Rainfall-runoff and flood inundation predictions using RRI model:

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Introduction

Rainfall-Runoff-Inundation (RRI) model is a two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously (Sayama et al., 2012). When flooding occurs, the information of current situation on inundation extent and depths is one of the most essential information for emergency responses and evacuations. The original concept of the RRI model development is to simulate large scale flooding such as the ones in Thailand in 2011 (Sayama et al., 2015a; Sayama et al., 2015b) and Pakistan in 2010 (Sayama et al., 2012; Ushiyama et al., 2014) by simulating rainfall-runoff and inundation in an integrated manner. The model is also demonstrated recently in Japanese river basins (Kuribayashi et al., 2016) by reflecting more detailed cross sections and radar rainfall input to achieve detailed hazard mapping and real-time flood inundation predictions. The model has been applied also to assess flood risk (Sriariyawat et al., 2013; Shrestha et al. 2015) and benefit (Juarez-Lucas; 2016) at the river basin scale.

Theory

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, 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. 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.

How to use RRI model

The package of the RRI model is available from the website of ICHARM, Public Works Research Institute, Japan: https://www.pwri.go.jp/icharm/research/rri/rri_top.html

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 by ICHARM to support users for efficient model building and result visualization with HydroSHEDS dataset.

For non-experts in hydrologic modeling, it is recommended to use RRI-GUI to learn the basic steps with RRI-GUI. Refer to the RRI Manual included in the above package on the tutorial of RRI-CUI, followed by more detail descriptions and application examples.

The following part explains the use of RRI Graphical User Interface (GUI)

1. Pre-setting

1) Unzip “RRI_1_4_2.zip” and save it under a working folder (e.g. C:/”).
2) Check your PC is 32 or 64 bit. (My Computer → Property)

3) 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”.

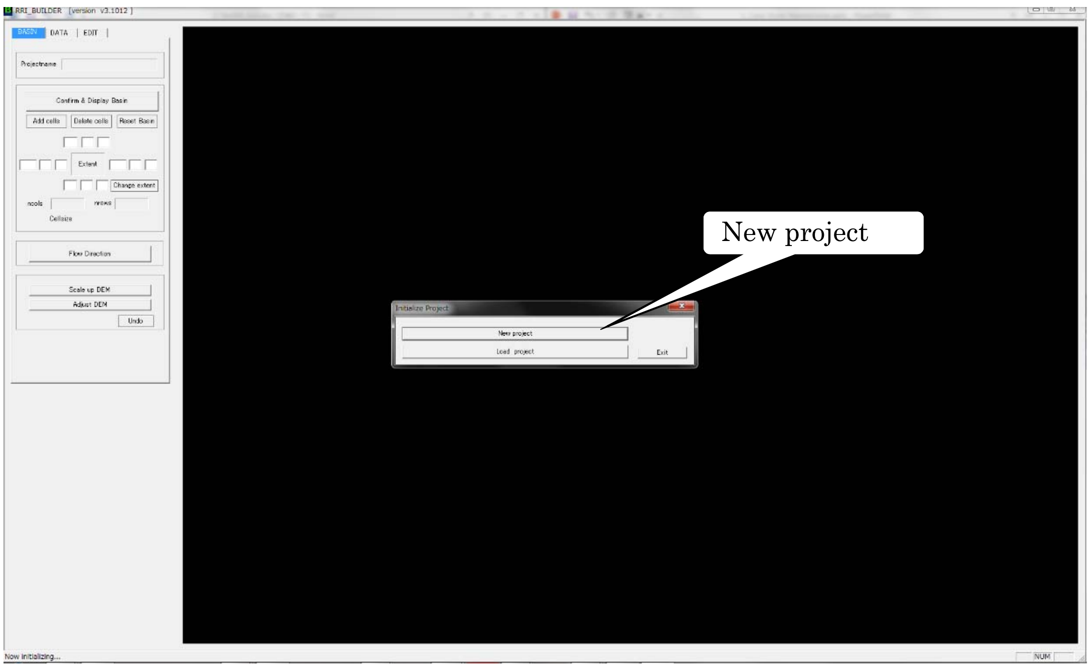
4) Execute RRI_BUILDER_64.exe

(for 32 bit machine, execute RRI_BUILDER_32.exe)

2. Model application and running with RRI_Builder

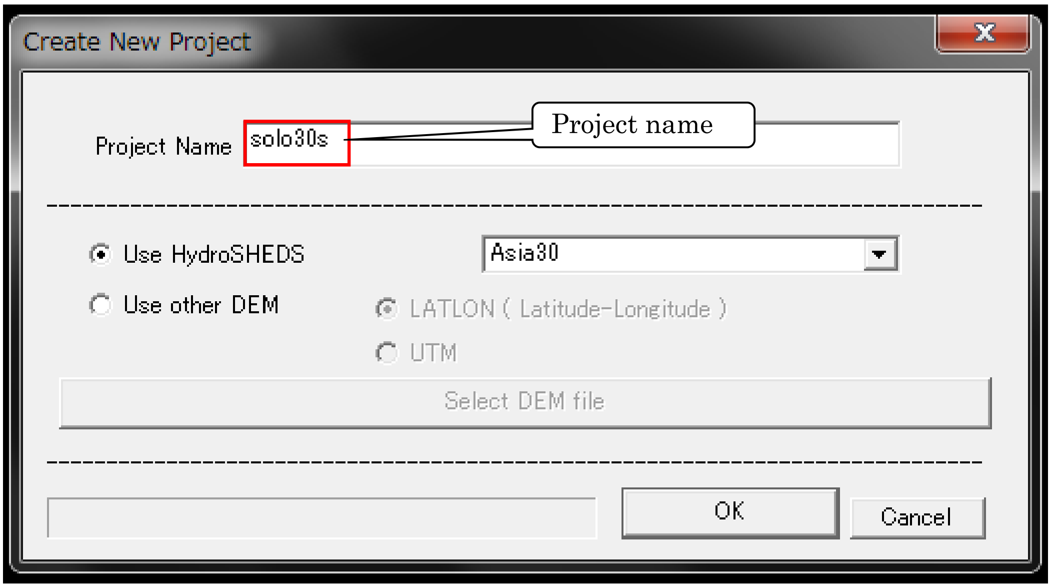
Preparing Input Topography Data

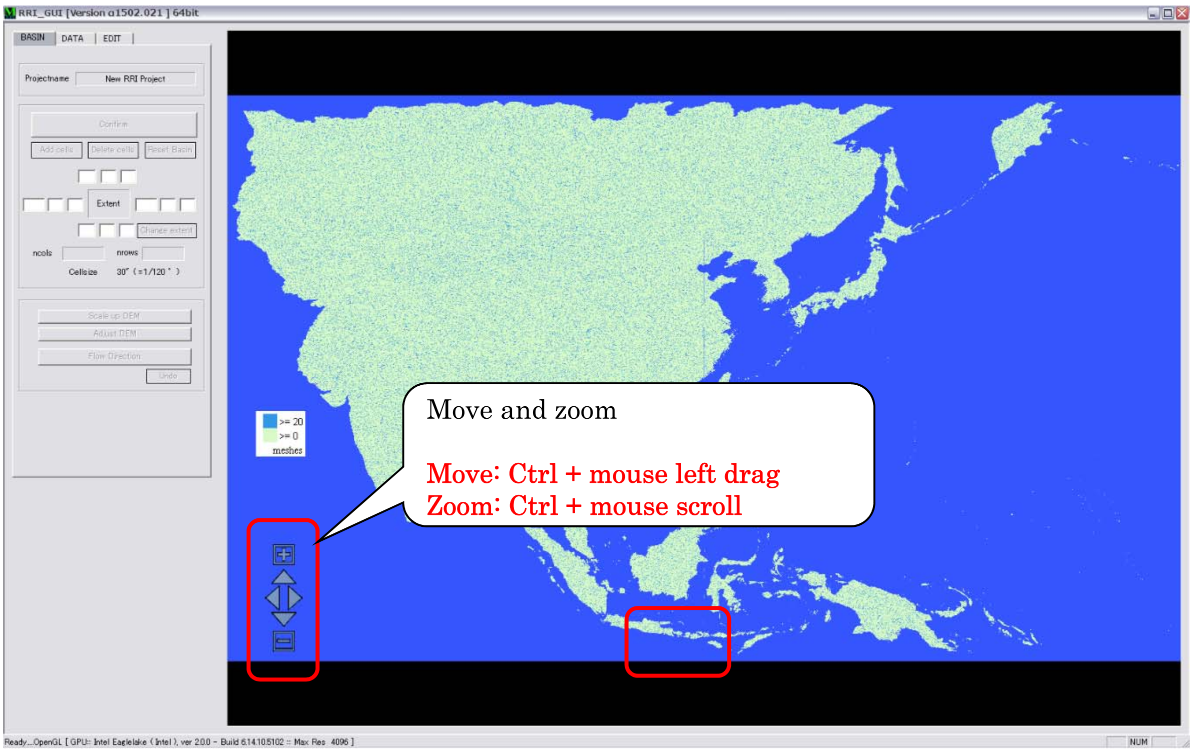
The first screen of the “RRI_BUILDER_64.exe” is to choose “New Project” or “Load Project”.



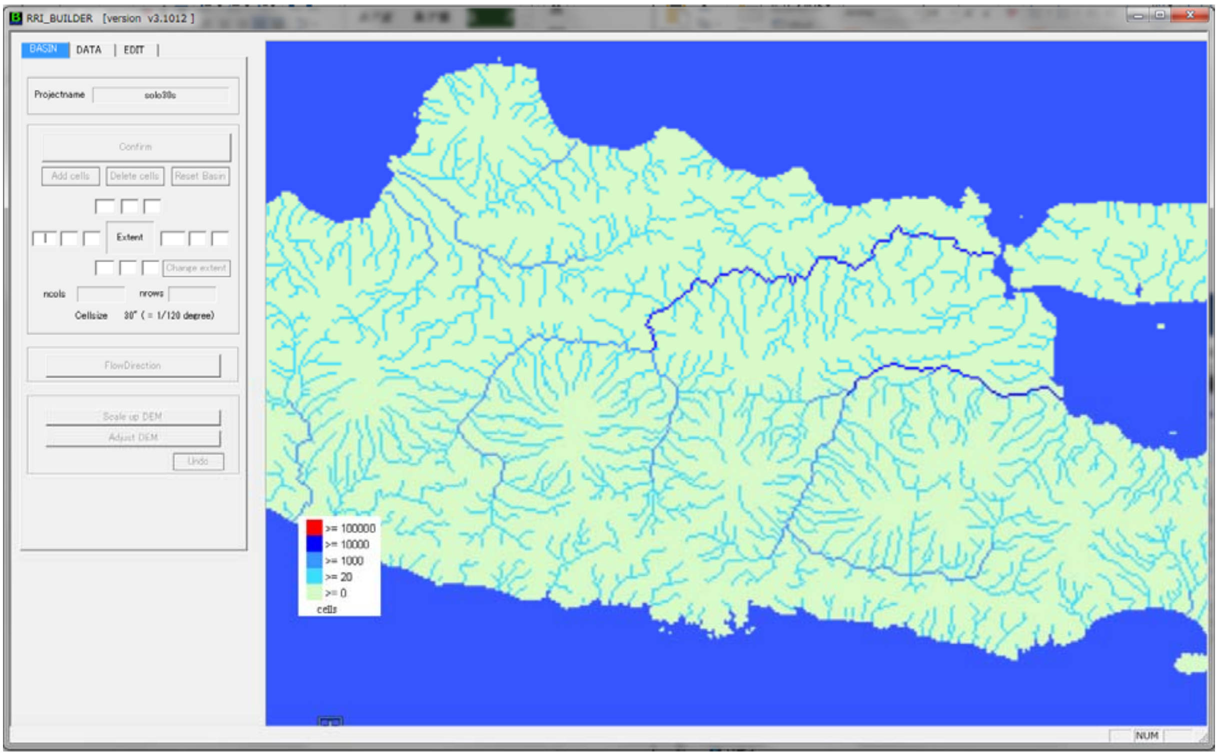
Select “New Project” in this exercise.

