Lon	73.51	71.47	71.47	71.04	70.38	73.06	73.10	73.06	72.19	72.26
4	0	0	0	0	15	0	6	91	32	0	15
5	86400	0	0	0	50	0	60	-999	-999	23	20
6	172800	5	-999	-999	31	46	52	10	29	45	85
7	259200	18	-999	-999	1	7	0	5	3	0	0
8	345600	0	0	0	0	0	0	0	0	0	0
9	432000	0	0	0	0	0	0	0	0	0	0
10	518400	0	0	0	0	0	0	0	0	0	0
11	604800	6	0	0	0	0	0	-999	3	0	1
12	691200	11	27	4	1	6	1	68	19	0	15
13	777600	0	5	14	59	6	12	31	30	15	52
14	864000	0	0	2	-999	0	3	120	156	4	17
15	950400	0	0	0	0	0	0	0	0	0	0
16	1036800	0	4	7	0	0	0	0	0	0	0
17	1123200	0	0	8	3	0.7	0	0	0	0	0

Note that the first column of the excel sheet represents the time stamp of the rainfall data in second. For example, at the row of 172800 sec, the daily rainfall [mm/d] between time 86400 and 172800 sec was stored. Then all the data was copied to a text editor and save it as ASCII.

The ASCII file is the input data of /etc/rainThiessen program that generates the spatially distributed rainfall data. Note that the “gauge_map_lower_indus.txt” is also created after running /etc/rainThiessen program, so that one can check the spatial representation of each rain gauge (see the figure below after converting from the ASCII to Raster with ArcGIS).

gauge_map_lower_indus.txt



Here is the sample of the rainThiessen program input file (rainThiessen.txt).

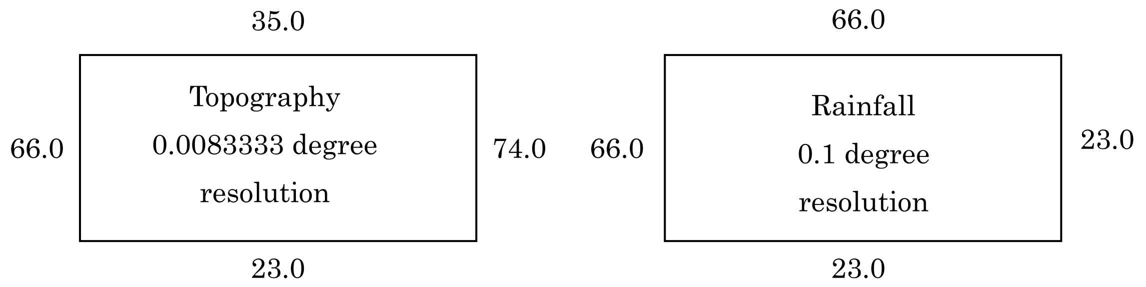
rainThiessen.txt

```
./indus/gauge_1d_2010.txt
24
./indus/rain_lower_indus_gauge_2010.dat
./indus/gauge_map_lower_indus.txt
ncols    80
nrows 120
xll 66.0
yll 23.0
cellsize 0.1
```

cellsize 0.1 → in degree

The rainfall data must cover all the simulation domain. However, it is not necesssary to have the same resolution or the same coverage area. For exmaple, 0.1 degree (approx. 10 km) may be fine enough to distribute the ground gauged rainfall for this case. Thus above rainThiessen.txt read by the rainThiessen program specifies the output resolution of 0.1 degree.

```
ncols          960
nrows          1440
xllcorner      66
yllcorner      23
cellsize       0.00833333333333
NODATA_value   -9999
```



No need to be the same extent or the same resolutions, as far as rainfall data covers entire simulation domain

RRI_Input.txt

```
RRI_Input_Format_Ver1_4_1

./infile/lowerindus/rain/rain_lower_indus_gauge_2010.dat
./infile/lowerindus/adem2_lid1k.txt
./infile/lowerindus/acc_lid1k.txt
./infile/lowerindus/adir_lid1k.txt

0            # utm(1) or latlon(0)
1            # 4-direction (0), 8-direction(1)
2568         # lasth
600          # dt
60           # dt_riv
104          # outnum
66.0d0       # xllcorner_rain
23.0d0       # yllcorner_rain
0.1 0.1      # cellsize_rain
```

xllcorner_rain, yllcorner_rain cellsize_rain (x, y) are specified in RRI_Input.txt

8.3 On Input Evapotranspiration

Current version of RRI Model does not have a function to estimate evapotranspiration from climate variables. However, by giving evapotranspiration rate as one of the input files, the model takes the equivalent amount of water from surface and subsurface storages.

The format of the evapotranspiration input is the same as rainfall. Hense the grid cell size and time step of evapotranspiration file can be arbitrary set. For example, to set the constant rate of evapotranspiration, one can prepare the following input file (e.g. evp_4mm.txt), in which the value of 0.166667 mm/h corresponds to 4 mm/d of evapotranspiration.

```
0 1 1
0.166667
10000000 1 1
0.166667
```

evp_4mm.txt

To read the evapotranspiration input file, set flag 1 on the L71 and specify the input file name. The coordinate of south west corner (xllcorner and yllcorner) as well as the cellsize (x and y direction) must be also set in L73-L75.

RRI_Input.txt

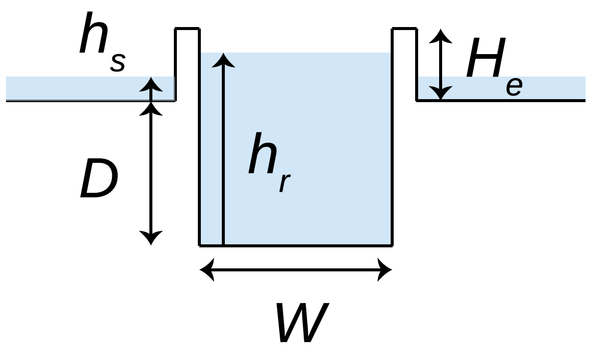
L71	1
L72	./infile/lowerindus/evp_4mm.txt
L73	66.0d0 # xllcorner_evp
L74	23.0d0 # yllcorner_evp
L75	1000.d0 1000.d0 # cellsize_rain

xllcorner_evp, yllcorner_evp cellsize_rain (x, y) are specified in RRI_Input.txt

Note that if sufficient water exists on a slope grid cell, and if the grid cell store water in the Green Ampt-Model, the model takes water from the cumulative water in GA model. If a user wants to avoid the evapotranspiration from the GA model, use flag "2" instead of "1" on L71.

8.4 On River Channel Geometry Setting

RRI Model assumes the rectangle shape for all river cross sections. To determine river cross sections (incl. width W, depth D and levee height H_e), the following two options are available.



A) Use empirical equations with parameters defined in RRI_Input.txt

B) Read the values from files and specify the files in RRI_Input.txt

```
L38  100                          # riv_thresh           }
L39  2.5d0                        # width_param_c        }
L40  0.4d0                        # width_param_s        }
L41  0.1d0                        # depth_param_c        }  Option A
L42  0.4d0                        # depth_param_s        }
L43  0.d0                         # height_param         }
L44  20                           # height_limit_param   }
L45
L46  1        ← 0 : Option A  /  1 : Option B (Read from files)
L47  ./infile/lowerindus/width_lid1k.txt     }
L48  ./infile/ lowerindus /depth_lid1k.txt   }  Option B
L49  ./infile/ lowerindus /height_lid1k.txt  }
L50
```

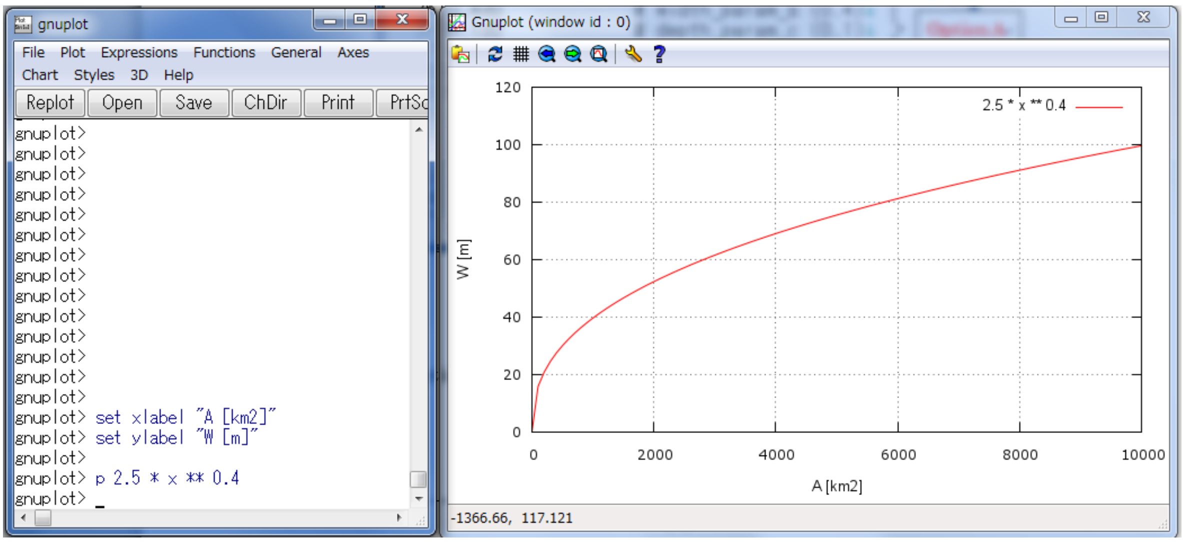
RRI_Input.txt

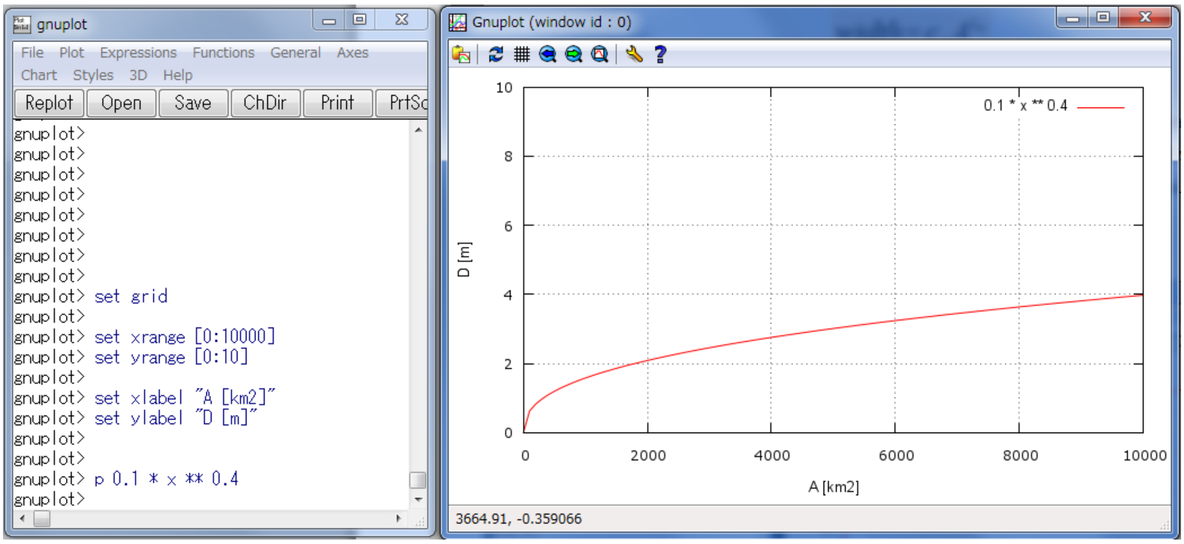
A) For the first option, the parameters of the following empirical equations must be appropriately set to represent target catchment condition (L38 – L44 of RRI_Input.txt).

$$width = c_w A^{s_w}$$

$$depth = c_d A^{s_d}$$

where A in the equations is the upstream catchment area [km²] for each river grid-cell. The unit of width and depth are [m]. The parameter "riv_thresh" defines the threshold of flow accumulation (i.e. number of upstream cells) to distinguish river grid cells or slope grid cells. Recall that for RRI model, slope exists even on a river grid cell.





<u>B) For the second option,</u> a user can prepare three files separately to represent width, depth, and height distributions. All those files must have the same number of row, column and resolution as the topography data (i.e. adem, acc and adir). The format of these data is ArcGIS ASCII format (i.e. the same as the topography data).

Note that the width file (e.g. ./infile/lowerindus/width_lid1k.txt) is used to decide whether each grid-cell has river or not (*width* > 0 is treated as a river grid cell). The values of depths and heights must be appropriately defined on a cell where the *width* > 0.

To support for creating the width, depth and height files, a Fortran program called /etc/makeRiver2/ can be used. The program reads "acc" file to calculate the upstream catchment area A [km^2] for each grid cell and a user can define different equations or fixed values within the program to create the three river cross section files.

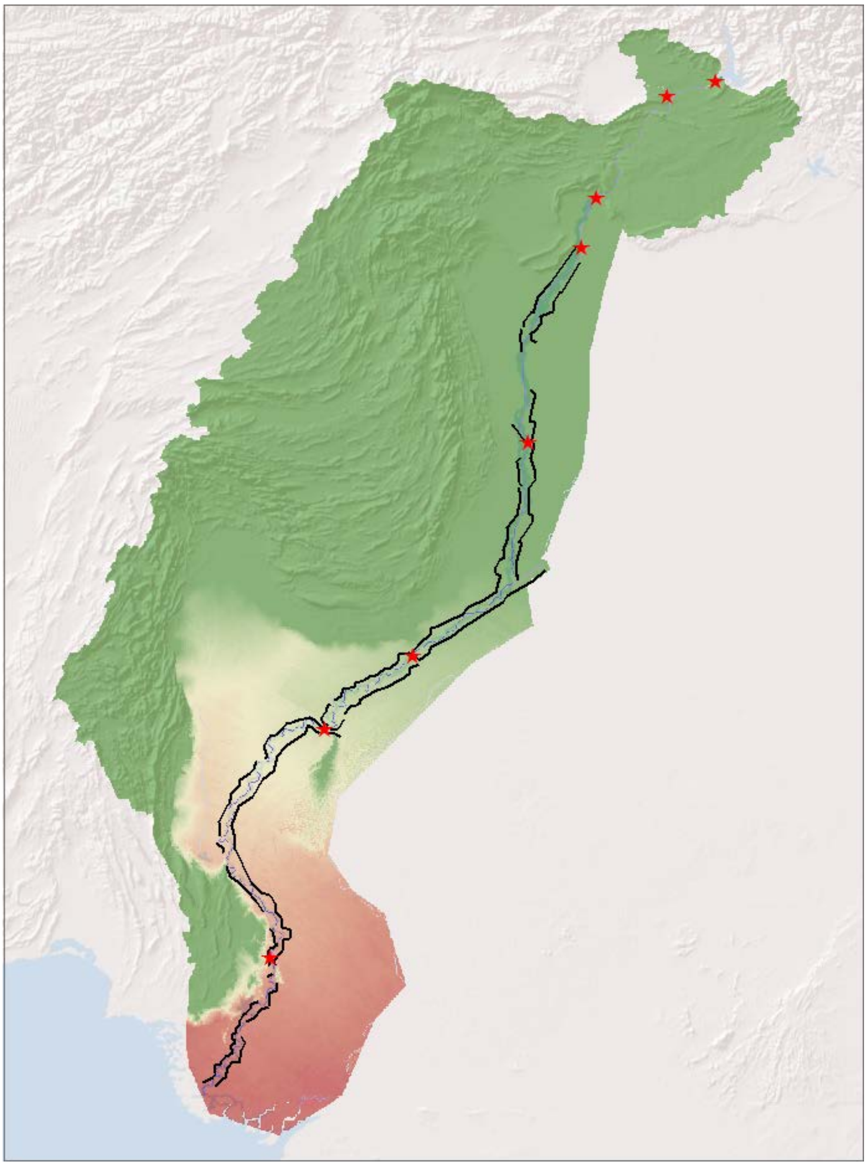
8.5 On Embankment Setting

There are two kinds of embankment settings in RRI simulation.

- A) Embankment along rivers
- B) Embankment on slope grid cells

<u>A) The first type of embankment</u> is illustrated in the figure of a river cross section. The effect of embankment is considered during the interaction of water between river and slope. To include the first type of embankment, the height value (*height* > 0) must be set on river grid cells (*width* > 0). Because of the RRI Model basic structure, a river is set as a centerline of a

slope grid, it is not possible to apply different embankment height for different side of the river for this option.



B) The second type of embankment represents roads, railways or other structures that prevent water to across. Since the embankment along the main Indus River is located a few kilometers apart from the main channel (see above figure), this second type suits better. The location information of the embankment was converted to raster data having the same resolution with topographic data on ArcGIS. The above mentioned "*height*" file specified in RRI_Input.txt can contain the height information (and therefore the embankment location information) on slope grid cells.

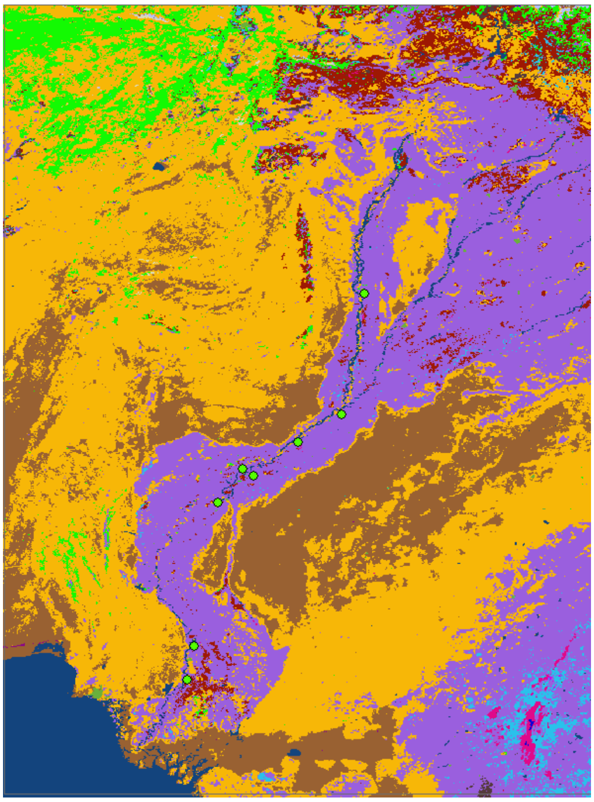
Note that even if a user intends to set a continuous embankment apart from a main river, if a tributary joins into the river and if the "*height*" value is set on a river grid cell where *width* >

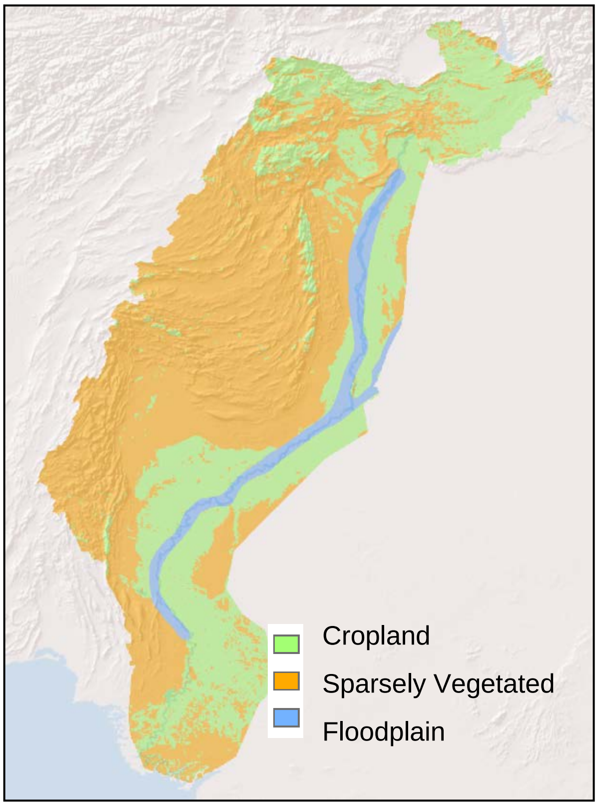
0, the embankment would be regarded as the embankment of Type A. As a result, the set embankment will be discontinuous at the location.

To avoid the situation and elevate DEM even on the tributary (or river grid cells), one can use the flag of "2" on L46.

8.6 On Land Class Setting

The effects of land cover (or soil type) can be reflected by assigning different model parameters. In this example, GLCC-V2 (Global Land Cover Characterization) provided by USGS was used. The original land cover data (left) is too detail to assign all different parameters; therefore, similar land cover types were merged into two categories: Cropland and Sparsely Vegetated, and also overlaid additional Floodplain polygon.





For re-classing the original land cover data, ArcGIS function [Spatial Analyst Tools] → [Reclass] → [Reclass by ASCII File] was used. The following lookup table was prepared by a text editor to define the re-class. Different lookup tables may be defined for different projects. Note that the number of the raster data (in this case 1, 2 and 3) corresponds to the column of parameter sets in RRI_Input.txt. Thus provide sequential numbers starting from 1 for representing different land covers.

Finally the re-classed land cover was converted to the ArcGIS/ASCII format and saved it as "lu_lid1k.txt". Note that the file can be read by RRI Model by indicating the file link in "RRI_Input.txt".

Lookup Table

(Indus Example)

1 : 1
2 : 1
3 : 1
4 : 1
5 : 1
6 : 1
7 : 1
8 : 2
9 : 1
10 : 1
11 : 1
12 : 1
13 : 1
14 : 1
15 : 1
16 : 1
17 : 1
18 : 1
19 : 2
20 : 1
21 : 1
22 : 1
23 : 1
24 : 1
99 : 1
100 : 1

Legend of GLCC-V2

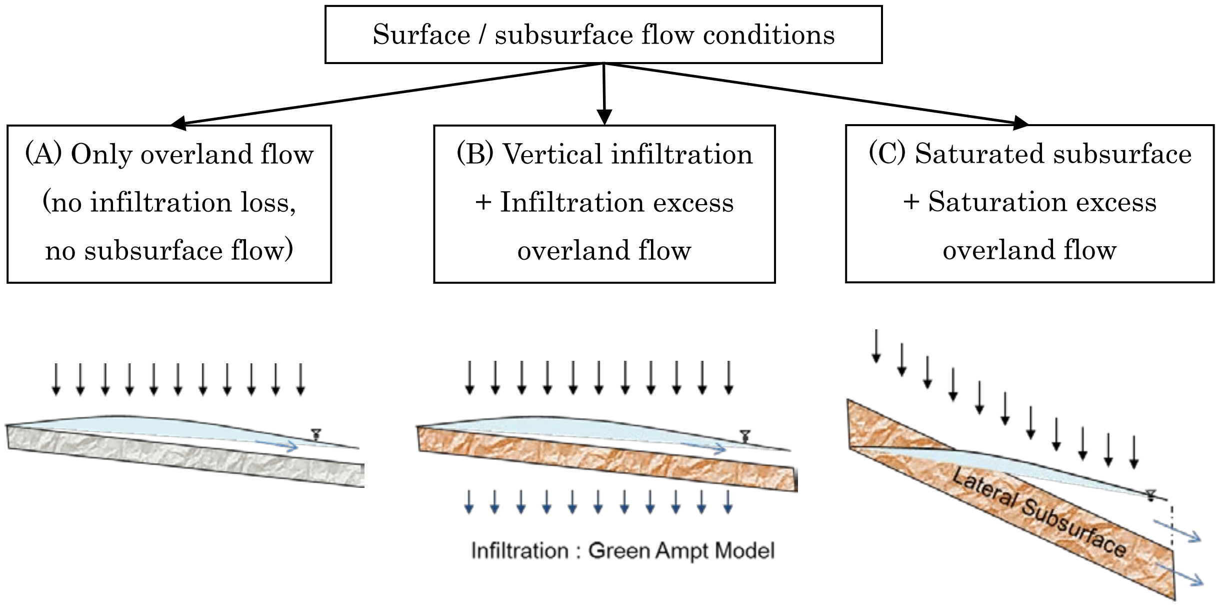
USGS Land Use/Land Cover System Legend (Modified Level 2)

Value	Description
1	Urban and Built-Up Land
2	Dryland Cropland and Pasture
3	Irrigated Cropland and Pasture
4	Mixed Dryland/Irrigated Cropland
5	Cropland/Grassland Mosaic
6	Cropland/Woodland Mosaic
7	Grassland
8	Shrubland
9	Mixed Shrubland/Grassland
10	Savanna
11	Deciduous Broadleaf Forest
12	Deciduous Needleleaf Forest
13	Evergreen Broadleaf Forest
14	Evergreen Needleleaf Forest
15	Mixed Forest
16	Water Bodies
17	Herbaceous Wetland
18	Wooded Wetland
19	Barren or Sparsely Vegetated
20	Herbaceous Tundra
21	Wooded Tundra
22	Mixed Tundra
23	Bare Ground Tundra
24	Snow or Ice
99	Interrupted Areas
100	Missing Data

8.7 On Parameter Setting

Model parameter values are defined in RRI_Input.txt. In this section, the general idea to decide model parameters are described first, then a calibrated model parameter set for the Indus River basin will be shown as an example.

For each land cover class, decide (A), (B) or (C) in the following figure depending on infiltration and subsurface processes, so that the number of calibration parameters will be limited.



Example of parameter values (their recommended ranges)

Parameters	Notation	(A)	(B)	(C)
n (River) ($m^{-1/3}s$)	ns_river		0.03d0 (0.015 ~ 0.04)	
n (Land) ($m^{-1/3}s$)	ns_slope		0.3 d0 (0.15 ~ 1.0)	
Soil depth (m)	soildepth		1.0 d0 (0.5 ~ 2.0)	
Porosity (-)	gammaa		0.471d0 (0.3 ~ 0.5)	
k_v (m/s)	kv	0.d0	5.56d-7	0.d0
S_f	Sf	inactive	0.273d0	inactive
k_a (m/s)	ka	0.d0	0.d0	0.1d0 (0.01-0.3)
Unsat. porosity (-)	gammam		Inactive	0.d0
β	beta	inactive	Inactive	inactive

Note: 0.d0 is used in RRI_Input.txt to represent double precision of 0.0.

For case (A), where only overland flow without infiltration or subsurface flow process are considered, set both kv and ka equal to 0.

For case (B), where vertical infiltration + infiltration excess overland flow are considered, set ka = 0, and the parameter "da" is equal to "soil depth" times "porosity".

For case (c), where saturated subsurface + saturation excess overland flow are considered, set kv = 0, and the infiltration limit (defined as a parameter in the previous versions of the RRI model) equals to "soil depth" times "porosity".

Note that the parameter values in the above table are just one example values (approximate ranges).

Note that even though the values in inactive part do not affect the simulation result, a double precision value like 0.0d0 must be filled in RRI_Input.txt (see the sample below).

* Set “ksg = 0.d0” to avoid groundwater computation, whose algorithm is under development and not completed at RRI ver1.4.2.

** If both ka and kv are set to be non-zero, RRI will stop with an error message.

The following figure shows an example of parameter settings

RRI_Input.txt

```
L18  0.03d0                        # ns_river
L19  3                             # num_of_landuse
L20  1 1 1                         # diffusion(1) or kinematic(0)
L21  0.15d0 0.15d0 0.15d0          # ns_slope
L22  1.0d0 1.0d0 1.0d0             # soildepth
L23  0.4d0 0.4d0 0.4d0             # gammaa
L24
L25  5.556d-7 6.056d-7 0.d0        # kv
L26  0.273d0 0.1101d0 0.d0         # Sf
L27
L28  0.1d0 0.1d0 0.1d0             # ka
L29  0.0d0 0.0d0 0.0d0             # gammam
L29  8.0d0 8.0d0 8.0d0             # beta
L31
L32  0.d0 0.d0 0.d0                # ksg
L33 - L36 are inactive under ksg = 0.d0
```

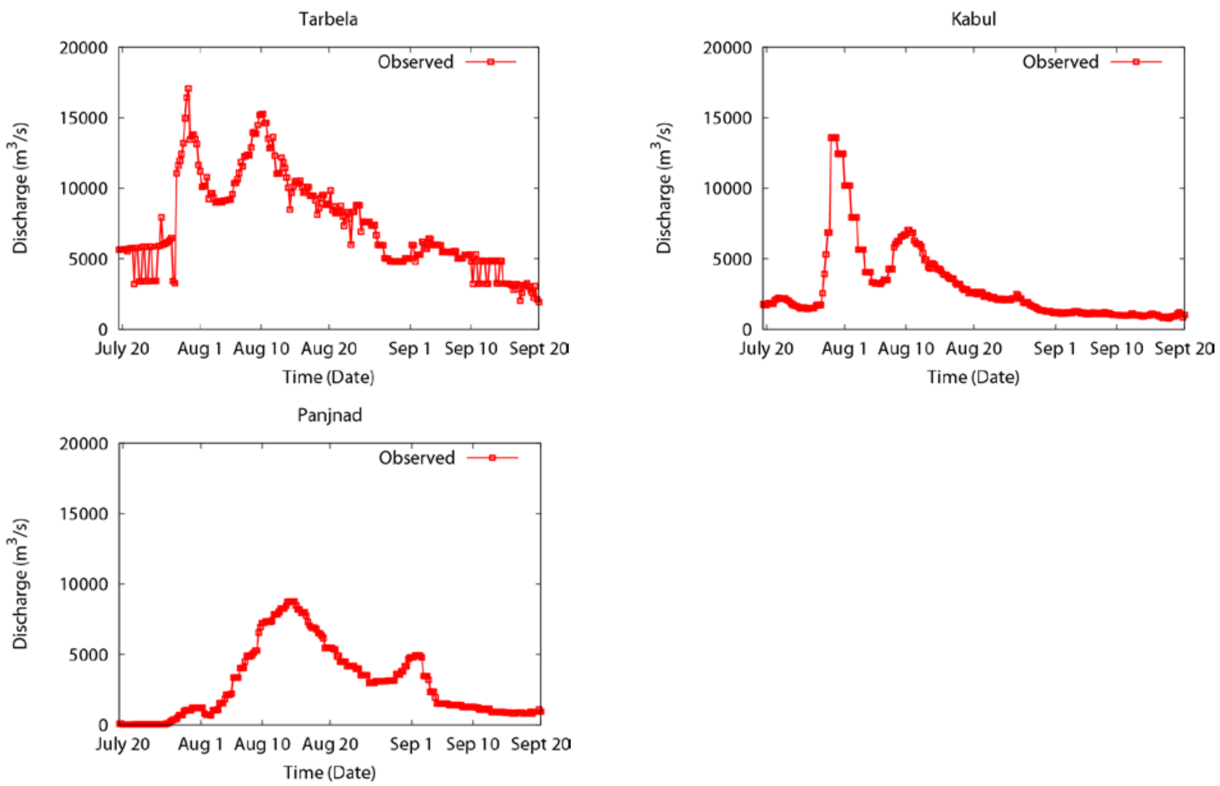
Reference Table : Green-Ampt Infiltration Parameters for different soil texture

Soil texture class	k_v (m/s)	ϕ [gammaa]	S_f (m)
Sand	6.54E-05	0.437	0.0495
Loamy sand	1.66E-05	0.437	0.0613
Sandy loam	6.06E-06	0.453	0.1101
Loam	3.67E-06	0.463	0.0889
Silt loam	1.89E-06	0.501	0.1668
Sandy clay loam	8.33E-07	0.398	0.2185
Clay loam	5.56E-07	0.464	0.2088
Silty clay loam	5.56E-07	0.471	0.273
Sandy clay	3.33E-07	0.43	0.239
Silty clay	2.78E-07	0.479	0.2922
Clay	1.67E-07	0.475	0.3163

From Rawls, W.J. et al.., 1992. Infiltration and soil water movement. In: Handbook of hydrology. New York: McGrow-Hill Inc., 5.1–5.51. (Units are conveted for RRI Model)

8.8 On Boundary Condition

The following river boundary conditions were set based on the observed discharges at the three locations during the 2010 flood.

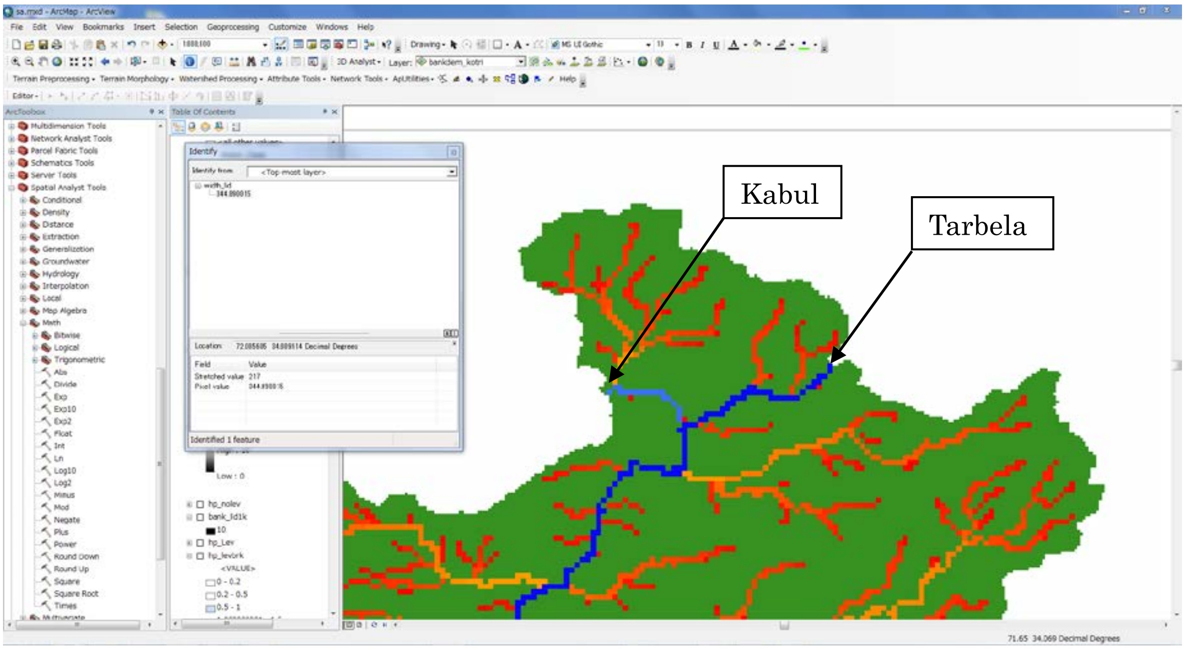


The steps to set river discharge boundary conditions are described below.

① Find locations to provide the boundary conditions.

Viewing acc values on ArcGIS can help you to identify appropriate position with lat lon information along a river channel. Use i (identify) icon to find out the coordinate.

Then use the "/etc/coordinate.xls" to convert from the lat lon coordinate to loc_i and loc_j. See Section 7.3 on the conversion in detail.



② Prepare a 1D boundary condition file with the following format.

The number of boundary condition setting points

The loc_i and loc_j of all points to give boundary conditions

3				
loc_i	110	119	680	
loc_j	803	719	602	
0	3936.041733	3007.249151	917.4658428	
21600	3936.041733	3007.249151	917.4658428	
43200	3936.041733	3007.249151	917.4658428	
64800	3879.408039	3044.061053	917.4658428	
86400	4813.86399	3015.744206	917.4658428	
108000	4700.596602	2944.952088	917.4658428	
129600	4842.180837	2899.645133	917.4658428	
151200	4672.279755	2922.29861	1093.030294	
…..	…..	….	….	

Time series of the boundary condition data (units: [m^3/s] for river discharge, and [m] for water depth)

③ Settings in RRI_Input.txt

After preparing the boundary conditon file (e.g. disc_lid1k_2010.txt) and move the file in the appropriate folder (e.g ./infile/lowerindus/), edit the RRI_Input.txt file as follows.

RRI_Input.txt

```
L51  0 0 0 0
L52  ./infile/lowerindus/hs_init_dummy.out
L53  ./infile/lowerindus/hr_init_lid1k.txt
L54  ./infile/lowerindus/hg_init_sample.out
L55  ./infile/lowerindus/gampt_ff_init_dummy.out
L56
L57  0 0
L58  ./infile/wlev_bound_dummy.txt
L59  ./infile/hr_bound_dummy.txt
L60
L61  0 1
L62  ./infile/qs_bound_dummy.txt
L63  ./infile/lowerindus/bounds/bound_lid_2010.txt
L64
```

Write the file name of river discharge boundary

Another option is to use two-dimension format for setting boundary conditons. In that case, prepare the following "setBound.txt" first as the input file to "/RRI/etc/setBound" program, which creates the input boundary conditon file (e.g. ./disc_lid1k_2010.txt) on two dimensional basis. The two-dimensional boundary condition files can be read with flag 2 on L61.

setBound.txt

```
../../Model/infile/lowerindus/adem_lid1k.txt
../../Model/infile/lowerindus/acc_lid1k.txt
../../Model/infile/lowerindus/adir_lid1k.txt
./infile/lowerindus/disc_Constant.txt
../../Model/infile/lowerindus/disc_lid1k_Constant.txt
3
119 719
110 803
680 602
```

In the above example of "setBound.txt", L1 to L3 are the paths to the topography files (dem, acc and dir). L4 is the 1D discharge file (input) prepared above and the L5 is the output of the setBound program. L6 indicates the number of points to give the boundary conditions, followed by the positions in loc_i and loc_j.

The created boundary condition files have the same format as the rainfall file. However, unlike rainfall files, the number of columns and rows must be exactly the same as the topography data, so that RRI Model knows where to give the boundary.

Note that discharge boundary conditions including along river and on slope must have the information of the directions. In other words, they should be vector values rather than the scalar values. To decide the direction of the discharge boundary conditions, RRI Model refers to the flow direction in "dir" file.

Water level boundary conditions on slope and/or river can be also set by changing the value on L57 to 1 and specitying the boundary condition file name. The file format is the same as the river discharge boundary condion.

8.9 On Initial Condition

RRI Model can take initial conditions for water depths on slope and river as well as the cumulative water depth in the Green-Ampt model. The format of the files is the same as the output of those variables, so that one can use the output of the RRI as the input for the next simulation.

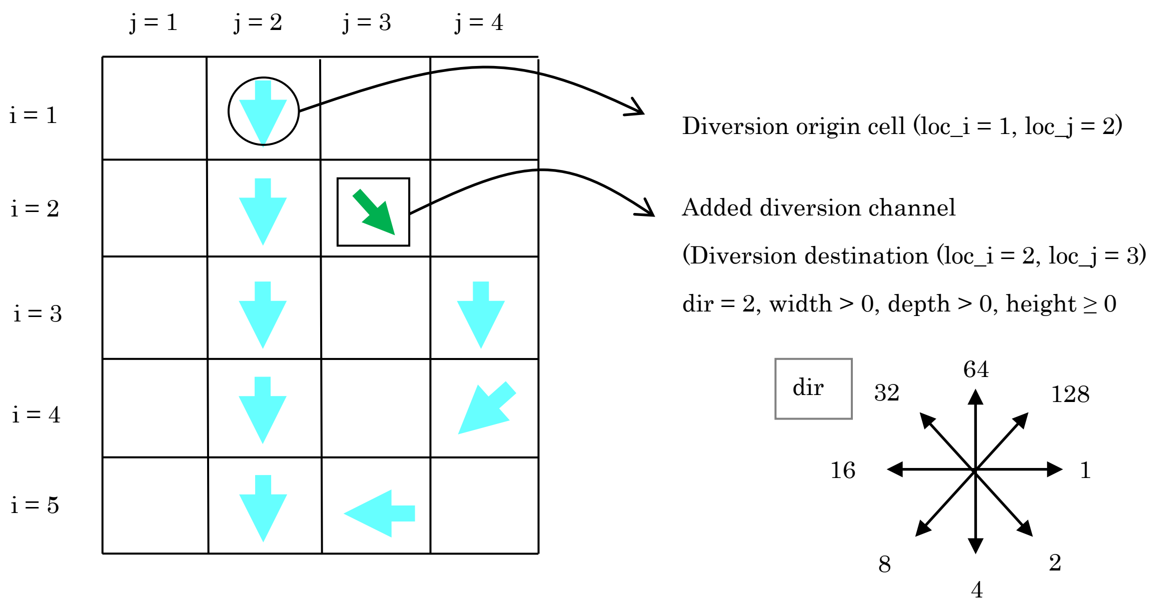
This feature enables the continuous long-term simulation. In order to read the initial conditions, L49 to L52 in the RRI_Input.txt must be edited in a same manner as the example of the boundary condition setting.

8.10 Diversion option (for advanced users)

RRI model can simulate the effect of diversion in a simple way. The portion of the diversion from a main channel to a diversion channel must be pre-defined by a model user and described in RRI_Div.f90 program. The followings are the basic steps to activate the option.

① Edit input river cross section files (i.e. width, depth, height) and flow direction files to add necessary diversion channels (e.g green arrow for the below figure).

② Check a origin cell (loc_i_org, loc_j_org) and a destination cell (loc_i_dest, loc_j_dest). Both the origin and destination cells must be specified on river grid-cells. Typically these two are adjacent, but not necessary (i.e. diverted water can jump into an apart cell).



