Republic of Fiji

PROJECT for Mainstreaming of Disaster Risk Reduction Project

Guideline on Flood Hazard / Risk Assessment

-Simplified Flood Simulation by RRI Model-

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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

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Chapter 1. Introduction

1.1 Introduction

Fiji is located in disaster prone area due to its geographical, geological and demographic conditions. Flood occurs almost every year due to cyclone and front. There is also a risk of tsunami due to earthquake frequently occurring in the surrounding ocean. In addition to these hazards, vulnerabilities brought about by living in small, reclusive and remote island countries increase the disaster risk in Fiji. According to the World Risk Index 2018 released by UN University, Fiji is the 10th high-risk country among 171 countries in the world.

Fiji has a certain level of capacity for disaster response based on its experience with past disasters by coordinating related agencies from national to local levels. Furthermore, some efforts have been taken already for mainstreaming DRR and promoting the pre-investment for DRR by developing the "Fiji National Disaster Risk Reduction Plan (NDRRP) 2018-2019" based on international framework such as the Sendai Framework.

However, there are several challenges in the institutional framework for the development of national and local DRR plans, and for the implementation of DRR projects, in the hazard assessment, etc.

Based on this situation, the followings from the "Sendai Framework for Disaster Risk Reduction / SFDRR" are very important in Fiji.

1) Understanding disaster risk

2) Strengthening disaster risk governance to manage disaster risk

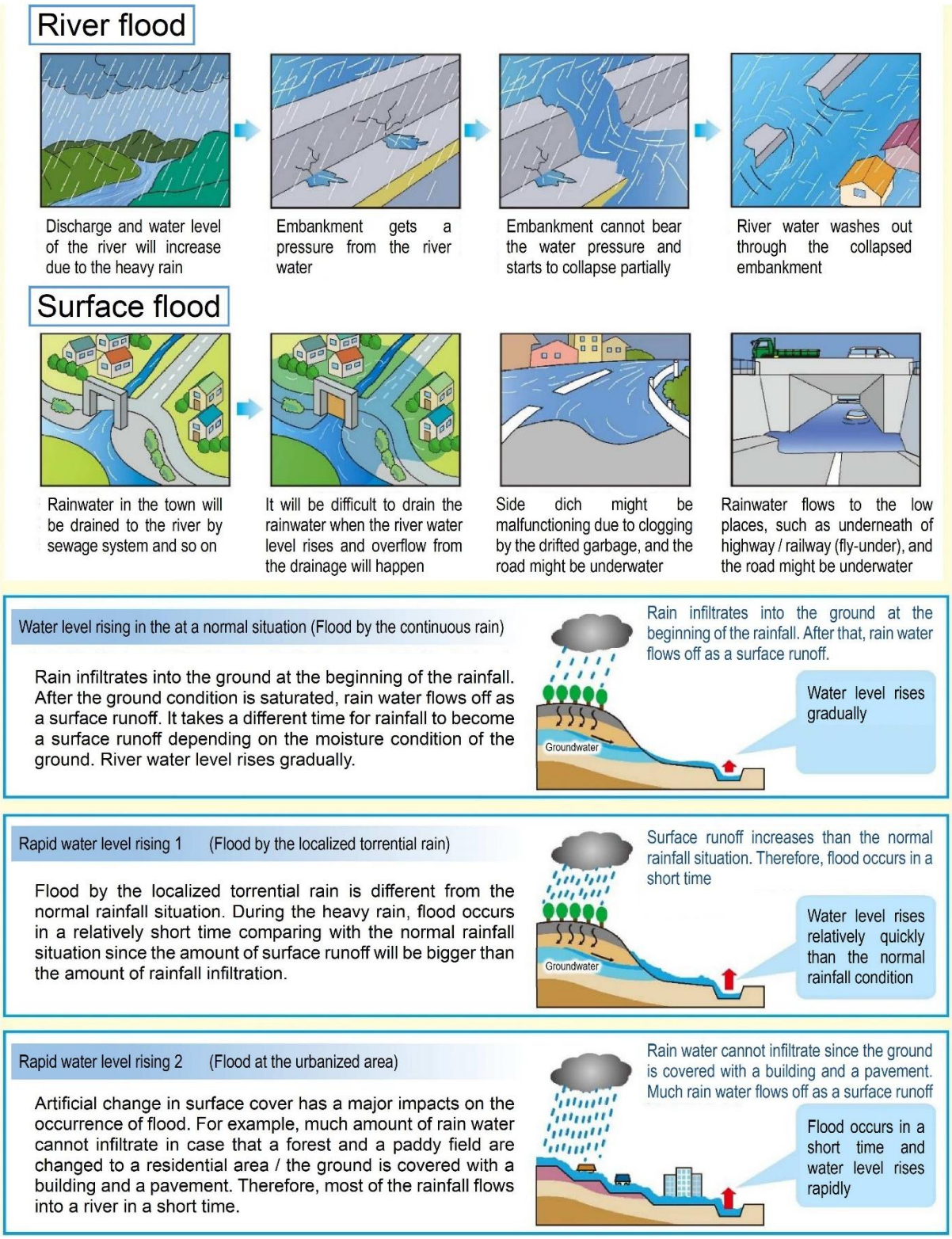
3) Investing in disaster risk reduction for resilience

4) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction

As mentioned above, it is necessary to clarify the flood hazards in order to understand the actual situation of the disasters and to implement appropriate measures against floods that are causing great damage.

1.2 Outbreak Mechanism of Floods

Flood is mainly classified as "River flood (fluvial)" and "Surface flood (pluvial)". Outbreak mechanism of each type of flood is illustrated in Figure 1 below.



Source: http://www.city.ohtawara.tochigi.jp/docs/2013082766069/files/resources_content_6525_20100331-123848.pdf

Figure 1-1 Schematic diagram of outbreak mechanism of flood

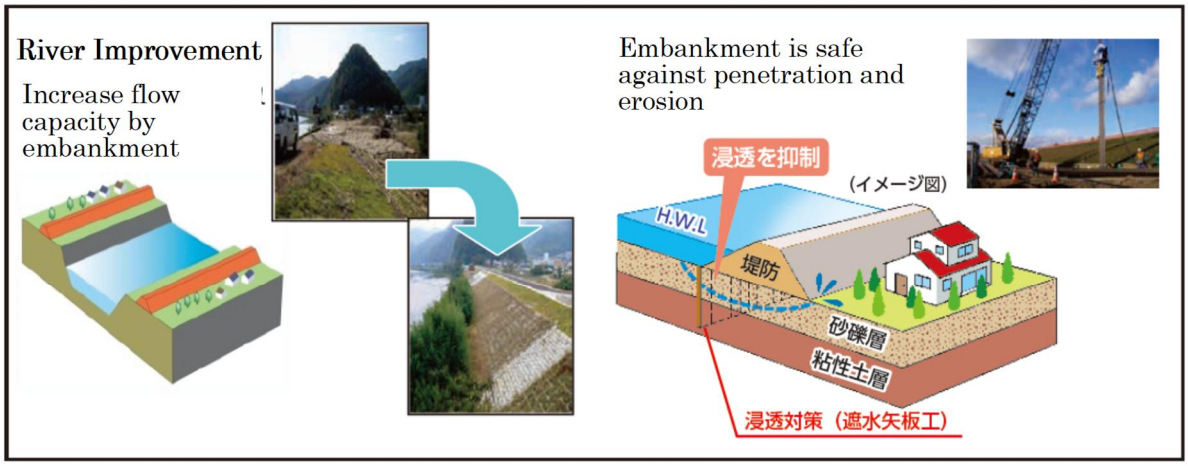
1.3 Risk Reduction through Countermeasures

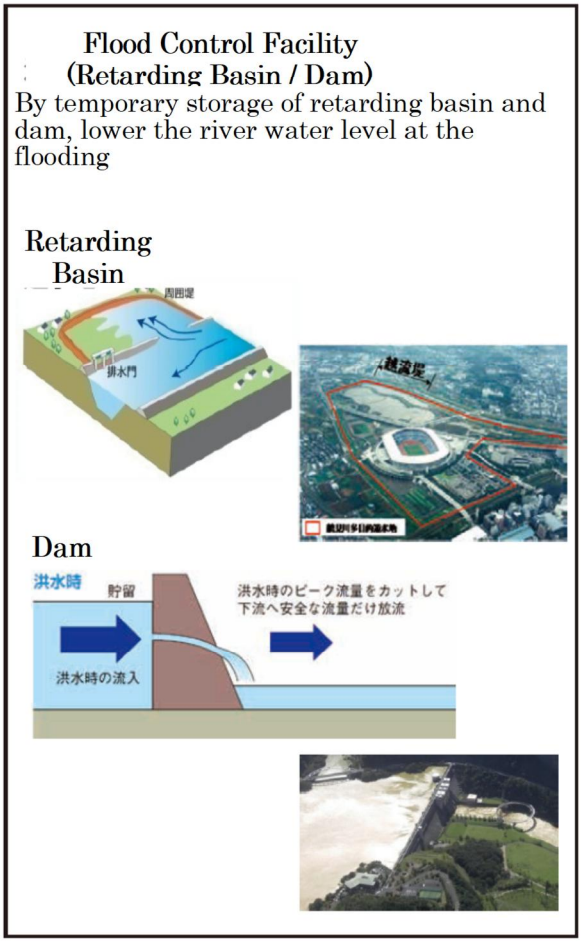
There are various measures against floods, one is how to improve the river itself, and the other is to implement measures across the basin.

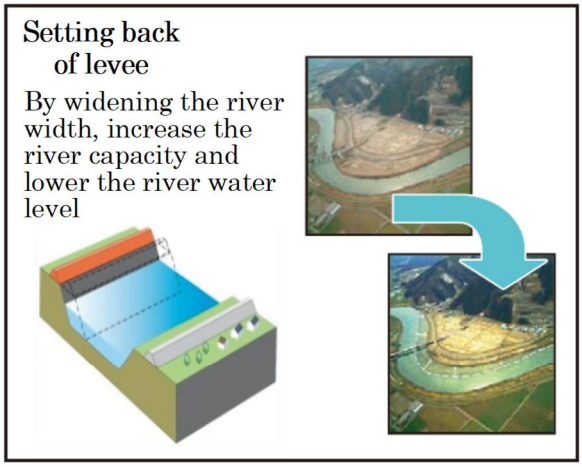
1.3.1 Measures to prevent floods

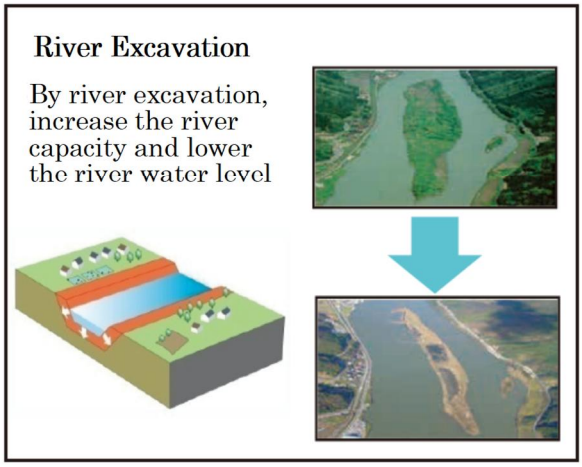
The following measures will be taken to ensure that the flood can flow safely.

- Increase the flood flow cross section
- Embankment construction to make flood run down safely
- Construction of a flood control facility to temporarily store floods and reduce flow to rivers





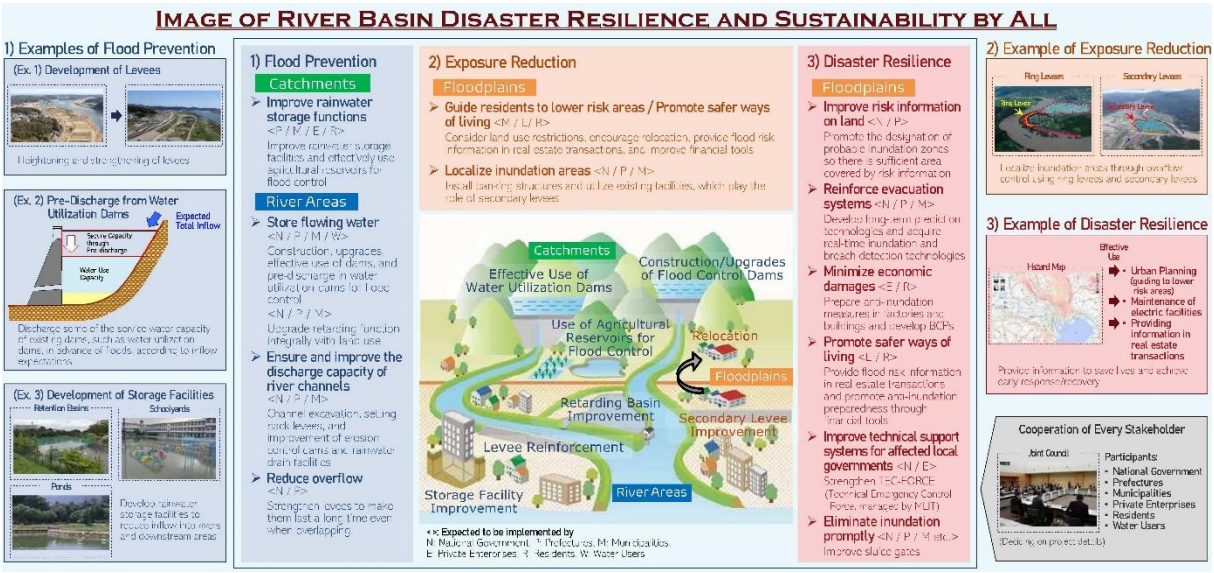




1.3.2 River Basin Disaster Resilience and Sustainability by All

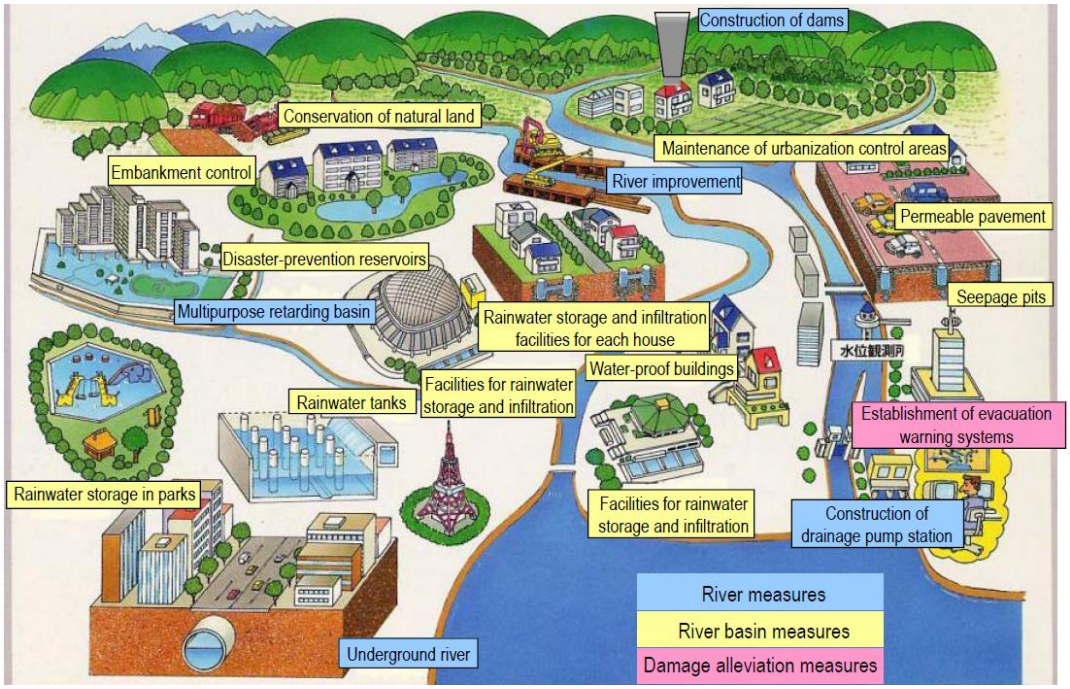
Combination of flood control measures should be examined considering the basin and flood characteristics. Comprehensive flood DRR measures in the basin can be called "River Basin Disaster Resilience and Sustainability by All", and it consists of 3 components, 1) flood prevention, 2) exposure reduction, and 3) disaster resilience (refer to Figure 1-2).

Flood prevention / River measures can be one of the major structural measures / one of the first steps to mitigate the flood damage directly, especially for the priority protection / designated area, even though the "River Basin Disaster Resilience and Sustainability by All" should be considered. In addition to river measures such as widening / excavating of rivers and retarding basins, river basin measures such as rainwater runoff control by rainwater storage and infiltration facilities and so on will be taken as the flood prevention actions (refer to Figure 1-2 and Figure 1-3).



Source: https://www.mlit.go.jp/river/kokusai/pdf/pdf21.pdf

Figure 1-2 Image of River Basin Disaster Resilience and Sustainability by All



Source: http://www.mlit.go.jp/river/basic_info/english/pdf/conf_01-0.pdf

Figure 1-3 Examples of flood control measures in Japan

1.4 Methodology of Flood Hazard Assessment

There are many hazard / risk assessment methods for each type of disaster, from simplified methods based on past disaster records to advanced methods based on simulations (refer to Figure 1-4 and Figure 1-6). Detailed characteristics of each methods are also explained in the appendix, "Study on Simplified Hazard / Risk Assessment Methods".

The purpose of the project is to promote disaster prevention projects to reduce disaster risk and to formulate local disaster prevention plans, so a method that can express the disaster risk reduction (DRR) quantitatively through implementation of countermeasures will be determined. On the other hand, it is preferable that the simplified method will be applied for Fiji considering the current C/Ps' experiences and capabilities regarding disaster hazard / risk assessment since the methods based on advanced simulation requires a lot of efforts and expertise and it is not realistic at the earlier stage of implementation of hazard / risk assessment.

There are various definitions of disaster risk, such as the disaster risk is determined by the "interaction of hazards, vulnerabilities, and exposures", but disaster hazard / risk assessments in the project is defined as follows.

Disaster Hazard Assessment : Assessment of potentially harmful natural phenomena that may cause damage to human life, assets, society, economy, etc.

Disaster Risk Assessment : Assessment of damage to human life, assets, etc. that disaster hazards can cause

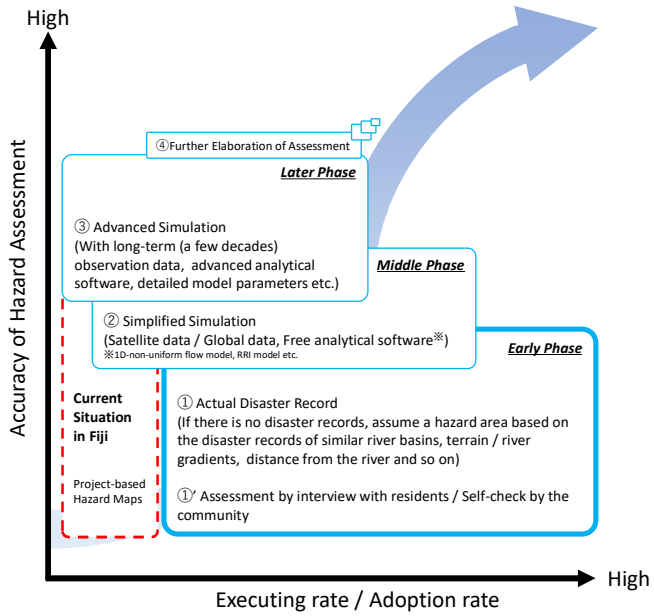


Figure 1-4 Image of Stepwise Hazard Assessment (in case of flood)

Regardless of location, flood hazards are assessed through conducting simulations and calculated by using analytical models and software such as the RRI (Rainfall-Runoff-Inundation) model, the HEC-RAS (U.S. Hydrologic Engineering Center's River Analysis System), MIKE11 and so on. Basically, analyses based on scientific evidence are implemented by using information including hydrometeorology, hydrography and geography.

The fundamental ideas behind hazard assessment methods in any disaster are common: hazards will be assessed based on flood strength of the disaster, which entities will suffer. Other factors such as geographical characteristics, landform conditions, and land use are taken into consideration when conducting these assessments. Generally, flood hazard is defined based on the combination of "event probability" and "scale of damage" of river flood and surface flood. The "scale of damage" is determined by flood strength (hazard).

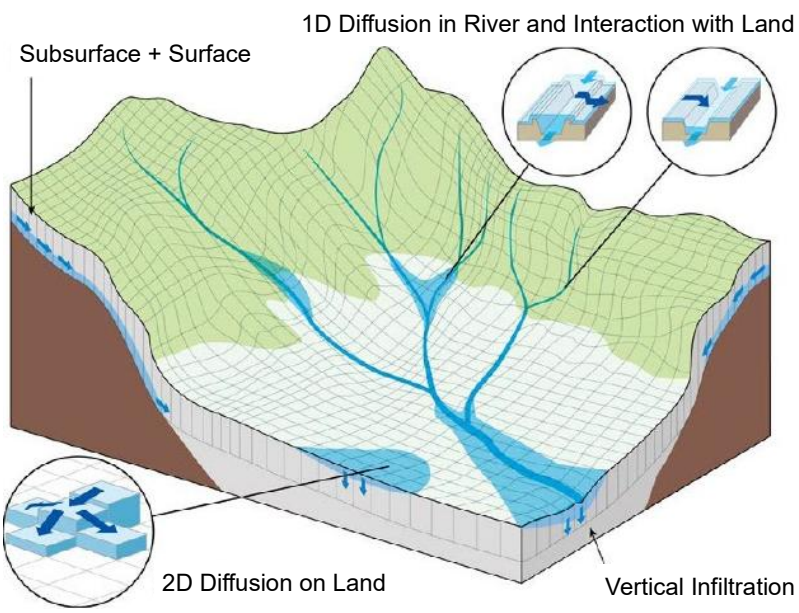
As for the flood hazard / risk maps, it is recommended to prepare them based on the simulations if appropriate data is available. If not, the historical information of inundation and the geographical characteristics could be substituted for the simulation data for estimating the projected inundation areas.

The first step in conducting a hazard assessment for river floods is to collect and arrange data on characteristics of river basins, meteorological and hydrological data, and other relevant information, such as the condition of maintenance of flood management facilities. The data is used to set rainfall scales and other external forces. This data is then used to run inundation simulations that provide runoff calculations, river hydraulic analyses, and inundation analyses. The hazard assessments provide an estimation of direct and indirect damages based on identified hazards (inundation areas, depth, duration, and arrival times).

As mention above, simplified analytical method, **the RRI (Rainfall-Runoff-Inundation) model**, to assess a flood hazard will be used in this project considering the current C/Ps' experiences and capabilities. Detailed procedure of developing the RRI model and utilizing the analytical result is explained hereafter.

The RRI model (and its manual) can be downloaded freely from the below URL.

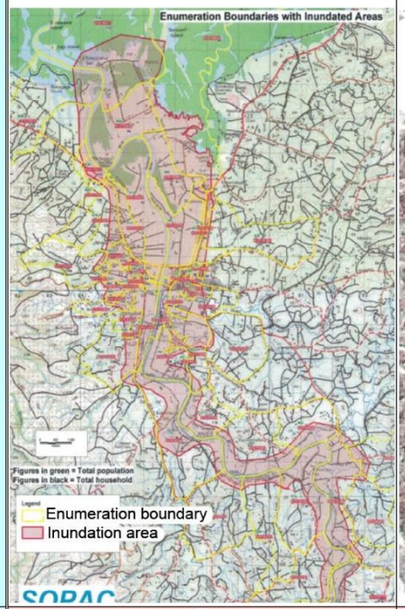
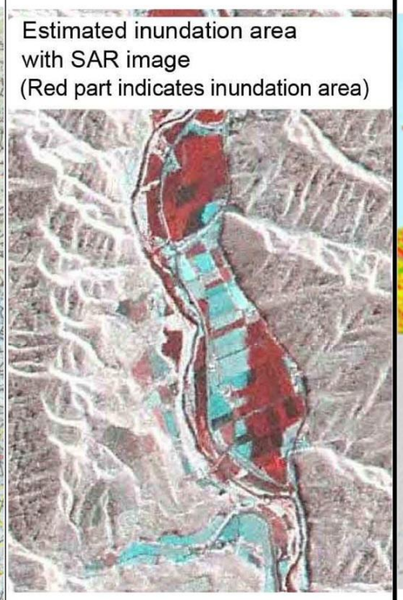
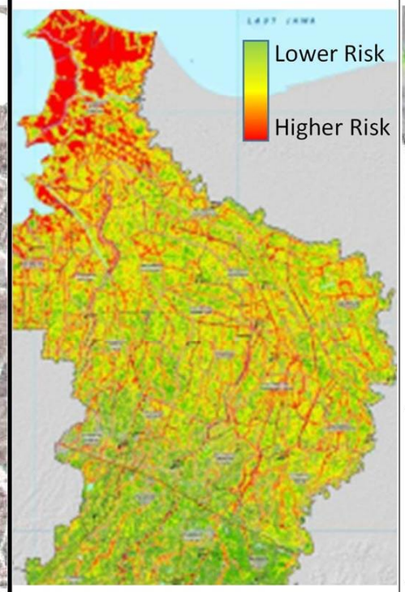
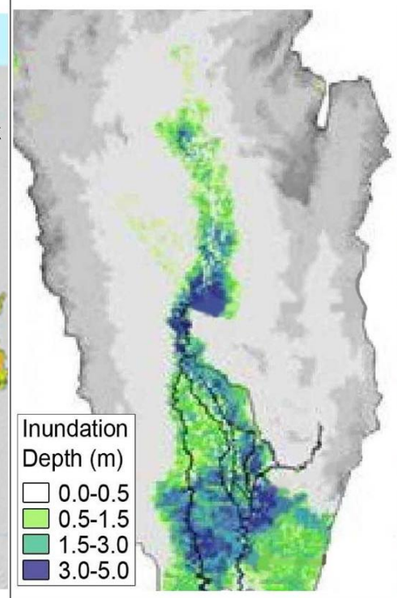
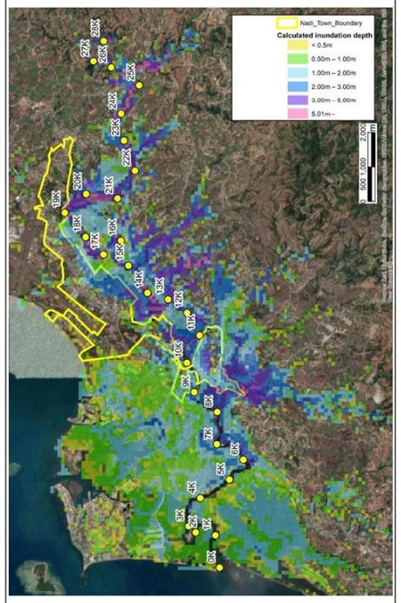
https://www.pwri.go.jp/icharm/research/rri/rri_top.html



RRI 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.

Figure 1-5 Schematic diagram of RRI model

Flood Hazard		Simplified	→	→	→	Detailed
Methods of Hazard Assessment		(1) Actual inundation records	(2) Analysis and reading of inundation area with satellite image (Optical / SAR images)	(3) Simplified assessment by hydrological information and Digital Elevation Model (DEM)	(4) Simplified runoff / flood analyses (RRI model etc.)	(5) Flood analysis
Images of the result of hazard assessment						
Level of Assessment		C Actual inundation area only	C Actual inundation area only	B Hazard area can be assumed	A Hazard area can be assessed by a simple simulation	A Hazard area can be assessed by a detailed simulation
Way to use		Damage investigation, DRR awareness	Damage investigation, DRR awareness	Estimation of damage, Planning of countermeasures	Estimation of damage, Planning of countermeasures and Evaluation of its effects	Estimation of damage, Planning of countermeasures and Evaluation of its effects
Assessable Items	Inundation Area	B Rather inadequate (Depends on survey)	A Adequate	A Adequate	A Adequate	A Adequate
	Inundation Depth	(B locally) (Rather inadequate)	C Inadequate	B Rather inadequate	A Adequate	A Adequate
	Several disaster events	C Inadequate	C Inadequate	C Inadequate	A Adequate	A Adequate
	Others	-	-	-	B Sort of adequate [Flood arrival and duration time]	A Adequate [Flood arrival and duration time, Velocity]
Conditions & Characteristics of the methods	Required data [Major data]	A Not many [Map, Inundation area information]	A Not many [Satellite image]	A Not many [Topographic map (Aerial photo), Elevation (DEM etc.), Rainfall data]	B Many (Utilization of global data) [Elevation (DEM), Rainfall data, Land use, River longitudinal and cross-section data (simple)]	C Many (High resolution) [Elevation (DEM), Hourly rainfall & discharge, Land use, River survey data (detailed)]
	Required techniques	A Not difficult	Optical: A / SAR: C Opt.: Not difficult / SAR: Need some expertise	B Not difficult - Need some expertise	C Little difficult – Need some experience / expertise	C Difficult – Need some experience / expertise
	Cost / Effort(Work)	Cost: A, Work: A Cost: Depends on the survey Work: Needs survey	Cost: B, Work: B Cost: Depends on the satellite images Work: Needs some effort	Cost: A, Work: B Cost: Utilize free data Work: Takes some time and effort	Cost: A, Work: C Cost: Utilize free data and software Work: Takes lots of time and effort	Cost: B, Work: C Cost: Depends on the available data Work: Takes lots of time and effort
	Accuracy	C Less accurate	B Sort of accurate (Depends on the images)	C Less accurate (basically only by elevation)	B Sort of accurate	A Relatively accurate
	Other major characteristics	× Reliability of collected information depending on the situation	● Not affected by time and weather in case of SAR image × Depending on satellite return and orbit	● Considering climate change as external force in case rainfall data is used	● Considering climate change as external force	● Considering climate change as external force

A: Good, B: Average, C: Poor

Figure 1-6 Summary of the major methods on flood hazard assessment

1.5 Preliminary Flood Hazard / Risk Assessment

Preliminary flood hazard and risk assessments can be conducted using the free data, such as the "Global Flood Map (GFM)", and the official statistical data, such as the census data. Priority areas to examine prior DRR investment can be selected based on the preliminary flood hazard and risk assessments.

The GFM (https://www.wri.org/data/aqueduct-floods-hazard-maps) and its methodology (https://files.wri.org/d8/s3fs-public/aqueduct-floods-methodology.pdf) are available on the website. Figure 1-7 shows the inundation area in the Viti Levu Island by the 1-in-50 year flood. This will be considered as a preliminary flood hazardous area. Flood hazardous area might be segmented geographically or by area or by town (refer to Figure 1-7) for the following preliminary flood risk assessment.

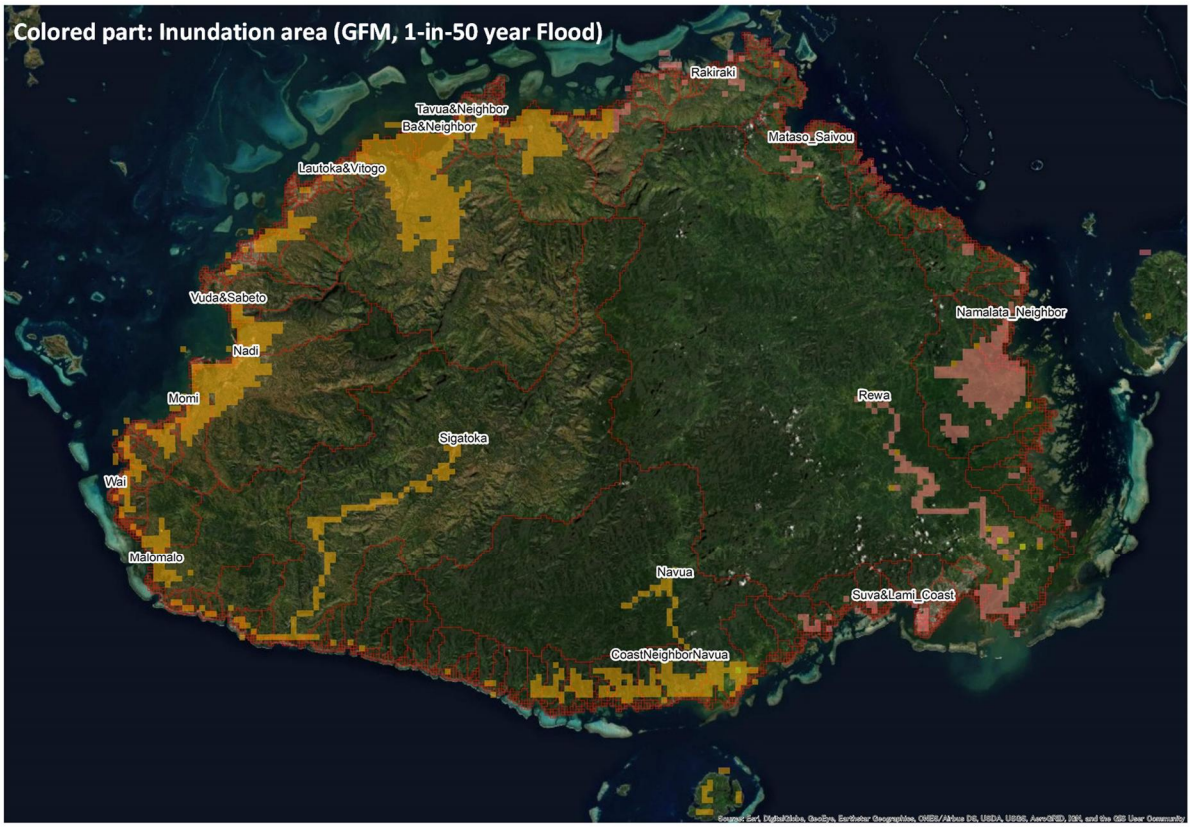


Figure 1-7 Global Flood Map (GFM, 1-in-50 year Flood)

Fundamental exposure / vulnerability data (spatial data) are overlapped on the flood hazardous area. This information will be considered as flood risks. Fundamental exposure / vulnerability data, such as distribution of population, household, businesses and lifelines and so on (refer to the following items) can be used as risk indicators. Most of the fundamental exposure / vulnerability data are collected from the Bureau of Statistics in this Project.

- Population, households
- Business
- Health social welfare facility
- Hotels
- Schools
- Lifeline (power, gas, water etc.)
- Emergency Operation Base
- Farm

As for the preliminary flood risk assessment, simply counting the fundamental exposure / vulnerability data in the flood hazardous area. “Attribute search” and “Spatial search” of the ArcGIS shall be used to select / highlight the spatially distributed exposure / vulnerability data. Figure 1-8 shows an example of counting the household and population in the flood hazardous area in the “Ba & Neighboring” basins.

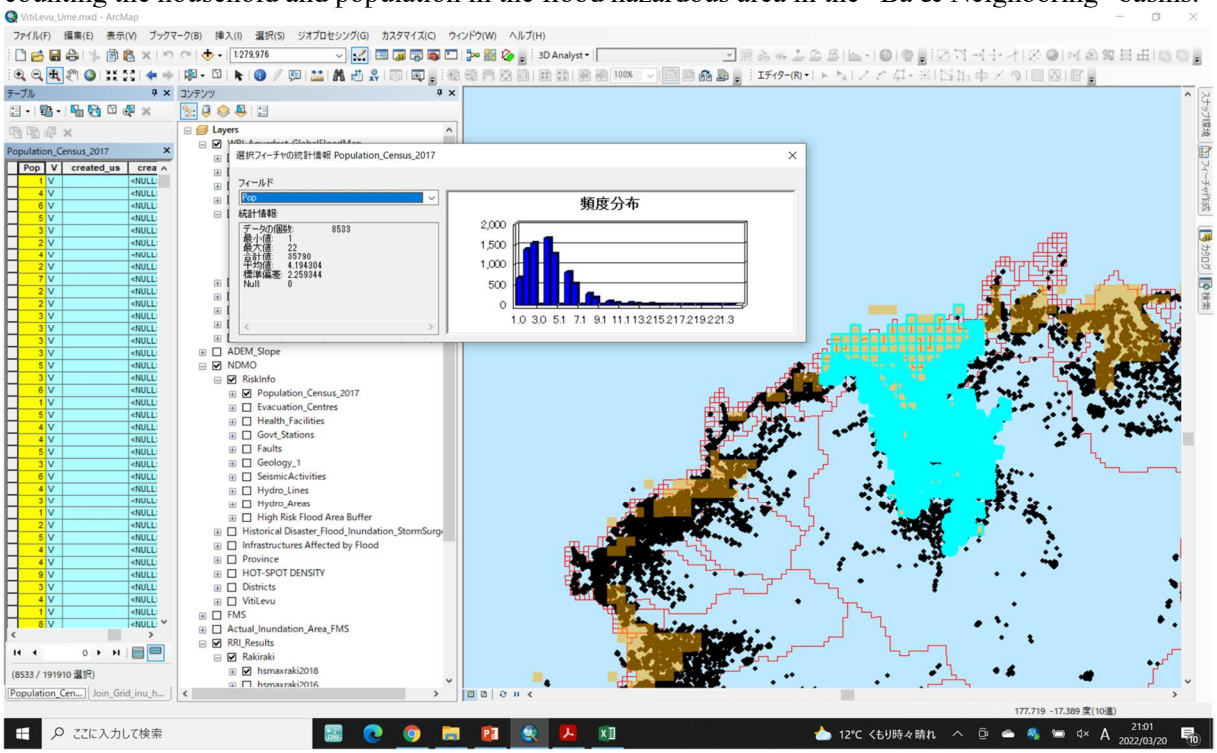


Figure 1-8 Overlapped GFM and Household / Population data

Counted exposure / vulnerability data by basin / area / town are shown in Table 1-1. Here, “People required support for evacuation” is defined as;
“Elderly people (above 55 years old or 60 years old)” + “Babies and infants (below 7 years old)” + “Pregnant woman (here, one-fourth the population of 0 years old)” + “Disabled people (here, 4% the population of below 55 years / 60 years old exclusive of babies, infants and pregnant woman”).

Table 1-1 Result of the Preliminary Flood Risk Assessment (Household, Population and Business in the Flood Hazardous Areas)

Inundation area, affected household & population and infrastructures based on the Global Flood Map (GFM, 1-in-50 year Flood)[1)]

Basin	Assumed																									
				Risky Age Group (Need Assistance for Evacuation)																						
	Inundation Area[2)] (km²)	Affected Household[3)]	Affected Population[3)]	Affected Female	(%)	Age group 0-4 years	(%)	Age group 5-9 years	(%)	Age group Above 55 years	(%)	Age group Above 60 years	(%)	People required support for evacuation 55year-	(%)	People required support for evacuation 60year-	(%)	Affected Business[3)]
Ba & Neighbor	199.9	8,533	35,790	17,426	49%	3,111	9%	3,178	9%	6,062	17%	3,958	11%	11,608	32%	9,588	27%	824
Lautoka & Vitogo	39.2	4,787	21,680	10,813	50%	2,031	9%	1,971	9%	2,969	14%	1,922	9%	6,521	30%	5,516	25%	127
Nadi	74.2	10,138	43,557	21,678	50%	4,351	10%	3,963	9%	5,540	13%	3,566	8%	12,969	30%	11,073	25%	1,214
Sigatoka	65.9	2,403	10,227	5,081	50%	1,024	10%	1,065	10%	1,516	15%	1,012	10%	3,305	32%	2,822	28%	103
Navua	44.7	1,484	6,599	3,266	49%	681	10%	643	10%	949	14%	632	10%	2,108	32%	1,804	27%	122
Coastal Neighbor Navua	92.7	1,420	6,285	3,109	49%	681	11%	659	10%	957	15%	650	10%	2,110	34%	1,814	29%	56
Rewa	99.3	4,678	21,732	10,794	50%	2,278	10%	2,121	10%	3,007	14%	1,900	9%	6,867	32%	5,804	27%	433
Namalata Neighbor	116.5	1,463	6,873	3,111	45%	776	11%	799	12%	896	13%	575	8%	2,225	32%	1,916	28%	76
Rakiraki	11.4	665	2,809	1,387	49%	261	9%	269	10%	423	15%	276	10%	886	32%	744	26%	248
Tavua & Neighbor	94.7	3,030	13,232	6,489	49%	1,337	10%	1,316	10%	2,037	15%	1,350	10%	4,339	33%	3,679	28%	210
Vuda & Sabeto	34.2	2,235	9,851	4,893	50%	949	10%	889	9%	1,379	14%	895	9%	3,015	31%	2,551	26%	182
Momi	51.3	2,176	9,167	4,504	49%	847	9%	807	9%	1,327	14%	832	9%	2,805	31%	2,329	25%	63
Suva & Lami Coast	22.0	4,378	18,885	9,128	48%	1,739	9%	1,535	8%	2,478	13%	1,666	9%	5,476	29%	4,697	25%	1,350

Actual Damage		
Frequency of Flood damage[4)]	Year[4)]	Damaged infrastructures in GFM inundation area[4)]
5	2012Jan&Mar, 2016, 2018, 2019	84
4	2012Jan&Mar, 2016, 2018	31
4	2012Jan&Mar, 2016, 2018	54
4	2012Jan&Mar, 2018, 2019	21
1	2016,	10
1	2012,	6
3	2012Jan&Mar, 2016	10
-	Unknown	4
3	2012Jan&Mar, 2016	17
5	2012Jan&Mar, 2016, 2018, 2019	41
3	2012Jan&Mar, 2018	17
5	2012Jan&Mar, 2016, 2018, 2019	18
-	Unknown	2

1) inunriver_historical_000000000WATCH_1980_rp00050.tif (source: https://www.wri.org/data/aqueduct-floods-hazard-maps)
2) Difference of inundation depth is not considered
3) Based on the 2017 Census (Household & Population) and the Census (Business)
4) Based on the "Infrastructures Affected by Flood" prepared by NDMO

Below GIS data were used for the preliminary flood risk assessment in this project.

- Population_Census_2017.shp
- Fiji_2017_EAs.shp
- Fiji_BR_2018.shp
- Historical Disaster_Flood_Inundation_StormSurge.shp

Chapter 2. Preparation of a Fundamental Data for the RRI model

A flowchart of development of the RRI model is as shown in Figure 2-1. There are 2 major steps for development the RRI model, "Preparation of a fundamental data for the RRI model" and "Trial & Error Calculation".

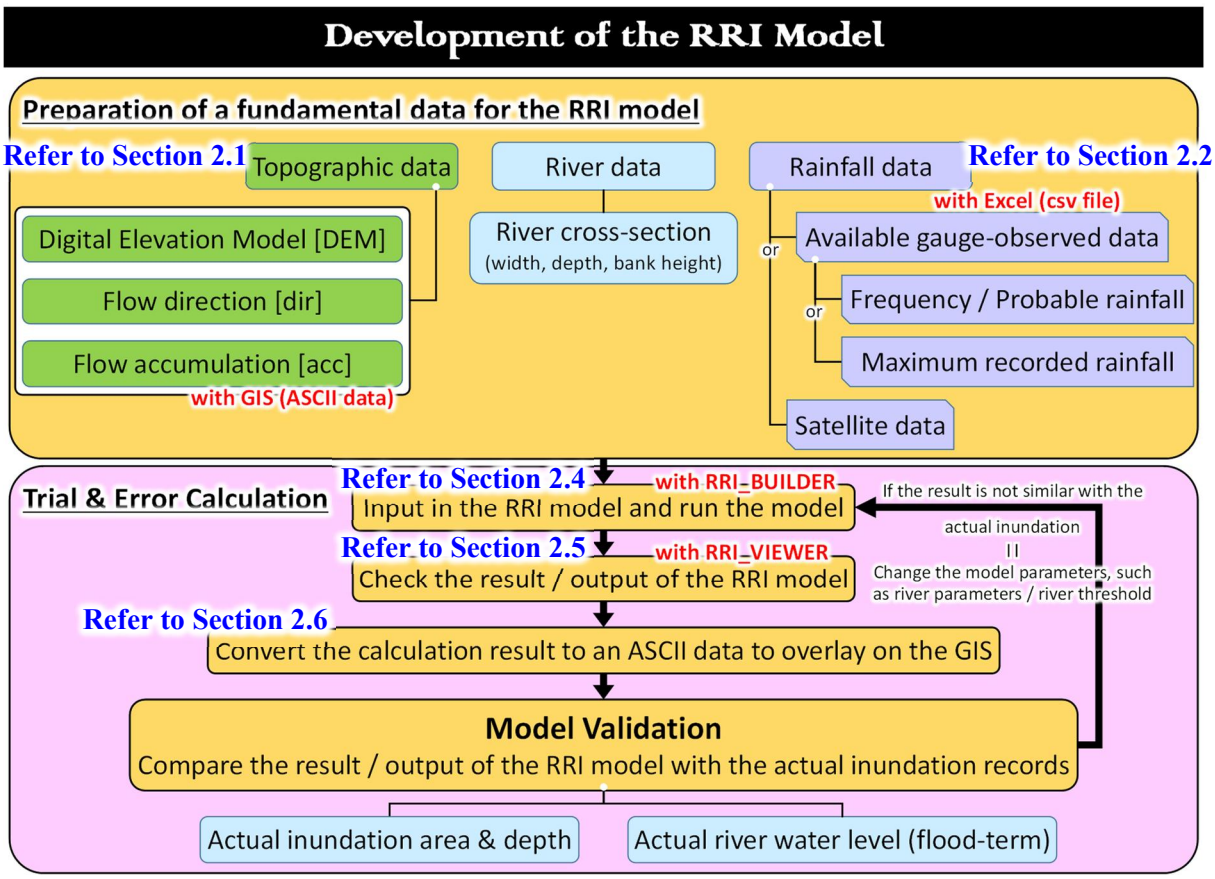


Figure 2-1 Flowchart of development of the RRI model

Topographic data, such as DEM (digital elevation model), flow direction, flow accumulation and watershed / river catchment area, are the one of the essential data. Also, rainfall data is given as an extra force in the model. If there are river data, such as river cross-sections to check the actual river width, depth and bank elevation, it might be utilized to develop the river model (refer to Figure 2-2).