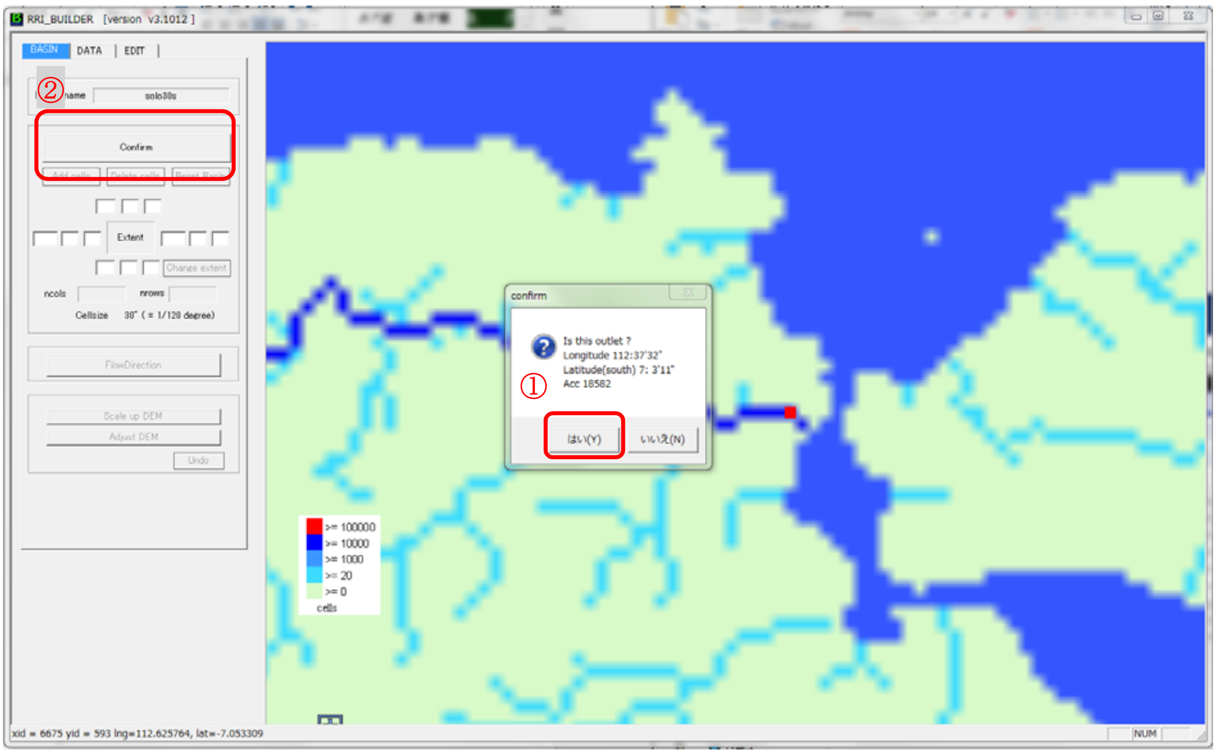
Type in a new project name (e.g. “solo30s”) with the selections of “Use HydroSHEDS” and “Asia30”, then click “OK”.



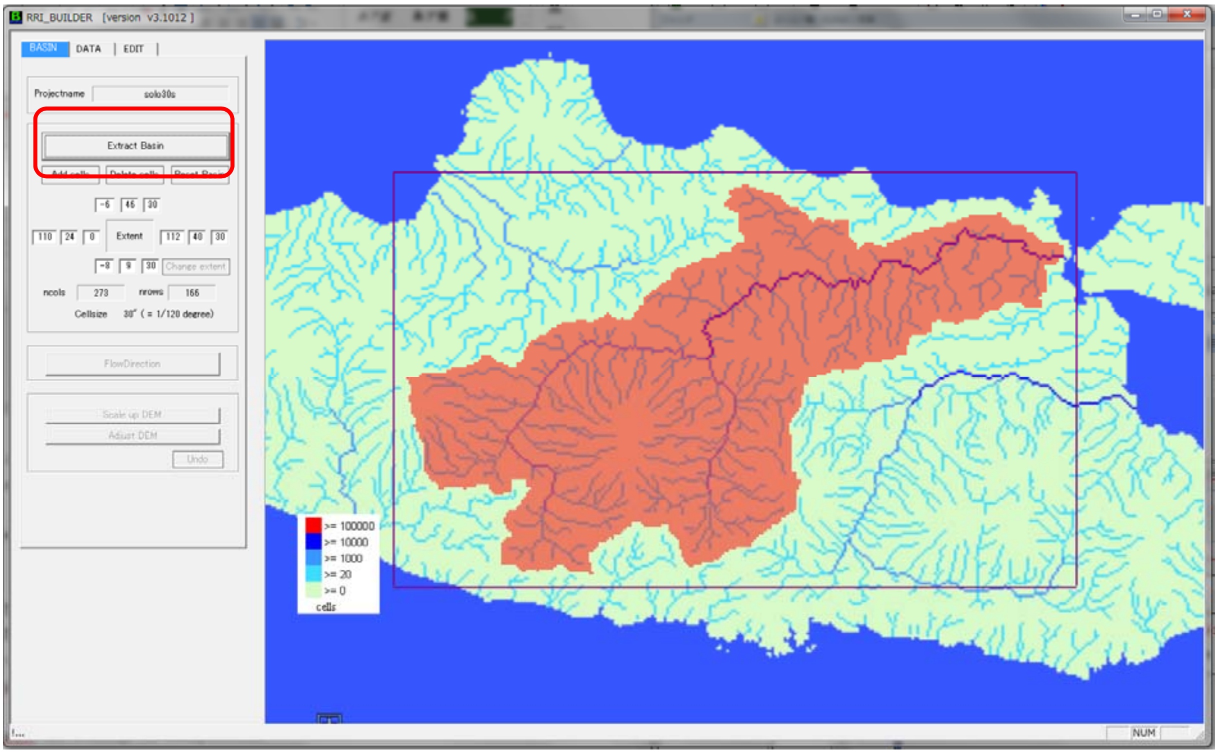


Zoom into Java Island in Indonesia





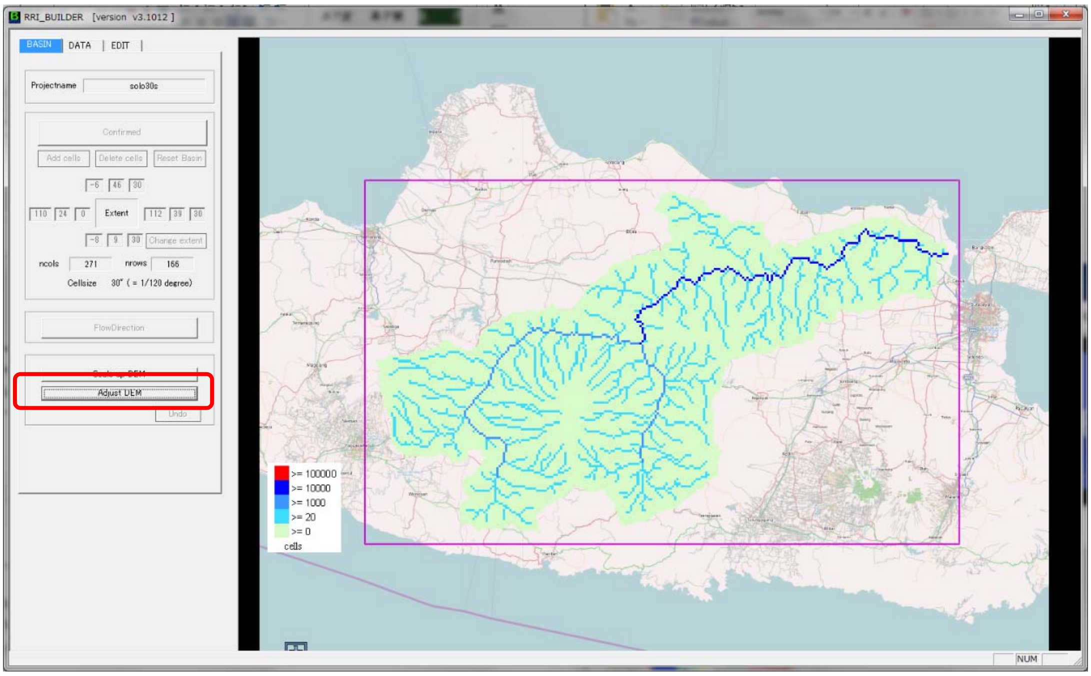
After zoom into the outlet area of the Solo River basin, click a pixel along the main river near the river mouth (not necessary to be exactly the same as the above example). Then choose “Yes” on the window and “Confirm” on the left panel.



Click “Extract Basin” after you confirm the area of the basin.

(If not satisfactory, click “Reset Basin” and retry it.)

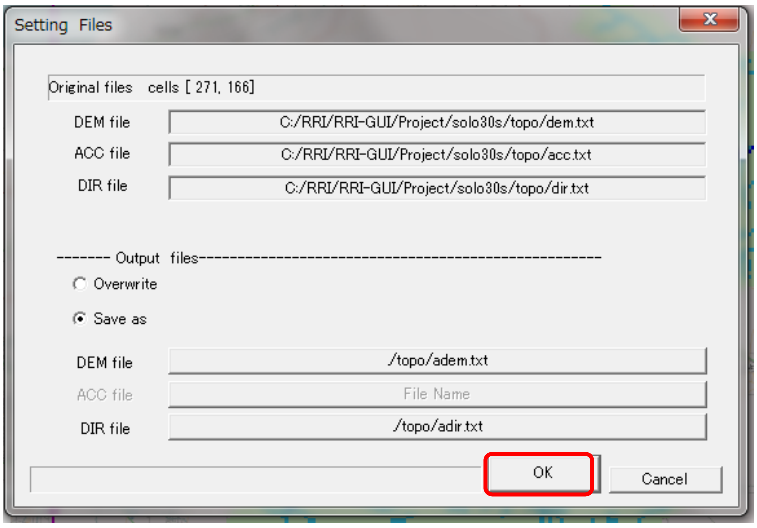
If the background map is available, the following extracted basin will be displayed. (Even the background image is not shown for some reasons, it is essentially no problem for the following simulation).