③ Prepare a file to specify the origin and destination cells based on the following format. One can list up multiple lines if more than one diversion should be considered. "div_rate" specifies the ratio of discharge diverted from the main river to the diversion..

```
1    2    2    3    0.2                          div_sample.txt

loc_i_org   loc_j_org   loc_i_dest   loc_j_dest   div_rate
```

④ Activate this option by setting flag 1 on L70 and specify the diversion file name (e.g. div_sample.txt) on L71 in RRI_Input.txt.

8.11 Dam option (for advanced users)

RRI model can simulate the effect of dam reservoirs in a simple way. The dam model has two parameters: outflow discharge and maximum storage volume. The model takes storage volume as a state variable, which continues being updated based on simulated inflow and outflow. The outflow is maintained at a certain discharge rate that is lower than the inflow rate until the storage volume reaches the dam's maximum storage level. After the storage volume exceeds the maximum level, the model is designed to release the water at the same rate as the inflow rate. The parameters must be determined based on dam operation records. The followings are the basic steps to activate the dam model.

① Prepare a dam parmmeter file by the following format.

2					
Bhumibol	166	71	5800000000	150	dam_sample.txt
Sirikit	135	166	3510000000	500	

dam names, loc_i_dam, loc_j_dam, storage volume [m^3], constant discharge [m^3/s]

② Activate the dam model by setting flag 1 on L65 and specify the dam file name on L66 in RRI_Input.txt.

8.12 Arbitrary cross sections (for advanced users)

In addition to the rectangular river cross sections, the RRI Model can incorporate also arbitrary cross section directly. The followings explain the procedure to reflect cross section information to the model.

① Use "section.f90" program in the "etc" folder to prepare cross section files (e.g. sec_000001.txt) based on cross section coordinate information files (e.g. CS99C2.txt).

② Prepare a map file (e.g. sec_map.txt) to define which river grid cells should reflect which cross section files (e.g. sec_000001.txt).

③ Change RRI_Input.txt setting to read sec_map.txt and the cross section files.

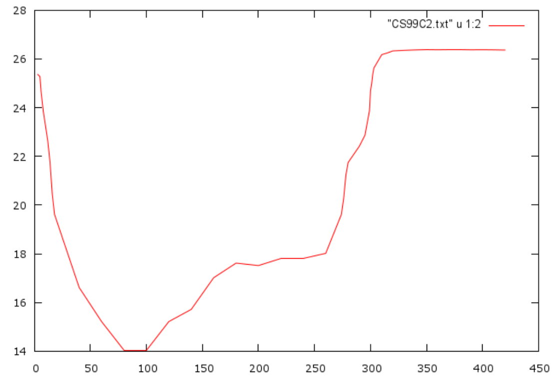
④ (Optional) prepare and read river length file from the RRI_Input.txt

The followings explain the detailed step to reflect the cross section information.

① The following steps use "RRI-CUI/etc/section/section.f90" program. Suppose cross section coordinate information files are available in the following format.

3.000000	25.35900	CS99C2.txt
5.000000	25.27600	
6.000000	24.65500	
8.000000	23.83900	
…	…	

(First column: x, second column: z)

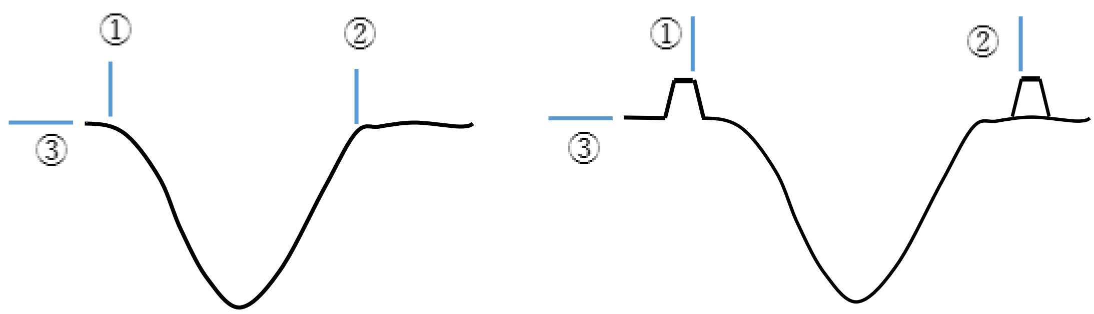


Prepare "section.txt" file accordingly to be inputted to "section.f90" program.

section.tx

```
CS99C2.txt
sec_000001.txt
0.03   ! Manning's roughness in river
100     ! div
25.     ! datum level
1        ! startx
30      ! endx
```

where the first two lines are input and output file names and the third line sets the Mannings's roughness in the river. The fourth line defines "div", which determines the number of divisions in depth directions, with 100 divisions in the above example. The fifth line is a datum level (m), which is the elevation of floodplain level identified from the cross section information (e.g. CS99C2.txt) as shown in the figure below. The RRI Model sets the defined cross section in a way that this datum level will be equal to the DEM elevation at each grid-cell.



For example, suppose the DEM of a grid-cell to set a river cross section is 24 m, while the estimated flood plain level read by the cross section file (i.e. elevation of ③ in the above figure) is 25 m. In this case, a user has the following two options.

a) Regardless the elevation information contained in the cross section data, prioritize the elevation of DEM 24 m and the floodplain level in the cross section will be at 24 m. For this option, please set the above “datum level” as 25 m. This means that the 25 m in the cross section will be regarded as the datum and this level will be the same as the DEM.
b) If both absolute elevation information contained in the DEM and cross section files are reliable and they are generally consistent each other, the user may set “datum level” as 24 m to use the elevation information contained in the cross section file directly. This means that the level of 24 m in the cross section will be equal to the level in DEM.

For L6 (startx) and L7 (endx) in the “section.txt”, please set minimum and maximum x coordinates, which should be within a river grid-cell, as shown in the above figure ① and ②.

Based on the above setting, “section.f90” will automatically proceed the following steps.
STEP 1: The program measures depth (d) and levee height (h). The depth (d) is the elevation difference between the deepest position in the cross section and the level of ③. The height (h) is the smaller elevation either ①or ②measured from ③.
STEP 2: It divides a cross section into the number of “div” (i.e. 100 in this case) from the deepest point to the datum level.
STEP 3: It outputs perimeters, widths and the Manning’s roughness parameters corresponding to each depth.

An example of output files by section.f90 (e.g. sec_000001.txt)

div	d	h	sec_000001.txt
100	10.98000	0.00000	
0.11339	23.78646	23.77967	0.03000
0.22678	27.57293	27.55933	0.03000
0.34017	31.35939	31.33900	0.03000
0.45356	35.14586	35.11867	0.03000
…			
11.11222	298.35455	295.76846	0.03000
11.22561	298.56949	295.95105	0.03000
11.33900	300.62881	298.00000	0.03000
depth	perimeter	width	roughness

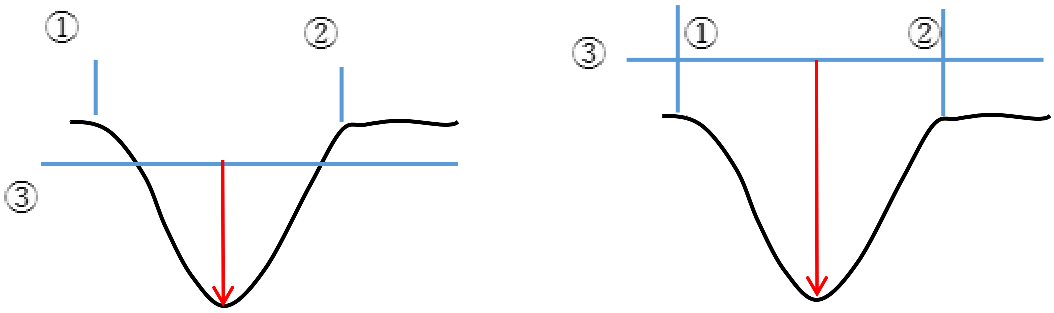
* section.f90 reads the Manning's roughness as a single parameter and set the constant value in the output file. However as shown in the above figure, the file can set different composite Manning's roughness values depending on water depths. One may change the roughness values if necessary.

② Prepare a section map file (e.g. sec_map.txt") to define the position of grid-cells to set cross section files. The "sec_map.txt" should have the same format (and size) as the dem.txt and contains numbers (greater than 1) at grid cells, whose numbers corresponding to cross section files. For example, if "sec_map.txt" indicates "5" at a particular grid cell, the RRI Model will find "sec_000005.txt" and reads and assigns the cross section information.

③ By setting 1 in L83 of RRI_Input.txt, the model will read "./riv/sec_map.txt" and corresponding river cross section files (e.g. sec_******.txt).

④ If necessary, a user may set river length at each grid-cell defined by "length.txt", whose format and the matrix size must be the same as "dem.txt". In that case, set 1 in the L80 and reads "./riv/length.txt" from the RRI_Input.txt. This can be activated when rivers are meandering or one would like to reflect distant information contained in cross sections.

(Reference) The method of RRI calculation depending on the datum level ③.



In case of left panel in the upper figure, the model will start exchange water between the river and slope cells once the river water exceeds the level of ③. As a result, the modeled river sections become smaller than the actual one indicated by the figure.

In case of right panel in the upper figure, the model does not exchange water between the river and slope cells unless the river water exceeds the level of ③. As a result, the modeled river sections become larger than the actual one indicated by the figure.

9. Use of RRI Graphical User Interface (GUI)

This section explains how to use RRI-GUI to apply the model at a basin and visualize the simulation results.

9.1 Pre-setting

1) Unzip "RRI_1_4_2.zip" and save it under a working folder (e.g. C:/").

3) Check your PC is 32 or 64 bit. (My Computer → Property)

4) Install two programs saved in "RRI-GUI/Pre-setting"

① w_fcompxe_redist_intel64.msi

② vcredist_x64.exe

(for 32 bit, install vcredist_x86.exe and w_fcompxe_redist_ia32.msi)

For "vcredist_x64.exe", you may encounter an error message suggesting you have already the newer version of "Microsoft Visual C++ 2010 Redistributable". In that case, you can just close the error message and cancel to install "vcredist_x64.exe".

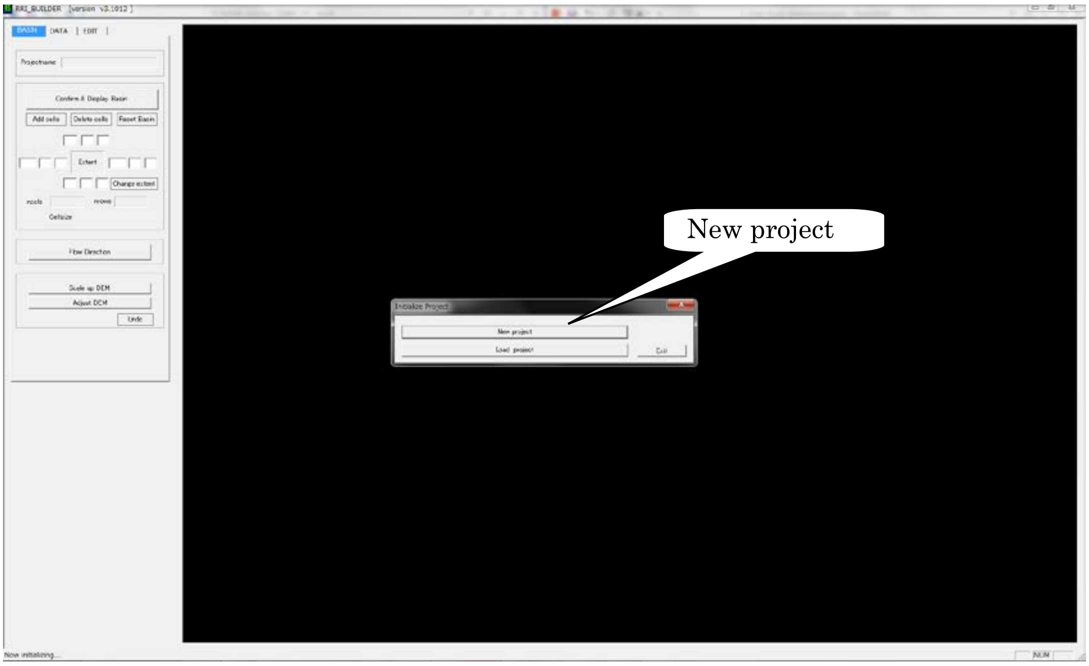
5) Execute RRI_BUILDER_64.exe

(for 32 bit machine, execute RRI_BUILDER_32.exe)

9.2 Model application and running with RRI_BUILDER

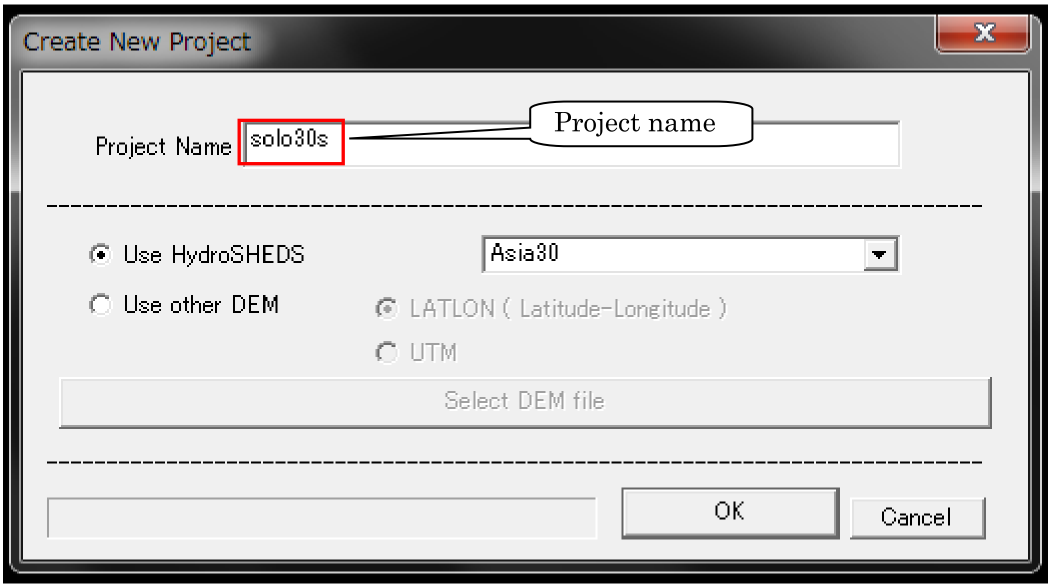
9.2.1 Preparing Input Topography Data

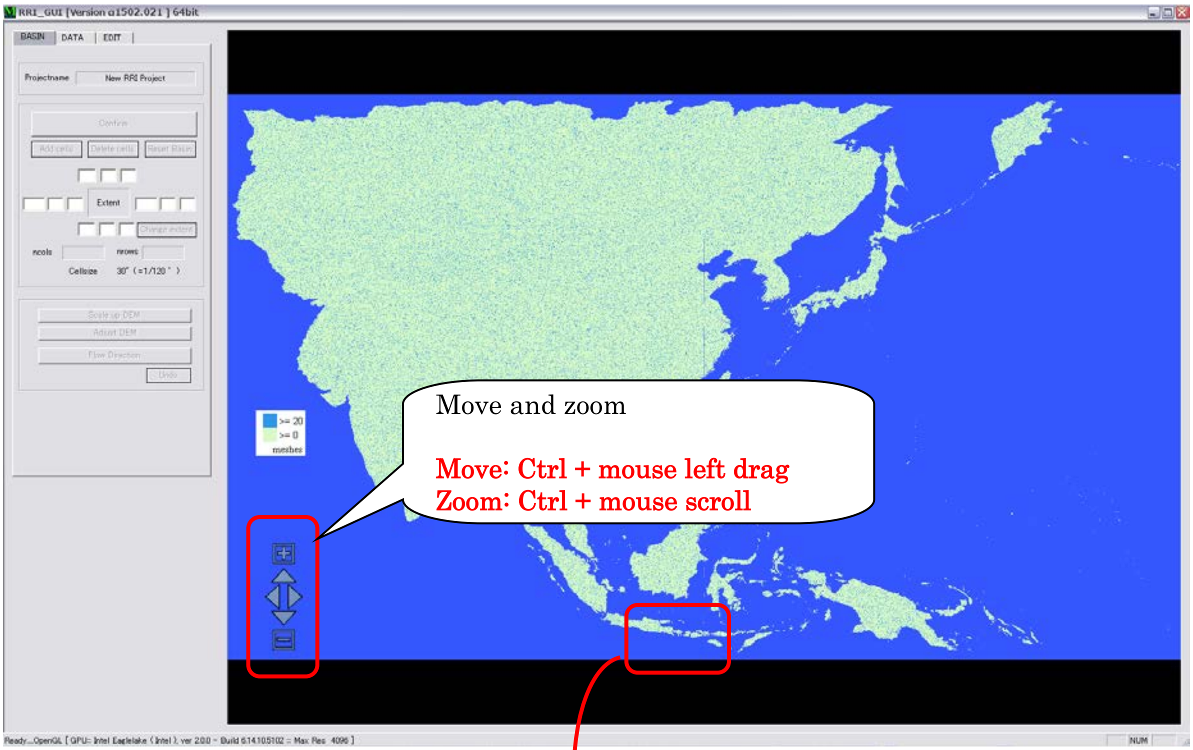
The first screen of the "RRI_BUILDER_64.exe" is to choose "New Project" or "Load Project".



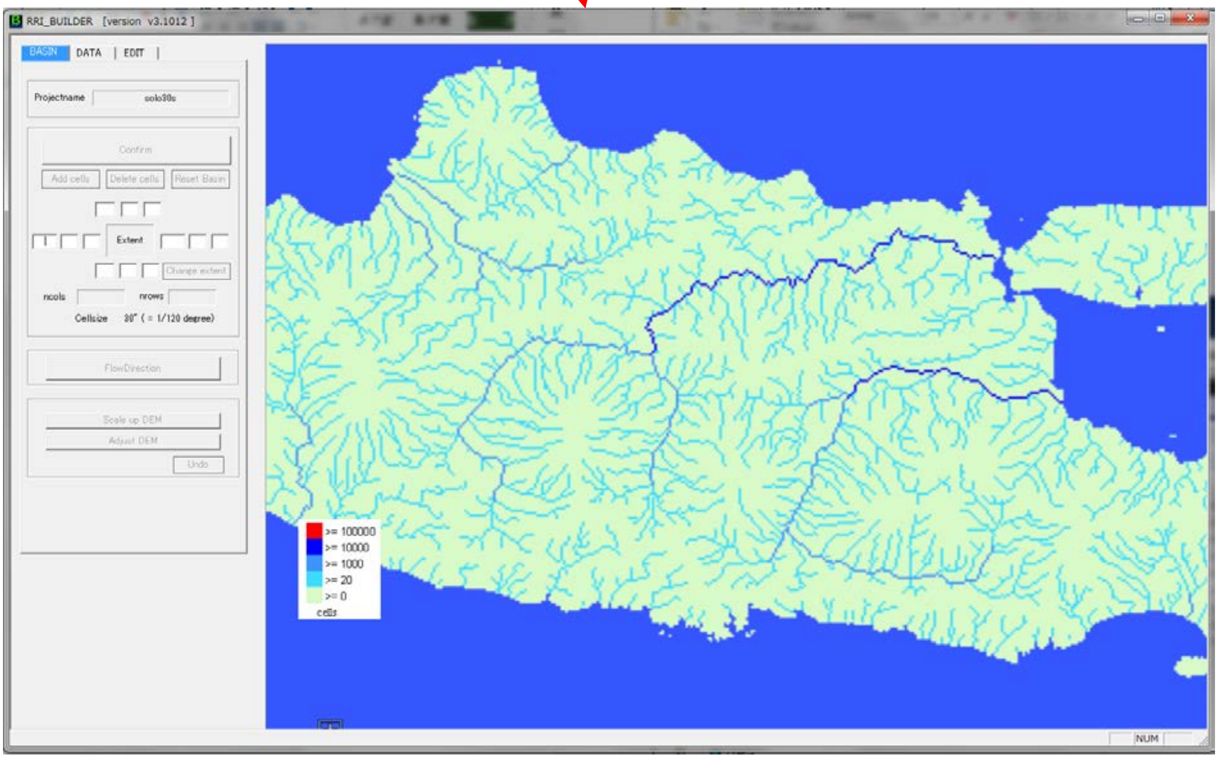
Select "New Project" in this exercise.

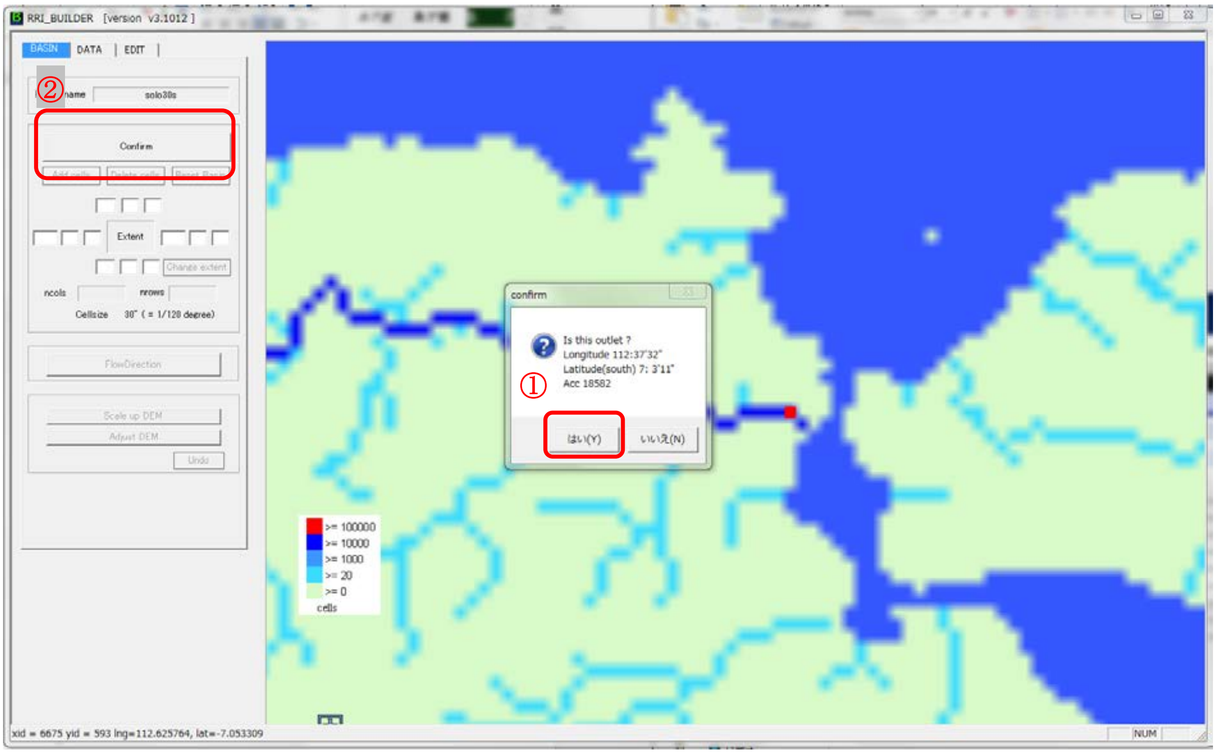
Type in a new project name (e.g. "solo30s") with the selections of "Use HydroSHEDS" and "Asia30", then click "OK".



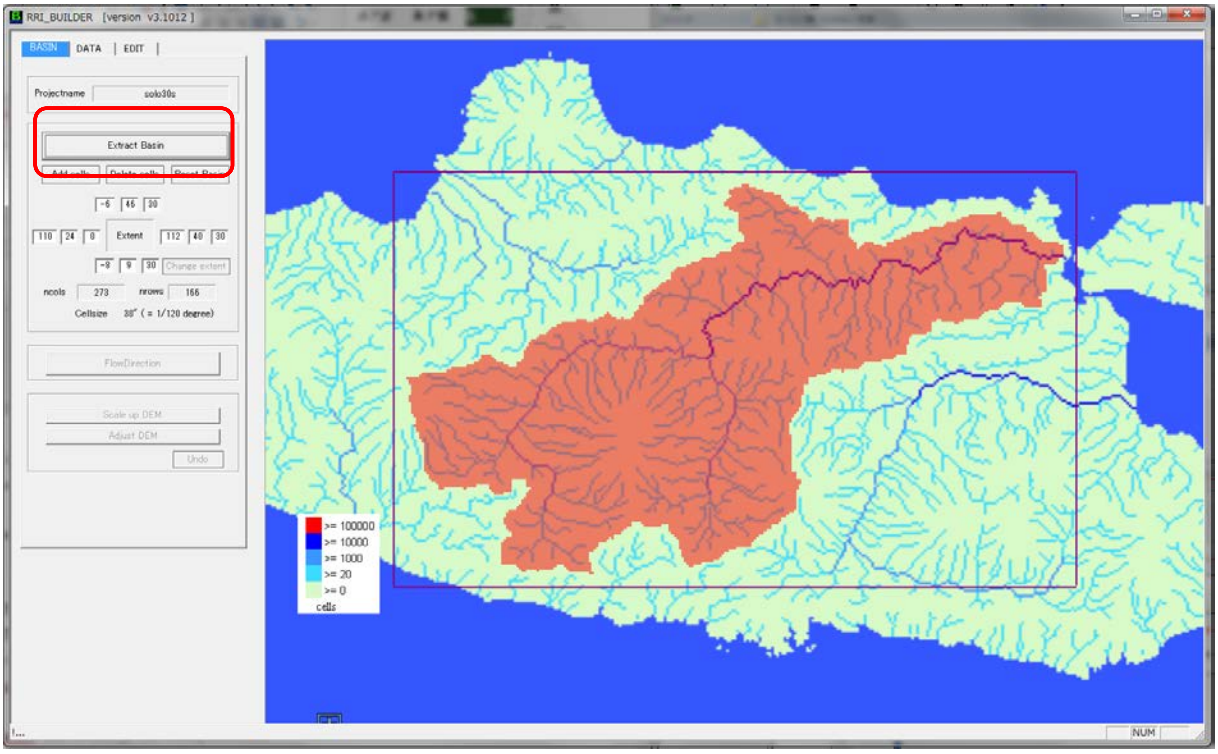


Zoom into Java Island in Indonesia



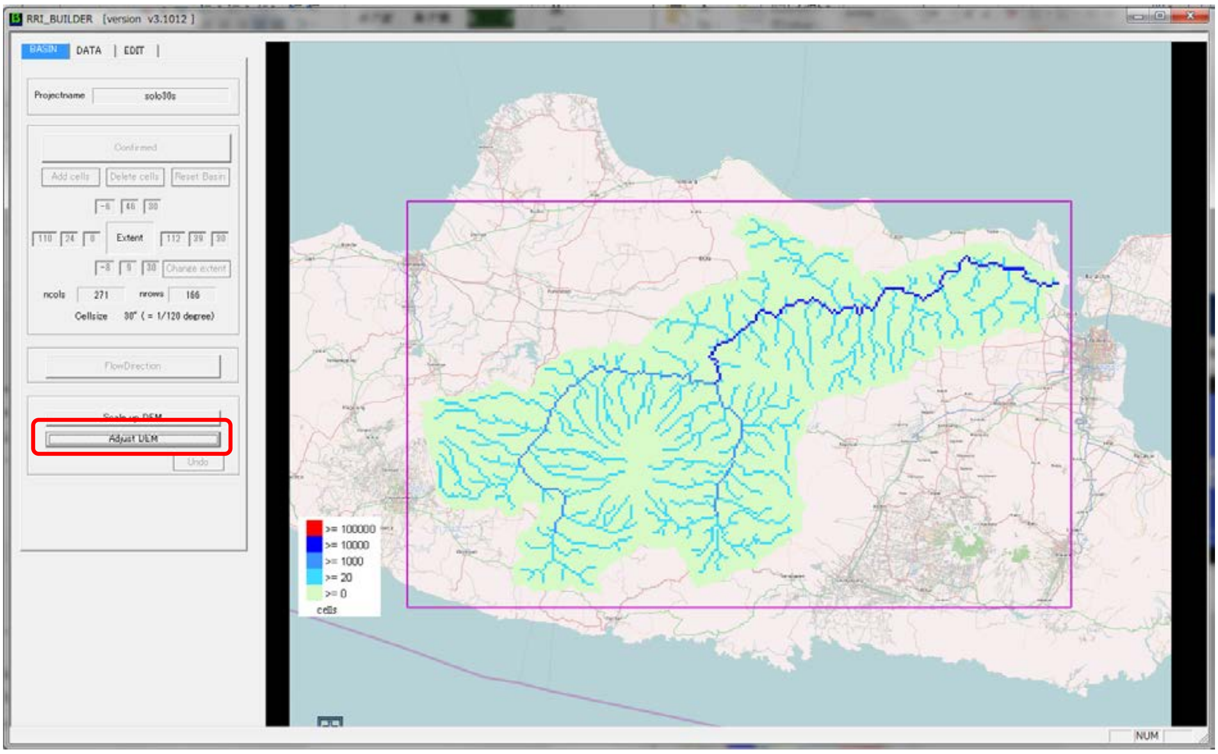


After zoom into the outlet area of the Solo River basin, click a pixel along the main river near the river mouth (not necessary to be exactly the same as the above example).
Then choose "Yes" on the window and "Confirm" on the left panel.



Click "Extract Basin" after you confirm the area of the basin.
(If not satisfactory, click "Reset Basin" and retry it.)

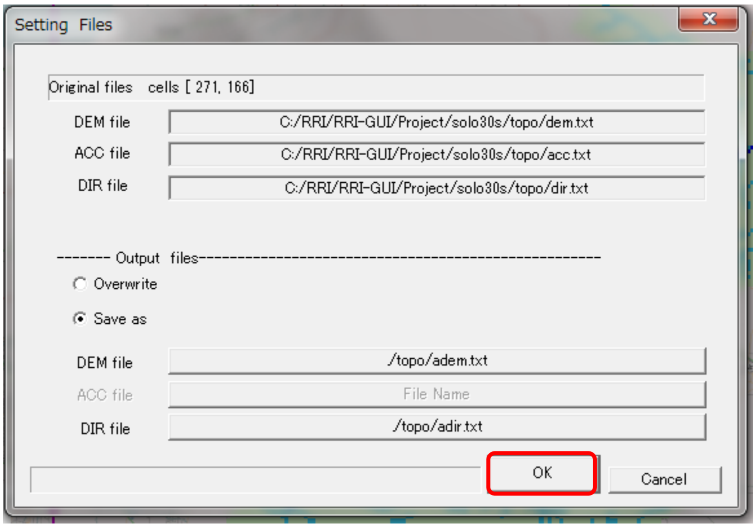
If the background map is available, the following extracted basin will be displayed. (Even the background image is not shown for some reasons, it is essentially no problem for the following simulation).



(Optional)

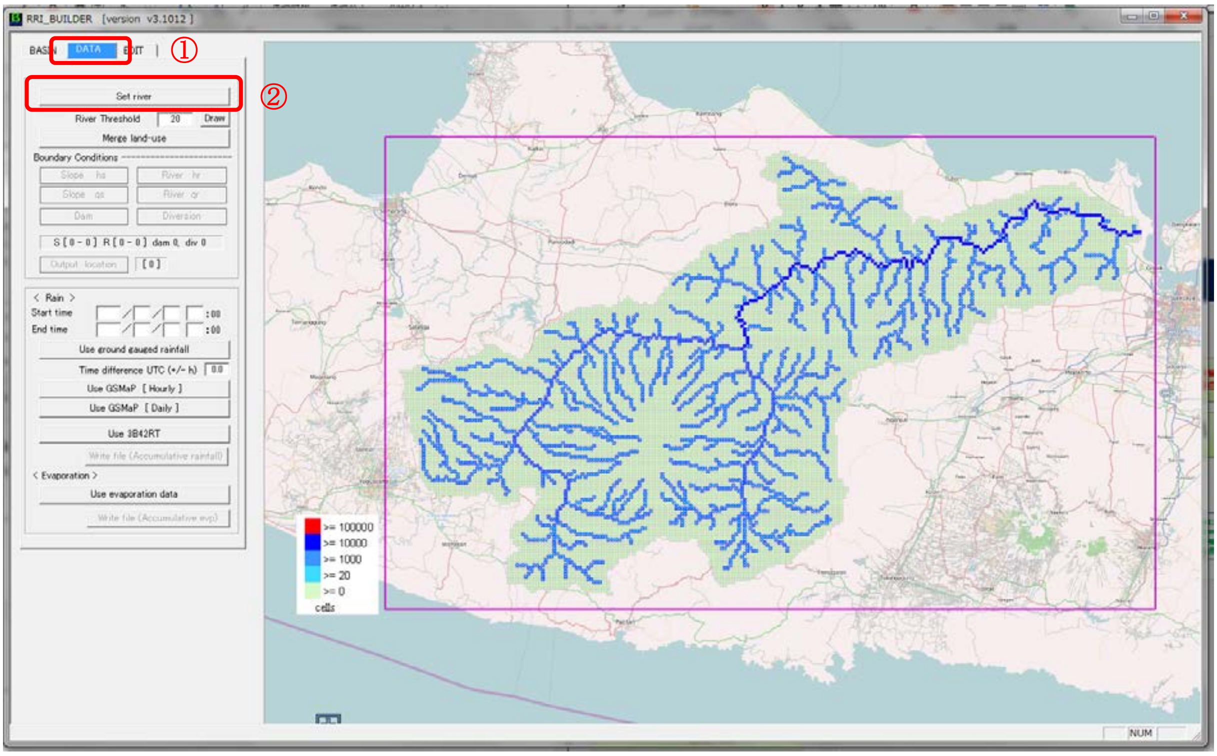
The step of "Scale up DEM" is an optional. Use this option in case you want to scale up the DEM for example changing the model resolution from 30 second to 60 seconds.

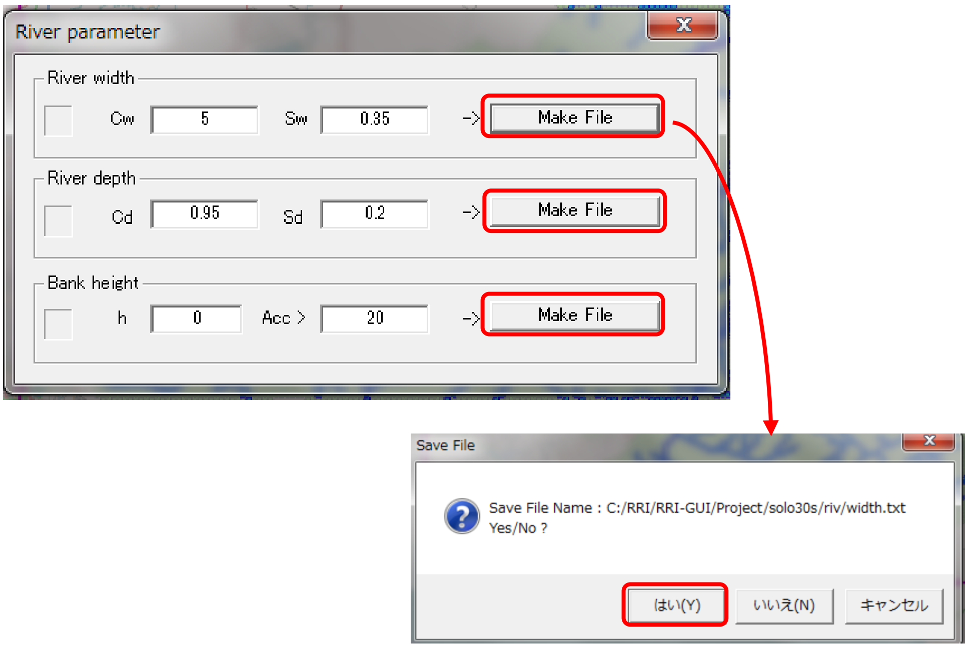
The next step is to execute "AdjustDEM". This procedure is always necessary for the stable simulation.



Choose OK with the default setting. (you will see a command screen running AdjustDEM program).

Now select “DATA” Tab on the left top and click “Set river”.



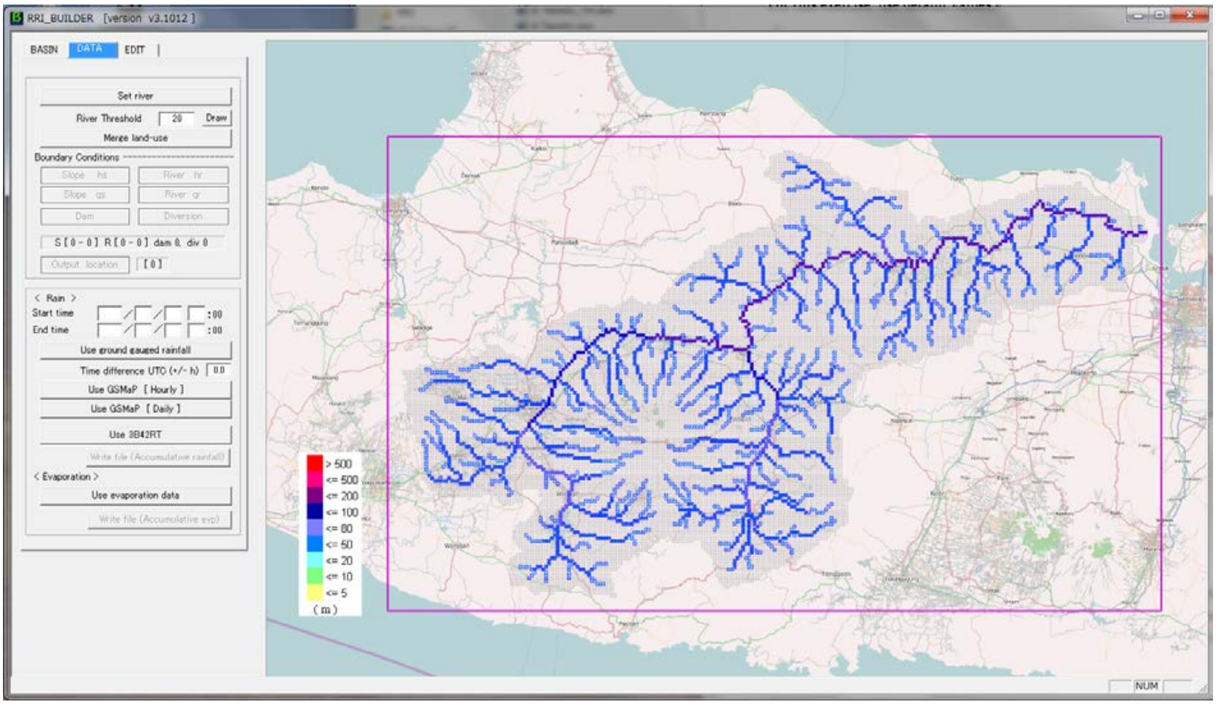


Click all the three “Make File” on River parameter setting.

These values are the parameters to determine the cross sections based on the equations.

For this exercise, use default values.

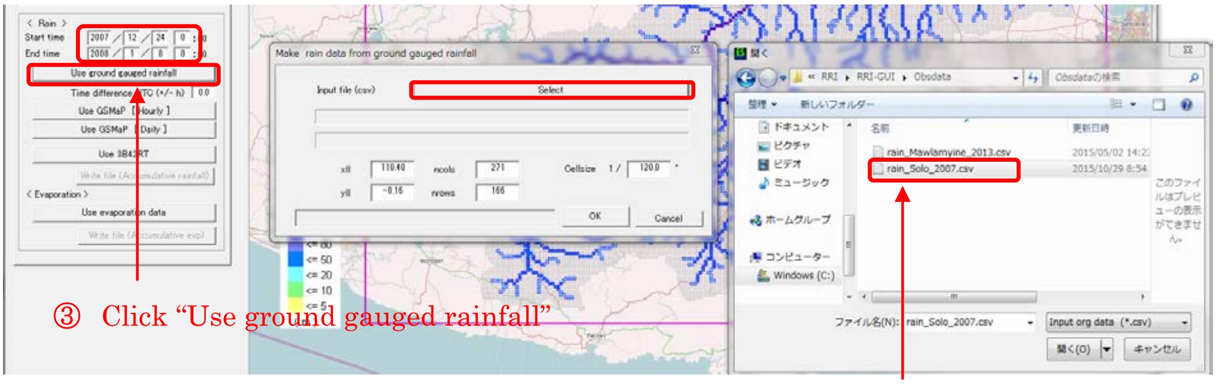
After confirming the three green signs, close this window.