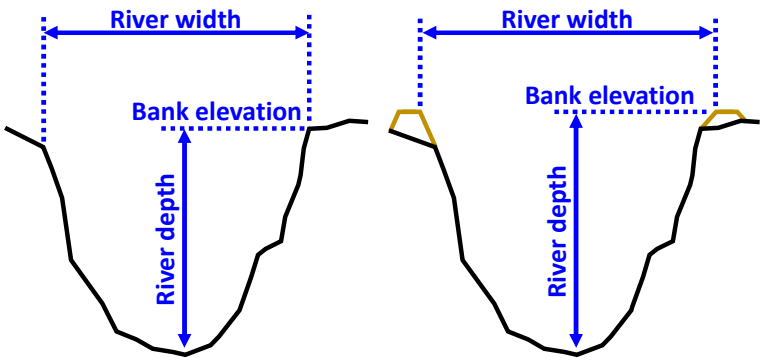


Figure 2-2 Diagram of a river cross-section
(left: Natural condition, right: with river banks)

2.1 Elevation Data, Flow Direction / Accumulation and Watershed

DEM data is used to calculate a flow direction, flow accumulation and watershed. There are many options of free DEM data, such as ASTER GDEM, HydroSHEDS, SRTM3 and the GTOPO30 as mentioned below (refer to 2.1.1 4)). If you already have a DEM data, you can also use it.

How to download and prepare a DEM, flow direction / accumulation and watershed using ASTER GDEM (section 2.1.1) **and HydroSHEDS** (section 2.1.2) **is explained hereafter.** If you have some available DEM data, you can skip some of the instructions below.

Major preparation steps are as shown below. **The detailed instruction of each step is shown in the following sections, especially "With ASTER GDEM"** and "With HydroSHEDS" (depending on the data).

1) **"Mosaic"** [Merge the downloaded DEMs]

2) **"Create a rectangle polygon to 'Extract / Clip' the above mosaic DEM"** [Rectangle polygon to cover all the area, Viti Levu Island / each river basin, including the river mouths and alluvial fans based on the HydroSHEDS' watersheds or any shape files]

3) **"Extract / Clip by mask"** [Extract "1) Mosaic DEM" by mask, "rectangle polygon"]

4) **"Check a number of column and row and cell size"** [Check the property of the extracted / clipped DEM (Right click on the DEM > property > source tab, then "column and row" and "cell size") * In case the number of column or row exceeds 1,000, you need to "**Aggregate**" since the limit of calculation grids of the RRI is 1,000 for both column and row. The grid size of the ASTER GDEM is 1 arc-second (approximately 30m)]

5) **"Aggregate"** [Aggregate to make the number of column or row of the DEM to be less than 1,000. If you set the cell factor as "3", above ASTER GDEM 1 arc-second will be 3 arc-second (=approximately 90m), if you set the cell factor as "5", it will be aggregated as 5 arc-second (=approximately 150m). Aggregate method should be "Mean (average)". *Be careful, default setting of Aggregate method is set as "Sum". Make sure to change it to "Mean"] [In case of the QGIS, "right click on the DEM > Export", then you can change a cell size]

6) **"Fill"** [Fill ("ArcHydro > Fill") the above aggregated DEM]

   [In case of the QGIS, "Click on Processing > Toolbox > SAGA > Terrain Analysis > preprocessing > Fill Sinks"]

7) **"Flow direction"** [Make a Flow direction ("ArcHydro > Flow direction") using the above filled DEM]

8) **"Flow accumulation"** [Make a Flow accumulation ("ArcHydro > Flow accumulation") using the above filled DEM and flow direction]

9) **"Watershed"** [Make a Watershed ("ArcHydro > Watershed") using the above "Flow point" and "Flow direction". You need to make a "Flow point (river mouth / river outlet point)" to run the watershed process. Therefore, you make a new POINT shape file and plot the outlet point with the "editor". Its coordinate system must be same as the above raster data *Error due to different coordinate system sometimes occurs]

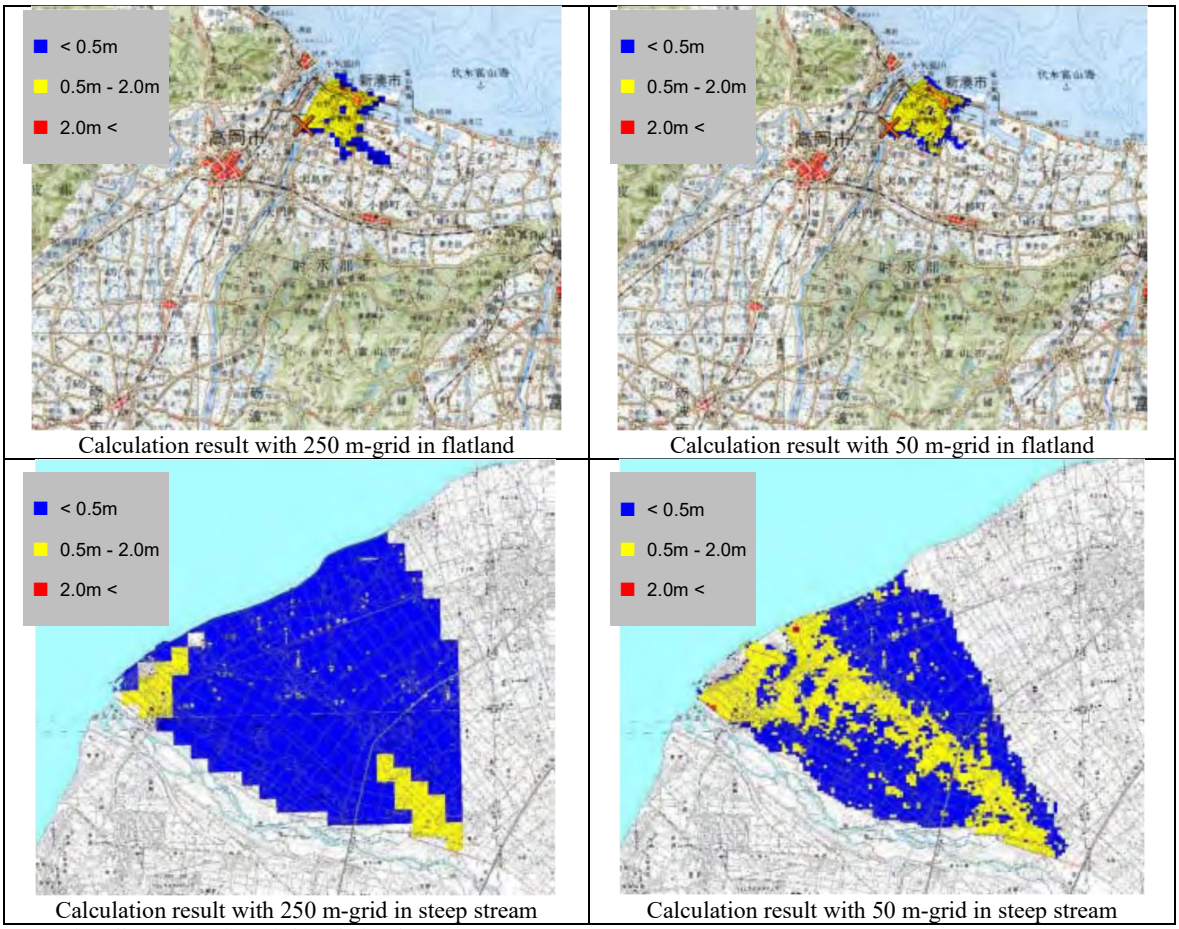
10) **"Extract / Clip by the watershed"** [Extract the above "Fill (DEM)", "Flow direction" and "Flow accumulation" by the above "Watershed"]

11) **<u>"Check a number of column and row and cell size again"</u>** [Check the property of the extracted / clipped raster data once again to make sure the numbers of column and row do not exceed 1,000]

12) **<u>"Convert, Raster to ASCII"</u>** [Convert above extracted raster data, "Fill (DEM)", "Flow direction" and "Flow accumulation" by the "Watershed", to ASCII files (Conversion tool > Raster to ASCII). Save the output ASCII files in the project folder of the RRI model. Name of the ASCII files should be, "dem.txt" for Fill (DEM), "dir.txt" for Flow Direction and "acc.txt" for Flow Accumulation]

Consideration: DEM / Calculation Grid Size

Calculation grid size shall be set appropriately in order to reproduce the actual phenomenon considering gradient in the flood plain. Figure 2-3 shows the difference in the calculation results with 250 m-grid and 50 m-grid.



Source: http://www.hrr.mlit.go.jp/river/gsiryo/

Figure 2-3 Comparison of the difference in the calculation results with 250 m and 50 m-grids

Finer grid size shall be applied in case that the flood plain is steep, since elevation difference among adjacent grids will be higher if the grid size is wide. Advisable elevation difference among adjacent grids is less than 50 cm.

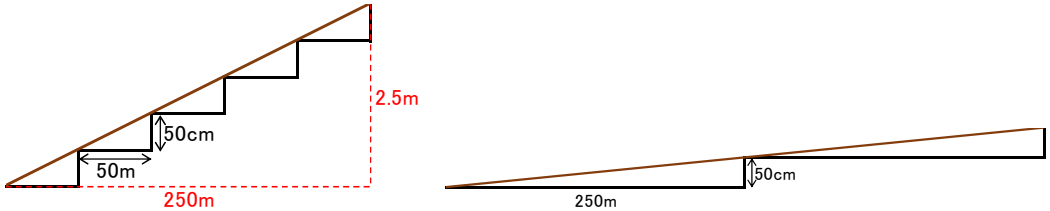
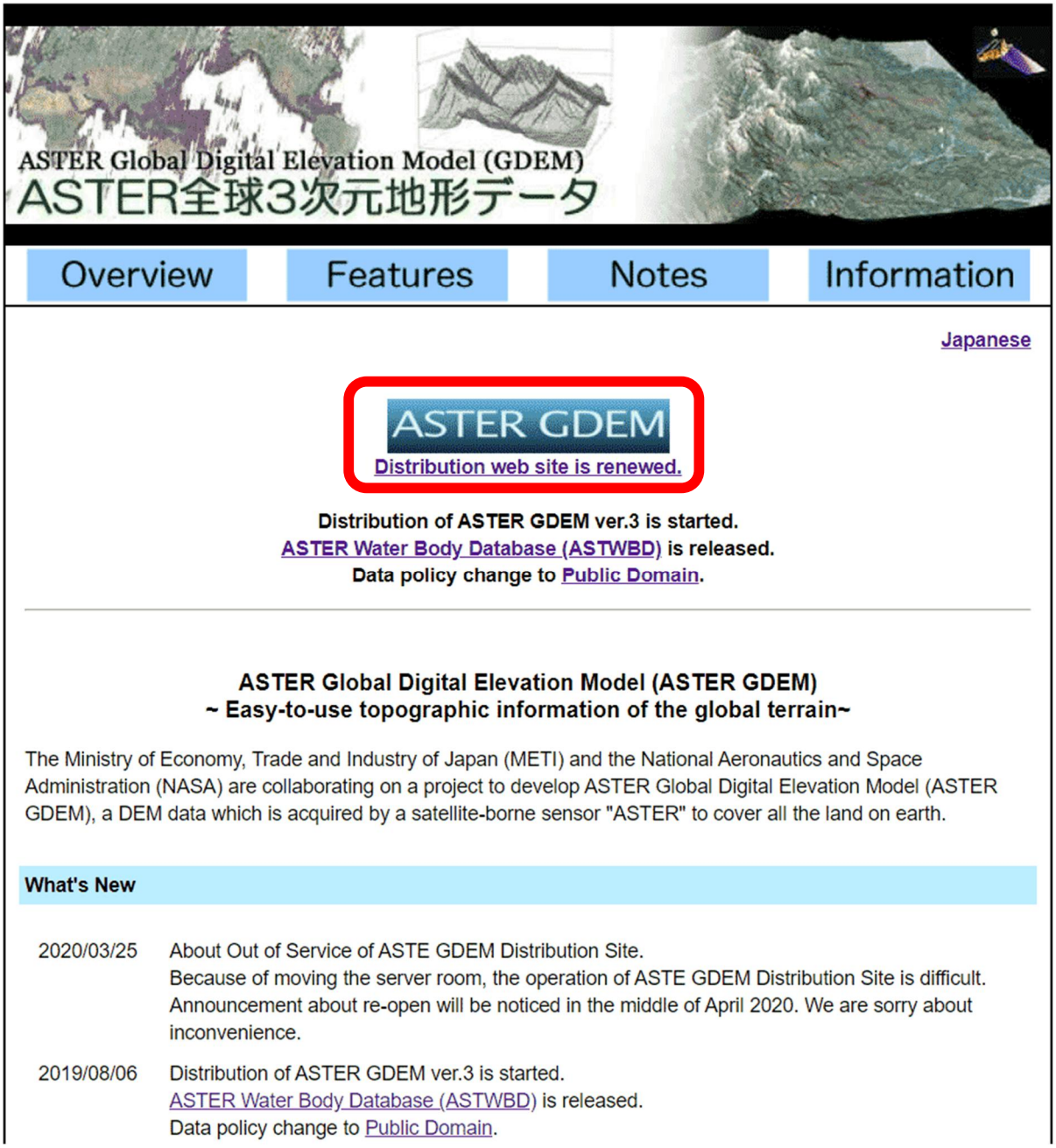


Figure 2-4 Schematic diagram of relation between grid size and elevation difference

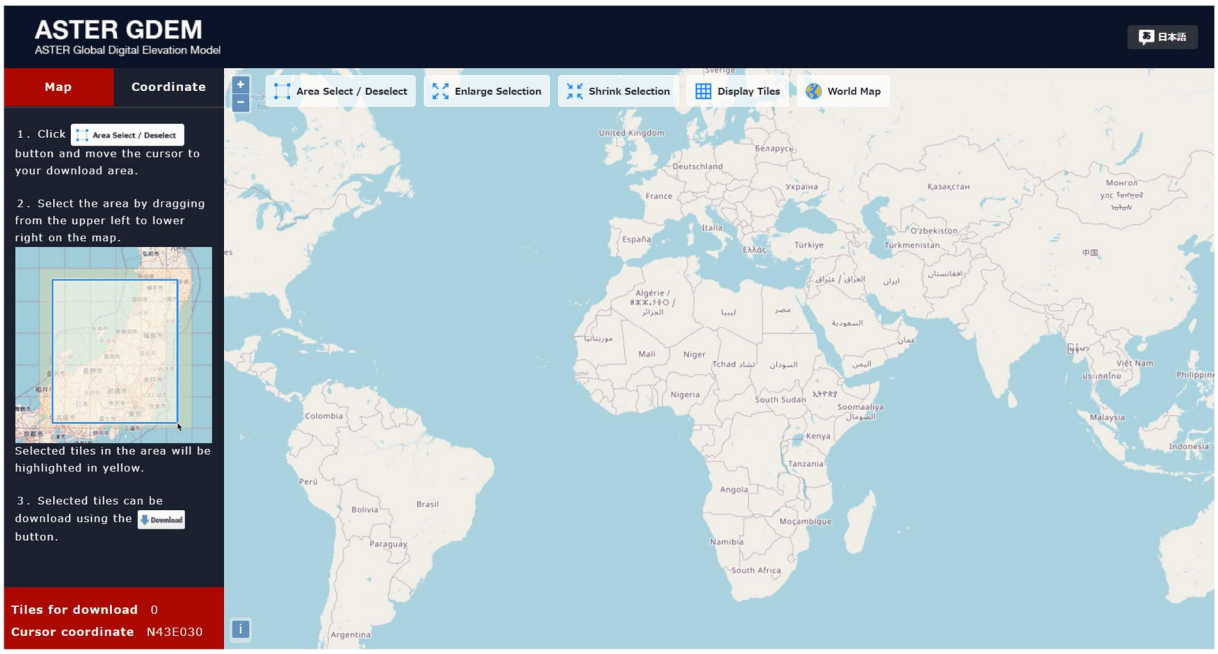
2.1.1 With ASTER GDEM

1) Free digital elevation model (DEM) data is available on the website below.

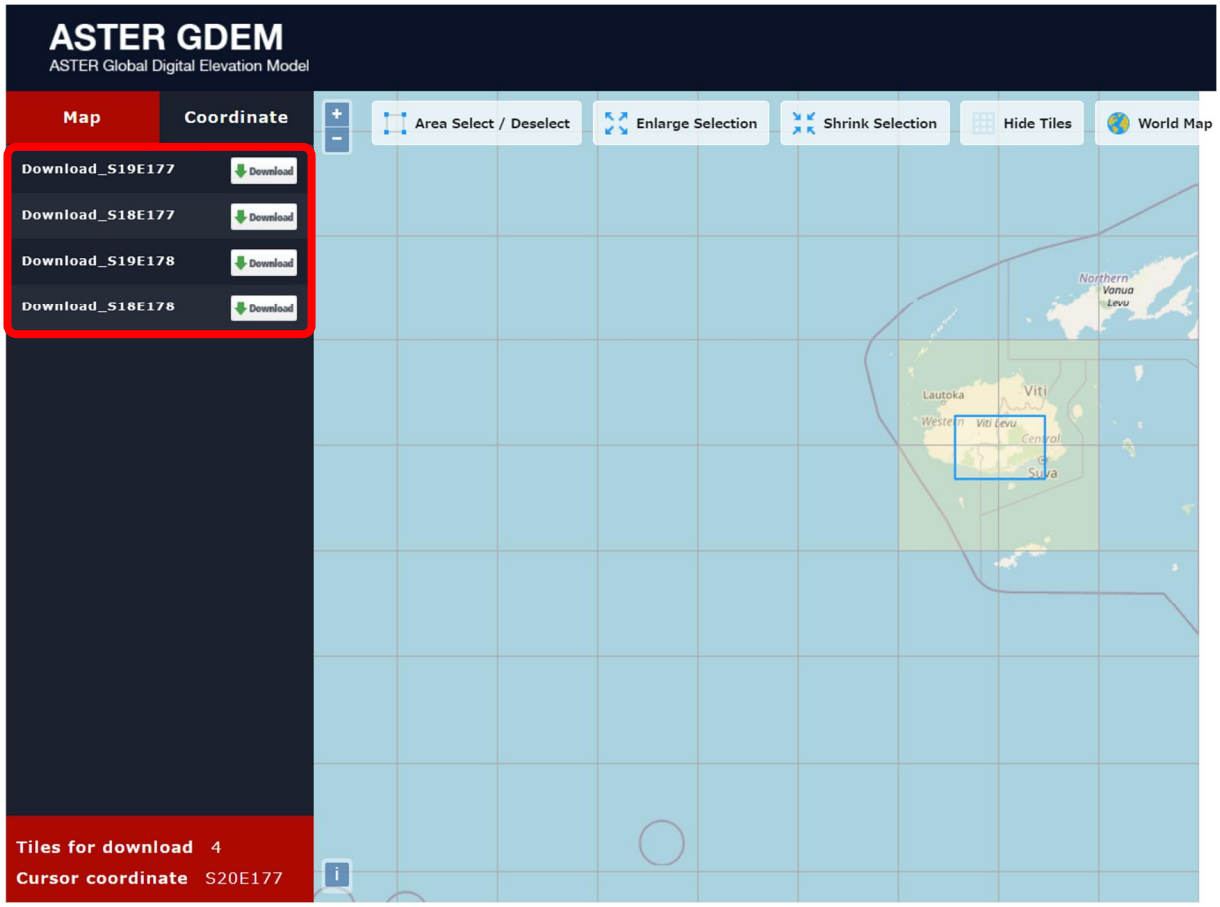
https://ssl.jspacesystems.or.jp/ersdac/GDEM/E/index.html



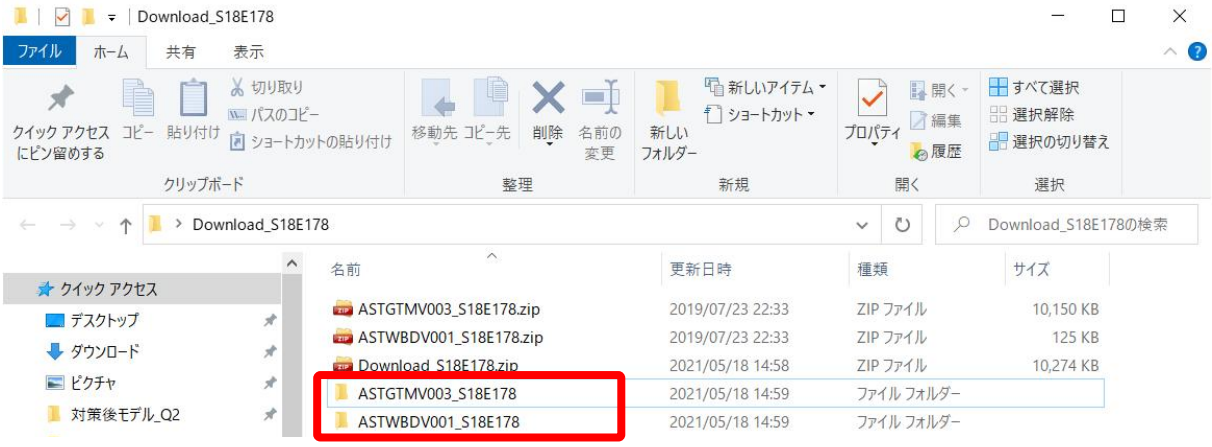
2) You'll find the world map as below. Then, zoom in on Fiji.



3) Select / highlight the target area. Then you can download the DEM data.

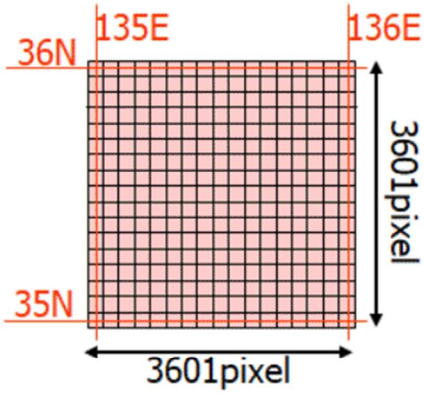
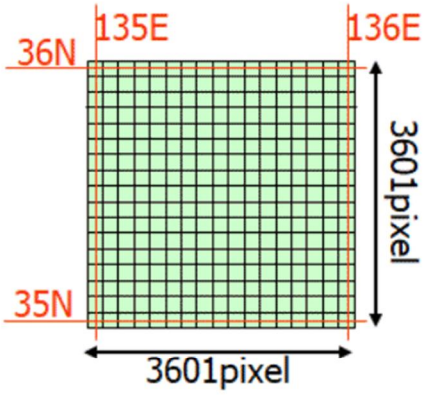


4) Unzip the downloaded DEM data. DEM data has 2 types of data, “ASTGTM (Aster GDEM) and ASTWBD (ASTER Water Body Database)”.



Both ASTGTM and ASTWBD consist 2 files. Formats of both data are as follows. Basically, we will use “ASTGTM…._dem.tif” data.

Format of ASTER DEM

File Name(Example of N35~36,E135~136)	ASTGTMV003_ N35E135_dem.tif	ASTGTMV003_ N35E135_num.tif
	DEM data	QA plane data
		
Output format	GeoTIFF, signed 16 bits	GeoTIFF, unsigned 8 bits
Geographic coordinates	Geographic latitude and longitude	
Tile Size	3601-by-3601 pixels (1-by-1 degree)	
Posting interval	1 arc-second	
DN values	1m/DN referenced to the WGS84/EGM96 geoid-9999 for void pixels, and 0 for sea water body	Stacking number or reference DEM (Refer to Table3 in User Guide)
Coverage	North 83 degrees to south 83 degrees, 22,912 tiles (1-by-1 degree) without tile shows ocean area	

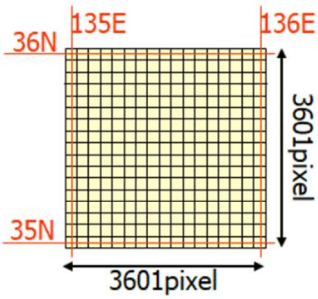
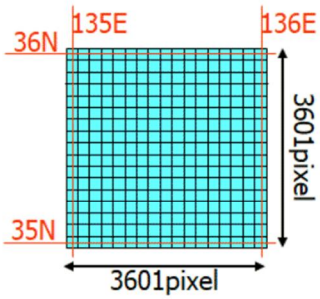
*The detail is described in User Guide.

*Here is the ASTWBD format.

Outline of ASTWBD

* ASTWBD shows the water area and its elevation with the same area and format as GDEM.
* The water area are classified to sea, lake and river.

Format of ASTWBD

File Name(Example of N35~36,E135~136)	ASTWBDV001_N35E135_dem.tif	ASTWBDV001_N35E135_att.tif
	Elevation of waterbody	Classification of waterbody
		
Output format	GeoTIFF, signed 16 bits	GeoTIFF, unsigned 8 bits
Geographic coordinates	Geographic latitude and longitude	
Tile Size	3601-by-3601 pixels (1-by-1 degree)	
Posting interval	1 arc-second	
DN values	1m/DN referenced to the WGS84/EGM96 geoid-9999 for land and void pixels, and 0 for sea water body	Land:0, Sea:1, River:2, Lake:3
Coverage	North 83 degrees to south 83 degrees, 22,886 tiles (1-by-1 degree) without tile shows ocean area	

*The detail is described in User Guide.

Even though there are some other free available DEM data, Aster GDEM is the latest and the posting interval is finer than other free DEM data, such as SRTM3 and the GTOPO30. *The DEM data might be updated. SRTM3 provides free 30m-posting-interval data as of 2022.

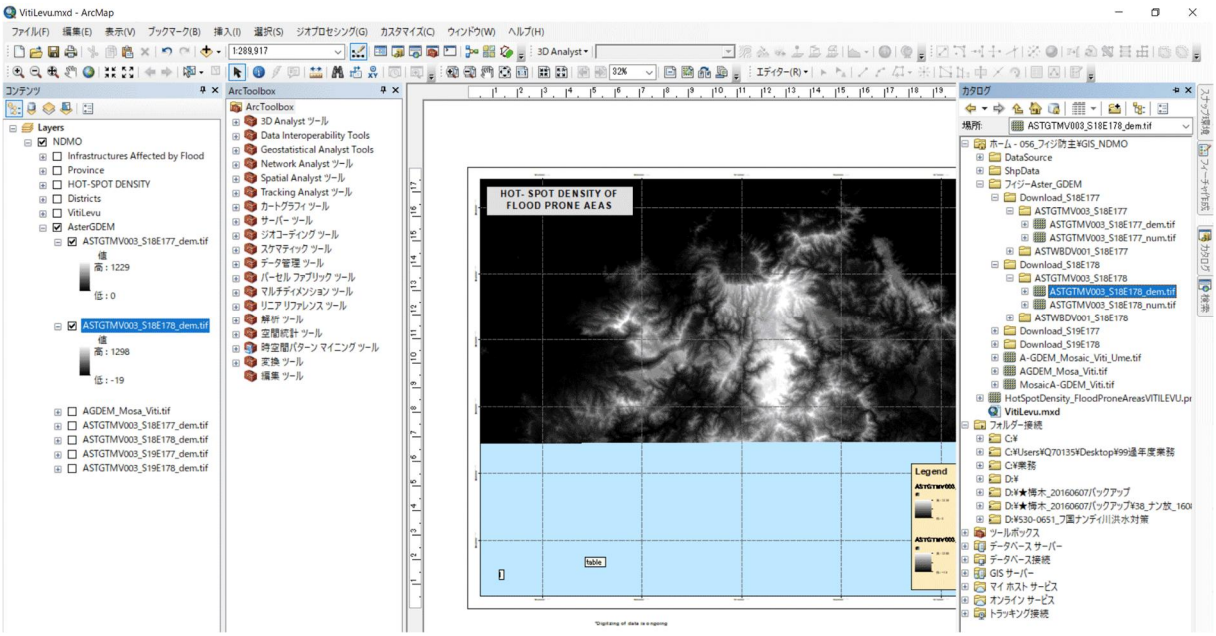
Comparison with other DEMs

	ASTER GDEM	SRTM3*	GTOPO30**	10 m mesh digital elevation data
Data source	ASTER	Space shuttle radar	From organizations around the world that have DEM data	1:25,000 topographic map
Generation and distribution	METI/NASA	NASA/USGS	USGS	GSI
Release year	2009 ~	2003 ~	1996 ~	2008~
Data acquisition period	2000 ~ ongoing	11 days (in 2000)		
Posting interval	30m	90m	1000m	about 10m
DEM accuracy (stdev.)	7~14m	10m	30m	5m
DEM coverage	83 degrees north ~ 83 degrees south	60 degrees north ~ 56 degrees south	Global	Japan only
Area of missing data	Areas with no ASTER data due to constant cloud cover (supplied by other DEM)	Topographically steep area (due to radar characteristics)	None	None

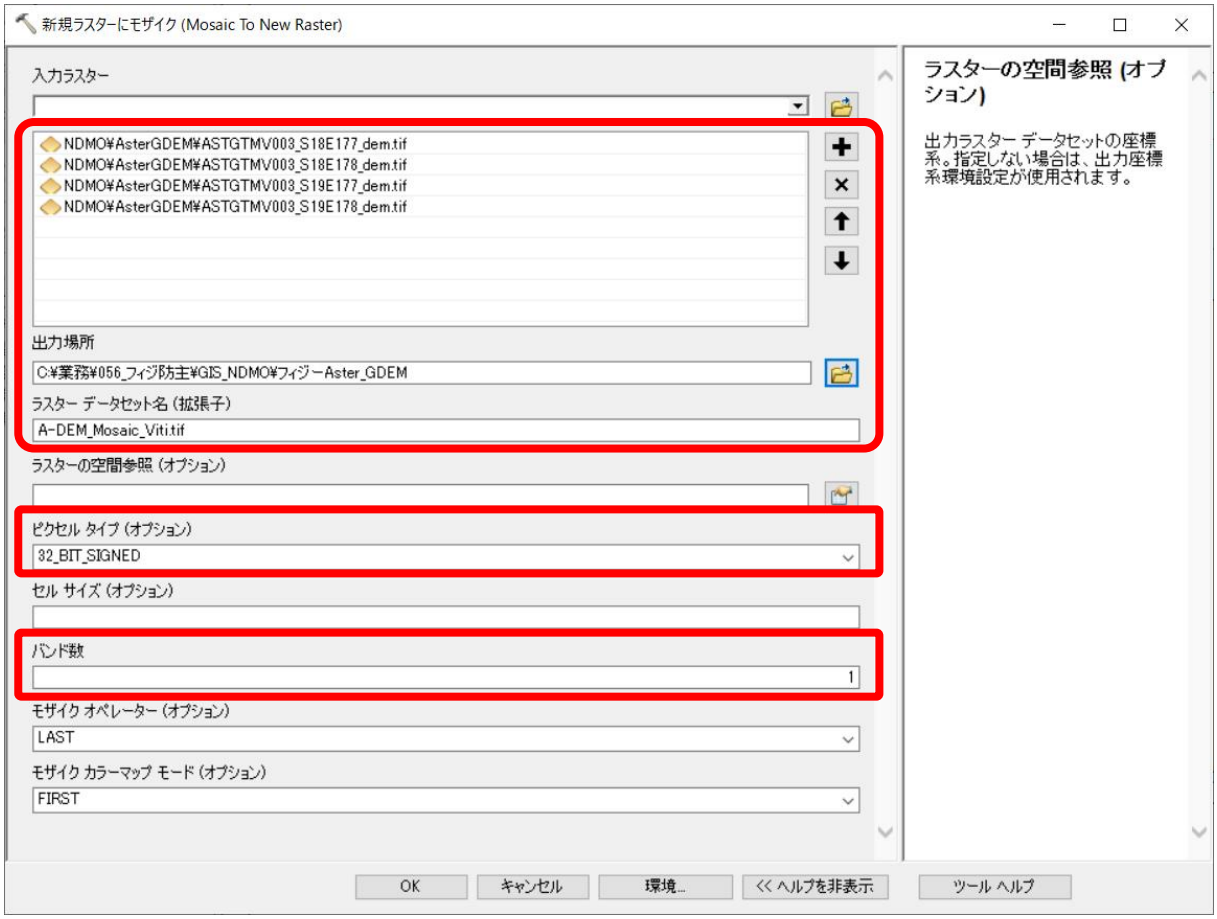
in 2009

*SRTM3: Shuttle Radar Topography Mission Data at 3 Arc-Seconds
**GTOPO30: Global 30 Arc-Second Elevation Data Set

5) Now, we will move to the GIS. Place the downloaded DEM data in your GIS folder. And add the "….dem.tif" data in the ToC (Table of Contents) of the GIS.



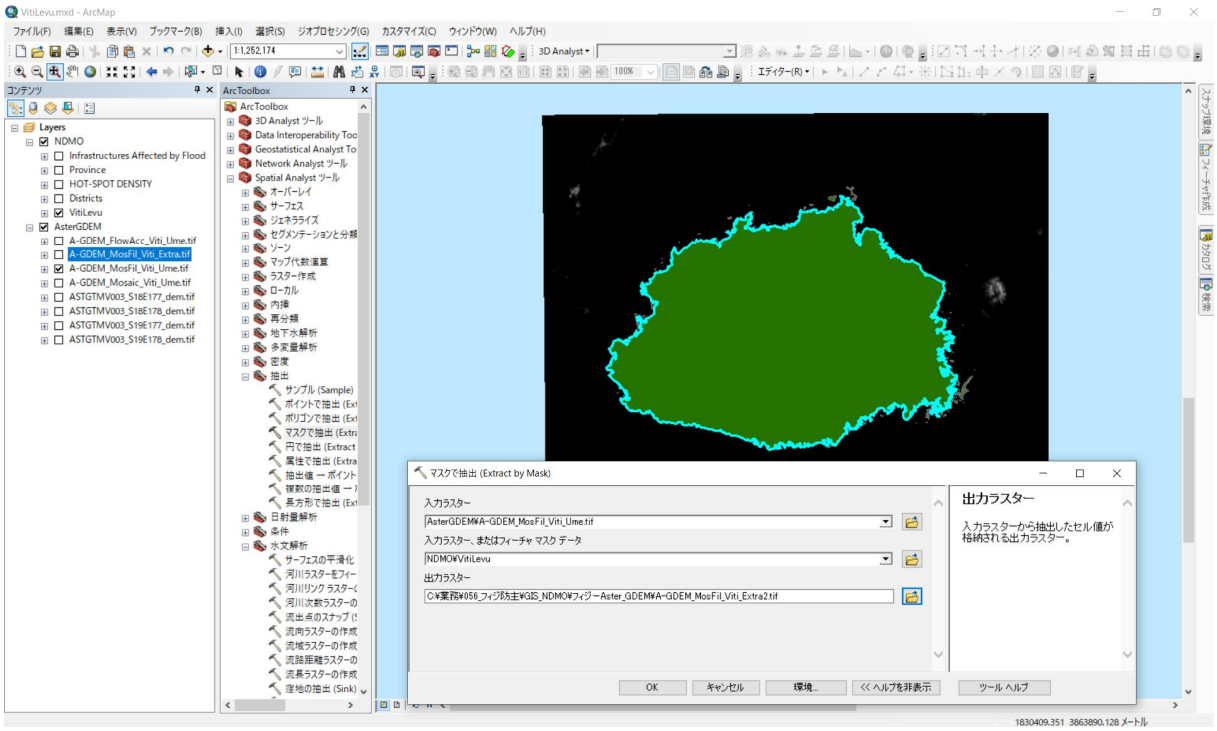
6) Viti Levu are consists of 4 dem.tif data, S18E177 & 178, S19E177 & 178. Therefore, now we combine / merge them into one Raster data set. Search a command, "**Mosaic** to New Raster" on the ArcGIS, then set the parameters as below. Pixel type can be "signed 32 bit".



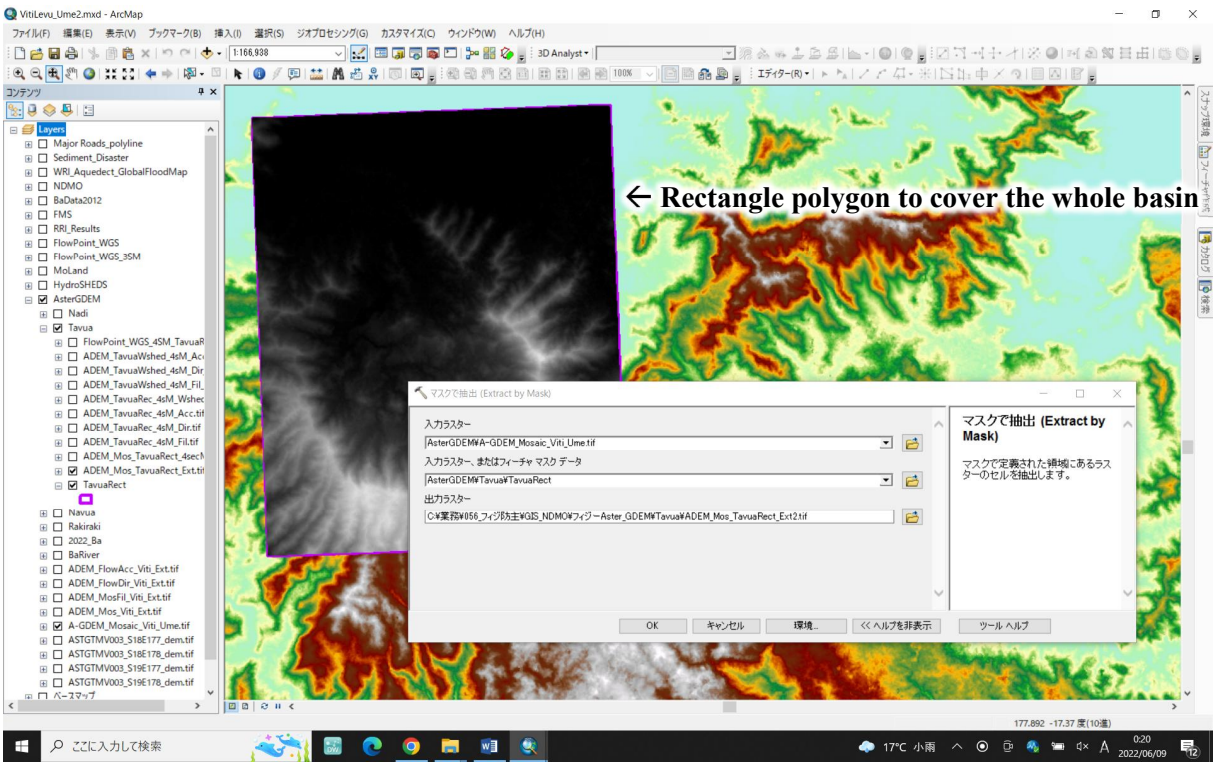
*If the ArcGIS shows any errors on processing commands, **it is better to do on a new map (simpler ToC)** / simpler directory / file name / coherent coordination.

7) Extract only the Viti Levu Island from the combined raster. Search a command, “Extract by Mask” on the ArcGIS, then set the parameters as below. *Caution: Shape files of “Viti Levu” or “coastal line” might not be suitable to use as a mask, since the some river mouths and alluvial fans might not be covered. In that case, you might create a rectangle polygon mentioned on the next section.

After you extract / clip the DEM for Viti Levu Island, you can also extract / clip only for the target river basin.



8) To focus on the specific river basin, you can **<u>create a rectangle polygon</u>** (or any polygons which can cover the whole basin including the river mouths and alluvial fans) to ‘Extract / Clip’ the above mosaic DEM. Wider polygon to cover the whole basin is preferable.



9) Check the property of the extracted / clipped DEM (Right click on the DEM > property > source tab, then "column and row" and "cell size") *In case the number of column or row exceeds 1,000, you need to "Aggregate" since the limit of calculation grids of the RRI is 1,000 for both column and row. The grid size of the ASTER GDEM is 1 arc-second (approximately 30m).

In the case of Modifying Elevation (using point elevation, LiDAR data, etc…)

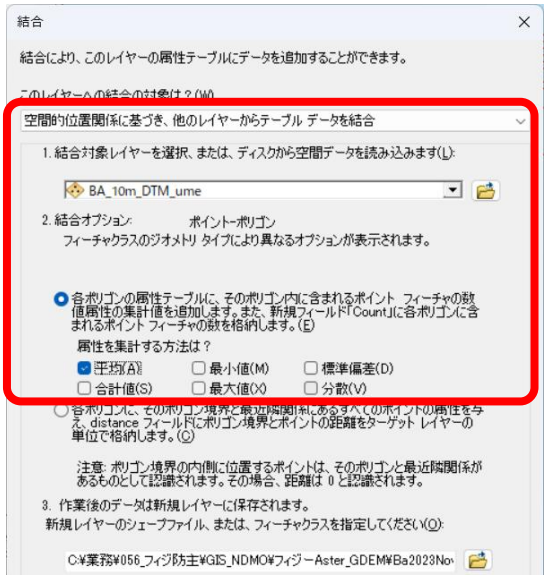
Ex) To combine 2 elevation data, ASTER GDEM (raster) and LiDAR surveyed elevation (vector) using "Join"

i. Convert the elevation data (raster data based on the ASTER GDEM) to vector "point" data. Raster to Point [Raster to Point command] (you cannot convert raster to polygon directly since created polygon will be non-uniform shape. Therefore we create the Grid Index Feature below). Considering the mighty long time for processing of "Join", it is better to use already "Aggregated and Filled raster data" (in the case of Ba, "ADEM_BaWshed_6sM_Fil_ExtR.tif" is converted to vector).

ii. Create a grid (polygon) shape file by "Grid Index Features" command (refer to "2.6 4)")

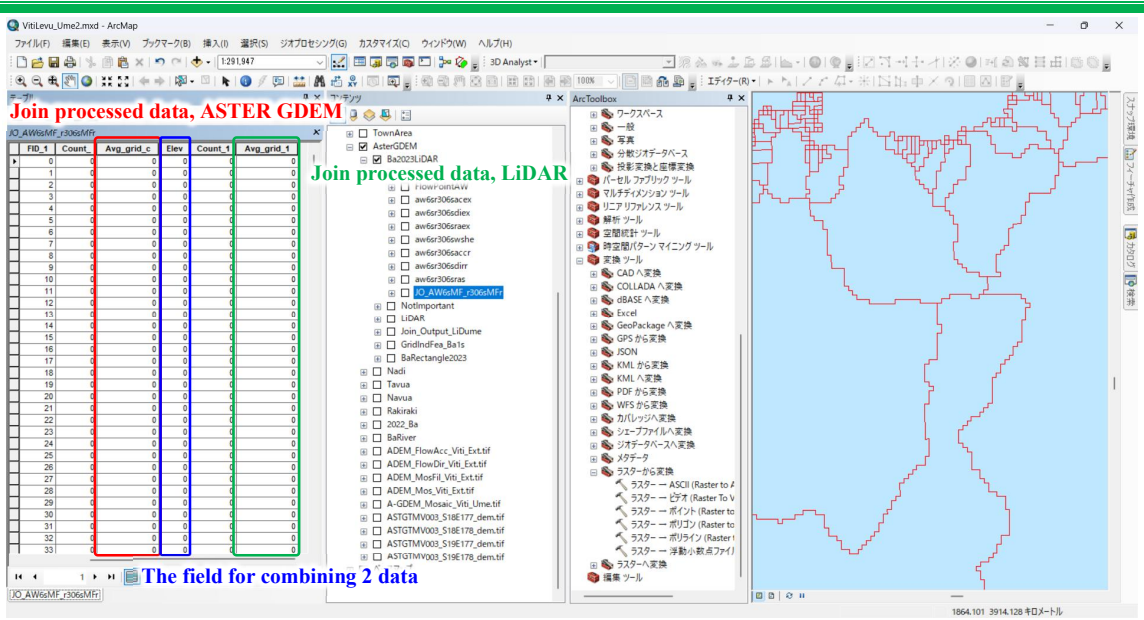
iii. Need to adjust the coordinate system. LiDAR data is set as "Fiji Map Grid (projected coordinate system)" and ASTER GDEM is set as "WGS 1984 (geographic coordinate system, GCS)". Either coordinate system is okay, but since the GCS is basically used for the RRI model so you should set both elevation data as the GCS.

iv. You may need some preparation for LiDAR data. "Join" did not work properly using the given data. First, copy the original give LiDAR data (BA_10m_DTM.shp) and add a field on the attribute table, such as "Elevation". Then, do "Calculate Field" and set the newly created "Elevation = z (elevation value of the LiDAR data)". Lastly, you should delete all unneeded fields (Data management tool > Field > Delete Field).



v. For "Join", it is better to work on a new mxd. You should add only the necessary data (2 vector elevation data and Grid Index Feature) on the new mxd.

vi. Right click on the created Grid Index Feature, then "Join". Select the vector point elevation to join (either ASTER GDEM or LiDAR). It might take more than 24 hours for processing depends on the PC performance and the internet access.