(Optional)

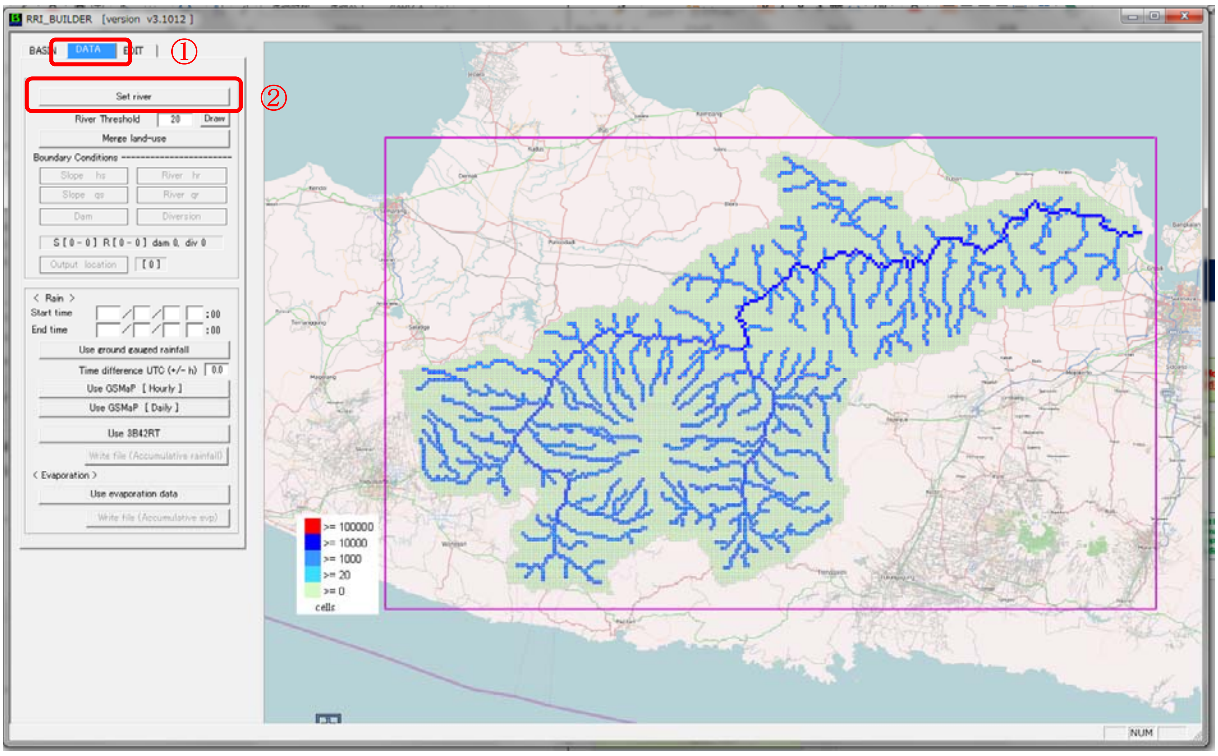
The step of "Scale up DEM" is an optional. Use this option in case you want to scale up the DEM for example changing the model resolution from 30 second to 60 seconds.

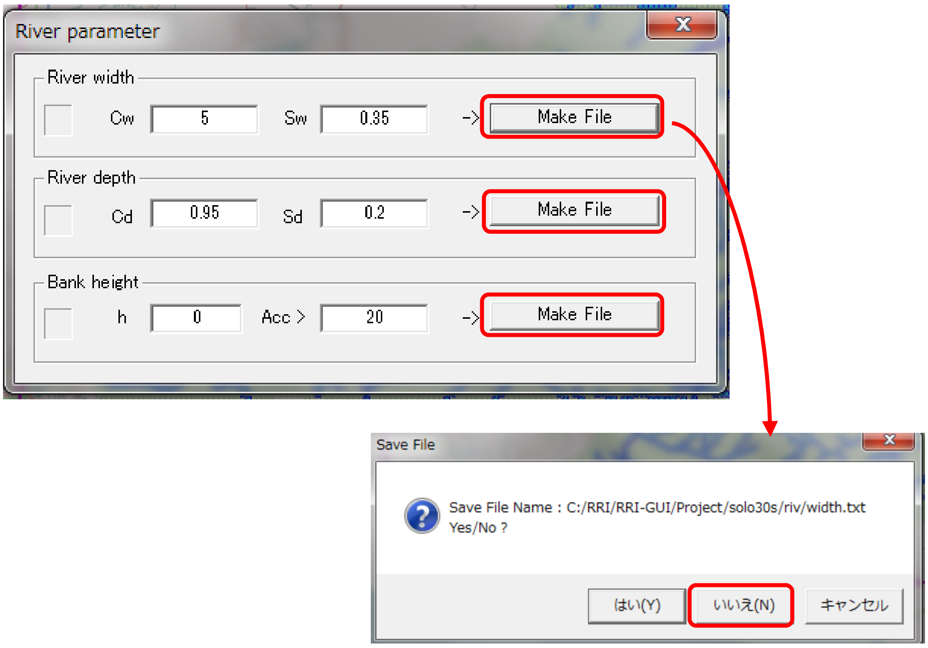
The next step is to execute "AdjustDEM". This procedure is always necessary for the stable simulation.



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".

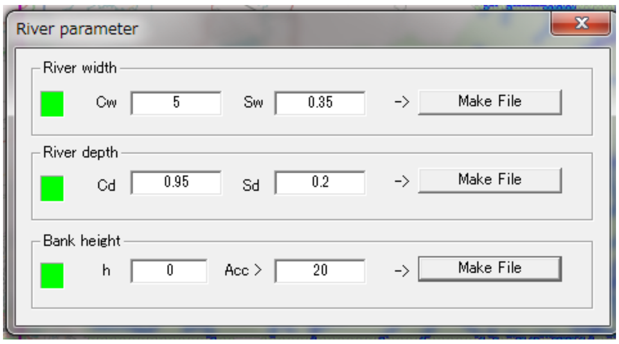




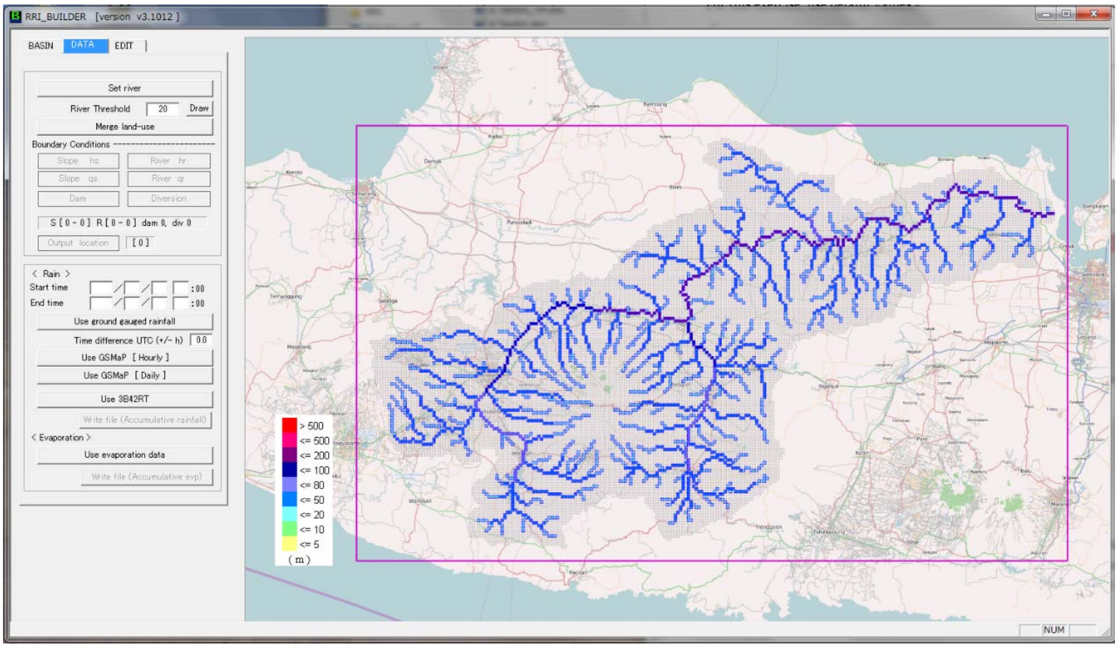
Click all the three “Make File” on River parameter setting.

These values are the parameters to determine the cross sections based on the equations.

For this exercise, use default values.



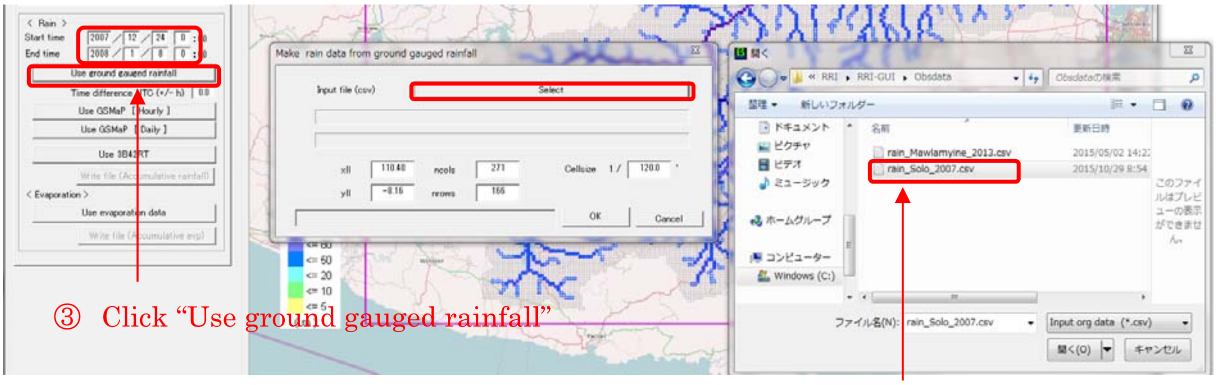
After confirming the three green signs, close this window.



1) 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

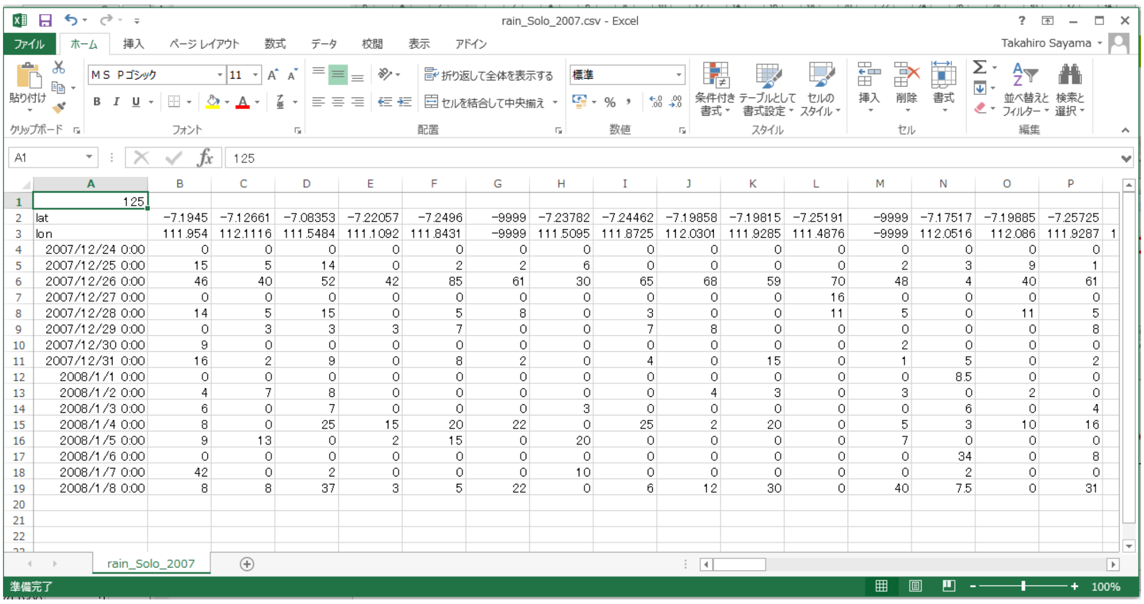


③ Click “Use ground gauged rainfall”

② Click “Select” to find a input rainfall file

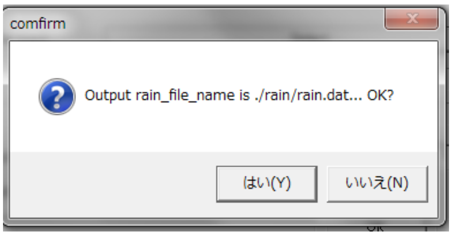
(In this excercise, “RRI-GUI/Obsdata/rain_Solo_2007.csv”)

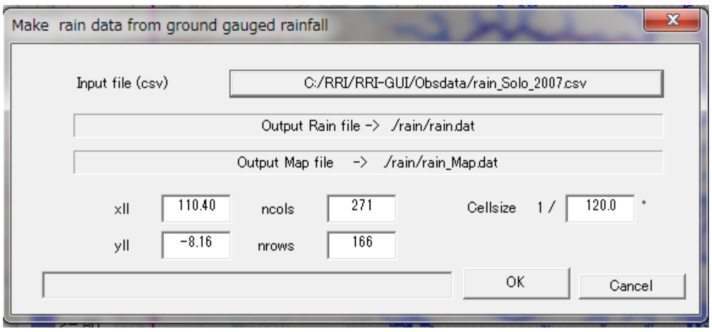
An input rainfall file must be the following format saved as csv. The file can be prepared by a text editor or Excel (saved as csv).