9.2.2 Preparing Input Rainfall Data

① Set "Start time" and "End time" under <Rain>

Start : 2007/12/24 0:00, End : 2008/1/8 0:00

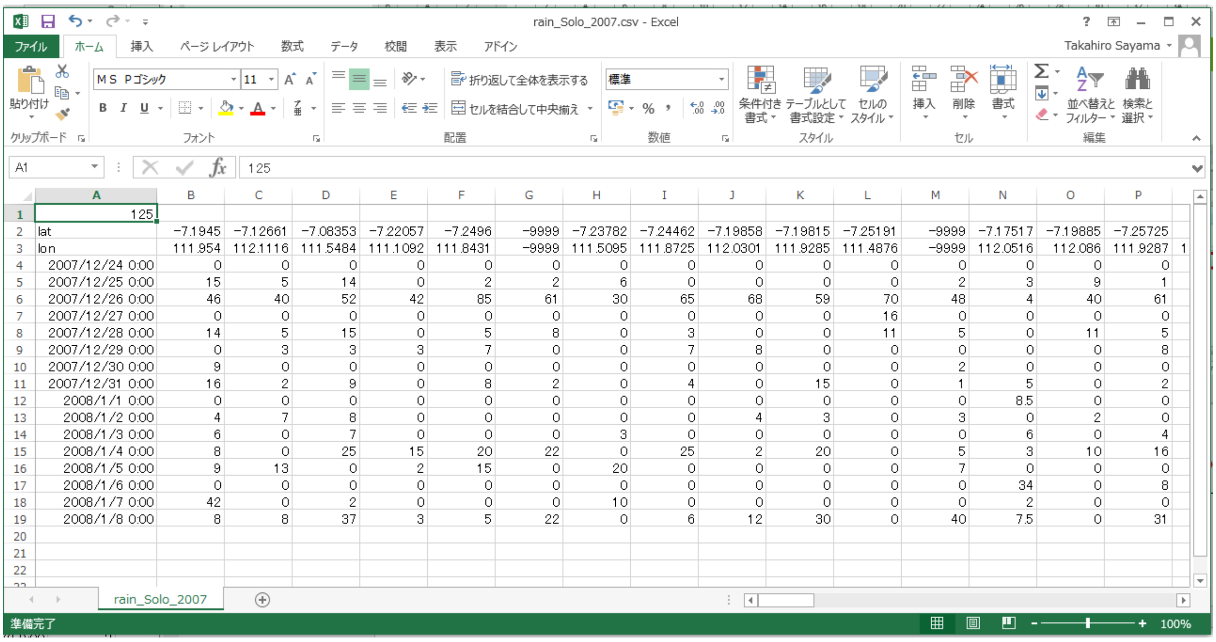


③ Click "Use ground gauged rainfall"

② Click "Select" to find a input rainfall file

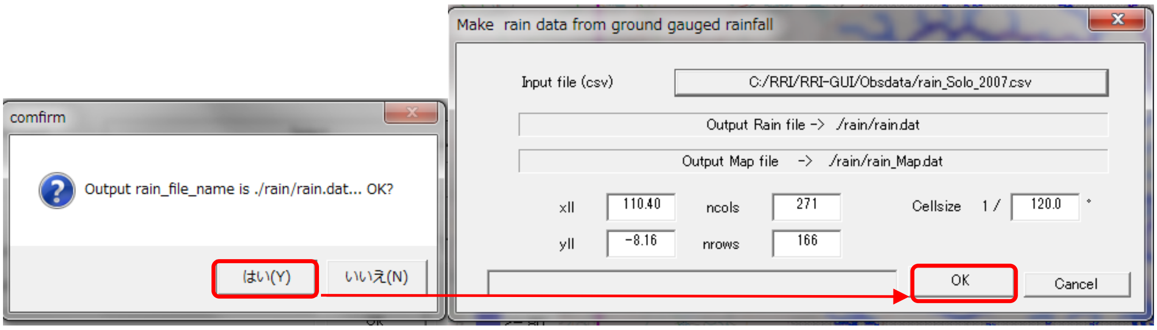
(In this exercise, "RRI-GUI/Obsdata/rain_Solo_2007.csv")

An input rainfall file must be the following format saved as csv. The file can be prepared by a text editor or Excel (saved as csv).

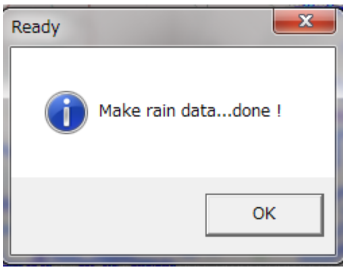


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	125															
2	lat	-7.1945	-7.12661	-7.08353	-7.22057	-7.2496	-9999	-7.23782	-7.24462	-7.19858	-7.19815	-7.25191	-9999	-7.17517	-7.19885	-7.25725
3	lon	111.954	112.1116	111.5484	111.1092	111.8431	-9999	111.5095	111.8725	112.0301	111.9285	111.4876	-9999	112.0516	112.086	111.9287
4	2007/12/24 0:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2007/12/25 0:00	15	5	14	0	2	2	6	0	0	0	0	2	3	9	1
6	2007/12/26 0:00	46	40	52	42	85	61	30	65	68	59	70	48	4	40	61
7	2007/12/27 0:00	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0
8	2007/12/28 0:00	14	5	15	0	5	8	0	3	0	0	11	5	0	11	5
9	2007/12/29 0:00	0	3	3	3	7	0	0	7	8	0	0	0	0	0	8
10	2007/12/30 0:00	9	0	0	0	0	0	0	0	0	0	0	2	0	0	0
11	2007/12/31 0:00	16	2	9	0	8	2	0	4	0	15	0	1	5	0	2
12	2008/1/1 0:00	0	0	0	0	0	0	0	0	0	0	0	0	8.5	0	0
13	2008/1/2 0:00	4	7	8	0	0	0	0	0	4	3	0	3	0	2	0
14	2008/1/3 0:00	6	0	7	0	0	0	3	0	0	0	0	0	6	0	4
15	2008/1/4 0:00	8	0	25	15	20	22	0	25	2	20	0	5	3	10	16
16	2008/1/5 0:00	9	13	0	2	15	0	20	0	0	0	0	7	0	0	0
17	2008/1/6 0:00	0	0	0	0	0	0	0	0	0	0	0	0	34	0	8
18	2008/1/7 0:00	42	0	2	0	0	0	10	0	0	0	0	0	2	0	0
19	2008/1/8 0:00	8	8	37	3	5	22	0	6	12	30	0	40	7.5	0	31

Please note that the format is slightly different from the one used by the Thiessen Polygon program explained for RRI-CUI (Command User Interface). The first column of the fille (L4-) is date and time. Currently the date and time must be in the form of "yyyy/mm/dd h:mm".

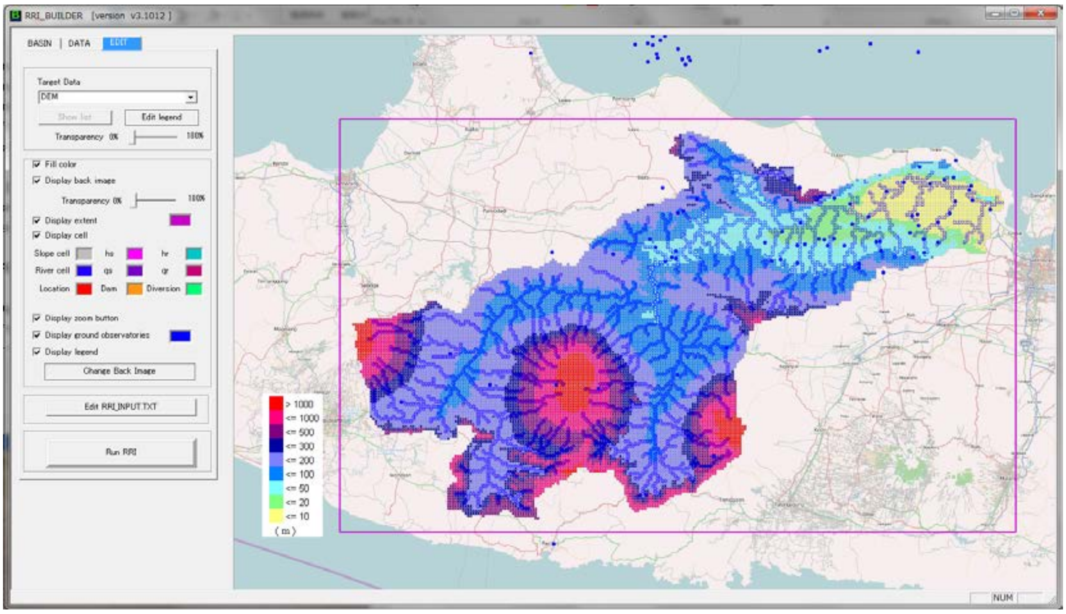


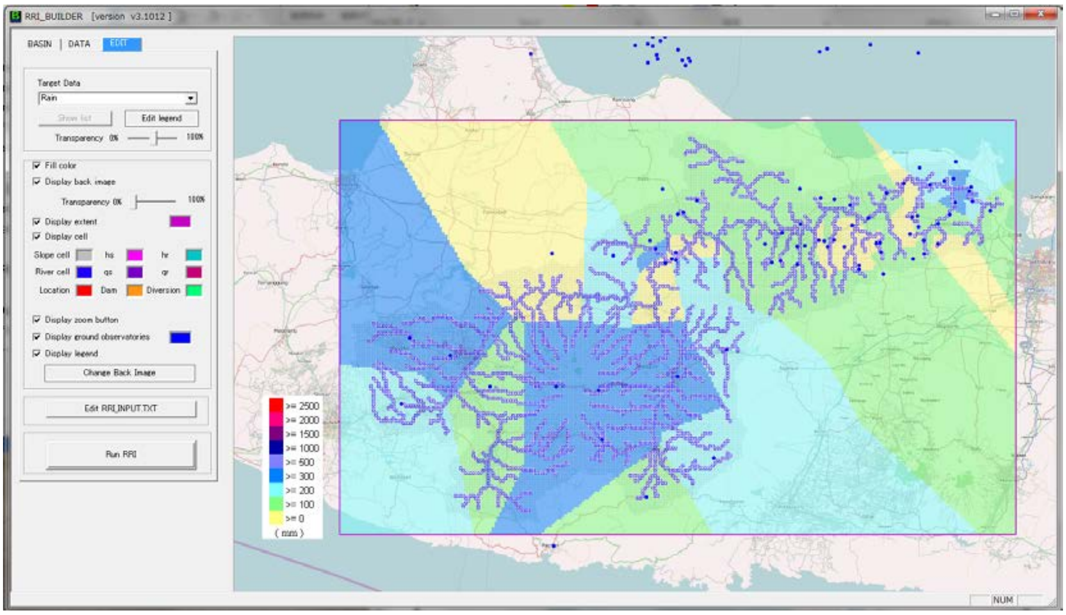
After selecting the input csv file, please choose "Yes" on the confirmation window then click "OK" with the default setting of the creating rainfall distribution file.



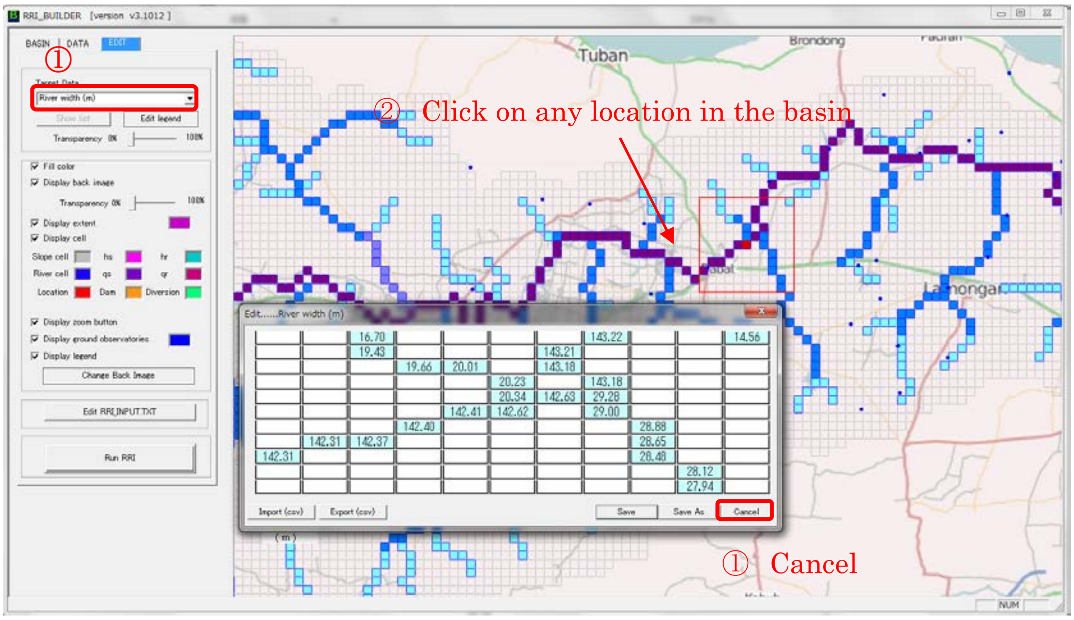
9.2.3 Running RRI Model

Select “Edit” tab after the topographic and rainfall data is ready.
You can confirm different distributions including DEM, ACC, DIR, River Width, River Depth, Bank height as well as cumulative Rain.

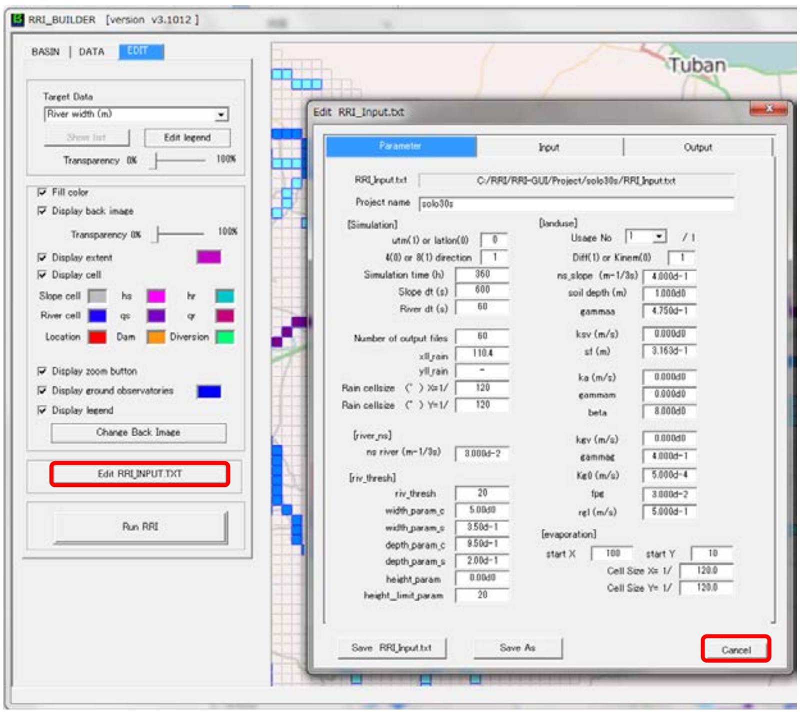




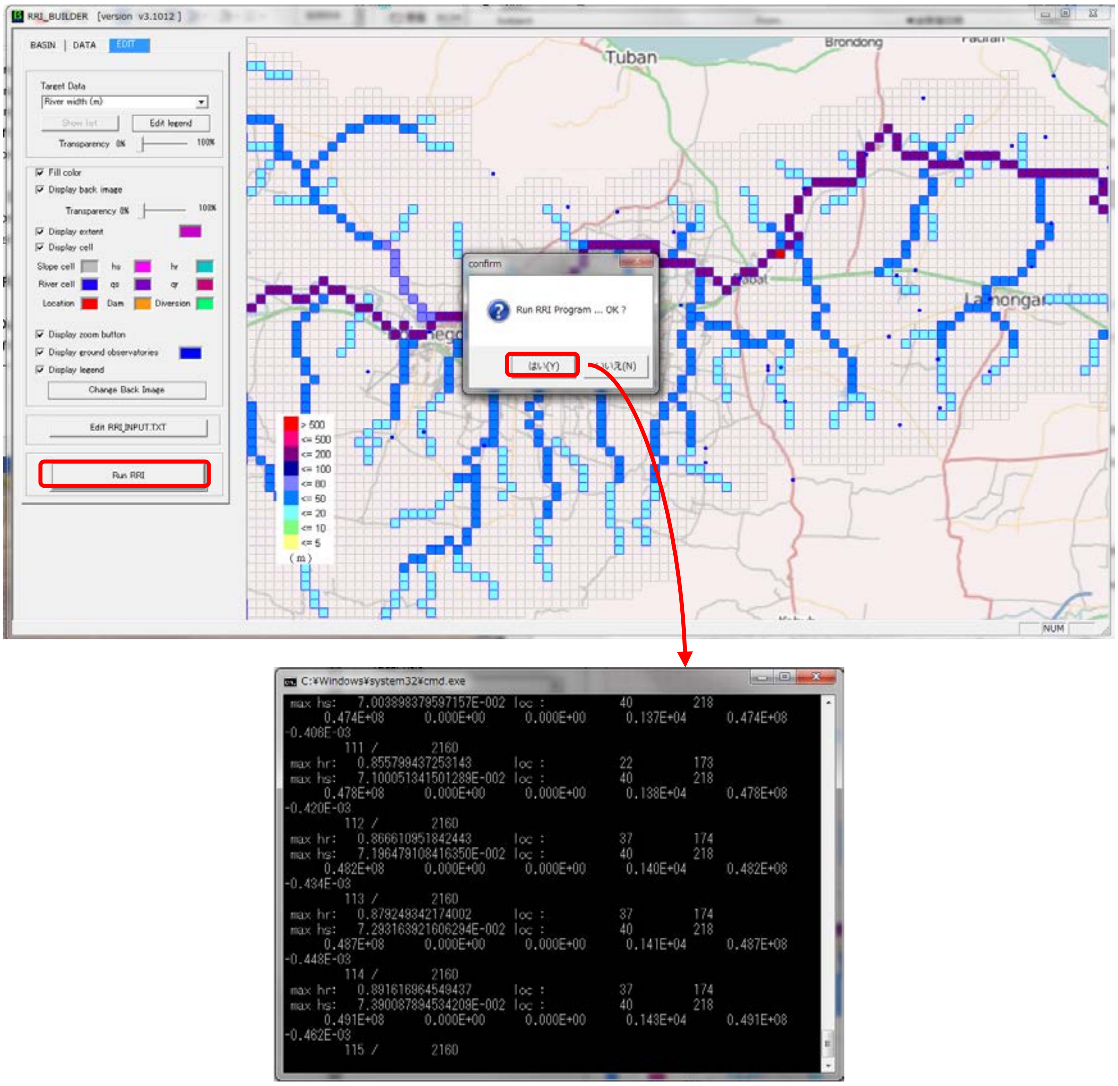
These distribution files except for the cumulative rainfall, can be edited on the window. For example you can choose river width and select any area inside the basin to display the following image. (For this exercise, no need to change the values.)



In addition, you find parameter and other input file settings if you click "Edit RRI_INPUT.TXT". The editting the values will be reflected to the RRI_Input.txt file, which is the control file of the RRI model. (For this exercise, no need to change the values.)

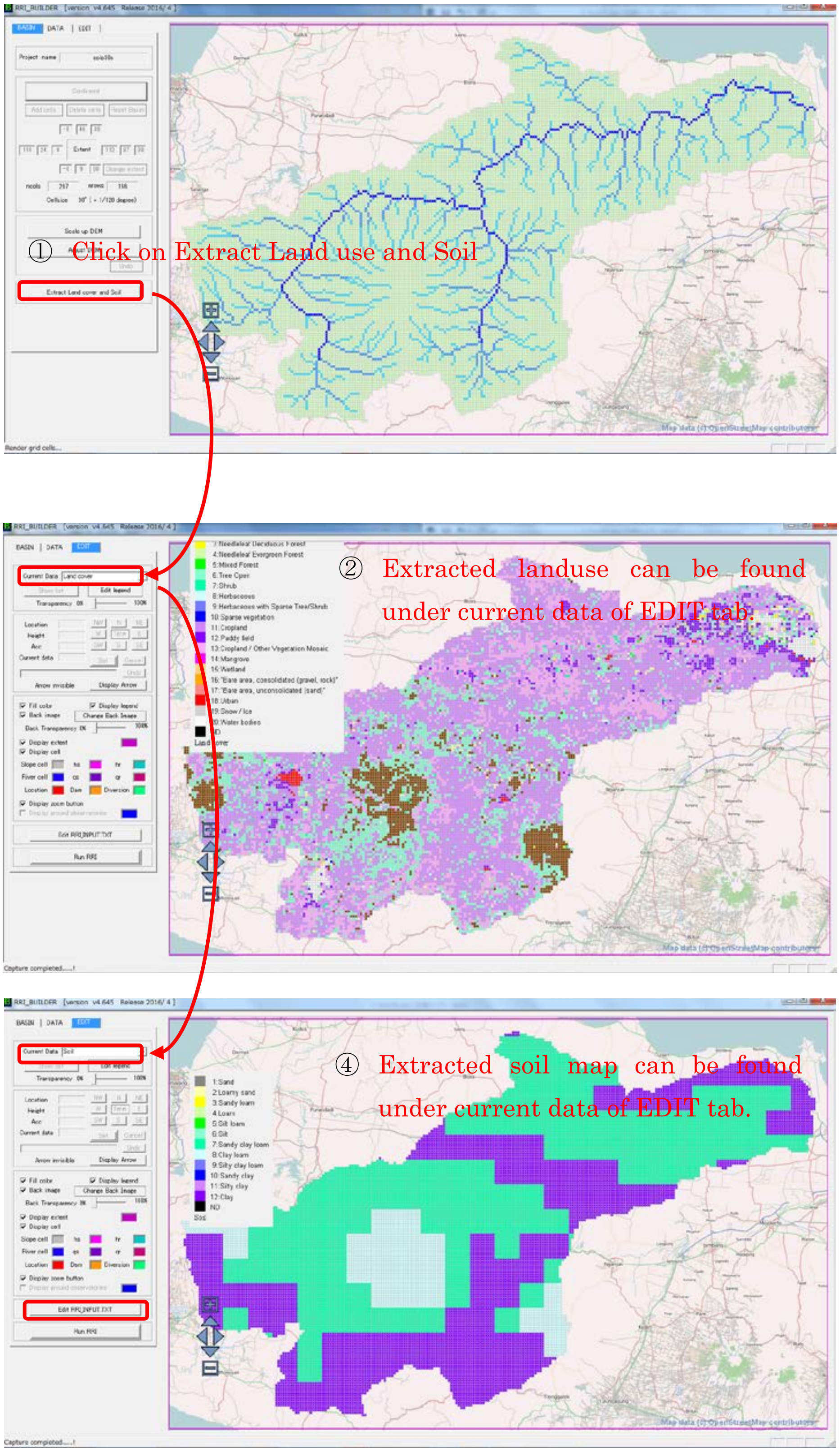


Finally, click "Run RRI" and "OK" to start the simulation.



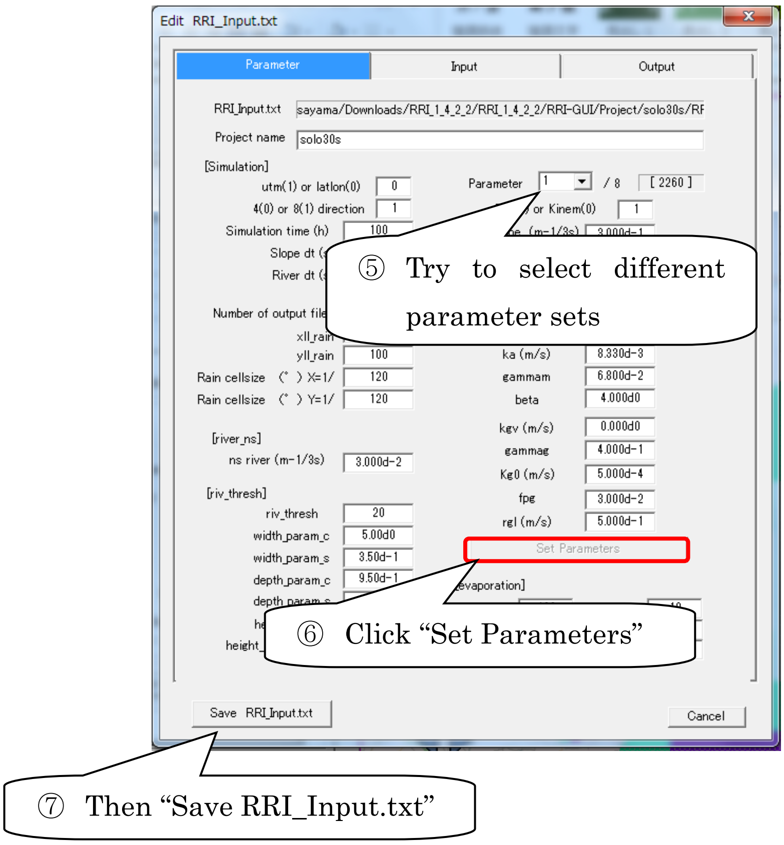
9.2.4 Additional functions of RRI_BUILDER

The latest version of "RRI_BUILDER.exe" has a function to use global dataset for landuse and soil distribution to assign different sets of model parameters. To read the maps for the target river basin, one can click "Extract Land cover and Soil" under BASIN tab.



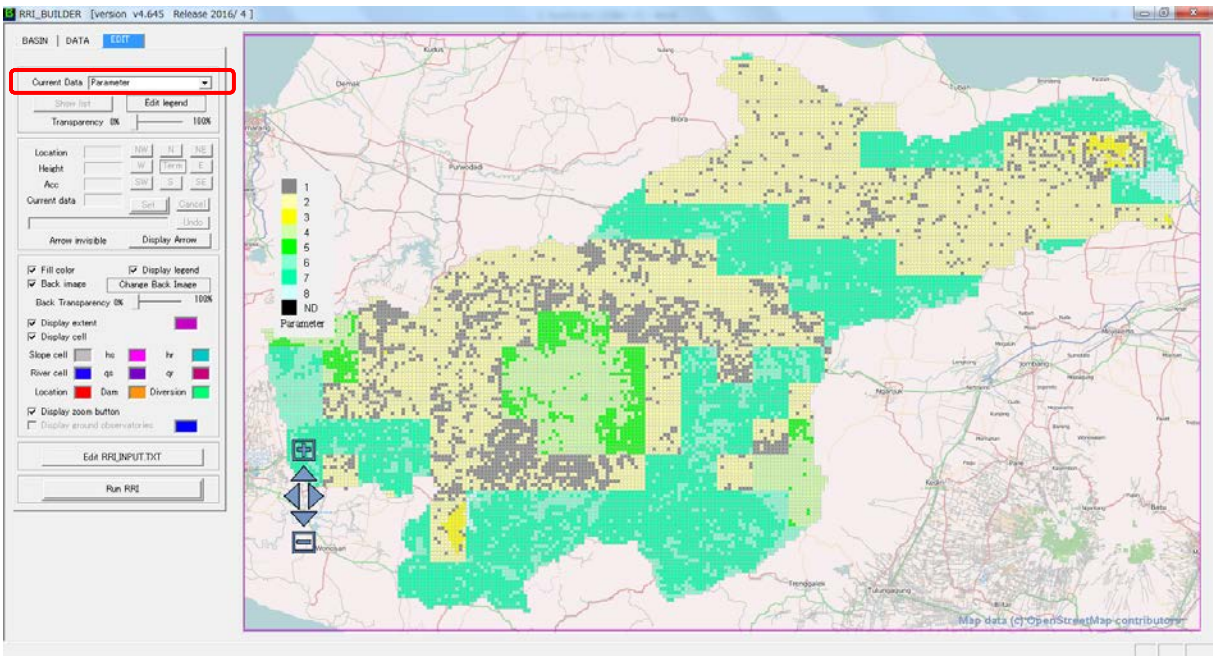
③ Click "EDIT RRI_Input.txt" to set different values for each combination of the landuse and soil distribution.

Under "EDIT RRI_Input.txt", click "Set Parameters", so that different parameters are assigned (e.g. 1, 2, 3, … 8), which can be confirmed by selecting "Parameter".



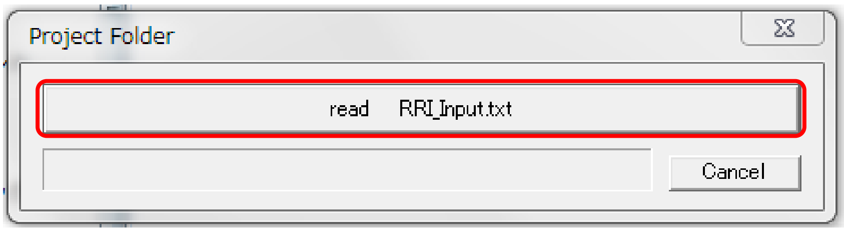
Finally Save "RRI_Input.txt" to update the RRI_Input.txt file.

Note that now new map called "Parameter" is created under Current Data of Edit tab. The map shows the distributions of ID numbers, corresponding to the above parameter set created by the combination of landuse and soil distribution. For example, the area with the gray color in the following map (i.e. ID = 1) will be assigned with parameter set 1.

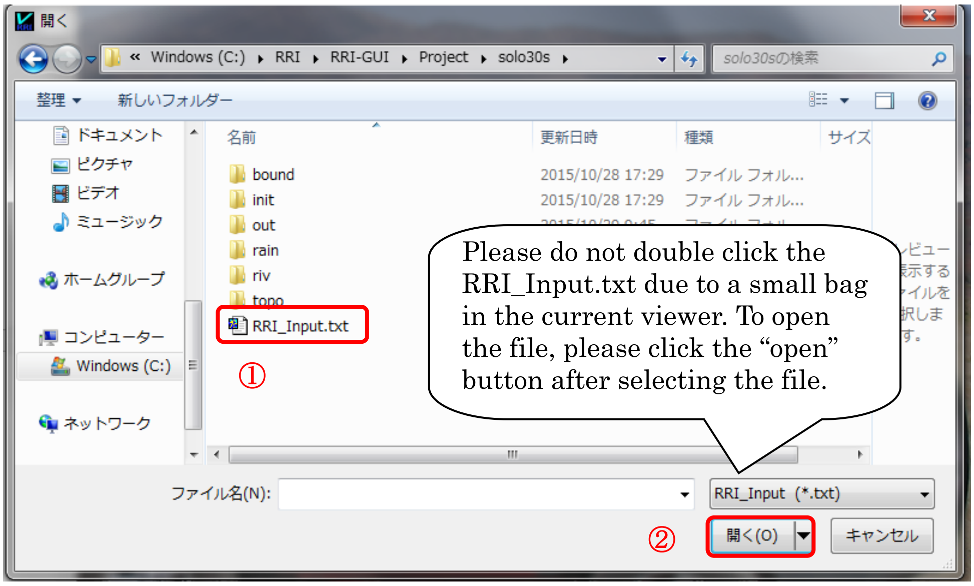


9.3 Visualizing results with RRI_VIEWER

Execute “RRI_VIEWER_64.exe” (or _32.exe for a 32 bit machine).

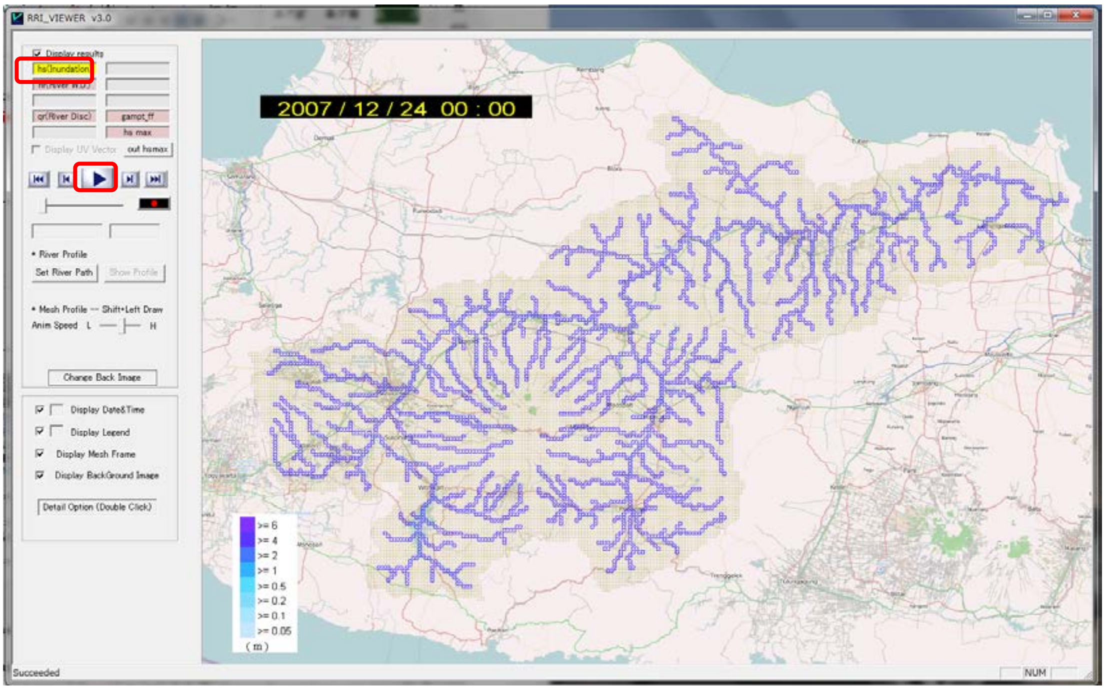


Read RRI_Input.txt file prepared in the previous subsection. In this exercise, find **RRI-GUI/Project/solo30s**

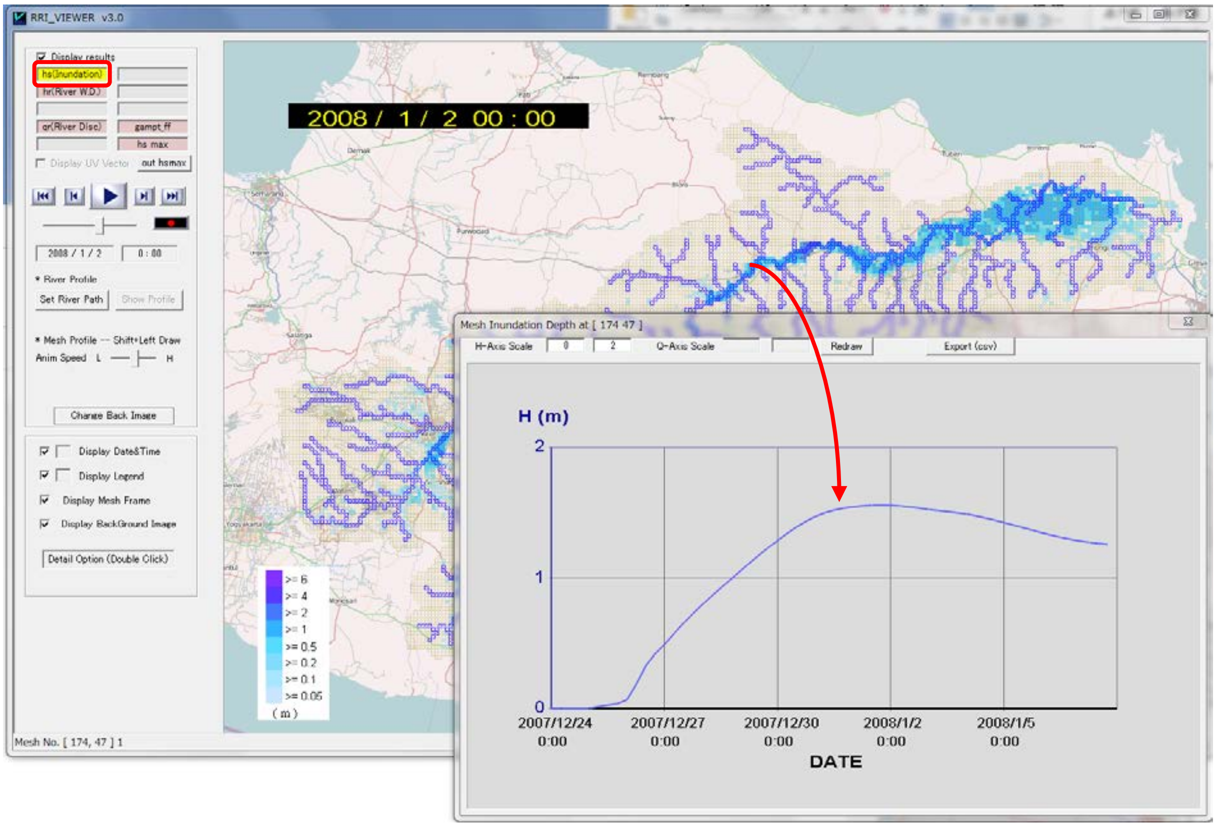


9.3.1 Visualize flood inundation

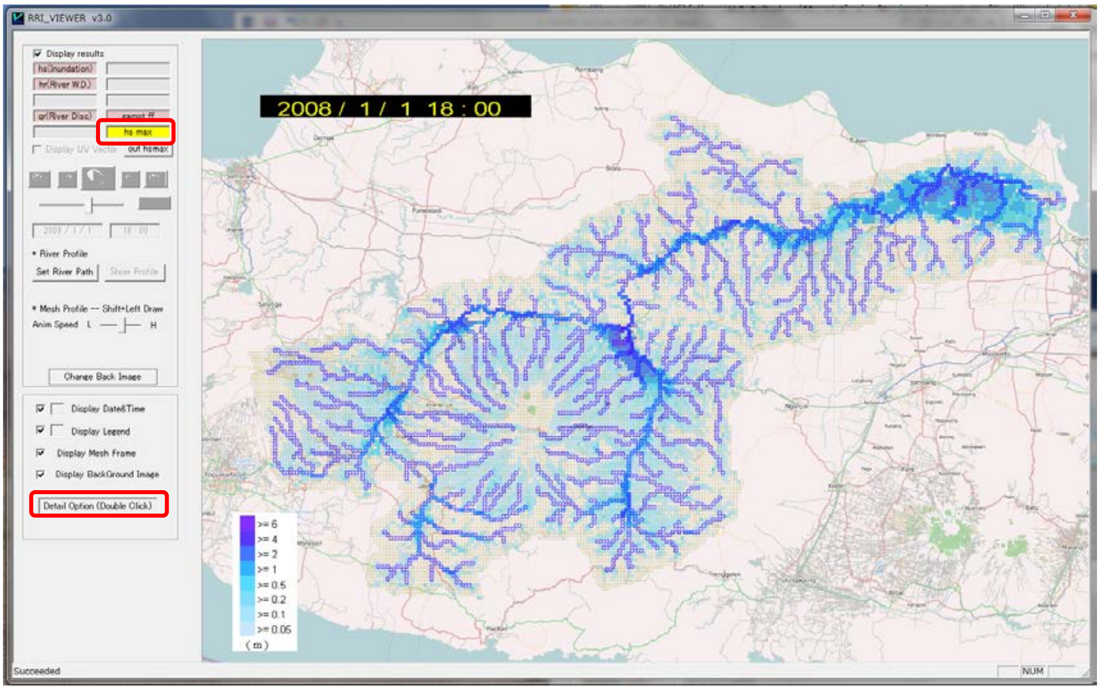
On the displayed map image, one can use CTRL and left drag to move the map and also CTRL and mouse scroll to zoom in and out. This operation is the same as RRI_BUILDER_64.exe



To display the animation of flood inundation depth distribution, please select inundation on the top left panel and click the start button.

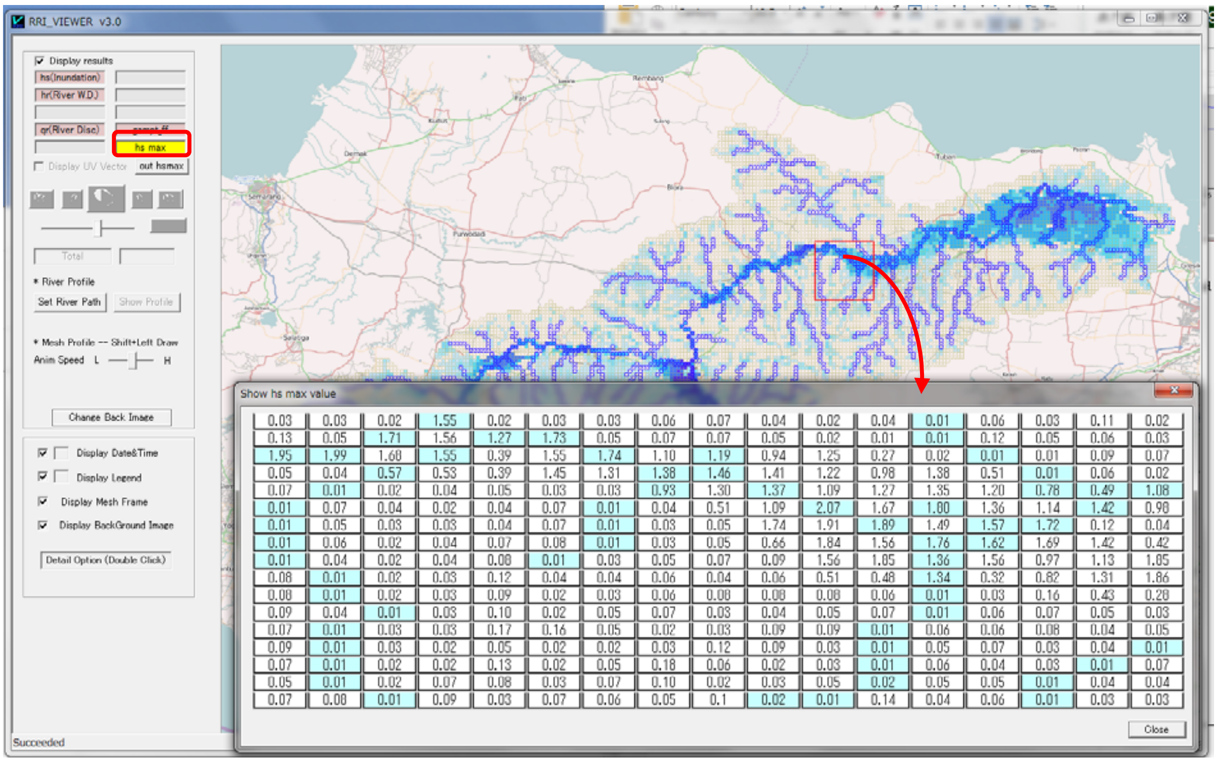


After stopping the animation, try to click any grid cell inside a basin to visualize the time seris of flood inundation depths.