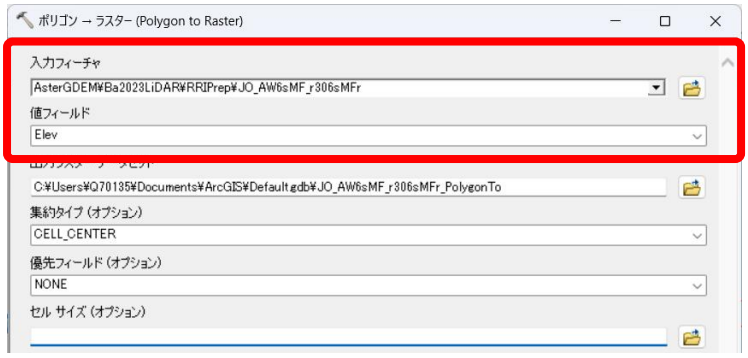
vii. After "Join" of the first data (such as ASTER GDEM), it might be better to create a new field, such as "Elev (to combine both data)" on the attribute table to combine both elevation data. Then, same as "iv", Calculate Field > "Elev = average elevation (joined one)". Delete all unneeded fields.

viii. Continue the same procedure of "vi" and "vii" for another vector point elevation data (such as LiDAR data / you need to create one more new field for another vector point elevation).

ix. LiDAR data is much precise than the ASTER GDEM. Therefore, the grids which have LiDAR point elevation should use the LiDAR data only. "Attribution search" > "Avg_grid_1 > 0 (in the above case)". Now you do "Calculate Field" only for the selected grids, "Elev = Avg_grid_1". Just in case that the Joint link / data might disconnected, you should "data export".

x. **IMPORTANT:** Due to the inconsistency of both vector point elevation and Grid Index Features, some grids might miss joining the elevation. You need to check especially the edge of data range of both elevation data. If you find out the missing elevation grids, you need to modify manually using editor (refer to the adjacent point elevation for the elevation of the missing grids).

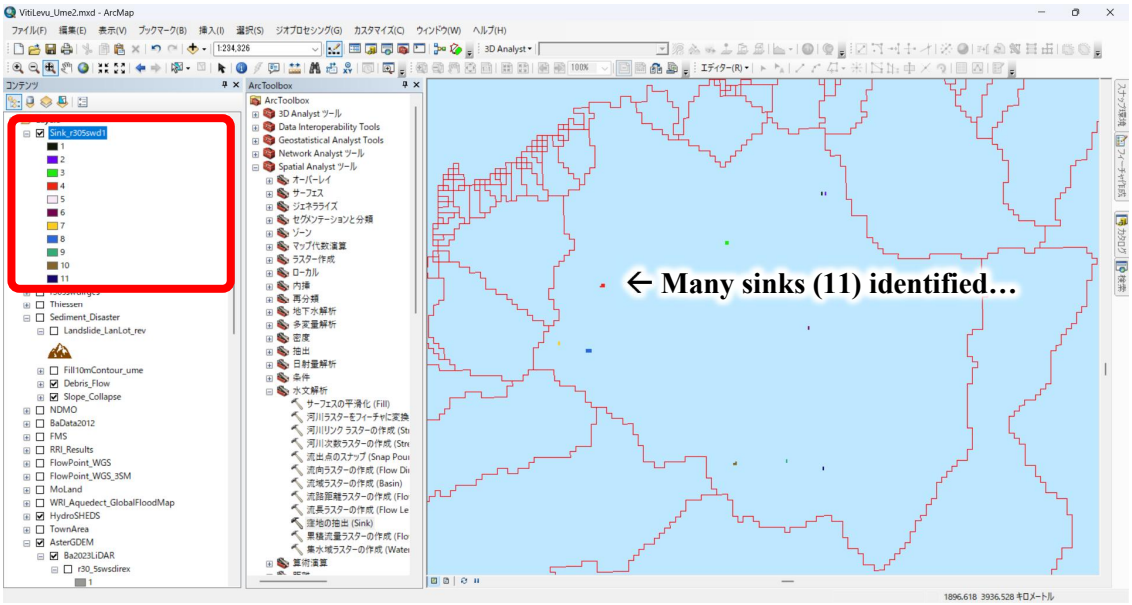
xi. You could manage to combine 2 elevation data. Now you need to convert the vector data back to raster data. Conversion tool > Conversion to Raster > Polygon to Raster (you need to select the "Value field" as "Elev")".



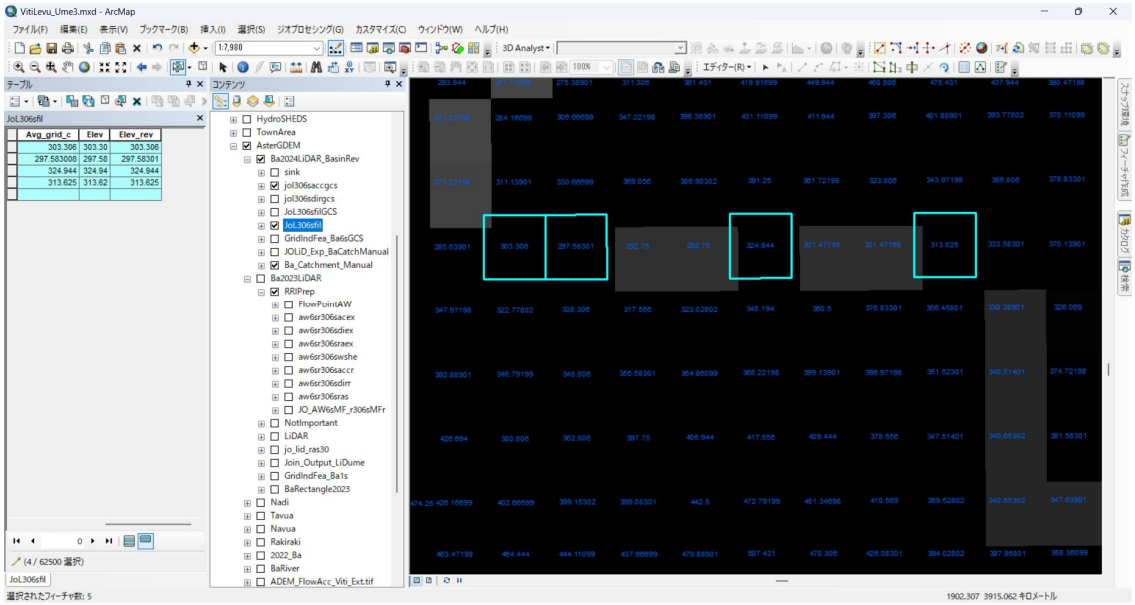
* I do not know why but the converted raster data is slightly moved than the vector Grid Index Feature…

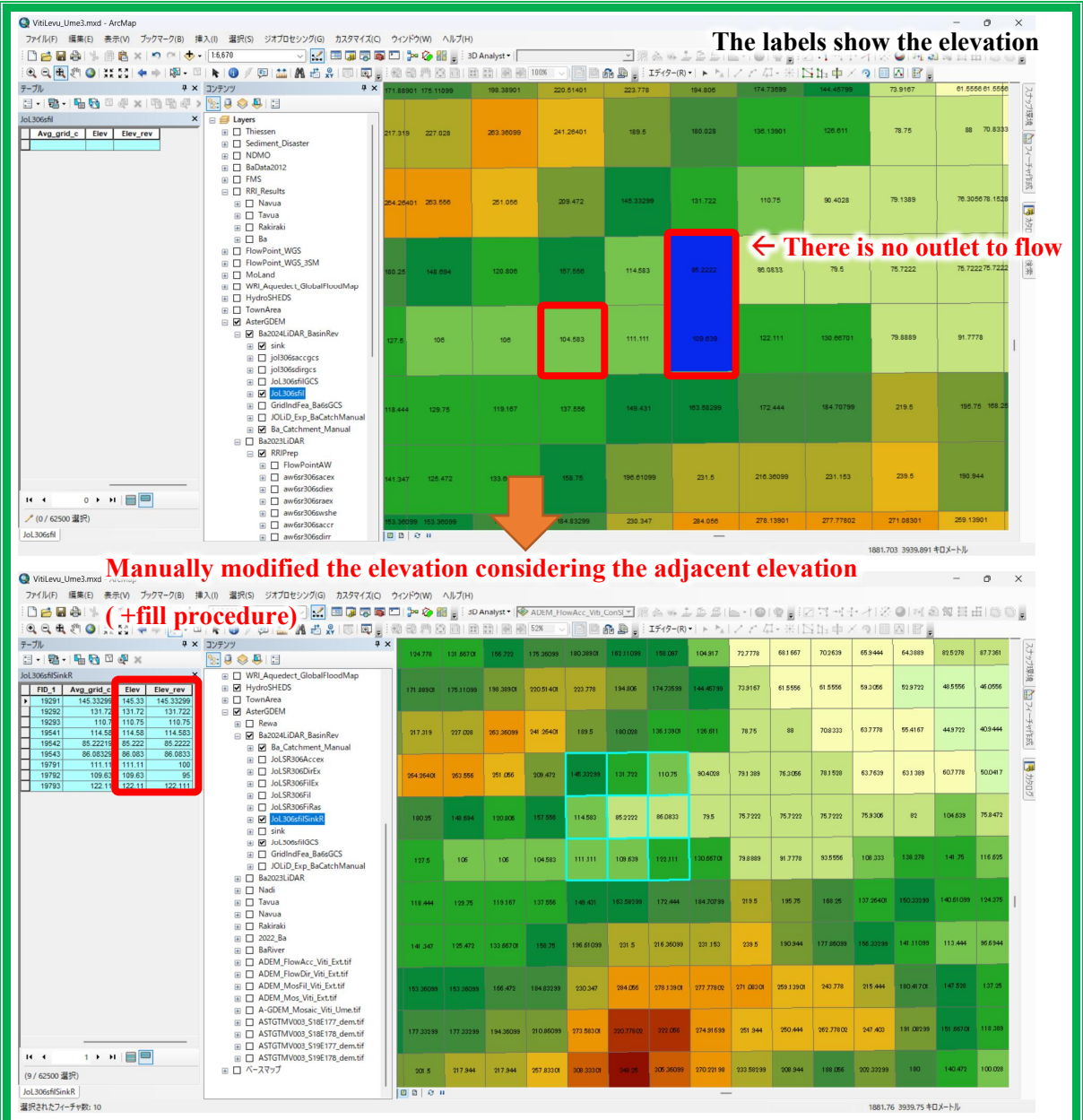
IMPORTANT: If there are any sinks in the flow direction raster, it will cause malfunctioning of the RRI calculation. So, it is better to check the sinks using the sink command (after you create the flow direction [refer to 12)]). Search a command, "Sink (Spatial Analyst Tool)" on the

ArcGIS. If you find any sinks, you need to modify the elevation data (manually), especially on the vector elevation data. Check and modify the elevation surrounding the sinks to make it flows.

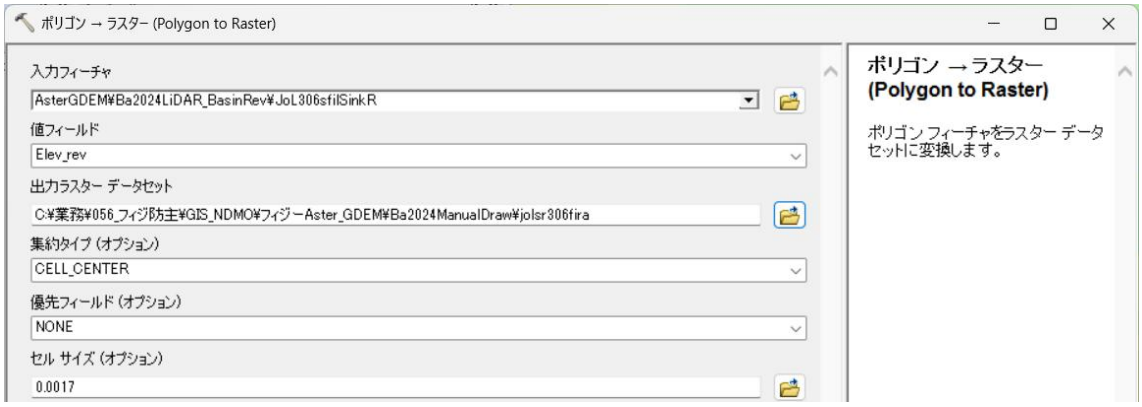


xii. You also need to check the continuousness of the flow accumulation. If there are non-contiguous sections shown as below, you need to check one by one and modify the elevation manually.



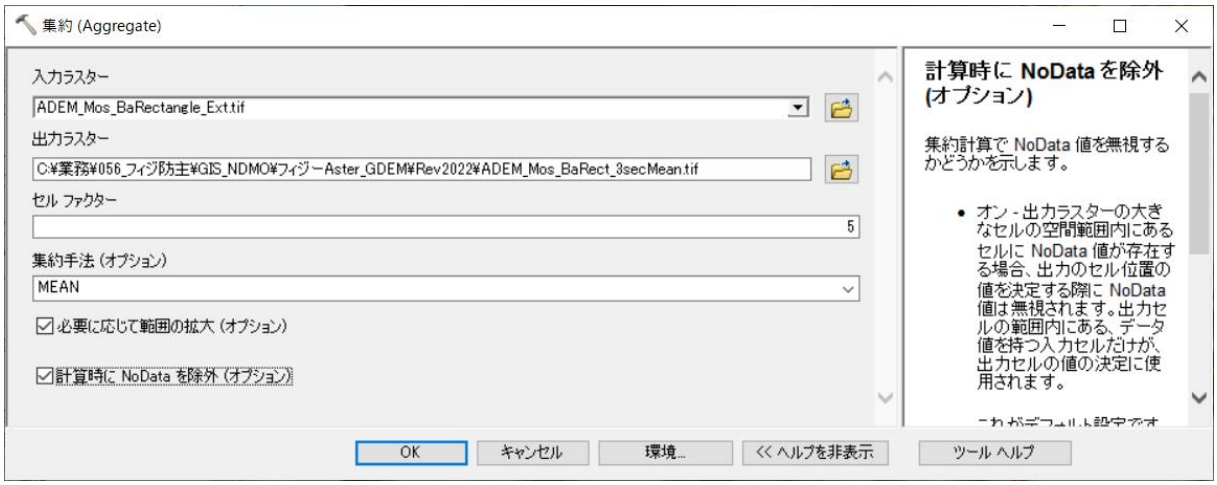


xiii. After you modify the elevation in the Vector data, it needs to be converted to the Raster data. There might be some options to do it, but maybe you can use "Polygon to Raster" if you have an extension of the "Spatial analyst".



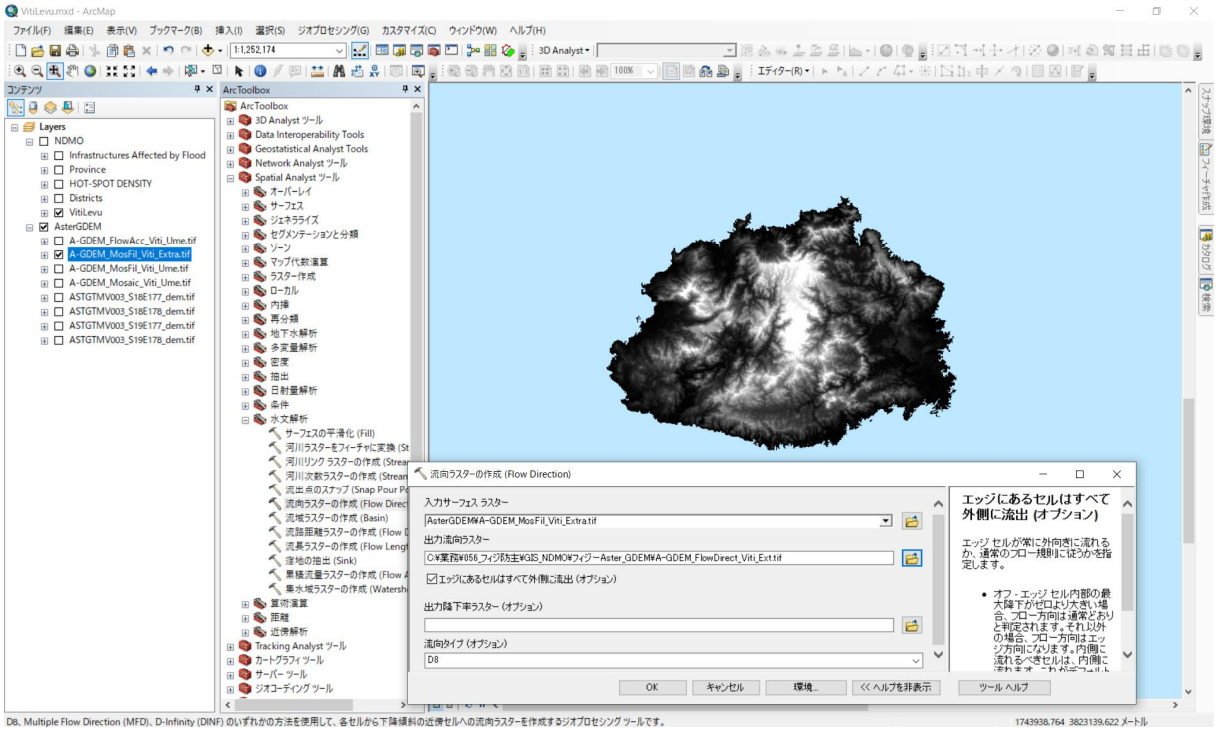
xiv. Now you continue the below procedures.

10) Aggregate if the downloaded DEM is too high resolution (Aggregate to make the number of column or row of the DEM to be less than 1,000), you might degrade the resolution. Search a command, “Aggregate” on the ArcGIS. If you set the cell factor as “3”, above ASTER GDEM 1 arc-second will be 3 arc-second (=approximately 90m), if you set the cell factor as “5”, it will be aggregated as 5 arc-second (=approximately 150m). Aggregate method should be “Mean (average)”. *Be careful, default setting of Aggregate method is set as “Sum”. Make sure to change it to “Mean”.

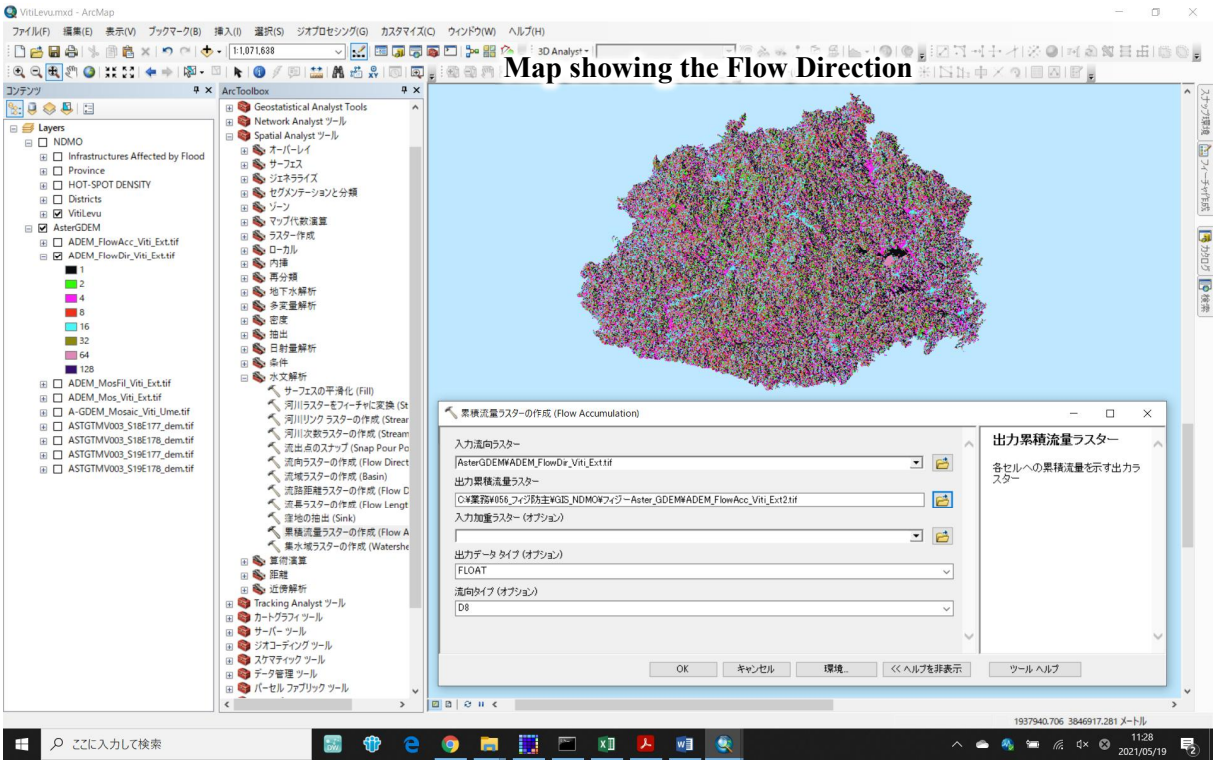


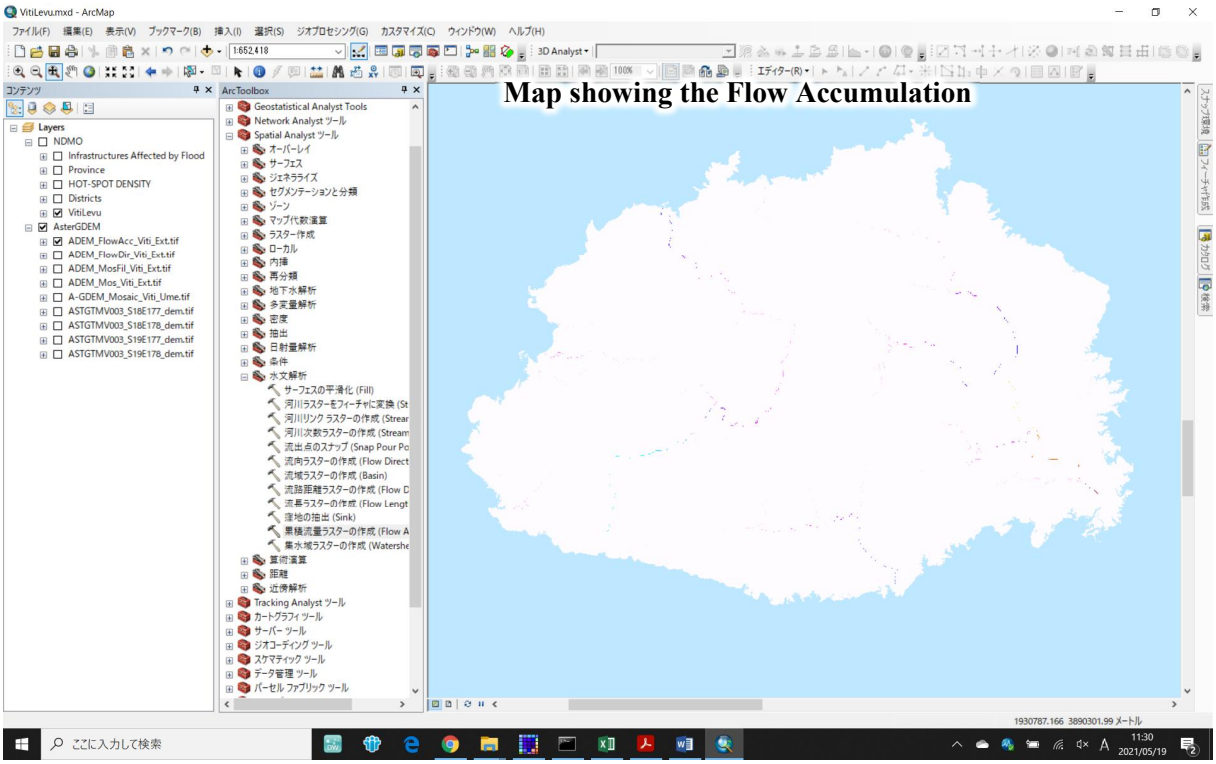
11) Fill the “low-lying depression” points. If there are low-lying depression points, flow direction gathers towards those points and there is no way out of the flow. It will cause a calculation error. Search a command, “Fill” on the ArcGIS, then just set the input raster data (in this case, above extracted DEM raster data / aggregated DEM raster data) and output raster data.

12) Create “Flow Direction” raster. Search a command, “Flow Direction” on the ArcGIS, then set the parameters as below using the “filled + extracted DEM raster data” created in 11).

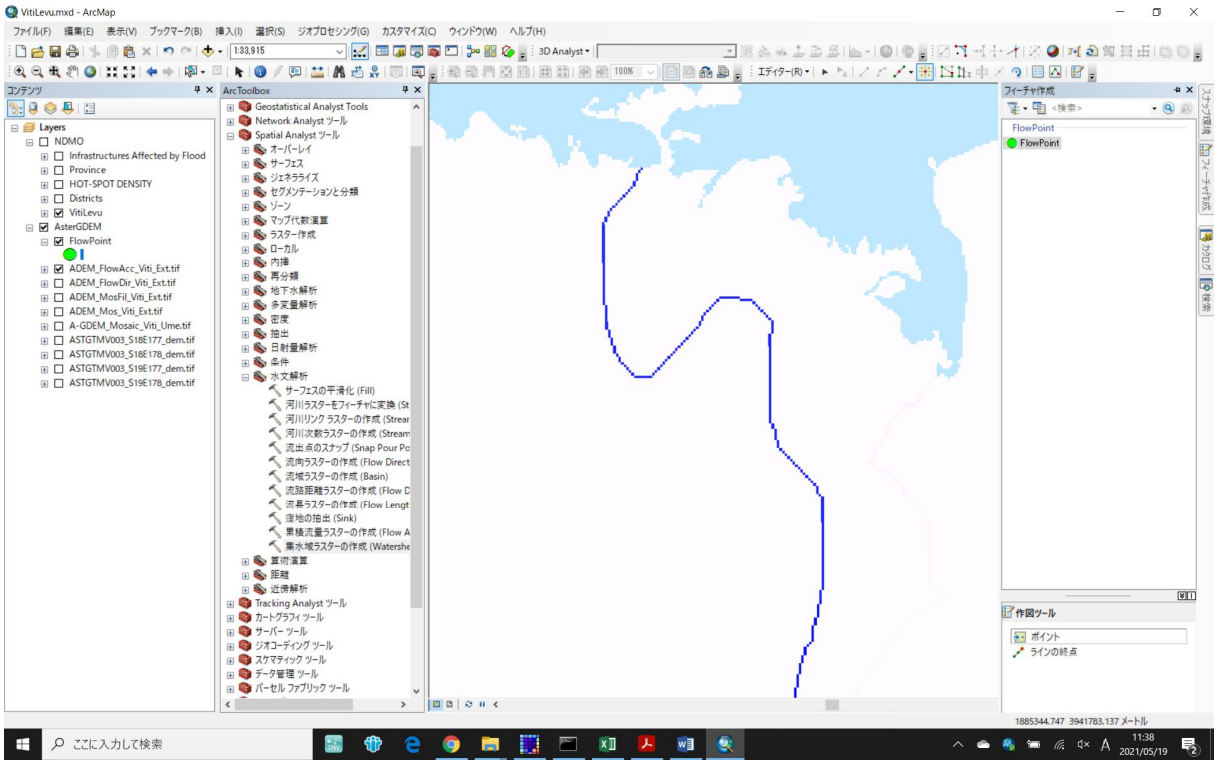


13) Create “Flow Accumulation” raster. Search a command, “Flow Accumulation” on the ArcGIS, then set the parameters as below using the “Flow Direction raster” created in 12).

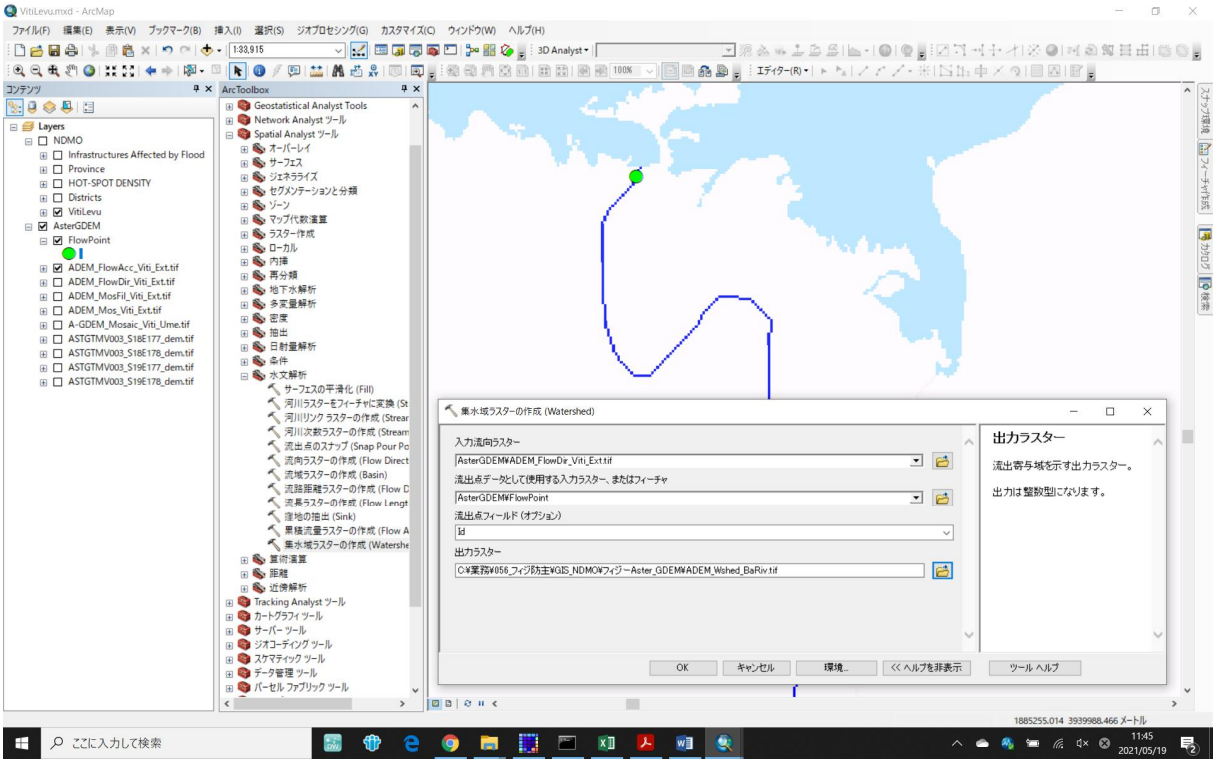


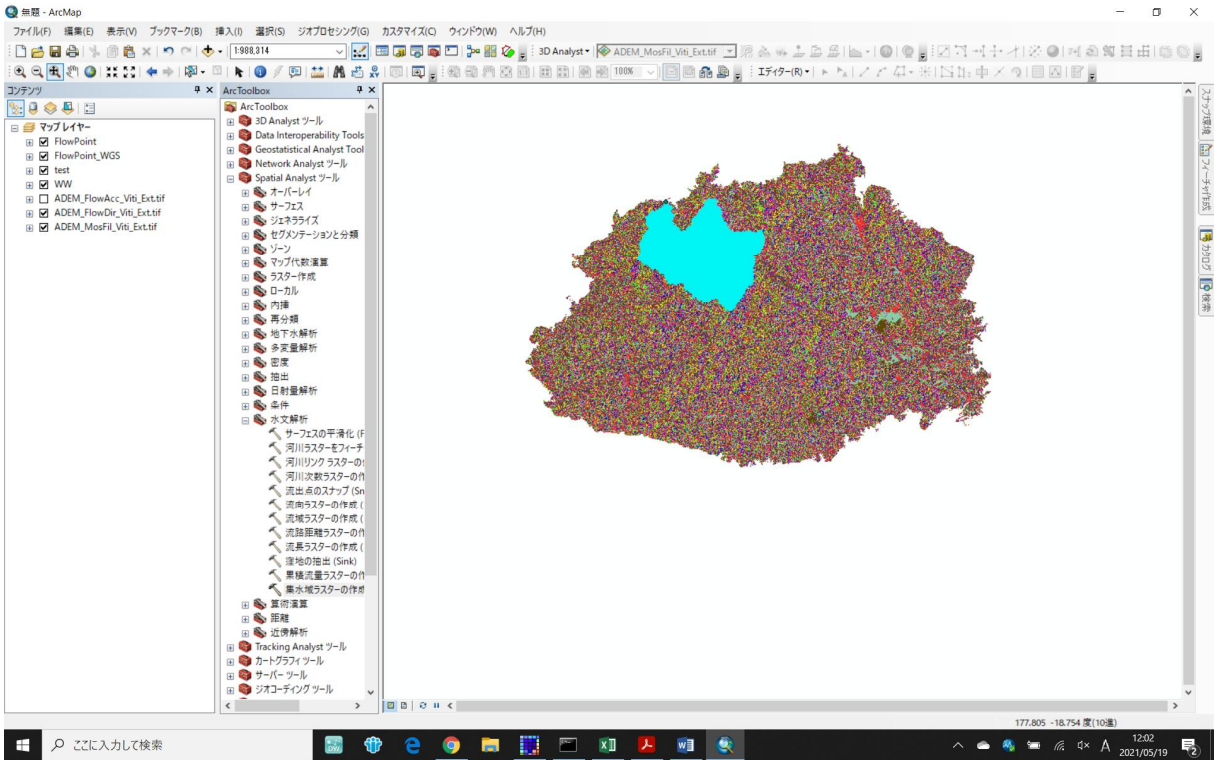


14) Create a new shape file, point shape to edit an outlet point of the target watershed / river basin (You need to select the appropriate coordination system, such as Fiji Map Grid or GCS_WGS_1984). Then, Start editing > Put the outlet point at the downstream of the target river > Save editing > Finish editing.

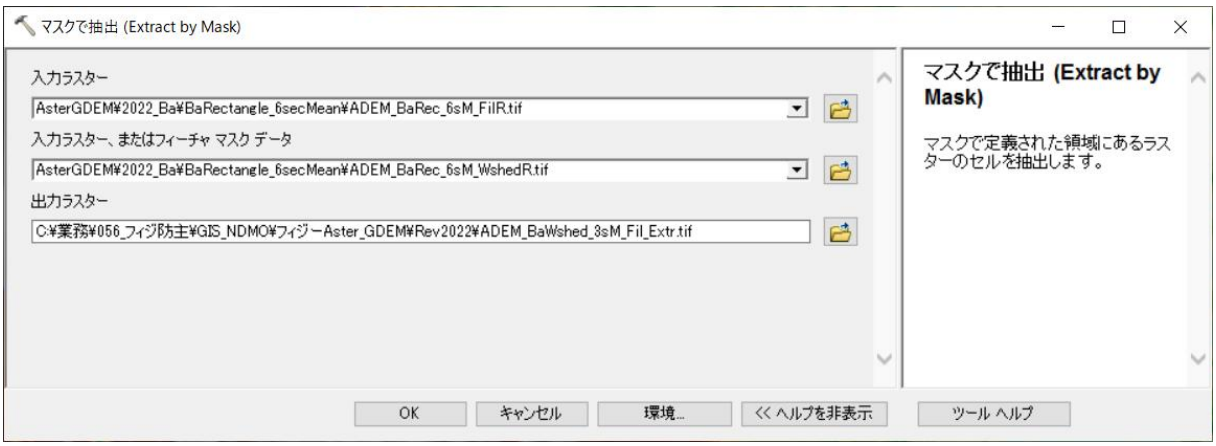


15) Create a "Watershed" raster. Search a command, "Watershed" on the ArcGIS, then set the parameters as below using the "Flow Direction raster" created in 12) and the point data created in 14). *If an error appears and the watershed cannot be created, it might be due to a mismatch of coordination system. In that case, create a new map and adding the necessary raster data, such as flow direction and point data, then create a watershed raster again.





16) Now extract the above created “Fill (DEM)”, “Flow direction” and “Flow accumulation” by the above created “Watershed”. “Extract by Mask” on the ArcGIS, then set the parameters as below. Input raster will be “Fill” or “Flow direction” or “Flow accumulation”, which are created above. And the Input Mask Raster will be “Watershed”. Repeat the same procedure for all the input raster data.



17) After extracting the raster data by watershed, check a number of column and row and cell size once again to make sure the numbers of column and row do not exceed 1,000 (Right click on the extracted raster data > property > source tab, then "column and row" and "cell size").

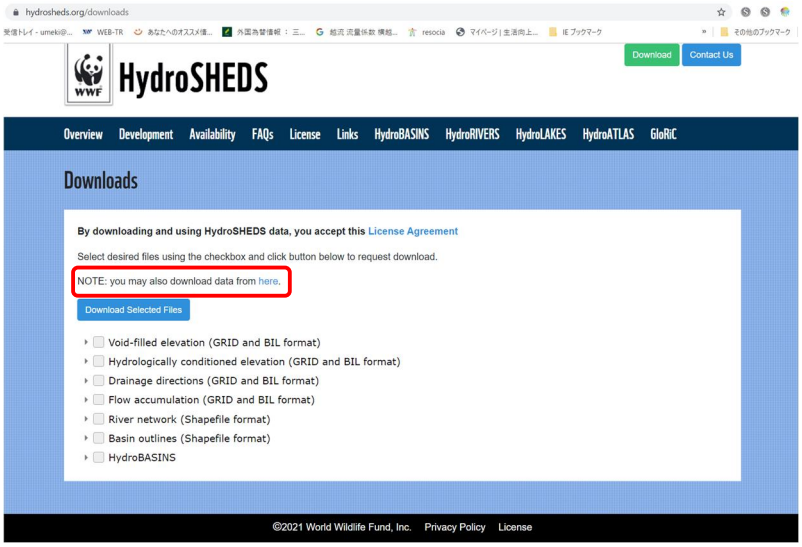
18) The final step is converting the above raster data to ASCII file. Search for the command, "Raster to ASCII", then convert the above extracted raster data, "Fill (DEM)", "Flow direction" and "Flow accumulation" by the "Watershed", to ASCII files (Conversion tool > Raster to ASCII).You should save the output ASCII files in the project folder of the RRI model (If you have not prepared a folder for the RRI model, you can move the ASCII files later to your project folder of the RRI model later). Name of the ASCII files should be, "dem.txt" for Fill (DEM), "dir.txt" for Flow Direction and "acc.txt" for Flow Accumulation.

[You can skip Section 2.1.2 if you finished creating above 3 ASCII files]

2.1.2 With HydroSHEDS

1) There is another option for free digital elevation model (DEM) data and so on and it is available on the website below. Then, unzip the downloaded data, such as DEM data, DIR, ACC, RIV, and BAS and so on.

https://www.hydrosheds.org/downloads



Data availability

The HydroSHEDS database provides a suite of raster and vector datasets, covering many of the common derivative products used in hydrological analyses. The HydroSHEDS data layers are being developed for all landmasses of the globe from 56° South to 84° North (i.e. excluding Antarctica). The data is prepared in seamless mode (no edge effects) and is provided as global or regional maps, or in 5-degree by 5-degree tile coverage. HydroSHEDS is produced on a continental basis. The drainage direction maps—which represent the primary data layer from which all other products are derived—have been completed or are scheduled for release as follows:

Original regions (56°S to 60°N)	
South America	Completed (May 2006)
Central America (Mexico and Caribbean)	Completed (March 2007)
Asia	Completed (March 2007)
Africa	Completed (October 2007)
Australasia	Completed (March 2008)
Europe and Middle East	Completed (October 2008)
North America (USA and Canada)	Completed (January 2009)
Appended regions (north of 60°N)	
Arctic (northern Canada)	Scheduled for December 2015
Scandinavia and Iceland	Scheduled for December 2015
Siberia	Scheduled for December 2015
Greenland	Scheduled for December 2015

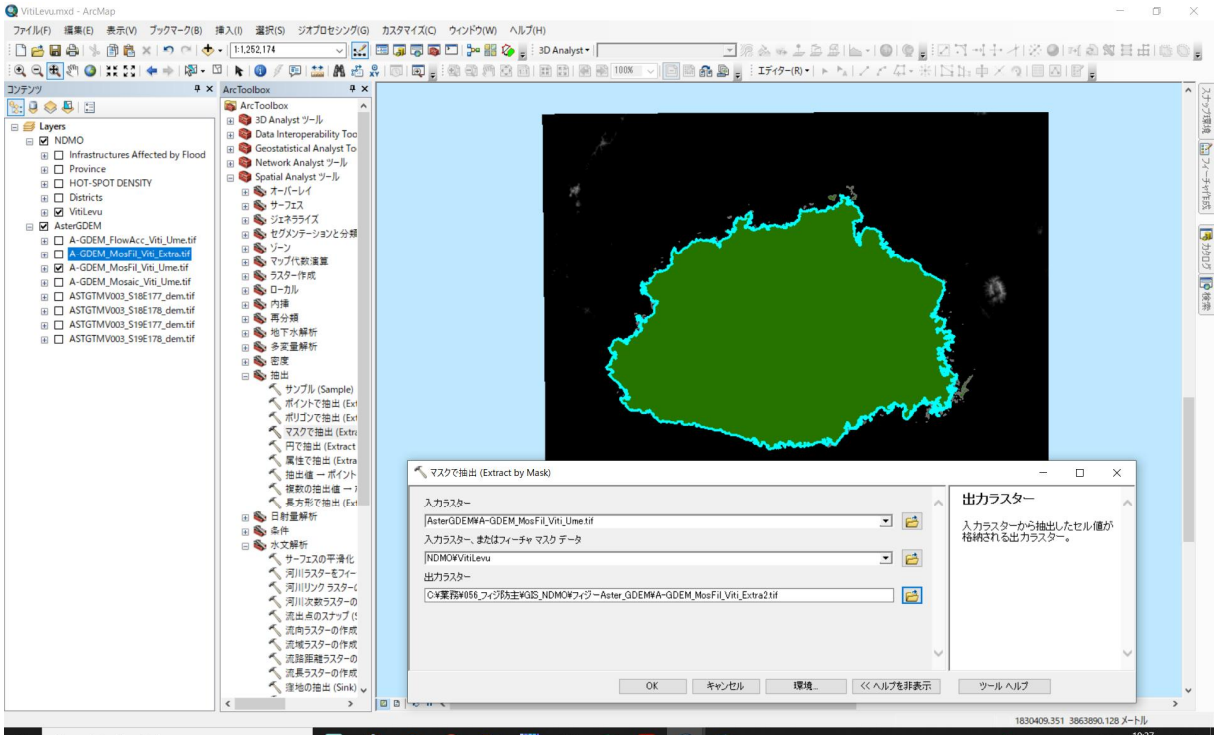
Data layers

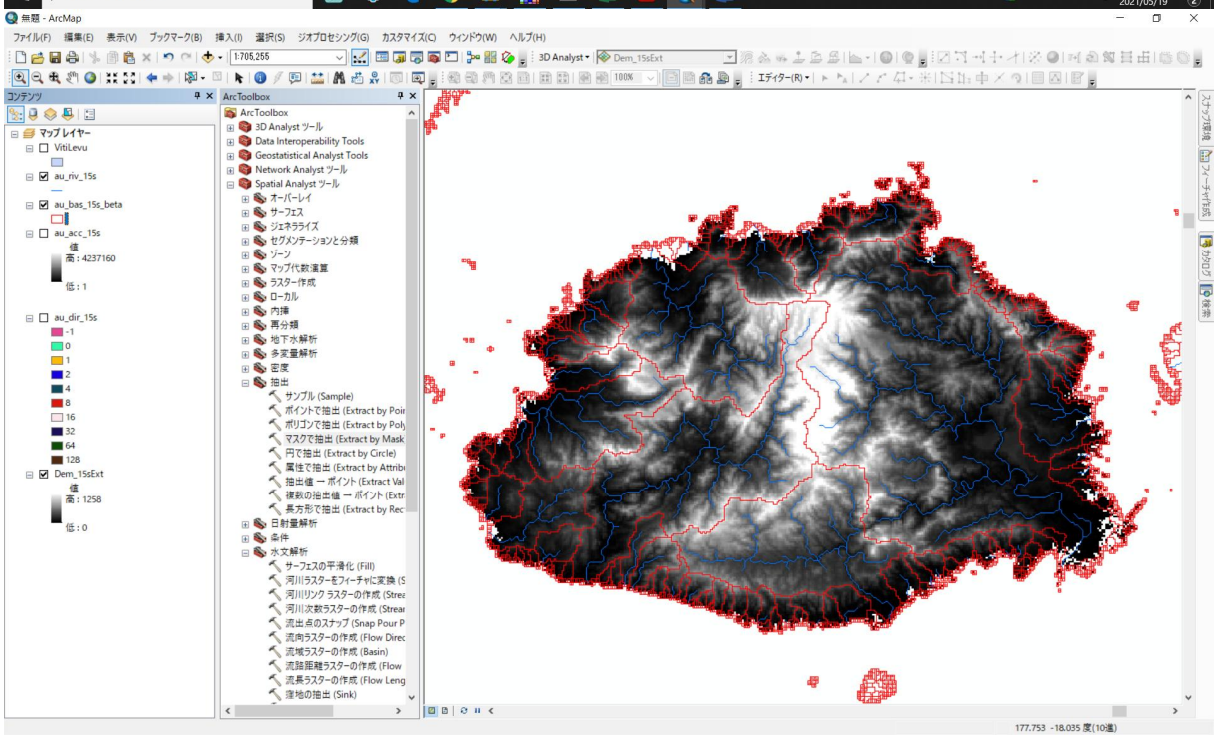
At this time, HydroSHEDS provides several core data layers at 3 arc-second, 15 arc-second, and 30 arc-second resolutions, including elevation surfaces, drainage directions, river networks, and watershed boundaries. Additional data layers are under construction, and future data developments are planned. Currently, the following data layers and resolutions are available:

Index	HydroSHEDS data layer	Format	Resolution(s)
DEM	Void-filled elevation	Raster	3 sec, 15 sec, 30 sec
CON	Hydrologically conditioned elevation	Raster	3 sec
DIR	Drainage directions	Raster	3 sec, 15 sec, 30 sec
ACC	Flow accumulation (number of cells)	Raster	15 sec, 30 sec
RIV	River network (lines)	Vector	15 sec, 30 sec
BAS	Drainage basins (polygons)	Vector	15 sec, 30 sec

As the primary data layer, the **drainage direction maps** define the direction of flow from each cell in the conditioned DEM to its steepest down-slope neighbor. Values of flow direction vary from 1 to 128. All final outlet cells to the ocean are flagged with a value of 0. All cells that mark the lowest point

2) The data contains all Australian area data, so here, extract only the Viti Levu Island. Search a command, “Extract by Mask” on the ArcGIS, then set the parameters as below. Extract DEM, Flow direction and accumulation by Mask. You can also extract the river (polyline shape) and basin (polygon shape) data by highlighting all the rivers / basins in the Viti Levu Island through “Spatial Search” and “Data Export”.