	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".

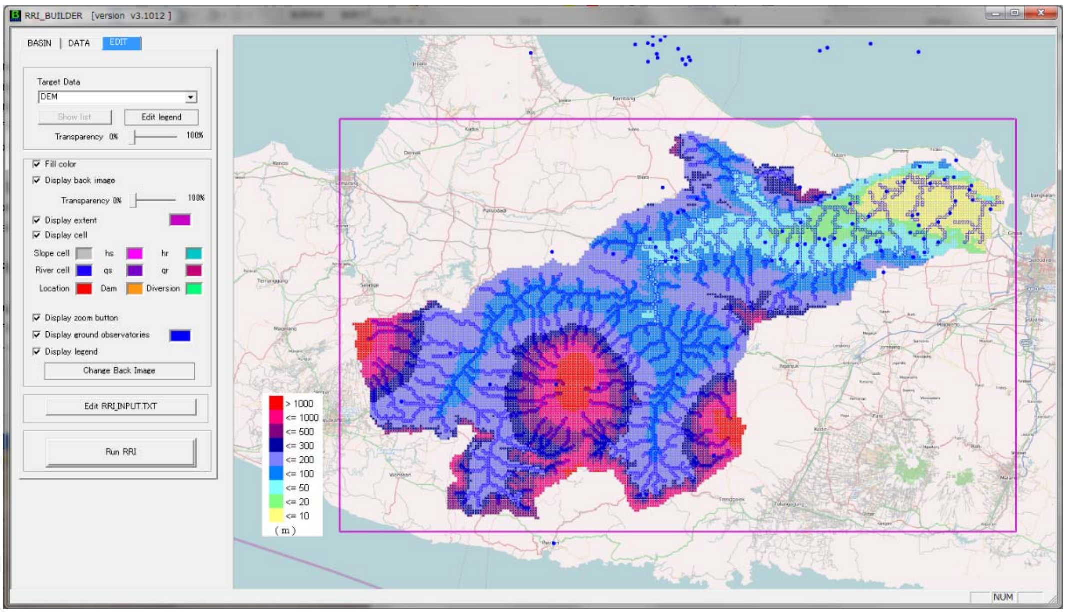


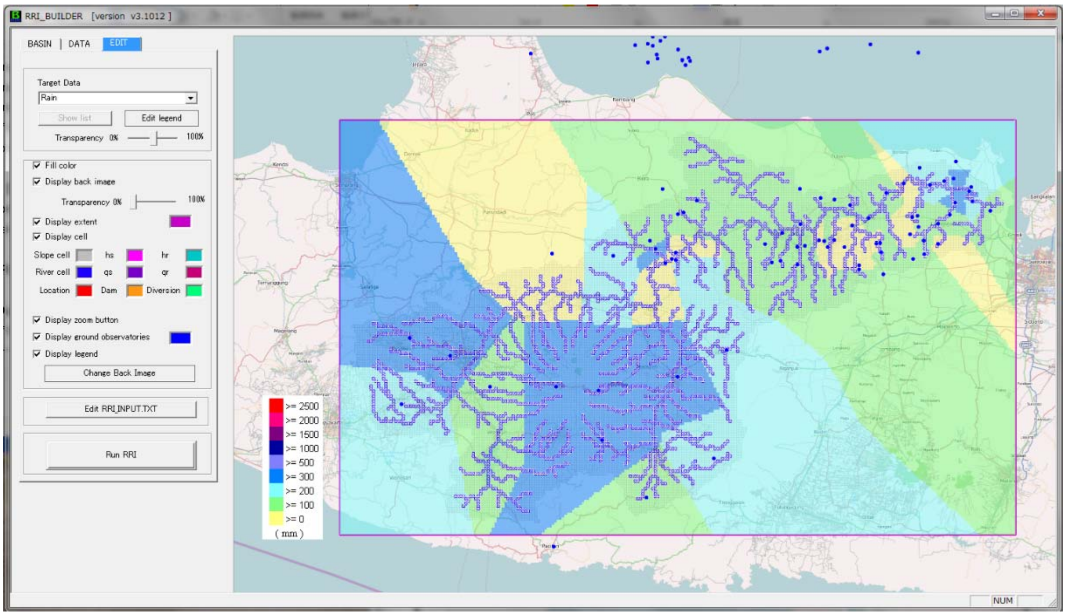


After selecting the input csv file, please choose "Yes" on the confirmation window then click "OK" with the default setting of the creating rainfall distribution file.

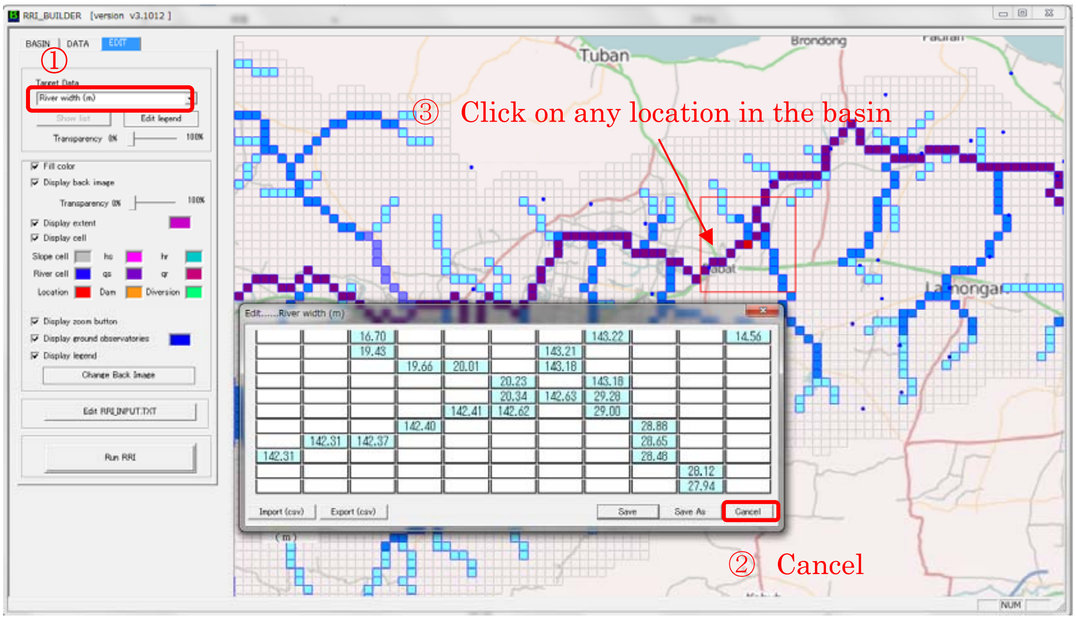
2) Running RRI Model

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.

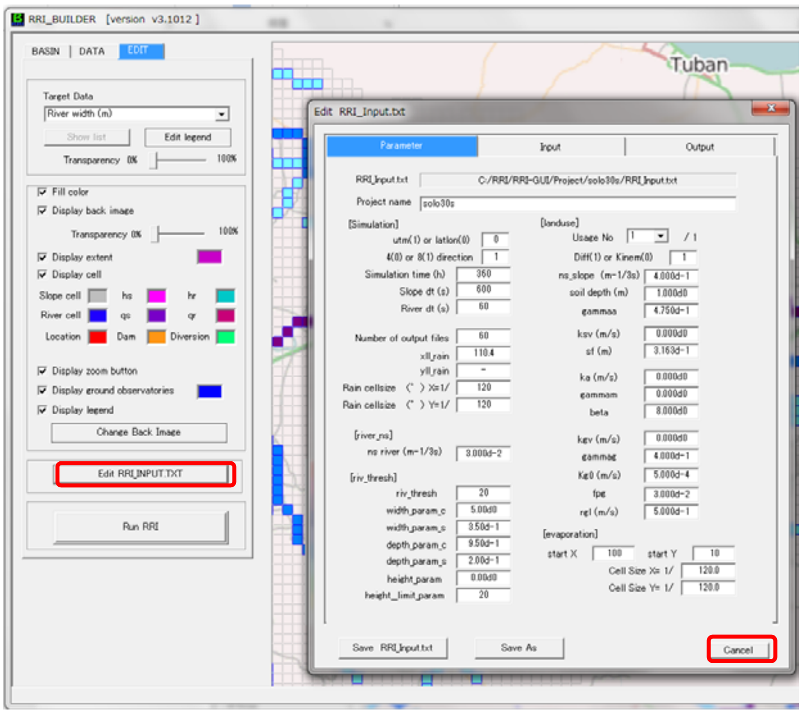




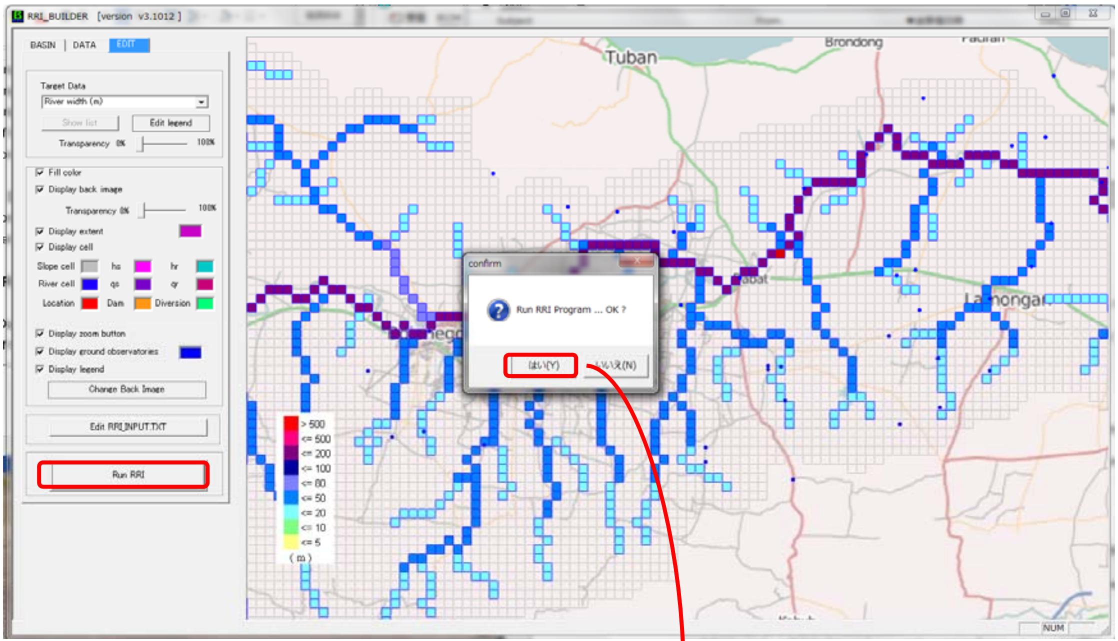
These distribution files except for the cumulative rainfall, can be edited on the window. For example you can choose river width and select any area inside the basin to display the following image. (For this exercise, no need to change the values.)