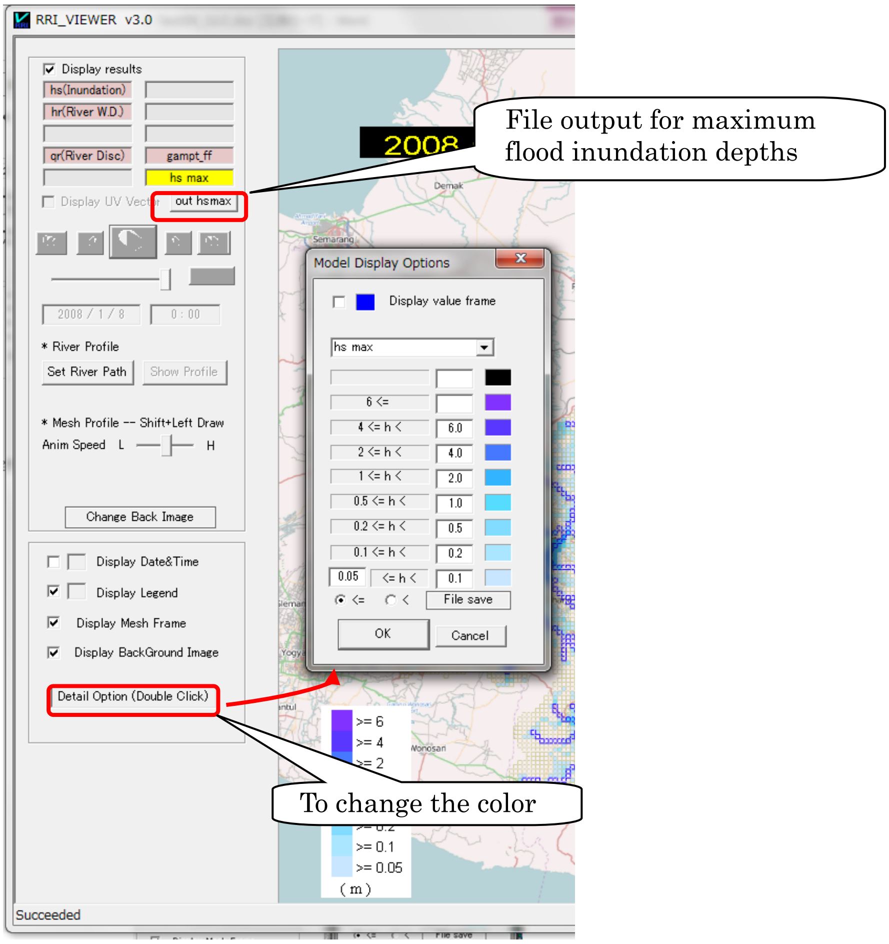
Then display the maximum inundation depth distribution by choosing hs max.

For the maximum inundation depths, one can check values by selecting a area on the map.



0.03	0.03	0.02	1.55	0.02	0.03	0.03	0.06	0.07	0.04	0.02	0.04	0.01	0.06	0.03	0.11	0.02
0.13	0.05	1.71	1.56	1.27	1.73	0.05	0.07	0.07	0.05	0.02	0.01	0.01	0.12	0.05	0.06	0.03
1.95	1.99	1.68	1.55	0.39	1.55	1.74	1.10	1.19	0.94	1.25	0.27	0.02	0.01	0.01	0.09	0.07
0.05	0.04	0.57	0.53	0.39	1.45	1.31	1.38	1.46	1.41	1.22	0.98	1.38	0.51	0.01	0.06	0.02
0.07	0.01	0.02	0.04	0.05	0.03	0.03	0.93	1.30	1.37	1.09	1.27	1.35	1.20	0.78	0.49	1.08
0.01	0.07	0.04	0.02	0.04	0.07	0.01	0.04	0.51	1.09	2.07	1.67	1.00	1.36	1.14	1.42	0.98
0.01	0.05	0.03	0.03	0.04	0.07	0.01	0.03	0.05	1.74	1.91	1.89	1.49	1.57	1.72	0.12	0.04
0.01	0.06	0.02	0.04	0.07	0.08	0.01	0.03	0.05	0.66	1.84	1.56	1.76	1.62	1.69	1.42	0.42
0.01	0.04	0.02	0.04	0.08	0.01	0.03	0.05	0.07	0.09	1.56	1.05	1.36	1.56	0.97	1.13	1.05
0.08	0.01	0.02	0.03	0.12	0.04	0.04	0.06	0.04	0.06	0.51	0.48	1.34	0.32	0.82	1.31	1.86
0.08	0.01	0.02	0.03	0.09	0.02	0.03	0.06	0.08	0.08	0.08	0.06	0.01	0.03	0.16	0.43	0.28
0.09	0.04	0.01	0.03	0.10	0.02	0.05	0.07	0.03	0.04	0.05	0.07	0.01	0.06	0.07	0.05	0.03
0.07	0.01	0.03	0.03	0.17	0.16	0.05	0.02	0.03	0.09	0.09	0.01	0.06	0.06	0.08	0.04	0.05
0.09	0.01	0.03	0.02	0.05	0.02	0.02	0.03	0.12	0.09	0.03	0.01	0.05	0.07	0.03	0.04	0.01
0.07	0.01	0.02	0.02	0.13	0.02	0.05	0.18	0.06	0.02	0.03	0.01	0.06	0.04	0.03	0.01	0.07
0.05	0.01	0.02	0.07	0.08	0.03	0.07	0.10	0.02	0.03	0.05	0.02	0.05	0.05	0.01	0.04	0.04
0.07	0.08	0.01	0.09	0.03	0.07	0.06	0.05	0.1	0.02	0.01	0.14	0.04	0.06	0.01	0.03	0.03

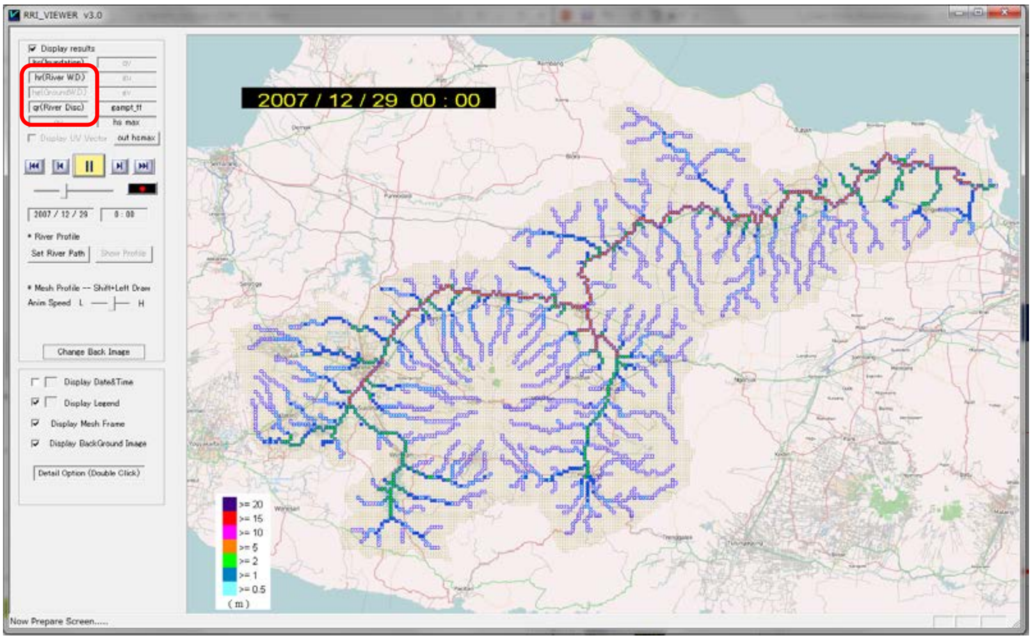
(Optional)



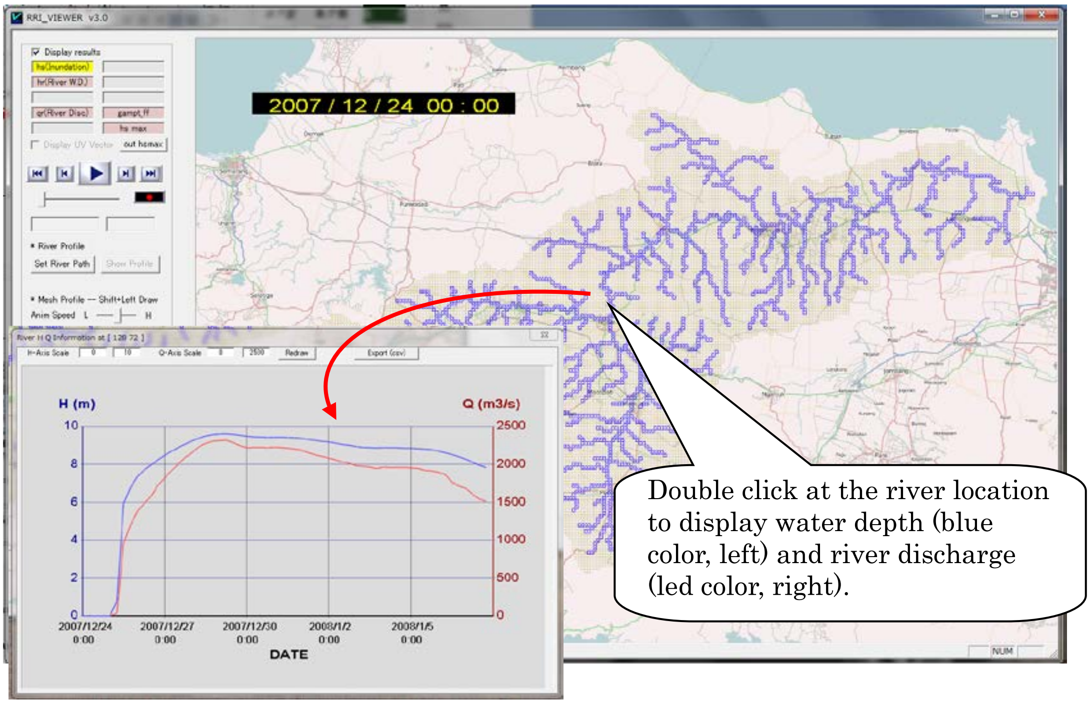
9.3.2 Visualize river discharge and water depth

To display the animation of river discharge or river water depth distribution, please select qr (River Disc.) or hr (River WD) on the top left panel and click the start button.

River discharge (qr) or
river water depth (hr)

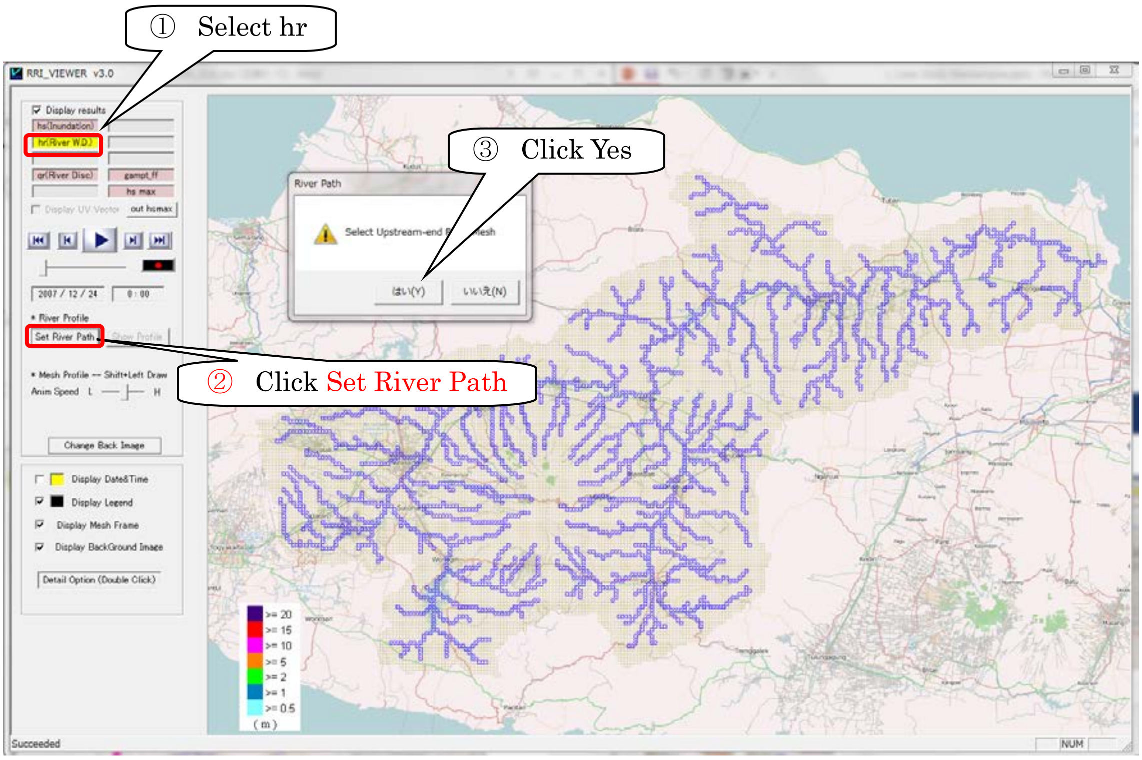


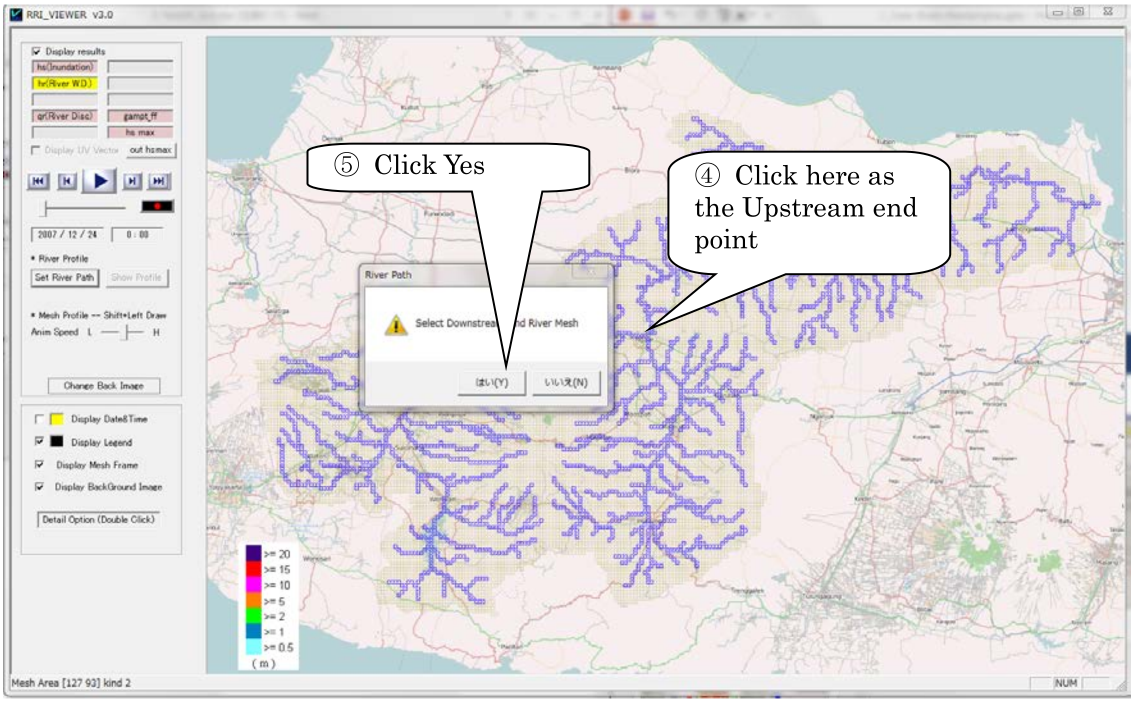
After stopping the animation, try to click any river grid-cell to visualize the time serises of river discharge (i.e. hydrograph) and river water depth.

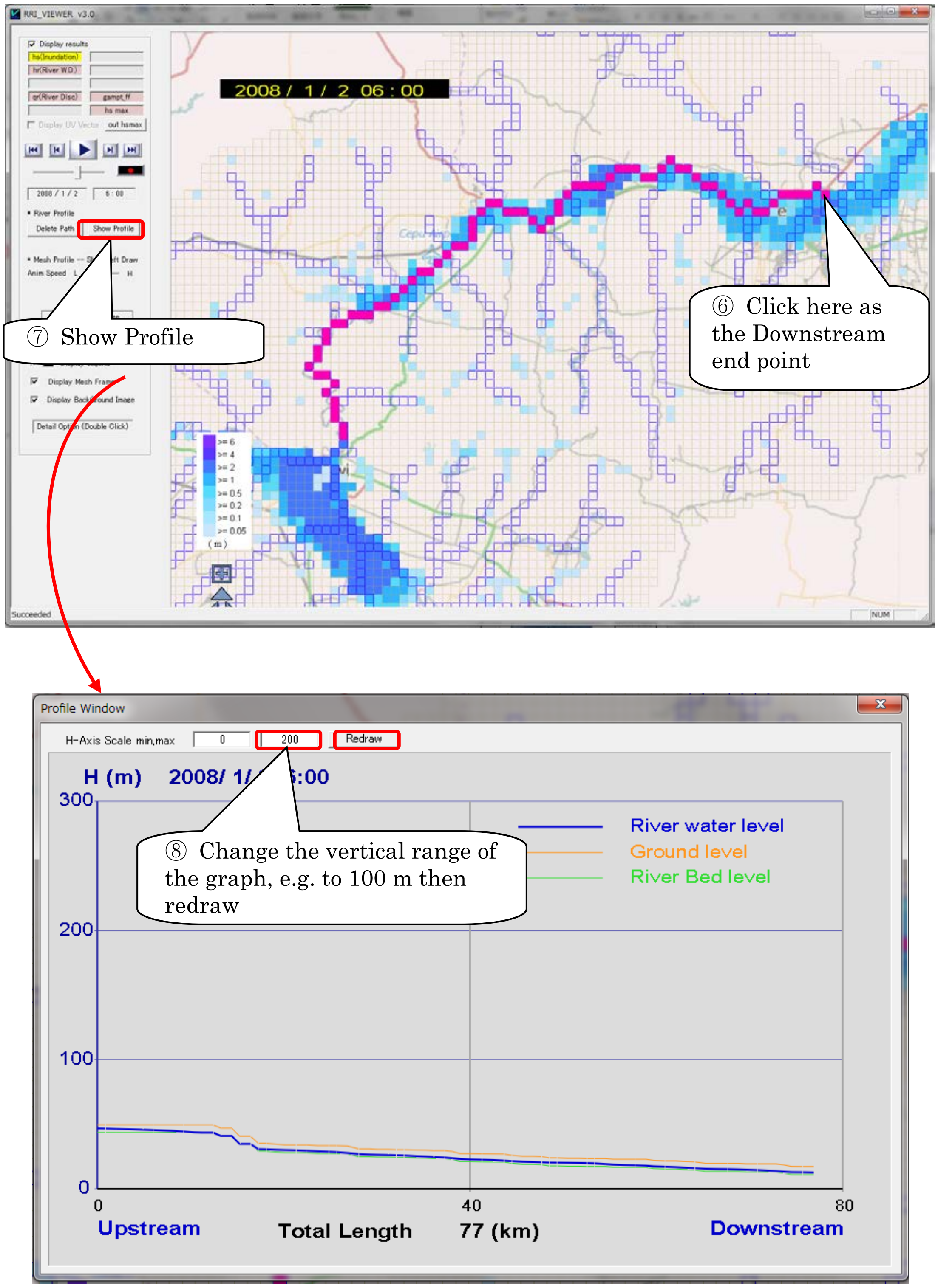


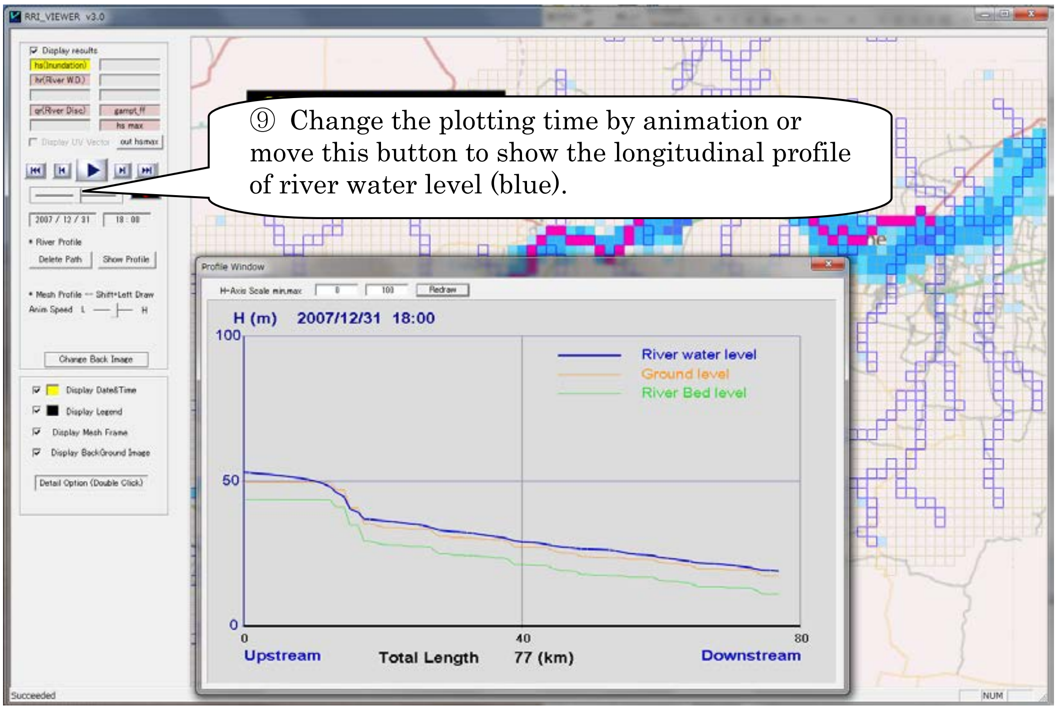
9.3.3 Visualize the longitudinal profile of river water level

To visualize the longitudinal profile of river water level, first select hr (River WD) and click “Set River Path” on the left pannel.


① Select hr
③ Click Yes
② Click Set River Path
RRI_VIEWER v3.0
River Path
はい(Y)
いいえ(N)
Succeeded


⑤ Click Yes
④ Click here as the Upstream end point
RRI_VIEWER v3.0
River Path
はい(Y)
いいえ(N)
Mesh Area [127 93] kind 2

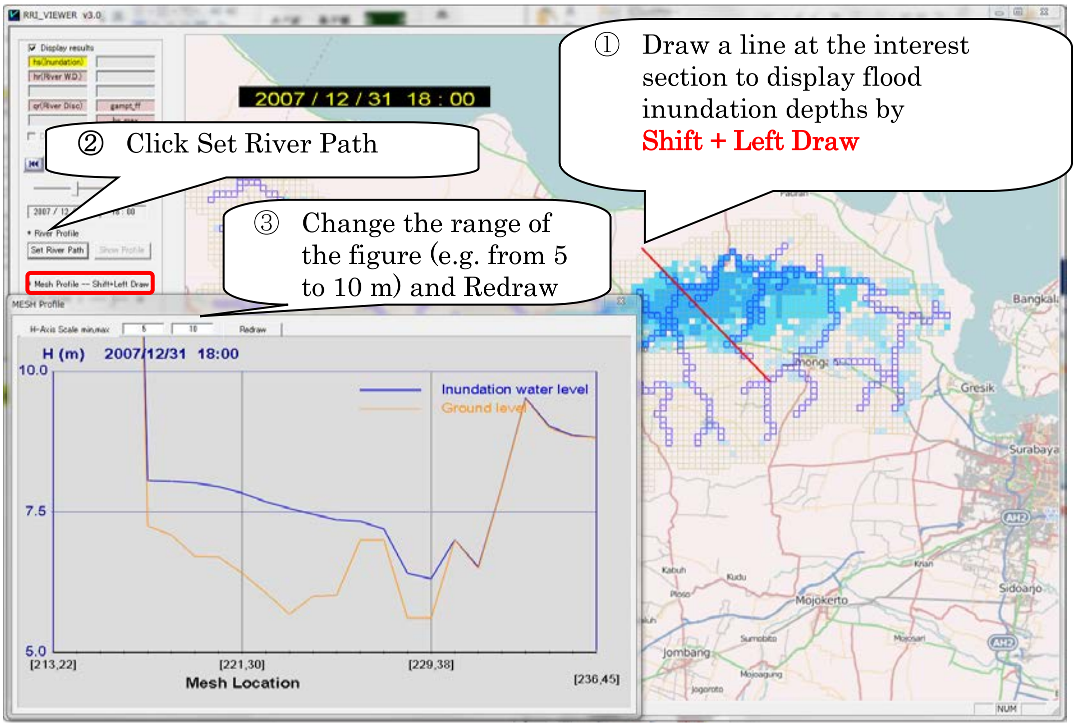

RRI_VIEWER v3.0
2008 / 1 / 2 06 : 00
Show Profile
⑦ Show Profile
⑥ Click here as the Downstream end point
Profile Window
H-Axis Scale min,max
0
200
Redraw
H (m)
⑧ Change the vertical range of the graph, e.g. to 100 m then redraw
River water level
Ground level
River Bed level
300
200
100
0
0
40
80
Upstream
Total Length
77 (km)
Downstream



Click "Delete Path" to delete the selected longitudinal path.

9.3.1 Visualize the profile of flood inundation depth

To visualize the profile of flood inundation depth, one can draw a profile line (e.g. red line below) as "Shift + Left Draw".



Crisis Management Center
Japan International Cooperation Agency

Project on capacity building for Ecosystem based Disaster Risk Reduction(Eco-DRR) through sustainable forest management

RRI model Training

Apply RRI model to a selected basin
～Case study in Kumanovo in Macedonia～

Dr. Keishi KUDO
Personnel of hydraulic model/Eco-DRR

02/Oct/2019

Outline

Today's outline is below.

1. **Explanation of target area**
2. **Exercise of data creation**

   a) dem data and dem adjustment

   d) dir data ※Flow Direction

   c) ACC data ※Flow Accumulation

   d) landuse and soil data

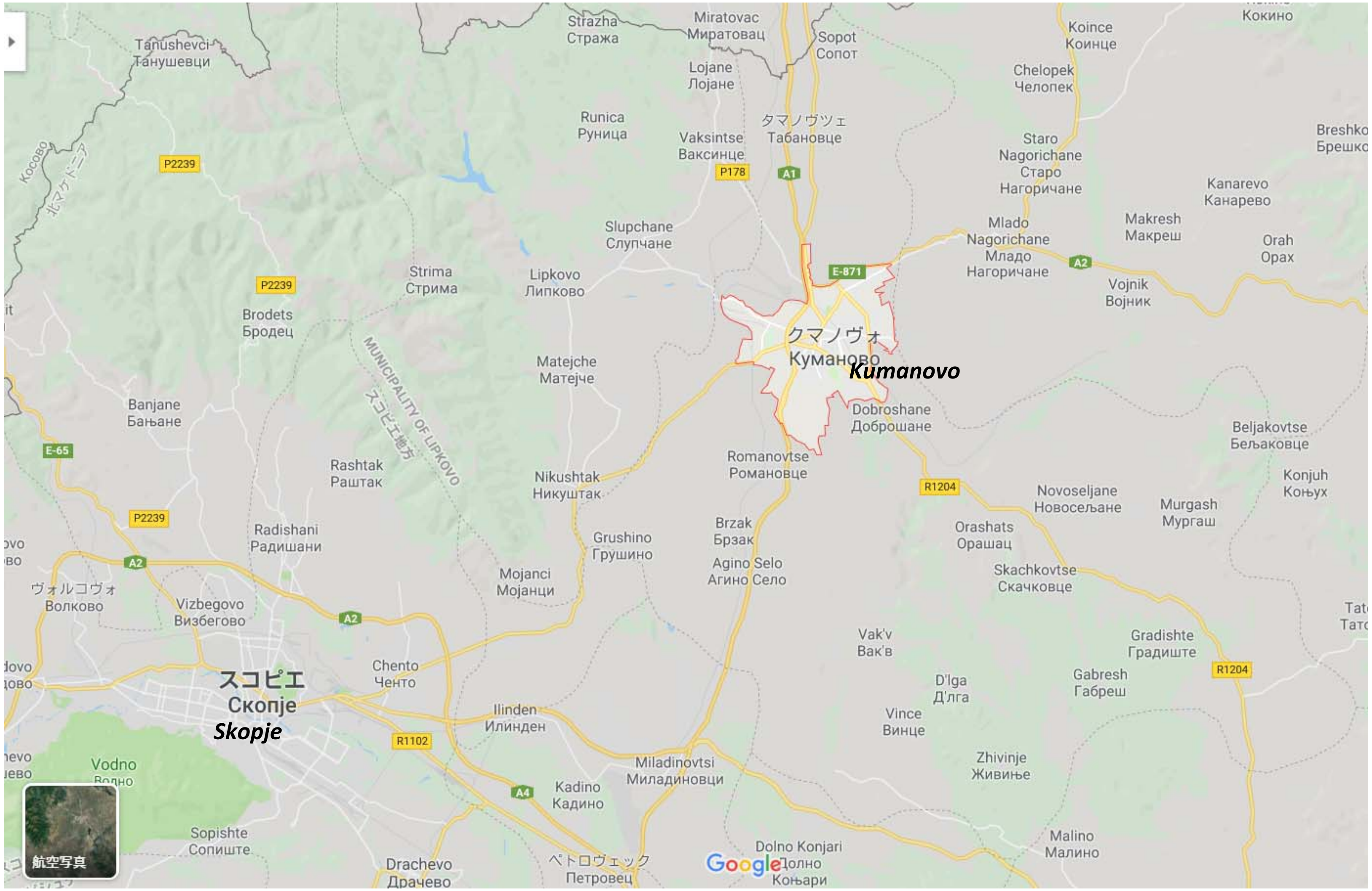
   e) River settings

   f) Rainfall data with Thiessen Polygon method
3. **Outline of Training on next day**

(1) Explanation of target area

1-1) Introduction

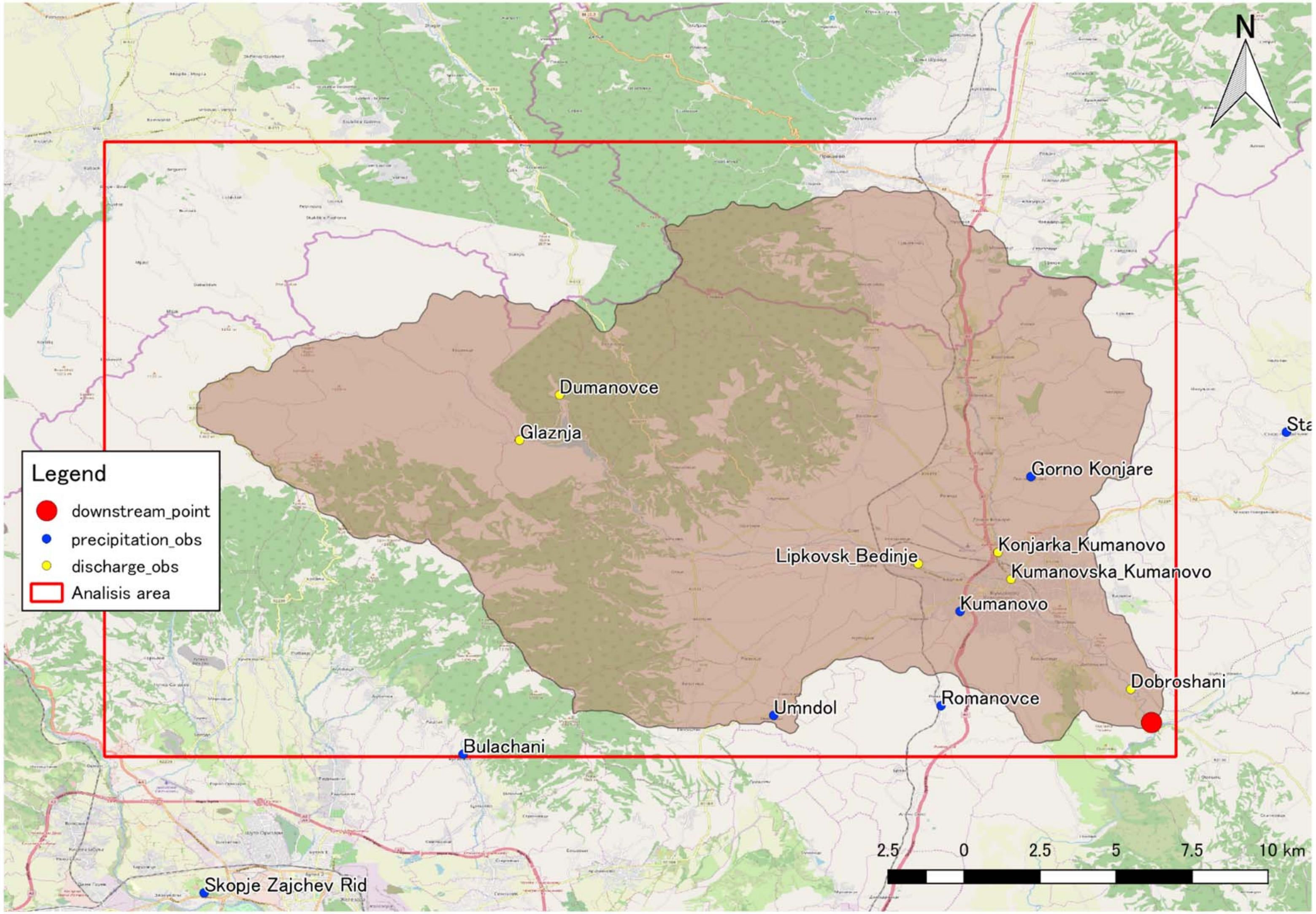
Kumanovo is located in the Northeast of Skopje.



(1) Explanation of target area

1-1) Introduction

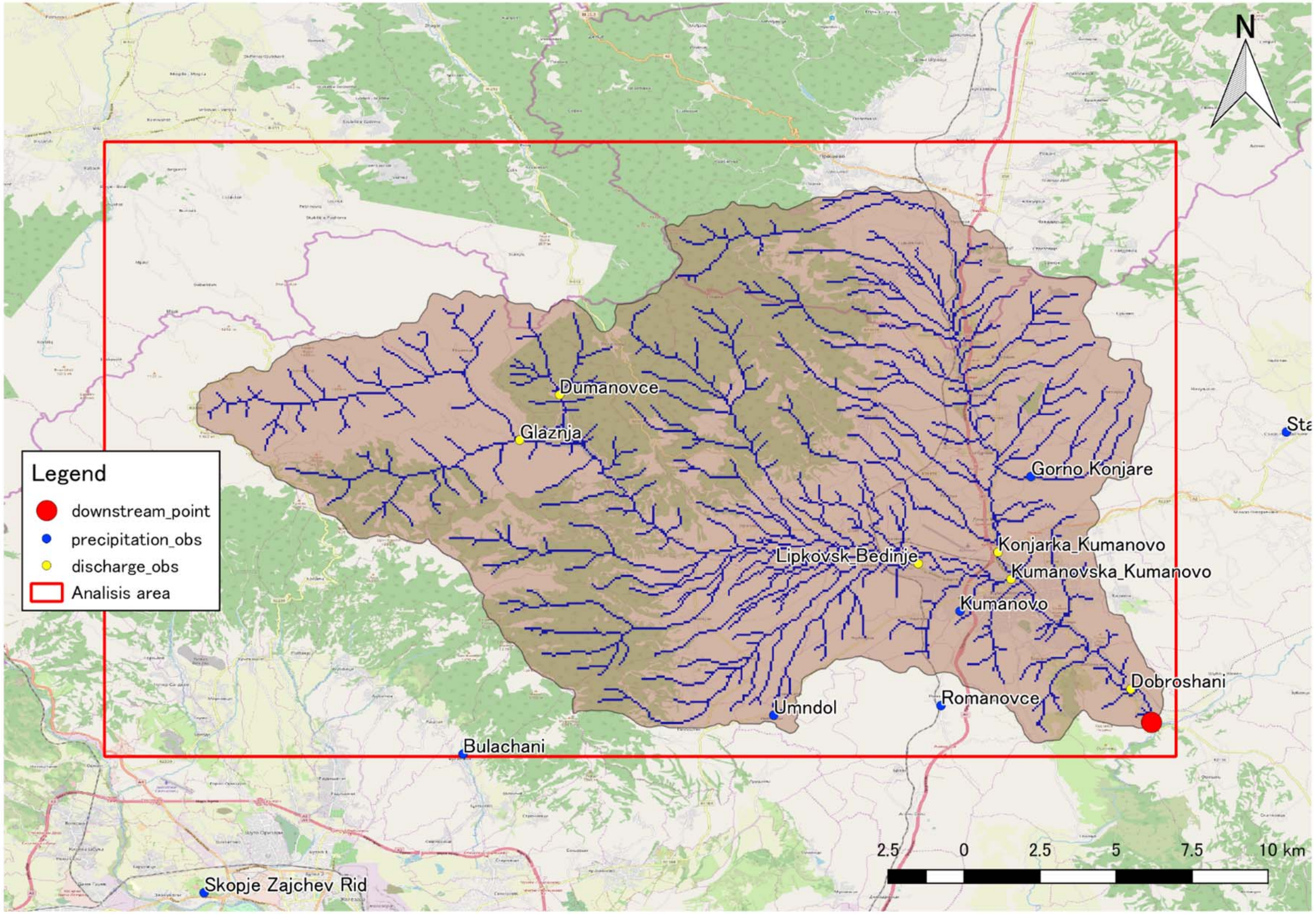
Analysis area at Kumanovo,
The 5 precipitation stations and the 6 discharge stations are installed.



(1) Explanation of target area

1-1) Introduction

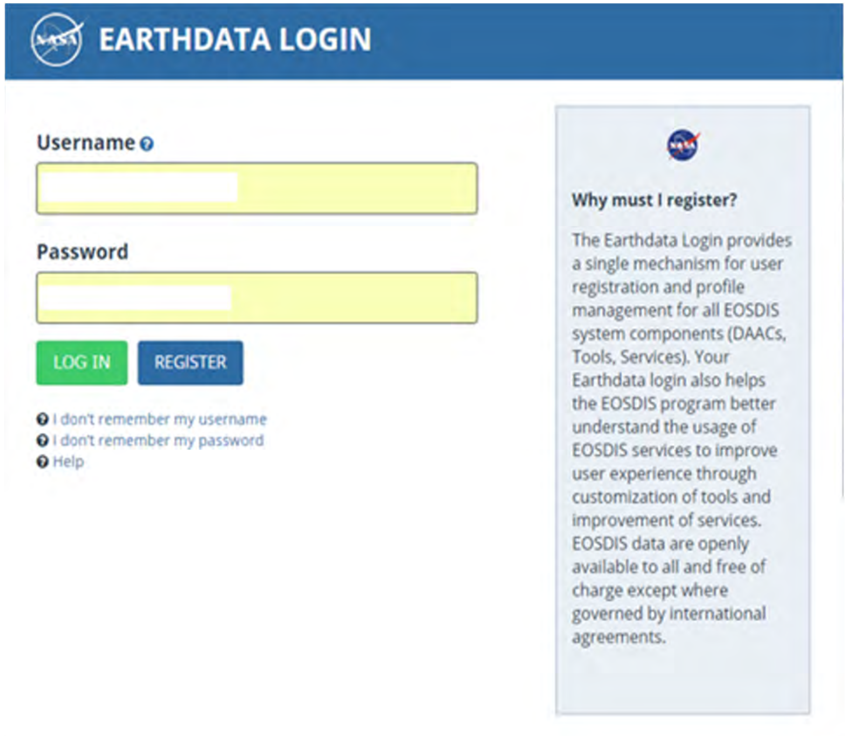
Analysis at Kumanovo,
Stream network is below.