3) Now, you follow the procedure 14) of 2.1.1With ASTER GDEM.

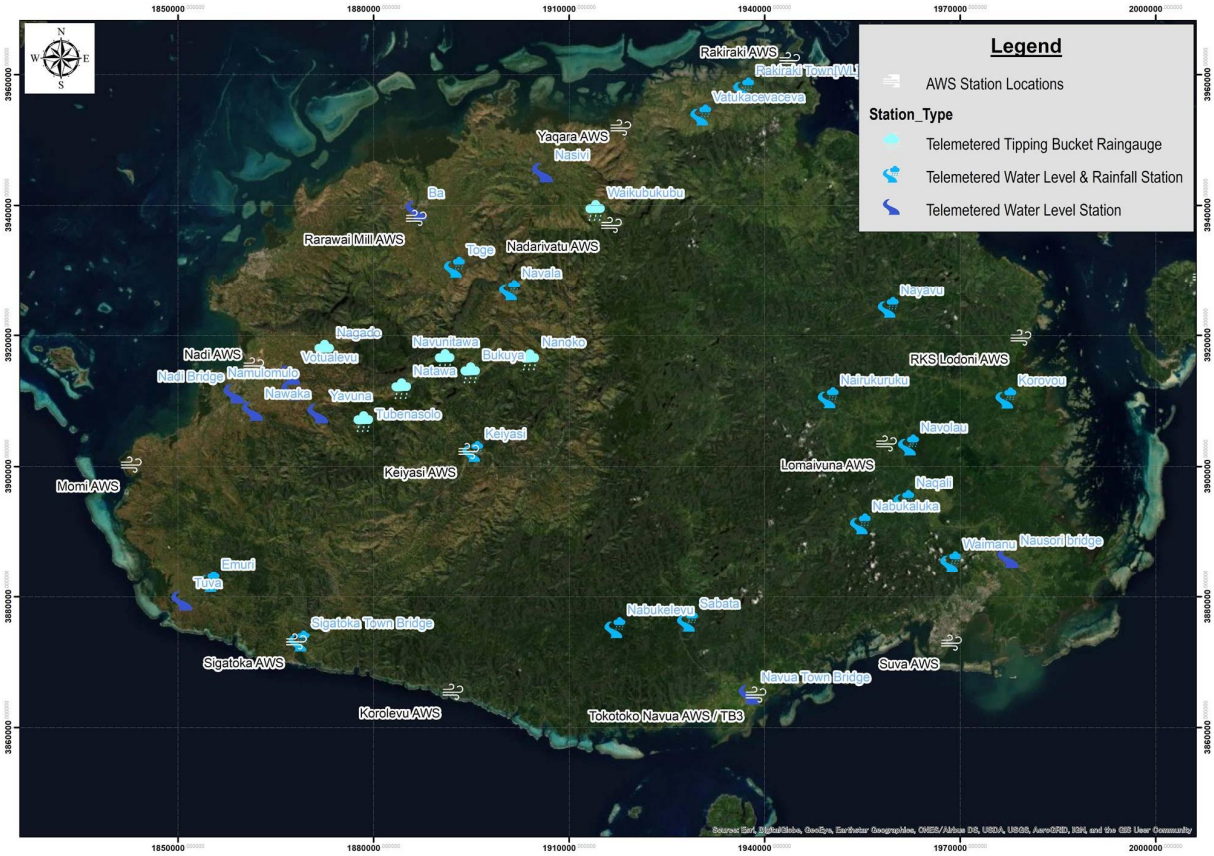
4) The website might be updated from time to time. The data is now categorized as “HydroSHEDS”, “HydroBASINS”, “HydroRIVERS” and so on as of 2022. You can download the data from the link: https://www.hydrosheds.org/hydrosheds-core-downloads

2.2 Rainfall Data

Rainfall data is one of the essential data to be set as an extra force in a hydraulic / hydrological analyses. Therefore, understanding the available data, such as location of the observation gauges / spatial distribution, type of the data (hourly / daily observation), time-series of data, is important.

Following steps will be taken to prepare for rainfall data.

1) List up and plot the observation gauges in the country to check the location of the gauges. "Average depth of rainfall over watershed area" is used in a flood simulation. Therefore, latitude and longitude of each observation gauge are required.



2) Check the availability of the observed data. It is preferable to organize the data as an inventory. In this project, "Daily_Rainfall_Inventory_(Name of the basin_Date).xlsx" is used to organize the observed data in the basin in order to utilize for a flood analysis.

Rainfall Inventory [Rakiraki]

Catchment	Station	Months	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
Rakiraki	FSC Penang MILL RF	Jan	2missing	*	*	*	*	*	*	*	*	*
		Feb	1missing	*	*	*	2missing	2missing	*	*	*	*
	Coordinate	Mar	*	*	*	*	1missing	*	1missing	*	*	*
Lat		Apr	*	*	*	1missing	1missing	6missing	*	*	*	*
Lon		May	*	*	*	*	2missing	*	*	*	*	*
		Jun	*	*	*	*	*	*	*	*	*	*
	Reference	Jul	*	*	*	*	*	*	*	1missing	*	*
	C	Aug	*	*	*	*	*	*	*	*	*	*
		Sep	*	*	*	*	*	*	*	*	*	*
		Oct	*	*	*	*	*	*	*	*	*	*
		Nov	*	*	*	1missing	*	*	*	*	*	*
		Dec	2missing	*	*	*	*	3missing	*	*	*	*
Rakiraki	Penang TB3	Jan	*	*	*	*	*	*	*	*	*	*
		Feb	*	*	*	*	*	*	*	*	*	*
	Coordinate	Mar	*	*	*	*	*	*	11missing	*	*	*
Lat		Apr	*	*	*	*	*	*	13missing	15missing	*	*
Lon		May	*	*	*	*	*	*	*	24missing	*	*
		Jun	*	*	*	*	*	*	*	*	*	*
	Reference	Jul	*	*	*	*	*	*	*	*	*	*
	E	Aug	*	*	*	*	*	*	*	*	*	*
		Sep	*	*	*	*	*	*	*	*	*	*
		Oct	*	*	*	*	*	*	*	*	*	*
		Nov	*	*	*	*	*	*	*	*	*	*
		Dec	*	*	*	*	*	*	*	*	*	*

3) Even though “How to use” the “Daily_Rainfall_Inventory_(Name of the basin_Date).xlsx” is written in the excel file, you can also follow a procedure as below.

DO NOT insert rows
DO NOT change the formulae
Basically DO NOT change "For Calculation / Cell Reference No."

1. Copy the original data

1) Copy / utilize the already prepared inventory file of other basins, then rename the file
2) Delete the data in "Columns B to I" in "Original Sheet" *If you need to add more stations, you can insert columns between Columns B to I **You can change the cell color if needed
3) Change the name of the stations in "Original Sheet", "Daily_Inventory" and "DailyMax"
4) Copy the date and rainfall from each station and paste special "Values" on the corresponding day
5) "Blank cells" are counted on the Inventory sheet, so if missing data are represented as other expressions, such as "missing" or "error", you need to modify the data *You can "Replace" (Ctrl+H) the data to modify

2. Modify the range of the Daily_Inventory

6) To modify the range of the daily inventory, simply copy the existing formulae. Therefore, check the "start and end days" of observations for each station
7) Highlight 4 columns (existing formulae) and drag to the start / end of observation [refer to the right figure]
8) Delete the data in no-observed month / year [refer to the right figure]

3. Modify the range of the DailyMax

9) Basically it is similar with above "2."
10) Highlight 4 columns (existing formulae, including the row of "Annual Max") and drag to the start / end of observation
11) Delete the data in no-observed month / year [refer to the right figure]

4. Check any abnormal data on Daily_Inventory and DailyMax

12) You might find some abnormal values / errors in the data, so you need to look through the data [refer to the right figure]
13) You night need to modify the above abnormal values / errors

5. If you need to add more stations in "Daily_Inventory"

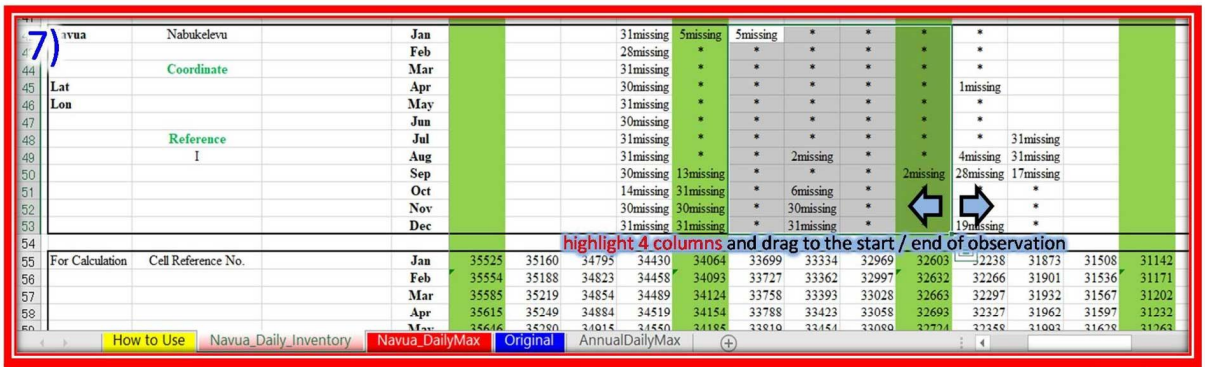
14) Highlight 13 rows (including narrow blank row on the top) and copy, then insert copied cells below [refer to the below figure]
15) Make sure the style / form is similar with others, then change the name, coordinate and reference No.
16) Highlight 13 rows (including blank row on the bottom), which have formulae, and copy, then paste below [refer to the below figure]
17) Change the reference No. on "Column DH*" (in order of C, E, G, I, K, M, O, Q....) [refer to the below figure]
18) Now follow "2." step and make sure the "missings" are counted properly
*if you inserted some more years based on the step "7.", the location of the reference No. "Column DH" will change
add) Insert columns on "Original" sheet next to Column "I" for additional stations [refer to the below figure]

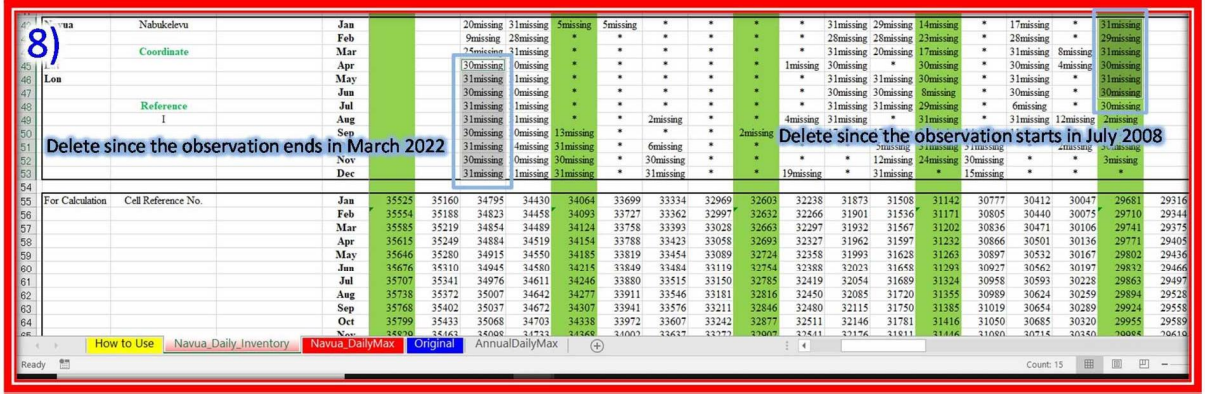
6. Add more stations in "DailyMax"

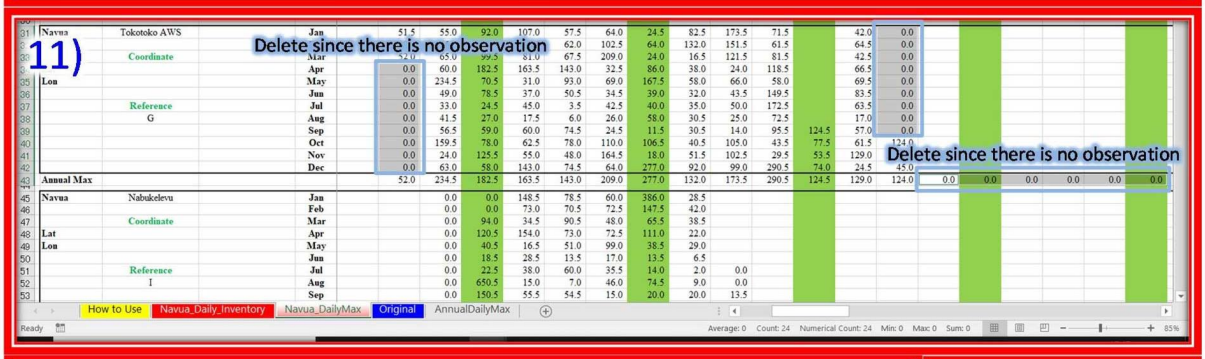
19) Do the similar procedures as "5."
20) Highlight 14 rows (including narrow blank row on top and Annual Max row) and copy, then insert copied cells below [refer to the below figure]
21) Make sure the style / form is similar with others, then change the name, coordinate and reference No.
22) Highlight 14 rows (including blank rows on the bottom), which have formulae, and copy, then paste below [refer to the below figure]
23) Change the reference No. on "Column DH*" (in order of C, E, G, I, K, M, O, Q....)
24) Now follow "3." step and make sure the daily maximum precipitations are read properly
*if you inserted some more years based on the step "7.", the location of the reference No. "Column DH" will change

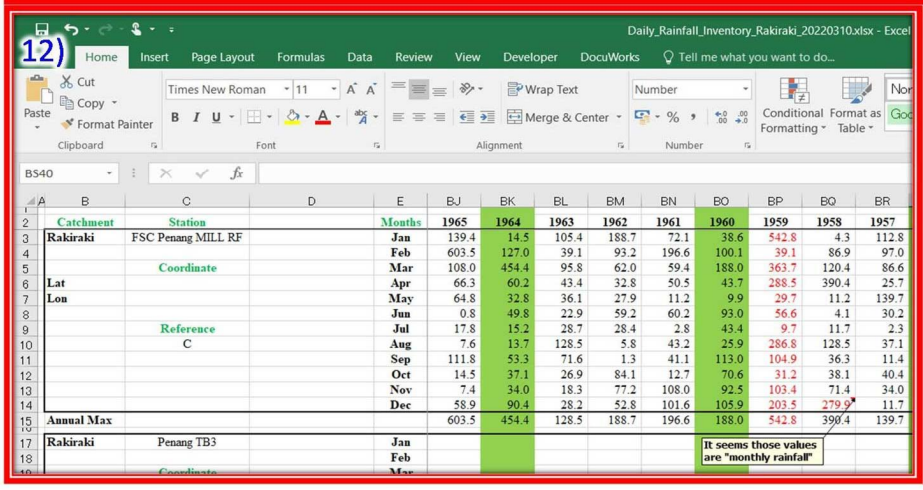
7. If you need to add more years(after 2031 or before 1926)

25) Insert columns next to the year you want to add [refer to the below figure]
26) Highlight 4 columns from "Cell Reference No." to the end (the blank row in the bottom), which have formulae [refer to the below figure]
27) Then drag to the right to copy the highlighted cells [refer to the below figure]
28) Adjust / modify the style [refer to the below figure]
29) Repeat the same procedures above, 25) to 28) for "DailyMax" sheet


7)
highlight 4 columns and drag to the start / end of observation
How to Use
Navua_Daily_Inventory
Navua_DailyMax
Original
AnnualDailyMax


8)
Delete since the observation ends in March 2022
Delete since the observation starts in July 2008
How to Use
Navua_Daily_Inventory
Navua_DailyMax
Original
AnnualDailyMax


11)
Delete since there is no observation
Delete since there is no observation
How to Use
Navua_Daily_Inventory
Navua_DailyMax
Original
AnnualDailyMax


12)
Daily_RainfalI_Inventory_Rakiraki_20220310.xlsx - Excel
It seems those values are "monthly rainfall"

14)

highlight 13 rows (including narrow blank row on the top) and copy

insert copied cells below

Change the name, coordinate and reference No.

16)

highlight 13 rows (including blank row on the bottom) and copy

paste below (DO NOT insert)

17)

change the reference no on "Column DH" (in order of C, E, G, I, K, M, O, Q....)

insert columns next to Column "I" on "Original" sheet

add)

	B	C	D	E	F	G	H	I	J	K	L
	Date	FSC Penang MILL RF	Date	Penang TB3	Date	Rakiraki AWS	Date	Vanukacevaceva Upstream RF			
lat											
lon											
1926/11/1 9:00	11/1/1926	0.0							1926		
1926/11/2 9:00	11/2/1926	0.3									
1926/11/3 9:00	11/3/1926	0.0									
1926/11/4 9:00	11/4/1926	0.5									
1926/11/5 9:00	11/5/1926	0.0									
1926/11/6 9:00	11/6/1926	0.0									
1926/11/7 9:00	11/7/1926	0.0									
1926/11/8 9:00	11/8/1926	0.0									
1926/11/9 9:00	11/9/1926	2.8									
1926/11/10 9:00	11/10/1926	2.5									
1926/11/11 9:00	11/11/1926	0.0									
1926/11/12 9:00	11/12/1926	0.0									
1926/11/13 9:00	11/13/1926	59.7									
1926/11/14 9:00	11/14/1926	0.0									
1926/11/15 9:00	11/15/1926	0.0									
1926/11/16 9:00	11/16/1926	0.0									
1926/11/17 9:00	11/17/1926	0.0									
1926/11/18 9:00	11/18/1926	0.0									
1926/11/19 9:00	11/19/1926	2.3									
1926/11/20 9:00	11/20/1926	0.8									
1926/11/21 9:00	11/21/1926	0.0									
1926/11/22 9:00	11/22/1926	0.0									
1926/11/23 9:00	11/23/1926	1.0									
1926/11/24 9:00	11/24/1926	0.0									
1926/11/25 9:00	11/25/1926	0.0									
1926/11/26 9:00	11/26/1926	0.0									
1926/11/27 9:00	11/27/1926	0.5									
1926/11/28 9:00	11/28/1926	0.0									
1926/11/29 9:00	11/29/1926	0.0									
1926/11/30 9:00	11/30/1926	0.3									
1926/12/1 9:00	12/1/1926	0.0									
1926/12/2 9:00	12/2/1926	31.8									
1926/12/3 9:00	12/3/1926	3.0									

"Missing" was replaced as blank

Rakiraki_Daily_Inventory | Rakiraki_DailyMax | Original | Sheet3

20)

			Dec											63.0	58.0	143.0	74.5
l Max													52.0	234.5	182.5	163.5	143.0
	Nabukelevu		Jan										46.0	0.0	0.0	148.5	78.5
			Feb										51.5	0.0	0.0	73.0	70.5
	Coordinate		Mar										53.0	0.0	94.0	34.5	90.5
Lat			Apr											0.0	120.5	154.0	73.0
Lon			May											0.0	40.5	16.5	51.0
			Jun											0.0	18.5	28.5	13.5
	Reference		Jul											0.0	22.5	38.0	60.0
	I		Aug											0.0	650.5	15.0	7.0
			Sep											0.0	150.5	55.5	54.5
			Oct											0.5	0.0	53.5	86.5
			Nov											0.0	0.0	97.0	0.0
			Dec											0.0	0.0	0.0	0.0
Annual Max													53.0	0.5	650.5	154.0	90.5
Navua	New		Jan										#REF!	#REF!	#REF!	#REF!	#REF!
													#REF!	#REF!	#REF!	#REF!	#REF!
	Coordinate		Mar										#REF!	#REF!	#REF!	#REF!	#REF!
Lat			Apr											#REF!	#REF!	#REF!	#REF!
Lon			May											#REF!	#REF!	#REF!	#REF!
			Jun											#REF!	#REF!	#REF!	#REF!
	Reference		Jul											#REF!	#REF!	#REF!	#REF!
	K		Aug											#REF!	#REF!	#REF!	#REF!
			Sep											#REF!	#REF!	#REF!	#REF!
			Oct											#REF!	#REF!	#REF!	#REF!
			Nov											#REF!	#REF!	#REF!	#REF!
			Dec											#REF!	#REF!	#REF!	#REF!
Annual Max													#REF!	#REF!	#REF!	#REF!	#REF!
For Calculation	Cell Reference No.		Jan	38082	37717	37352	36986	36621	36256	35891	35525	35160	34795	34430	34064	33699	33334
			Feb	38110	37745	37380	37015	36649	36284	35919	35554	35188	34823	34458	34093	33727	33362
			Mar	38141	37776	37411	37046	36680	36315	35950	35585	35219	34854	34489	34124	33758	33393
			Apr	38171	37806	37441	37076	36710	36345	35980	35615	35249	34884	34519	34154	33788	33423
			May	38202	37837	37472	37107	36741	36376	36011	35646	35280	34915	34550	34185	33819	33454

highlight 14 rows (including narrow blank row on the top and Annual Max row) and copy

insert copied cells below

Change the name, coordinate and reference No.

How to Use | Navua_Daily_Inventory | Navua_DailyMax | Original | AnnualDailyMax

22)

Catchment	Station	Months	2031	2030	2029	2028	2027	2026	2025	2024
		Dec								
	Nabukelevu	Jan								
		Feb								
		Mar								
		Apr								
		May								
		Jun								
		Jul								
		Aug								
		Sep								
		Oct								
		Nov								
		Dec								
	New	Jan								
		Feb								
		Mar								
		Apr								
		May								
		Jun								
		Jul								
		Aug								
		Sep								
		Oct								
		Nov								
		Dec								

highlight 14 rows (including blank rows on the bottom) and copy

paste below (DO NOT insert)

(Ctrl)

25)

insert columns

Catchment	Station	Months	2031	2030	2029	2028	2027
	K	Aug					
		Sep					
		Oct					
		Nov					
		Dec					
For Calculation	Cell Reference No.	Jan	38082	37717	37352	36986	36621
		Feb	38110	37745	37380	37015	36649
		Mar	38141	37776	37411	37046	36680
		Apr	38171	37806	37441	37076	36710
		May	38202	37837	37472	37107	36741
		Jun	38232	37867	37502	37137	36771
		Jul	38263	37898	37533	37168	36802
		Aug	38294	37929	37564	37199	36833
		Sep	38324	37959	37594	37229	36863
		Oct	38355	37990	37625	37260	36894
		Nov	38385	38020	37655	37290	36924
		Dec	38416	38051	37686	37321	36955
	Navua Manual	Jan					
		Feb					
		Mar					
		Apr					
		May					
		Jun					
		Jul					
		Aug					
		Sep					
		Oct					
		Nov					
		Dec					
	Tokotoko TB3	Jan					
		Feb					
		Mar					
		Apr					
		May					
		Jun					
		Jul					
		Aug					

How to Use | Navua_Daily_Inventory | Navua_DailyMax | Original | AnnualDailyMax

26)

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	hment	Station		Months						2031	2030	2029	2028	2027	2026	2025	2024
65				Nov													
66				Dec													
67																	
68	For Calculation	Cell Reference No.		Jan						38082	37717	37352	36986	36621	36256	35891	35525
69				Feb						38110	37745	37380	37015	36649	36284	35919	35554
70				Mar						38141	37776	37411	37046	36680	36315	35950	35585
71				Apr						38171	37806	37441	37076	36710	36345	35980	35615
72				May						38202	37837	37472	37107	36741	36376	36011	35646
73				Jun						38232	37867	37502	37137	36771	36406	36041	35676
74				Jul						38263	37898	37533	37168	36802	36437	36072	35707
75				Aug						38294	37929	37564	37199	36833	36468	36103	35738
76				Sep						38324	37959	37594	37229	36863	36498	36133	35768
77				Oct						38355	37990	37625	37260	36894	36529	36164	35799
78				Nov						38385	38020	37655	37290	36924	36559	36194	35829
79				Dec						38416	38051	37686	37321	36955	36590	36225	35860
80																	
81		Navua Manual		Jan													
82				Feb													
83				Mar													
84				Apr													
85				May													
86				Jun													
87				Jul													
88																	
89				Sep													
90				Oct													
91				Nov													
92				Dec													
93																	
94		Tokotoko TB3		Jan													
95				Feb													
96				Mar													
97				Apr													
98				May													
99				Jun													
100				Jul													
101				Aug													
102				Sep													
103				Oct													
104				Nov													

highlight 4 columns from "Cell Reference No." to the end (the blank row in the bottom), which have formulae

27)

131				Dec													
132																	
133		New		Jan													
134				Feb													
135				Mar													
136				Apr													
137				May													
138				Jun													
139				Jul													
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148																	

Then drag to the right to copy the highlighted cells

How to Use | Navua_Daily_Inventory | Navua_DailyMax | Original | AnnualDailyMax

28)

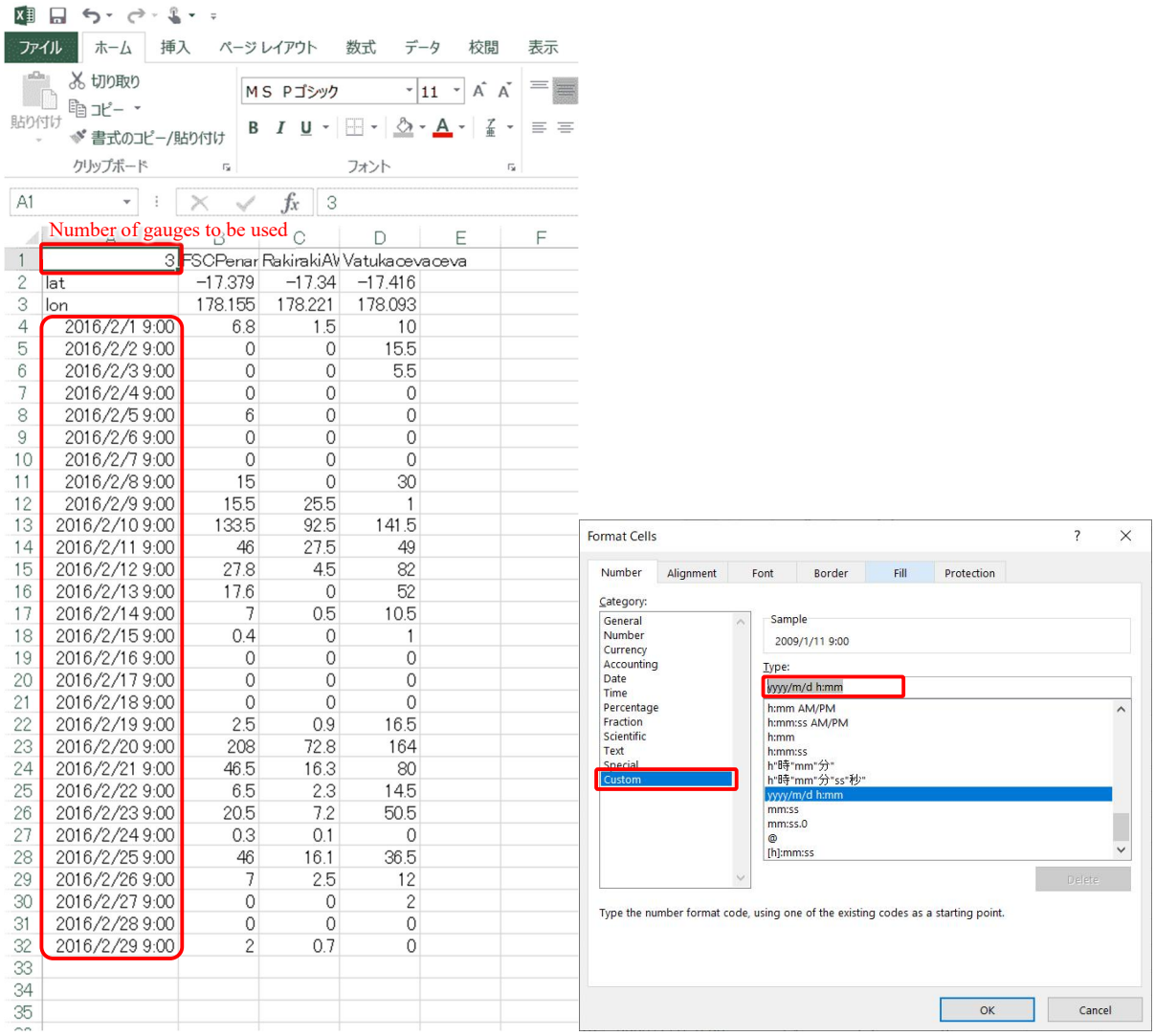
	B	C	D	E	F	G	H	I	J	K	L	M	N
2	tchment	Station		Months	2036	2035	2034	2033	2032	2031	2030	2029	2028
3	Navua	Navua Manual		Jan									
4				Feb									
5		Coordinate		Mar									
6	Lat			Apr									
7	Lon			May									
8				Jun									
9		Reference		Jul									
10		C		Aug									
11				Sep									
12				Oct									
13				Nov									
14				Dec									
15													
16	Navua	Tokotoko TB3		Jan									
17				Feb									
18		Coordinate		Mar									
19	Lat			Apr									
20	Lon			May									
21				Jun									
22		Reference		Jul									
23		E		Aug									
24				Sep									
25				Oct									
26				Nov									
27				Dec									
28													
29	Navua	Tokotoko AWS		Jan									
30				Feb									
31		Coordinate		Mar									
32	Lat			Apr									
33	Lon			May									
34				Jun									
35		Reference		Jul									
36		G		Aug									
37				Sep									
38				Oct									
39				Nov									
40				Dec									
41													
42	Navua	Nabukelevu		Jan									
43				Feb									
44		Coordinate		Mar									

adjust / modify the style

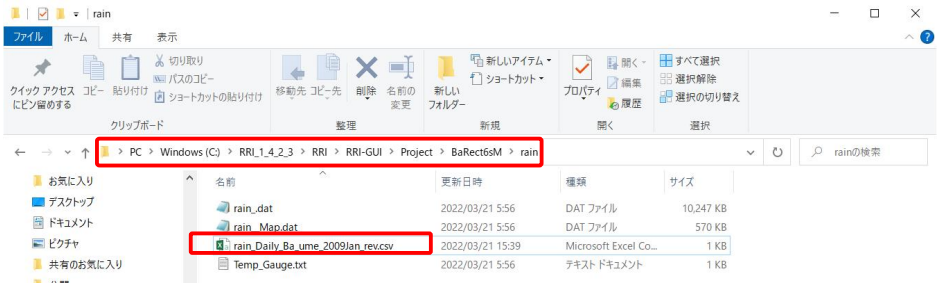
How to Use | Navua_Daily_Inventory | Navua_DailyMax | Original | AnnualDailyMax

4) After preparation of the inventory, you will decide the target date (occurrence date of the passed flood or heavy rainfall events) for the RRI model calculation.

5) Now prepare an input rainfall data for the RRI model as a CSV file. It is consist of “number of rainfall gauges in the watershed to be used for a calculation”, “name of the stations/gauges”, “location (latitude and longitude) of the gauge”, “date and time (it needs to be in this order, “Year / Month / Date / Time”. You might need to adjust the format cells, [yyyy/m/d h:mm]. If you cannot find the appropriate format in the category of “Date” or “Time”, you can click on Custom category and create a new type as yyyy/m/d h:mm)” and “precipitation”.



6) Copy and paste the necessary data / information from the rainfall inventory and prepare the file like as above. Then, save as a CSV file. You can put the CSV file in the “rain” folder in your “Project” folder (refer to the directory below, depending on where you create the RRI folder).

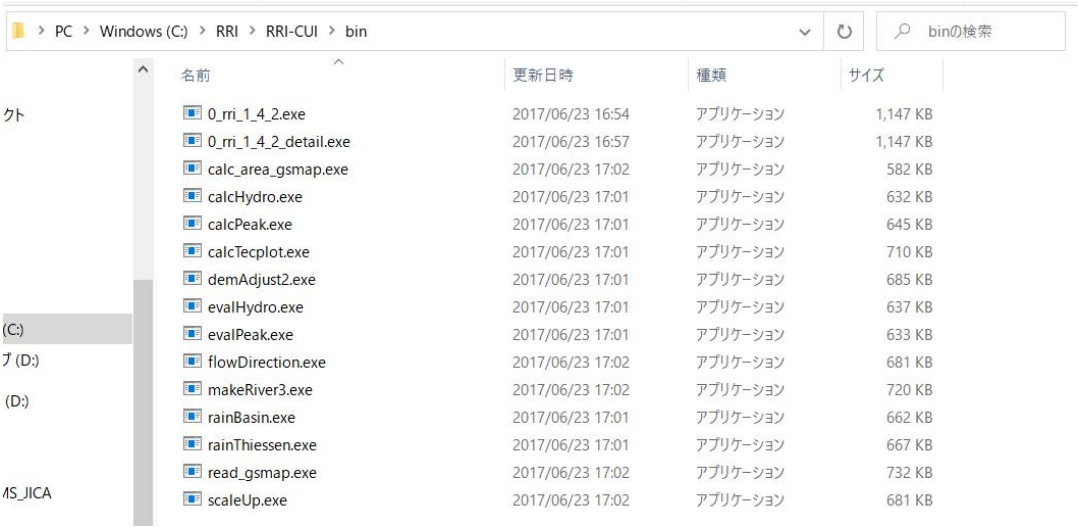


2.3 Adjustment of the Computer Settings - Common Errors you might find-

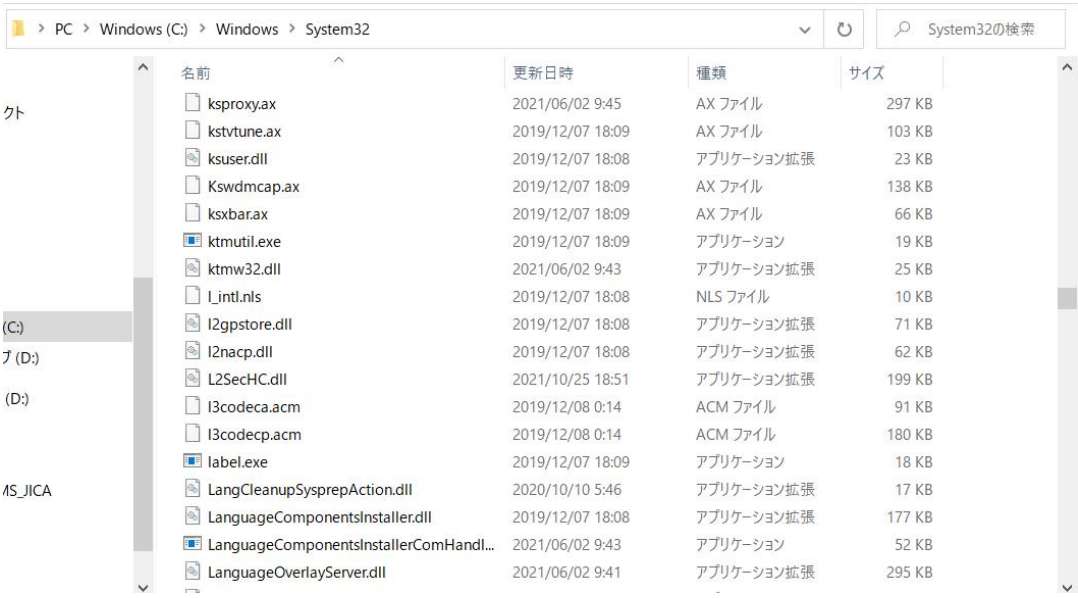
2.3.1 Preparation for the RRI Model (for RRI-Graphical User Interface, GUI)

1) After preparation of the raster data, DEM, Flow Direction / Accumulation and Watershed, now follow the RRI manual, **p.3-1 or p.9-1 (depends on the version of the RRI manual)**. Extract each raster data for the target river basin.

2) Some of the external / optional exe-files are in the RRI-CUI folder and it can be used even for GUI, so the below procedure might be needed.



3) When you set the rain data or run the model, errors, such as "**libiomp5md.dll** cannot be found", might be detected and it might fail to function. In this case, you can try to put "libiomp5md.dll" file into "**C:\Windows\System32**".



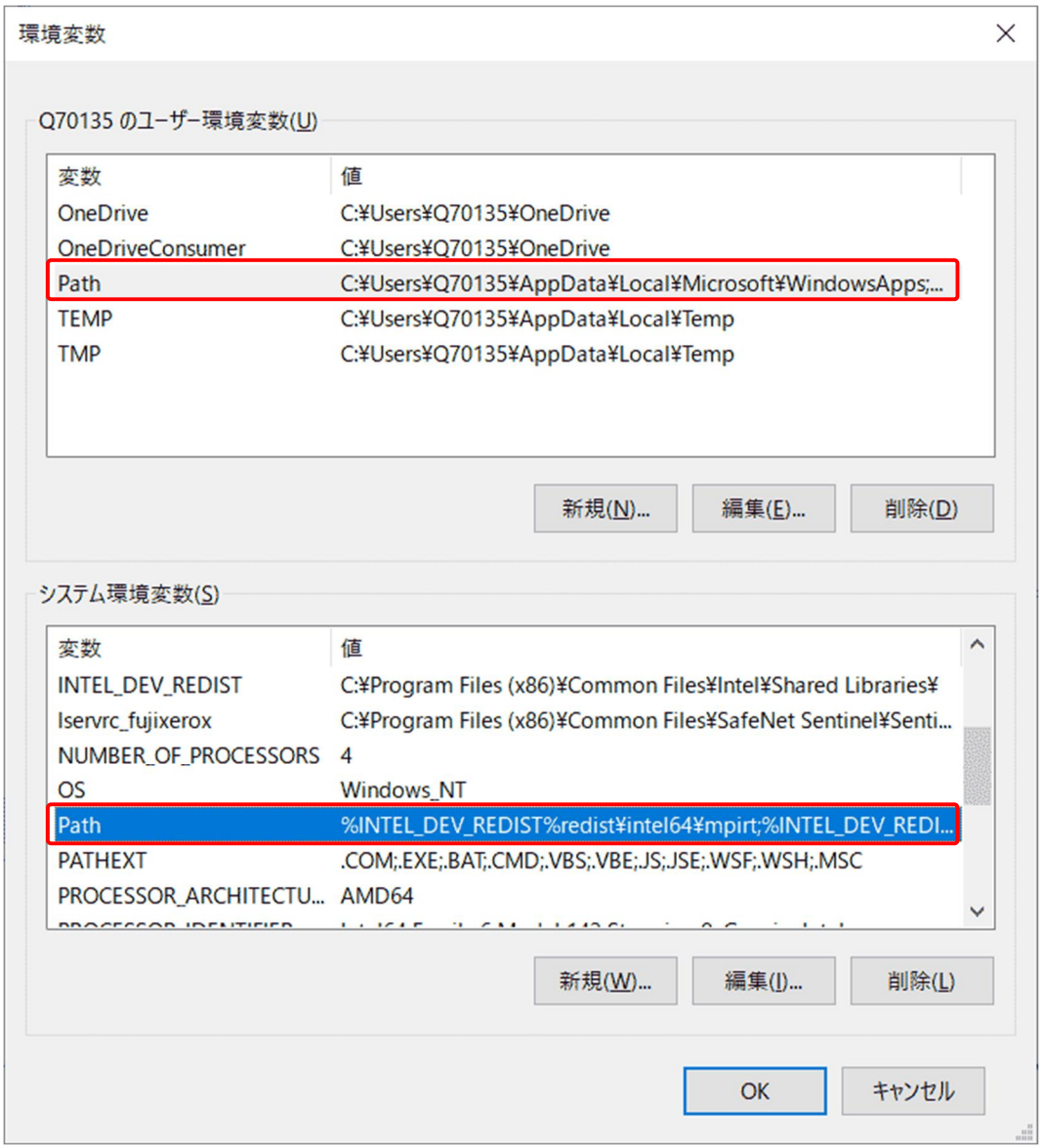
4) In case RRI-GUI gives any error messages when it is started, please check the latest version of vc_redist.x64 from the Microsoft webpage and install the latest version.

2.3.2 Preparation for the use of RRI-CUI

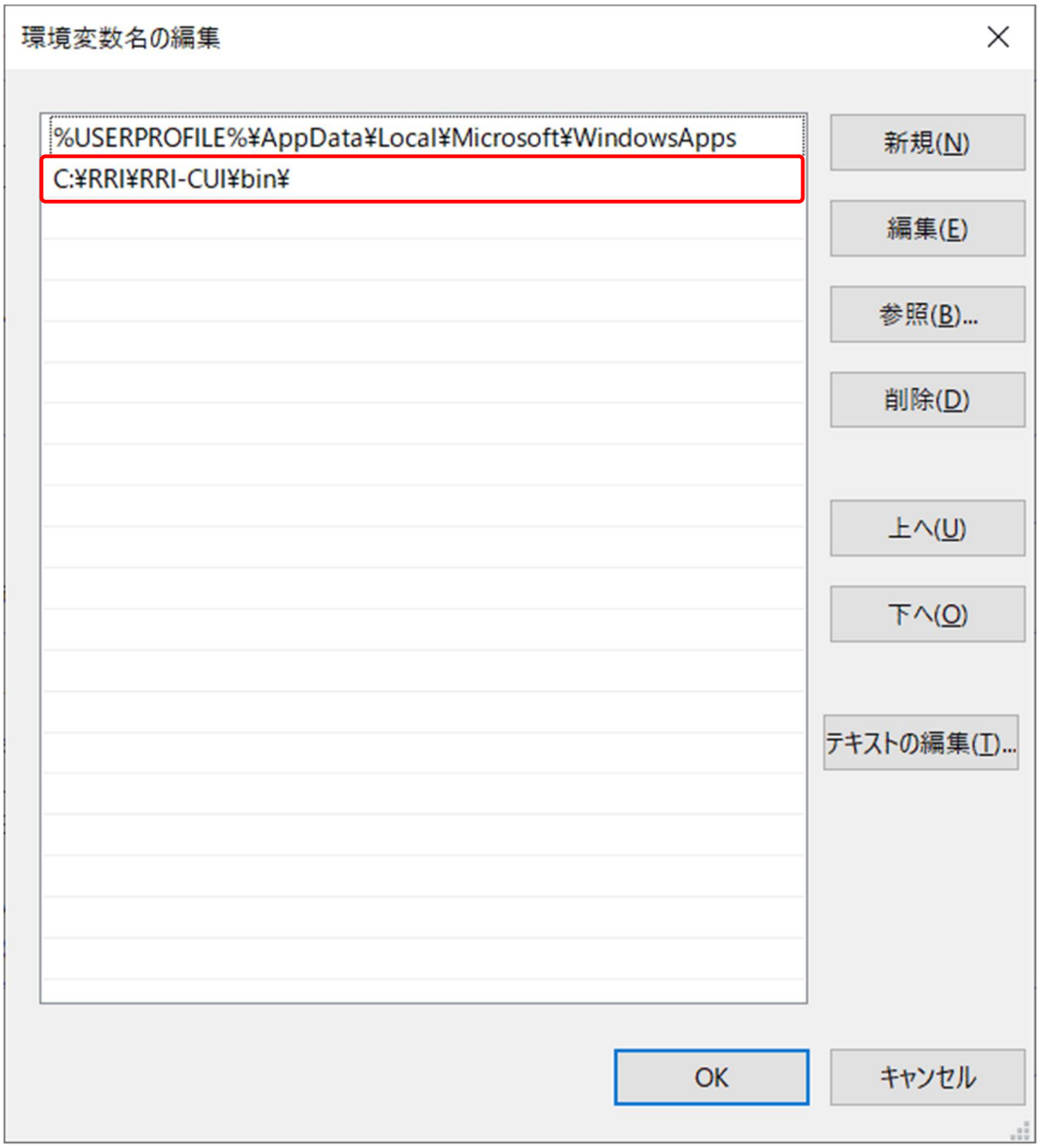
1) Basically follow the RRI manual, **p.2-1**. Before starting the RRI-CUI, we need to adjust the computer settings shown in the section 2-1 on the manual. Some parts on the manual are outdated, if so, refer to the below.