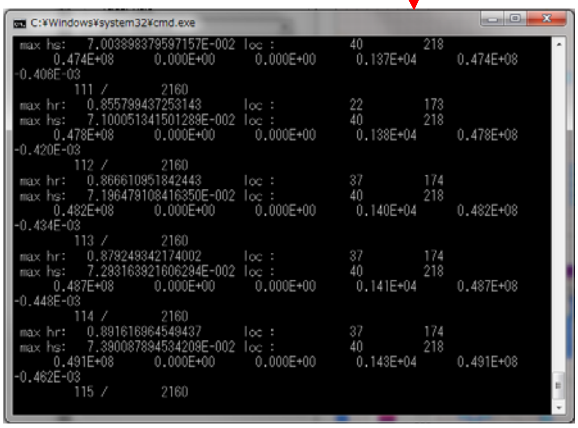


In addition, you find parameter and other input file settings if you click "Edit RRI_INPUT.TXT". The editting the values will be reflected to the RRI_Input.txt file, which is the control file of the RRI model. (For this exercise, no need to change the values.)



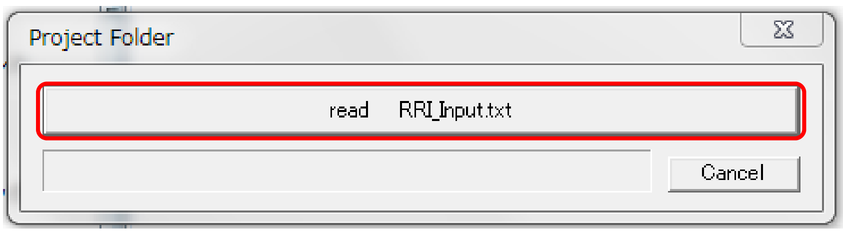
Finally, click "Run RRI" and "OK" to start the simulation.



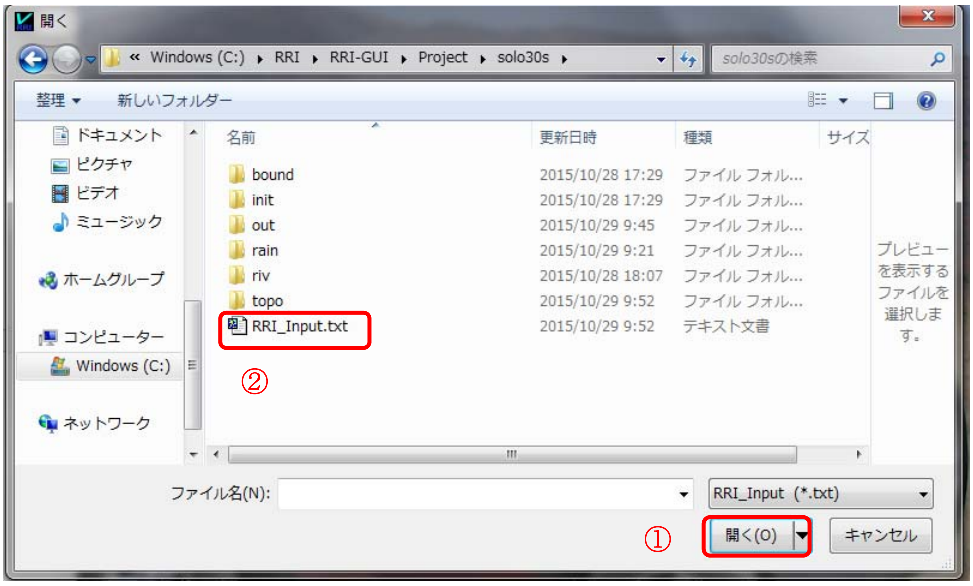


3. Visualizing results with RRI_VIEWER

Execute “RRI_VIEWER_64.exe” (or _32.exe for a 32 bit machine).

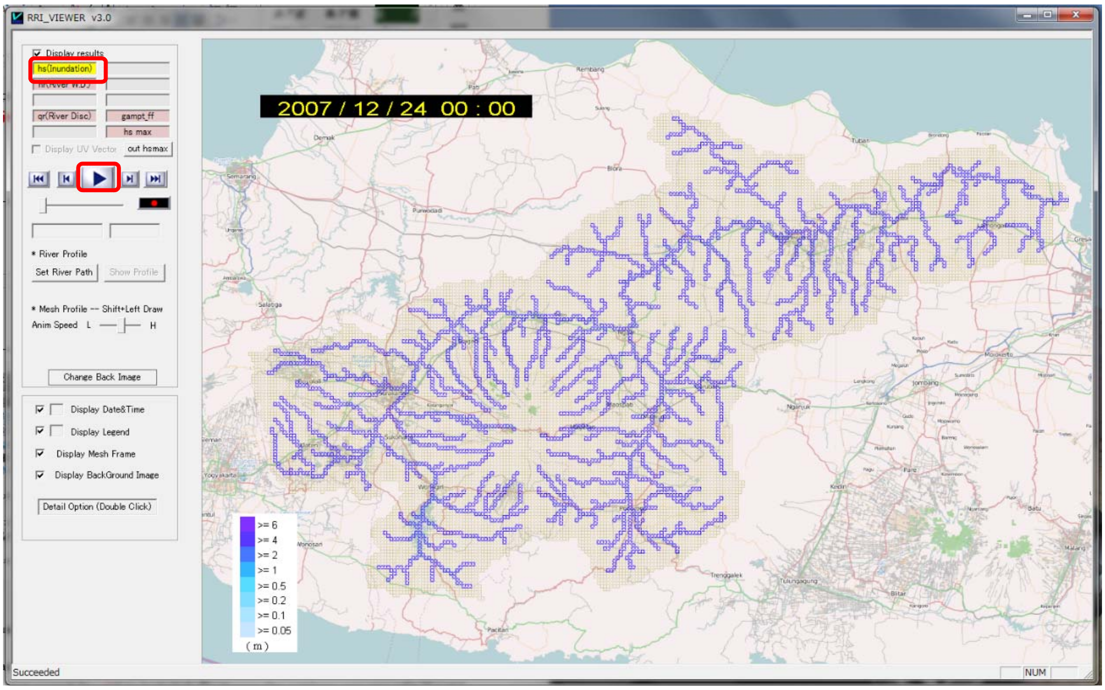


Read RRI_Input.txt file prepared in the previous subsection. In this exercise, find RRI-GUI/Project/solo30s

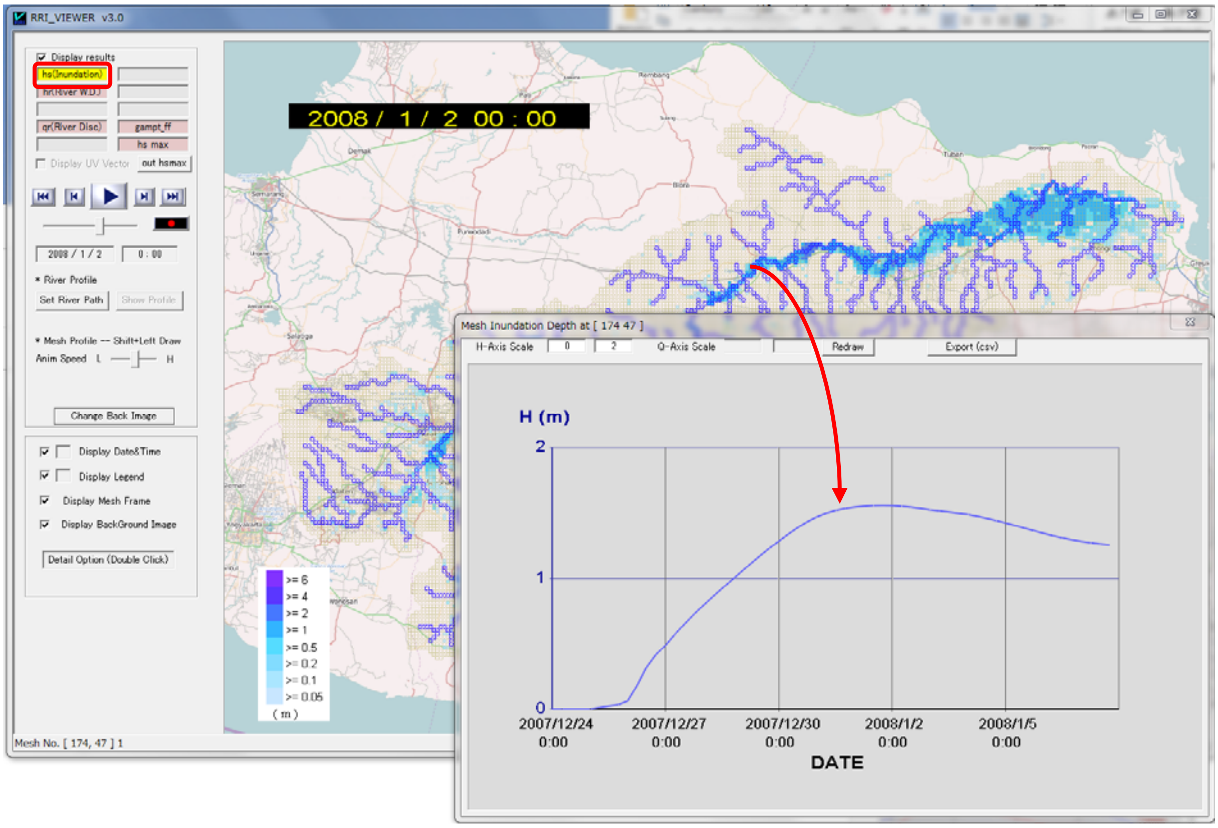


1) Visualize flood inundation

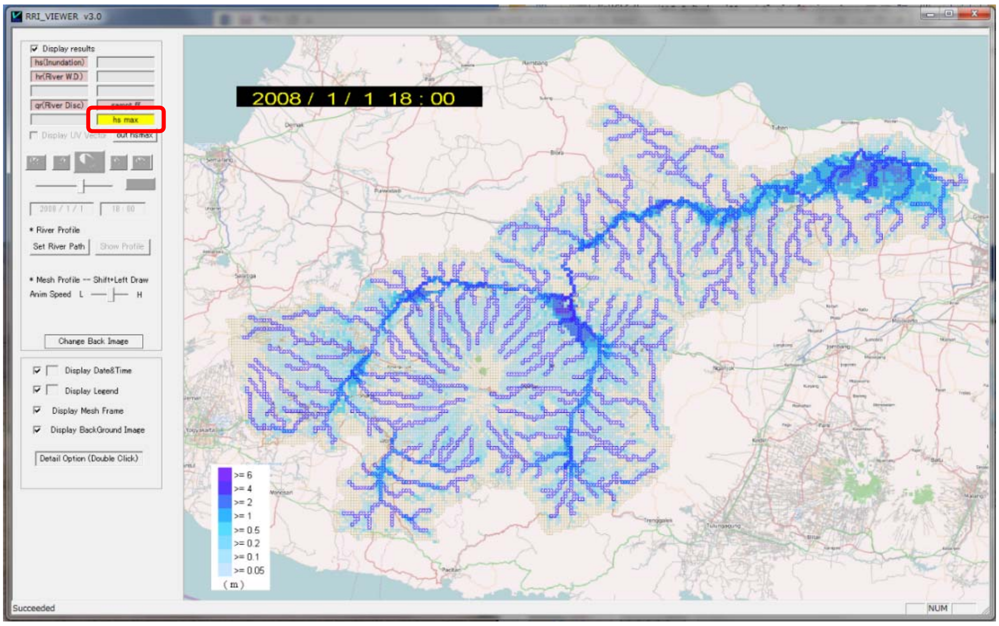
On the displayed map image, one can use CTRL and left drag to move the map and also CTRL and mouse scroll to zoom in and out. This operation is the same as RRI_BUILDER_64.exe



To display the animation of flood inundation depth distribution, please select inundation on the top left panel and click the start button.