1-2) Used DATA in RRI

① Topography data : SRTM(=Shutle Radar Topography Mission Height)

If you use data, need a registration.

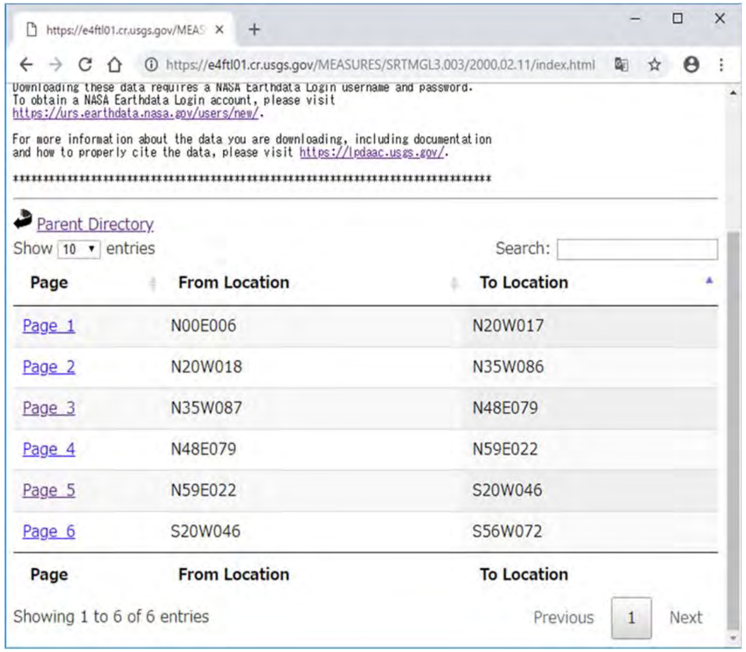


https://urs.earthdata.nasa.gov/users/new

In this lecture, you don't need the Registration.
We already have downloaded a data!

After

You can download a data.



https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL3.003/

The dem, dir and acc data's for RRI are made from above data!!

1-2) Used DATA in RRI

② Rainfall data

We collected the following data within analysis area.

- 5 precipitation stations data
- 4 discharge stations data
- Data interval is daily

Points within Kumanovo city

Down stream point in RRI

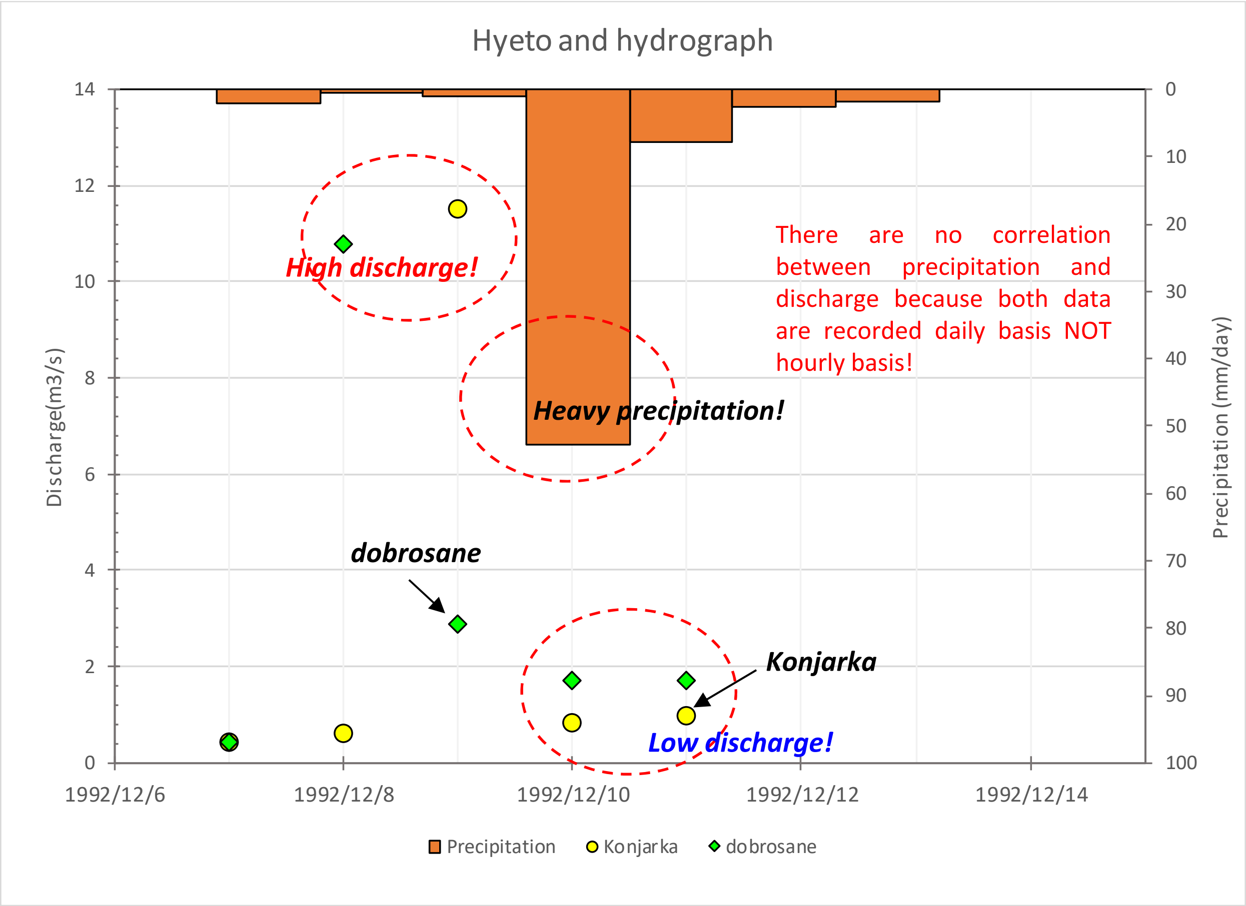
Event	Precipitation DATA					Discharge DATA				NOTE
	Bulachani	Gorno Konjare	Kumanovo	Romanovce	Umndol	konjarka_kumanovo	lipkovska_bedinje	kumanovska_kumanovo	kumanovska_dobrosane	
Dec-70						only H		only H	only H	Daily Precipitation: No Data, Daily Discharge: 1970/12/28～1971/1/4
Feb-86						only H		H and Q	H and Q	Daily Precipitation: No Data, Daily Discharge: 1986/2/1～1986/2/6, 1986/1/2～1986/1/7
Dec-92	○	○	○	○	○	H and Q		only H	H and Q	Daily Precipitation: 1992/12/6～1992/12/15, Daily Discharge: 1992/12/7～1992/12/11
Jul-94	○	○	○	○	○	H and Q			H and Q	Daily Precipitation: 1994/7/17～1994/7/26, Daily Discharge: 1994/7/21～1994/7/25
Jul-95	○	○	○	○	○	H and Q			H and Q	Daily Precipitation: 1995/7/16～1995/7/21, Daily Discharge: 1995/7/16～1995/7/21
Nov-99	○	○	○	○	○	H and Q		only H		Daily Precipitation: 1999/11/12～ 1999/11/22,
Feb-13	○	○	○	○	○	only H	only H		only H	Daily Precipitation: 2013/2/16～2013/2/28, Daily Discharge: 2013/2/24～2013/3/1
Oct-15	○	○	○	○	○	only H	only H		only H	Daily Precipitation: 2015/10/6～2015/10/13, Daily Discharge: 2015/10/9～2015/10/13

Precipitation DATA

Discharge DATA

1-2) Used DATA in RRI

② Rainfall data

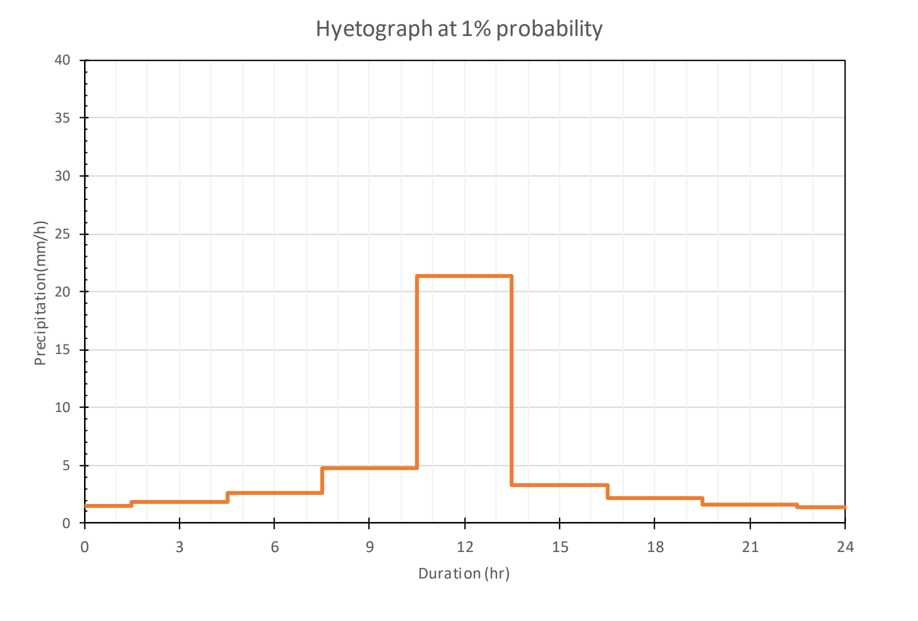


In this lecture, We decided using total rainfall of 1% probability for RRI.
※Total rainfall probability was estimated from formula by Blinkov and Jagev (2004).

1-2) Used DATA in RRI

② Rainfall data

For example,
below figure shown hyetograph at 1% probability



Precipitation at each probability

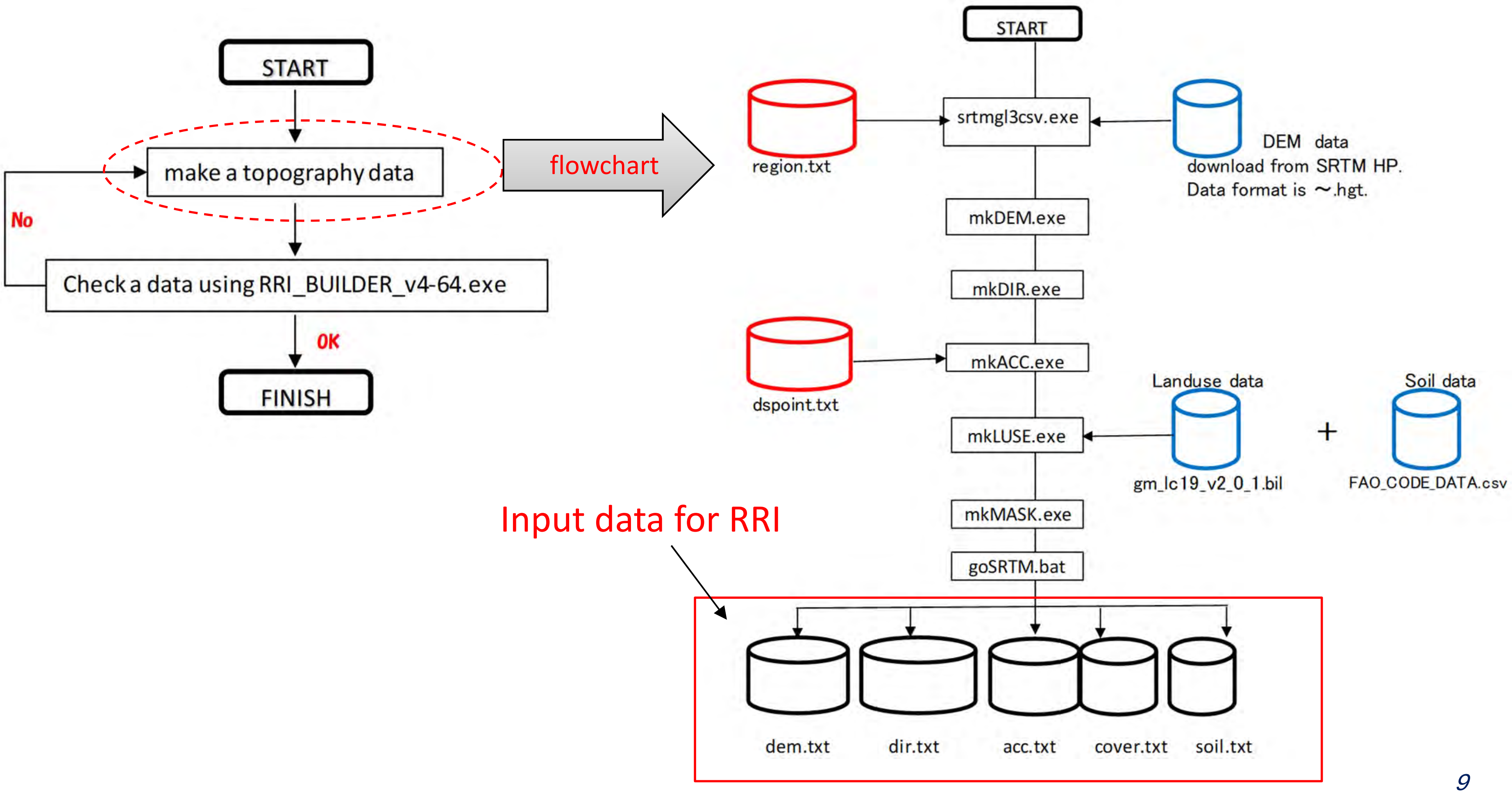
Time		Precipitation(mm)		
sec	hour	1%	2%	4$
0	0	0.0	0.0	0.0
10800	3	4.5	4.1	3.7
21600	6	5.6	5.1	4.6
32400	9	7.8	7.0	6.3
43200	12	14.4	13.0	11.6
54000	15	64.0	57.6	51.0
64800	18	9.9	8.9	8.0
75600	21	6.5	5.9	5.2
86400	24	5.0	4.5	4.0
97200	27	0.0	0.0	0.0
108000	30	0.0	0.0	0.0
118800	33	0.0	0.0	0.0
129600	36	0.0	0.0	0.0
140400	39	0.0	0.0	0.0
151200	42	0.0	0.0	0.0
162000	45	0.0	0.0	0.0
172800	48	0.0	0.0	0.0
Total		117.7	106.1	94.3

(2) Exercise of data creation

2-1) Make a topography data

① Make a dem, dir, acc data for RRI

Flowchart for make a data

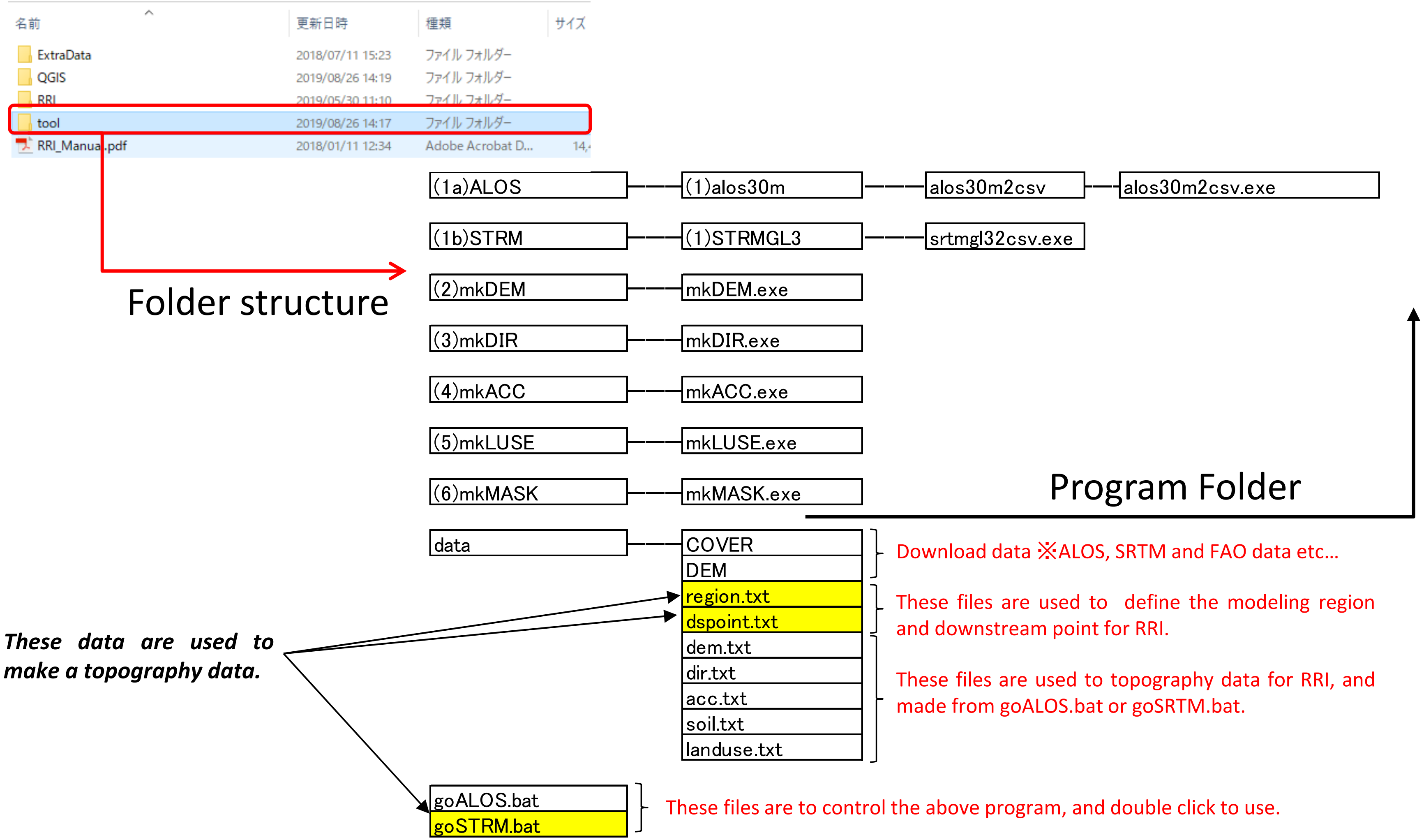


(2) Exercise of data creation

2-1) Make a topography data

① Make a dem, dir, acc data for RRI

Check a tool folder from USB.

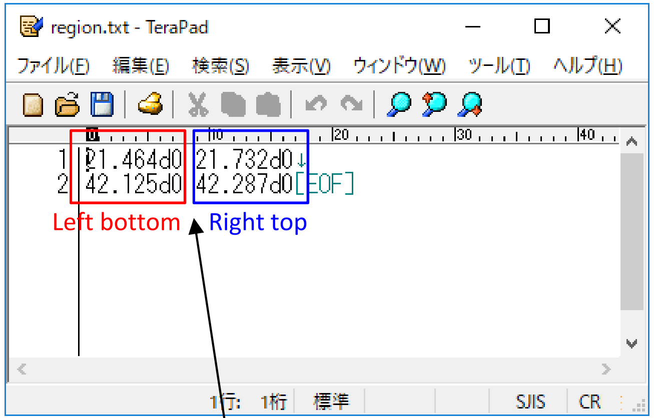


2-1) Make a topography data

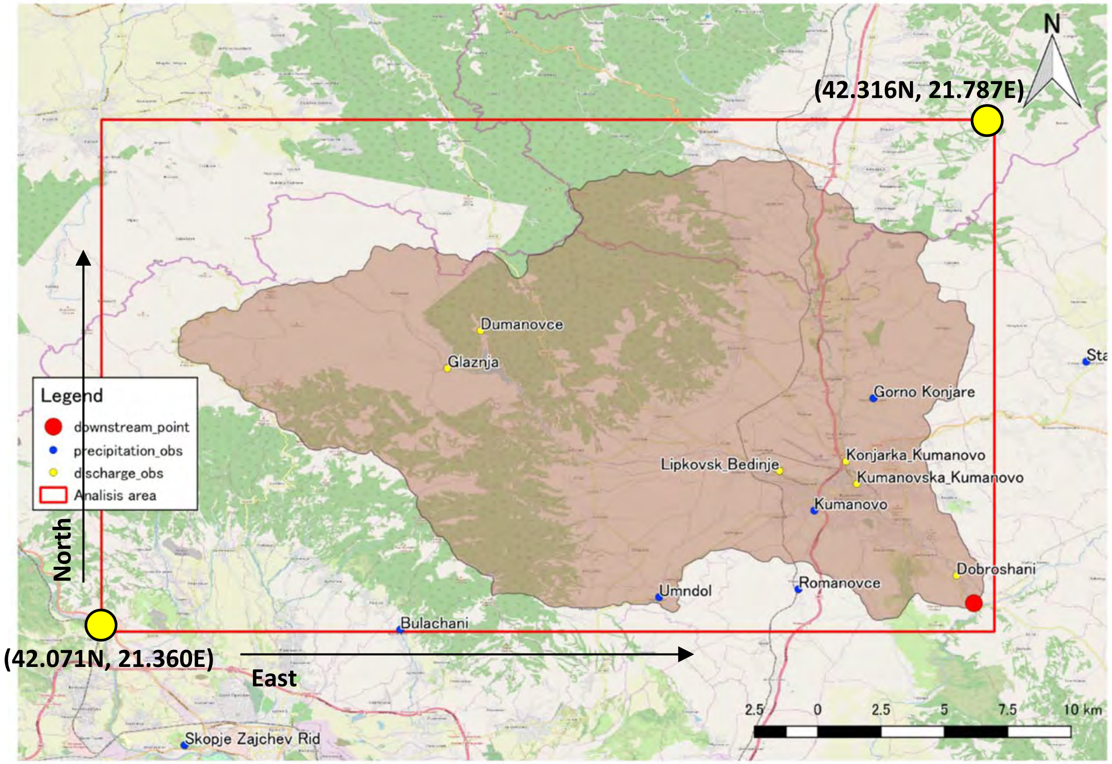
① Make a dem, dir, acc data for RRI

1st step: Define the modeling region

Click the "region.txt"



Rewrite to the coordinate of "left bottom" and "right top" in modeling region.



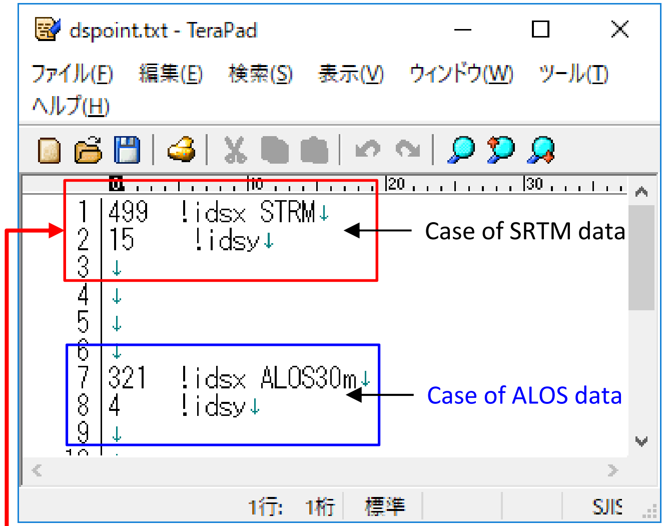
(2) Exercise of data creation

2-1) Make a topography data

① Make a dem, dir, acc data for RRI

2nd step: Define the downstream point for RRI

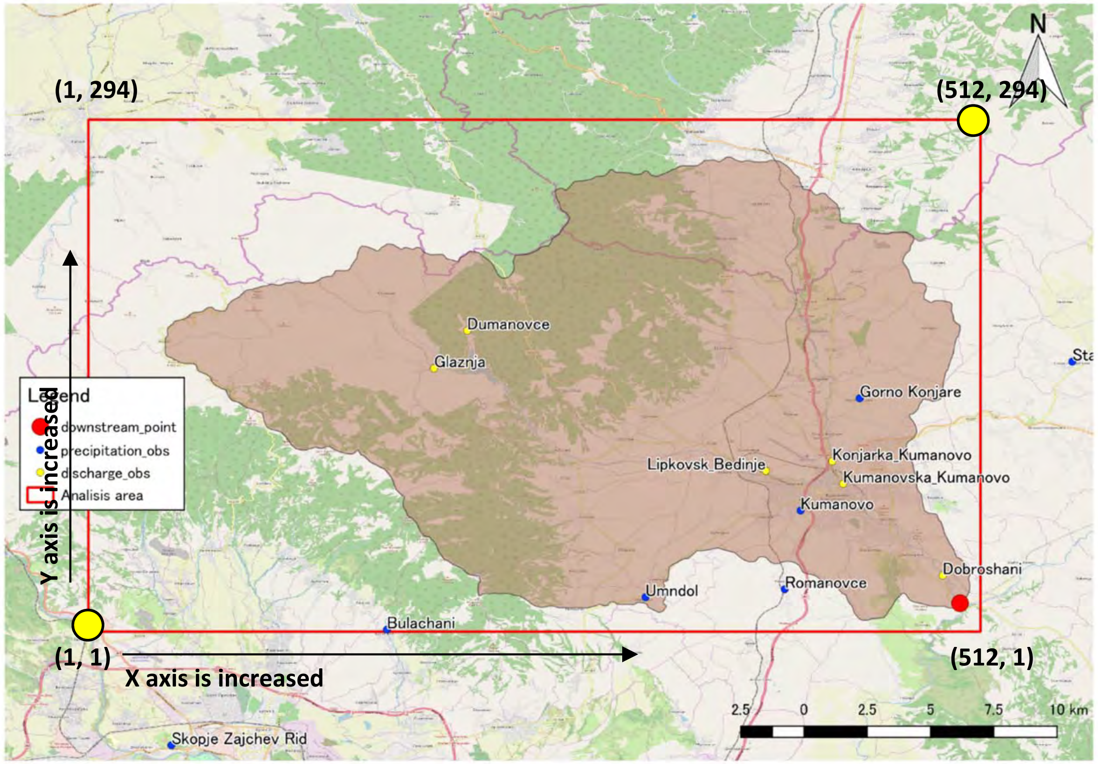
Click the “dspoint.txt”



In this lecture

Rewrite to coordinates (x, y) of “downstream point” within modeling region.

Please rewrite to (162, 138)



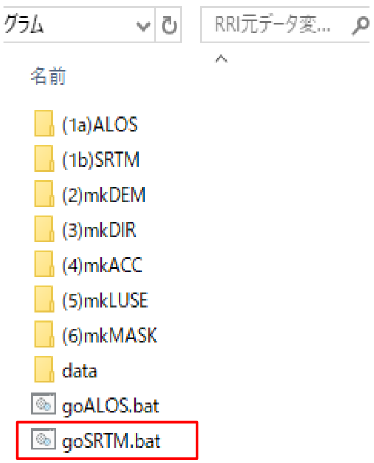
(2) Exercise of data creation

2-1) Make a topography data

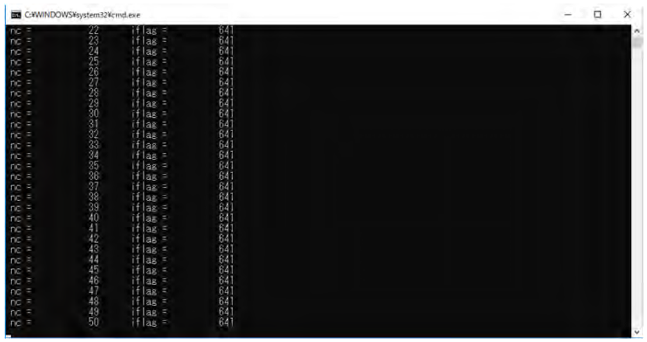
① Make a dem, dir, acc data for RRI

3rd step: Make a topography data

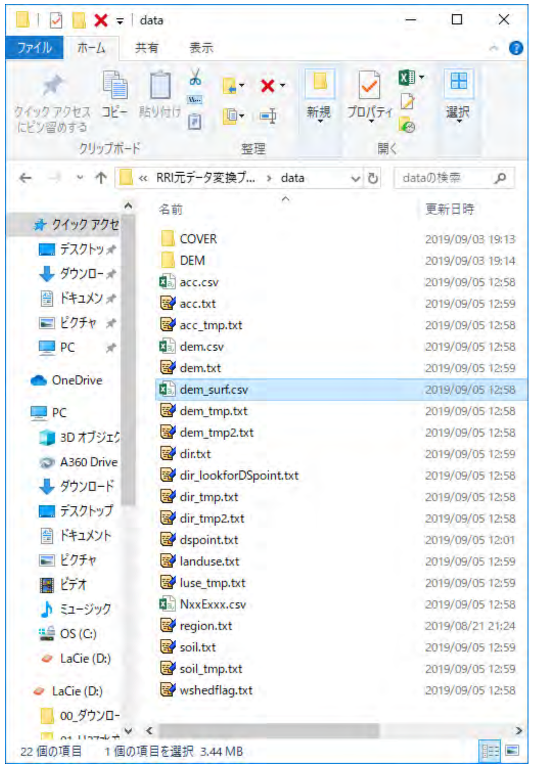
Double Click the "goSRTM.bat"



Run the program!



After executed "goSRTM.bat"



18 files are made to data folder.

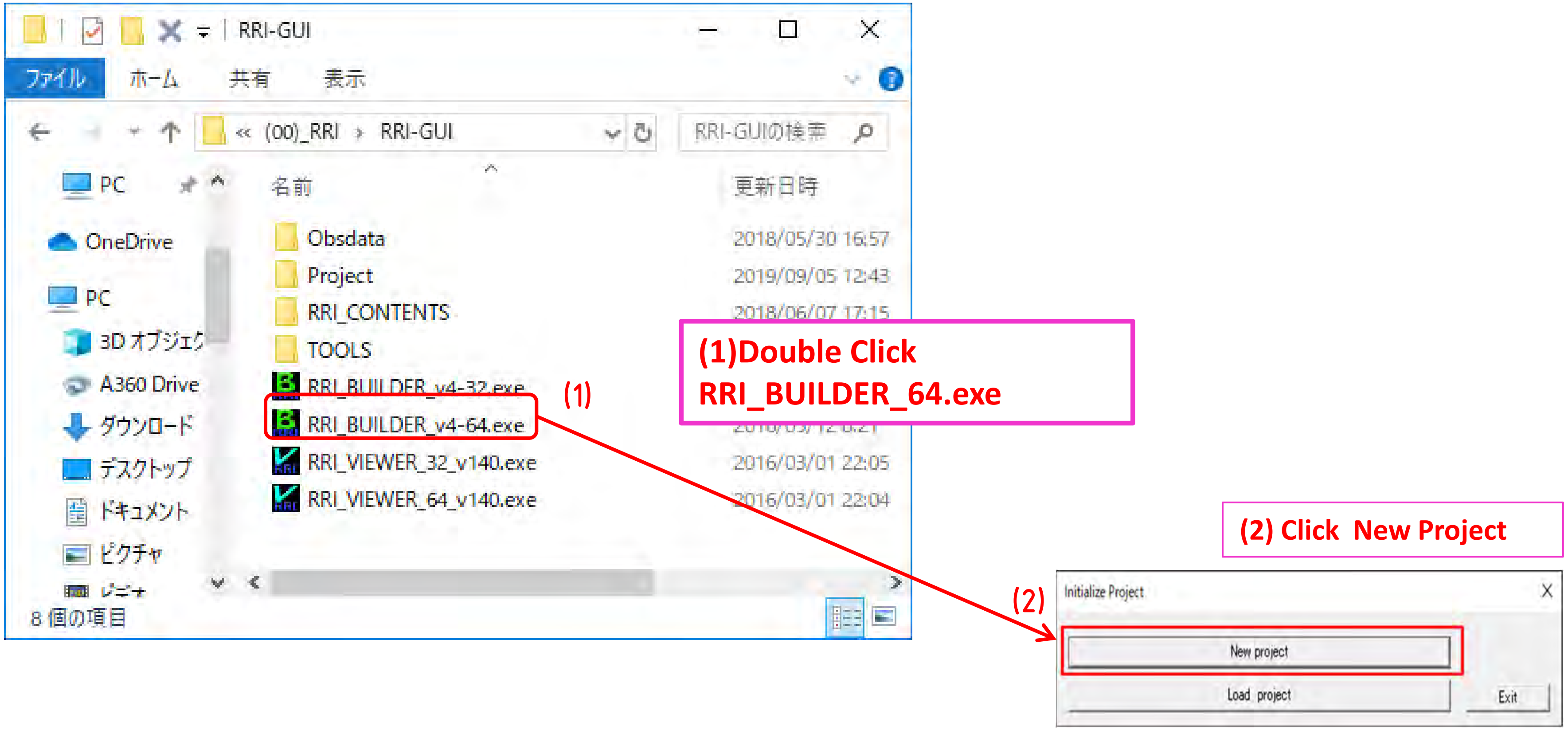
Using data
1. dem.txt 2.acc.txt 3.dir.txt

2-1) Make a topography data

① Make a dem, dir, acc data for RRI

4th step: Check the topography data using “RRI_BUILDER_v4-64.exe”

★Start up RRI and Create new project

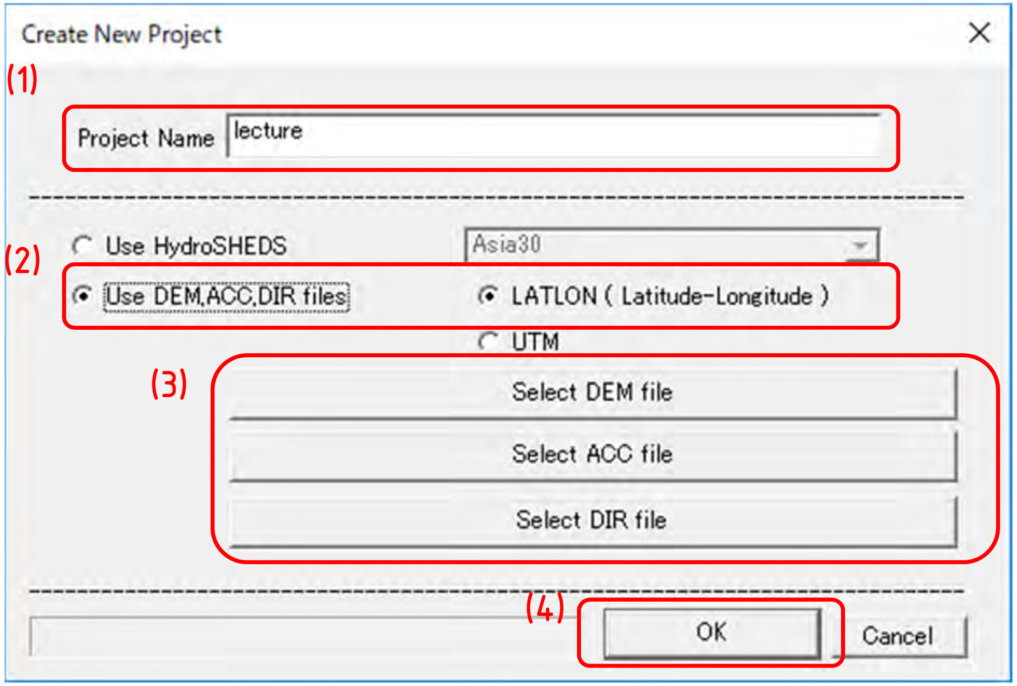


2-1) Make a topography data

① Make a dem, dir, acc data for RRI

4th step: Check the topography data using “RRI_BUILDER_v4-64.exe”

★Create New Project Folder



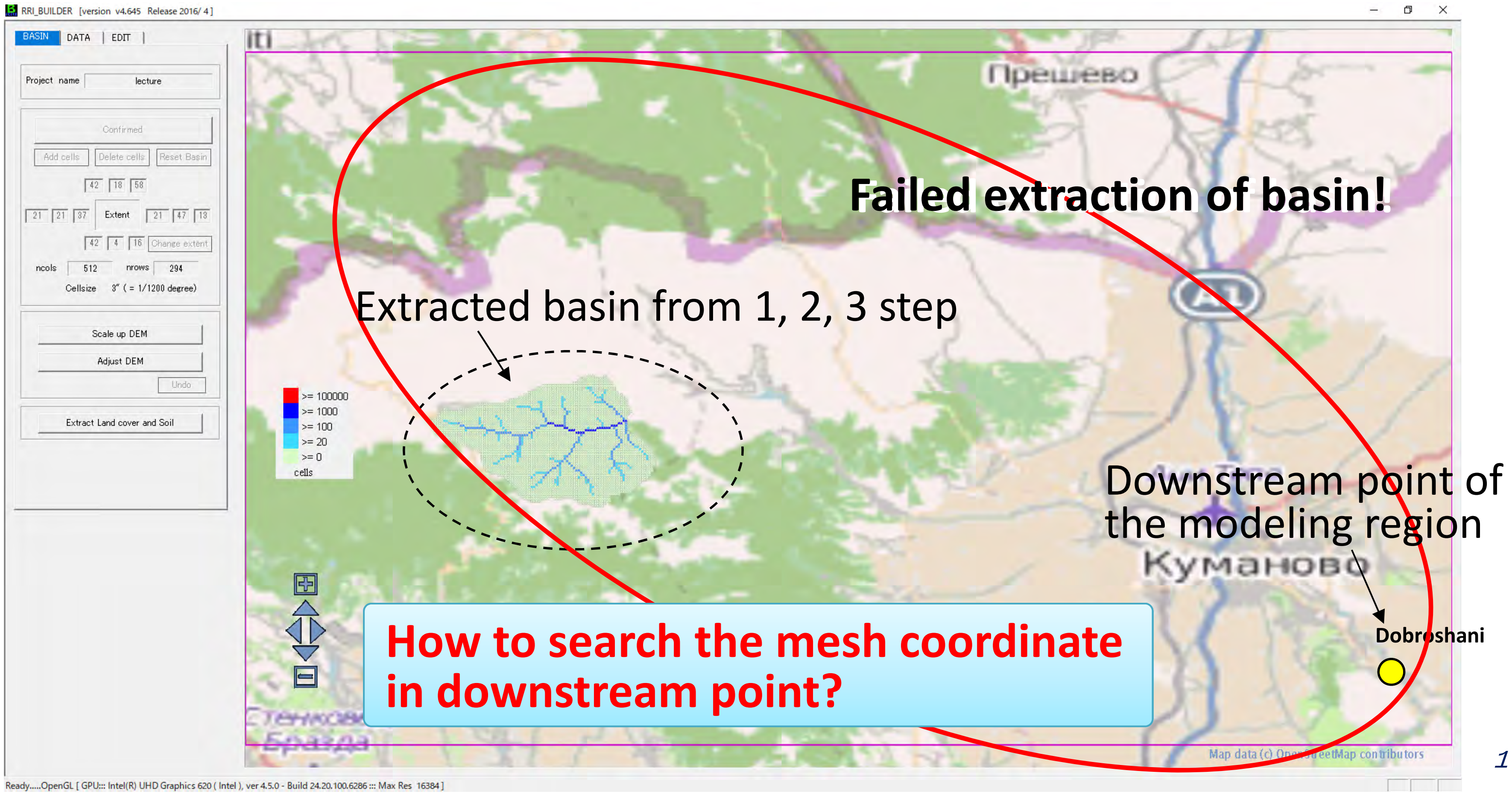
(1) Type a new project name (e.g. “lecture”) to create a new project folder
(2) Select “Use DEM, ACC, DIR files” and “LATLON(Latitude-Lognitude)”
(3) Select “Select DEM file etc.”, and choose dem.txt, acc.txt and dir.txt in data folder
※ each files has been made from 3rd step
(4) Click "OK"

2-1) Make a topography data

① Make a dem, dir, acc data for RRI

4th step: Check the topography data using “RRI_BUILDER_v4-64.exe”

★Check the topography data



2-1) Make a topography data

① Make a dem, dir, acc data for RRI

5th step: Revise the mesh coordinates (x, y) of “downstream point”

(1) Open the “dir.txt or dir_temp.txt” in a data folder using EXCEL
(2) Insert new row or column on the top of Values of flow direction
(3) Write the mesh coordinates(x, y) in a new row and column ※Origin is "left bottom“
(4) Search the mesh coordinates (x, y) of “downstream point” while tracking according to the right figure rule

Mesh coordinates of x

Mesh coordinates of y	97	98	99	100	101	102	103	104	105	106	107	108	109	
18	7	8	7	1	7	5	7	6	7	7	8	7	7	18
17	7	6	7	6	7	7	7	6	8	7	6	1	8	17
16	6	1	8	7	7	8	7	7	8	7	6	7	8	16
15	5	8	7	1	8	8	7	8	7	7	6	8	7	15
14	8	7	6	8	1	1	7	1	8	8	7	7	6	14
13	7	7	8	7	7	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	8	8	7	6	8	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	7	7	6	7	7	7	6	8	1	8	7	8	7	11
10	7	7	6	1	8	7	6	7	7	8	8	8	7	10
9	7	7	7	7	7	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
8	8	7	7	7	6	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
7	1	8	7	6	5	8	7	6	8	7	1	1	1	7
6	7	8	7	7	7	7	7	6	1	8	7	1	8	6
5	7	1	1	8	7	7	6	5	7	1	8	8	1	5
4	7	1	8	7	7	7	8	7	6	7	7	1	8	4
3	7	7	1	8	7	7	1	8	7	7	6	6	8	3
2	8	7	8	1	8	7	8	1	1	7	5	7	1	2
1	7	7	7	7	7	7	7	7	7	7	7	7	7	1
	97	98	99	100	101	**102**	103	104	105	106	107	108	109	

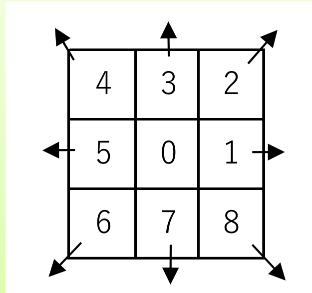
(x,y)=(102,2)

① Select a mesh close to the downstream point.
※ Numbers indicate the flow direction (see right figure).