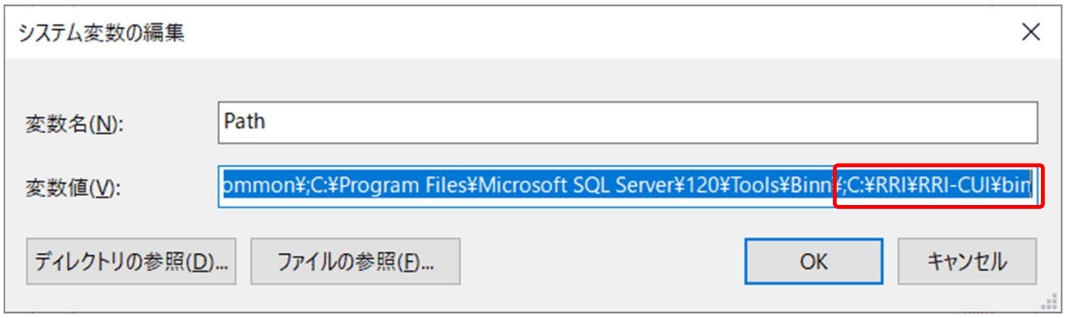
2) Right click on the PC / My Computer icon → (if the windows shows the "System") Then, click "detail setting of the system" → Advanced tab / Environment Variables → Find PATH, and click

to edit it → The manual says “under User’s Variables”, but maybe we need to edit both “User’s Variables” and “System Environment Variables”.



3) 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. If “/” is not accepted by your computer, it needs to be “¥” instead of “/”. Note: Don’t 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 (If “line break” is accepted, not necessary to add at the end of line nor “;”, like as below [For User’s Variables]. For “System Environment Variables”, you need to add at the end of line with “;”.).





4) Now. Run the sample model. Open Command Prompt and type in "cd C:/RRI/RRI-CUI/Project/solo30s/" ("cd" means "Change Directory", so, you need to move to the directory / folder you put the RRI model folder).
5) To run the model, type in "0_rri_1_4_2.exe" and enter to execute RRI Model with "RRI.Input.txt". Running the RRI model takes time, depending on the model / basin size or number of grids. It could take a couple of hours to finish the calculation.
6) After you finish the calculation, move to "Post Analysis". It's better to run some programs before you close the command prompt. First, type in "calcHydro.exe" to compute time series data from RRI output files. Second, type in "calcPeak.exe" to compute peak inundation depth.

2.4 Run the RRI Model (GUI)

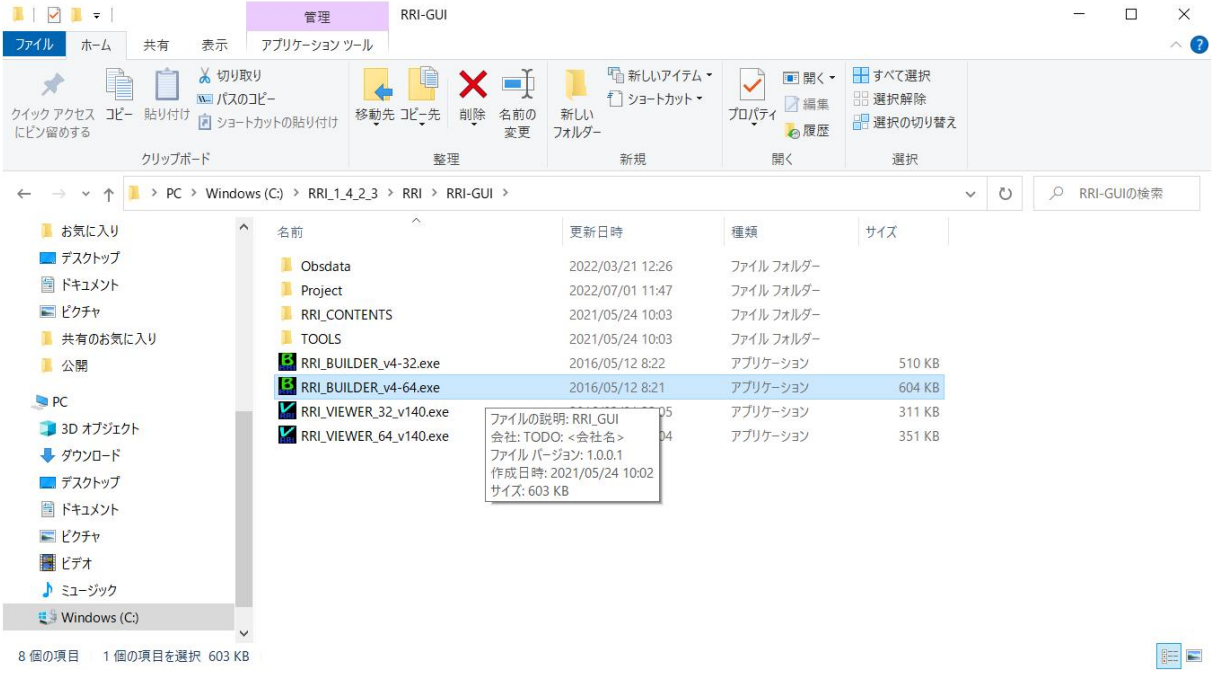
How to Run RRI-GUI is explained hereafter. You can also refer to the RRI_Manual.pdf (It should be in your "RRI" folder).

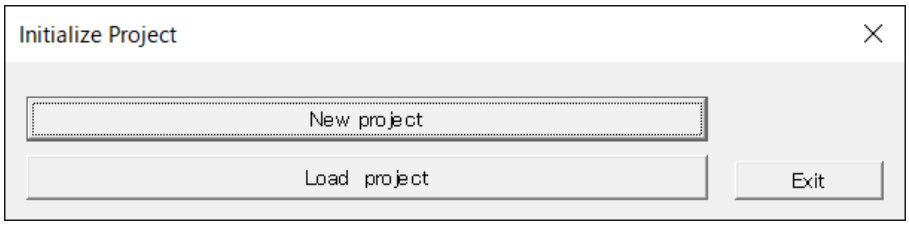
Major steps are as shown below. **The detailed instruction of each step is shown in the following sections**.

1) **"Open "RRI_BUILDER.exe"** [RRI_BUILDER_v4-64.exe (for 64-bit-OS)]
2) **"New project or Load project"** [Select DEM, ACC and DIR files (ASCII format) for New project. Select "RRI_Input.txt" for Load Project]
3) **"Extract Land cover and Soil"** [Just click on the button. Then, Soil.txt and Cover.txt files will be appeared in "topo" folder]
4) **"Move to "Data" tab, then Set river"** [Adjust the river threshold and parameters, if needed. Click on "Make file", then "Set river parameter". You can directly / manually modify the river conditions in "Edit" tab later]
5) **"Set <Rain> Start time and End time"** [Order in time needs to be "yyyy / m / d h.mm". After setting the time, click on "Use ground gauged rainfall"]
6) **"Move to "Edit" tab, then check the model condition"** [You can directly / manually modify the river conditions, if needed]
7) **"Run RRI"** [If everything is set and ready, click on Run RRI. Calculation will start. Calculation time depends on the number of cells, number of rivers and number of date and so on. It might take several tens of minutes to a few hours. * DO NOT close the command prompt window. While the widow is on the screen, the calculation procedure is ongoing.]
8) **"Check the calculation result with the RRI_VIEWER.exe"** [refer to the next section]

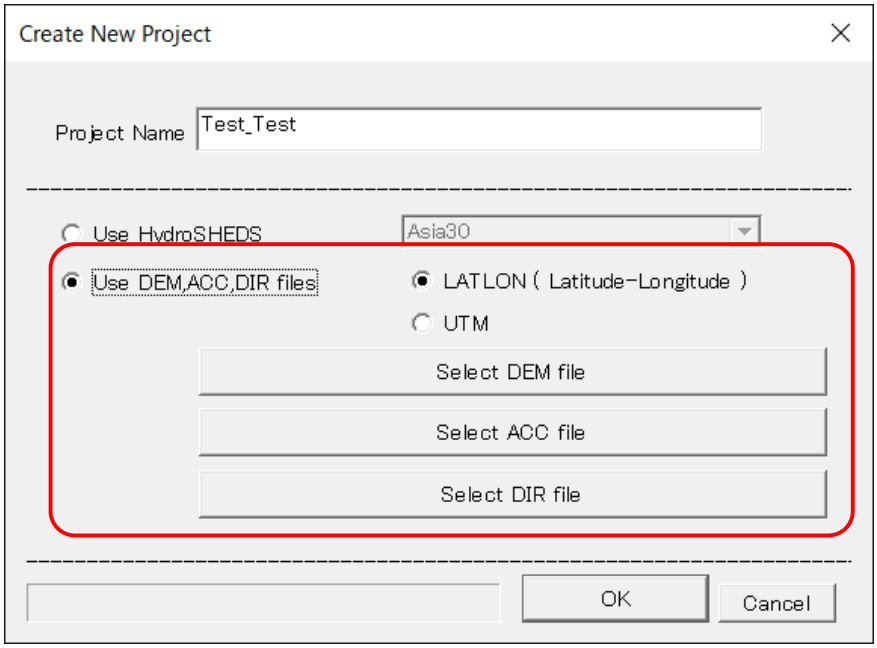
2.4.1 Detailed steps of RRI-GUI

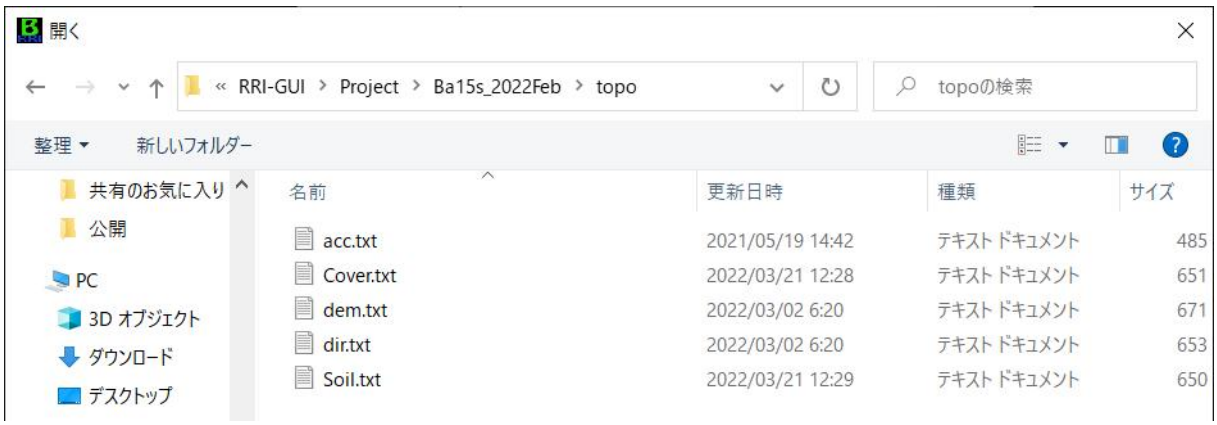
1) Open “RRI_BUILDER_v4-64.exe (for 64-bit operating system, -32 is for 32-bit operating system). Then, chose “New project (if you create a new RRI model)” or “Load project (if you already have a created RRI model and need to modify or run the model)”.



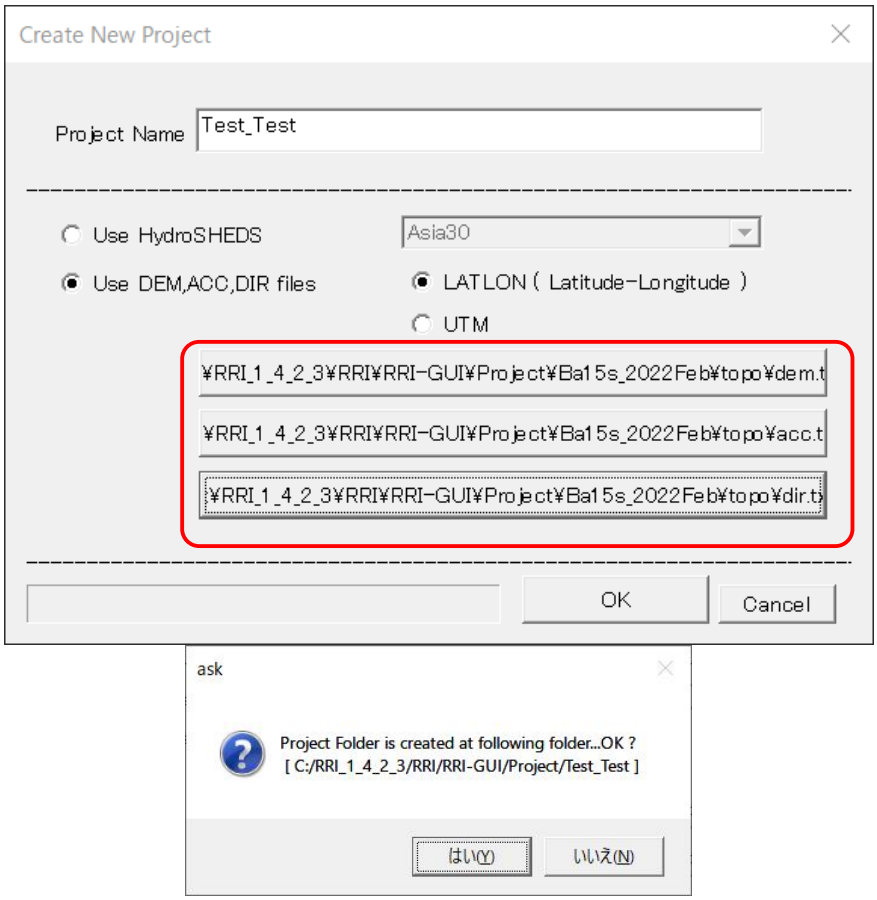


2) If you create a new project, you need to put “Project Name” and choose “Use DEM, ACC, DIR files (LATLON, Latitude-Longitude). Then select DEM (Filled DEM), ACC (Flow accumulation) and DIR (Flow direction) files (ASCII format), which you created by the GIS in 2.1.1. You might put those ASCII data (DEM, ACC, DIR) in the “topo” folder in the “Project” folder.



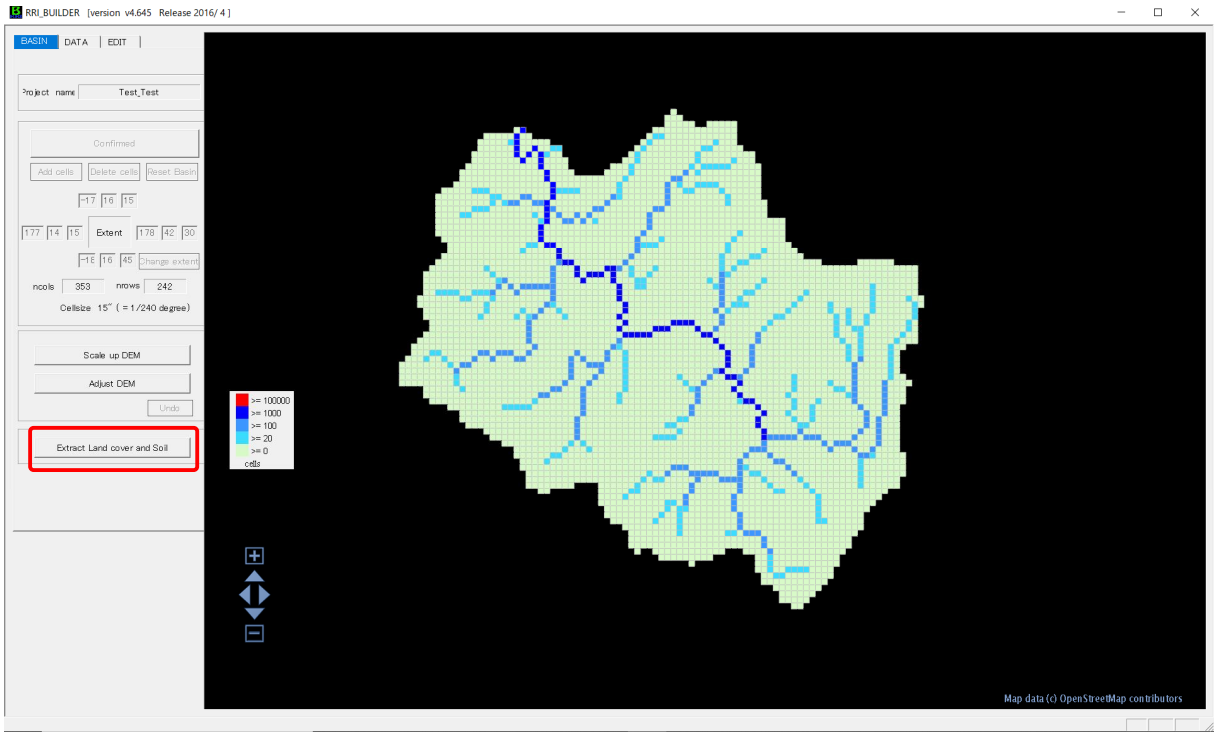


3) Once you select the relevant ASCII files, the window will be like as below. Then, click “OK”. Pop-up window will appear, but just click “Yes (Y)”.

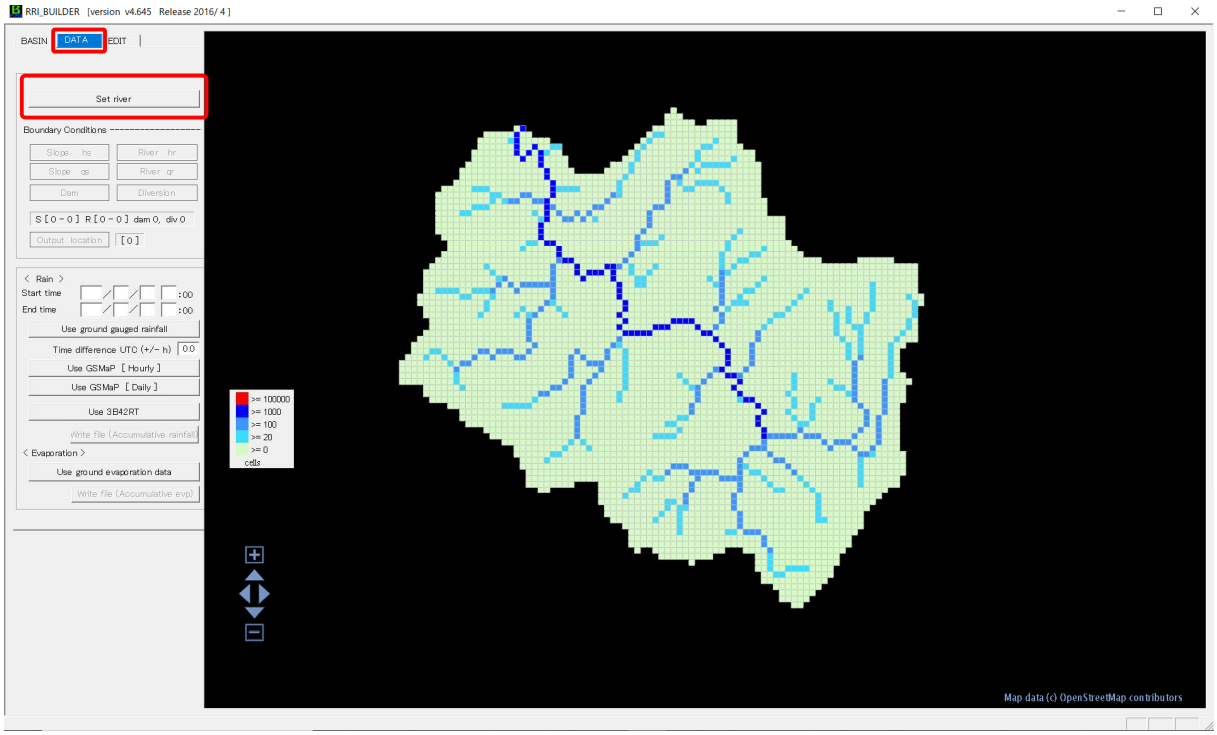


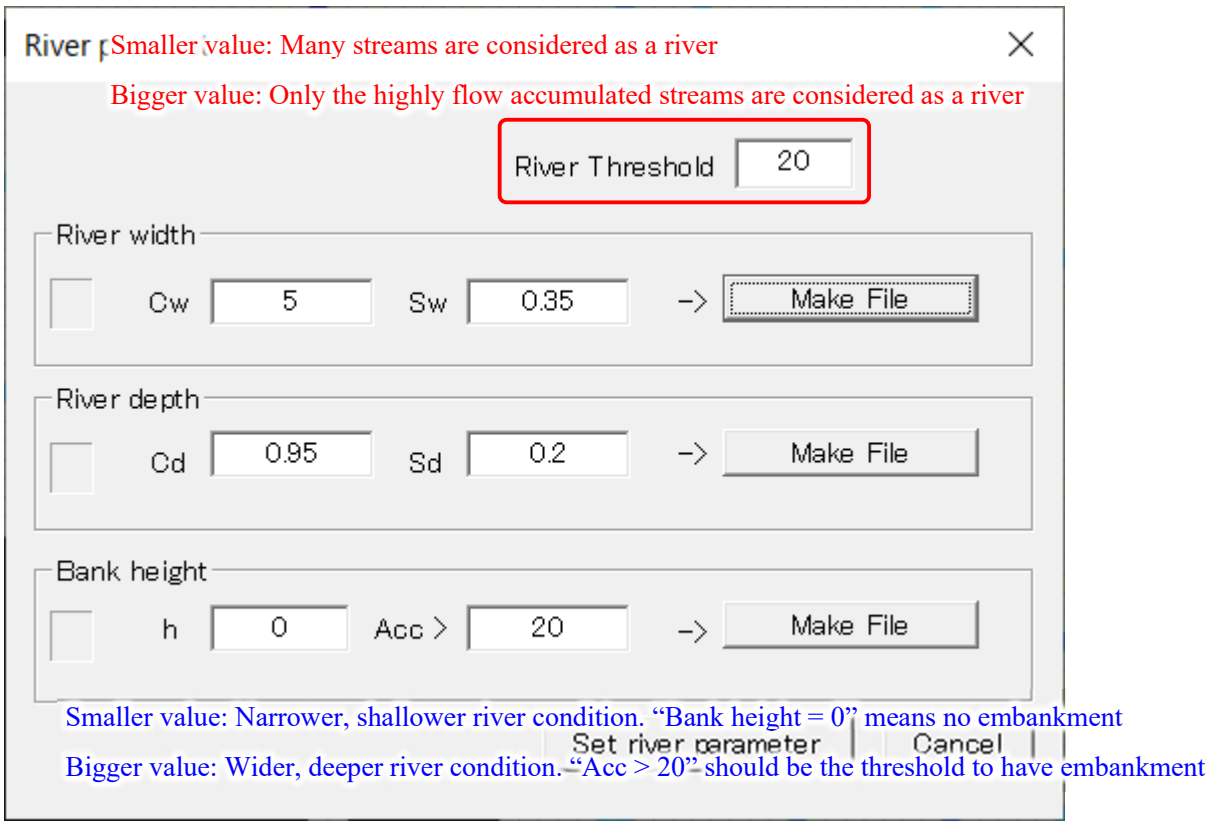
4) If you load the project, open the “RRI_Input.txt” of your target model (it should be in your “Project” folder).

5) DEM, Flow accumulation and Flow direction data are read in the RRI model. And the screen shows the target watershed and water channel (based on the flow accumulation). FAO's land cover and soil data can be read by clicking on "Extract Land cover and Soil". Soil.txt and Cover.txt files will be automatically appeared in the "topo" folder.

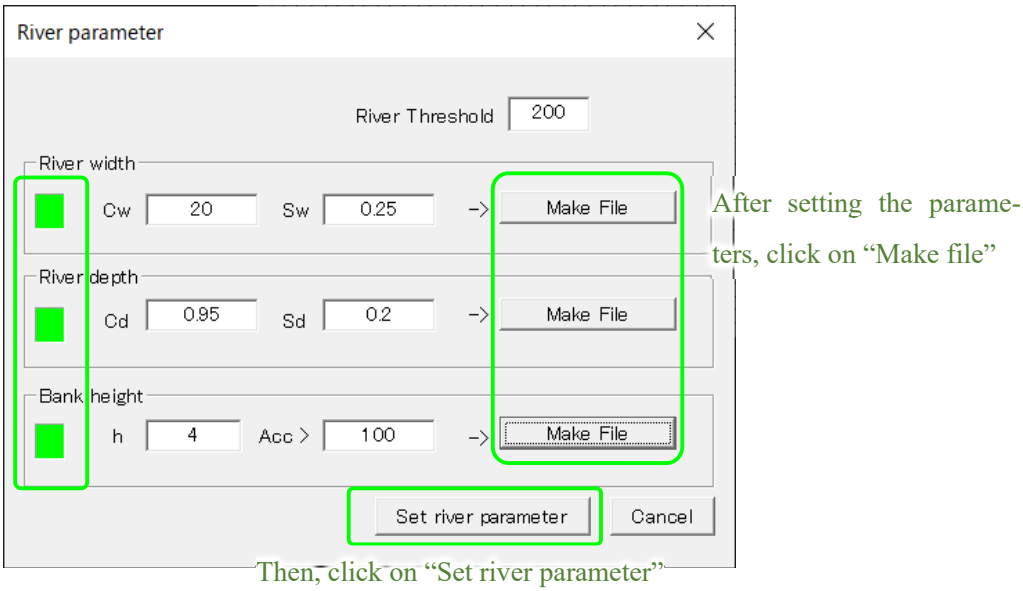


6) Move to "Data" tab. Firstly, "Set river". Default river parameters are already set. You can adjust the "River threshold", River width and depth and bank height depending on the actual situation of the river (you can refer to the actual river survey result, river width and depth at the certain cross sections). Same parameters will be applied for entire river system. You can manually modify the river width, depth and bank height by directly modifying the river files, if needed. You can use the default river parameters.



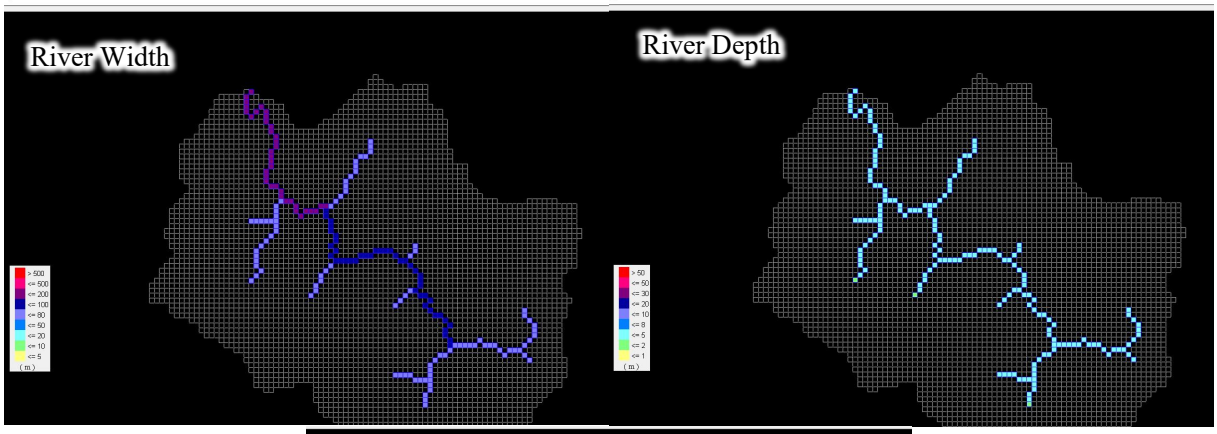


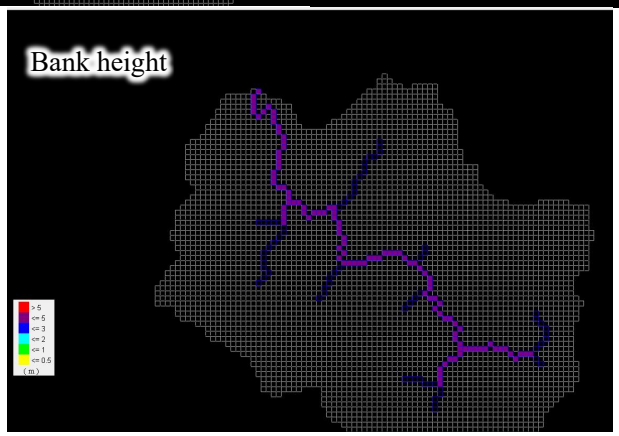
7) Following river parameter shows the example of the changes in the model [refer to the next page]. In any cases, after setting the river parameter, you should click "Make file" and make sure the blank boxes turns to green. Then, click "Set river parameter".



Example of the river condition using the above river parameters.

- Since the river threshold was set as higher value, only the major streams as considered as a river
- Since the bigger value for width was set, river width is wide.
- Since the bigger value for depth was set, river depth is deep.
- Bank height was set as 4m for the river, which flow accumulation is more than 100.

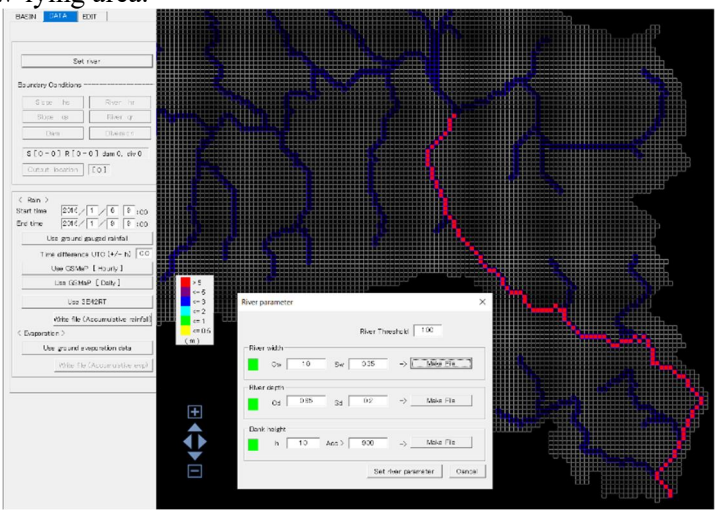




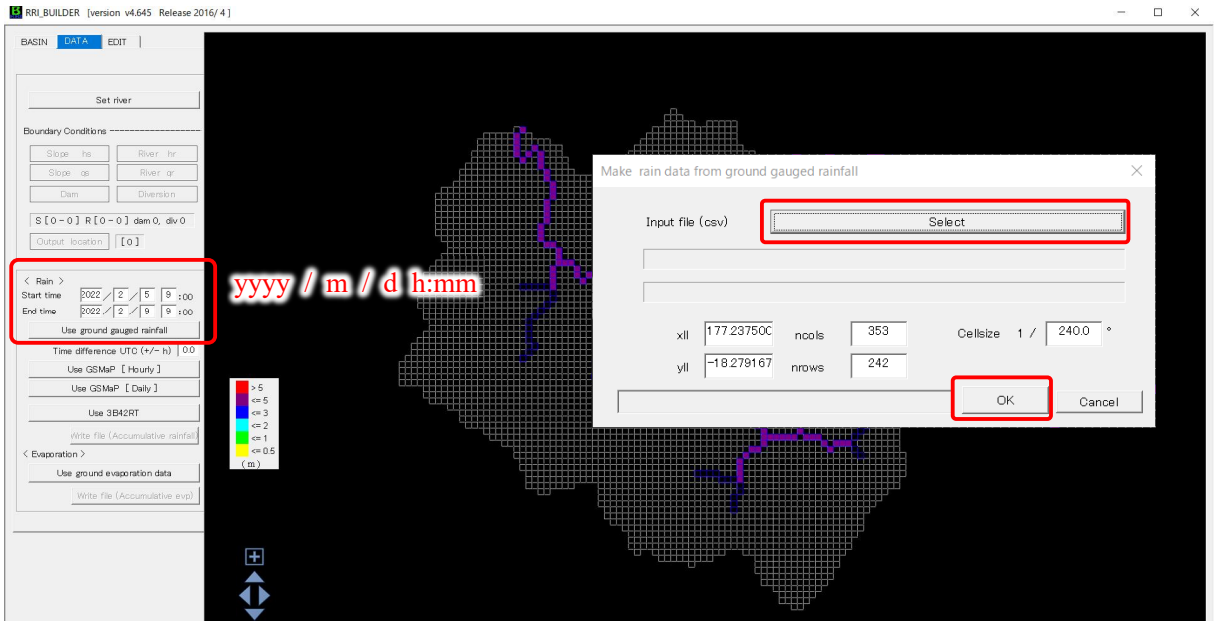
*Especially for “Bank height”, it seems the "Acc threshold" for bank height is different from the river threshold. Therefore,

1) Go to "Edit"-tab and change the current data as "Bank height"
2) Go back to "Data"-tab and "Set river"
3) Change the "Acc threshold" on bank height (Trial & error) *You should set the "h (=height)", too. (*It seems Flow accumulation = Acc threshold * approximately 30)
4) Make file for bank height and set river parameter

For Navua River, if you set Acc threshold as 900 - 980, embankment will be created only for the down-stream / along the low-lying area.

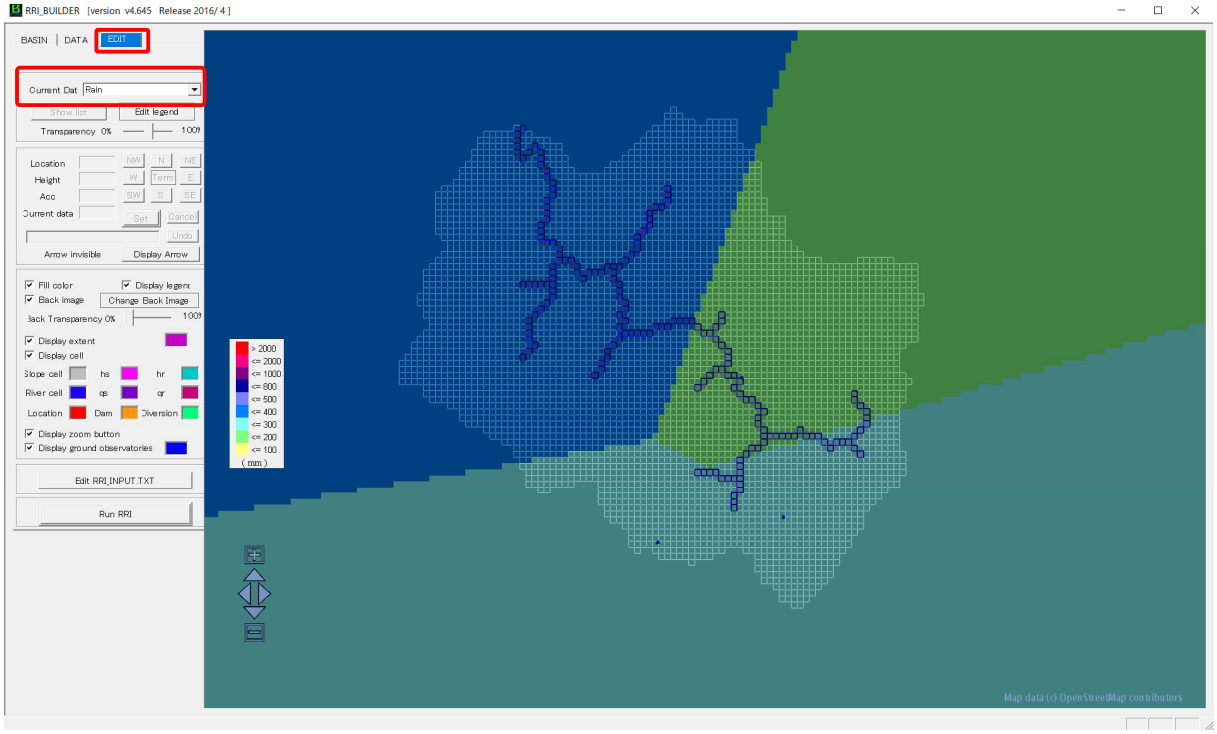


8) Set a starting time and an end time of the rain / flood event. It is considered as a calculation period. The order needs to be “year / month / date, and hour”. After setting the time, click on “Use ground gauged rainfall” > Select > Choose the CSV file > Yes (pop-up window) > OK > OK (pop-up window). *End time needs to be at least one day earlier than the input rainfall data. If your rainfall input data (CSV) has the data up to 29 February, the end time should be earlier than 28 February. Otherwise, error message will be appeared.

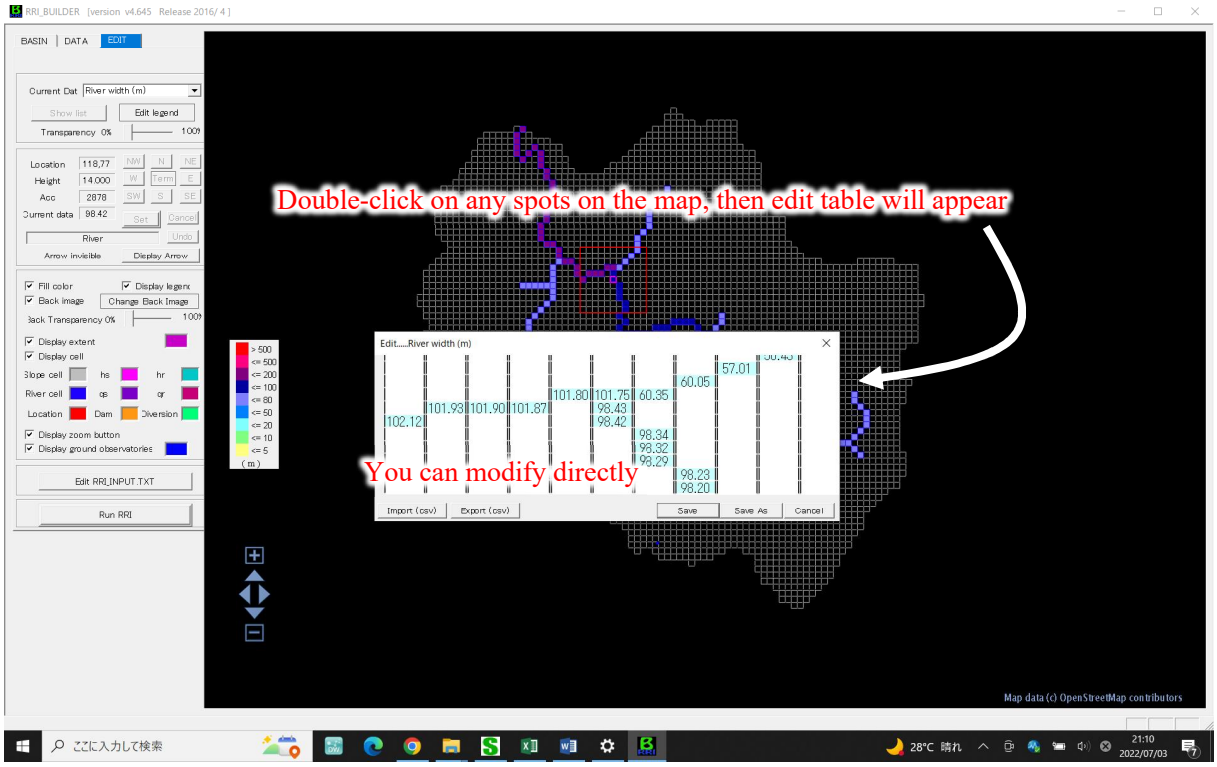


9) If the rain gauges are properly set in the model, rain condition will be something like below (it is based on the Thiessen Method. Colored areas show the coverage area of each rain gauge).

10) Move to “Edit” tab. You can check the current data / model conditions.



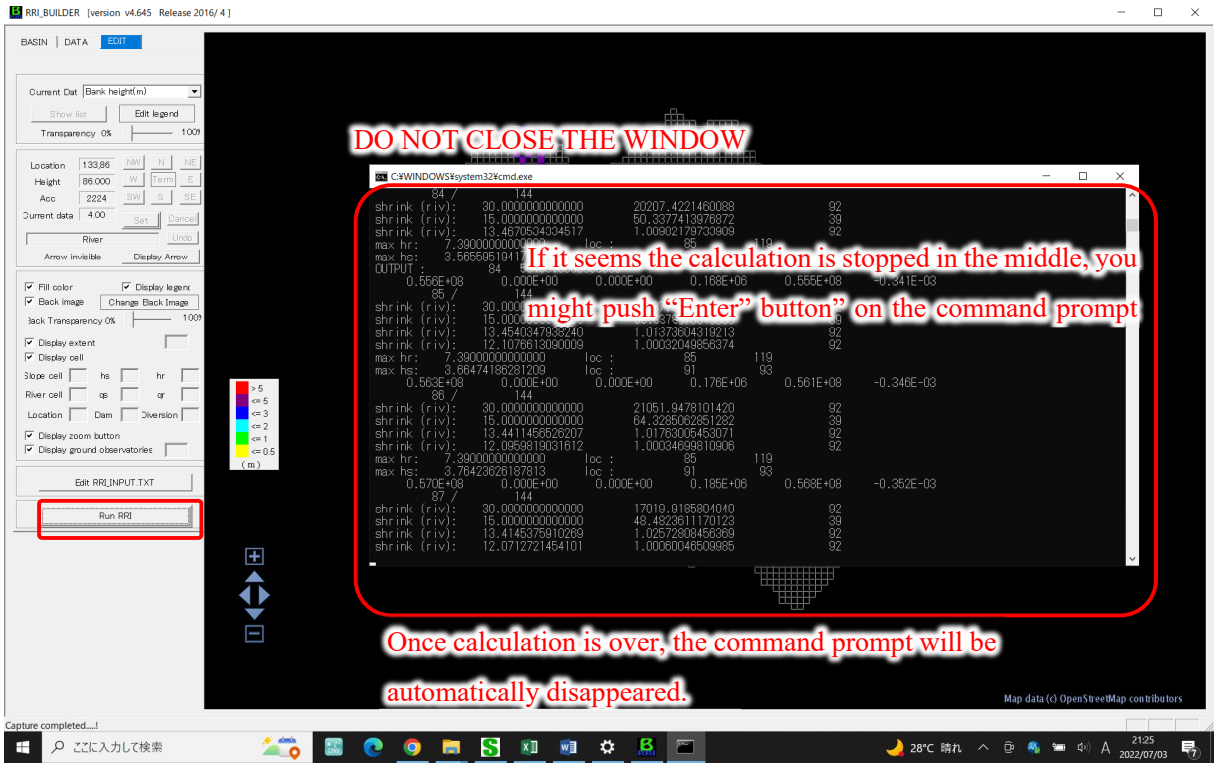
11) Some of the conditions, such as River width, depth and bank height can be modified manually and directly by double-clicking on the map, and directly input the value in the table.



12) Some of the conditions, such as River width, depth and bank height can be modified manually and directly by double-clicking on the map, and directly input the value in the table.

13) If everything is set and ready, click on Run RRI. Calculation will start. Calculation time depends on the number of cells, number of rivers and number of date and so on. It might take several tens of minutes to a few hours. * DO NOT close the command prompt window. While the widow is on the screen, the calculation procedure is ongoing.

14) Once the calculation completed, the command prompt will be automatically disappeared.

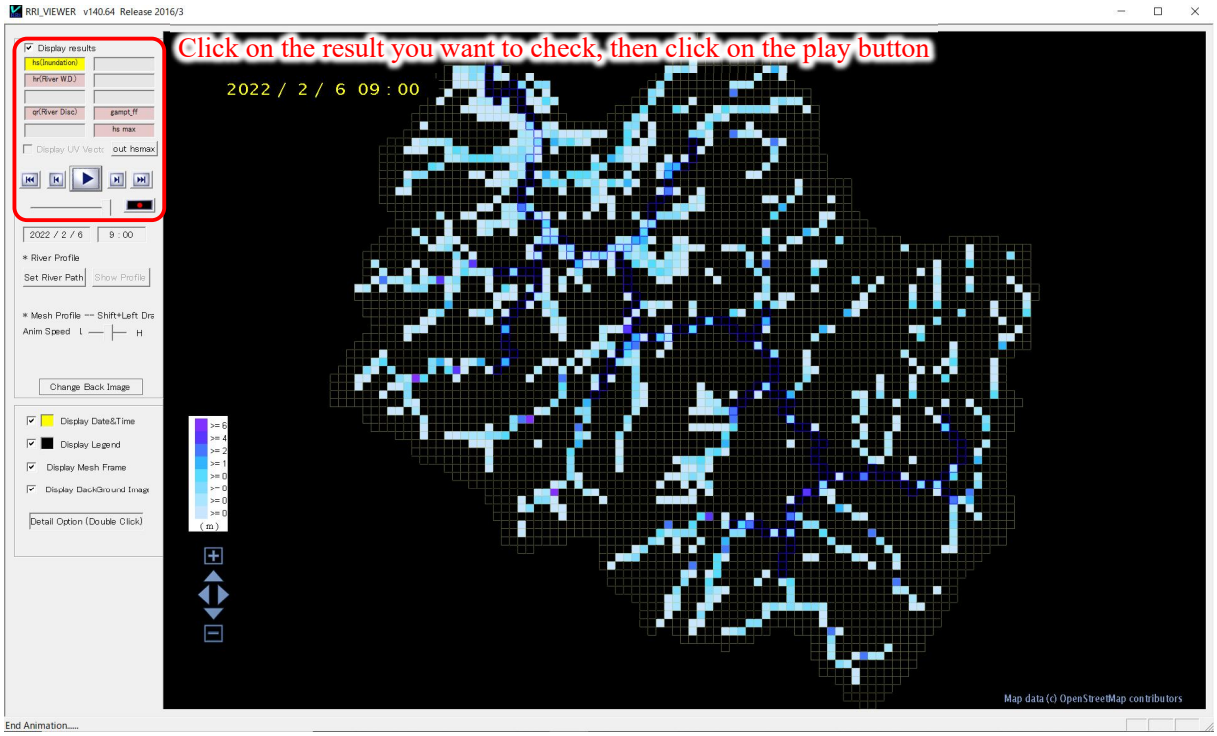


15) After the calculation is properly done, check the result with the "RRI_VIEWER" (refer to the following section).