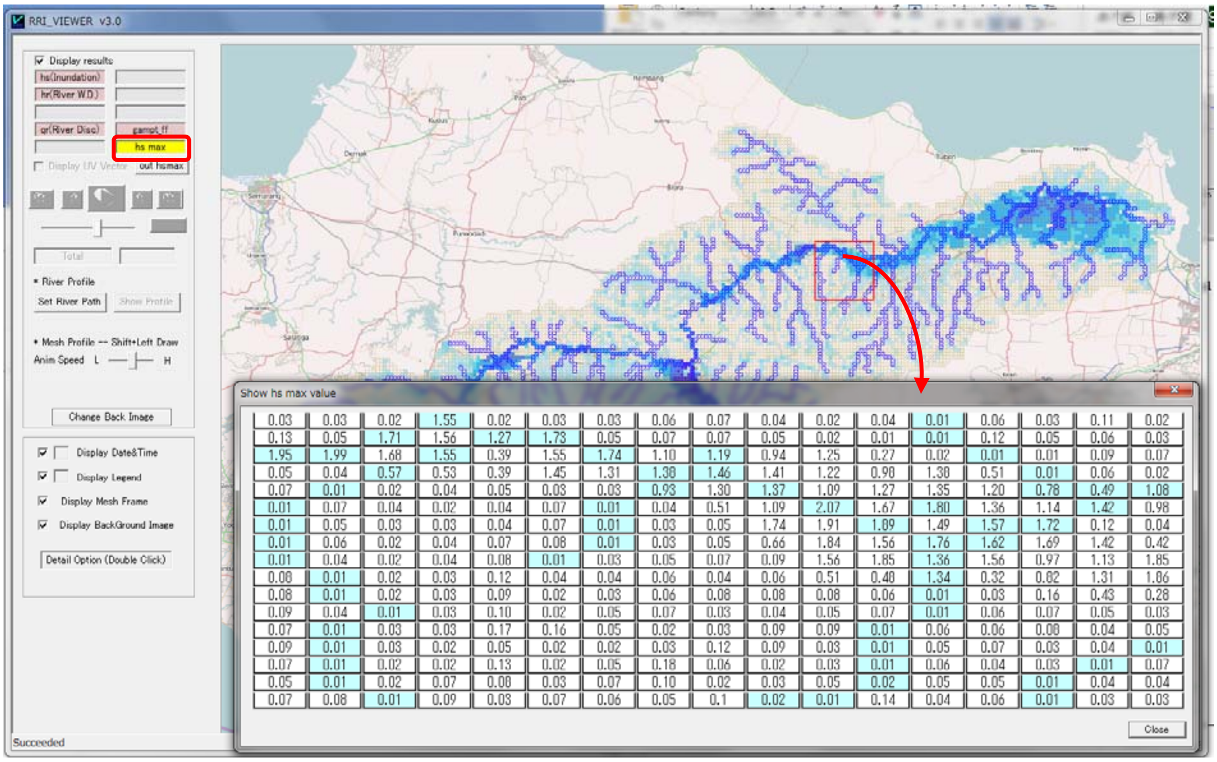


After stopping the animation, try to click any grid cell inside a basin to visualize the time seris of flood inundation depths.

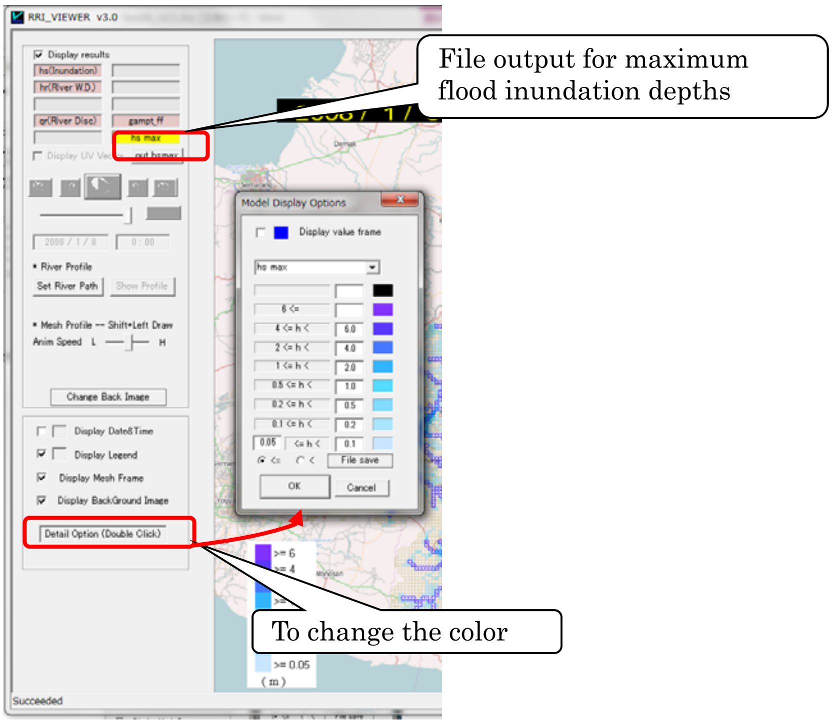


Then display the maximum inundation depth distribution by choosing hs max.

For the maximum inundation depths, one can check values by selecting a area on the map.

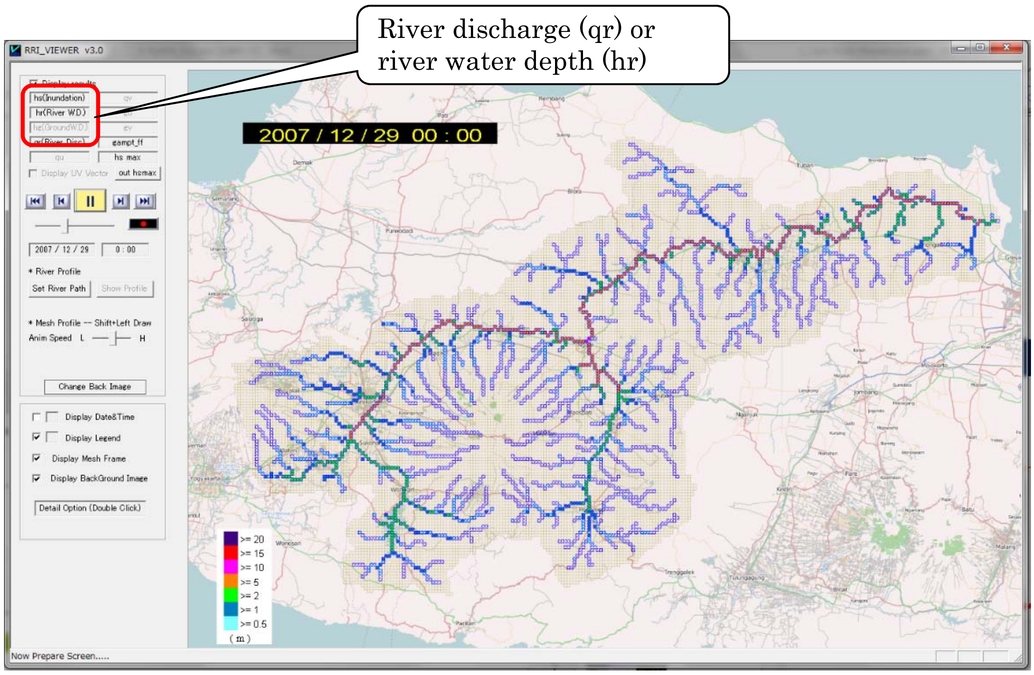


(Optional)

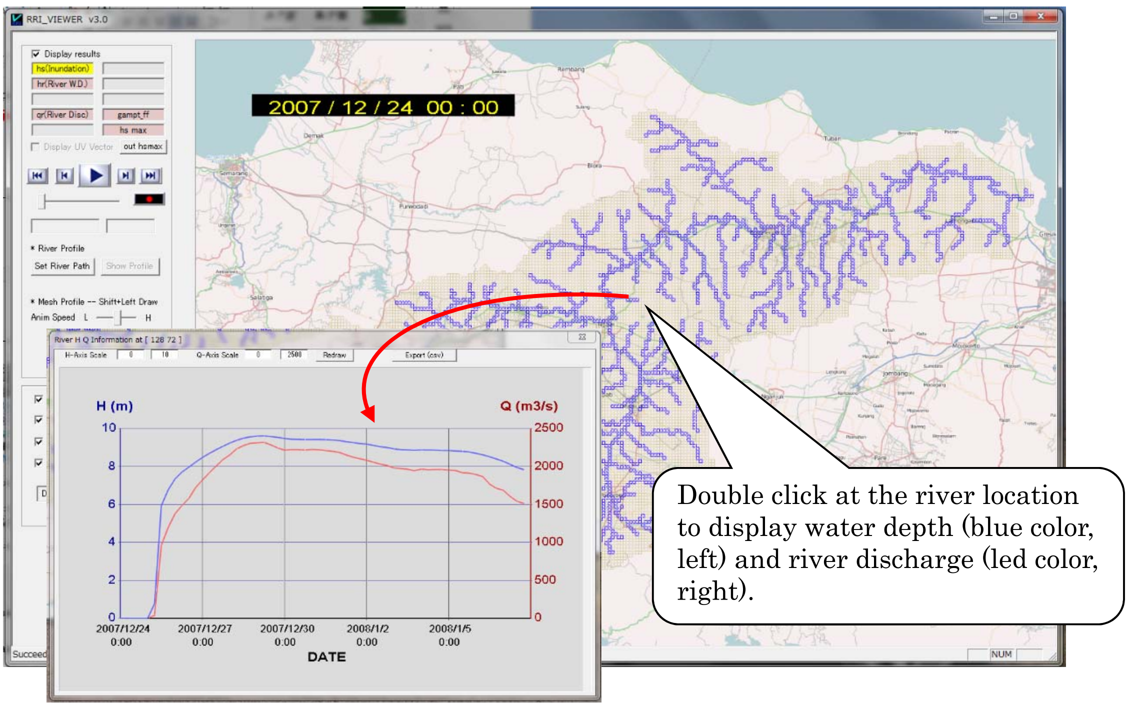


2) Visualize river discharge and water depth

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.