② Track according to the right figure rule

③ If "downstream point" is coordinate of y of 2 mesh from modeling region, very easily to search.

Values of flow direction



Here, please rewrite “dspoint.txt” to (499, 15) from (162, 138), and Double Click the “goSRTM.bat”

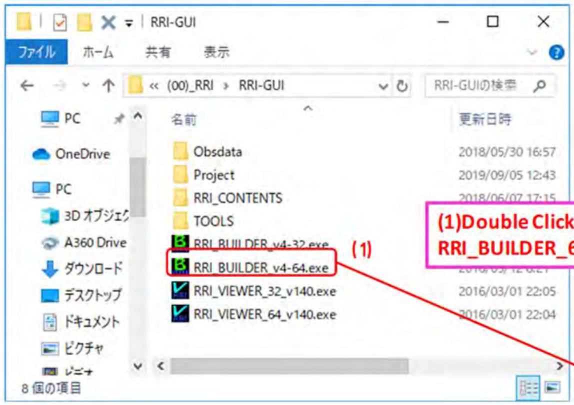
(2) Exercise of data creation
2-1) Make a topography data

① Make a dem, dir, acc data for RRI

5th step: Revise the mesh coordinates (x, y) of “downstream point”

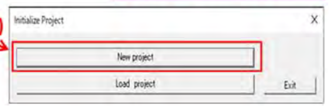
(5) Check again the topography data using “RRI_BUILDER_v4-64.exe”

★Start up RRI and Create new project

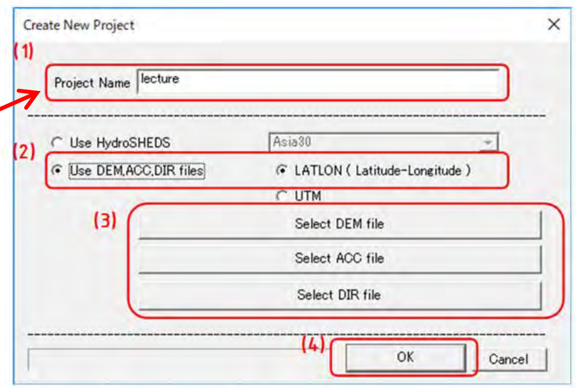


(1)Double Click RRI_BUILDER_64.exe

(2) Click New Project



★Create New Project Folder



Type a new project name (e.g. “lecture2”)

(1) Type a new project name (e.g. “lecture”) to create a new project folder
(2) Select “Use DEM, ACC, DIR files” and “LATLON(Latitude-Lognitude)”
(3) Select “Select DEM file etc.”, and choose dem.txt, acc.txt and dir.txt in data folder
※ each files has been made from 3rd step
(4) Click "OK"

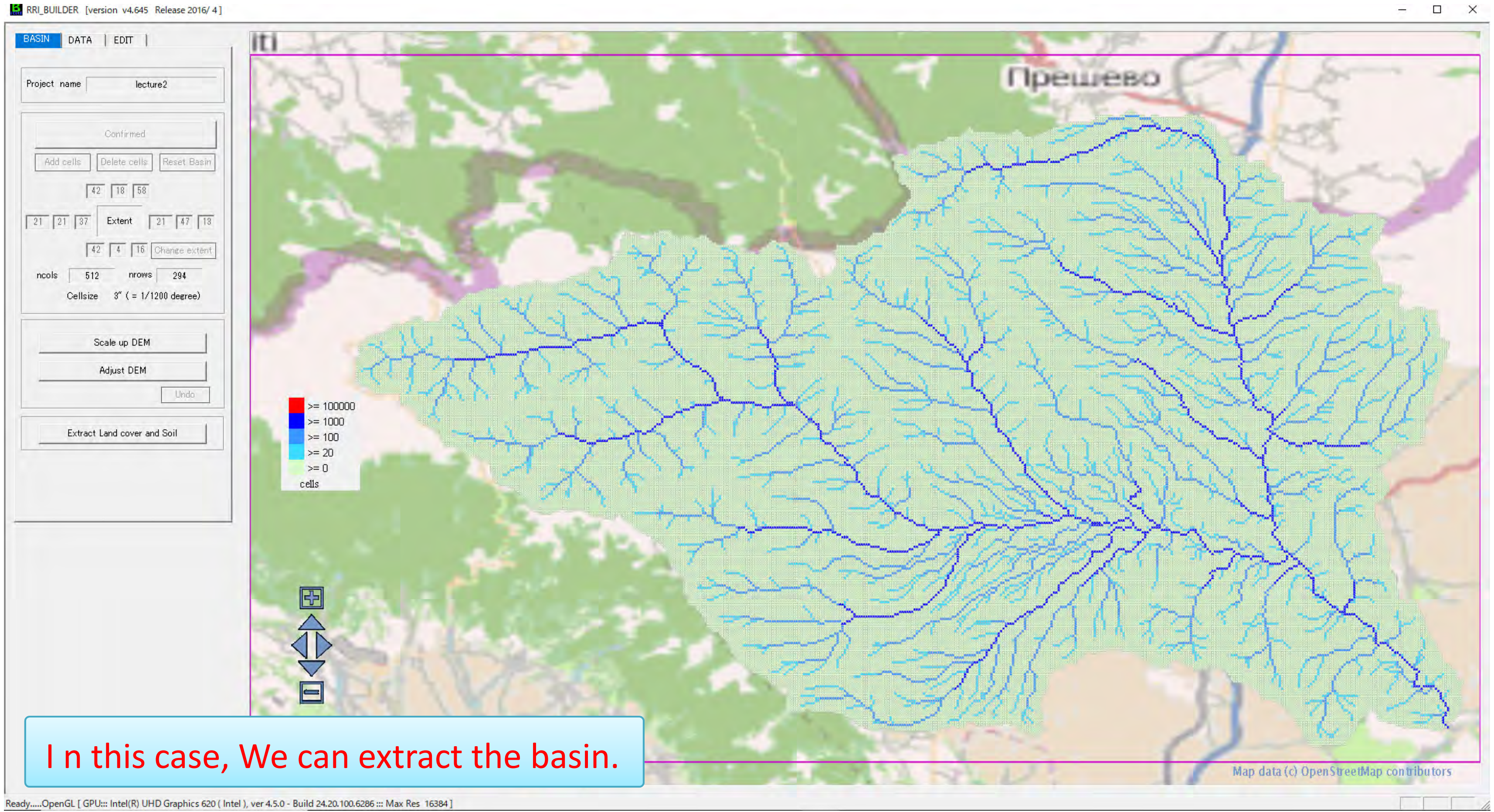
(2) Exercise of data creation

2-1) Make a topography data

① Make a dem, dir, acc data for RRI

5th step: Revise the mesh coordinates (x, y) of "downstream point"

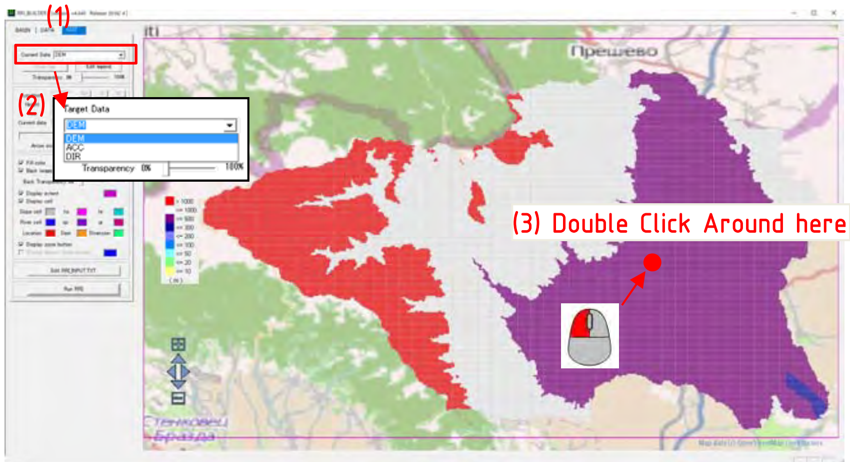
(6) Check again the topography data



2-1) Make a topography data

② Check extracted（created） data（dem, acc,dir)

◆ Check DEM(Digital Elevation Model) data



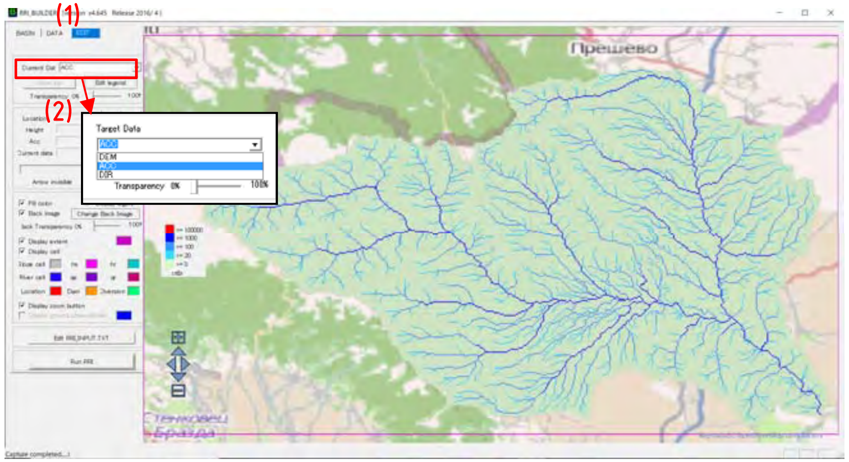
(4) Edit......DEM

512	500	488	477	470	462	452	444	437	430	426
523	504	489	474	464	455	448	440	432	429	423
516	499	484	471	460	449	442	436	430	425	421
506	489	476	464	453	442	436	432	427	422	418
495	480	468	458	447	437	432	426	423	417	414
475	470	458	449	441	433	426	422	419	415	412
456	456	448	440	434	427	422	418	414	413	411
438	436	434	430	427	422	419	417	413	410	408
448	435	426	422	420	419	417	414	412	409	407
462	445	433	426	421	419	415	414	412	410	407
461	444	432	426	417	414	413	411	409	408	407

Import (csv) Export (csv) Save Save As Cancel

(1) Click the “EDIT” Tab
(2) Select “DEM”
(3) Double click around here
(4) Check Extracted elevation can be confirmed

◆ Check ACC (Flow Accumulation) data



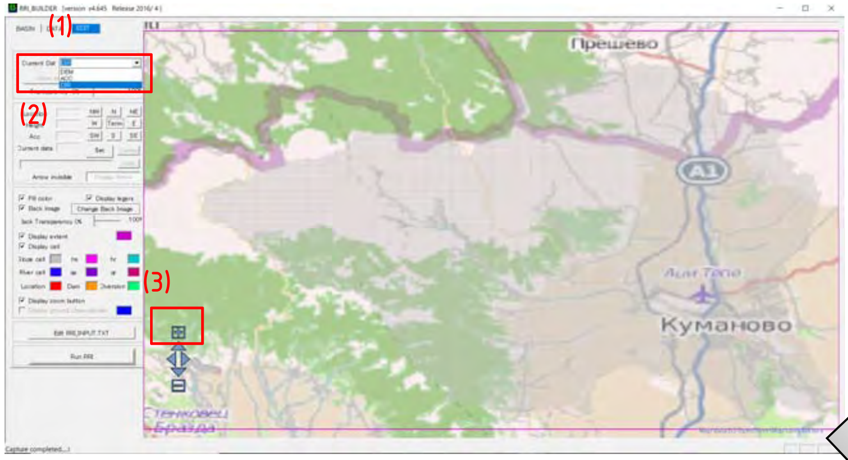
(1)Click the “EDIT” Tab

(2)Select ACC

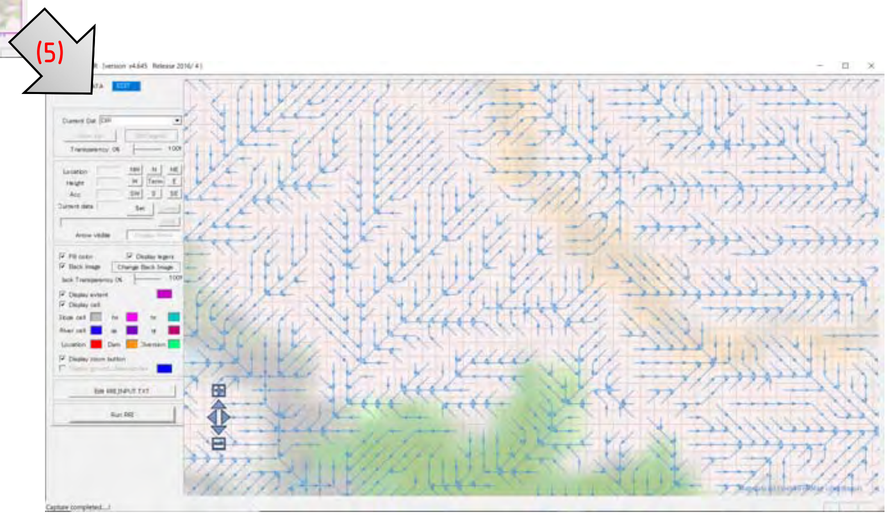
2-1) Make a topography data

② Check extracted（created） data（dem, acc,dir)

◆ Check DIR(Flow Direction) data



Enlarge map since flow direction is not displayed in small scale map display.



(1) Click the "EDIT" Tab
(2) Select "DIR"
(3) Enlarge map
(4) Select "DEM" or "ACC"
(5) Select "DIR"

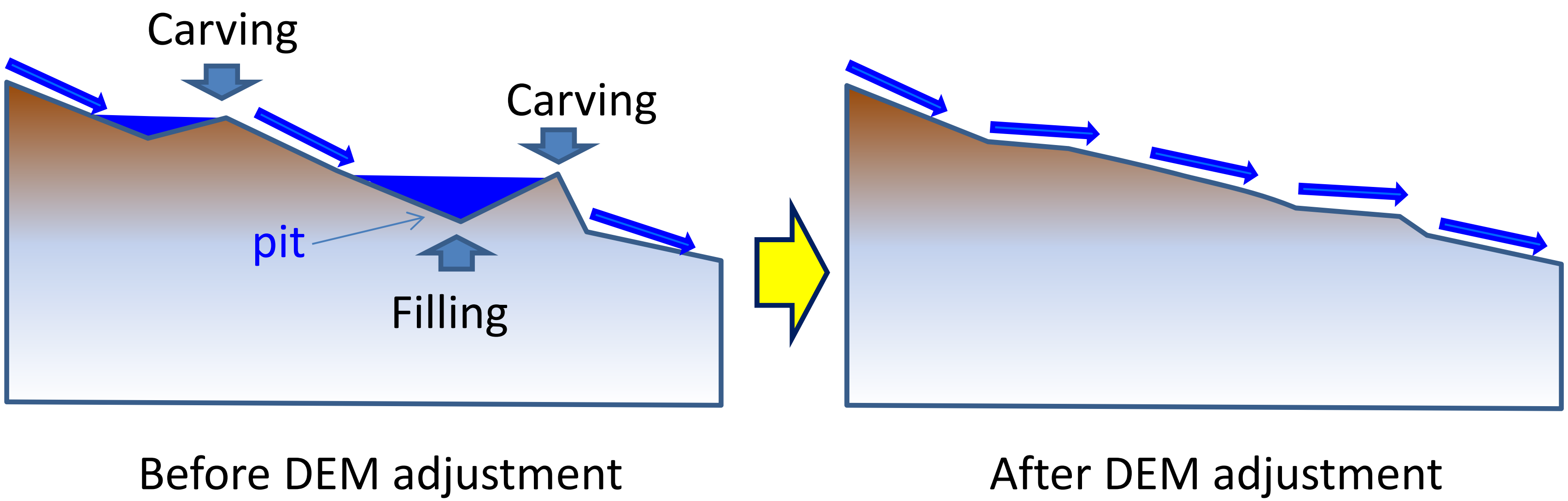
2-1) Make a topography data

③ Adjust DEM (Required)

Purpose: DEM adjustment by carving and filling

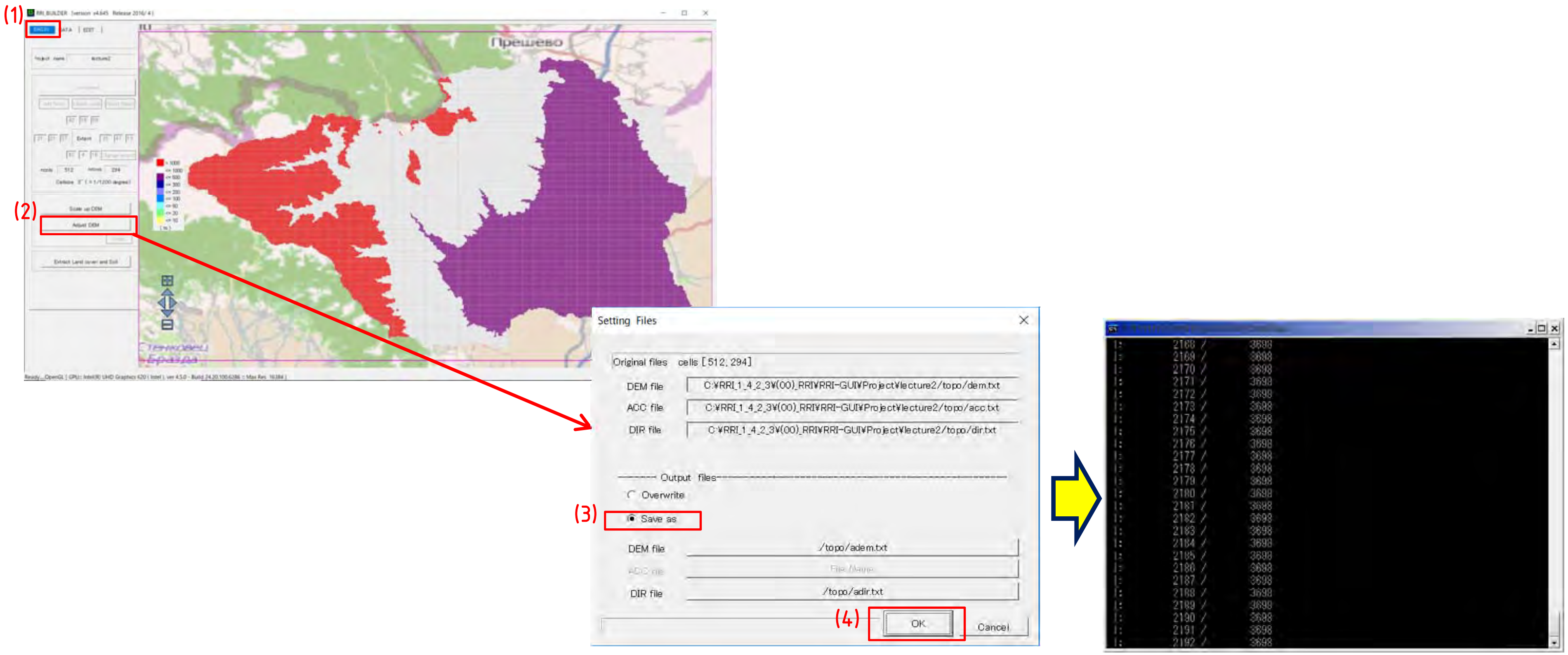
<u>DEM adjustment</u>

This program adjusts DEM by carving and filling to remove pits along flow line to avoid unrealistic discontinuity of elevation along flowline.



2-1) Make a topography data

③ Adjust DEM (Required)

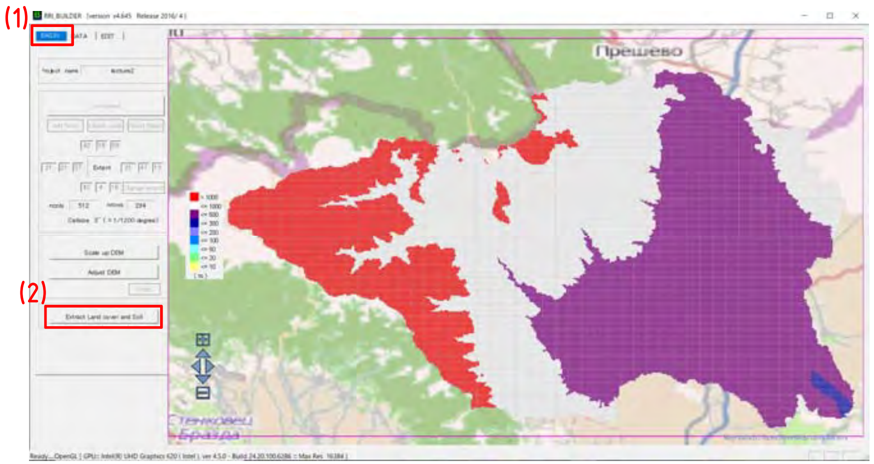


(1) Click the "BASIN" Tab
(2) Click "Adjust DEM" to open "Setting files" window
(3) Check Save as
(4) Click "OK"

(2) Exercise of data creation

2-1) Make a topography data

④ Extracte the landuse and soil data

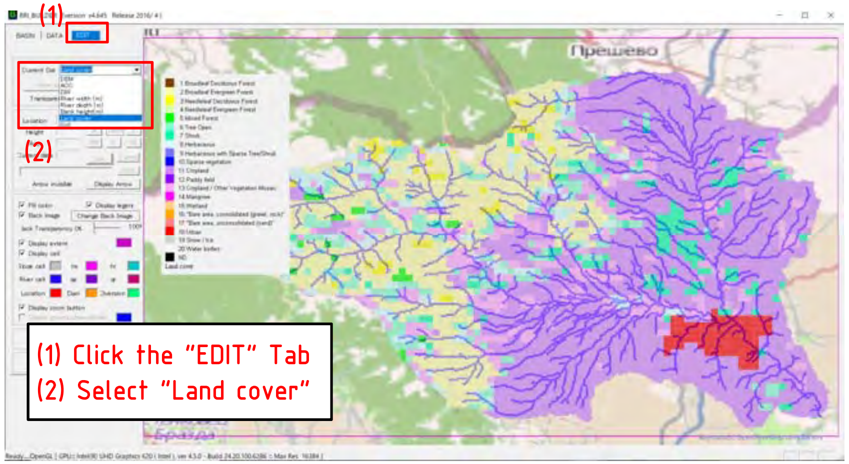


(1) Click the "BASIN" Tab
(2) Click "Extract Land cover and soil"

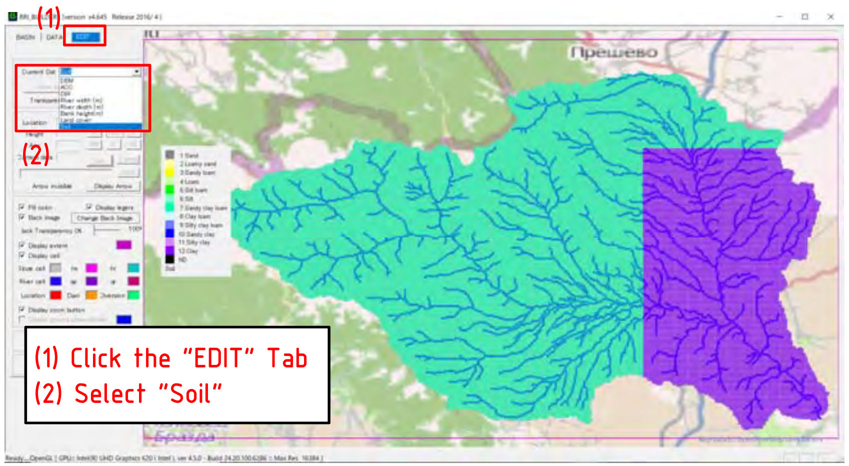
Note!
Landuse data is using USGS data.
Soil data is using FAO data.

★Check extracted data

Check landuse data

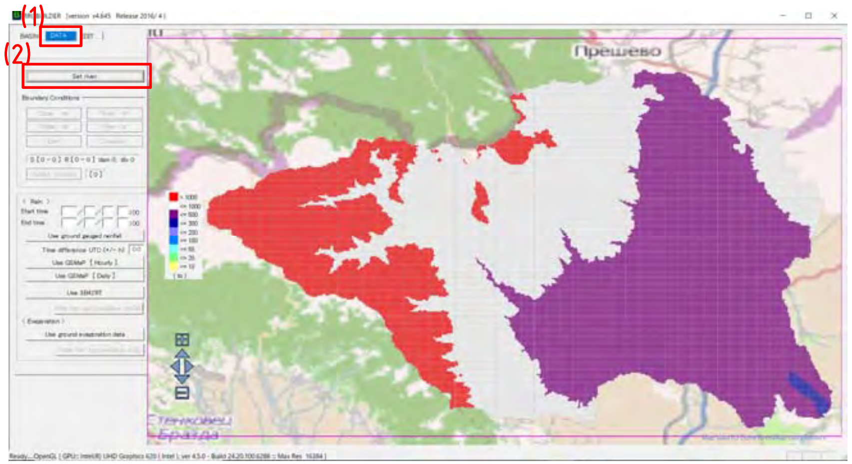


Check soil data



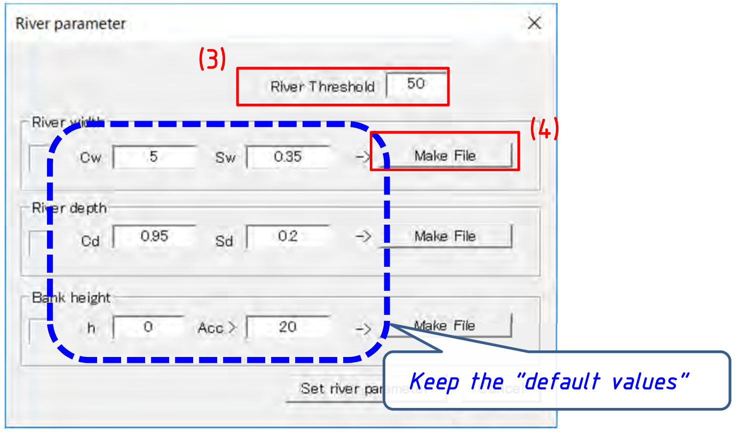
2-2) Make a river data

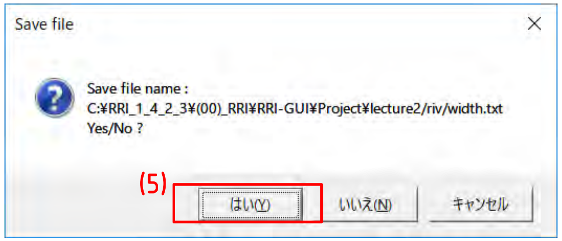
① River parameter settings

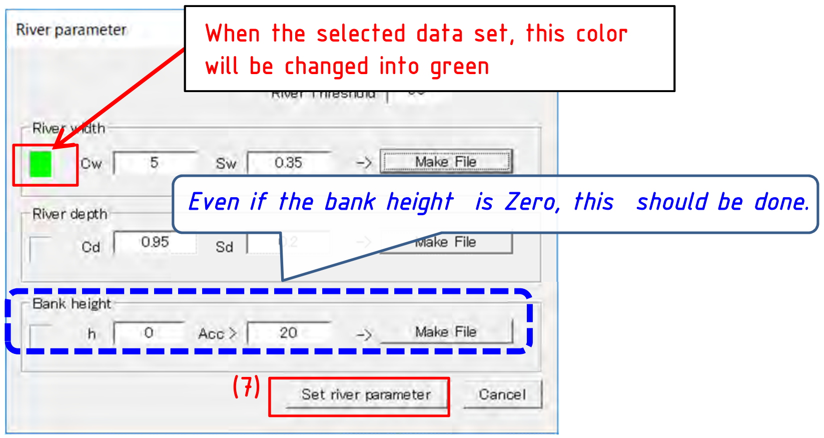


(1) Click "DATA" Tab
(2) Click "Set river" to open the River parameter window
(3) Set "river threshold as 50"
(4) Click "Make File" of river width
(5) Click "Yes"
(6) Continue "Make File" for [River depth] and [Bank height]
(7) Click "Set river parameter"

Note!
The parameter "river threshold" defines the threshold of flow accumulation (i.e. number of upstream cells) to distinguish river grid cells or slope grid cells. Recall that for RRI model, slope exists even on a river grid cell.

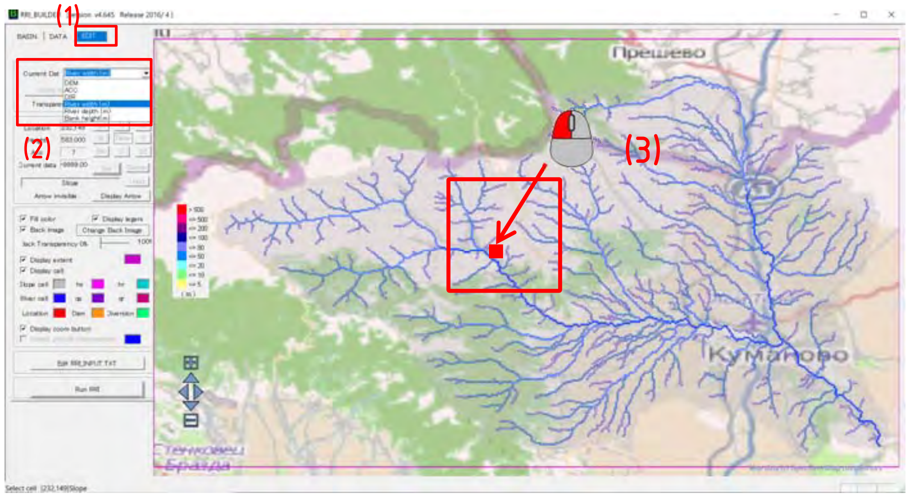


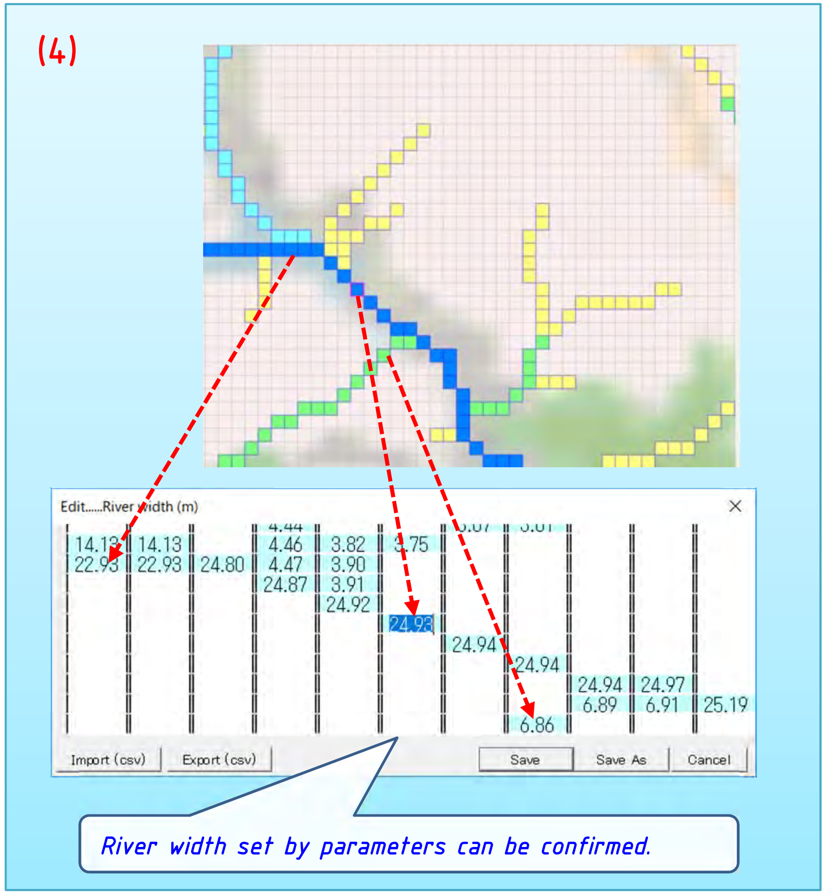




2-2) Make a river data

② Check the river data (River width)

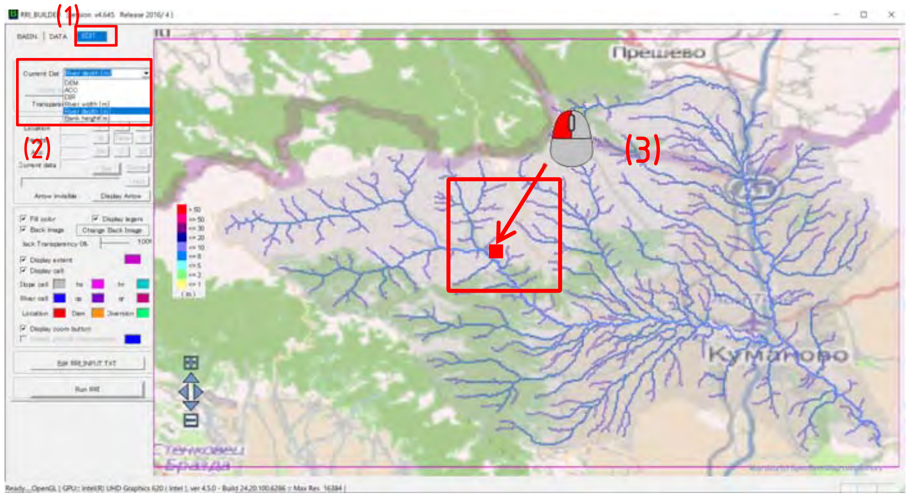




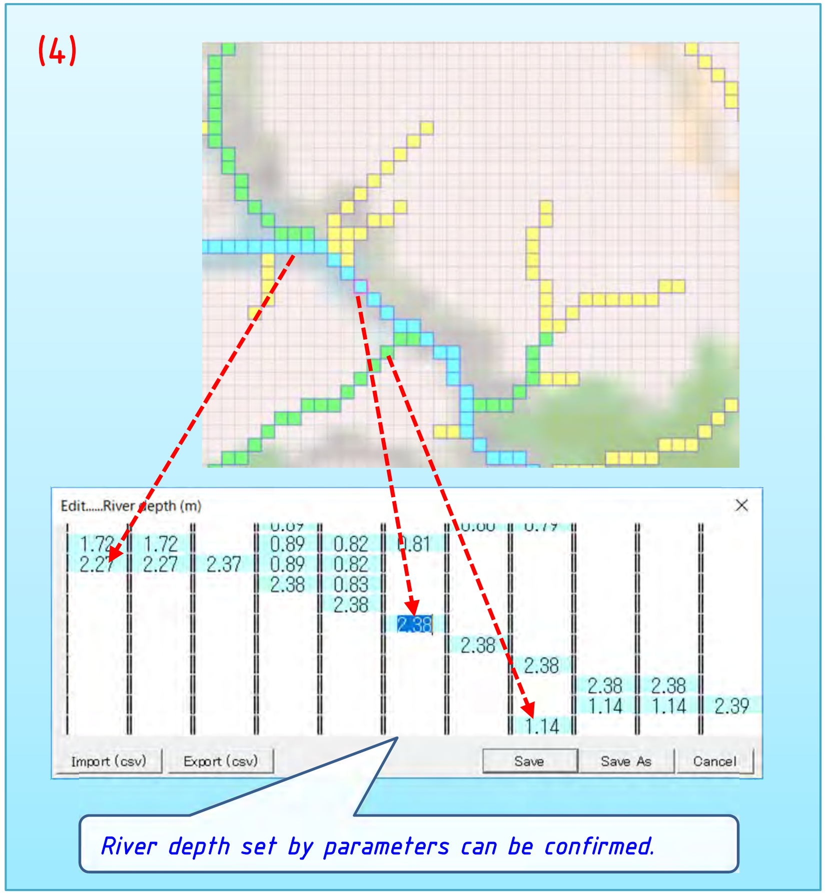
(1) Click the "EDIT" Tab
(2) Select River width
(3) Double click around here
(4) Check data show in "Edit .....River width (m)"

2-2) Make a river data

③ Check the river data (River depth)



(1) Click the "EDIT" Tab
(2) Select "River depth"
(3) Double click around here
(4) Check data show in "Edit .....River depth (m)"



(2) Exercise of data creation

2-3) Make a rainfall data with Thiessen Polygon method

To use ground gauged data for creating input rainfall for the RRI simulation, one can use “rainThiessen.exe”

① Rainfall data format

Number of rain gauge

Latitude and longitude of the rain gauge

16																
lat	42.01606	42.07163	42.21901	42.18183	42.11672	42.12833	42.09084	42.01653	42.19952	42.15128	42.08702	42.15883	42.17388	42.18256	42.20354	42.2201
lon	20.8792	21.5027	21.84812	21.72822	21.85052	21.70006	21.69249	21.39984	21.82969	22.03281	21.62606	21.87294	22.17087	22.29323	22.33113	22.42708
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10800	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526	4.517526
21600	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475	5.629475
32400	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218	7.768218
43200	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626	14.41626
54000	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951	64.01951
64800	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367	9.894367
75600	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958	6.492958
86400	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981	4.999981
97200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
118800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
129600	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
151200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
172800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Rainfall data (mm)

Time step of the data in second.
(note: start time from zero)
In this lecture, time step is 3h interval(10800 second).

Data format is csv file.
In this lecture, “RainModel1%@Kumanovo190827.csv” is used as rainfall data.

2-3) Extract rainfall data with Thiessen Polygon method

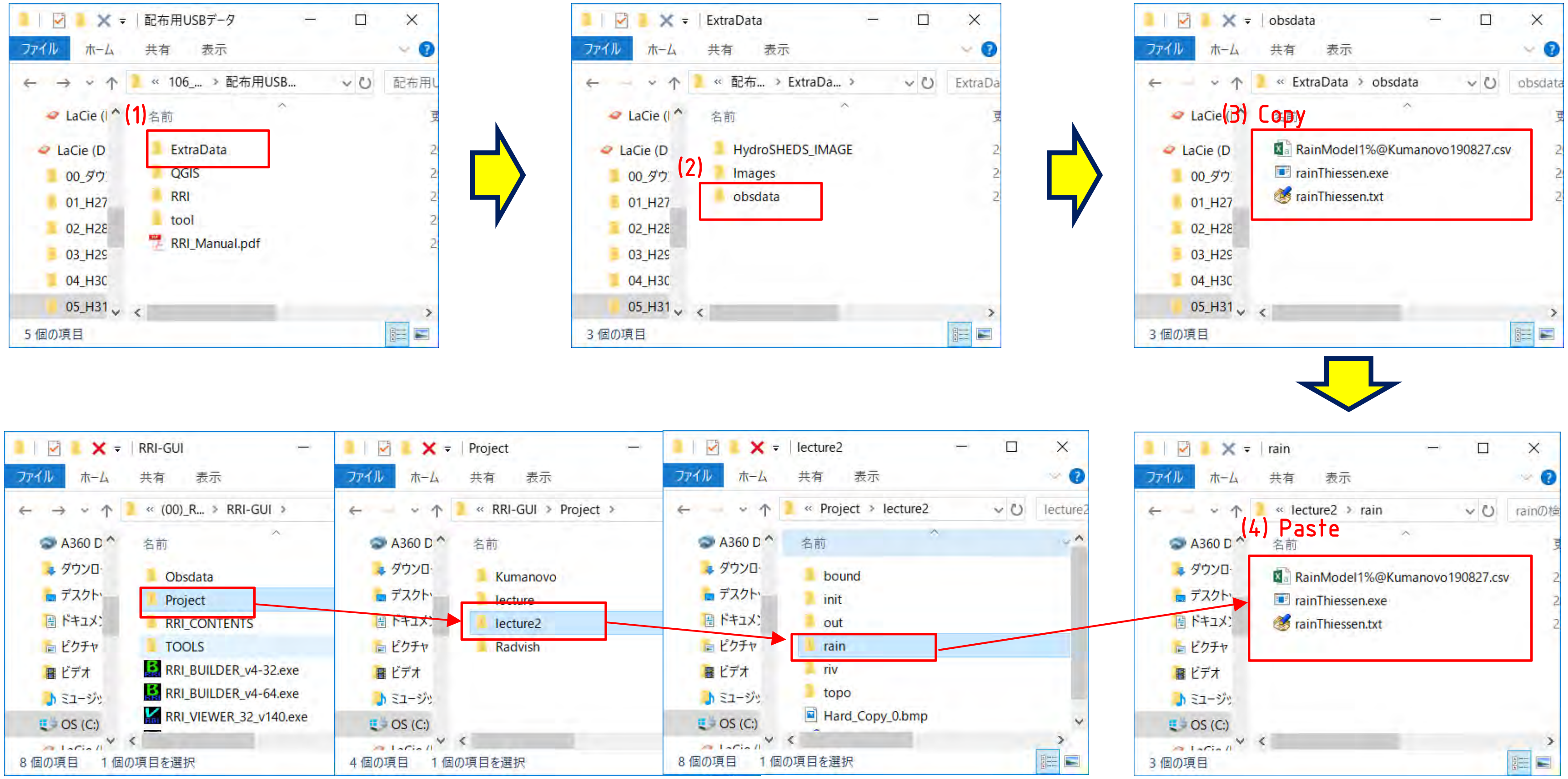
① Rainfall data format

In this lecture, following 16 stations are used as the rain gauge.