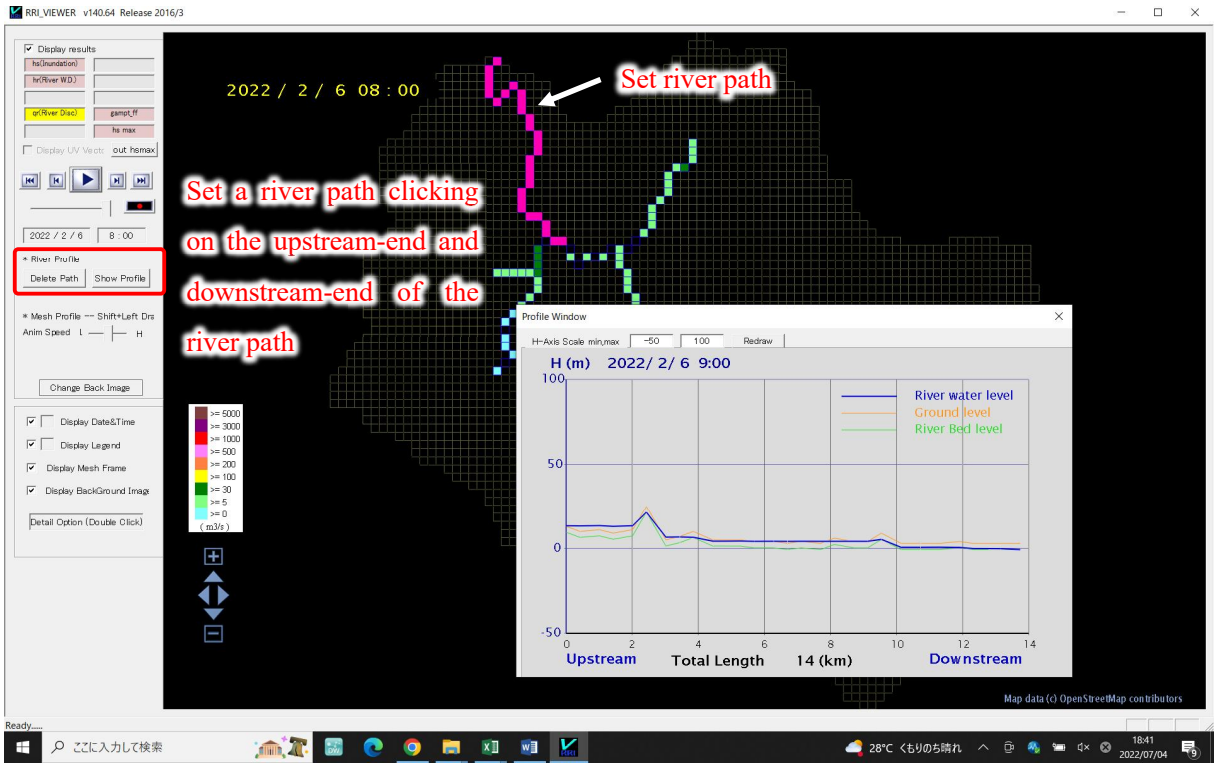
2.5 Check the Result / Output of the RRI Model

1) Open “RRI_VIEWER_v4-64.exe (for 64-bit operating system, -32 is for 32-bit operating system). Then, read “RRI_input.txt” in your calculated project holder.

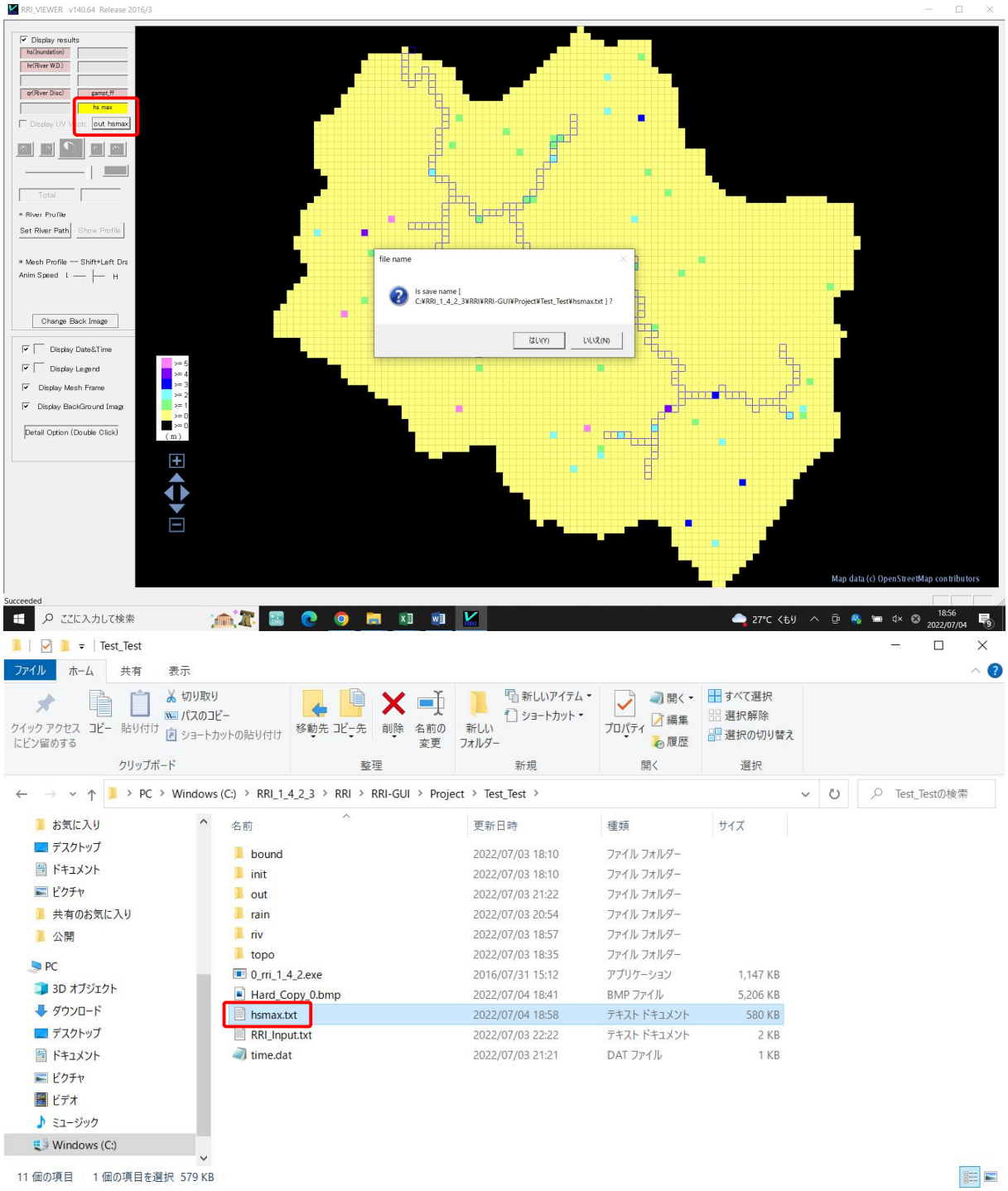
2) You can check the calculation results, such as spatial distribution of inundation, changes in water depth and discharge in chronological order / time series data. Spatial distribution of maximum inundation depth is also available.



3) Moreover, you can check the animation / time series of a longitudinal profile of the river (water level) by setting a river path. You can compare the water level and the ground level so that you can confirm when the water level exceeds the ground level and overflow occurs.

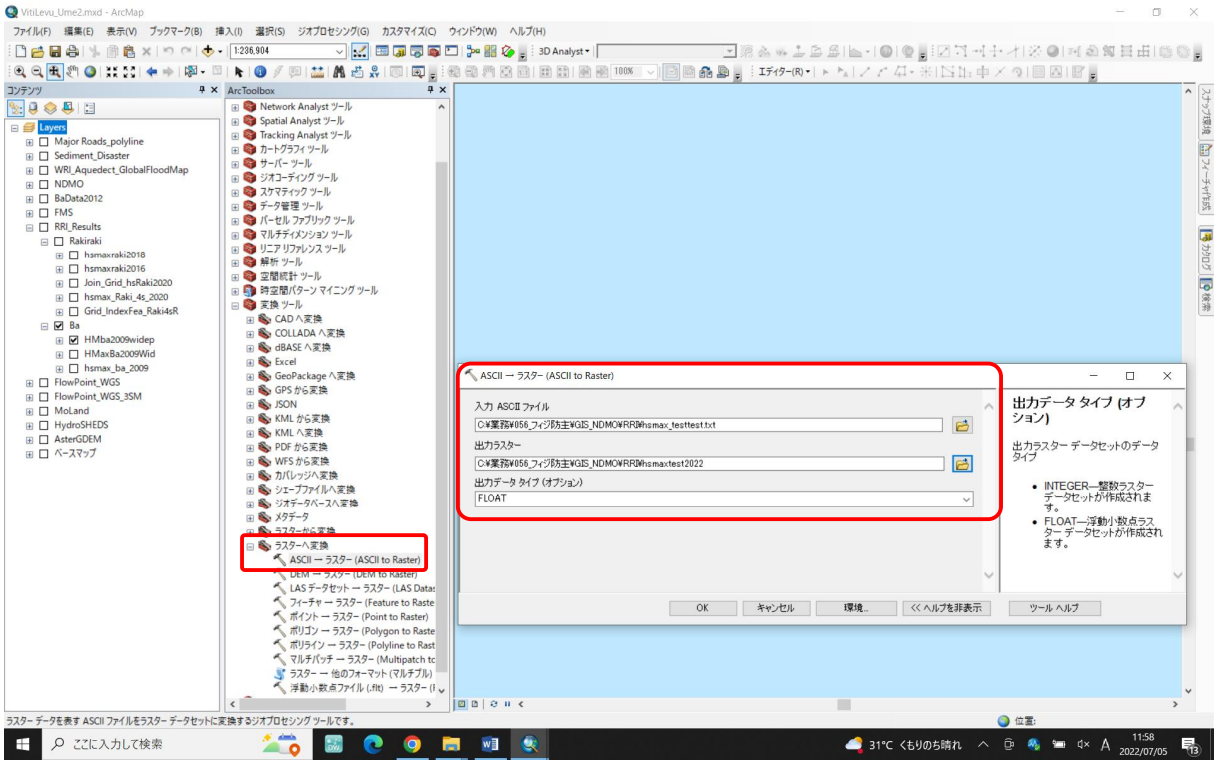


4) Spatial distribution of maximum inundation can be overlaid on the GIS. Click on “out hsmax”. “hsmax.txt” (maximum inundation) will be produced in your project folder.

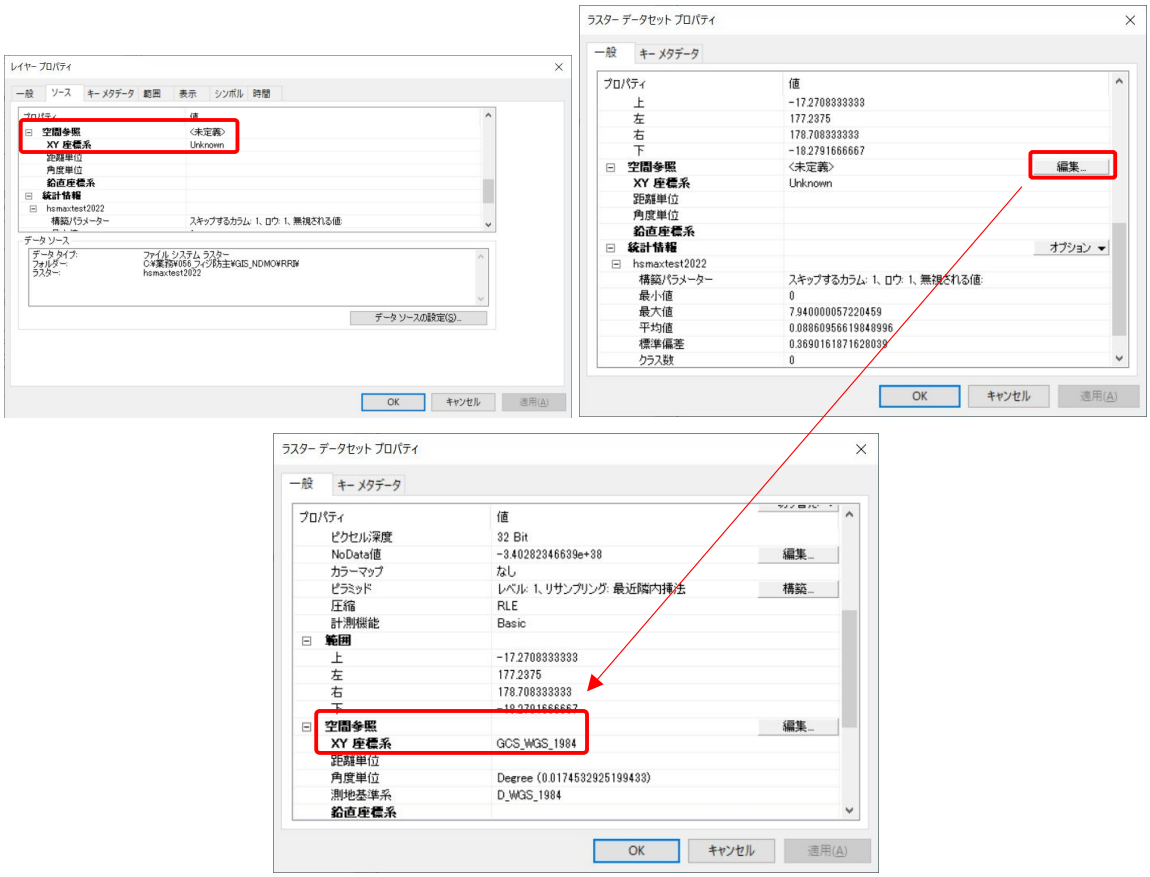


2.6 Convert and Overlay on the GIS

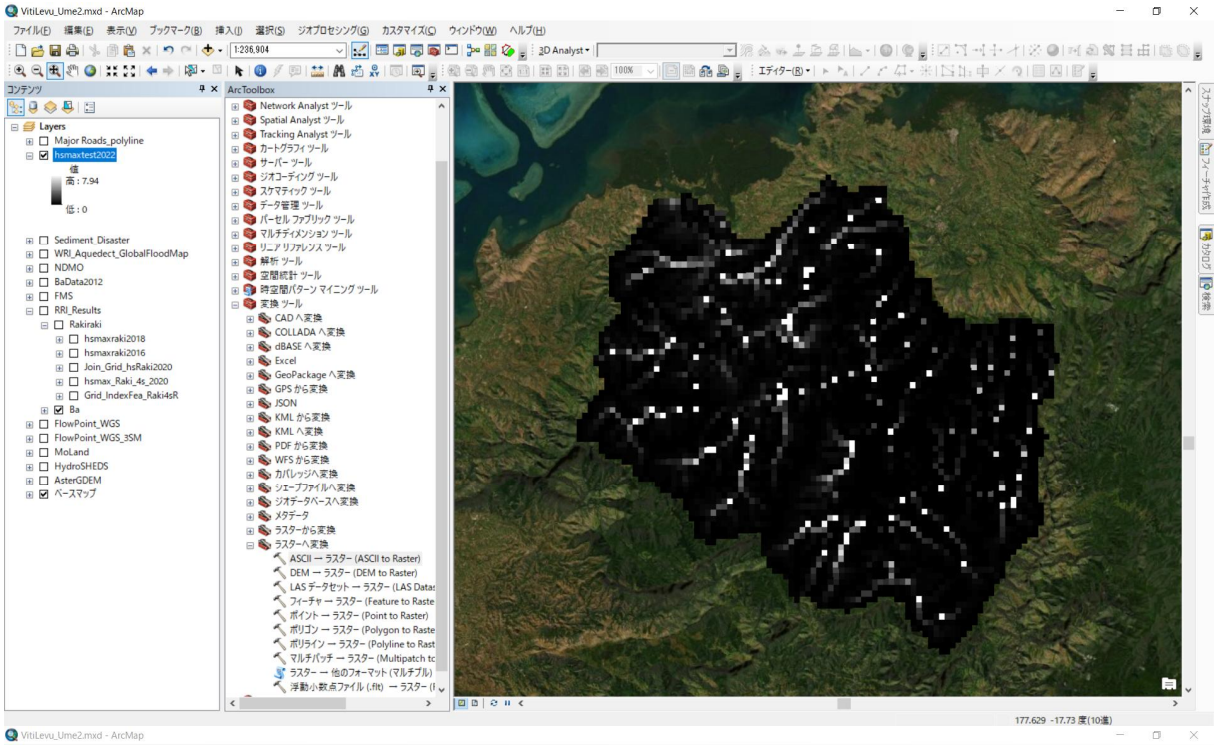
1) Copy the “hsmax.txt” to your GIS folder. It is better to rename the file, so add the basin name and date on “hsmax.txt”. On the GIS, “ASCII to Raster” and set the “hsmax.txt” as an input ASCII file. Data type should be “Float” since the inundation depth is not an integer.

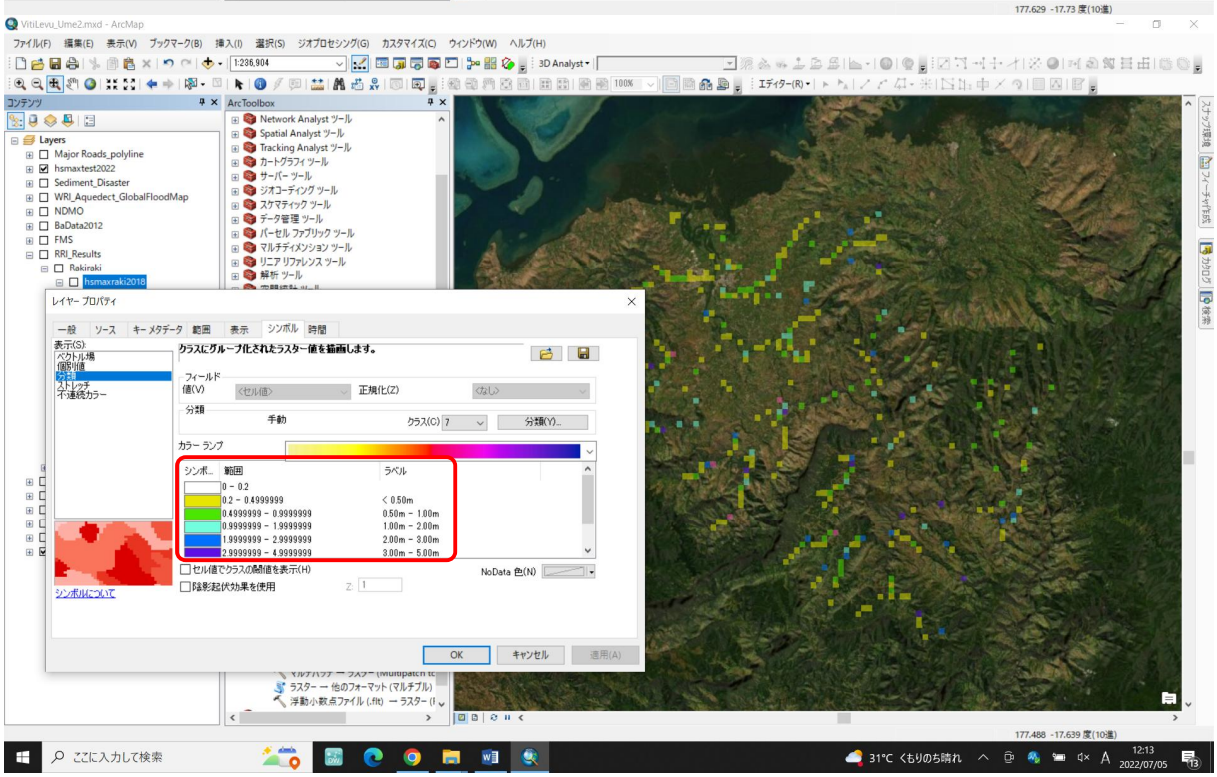


2) Added raster data’s geo-reference / coordinate is set as “unknown”. Therefore, right-click on the raster data in the catalog, and change the coordinate to “GCS_WGS_1984”.

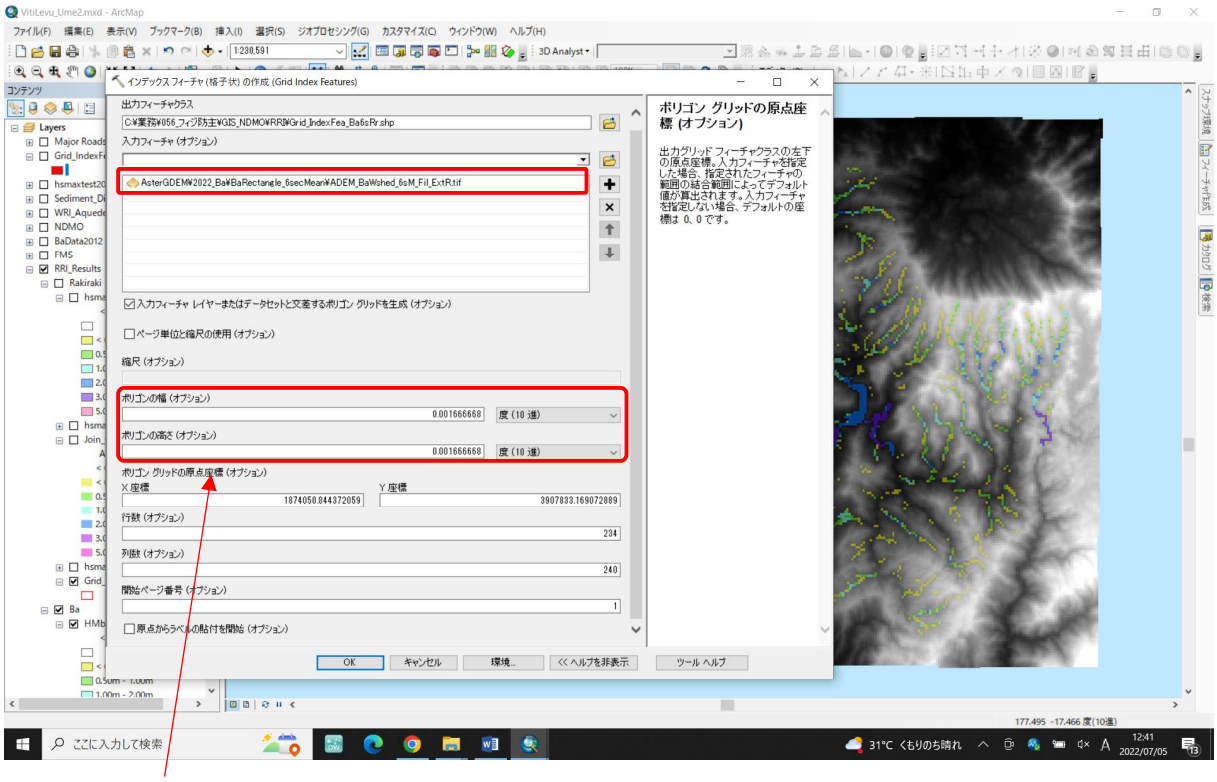


3) Adjust the symbol / color range like as below. Because each grid of the watershed has precipitation, if we put color even for the slight inundation depth, entire watershed will be painted. To avoid such a situation, small inundation depth such as less than 0.2m is set as solid color / blank. Also “transparency” in the “view” tag should be adjusted, such as 50%.



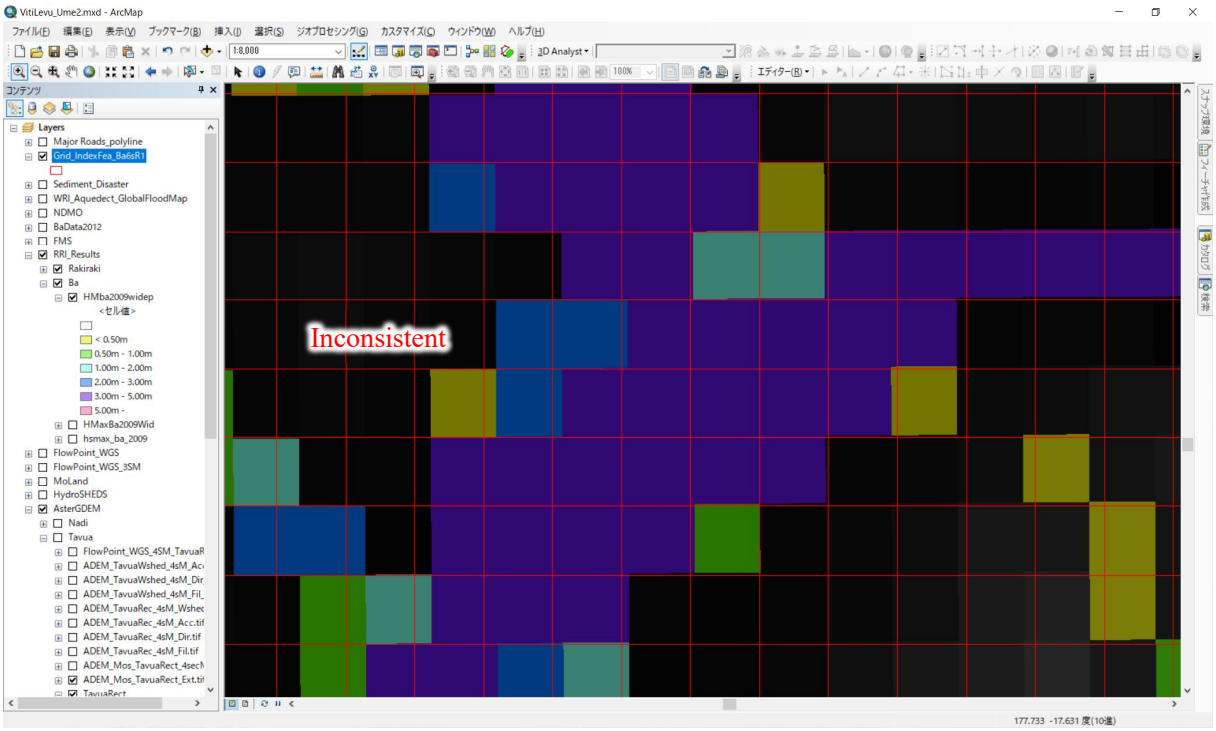


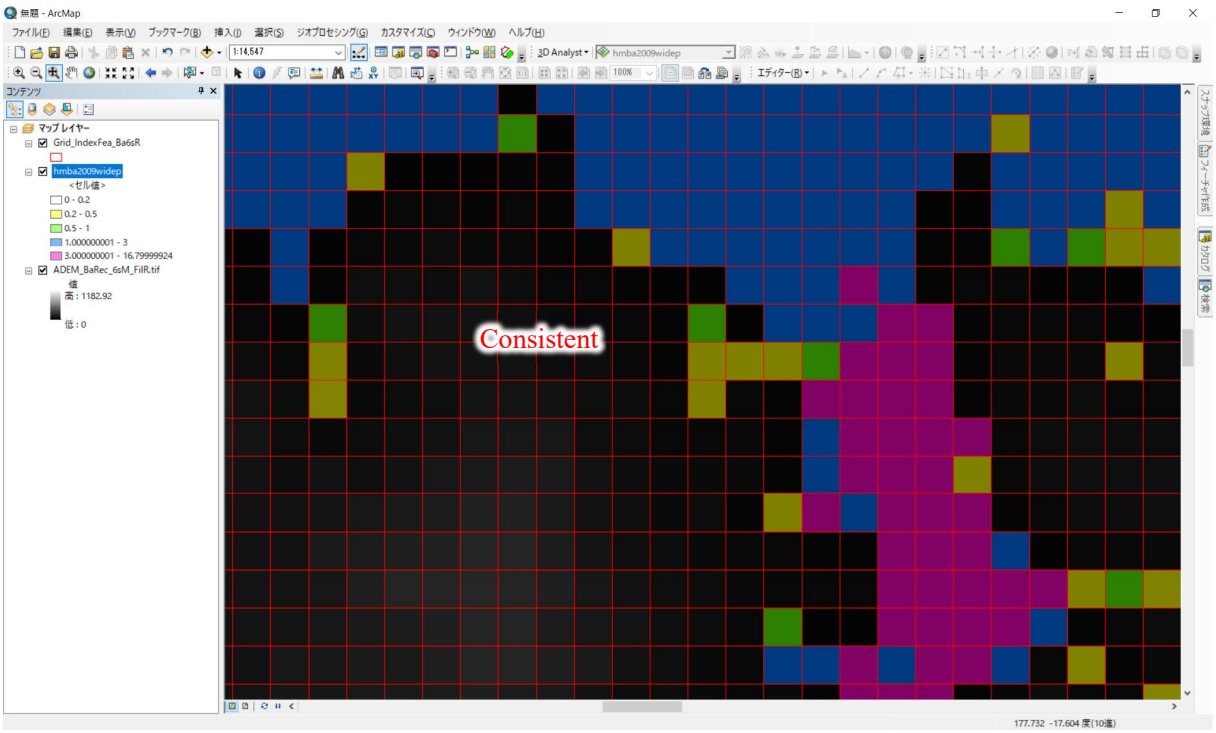
4) **IMPORTANT:** For risk assessment, it is preferable to convert the raster data to a shape file. So, create a grid (polygon) shape file by "Grid Index Features" command. You should set any rectangle shape files such as "Fill" as an input feature (option). Width and height of a polygon is depending on the grid / cell size of your calculation model (You need to set the same grid / cell size as your model). If you aggregated the cell / grid as 3- or 5-arc second, grid index feature to be created here should be the same size [refer to the below figure and table]. If you set an input feature (option), "origin point" and "number of column and row" will be automatically set depends on the width and height you set.



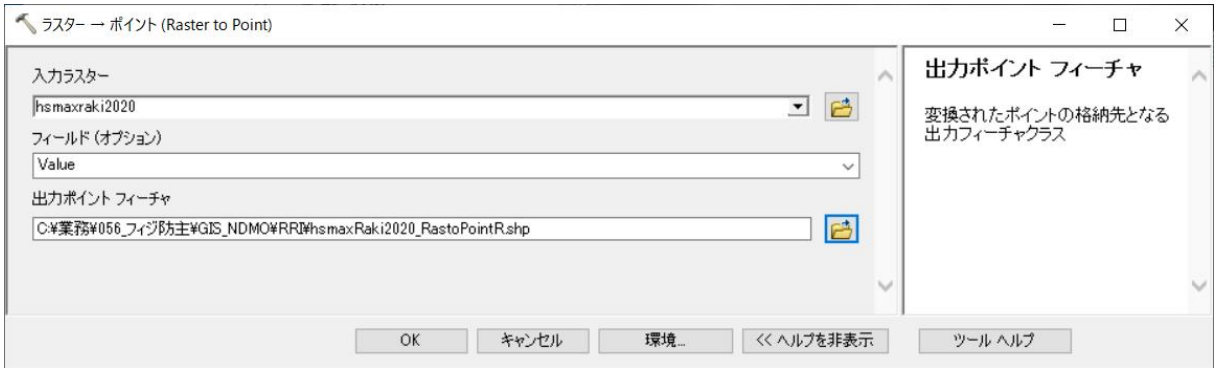
1 arc second	0.000277778
2 arc second	0.000555556
3 arc second	0.000833333
4 arc second	0.001111111
5 arc second	0.001388889
6 arc second	0.001666667
…	…
9 arc second	0.002500002
Convert "Degree, Minute, Second" to "Decimal degree" = ("second"/60+"minute")/60+"degree"	

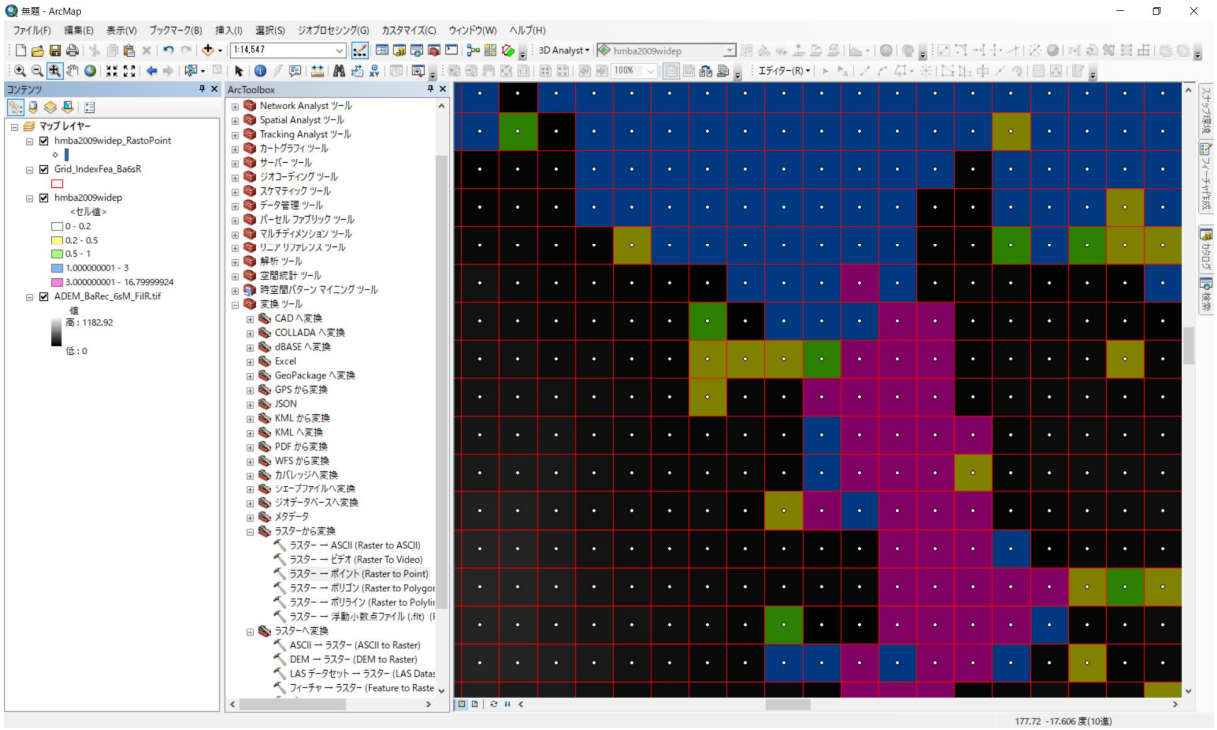
5) If you find the inconsistent grid as below, it must be due to the inconsistence of coordination of each shape file. In the below case, the coordinate of the created Grid Index Feature is Fiji Map Grid, and the coordinate of the “hsmax” raster is GCS_WGS_1984. In this case, you should work on the new map document, put any shape file with “GCS_WGS_1984”, and do “Grid Index Features” command.



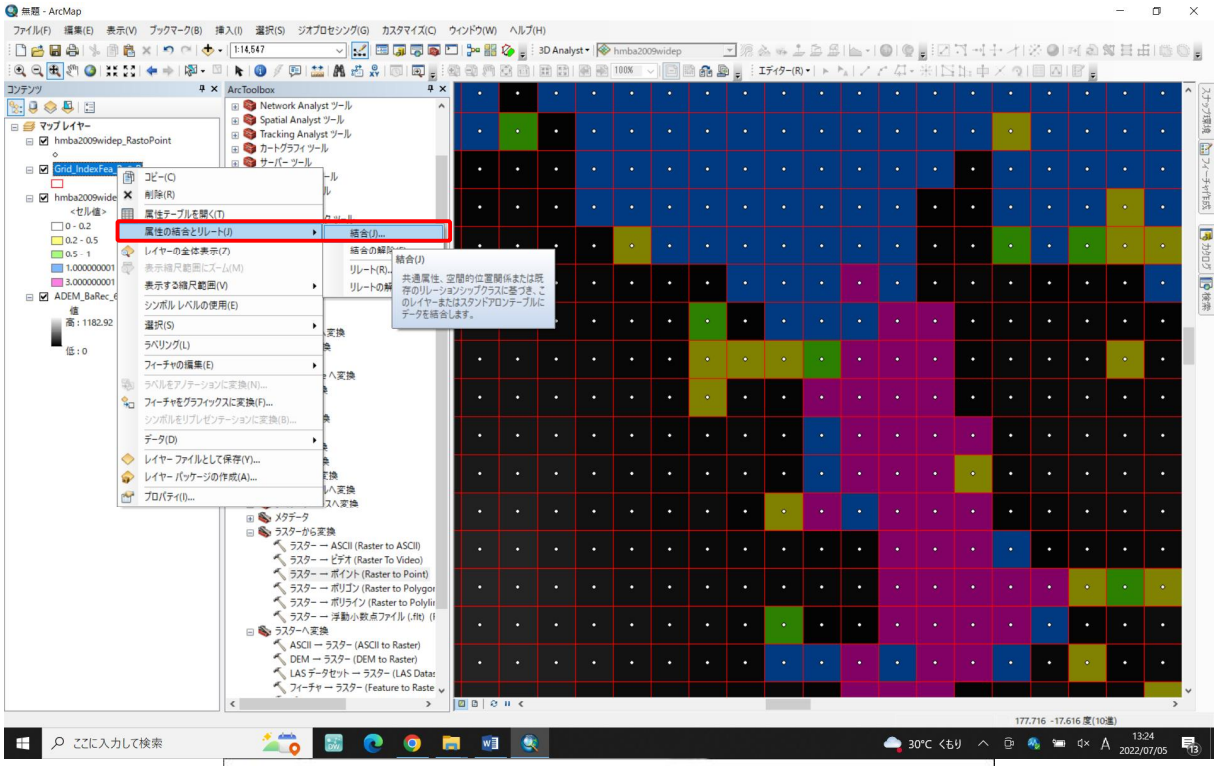


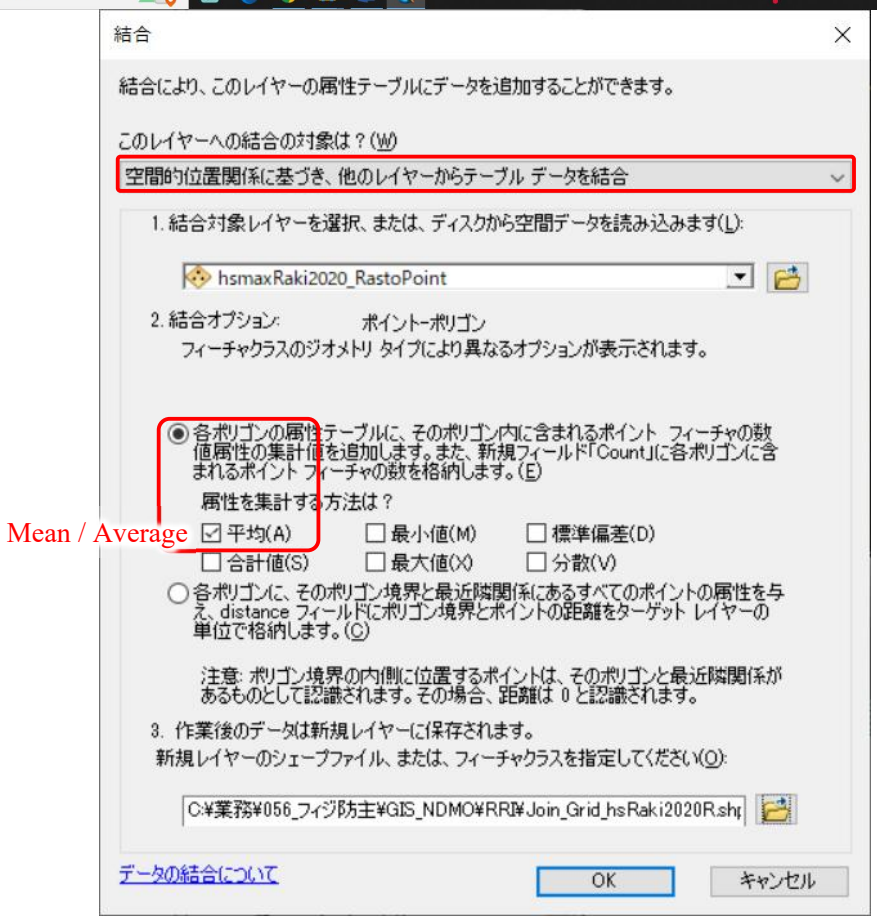
6) Now convert the “hsmax” raster to point [Raster to Point command] (you cannot convert raster to polygon directly, therefore we create the Grid Index Feature above). If you find any error, you should work on the new map document as well.



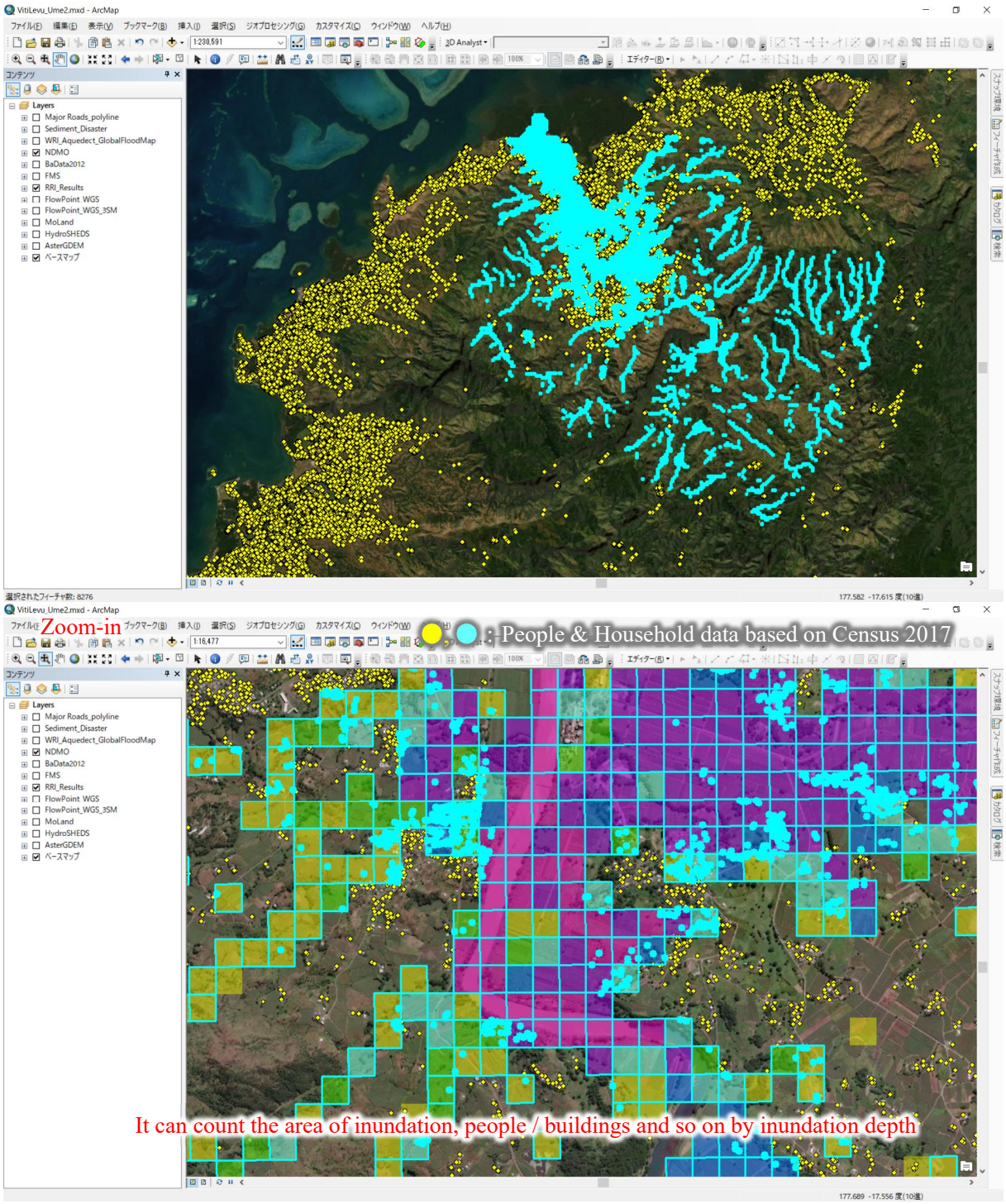


7) Right-click on the created “Grid Index Feature” > “Joins and relates” > “Join”. On the pop-up window, you should choose spatial join, and above converted point data will be used. Make sure that the counting method should be set as “Mean / Average”. This procedure might take time depending on the number of grids. It might take several tens of minutes.





8) Adjust the symbol / color range and transparency. Even though it looks the shape file is the same as raster data, you can use it to count people, households, buildings in the inundated area and so on by the combination of the “attribution search” and “spatial search”.