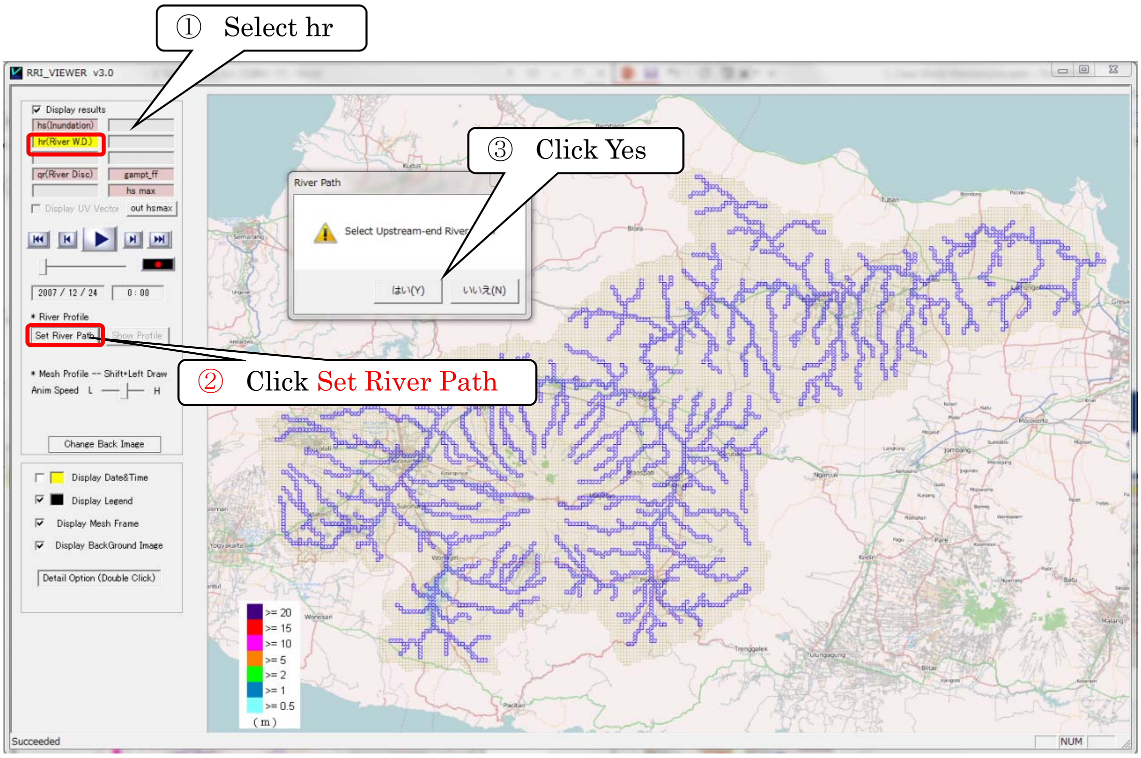


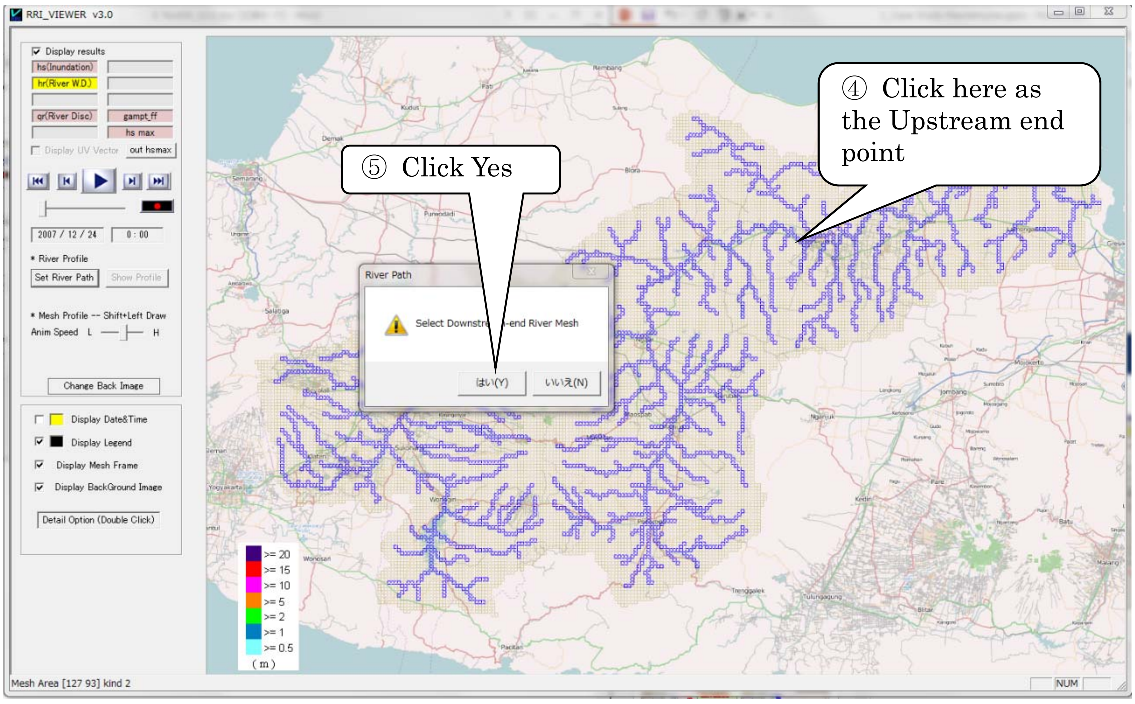
After stopping the animation, try to click any river grid-cell to visualize the time serises of river discharge (i.e. hydrograph) and river water depth.

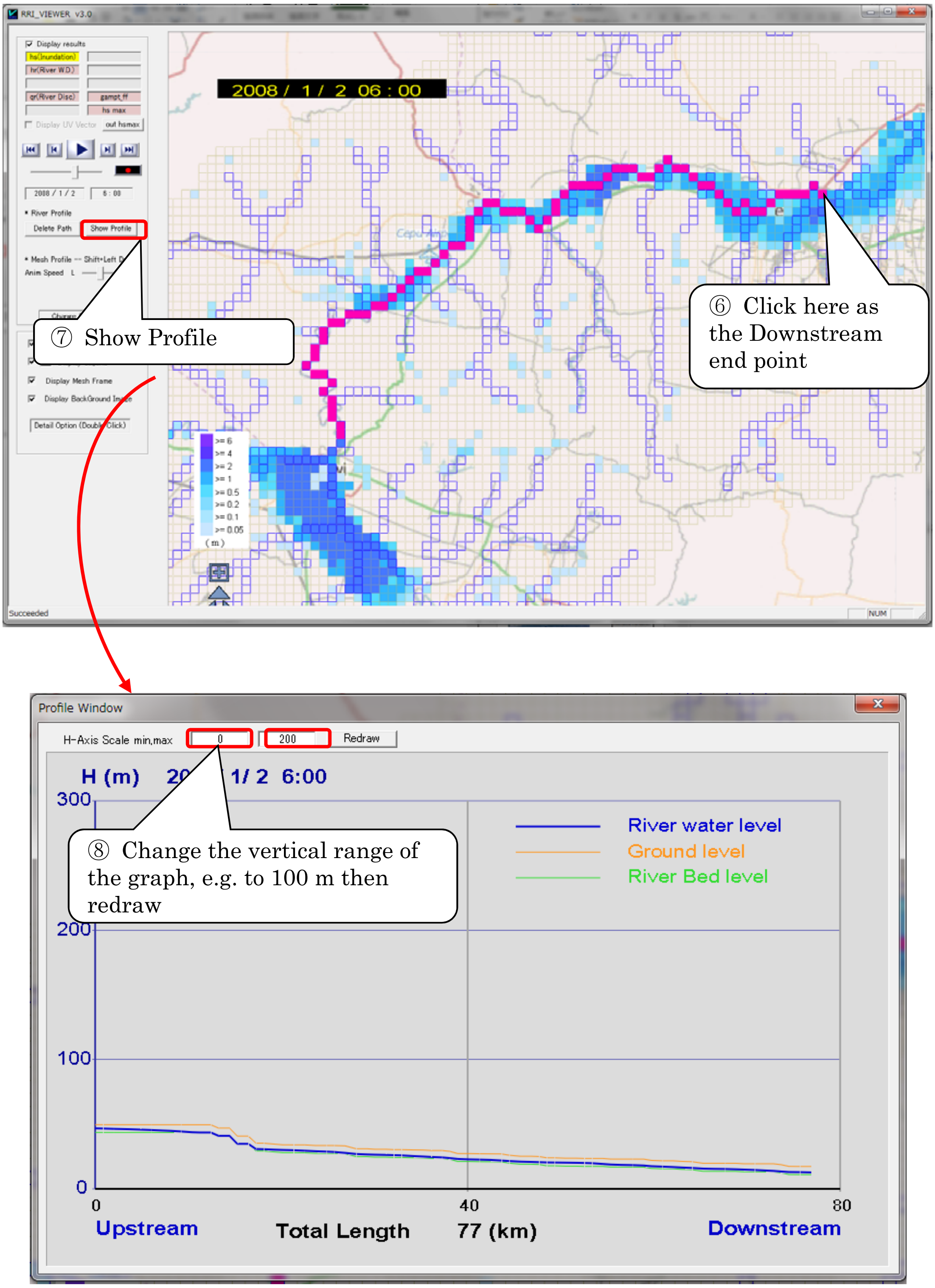


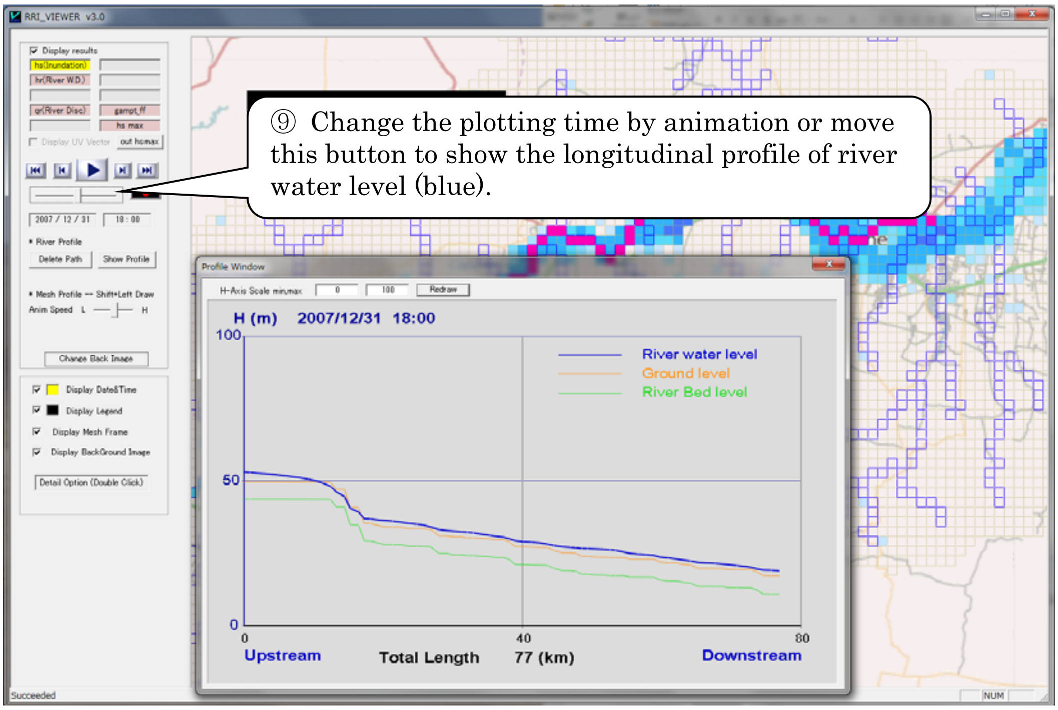
3) Visualize the longitudinal profile of river water level

To visualize the longitudinal profile of river water level, first select hr (River WD) and click “Set River Path” on the left pannel.