Name of the station	x	y
Popova Shapka	20.87920	42.01606
Bulachani	21.50270	42.07163
Dragomance	21.84812	42.21901
Gorno Konjare	21.72822	42.18183
Klechovci	21.85052	42.11672
Kumanovo	21.70006	42.12833
Romanovce	21.69249	42.09084
Skopje Zajchev Rid	21.39984	42.01653
Staro Nagorichani	21.82969	42.19952
Stracin	22.03281	42.15128
Umndol	21.62606	42.08702
Vojnik	21.87294	42.15883
Ginovci	22.17087	42.17388
Konopnica	22.29323	42.18256
Kriva Palanka	22.33113	42.20354
Uzem	22.42708	42.22010

2-3) Make a rainfall data with Thiessen Polygon method

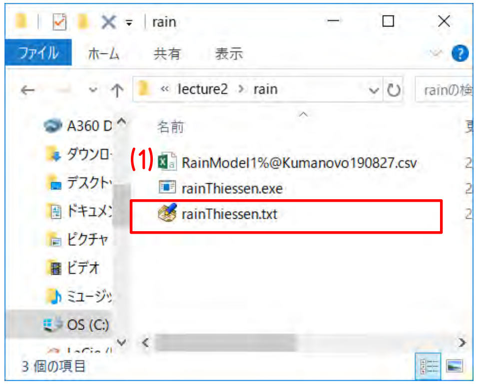
② Extract rainfall data with Thiessen Polygon method

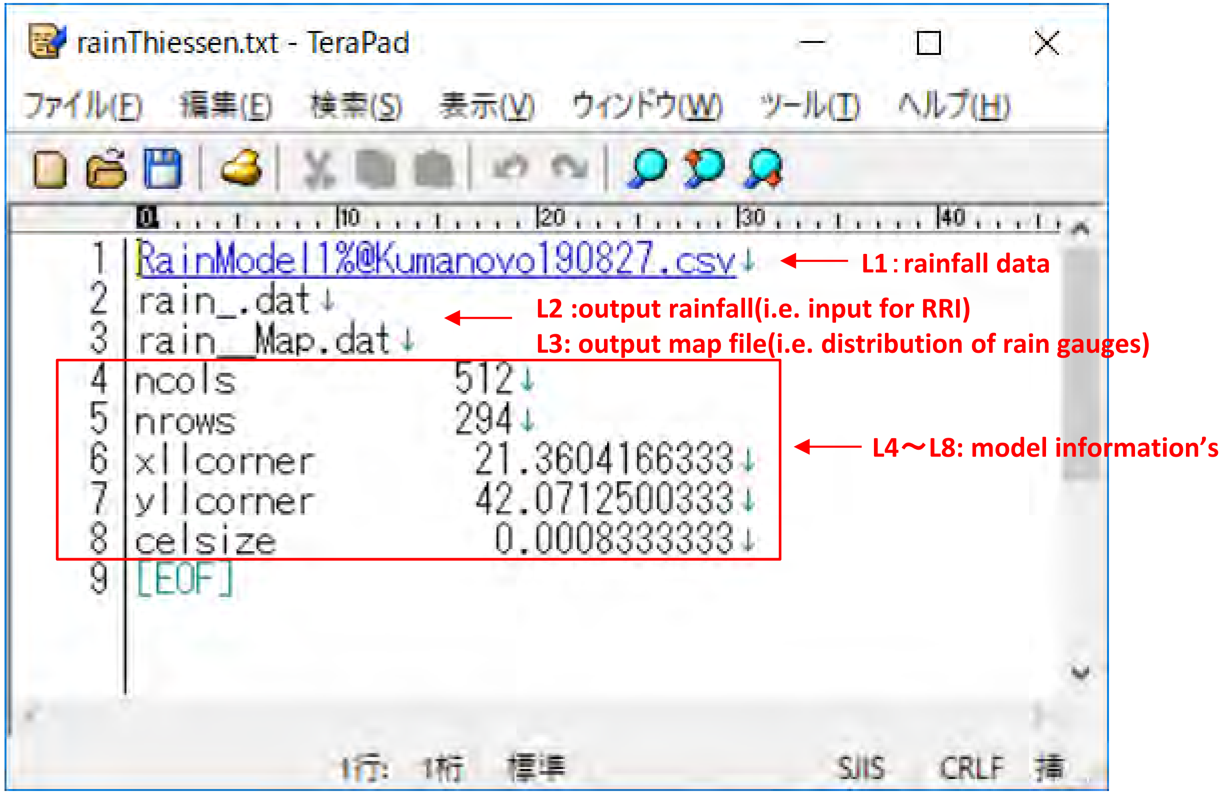


(1) Double click the "ExtraData" folder in a USB
(2) Double click the "obsdata" folder
(3) Copy the "RainModel1%@Kumanovo190827.csv", "rainThiessen.exe" and "rainThiessen.txt"
(4) Paste inside "RRI-GUI"→"Project"→"lecture2"→"rain" folder

2-3) Make a rainfall data with Thiessen Polygon method

② Extract rainfall data with Thiessen Polygon method



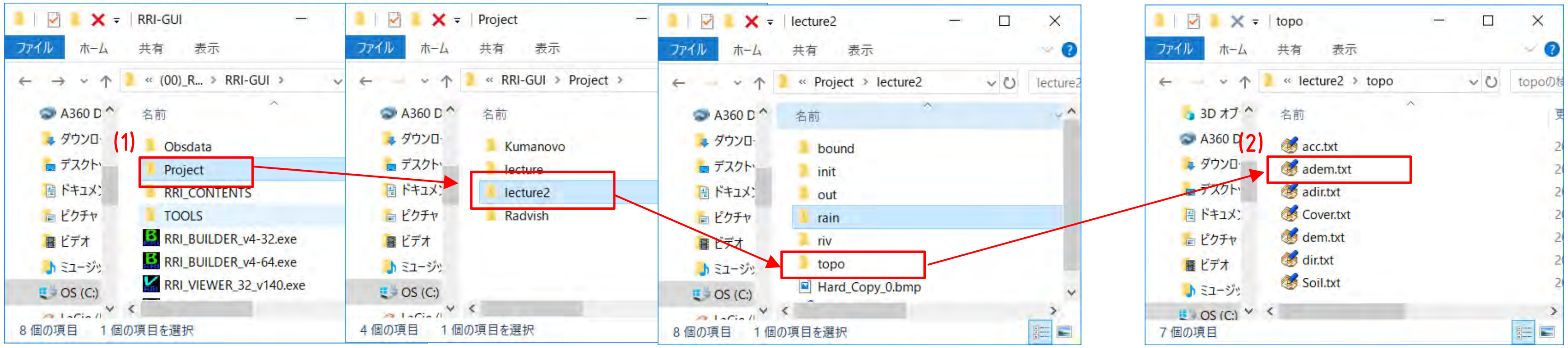


(1) Double click the "rainThiessen.txt"
(2) Write to L1 the "name of rainfall data"
(3) Write to L2 the "rain_.dat"
(4) Write to L3 the "rain_Map.dat"
(5) Write to L4～L8 the "model information's"

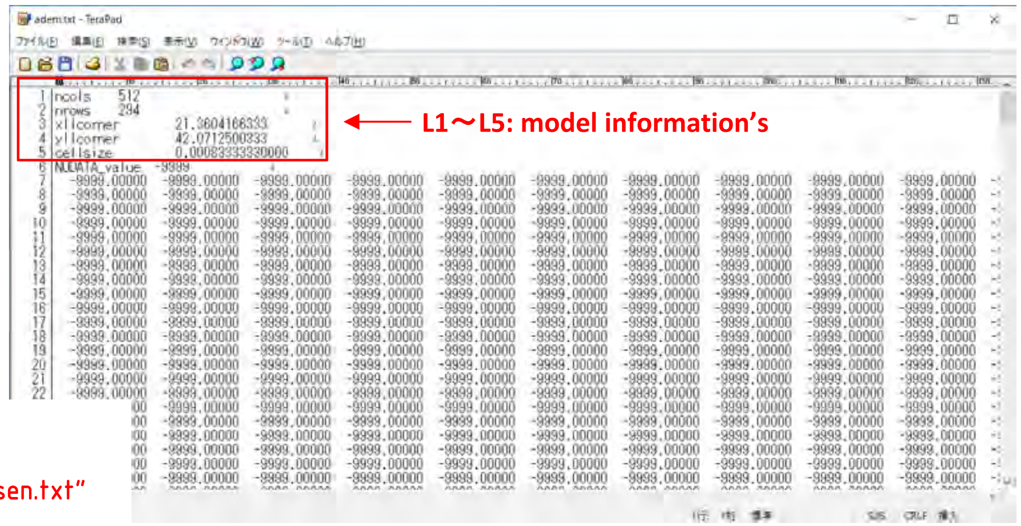
2-3) Make a rainfall data with Thiessen Polygon method

② Extract rainfall data with Thiessen Polygon method

Confirmation of "model information's"



(3)

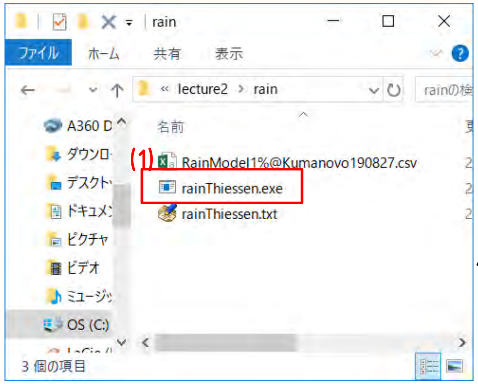


(1) Enter the "RRI-GUI"→"Project"→"lecture2"→"topo" folder
(2) Double click the "adem.txt"
(3) Copy the "L1〜L5" and paste to the "L4〜L8 of rainThiessen.txt"
(4) Save the "rainThiessen.txt"

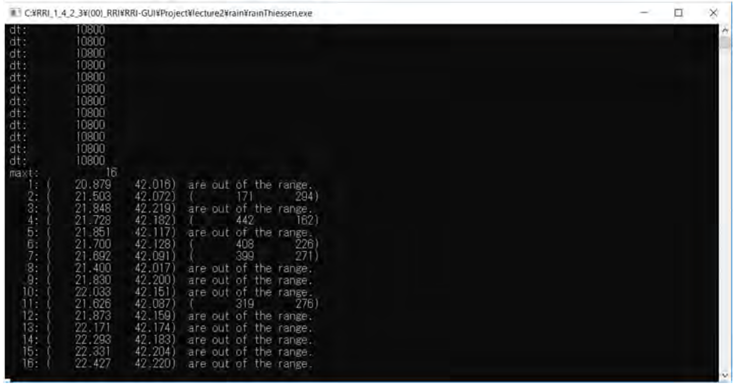
2-3) Make a rainfall data with Thiessen Polygon method

② Extract rainfall data with Thiessen Polygon method

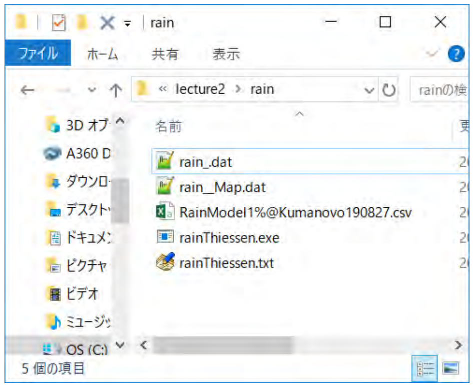
Run of the Thiessen program



Run the program!



Create a two files after run



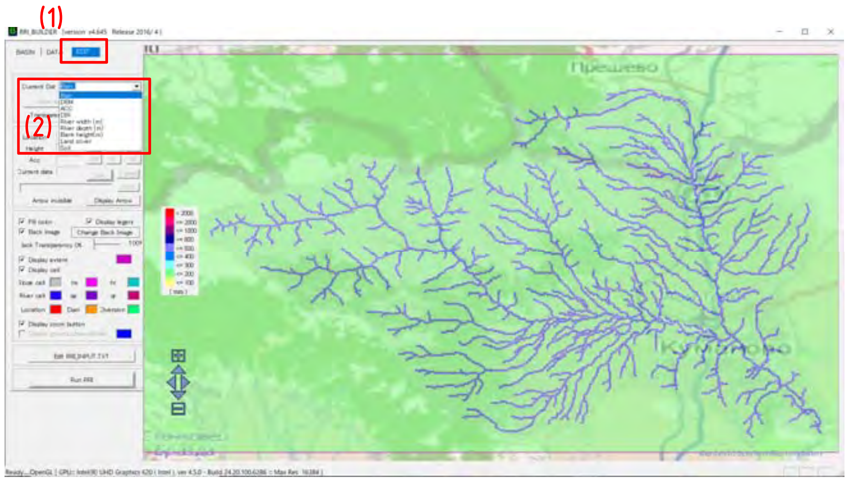
(1) Double click the "rainThiessen.exe"
(2) Run the program
(3) Confirm the new files (i.e. "rain_dat" and "rain_Map.dat"

(2) Exercise of data creation

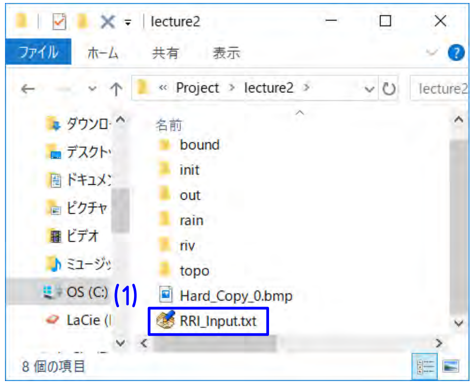
2-3) Make a rainfall data with Thiessen Polygon method

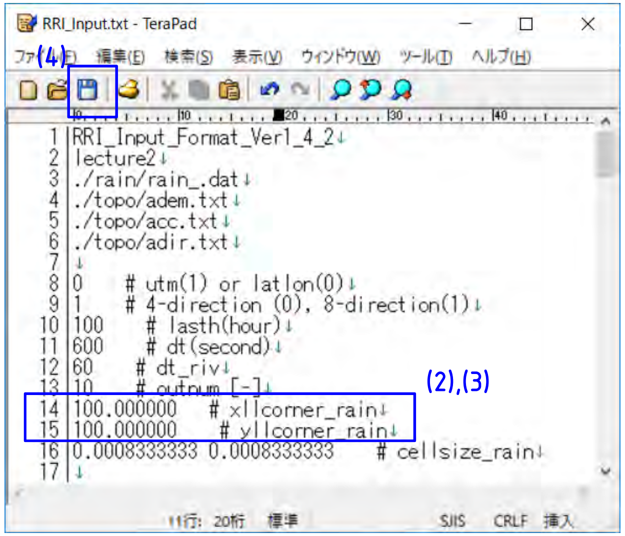
② Extract rainfall data with Thiessen Polygon method

Check the cumulative rainfall with Thiessen using "RRI_BUILDER_v4-64.exe"



(1) Click the "EDIT" Tab
(2) Select "Rain"





Note!
If rainfall is not displayed, check the L14～L15 of "RRI_Input.txt" of "lecture2" folder.
L14 and L15 is value of "left bottom" in the modeling region.
In this lecture, L14 is "21.360420" and L15 is "42.071250".

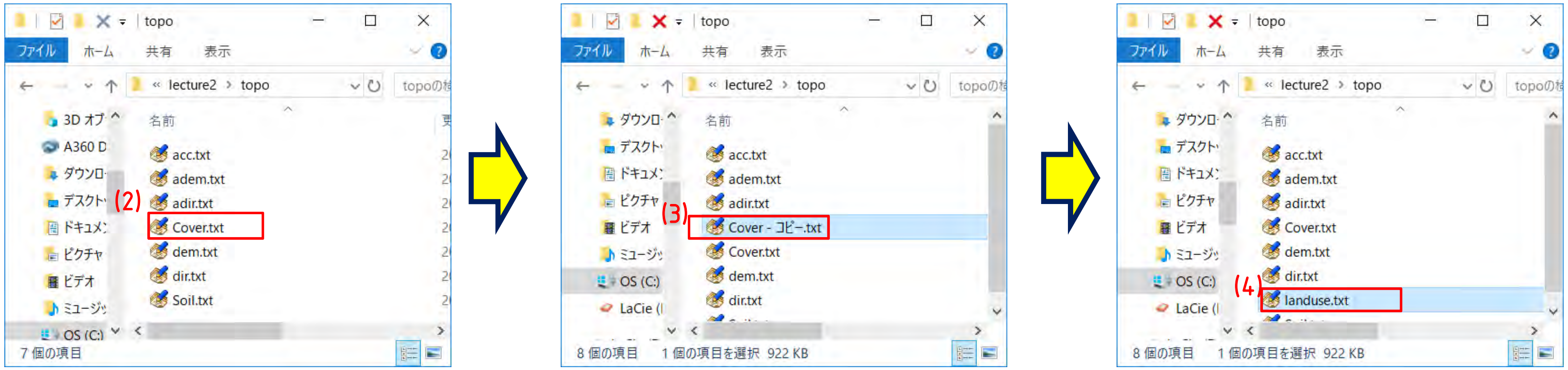
(1) Enter the "RRI-GUI"→"Project"→"lecture2" folder and click the "RRI_Input.txt"
(2) Write the L14 to "21.360420"
(3) Write the L15 to "42.071250"
(4) Save the "RRI_Input.txt"

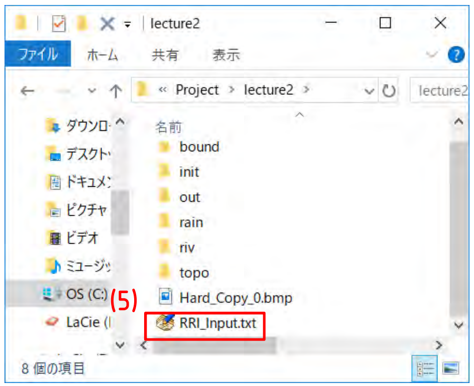
(2) Exercise of data creation

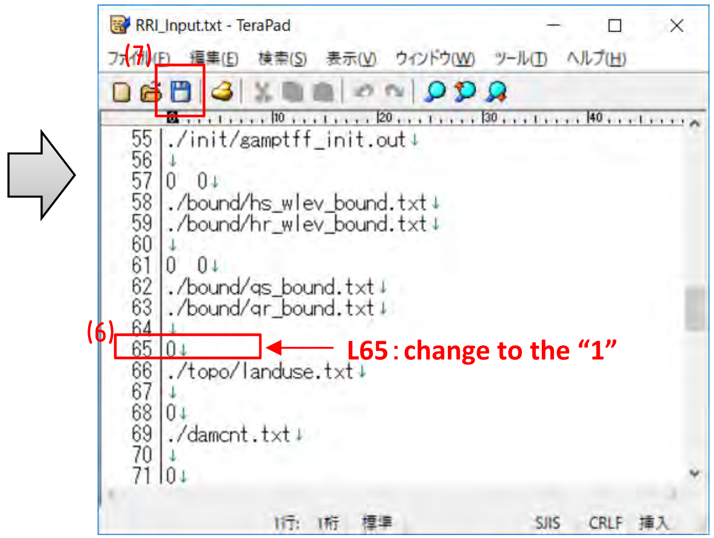
2-4) Setting of parameter and analysis conditions

① Parameter

Make a parameter file





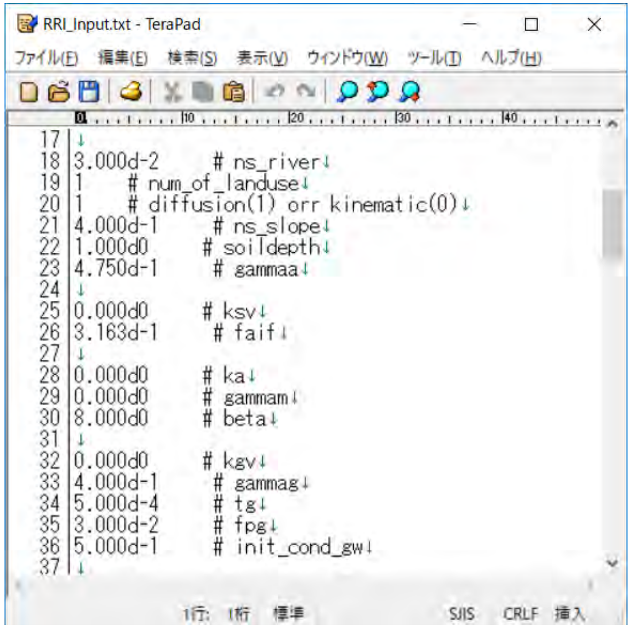


(1) Enter the "RRI-GUI"→"Project"→"lecture2"→"topo" folder
(2) Copy the "Cover.txt"
(3) Paste it at same folder
(4) Rename to the "landuse.txt"
(5) Double click the "RRI_Input.txt" of "lecture2" folder
(6) Rewrite the L65 to the "1" from "0"
(7) Save

2-4) Setting of parameter and analysis conditions

① Parameter

Setting of parameter value



Note!
L18: Manning’s roughness in river channel
L19: Number of landuse (Number of parameter)
L20: diffusion (1) or kinematic (0) [default : 1]
L21 : Manning’s roughness on slope cells
L22 : Soil depths [m]
L23 : Effective porosity [-]
L25, L26 : Green-Ampt infiltration model parameters
L28～L30 : lateral subsurface and surface model parameters
L32 ～L36: deep groundwater component, but algorithm is under development and not completed at RRI ver1.4.2

※The values of L20～L36 need only the number of landuse.

(1) Double click the “RRI_Input.txt”
(2) Rewrite the L18 to “4.000d-2”
(3) Rewrite the L19 to “20”

Number of landuse in the RRI

2-4) Setting of parameter and analysis conditions

① Parameter

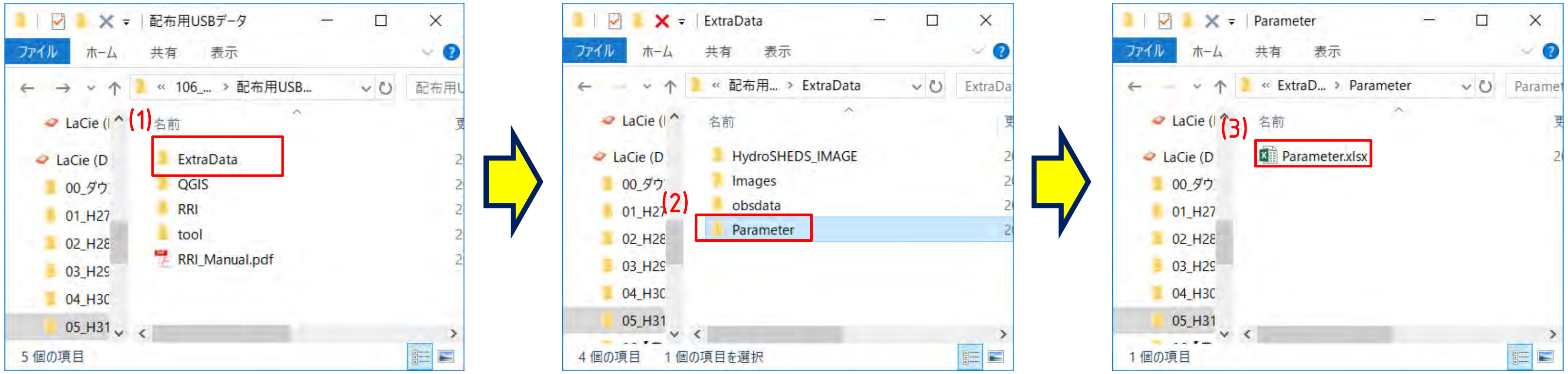
Setting of parameter value

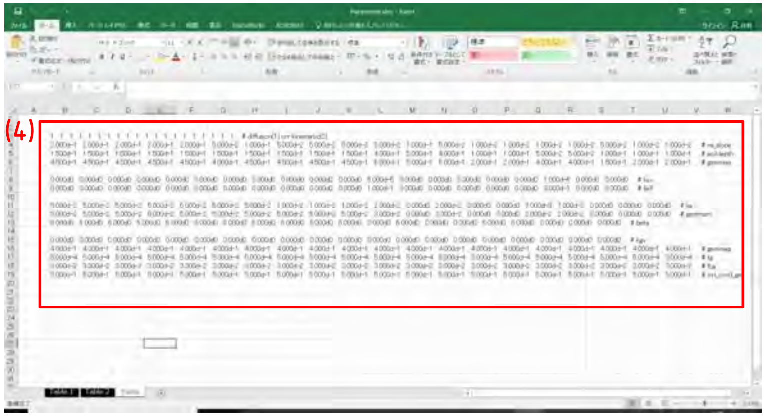
Row number	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Broadleaf Deciduous Forest	Broadleaf Evergreen Forest	Needleleaf Deciduous Forest	Needleleaf Evergreen Forest	Mixed Forest	Tree Open	Shrub	Herbaceous	Herbaceous with Sparse Tree/Shrub	Sparse vegetation	Cropland	Paddy field	Cropland / Other Vegetation Mosaic	Mangrove	Wetland	Bare area, consolidated (gravel, rock)	Bare area, unconsolidated (sand)	Urban	Snow / Ice	Water bodies
L21	ns_slope	2.000d-1	2.000d-1	2.000d-1	2.000d-1	2.000d-1	5.000d-2	1.000d-1	5.000d-2	5.000d-2	5.000d-2	5.000d-2	1.000d-1	5.000d-2	1.000d-2	1.000d-2	1.000d-2	1.000d-2	5.000d-2	1.000d-2	1.000d-2
L22	soildepth	1.500d-1	1.500d-1	1.500d-1	1.500d-1	1.500d-1	1.500d-1	1.500d-1	1.500d-1	1.500d-1	1.500d-1	4.000d-1	5.000d-1	4.000d-1	1.000d-1	1.000d-1	5.000d-2	5.000d-2	1.000d-1	1.000d-1	1.000d-1
L23	gammaa	4.500d-1	4.500d-1	4.500d-1	4.500d-1	4.500d-1	4.000d-1	4.500d-1	4.500d-1	4.500d-1	4.500d-1	6.000d-1	5.000d-1	6.000d-1	2.000d-1	2.000d-1	4.000d-1	4.000d-1	1.500d-1	2.000d-1	2.000d-1
L25	ksv	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	6.000d-5	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	1.000d-6	0.000d0	0.000d0
L26	faif	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	1.000d-1	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	3.000d-1	0.000d0	0.000d0
L28	ka	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	1.000d-2	1.000d-2	1.000d-2	2.000d-2	0.000d0	2.000d-2	0.000d0	0.000d0	7.000d-3	7.000d-3	0.000d0	0.000d0	0.000d0
L29	gammam	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	5.000d-2	3.000d-2	0.000d0	3.000d-2	0.000d0	0.000d0	2.000d-2	2.000d-2	0.000d0	0.000d0	0.000d0
L30	beta	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	6.000d0	0.000d0	6.000d0	0.000d0	0.000d0	6.000d0	6.000d0	0.000d0	0.000d0	0.000d0
L32	kgv	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0	0.000d0
L33	gammag	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1	4.000d-1
L34	tg	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4	5.000d-4
L35	fpg	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2	3.000d-2
L36	init_cond_gw	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1	5.000d-1

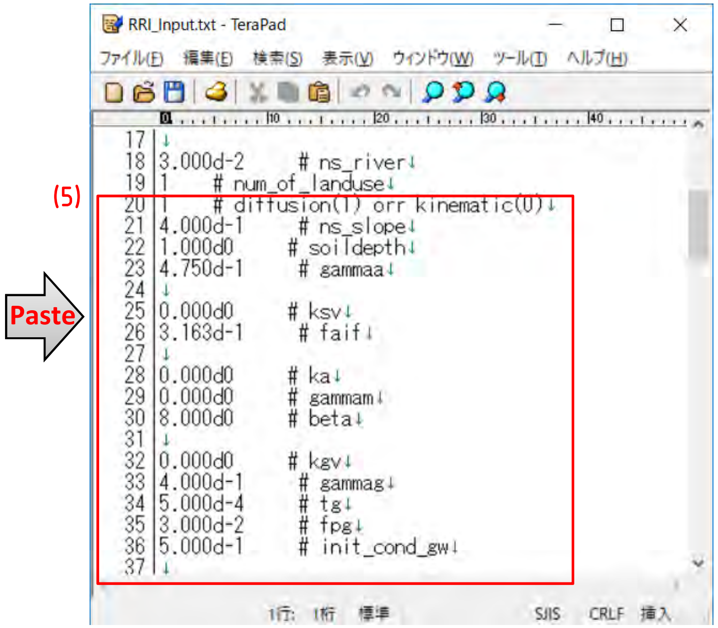
2-4) Setting of parameter and analysis conditions

① Parameter

Setting of parameter value



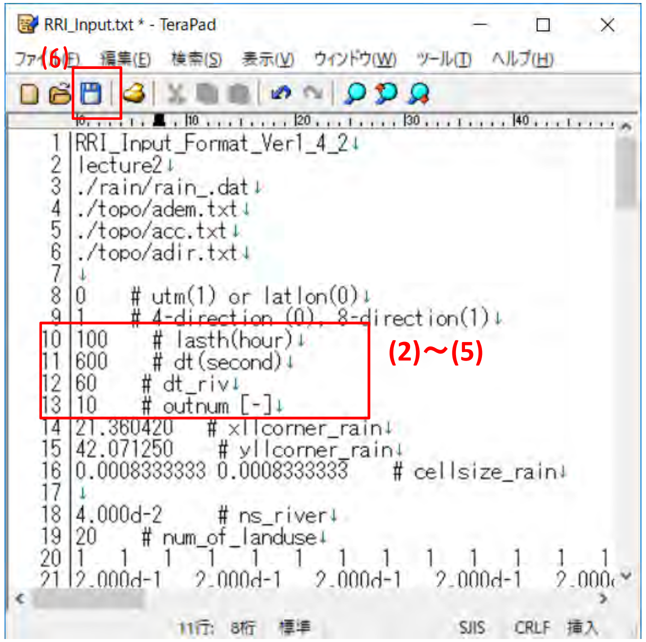




(1) Double click the "ExtraData" folder in a USB
(2) Double click the "Parameter" folder
(3) Double click the "Parameter.xlsx"
(4) Copy the text at "Paste sheets"
(5) Paste it at L20～L36

2-4) Setting of parameter and analysis conditions

② Analysis conditions

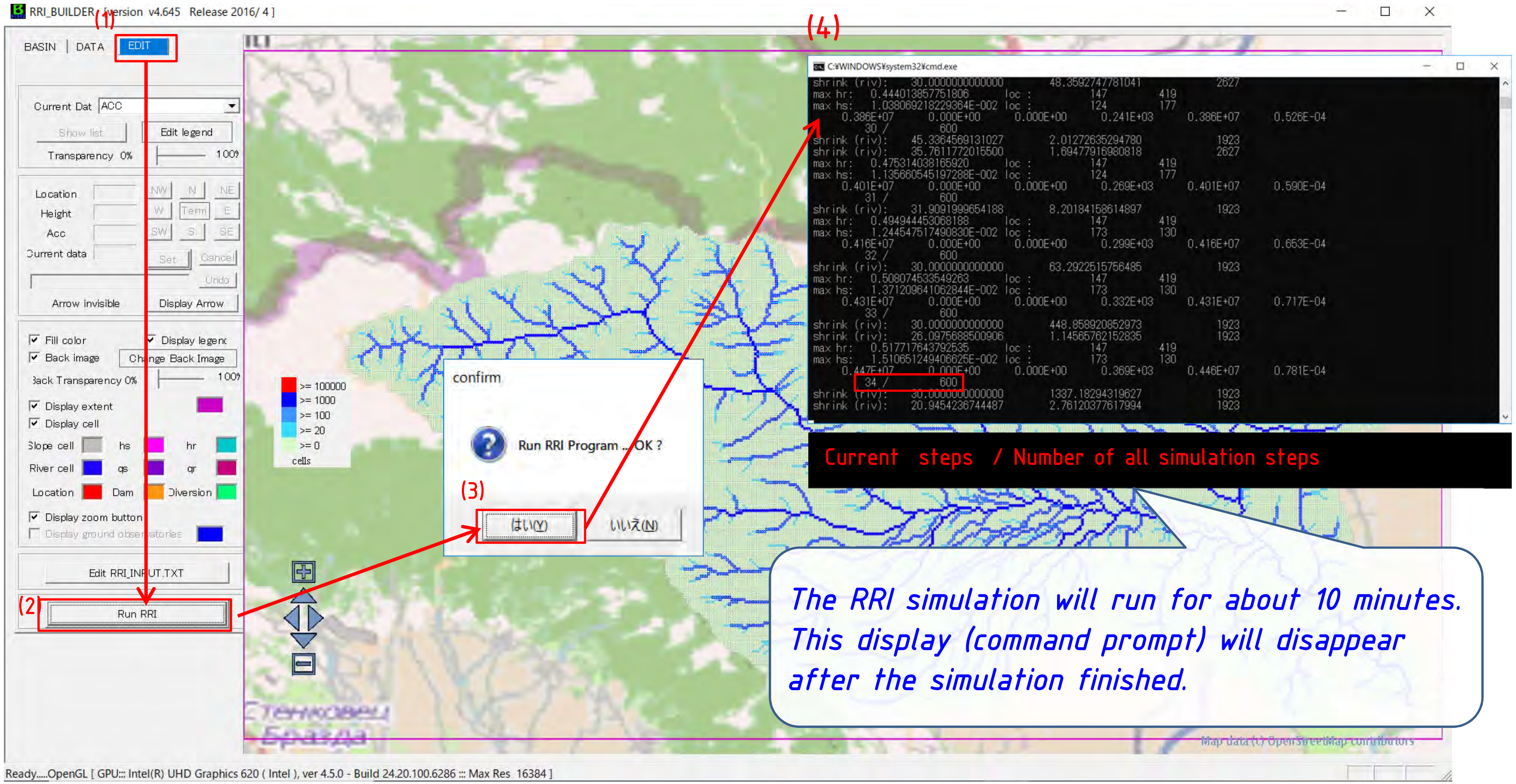


(1) Double click the "RRI_Input.txt"
(2) Rewrite the L10 to "48"
(3) Rewrite the L11 to "60"
(4) Rewrite the L12 to "6"
(5) Rewrite the L13 to "48"
(6) Save the "RRI_Input.txt"

Note!
L1 : Version of the control file format
L2 : Project name
L3 : Specifies the path to an input rainfall file
L4 : Specify the paths to input adjust dem file
L5 : Specify the paths to input acc file
L6 : Specify the paths to input adjust dir file
L8 : Topographic and rainfall data coordinate system (UTM (1) or Lat Lon(0)
L9 : Simulating with 4- (0) or 8-direction (1) by the two dimensional model [default : 1]
L10: Simulation period [hour]
L11: Simulation time step [sec], [default : 600 sec]
L12: Simulation time step for river [sec], [default : 60 sec]
L13: Number of output files
L14 ～L16 : South west coordinate and resolution of rainfall data

2-5) Execute RRI

★Now, you can run the RRI Model!!



(1) Click the EDIT Tab
(2) Click "Run RRI"
(3) Click "Yes"
(4) Run (Command prompt displays the process of the calculation during calculation)

(3) Outline of Training on next day

Tomorrow’s outline is below.

1. **Exercise of visualization of outputs**
   - **a) Inundation depth (2- dimensional)**
   - **d) Inundation depth time series (point)**
   - **c) River water depth (2- dimensional)**
   - **d) River discharge (2- dimensional)**
   - **e) Hydrograph time series (point)**
   - **f) Profile of river water level**
   - **g) Profile of inundation depth**
2. **Summary and Closing**

Crisis Management Center
Japan International Cooperation Agency

Project on capacity building for Ecosystem based Disaster Risk Reduction(Eco-DRR)
through sustainable forest management

RRI model Training

Apply RRI model to a selected basin
～Exercise of visualization of outputs～

Dr. Keishi KUDO
Personnel of hydraulic model/Eco-DRR

03/Oct/2019

Outline

Today outline is below.

1. **Exercise of visualization of outputs**
   a) Inundation depth (2- dimensional)
   d) Inundation depth time series (point)
   c) River water depth (2- dimensional)
   d) River discharge (2- dimensional)
   e) Hydrograph time series (point)
   f) Profile of river water level
   g) Profile of inundation depth
2. **Summary and Closing**

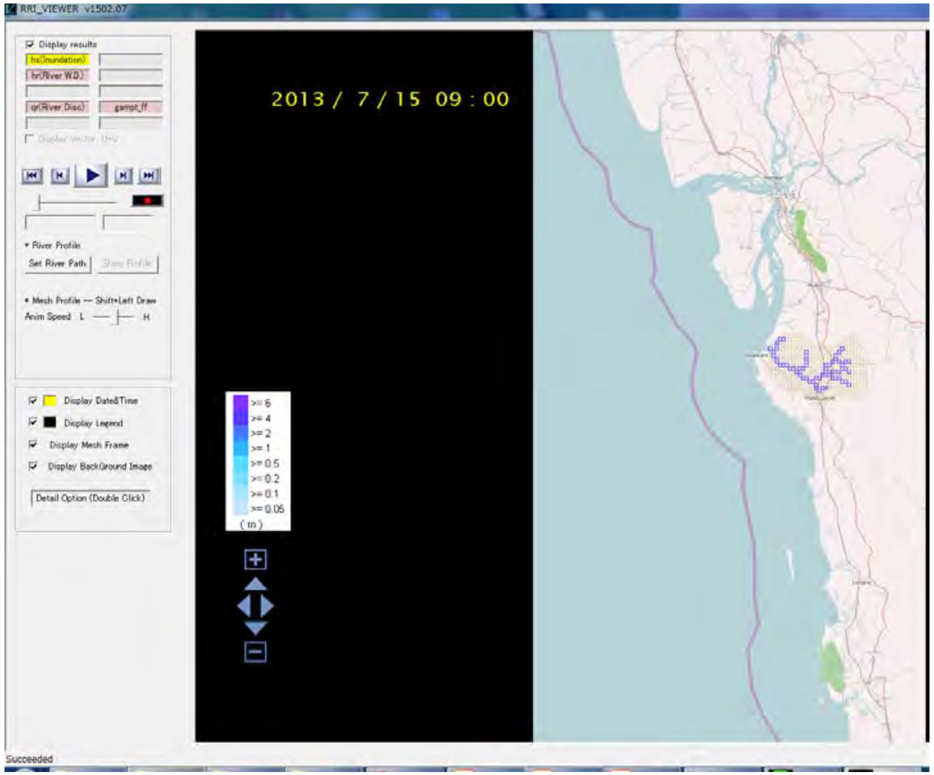
(1) Exercise of visualization of outputs

1-1) Overview of RRI_VIEWER

The GUI of RRI model is separated into two applications, Builder and Viewer.
To check the result of RRI model simulation, use RRI_VIEWER.exe.
In this lecture, we learn the following functions.