Chapter 3. Probable Rainfall

3.1 Introduction

In order to formulate countermeasures against heavy rainfall, the degree of rare heavy rainfall, such as once in 50 or 100 years, is statistically estimated from past precipitation observation data. The period during which the phenomenon can occur once during the period is called the return period (for example, if rainfall of 500 mm in one day occurs once in 50 years / 100 years, the return period is called 50 years / 100 years). Based on the analytical results, it is possible to formulate flood control measures, urban plans and so on that can minimize damage even in the event of large-scale heavy rains and floods, such as the 1-in-50-year flood event and so on.

Climate information, such as how heavy rainfall occurs in which areas and how often, can be used as a basis for various plans and measures. It is also thought to be useful for disseminating disaster prevention knowledge, such as knowing the characteristics of the region regarding heavy rainfall.

It should be noted that heavy rainfall that occurs 1-in-100-year (heavy rain with a return period of 100 years) does not necessarily occur once every 100 years. Return period of 100 years means “heavy rainfall that occurs once in 100 years when averaging over a long period of time”. It can happen twice or more in 100 years, or it can happen not even once. If you compare it to a dice, if you roll the dice six times, you may not get a single "six" roll, or you may get six times in a row. However, if you roll it hundreds of times, the "six" will appear on average 1 in 6 times.

3.2 Methodology

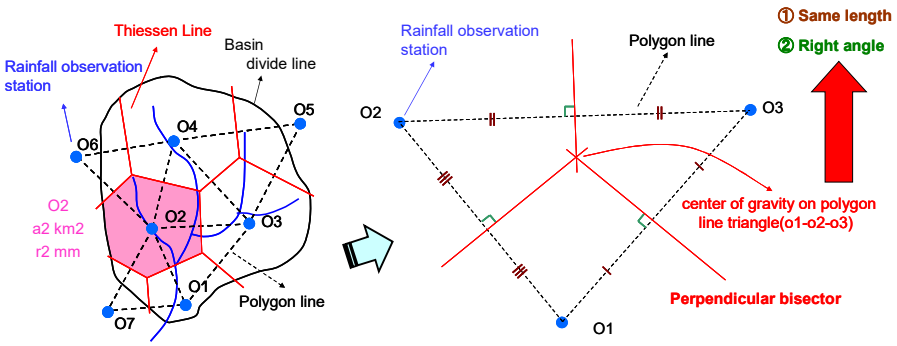
In Thiessen Method, the river basin is divided into small areas where each Point Rainfall (or Rainfall observation station) can be a representative, and then, Average Depth of Rainfall over Area is calculated by weighted averaging.

Shown as below, every Rainfall observation stations (near from the river basin) including the station located outside of the basin must be plotted on the map. Then, draw the perpendicular bisector of each station. These areas which divided by each perpendicular bisector represent the coverage area of each station in Thiessen Method.

$$r = \frac{a_1 r_1 + a_2 r_2 + \ldots + a_N r_N}{A}$$

$$A = a_1 + a_2 + \ldots a_N$$

r: Average rainfall(mm)
A: All Basin areas(km^2)
N: Number of rainfall observation points
a_i: Polygonal area(km^2)
r_i: *Rain*fall in each observation point(mm)



If Thiessen coefficient (a_i / A) is calculated in advance, it is easy to calculate Average Depth of Rainfall over Area.

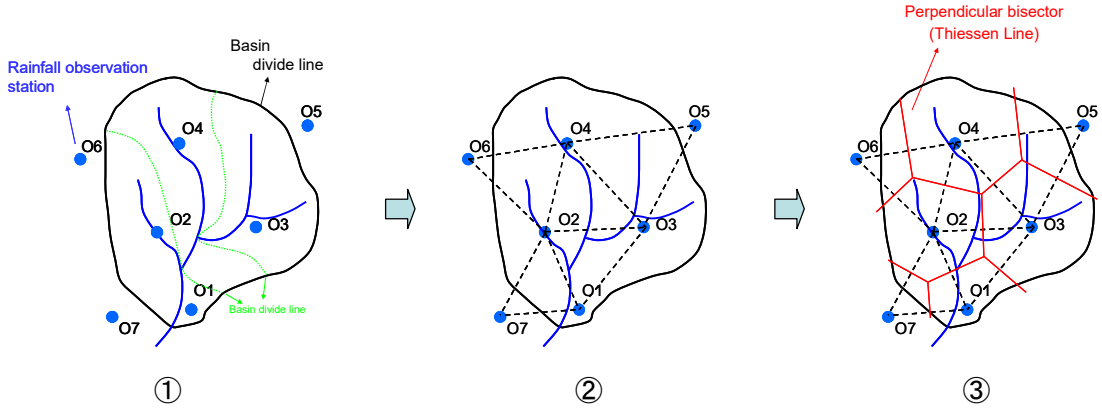
①. Dividing the river basin and plotting the all rainfall observation stations
(including the station located outside of the basin)

②. Connect adjacent stations with a straight line

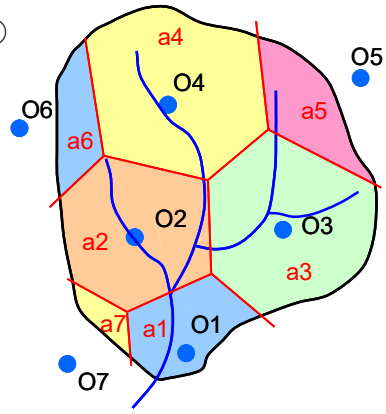
③. Draw the perpendicular bisector of each station

④. Counting each polygonal area and calculate Thiessen Coefficient
(If necessary, divide polygonal area into small areas based on each watershed)

⑤. Summing of “Each Thiessen Coefficient” × “Rainfall in each observation point (mm)”
equals “Average Depth of Rainfall Over Area (mm)”



④

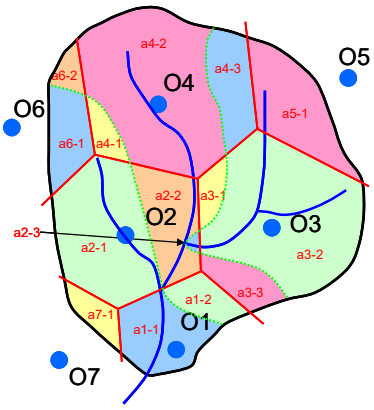


		O1	O2	O3	O4	O5	O6	O7	Total
Whole basin	Area (km2)	a1	a2	a3	a4	a5	a6	a7	A
	Thiessen Coefficient	a1/A	a2/A	a3/A	a4/A	a5/A	a6/A	a7/A	Must be 1.00

		O1	O2	O3	O4	O5	O6	O7	Total
Whole basin	Area (km2)	7.6	14.2	16.1	19.0	6.5	5.0	2.1	70.5
	Thiessen Coefficient	0.11	0.20	0.23	0.27	0.09	0.07	0.03	1.00

If necessary…

④



		O1	O2	O3	O4	O5	O6	O7	Total
Watershed I	Area (km2)	–	a2-3	a3-2	a4-3	a5-1	–	–	A-I
	Thiessen Coefficient	–	a2-3/A-I	a3-2/A-I	a4-3/A-I	a5-1/A-I	–	–	Must be 1.00
Watershed II	Area (km2)	a1-2	a2-2	a3-1 a3-3	a4-2	–	a6-2	–	A-II
	Thiessen Coefficient	a1-2/A-II	a2-2/A-II	(a3-1+a3-3)/A-II	a4-2/A-II	–	a6-2/A-II	–	Must be 1.00
Watershed III	Area (km2)	a1-1	a2-1	–	a4-1	–	a6-1	a7-1	A-III
	Thiessen Coefficient	a1-1/A-III	a2-1/A-III	–	a4-1/A-III	–	a6-1/A-III	a7-1/A-III	Must be 1.00
Whole basin	**Area (km2)**	**a1**	**a2**	**a3**	**a4**	**a5**	**a6**	**a7**	**A**
	Thiessen Coefficient	**a1/A**	**a2/A**	**a3/A**	**a4/A**	**a5/A**	**a6/A**	**a7/A**	**Must be 1.00**

		O1	O2	O3	O4	O5	O6	O7	Total
Watershed I	Area (km2)	–	0.3	13.2	4.7	6.5	–	–	24.7
	Thiessen Coefficient	–	0.012	0.535	0.190	0.263	–	–	1.00
Watershed II	Area (km2)	2.1	5.1	2.9	12.4	–	1.2	–	23.7
	Thiessen Coefficient	0.089	0.215	0.122	0.523	–	0.051	–	1.00
Watershed III	Area (km2)	5.5	8.8	–	1.9	–	3.8	2.1	22.1
	Thiessen Coefficient	0.249	0.398	–	0.086	–	0.172	0.095	1.00
Whole basin	**Area (km2)**	**7.6**	**14.2**	**16.1**	**19.0**	**6.5**	**5.0**	**2.1**	**70.5**
	Thiessen Coefficient	**0.11**	**0.20**	**0.23**	**0.27**	**0.09**	**0.07**	**0.03**	**1.00**

⑤ "Average Depth of Rainfall Over Area (mm)": $r = \frac{a_1}{A} r_1 + \frac{a_1}{A} r_2 + \ldots + \frac{a_N}{A} r_N$

		O1	O2	O3	O4	O5	O6	O7	Total
Whole basin	**Area (km2)**	**7.6**	**14.2**	**16.1**	**19.0**	**6.5**	**5.0**	**2.1**	**70.5**
	Thiessen Coefficient	**0.11**	**0.20**	**0.23**	**0.27**	**0.09**	**0.07**	**0.03**	**1.00**

×

Point Rainfall		O1	O2	O3	O4	O5	O6	O7	–
Rainfall (mm)	**2011/5/20 9:00 (Point)**	**1.0**	**3.0**	**2.5**	**20.1**	**22.2**	**10.3**	**1.2**	**–**
	2011/5/20 10:00 (Point)	**1.0**	**2.9**	**2.2**	**18.8**	**19.8**	**7.5**	**1.1**	**–**
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	**–**
	2011/5/20 24:00 (Point)	**1.3**	**3.2**	**3.5**	**18.1**	**26.7**	**7.4**	**1.2**	**–**

r : Average rainfall(mm)
A : All Basin areas(km^2)
N : Number of rainfall observation points
a_i : Polygonal area(km^2)
r_i : *Rain*fall in each observation point(mm)

Average Depth of Rainfall Over Area (mm)

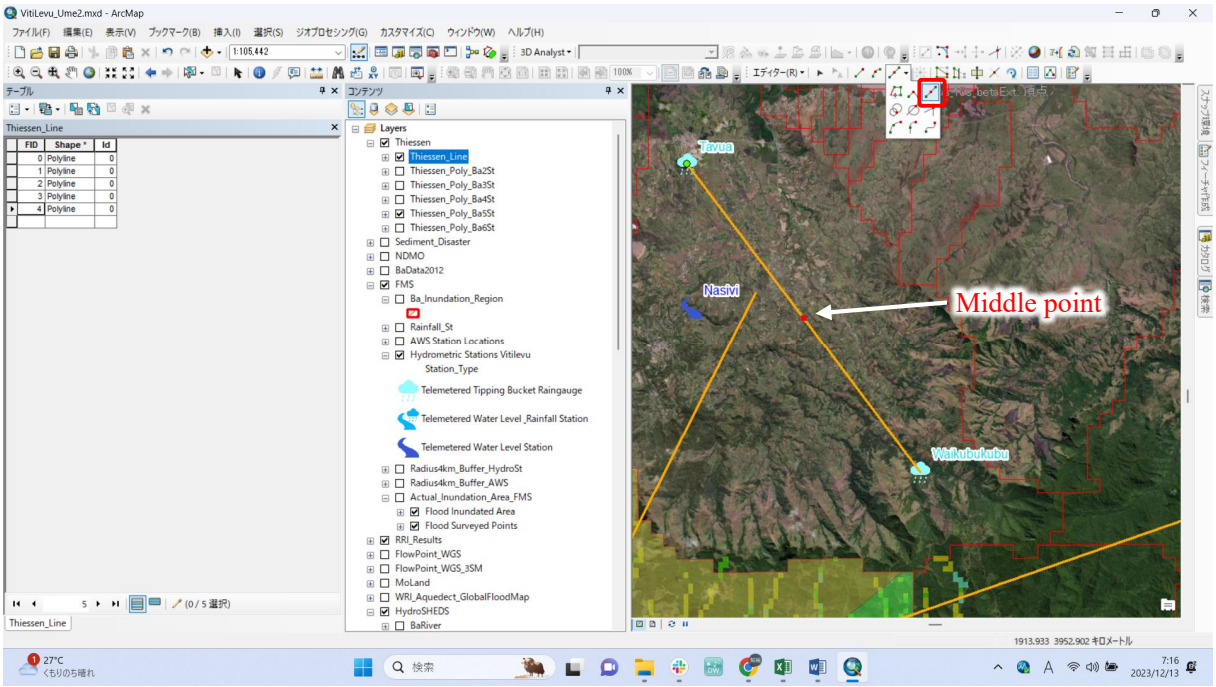
Surface Rainfall		O1	O2	O3	O4	O5	O6	O7	Average
Rainfall (mm)	**2011/5/20 9:00 (Area)**	**0.1**	**0.6**	**0.6**	**5.4**	**2.0**	**0.7**	**0.0**	**9.5**
	2011/5/20 10:00 (Area)	**0.1**	**0.6**	**0.5**	**5.1**	**1.8**	**0.5**	**0.0**	**8.7**
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	2011/5/20 24:00 (Area)	**0.1**	**0.6**	**0.8**	**4.9**	**2.5**	**0.5**	**0.0**	**9.5**

=0.1 + 0.6 + 5.4 + 2.0 + 0.7 + 0.0

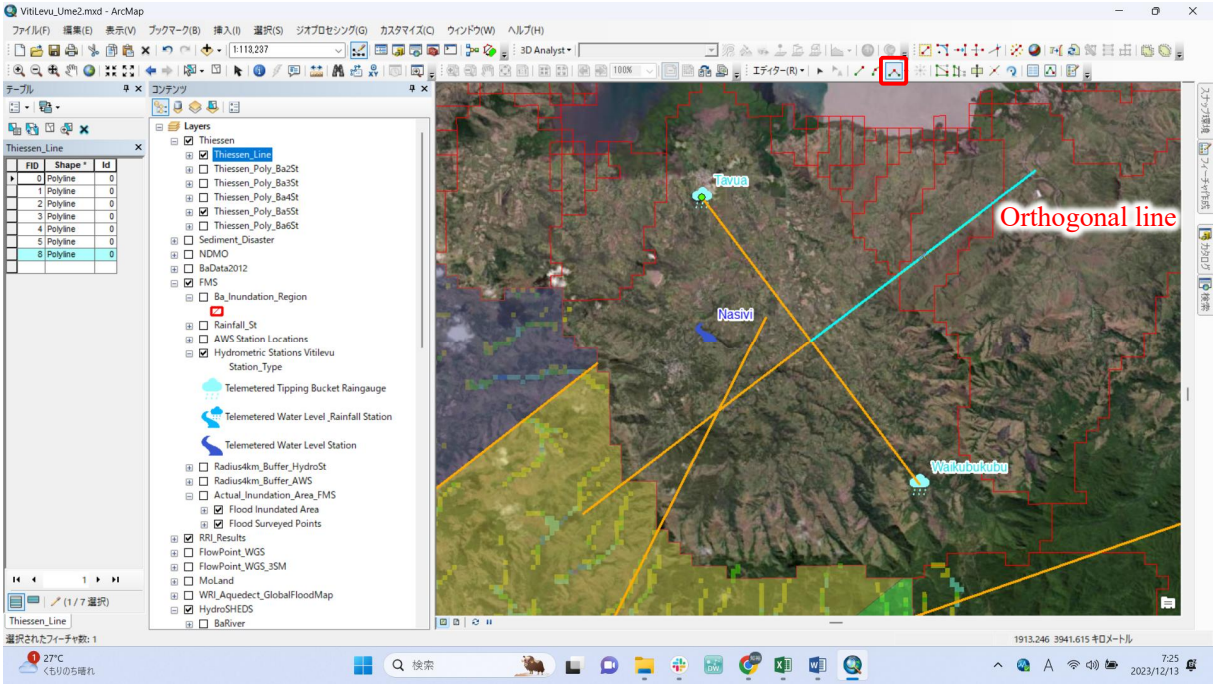
Ex) 0.20 × 2.9 Ex) 0.27 × 18.1

3.2.1 Drawing Thiessen Polygons Manually

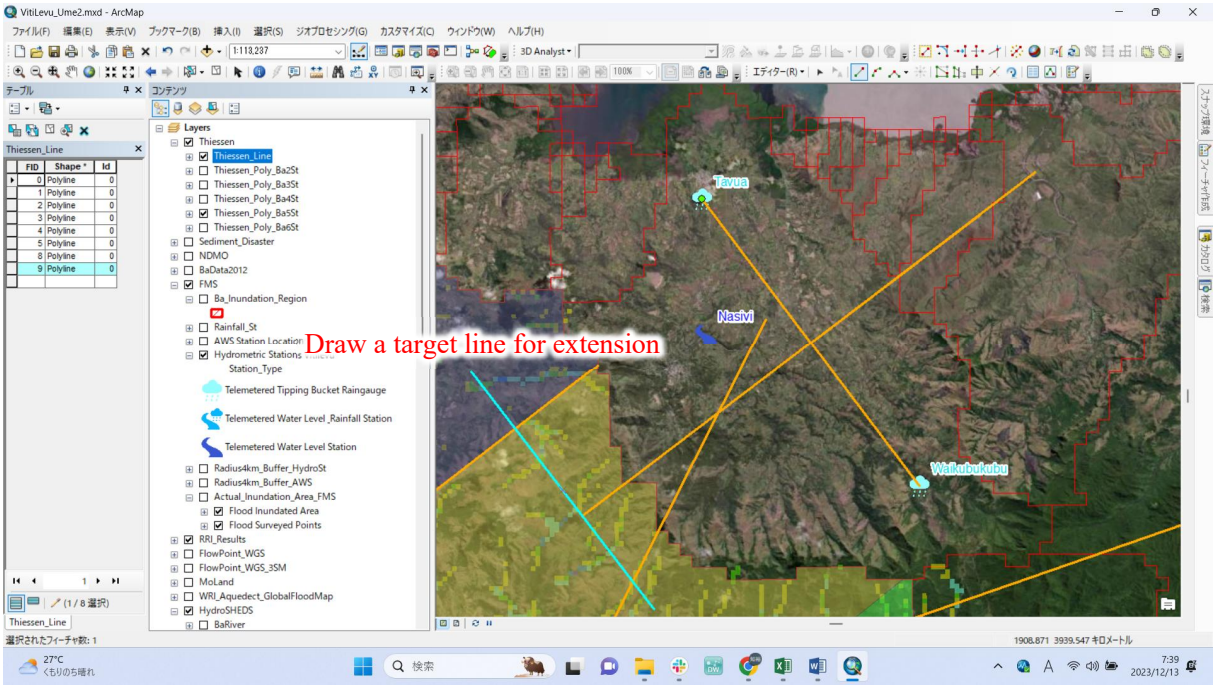
1) Draw a middle point between 2 rainfall stations. Start the editor, create features. Click on the "middle point".



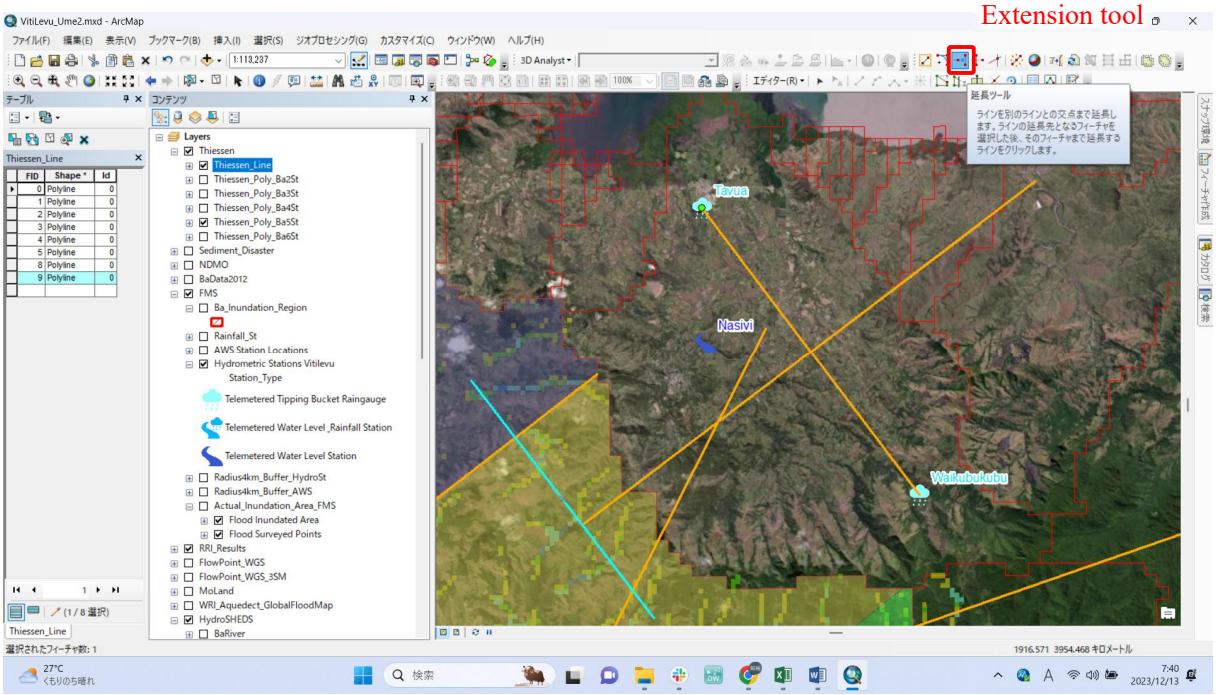
2) Now draw an orthogonal line from the middle point. Click on the "square / right angle". The line should cross the border of the watershed.



3) Now the orthogonal line shall be extended to the opposite side of the border of the watershed. To extend the line, you need to draw a line outside of the watershed.

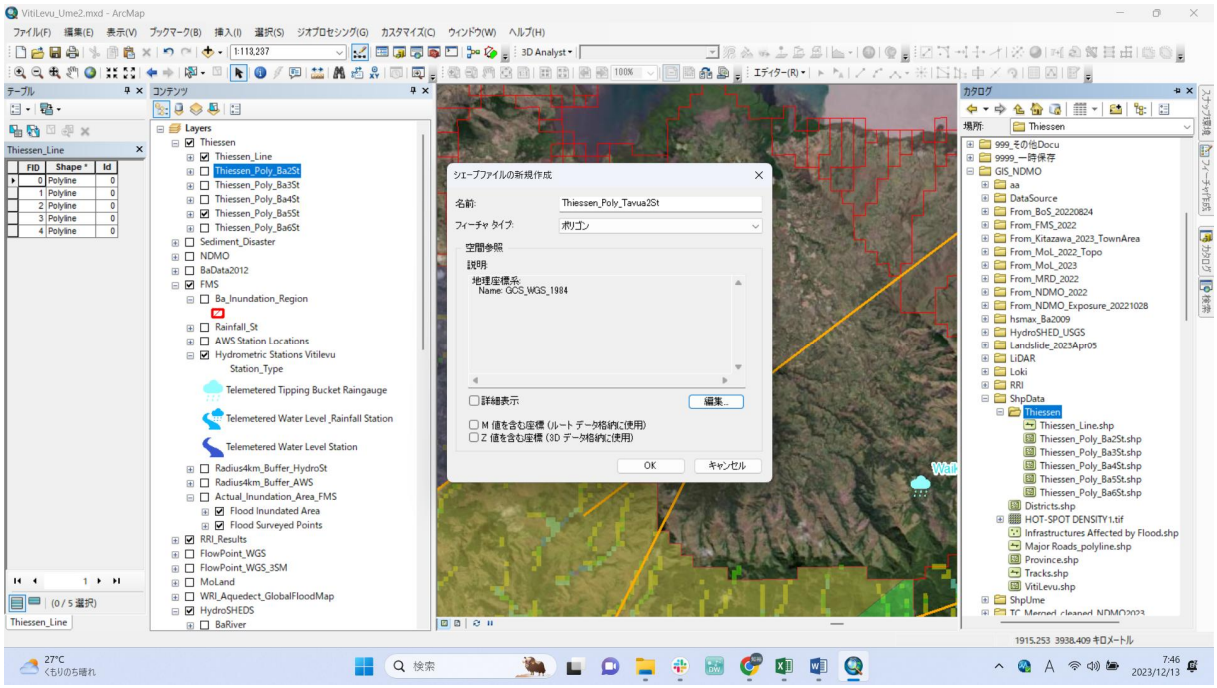


4) Extend the orthogonal line towards the target line using “extension tool”. First select the target line, then click on the orthogonal line to extend.

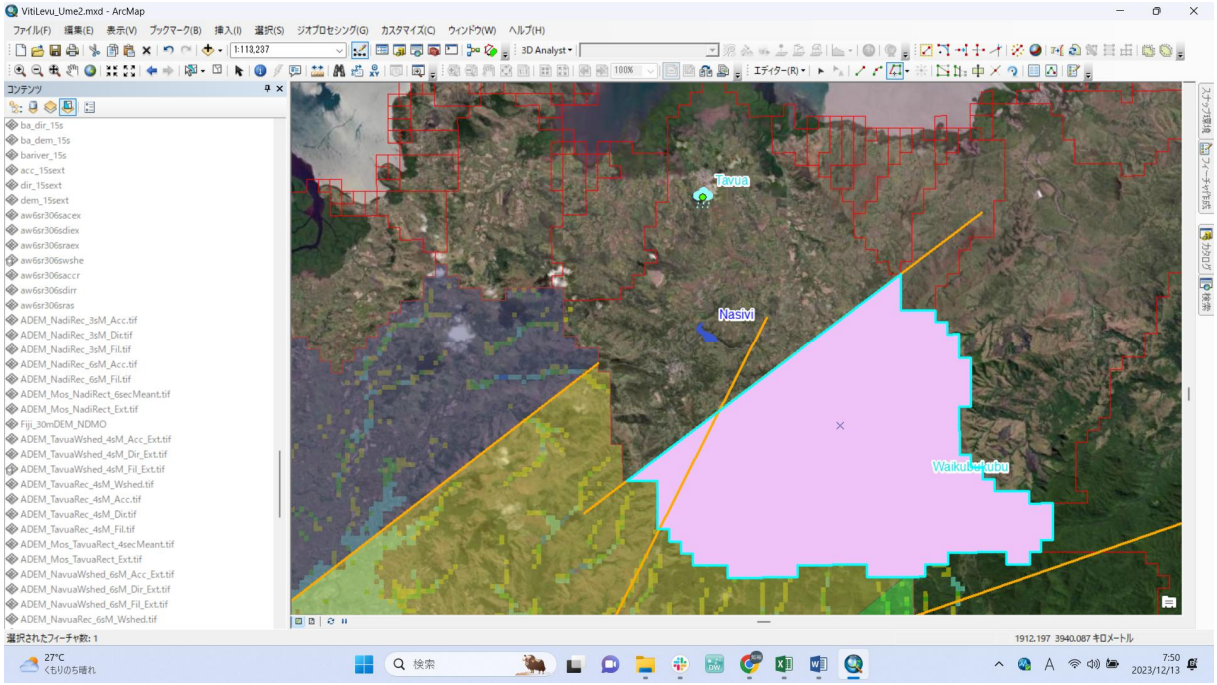


5) After drawing the complete orthogonal line over the watershed, you can delete the unnecessary lines. And then, make sure to save the edit.

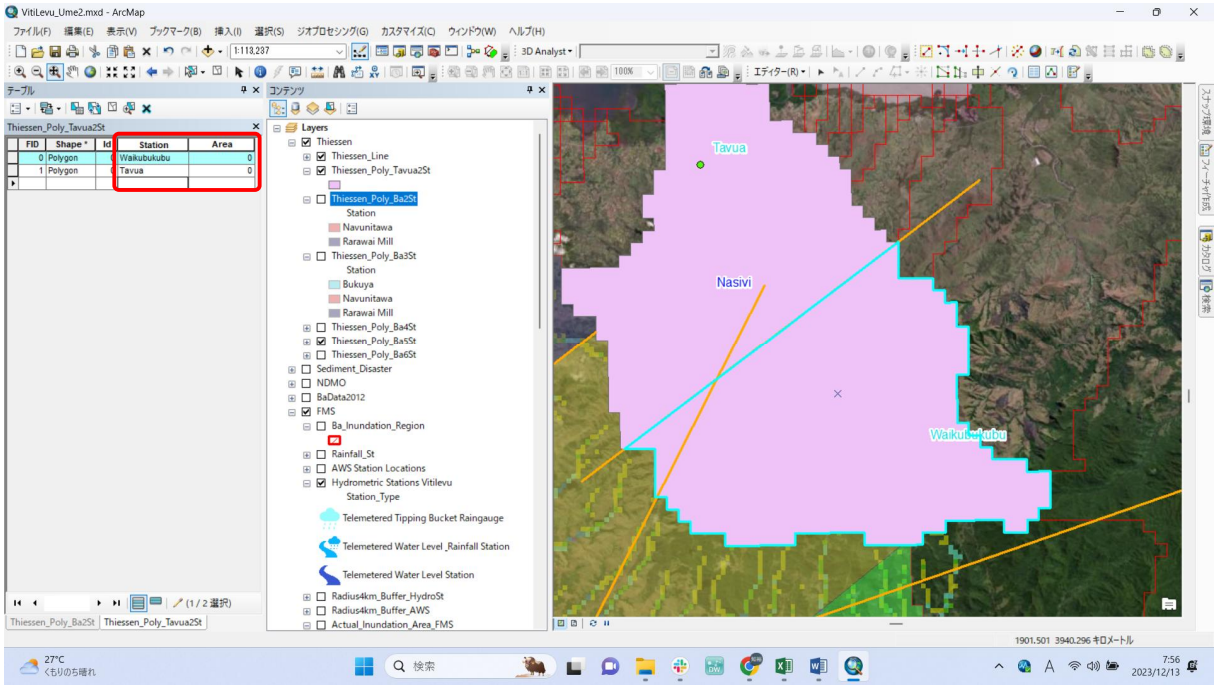
6) Now draw Thiessen polygons. Create a new shape file (polygon).



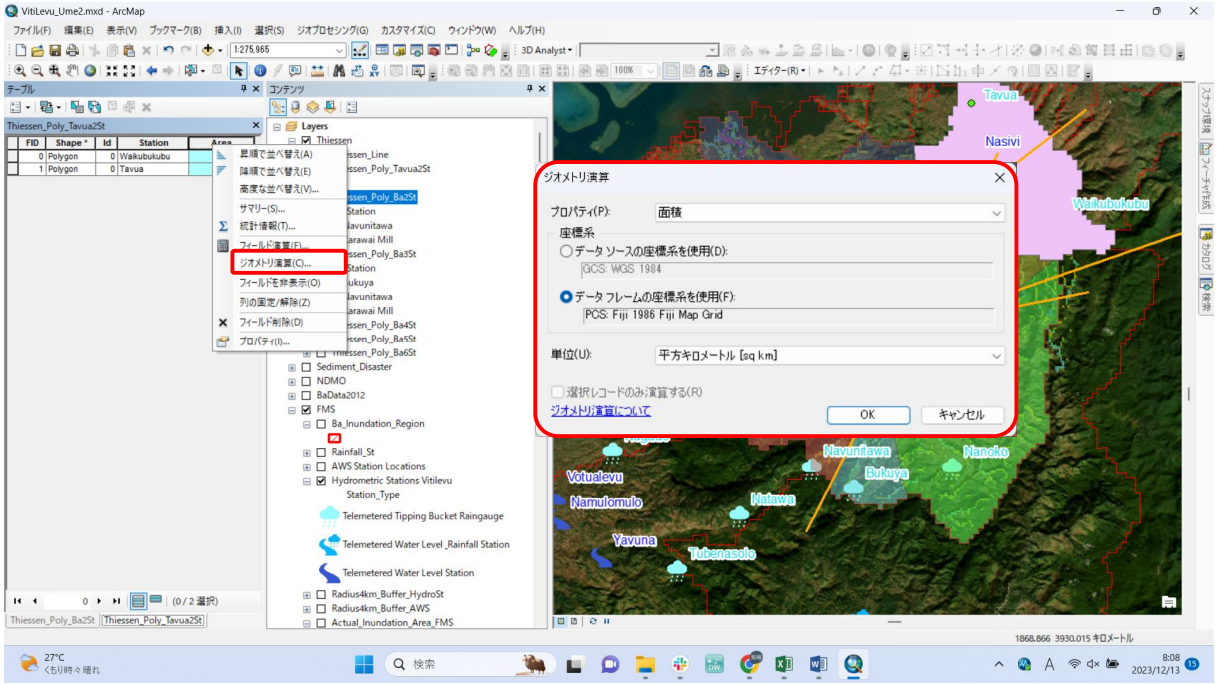
7) Start the editor and trace the orthogonal line and the border of the watershed.



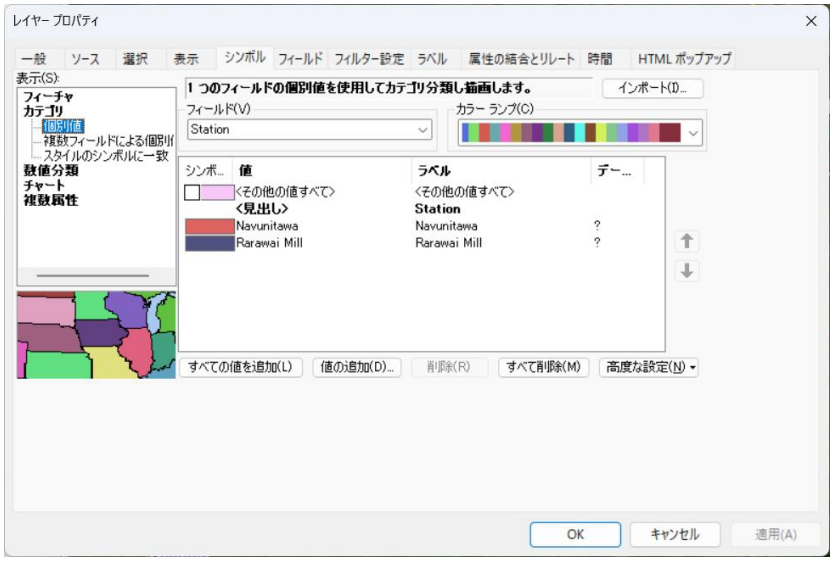
8) Finish editing and create 2 fields on the attribute table, “Station” and “Area”. Start editing again and input the name of stations for each coverage areas. Then, save editing.



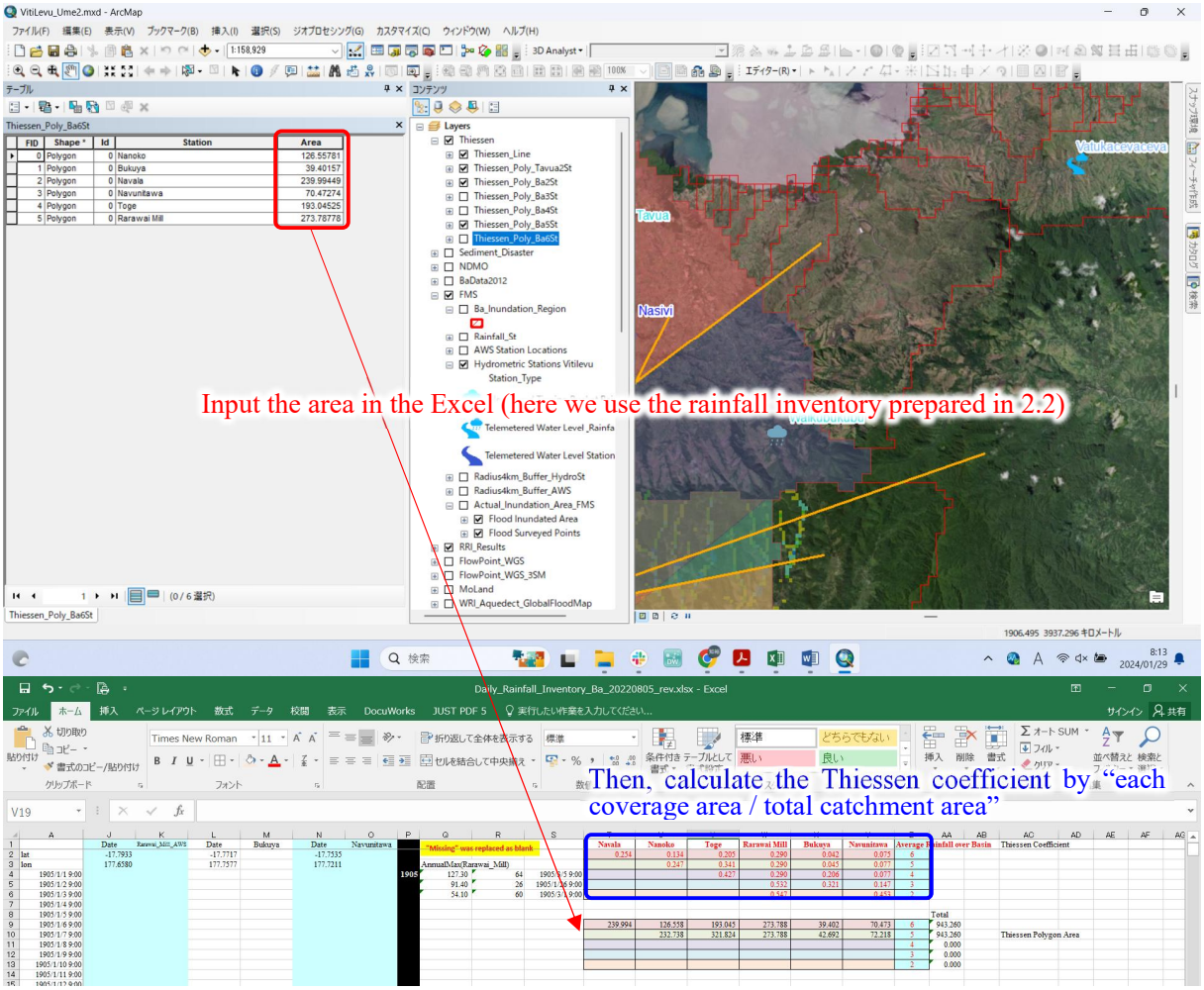
9) Coverage areas are calculated using “Geometry Calculation”. Right click on the field name, “Area”, on the attribution table. Then, select “Geometry Calculation”. Select area as property and chose the right unit. Thiessen coefficient will be “each coverage area / total catchment area” (calculate on the Excel and so on).



10) Symbol shall be arranged, too.



11) Thiessen coefficient of the each polygon will be calculated on the Excel based on the area of each Thiessen polygon.



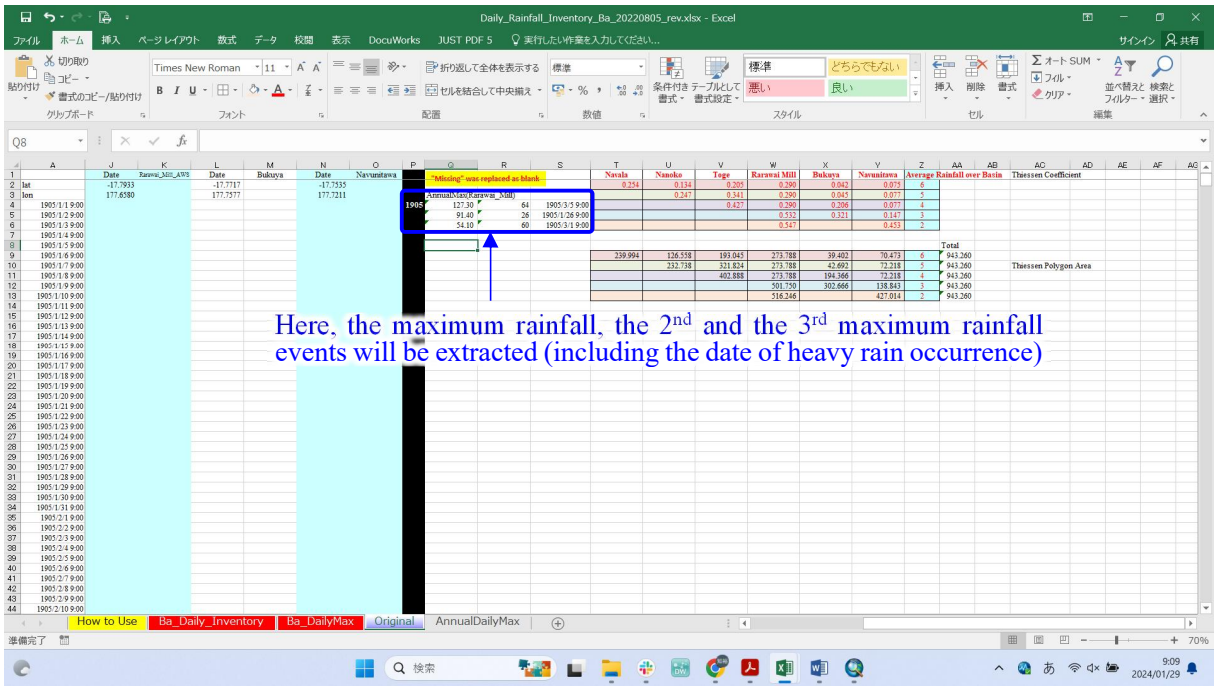
3.2.2 Preparing Input Rainfall Data for Statistical Analysis

1) As mentioned in the introduction, "Average Depth of Rainfall over Area" will be used. Therefore, Thiessen coefficients were calculated in the previous section. Now, calculate the "Average Depth of Rainfall over Area" based on the recorded / observed rainfall data and the Thiessen coefficients. Here, the Thiessen coefficients are calculated on the Excel of the rainfall inventory.

2) In the case of the Ba River basin, there are observed rainfall data (at least daily rainfall data) since 1905. However, the only one gauging station, the Rarawai Mill, is available from 1905 to 2010. Therefore, only the Rarawai Mill's observed data is used as a representative rainfall over the catchment area from 1905 to 2010.

3) Here, we use the "maximum annual rainfall" for the statistical analysis. However, the statistical analysis / hydrologic frequency analysis can be analyzed both with "annual maximum series" and "partial duration series[1]" of rainfall.

4) Therefore, maximum annual rainfall will be prepared using the rainfall inventory. The maximum, the 2nd and the 3rd maximum rainfall event are extracted using "MAX" and "LARGE" formulae of the Excel.



5) The Thiessen coefficients differs depending on the combination of the available observation station. Therefore, the procedure described in the previous section must be implemented for all the combinations. In case of the Ba River basin, basic combination of the available station are show as below. The Thiessen coefficients were calculated for all the combination.