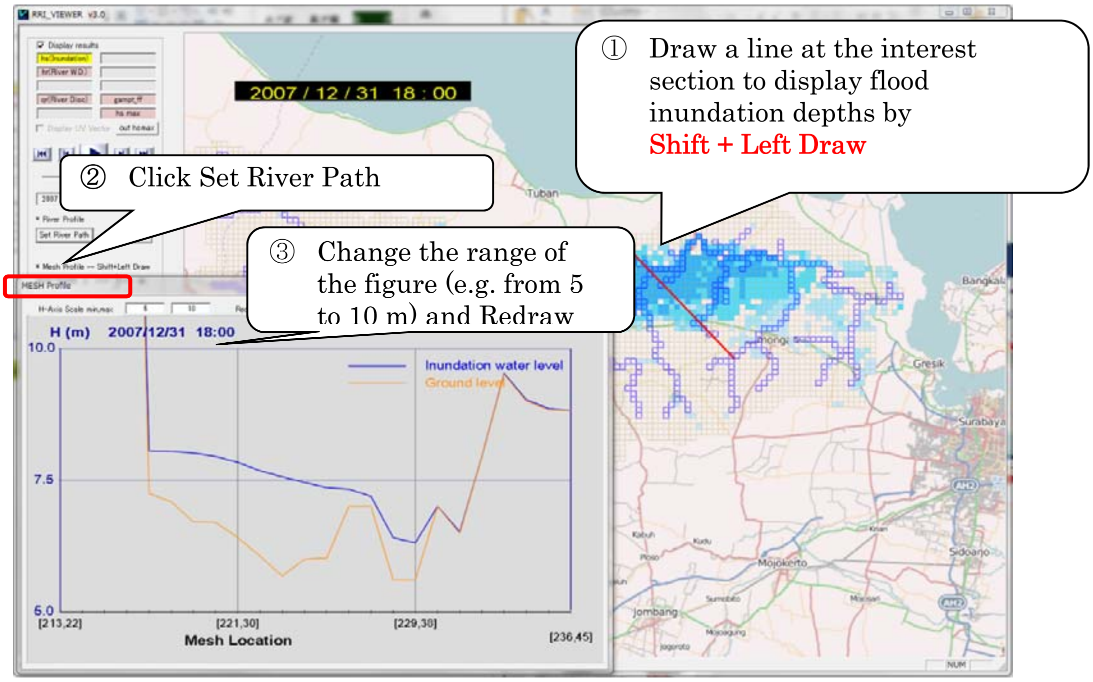

RRI_VIEWER v3.0
2008 / 1 / 2 06 : 00
⑦ Show Profile
⑥ Click here as the Downstream end point
Display Mesh Frame
Display BackGround Image
Succeeded
Profile Window
H-Axis Scale min,max
0
200
Redraw
H (m)
1/ 2 6:00
⑧ Change the vertical range of the graph, e.g. to 100 m then redraw
River water level
Ground 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.

4) 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".



Case Study: Climate change impact assessment in the Chao Phrya River basin

1) Background

Assessing the impact of climate change on large-scale flooding is one of the major concerns for water management. This section presents a method to evaluate the impact of climate change by using GCM output and the RRI model. The GCM used in this study is MRI-AGCM3.2S and 3.2H, the former one is the finest spatial resolution GCM in the world (20 km), while the latter one (60 km) is used to provide ensemble information with different cumulous schemes and sea surface temperature clusters to assess the uncertainty. In particular, this study focuses on flood inundation volumes in the Chao Phraya River basin in Thailand to evaluate how the frequency of devastating flooding like the one in 2011 will change in future under SRES-A1B scenario (2075-2099) (Sayama *et al.*, 2015c).

2) Study site

The case study site is the Chao Phraya River basin located in the northern part of Thailand. The basin area is approximately 160,000 km^2, which include the basins of four main tributaries namely Ping, Wang, Yom and Nan. The four rivers meet at the central location called Nakhon Sawan. The upstream and downstream of Nakhon Sawan is a widespread lowland area, whose longitudinal gradient is approximately 1/12,000. In the basin, there are two major dams: Bhumibol dam (13.5 billion m^3, operated since 1964) in the Ping River and Sirikit dam (9.5 billion m^3, operated since 1974) in the Nan River. The dam reservoirs are primarily used for water resources and also power generation. During the floods in 2011, the Bhumibol and Sirikit dam reservoirs store flood water. The storages of the two dam reservoirs were about 57 % and 63 % in the beginning of July, and they became almost full by the beginning of October.

The 2011 floods caused levee breaches and overtopping mainly on the left side of the main Chao Phraya River (between Nakhon Sawan and Ayutthaya). The floodwaters submerged seven industrial parks near Ayutthaya and then the northern and western parts of Bangkok. The central business district of Bangkok City barely escaped from severe flooding after emergency embankment and drainage from the canals. As a result, 813 people were killed or missing and the economic damage and losses were 46.5 billion USD.

3) Model application

The RRI model was applied to the entire Chao Phraya River basin. As the model was being set up, DEM, flow direction and flow accumulation were delineated from HydroSHEDS 30 sec and upscaled to 60 sec (approximately 2 km) resolution. Note that the RRI model uses flow direction and accumulation only to determine river channel locations but not for flood routing since the flow direction varies depending on local hydraulic gradients. River depths and widths were approximated by a non-liner equation with upstream contributing area as the explanatory variable. The parameters of the equation were estimated from regression analysis with cross 121 section data.

For the model calibration and validation as well as the following sensitivity analysis, we used a gauged rainfall observed by Royal Irrigation Department (RID) and Thai Meteorological Department (TMD) in Thailand. As for the potential evapotranspiration, we used Penman-Monthieth equation based on European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis. The ECOCLIMAP dataset, provided by Meteo France, was also used to identify seasonal and spatial variations of leaf area index. The periods of model calibration and validation are 1980-1999 and 2000-2011. We manually calibrated the parameter sets mainly focusing on the monthly discharge at Nakhon Sawan. In addition to the discharge, the model performance was also tested also in terms of flood inundation extents by comparing with remote sensing images. See Sayama et al. 2015a for more detailed model calibration and validation.

4) Results

Figure (A) shows simulated and observed monthly discharge at Nakhon Sawan (C2). In this calibration, the effect of the dam reservoirs were removed from the observed C2 discharge by adding inflow and subtracting outflow from the two major dam reservoirs to the observed monthly discharge. The result shows that the model can reproduce the C2 monthly river discharge fairly well for both calibration (NSE = 0.89) and validation (NSE = 0.89) periods. For the other upstream locations also, we evaluated the simulated monthly river discharge for the two periods, the examples at N1 and P1 are shown in the figure.

Figure (B) shows the spatial distributions of flood inundation frequency. We calculated annual maximum flood inundation depths for each year in the present and future climate conditions, and then counted how many times the annual peak inundation depths exceeded 0.5 m for each model grid-cell. Some areas close to the main river show very high frequency (e.g. more than 15 times among 25 years) even for the present condition, while some other areas such as south western part of the basin show relatively clear increase in the frequency. The visualization of the change in flood inundation frequency help for water management considering climate change impact.

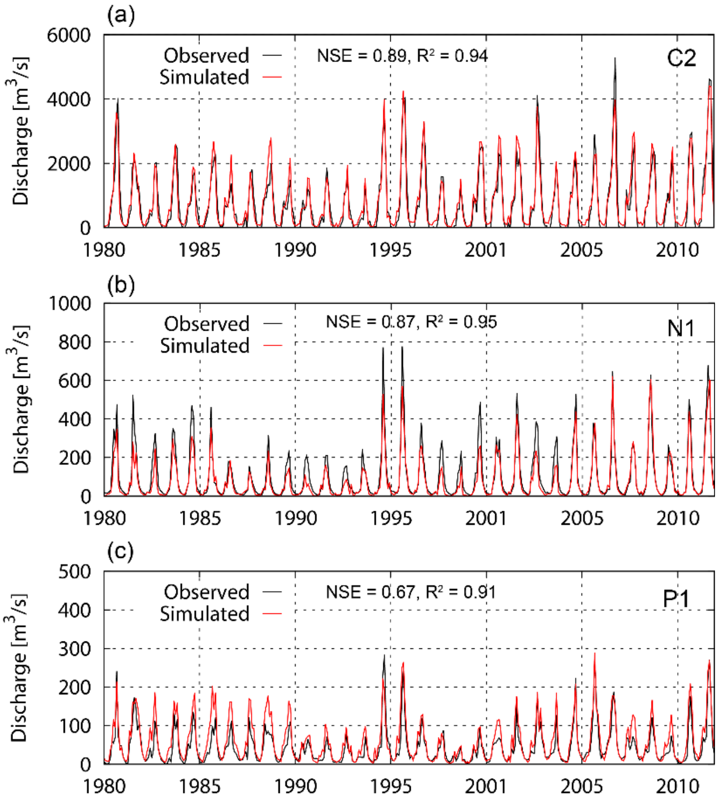


Figure (A) Model calibration (1980-1999) and validation (2000-2011) with monthly discharges at C2, N1 and P1

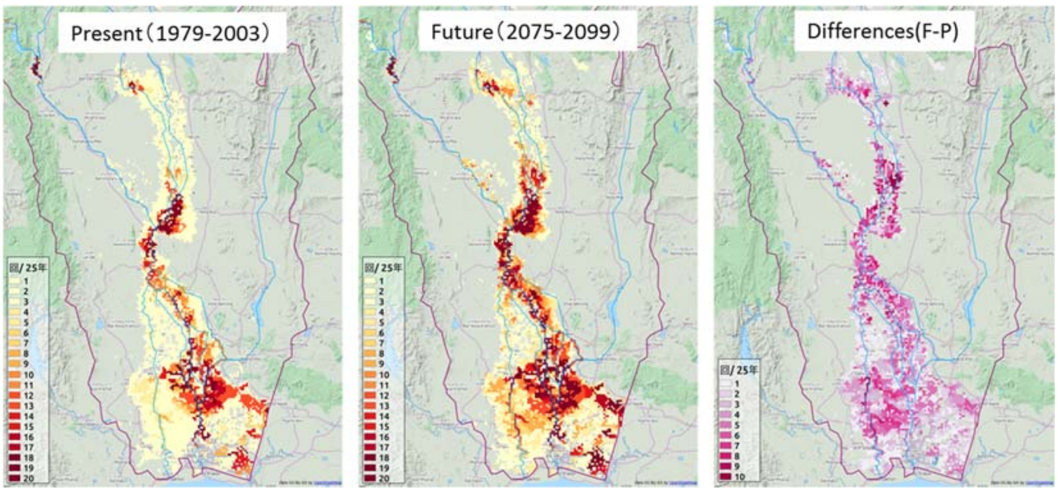


Figure (B) Frequency of estimated flood inundation per 25 years in the present climate (left), the future climate (mid) and their difference (right)

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