FUNCTIONS TO LEARN

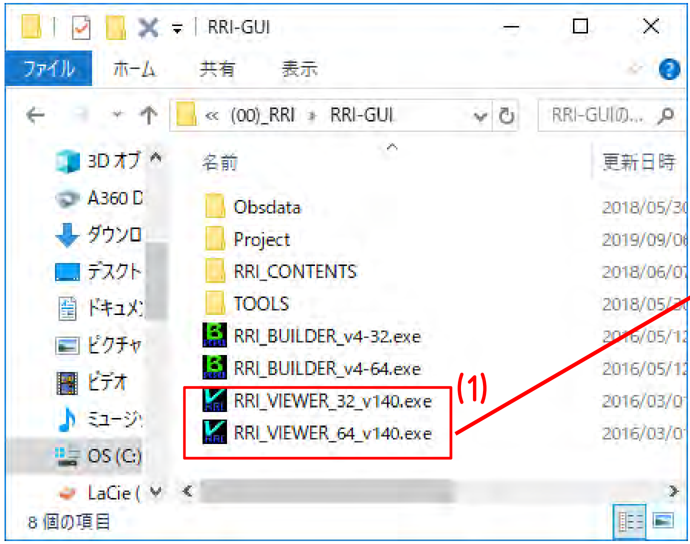
a. Inundation depth (2- dimensional)
b. Inundation depth time series (point)
c. River water depth (2- dimensional)
d. River discharge (2- dimensional)
e. Hydrograph time series (point)
f. Profile of river water level
g. Profile of inundation depth

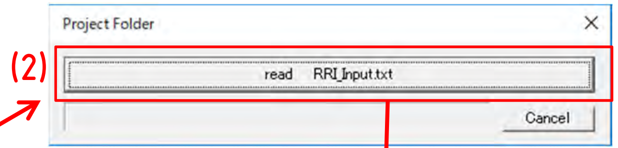


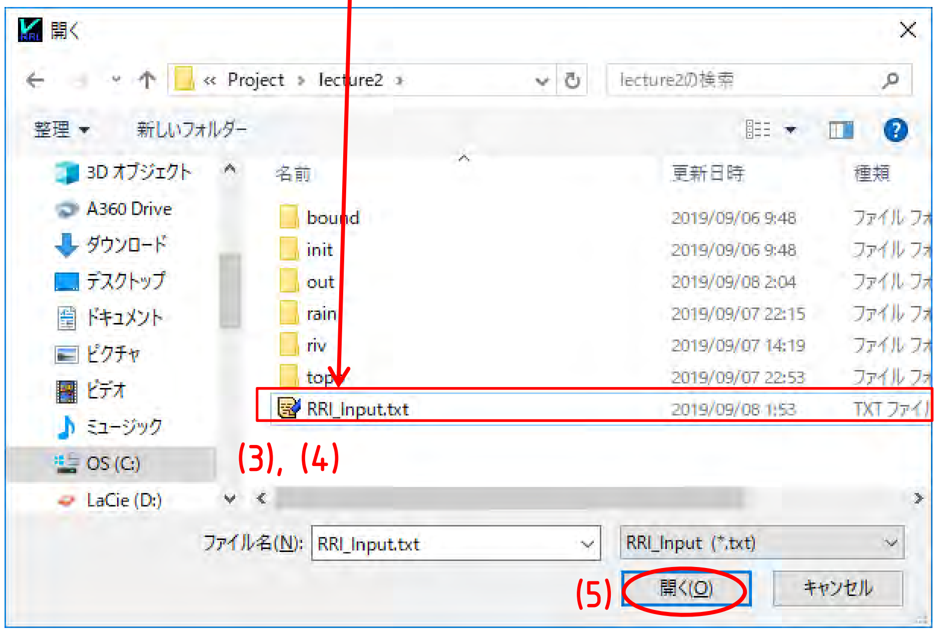
1-2) Start up RRI_VIEWER

★Start up RRI_VIEWER

Start up C:¥RRI¥RRI-GUI¥RRI_VIEWER_32.exe or RRI_VIEWER_64.exe





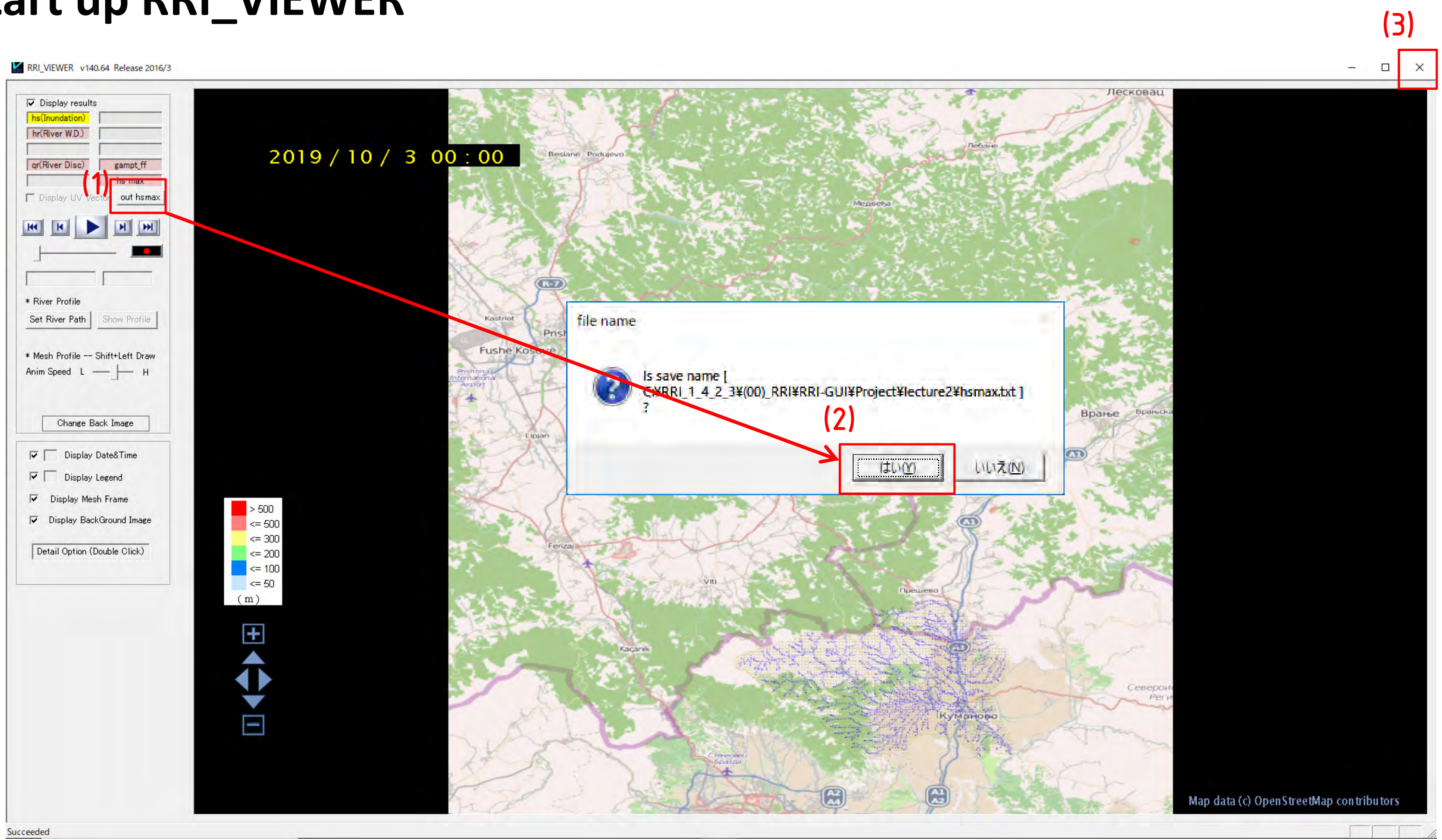


(1) Double Click
- RRI_VIEWER_32.exe or
- RRI_VIEWER_64.exe

(2) Click "read RRI_Input.txt"
(3) Go to C:¥RRI¥RRI-GUI¥Project¥lecture2
(4) Select RRI_Input.txt
(5) Click "Open"

1-2) Start up RRI_VIEWER

★Start up RRI_VIEWER



(1) Click "out hs max"
(2) Click "Yes"
(3) Click "EXIT"

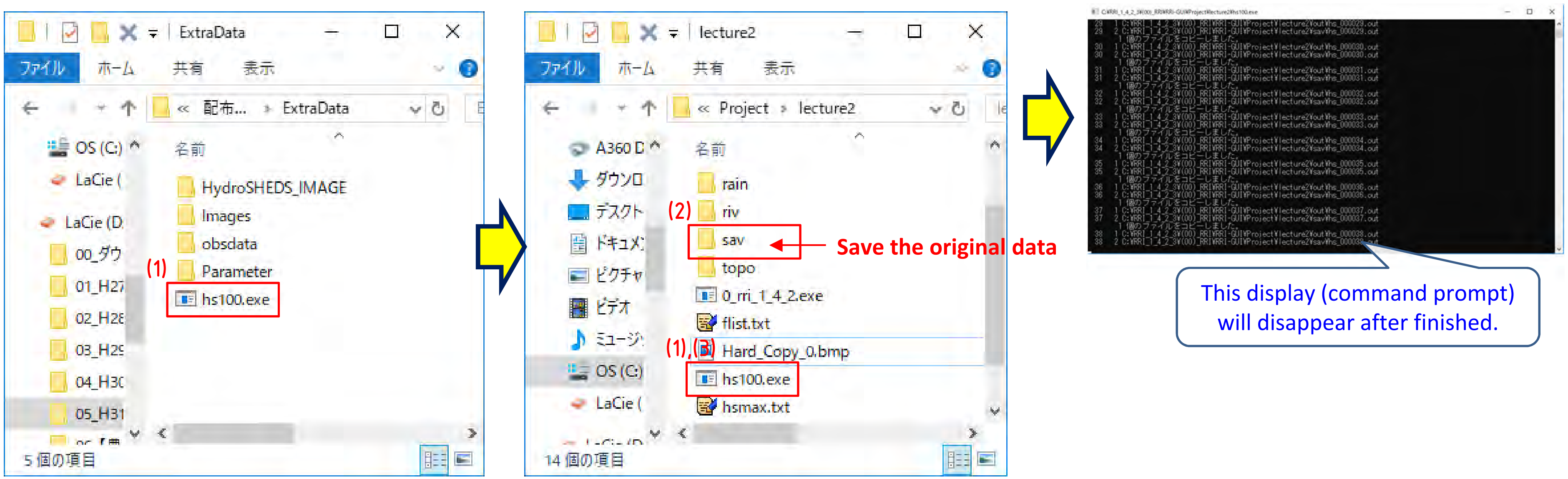
(1) Exercise of visualization of outputs

1-3) View the result

a. Inundation depth animation

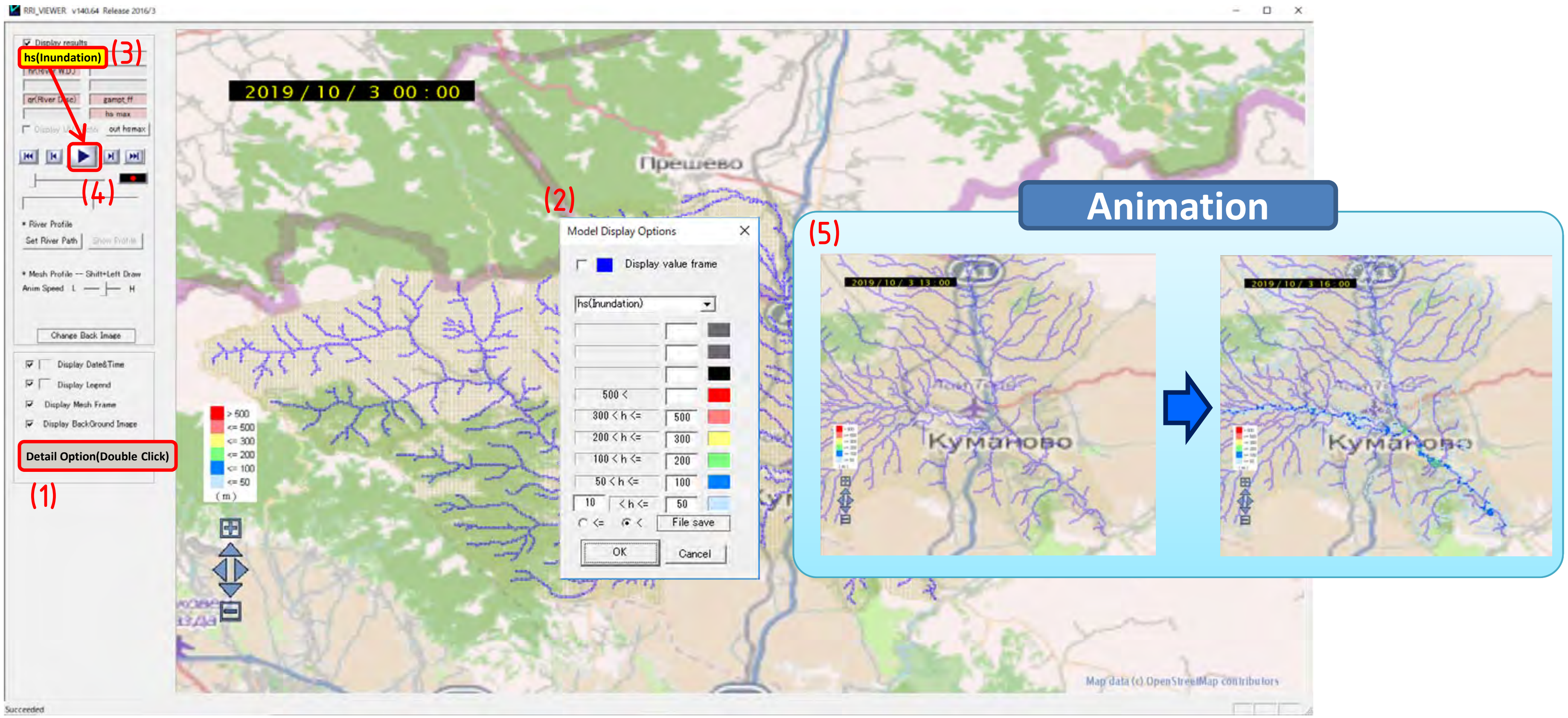
Note!
"RRI_VIEWER_64.exe" have bug that Inundation depth cannot set the value with a decimal point.
We created a program(hs100.exe) of hundredfold for inundation depth.

1. Copy "hs100.exe" from "ExtraData" folder and paste it under "lecture2" folder
2. Make a "new" folder under "lecture 2" folder and name for the "save" folder
3. Double click the "hs100.exe"



1-3) View the result

a. Inundation depth animation



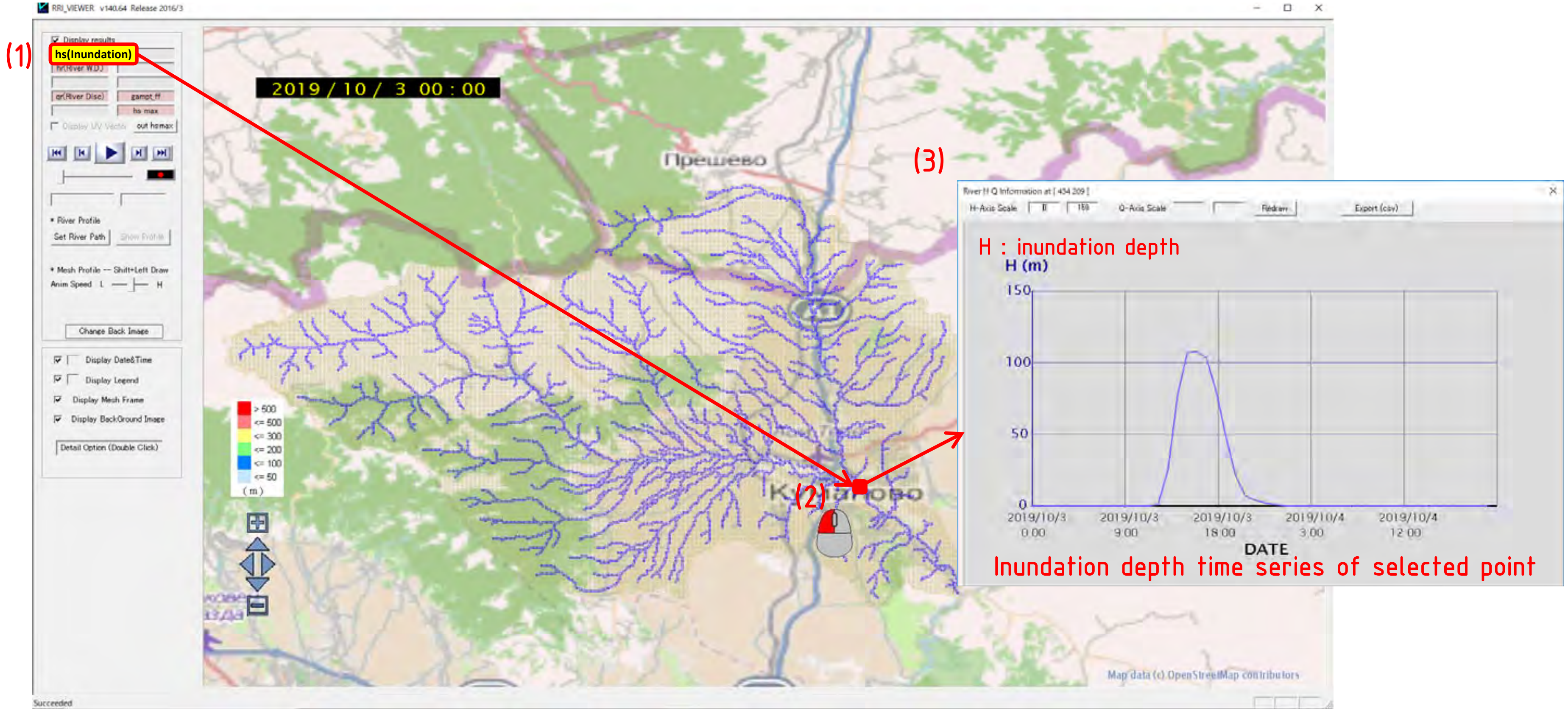
(1) Double Click to Open "Model Display Options" window
(2) Color legend can be changed.
(3) Click hs(Inundation)
(4) Click ▶ Animation button
(5) Check the results in animation

Note!
"hs" unit is "cm", does not "m".

(1) Exercise of visualization of outputs

1-3) View the result

b. Inundation depth time series

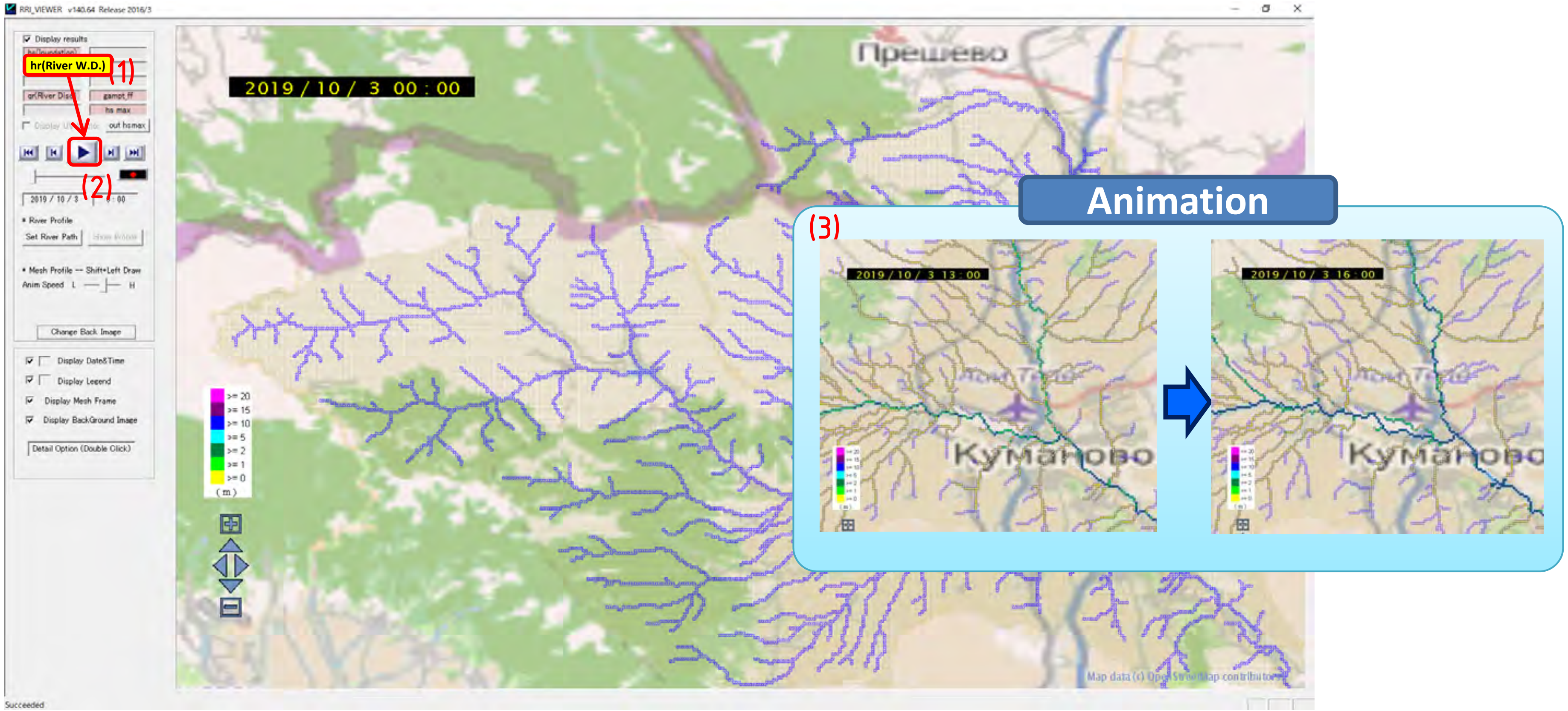


(1) Click hs(Inundation)
(2) Double Click on the cell to be shown
(3) Check the results of "Inundation Depth" time series at the selected cell

Note!
"hs" unit is "cm", does not "m".

1-3) View the result

c. River water depth animation



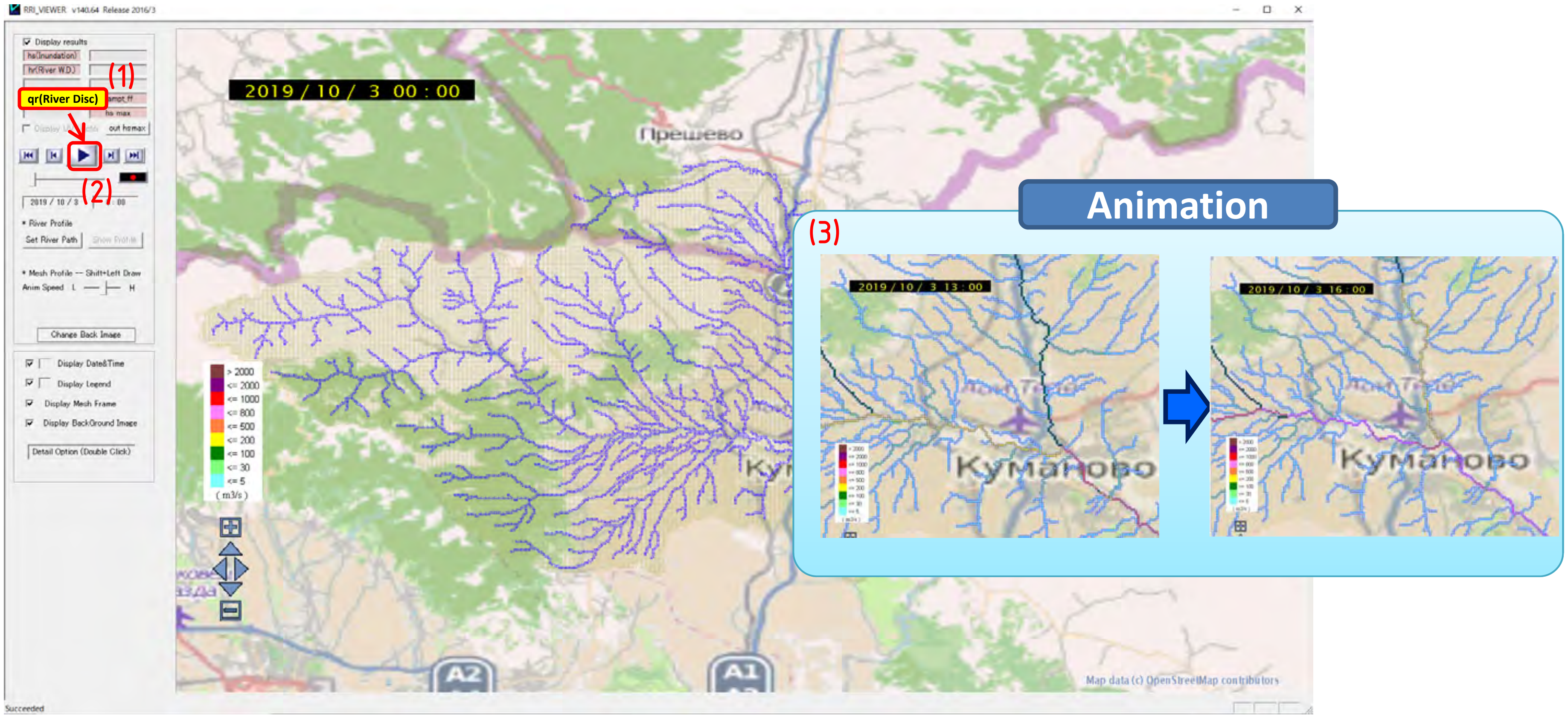
(1) Click "hr (River W.D)"

(2) Click ▶ Animation button

(3) Check the results of "River water depth" in animation

1-3) View the result

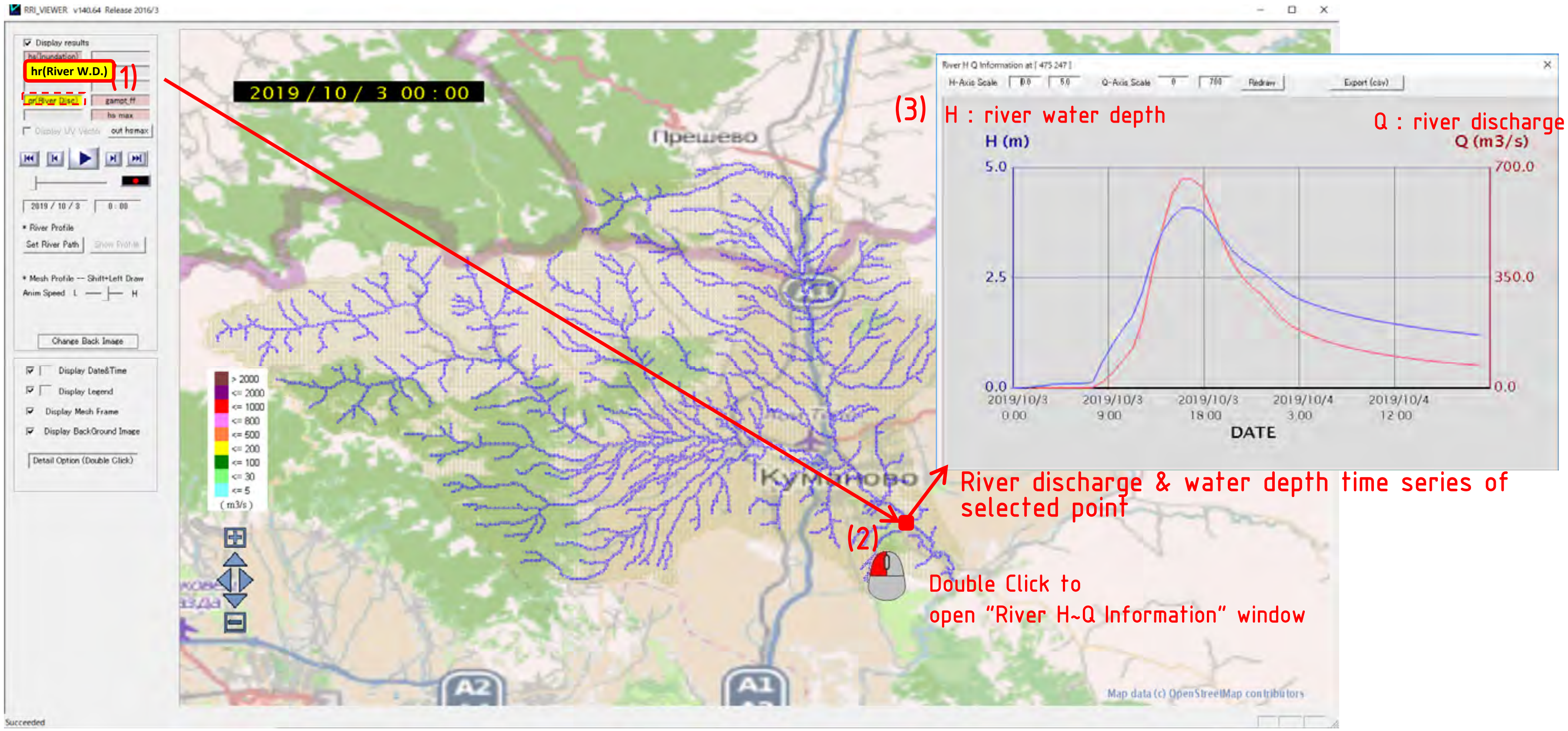
d. River discharge animation



(1) Click qr(River Disc)
(2) Click ▶ Animation button
(3) Check the results of "River discharge" in animation

1-3) View the result

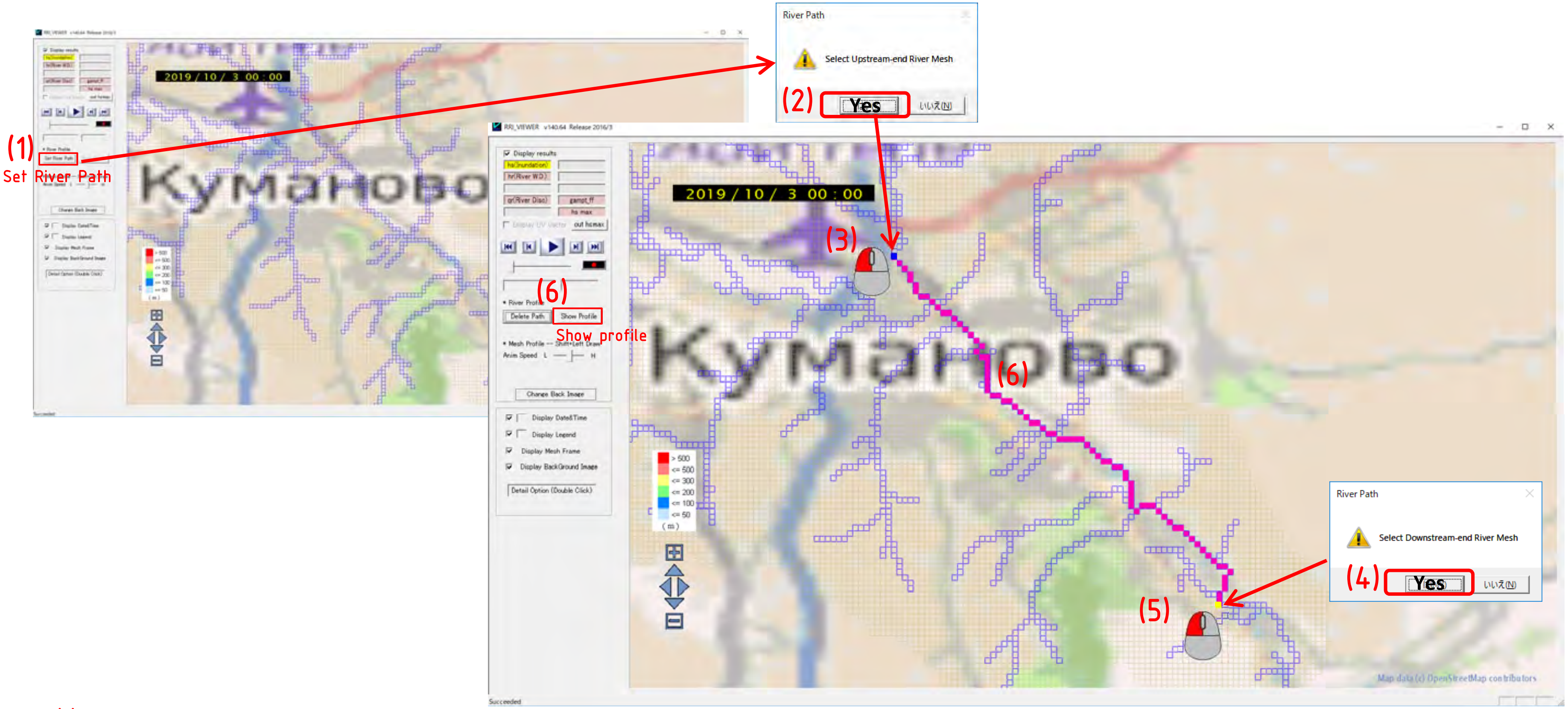
e. Hydrograph(River discharge & water depth) time series



(1) Click "hr(River W.D)" or "qr(River Disc.)"
(2) Double Click to open "River H~Q Information" window
(3) Check the results of "Water depth" or "River discharge" time series at the selected cell

1-3) View the result

f. Profile of river flow (1/2)

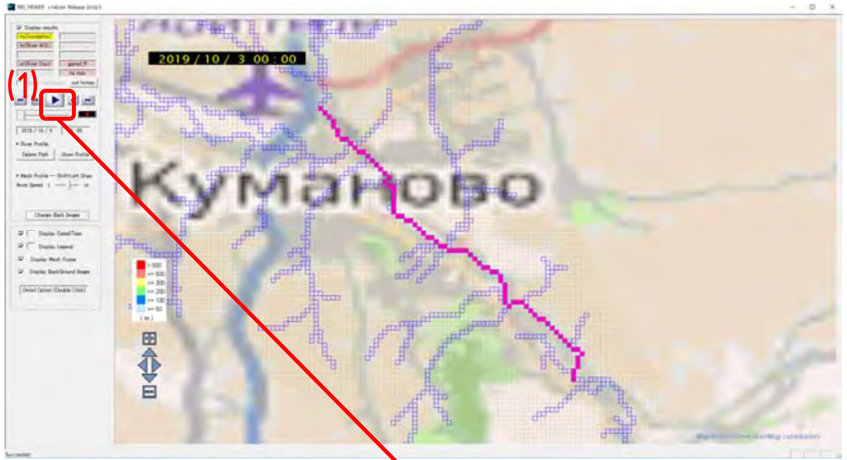


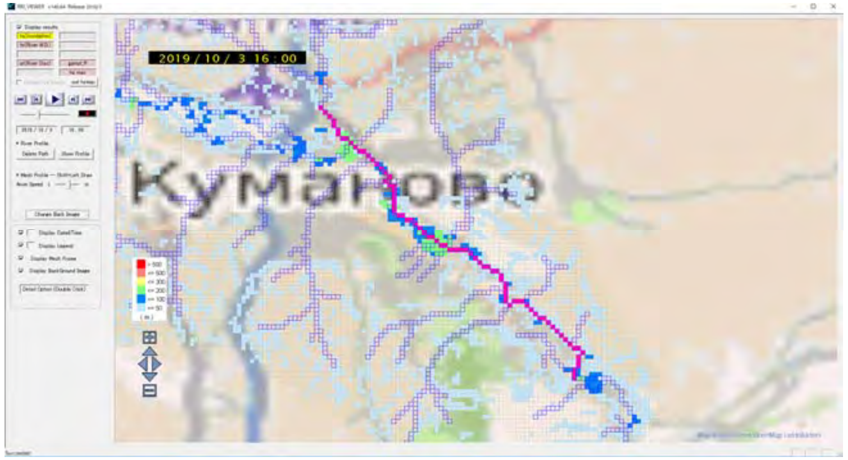
(1) Click "Set river path"
(2) Click "Yes" to select Upstream-end River Mesh
(3) Select "Upstream-end" River mesh by left click a cell
(4) Click "Yes" to select Downstream-end River Mesh
(5) Select "Downstream-end" River mesh by left click a cell
(6) Click "Show profile"

1-3) View the result

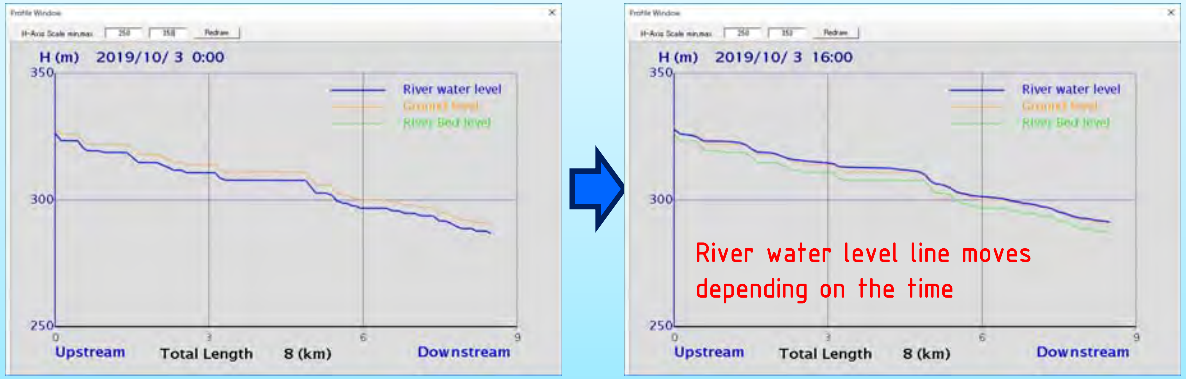
f. Profile of river flow (2/2)

(1)





Animation



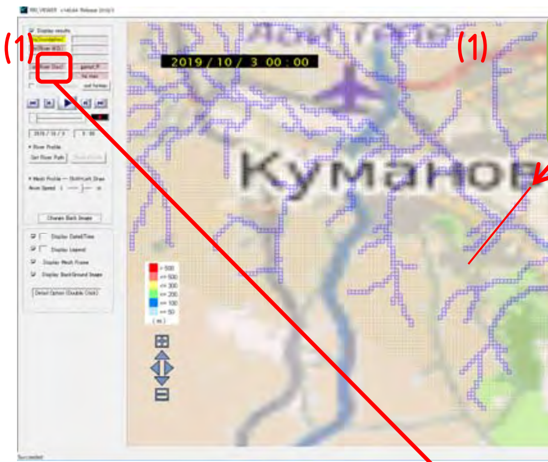
(1)Click ▶ to check the results in Animation

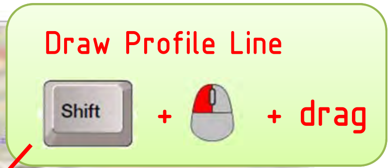
Note!
"hs" unit is "cm", does not "m".

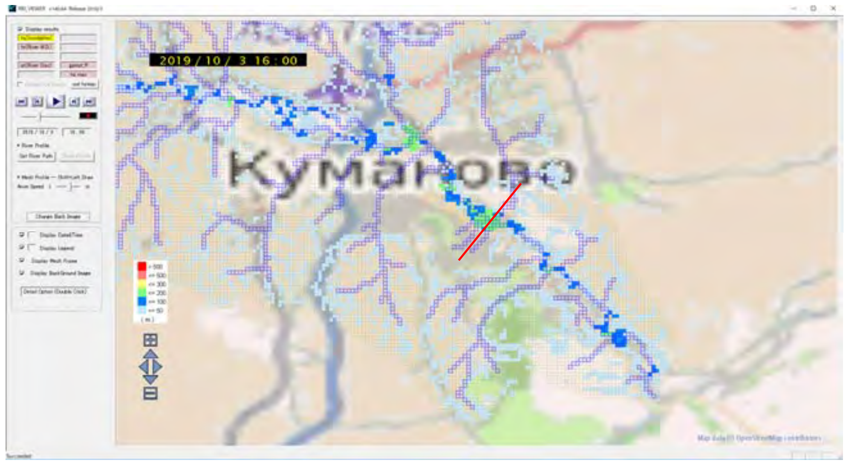
1-3) View the result

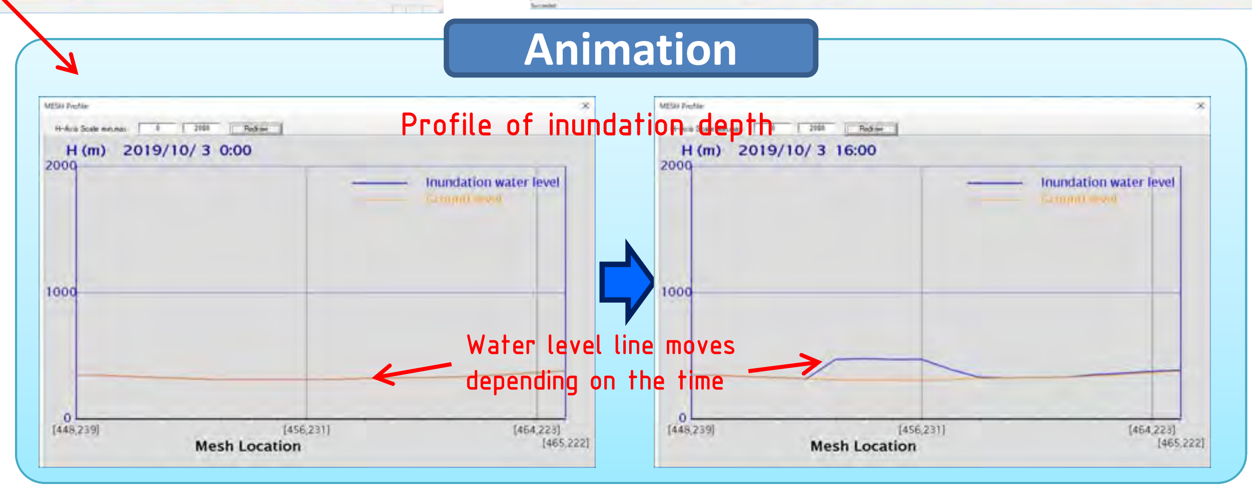
g. Profile of inundation depth

Profile of inundation depth also can be checked easily.









(1) Draw profile line : Shift + left mouse button, and drag
(2) "Mesh Profile" window opens automatically
(3) Click ▶ to check the profile of inundation depth in animation

Note!
"hs" unit is "cm", does not "m".