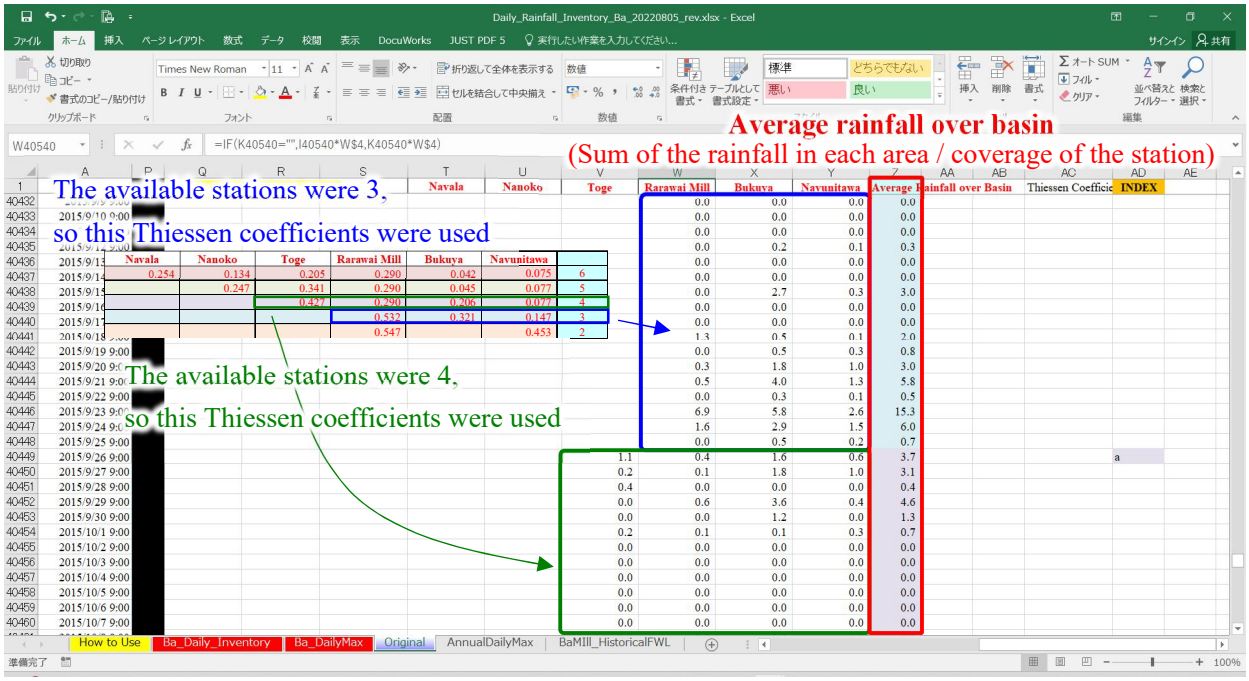
Thiessen Coefficient

Navala	Nanoko	Toge	Rarawai Mill	Bukuya	Navunitawa	
0.254	0.134	0.205	0.290	0.042	0.075	6
	0.247	0.341	0.290	0.045	0.077	5
		0.427	0.290	0.206	0.077	4
			0.532	0.321	0.147	3
			0.547		0.453	2

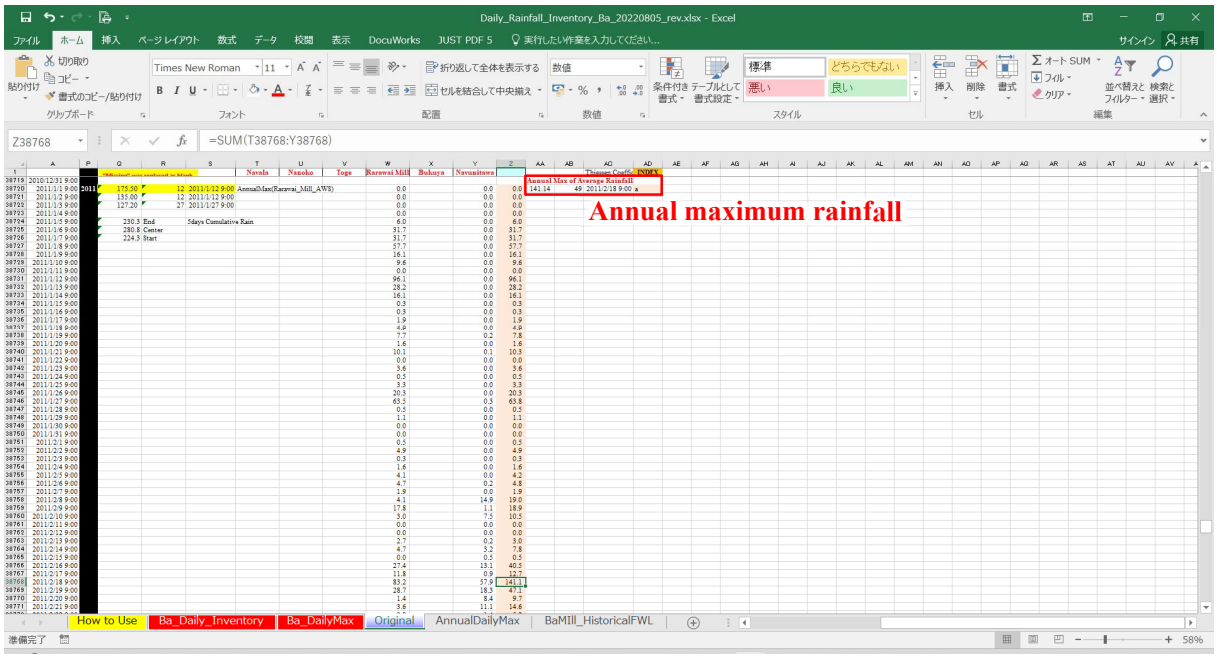
Thiessen Polygon Area							Total
239.994	126.558	193.045	273.788	39.402	70.473	6	943.260
	232.738	321.824	273.788	42.692	72.218	5	943.260
		402.888	273.788	194.366	72.218	4	943.260
			501.750	302.666	138.843	3	943.260
			516.246		427.014	2	943.260

[1] PARTIAL DURATION SERIES (PDS) - Time series that includes all precipitation amounts for a specified duration at a given station above a pre-defined threshold regardless of year; it can include more than one event in any particular year.

6) Daily average rainfall over area shall be calculated everyday based on the Thiessen coefficient calculated above. As mentioned above, the Thiessen coefficient to be used differs depending on the number of the available observation station / the combination of the observed stations.



7) After calculating the average rainfall over basin for all the days, annual maximum rainfall shall be identified for all the year.



Consideration: Error / Missing observation data

IMPORTANT: It seems that some / many of the observed data have error value or missing data. Especially the below cases are extracted as the maximum annual rainfall, however it seems the values are accumulated for a couple of days' (by the day before) precipitation. This kind of error value shall be checked manually… (Automatic judgement might be difficult).

Date	Rarawai_Mill_Manual
2008/12/27	35.7
2008/12/28	0.4
2008/12/29	2.5
2008/12/30	6.8
2008/12/31	0
2009/1/1	0
2009/1/2	0.3
2009/1/3	32.4
2009/1/4	0
2009/1/5	1.6
2009/1/6	22.4
2009/1/7	77.3
2009/1/8	283.5
2009/1/9	185.5
2009/1/10	0
2009/1/11	500
2009/1/12	60
2009/1/13	140
2009/1/14	90
2009/1/15	41
2009/1/16	54
2009/1/17	196
2009/1/18	110
2009/1/19	0
2009/1/20	1.9

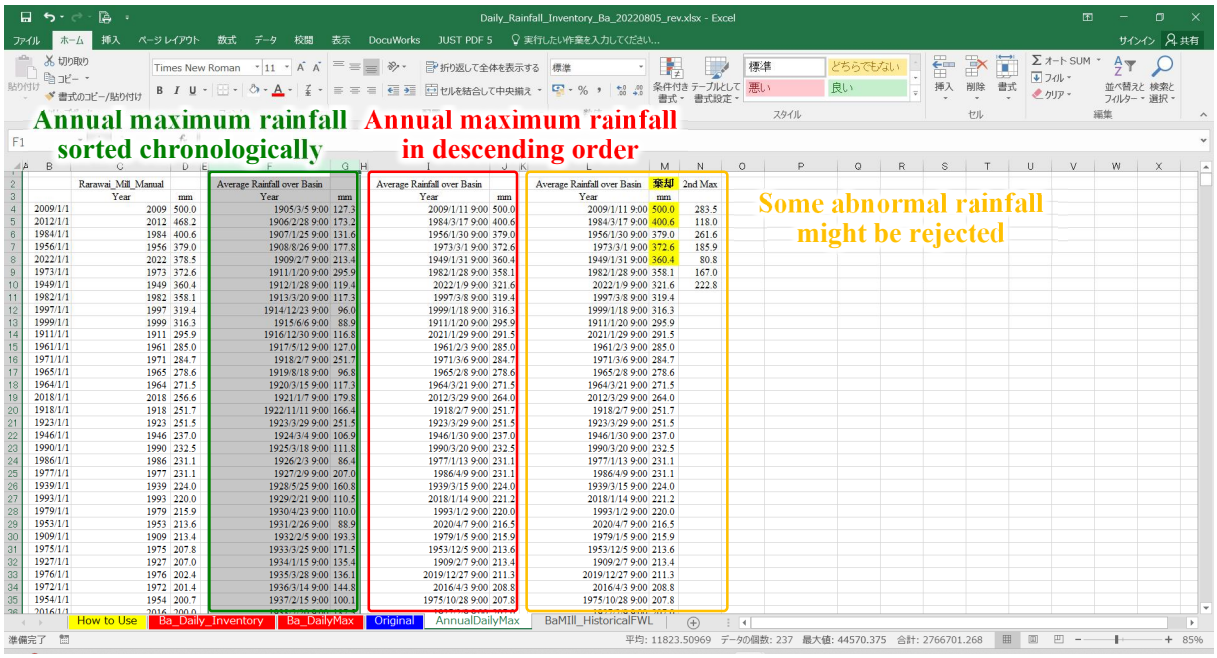
Susspicious data, but it reminds

Date	Rarawai_Mill_Manual	Date	Rarawai_Mill_AWS
1984/2/28	0		
1984/2/29	0		
1984/3/1	0		
1984/3/2			
1984/3/3			
1984/3/4	42.7		
1984/3/5	59.2		
1984/3/6	0		
1984/3/7	16.5		
1984/3/8	16.5		
1984/3/9	0		
1984/3/10	0		
1984/3/11	0		
1984/3/12	0		
1984/3/13	4.1		
1984/3/14	0		
1984/3/15			
1984/3/16			
1984/3/17	400.6		
1984/3/18	20.3		
1984/3/19	0		
1984/3/20	0		
1984/3/21	0		
1984/3/22	0		
1984/3/23			
1984/3/24			
1984/3/25	14.2		

Susspicious data, it might be previous 3 days accumulated value

In case the maximum annual rainfall seems wrong / error, the 2nd and the 3rd maximum rainfall were also extracted as a reference.

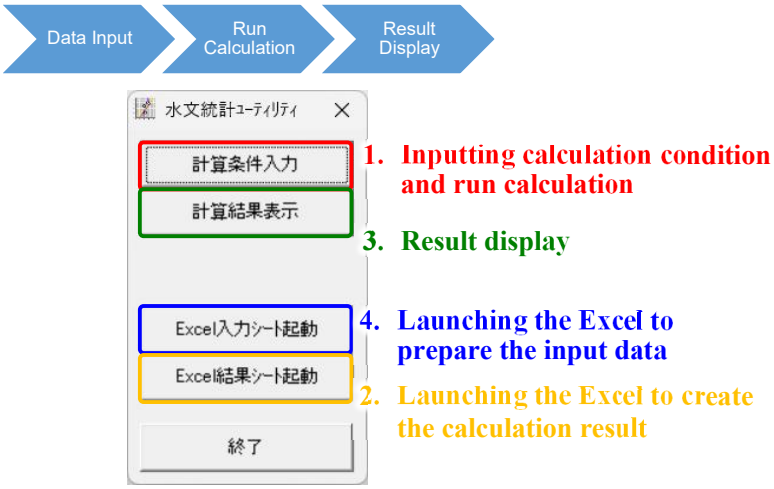
8) After identifying the annual maximum rainfall, it must be organized / listed in the other excel sheet shown as below (in chronological order and in descending order). Some of the abnormal maximum rainfalls shall be rejected as mentioned in the above consideration.



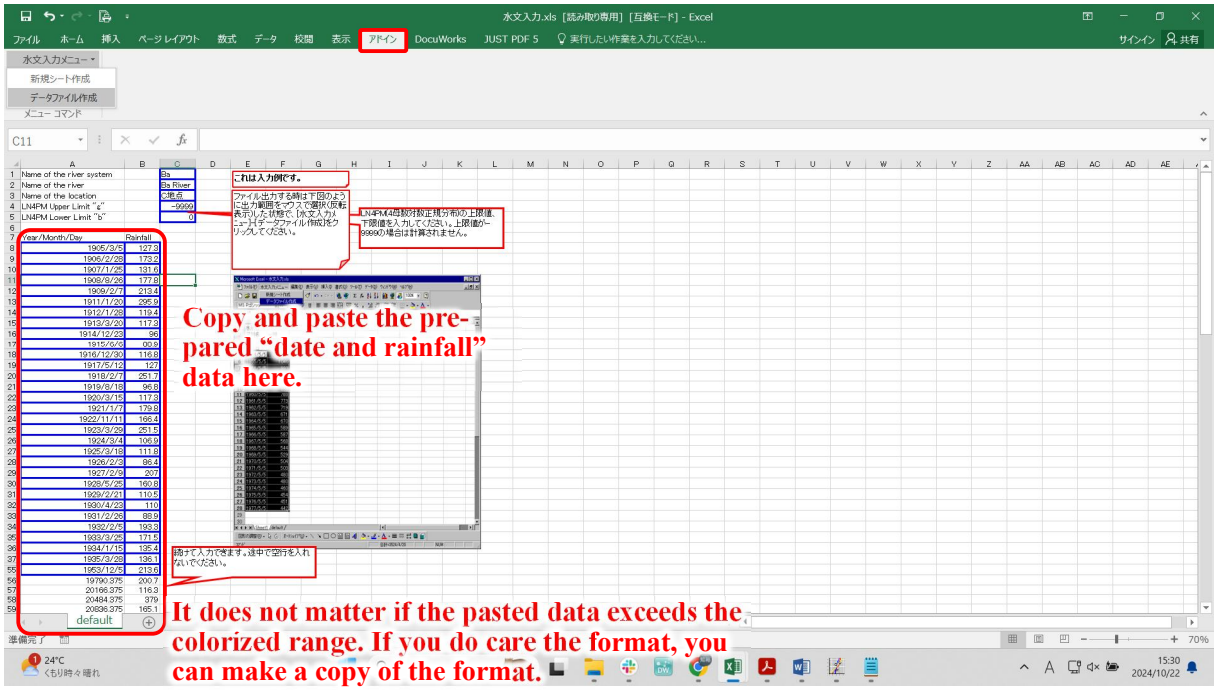
3.2.3 Statistical Analysis using the Software (Hydrological Statistics Utility)

1) The software can be downloaded freely. The software is very simplified and there are mainly 3 steps, 1. Data Input, 2. Run Calculation and 3. Result Display. As for the detailed manual, please refer to the appendix, "Hydrological Statistics Utility User's Manual".

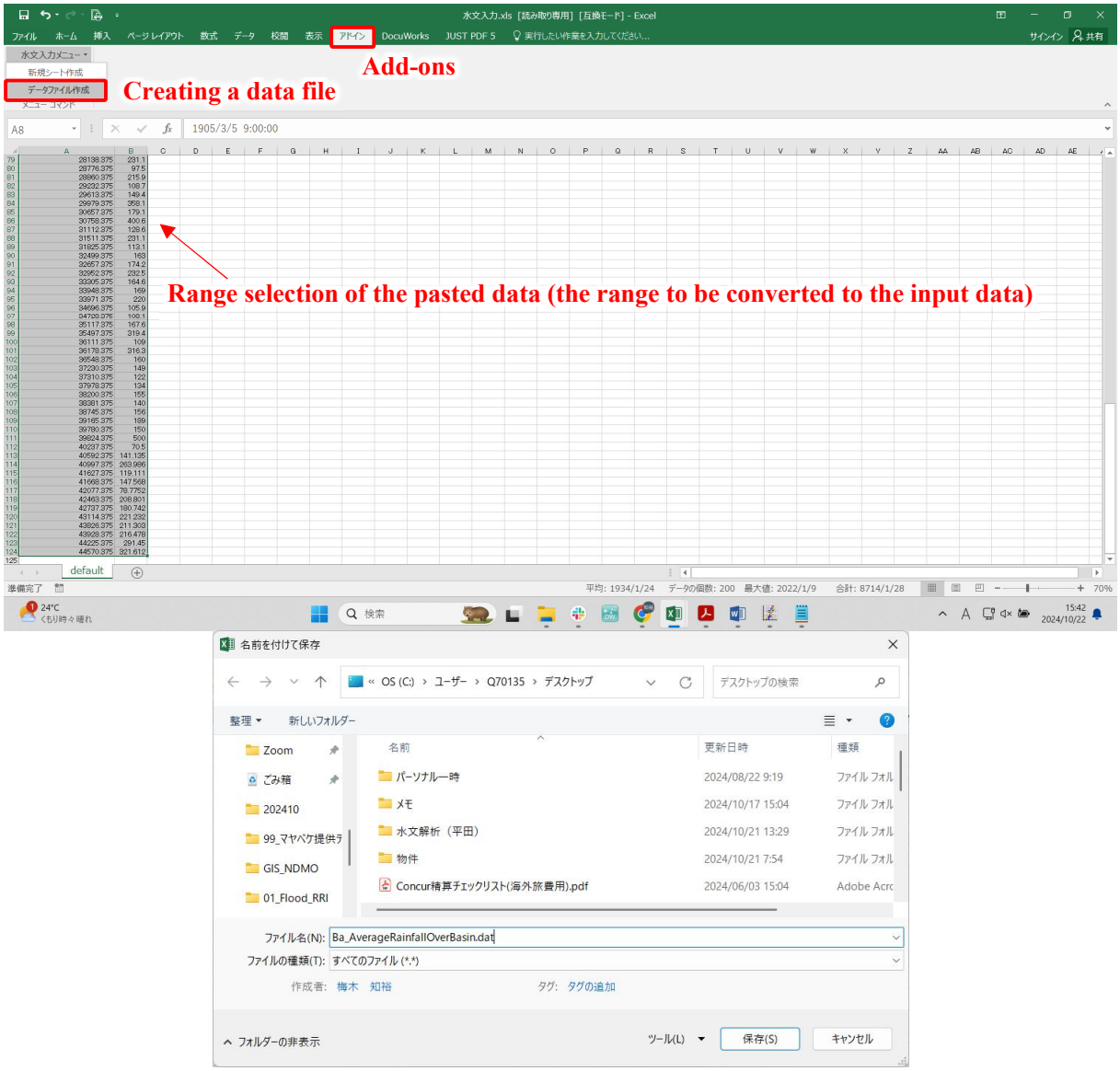
https://www.jice.or.jp/tech/software/rivers/hydrology/programdl



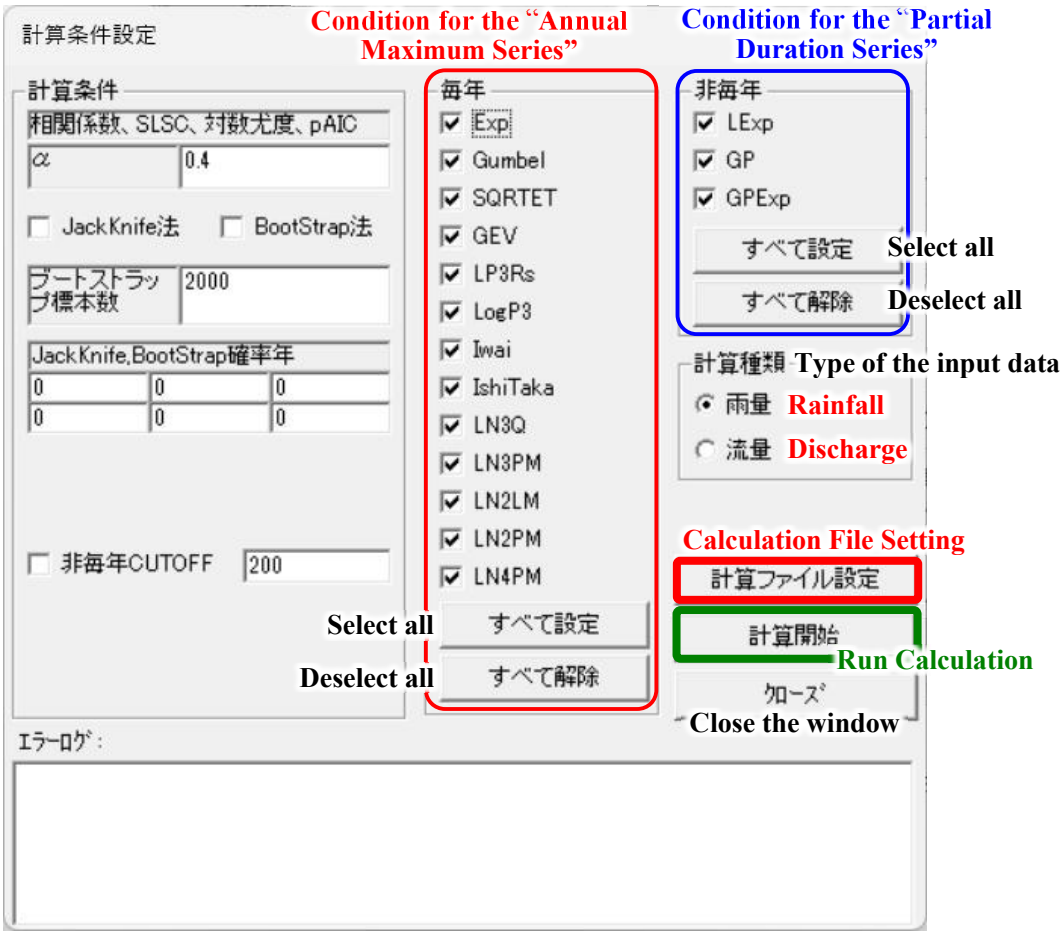
2) The Excel to prepare the input data will be launched by clicking the above blue highlighted button. Basically, you just need to copy and paste the rainfall data (date and rainfall) prepared in the previous section.



3) After pasting the data, select a range of cells of date and rainfall. Then, move to “Add-ons” and click “Creating a data file”. The window to save a file will open, so input a proper file name with the extension and save the file.



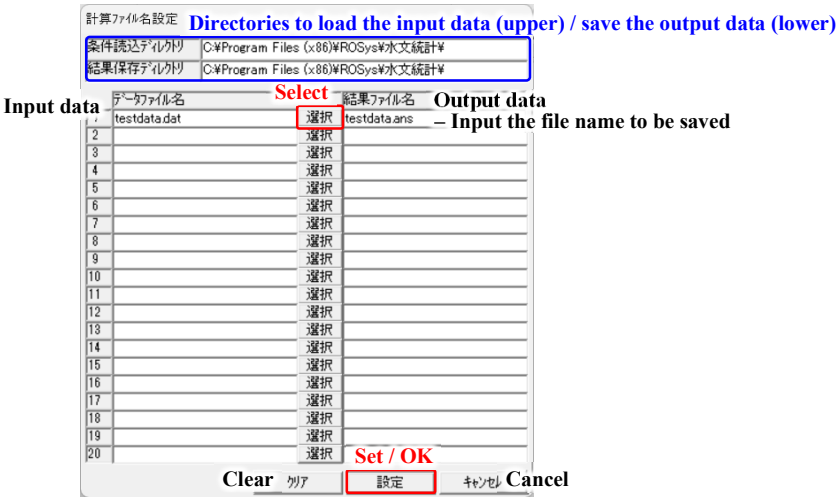
4) The window to set the calculation condition will be launched by clicking the above red highlighted button in the 1).



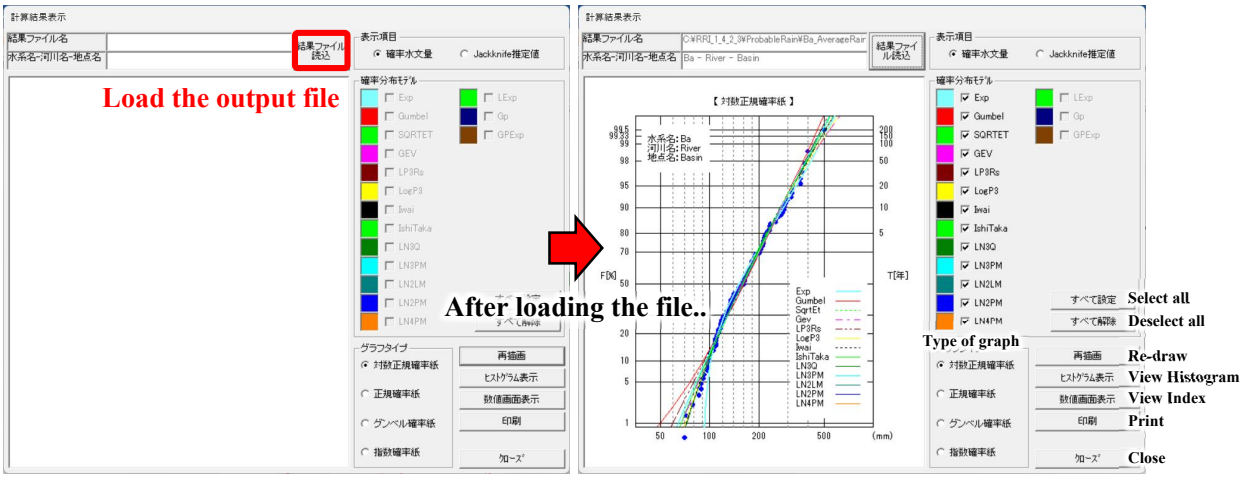
5) The "Jack Knife method" and the "Boot Strap method" are the simulations for the purpose of assessing the reliability of obtained estimates. You might tick the box of the Jack Knife method, however the Boot Strap method takes time to calculate (several hours), depending on the data / samples used, therefore it is not recommended to tick the box of the Boot Strap.

6) If the input data is the Annual Maximum Series, the conditions (tick boxes) of the Partial Duration Series can be deselected (vice versa for the calculation using the partial duration series).

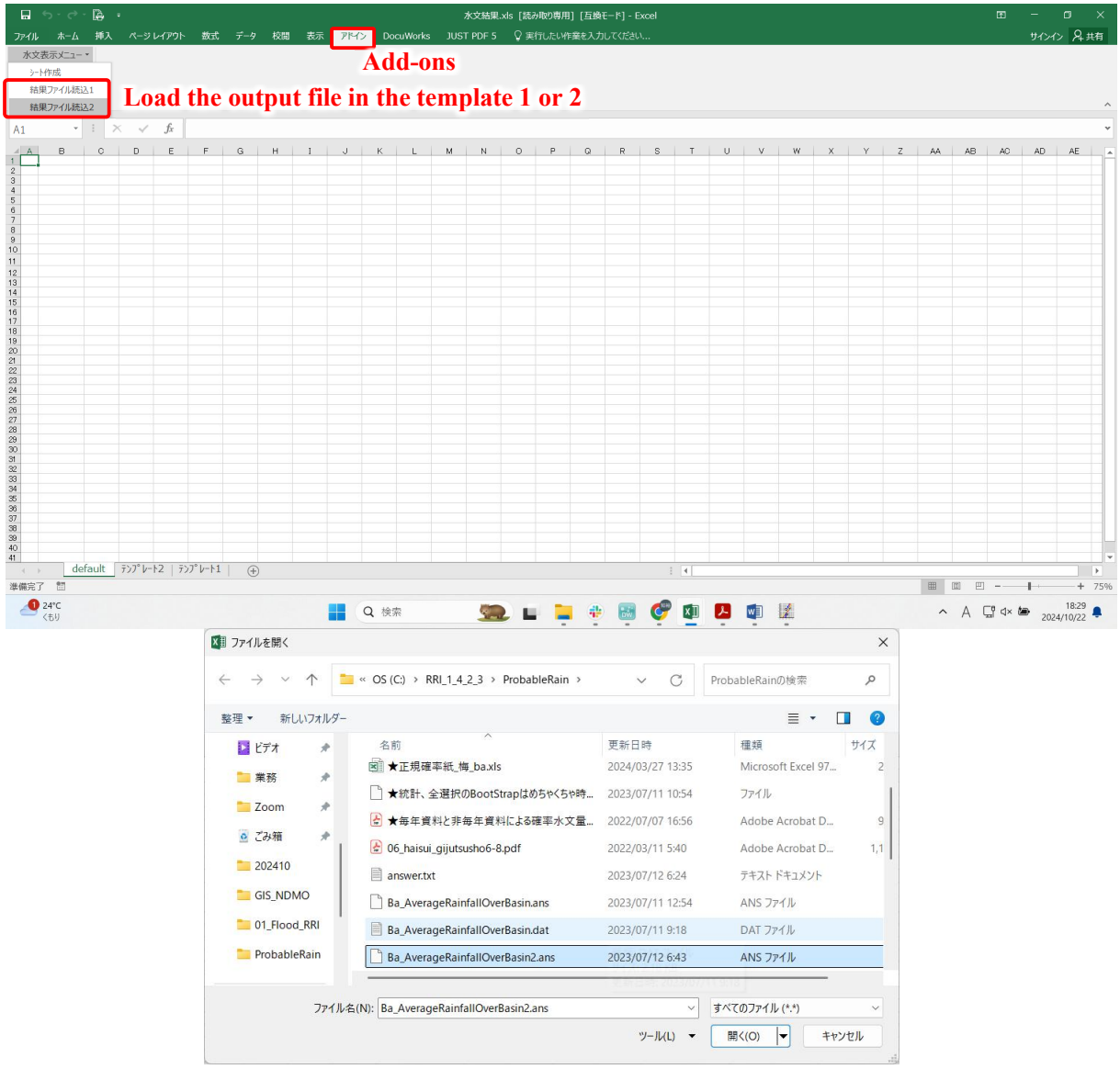
7) Click on "Select" and set the input data prepared. The directory to load the input data will be automatically changed. You can copy & paste the same directory to the directory to save the output data. As for the output data, you need to fill / write the name of the file to be created (the extension will be " .ans"). Click "Set / Ok" button and then, "Run Calculation".



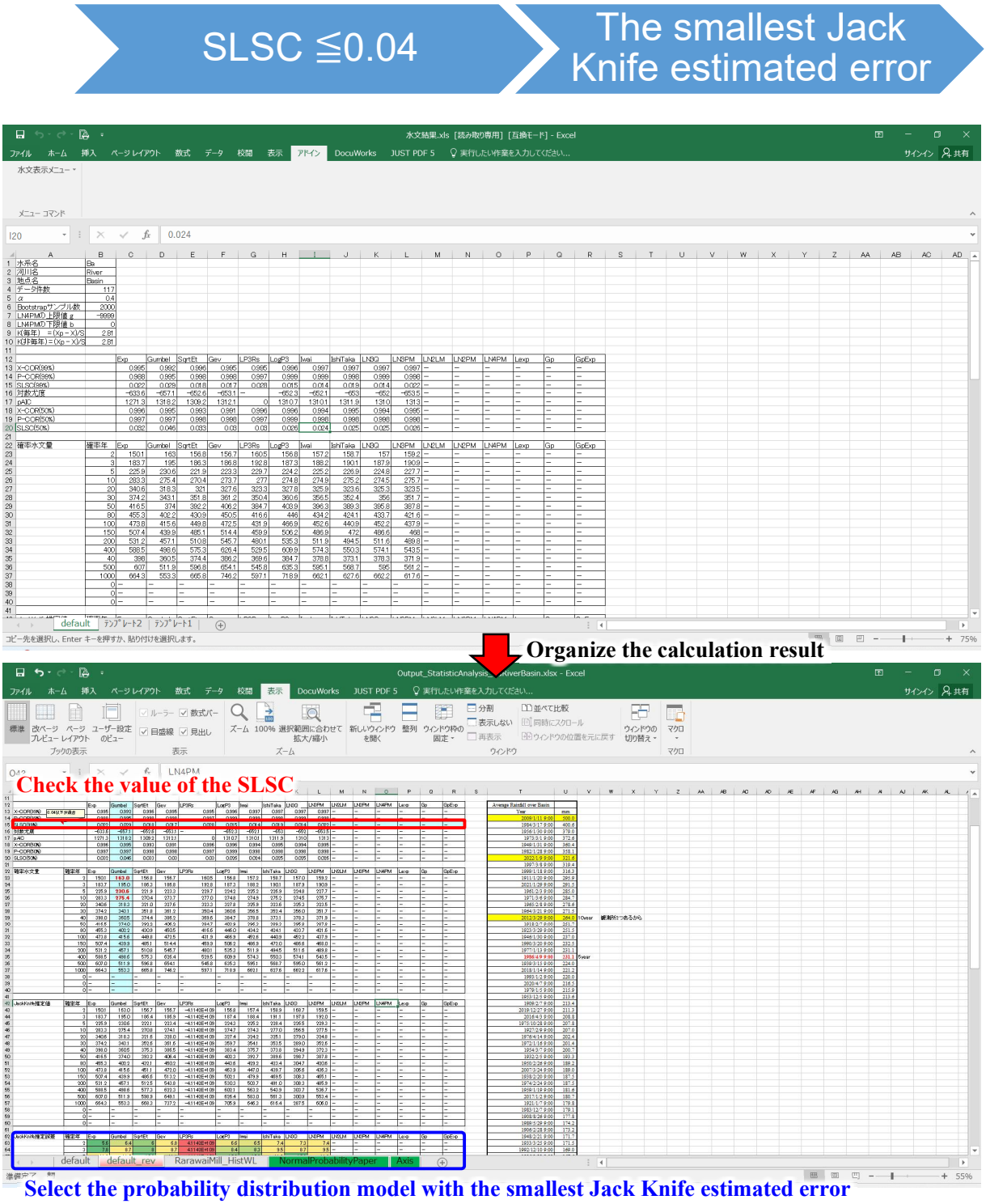
8) After the calculation, click the above green highlighted button in the 1) to open the result display. Please refer to the appendix for the further explanation.



9) The Excel to show the calculation result will be launched by clicking the above orange highlighted button in the 1). Move to "Add-ons" and click "Load the output file", then set the output file created above. Template 2 might be used for organizing the calculation result.



10) Basically there are 2 steps to check the goodness-of-fit, “1) if the value of SLSC is less than 0.04, it is evaluated as compliant (smaller value is better)” and “2) the smallest Jack Knife estimated error” will be adopted.



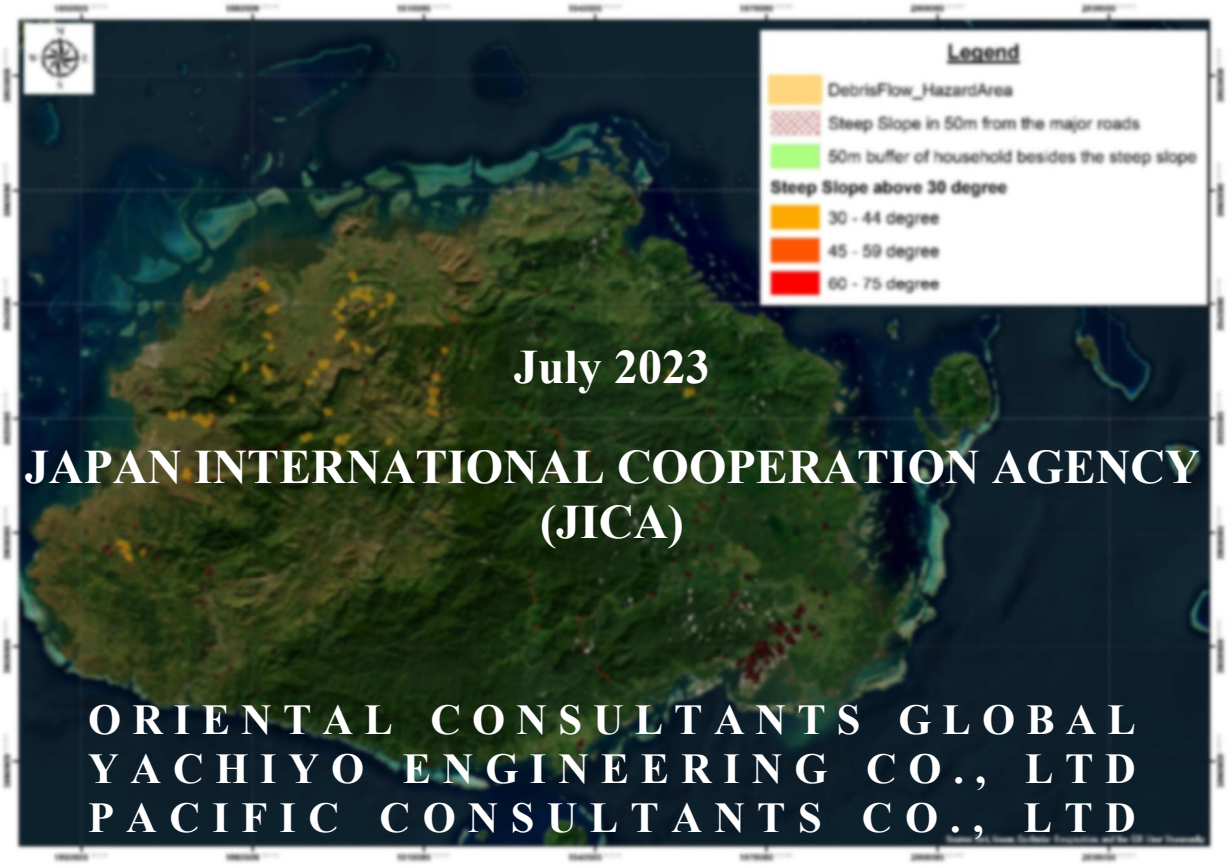
11) Based on the calculation result, you can identify the degree of rare heavy rainfall and the return period of the past observed rainfall and so on.

Republic of Fiji

PROJECT for Mainstreaming of Disaster Risk Reduction Project

Guideline on Sediment Disaster Hazard / Risk Assessment

-Simplified Assessment using GIS-



July 2023

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

ORIENTAL CONSULTANTS GLOBAL
YACHIYO ENGINEERING CO., LTD
PACIFIC CONSULTANTS CO., LTD

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APPEDIX - Study on Simplified Hazard / Risk Assessment Methods

Chapter 1. Introduction

1.1 Introduction

Fiji is located in disaster prone area due to its geographical, geological and demographic conditions. Flood occurs almost every year due to cyclone and front. There is also a risk of tsunami due to earthquake frequently occurring in the surrounding ocean. In addition to these hazards, vulnerabilities brought about by living in small, reclusive and remote island countries increase the disaster risk in Fiji. According to the World Risk Index 2018 released by UN University, Fiji is the 10th high-risk country among 171 countries in the world.

Fiji has a certain level of capacity for disaster response based on its experience with past disasters by coordinating related agencies from national to local levels. Furthermore, some efforts have been taken already for mainstreaming DRR and promoting the pre-investment for DRR by developing the "Fiji National Disaster Risk Reduction Plan (NDRRP) 2018-2019" based on international framework such as the Sendai Framework.

However, there are several challenges in the institutional framework for the development of national and local DRR plans, and for the implementation of DRR projects, in the hazard assessment, etc.

Based on this situation, the followings from the "Sendai Framework for Disaster Risk Reduction / SFDRR" are very important in Fiji.

1) Understanding disaster risk

2) Strengthening disaster risk governance to manage disaster risk

3) Investing in disaster risk reduction for resilience

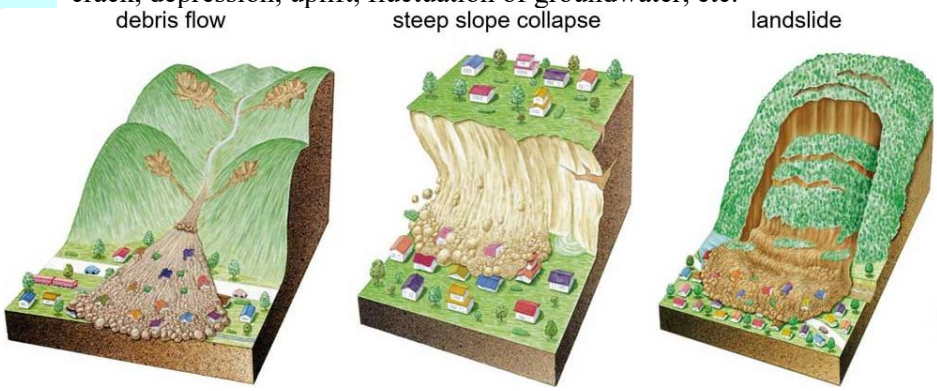
4) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction

As mentioned above, it is necessary to clarify the sediment related hazards in order to understand the actual situation of the disasters and to implement appropriate measures against disasters that are causing great damage.

1.2 Major Types of Sediment Disaster

Sediment disaster is defined as the movement causes damage to human lives and properties and so on directly and indirectly[1]. It is classified into three types (refer to Figure 1-1)[2, 3].

Debris flow	Sediment (soil and rock) produced by hill-slope collapse or from riverbed travelled downward under the influence of water from continuous rain or torrential rain. Although the flow velocity differs by the scale of debris flow, it sometimes reaches 20-40 km/hour.
Steep slope collapse	Abrupt collapse of a steep slope. Steep slope collapse often occurs on slope of ≥30°, very rapid (>10 mm/day), and no signs prior to the collapse.
Landslide	Downward movement of a slope or part of slope due to groundwater and gravity. Landslide mostly occurs on gentle slope (5-30°), moves very slow (0.01-100 mm/day), and many signs prior to movement. These signs include occurrence of crack, depression, uplift, fluctuation of groundwater, etc.



Source: NPO Sediment Disaster Prevention Publicity Center

Figure 1-1 Schematic diagram of outbreak mechanism of flood

Sediment disaster hazard can be expressed / evaluated as "Hazard area of sediment disaster, Reaching area / distance of soil mass / sediment, Areas where serious danger can occur (designated dangerous area, yellow / red zones)" and so on.

Sediment disasters in Japan occur in various parts of the country almost every year, and the number of dangerous areas where sediment disasters may occur has been increasing due to new residential land developments. It requires a lot of time and cost to implement structural measures at all those areas. Therefore, it is important to clarify dangerous areas by hazard assessment, and to enhance non-structural measures, such as the development of a warning and evacuation system and restrictions on certain development actions, along with structural measures[4].

---

1 Guidelines for Development of Warning and Evacuation System Against Sediment Disasters in Developing Countries – Basis of Sediment Disaster, 2004, https://www.mlit.go.jp/sogoseisaku/inter/keizai/gijyutu/pdf/sediment_e_02.pdf

2 https://www.ktr.mlit.go.jp/river/bousai/river_bousai00000078.html

3 Sediment disaster warning area based on the Sediment Disaster Prevention Law, nd, https://www.mlit.go.jp/river/sabo/sinpoupdf/gaiyou.pdf

4 http://www.sabo.pref.fukuoka.lg.jp/shiryou/images/4.pdf

1.3 Methodology of Sediment Disaster Hazard Assessment

There are many hazard / risk assessment methods for each type of disaster, from simplified methods based on past disaster records to advanced methods based on simulations and individual field survey (refer to Figure 1-2). Detailed characteristics of each methods are also explained in the appendix, "Study on Simplified Hazard / Risk Assessment Methods".

The purpose of the project is to promote disaster prevention projects to reduce disaster risk and to formulate local disaster prevention plans, so a method that can express the disaster risk reduction (DRR) quantitatively through implementation of countermeasures will be determined. On the other hand, it is preferable that the simplified method will be applied for Fiji considering the current C/Ps' experiences and capabilities regarding disaster hazard / risk assessment since the methods based on advanced method requires a lot of efforts and expertise and it is not realistic at the earlier stage of implementation of hazard / risk assessment.

There are various definitions of disaster risk, such as the disaster risk is determined by the "interaction of hazards, vulnerabilities, and exposures", but disaster hazard / risk assessments in the project is defined as follows.

Disaster Hazard Assessment : Assessment of potentially harmful natural phenomena that may cause damage to human life, assets, society, economy, etc.

Disaster Risk Assessment : Assessment of damage to human life, assets, etc. that disaster hazards can cause

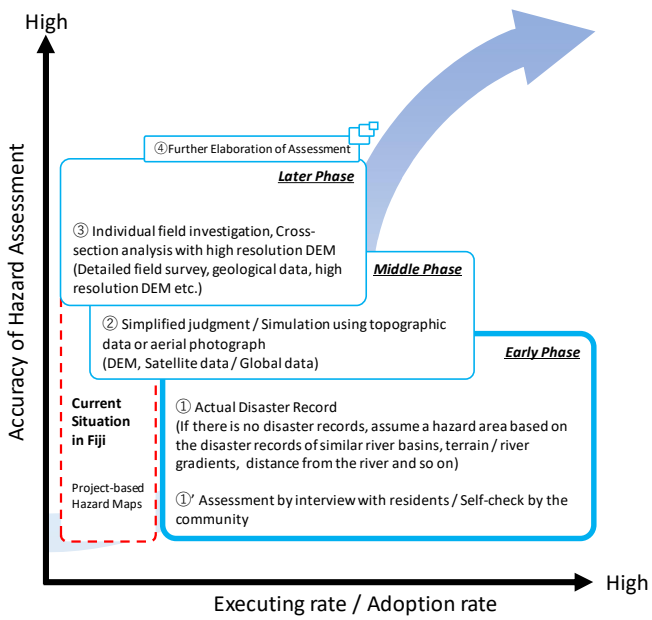


Figure 1-2 Image of Stepwise Hazard Assessment (in case of sediment related disaster)

Basically, analyses based on scientific evidence are implemented by using information including topography, geography, hydrometeorology and hydrography and so on. The fundamental ideas behind hazard assessment methods in any disaster are common: hazards will be assessed based on impact and extent of the disaster, which entities will suffer. Other factors such as geographical characteristics, landform conditions, and land use are taken into consideration when conducting these assessments.

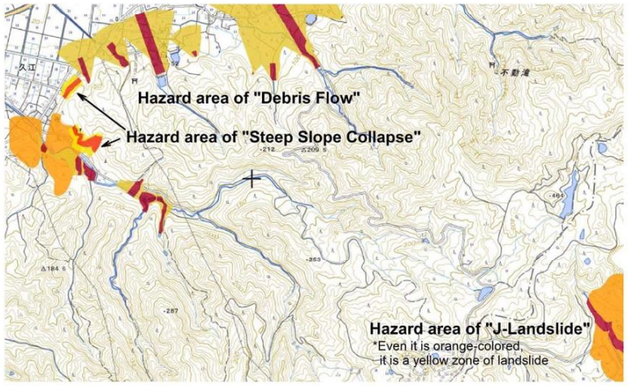
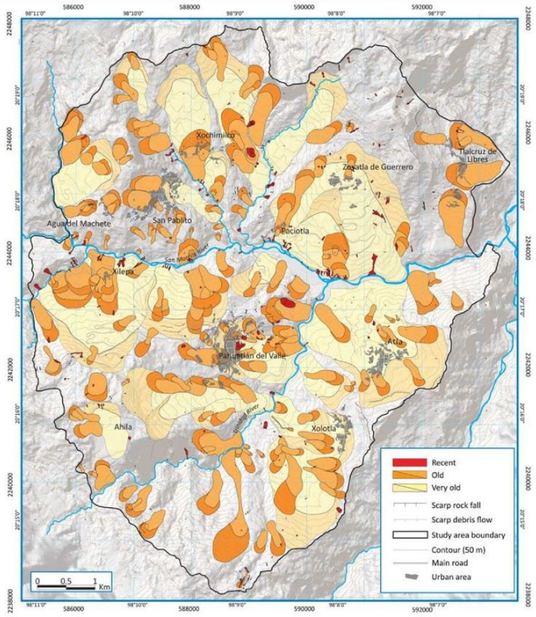
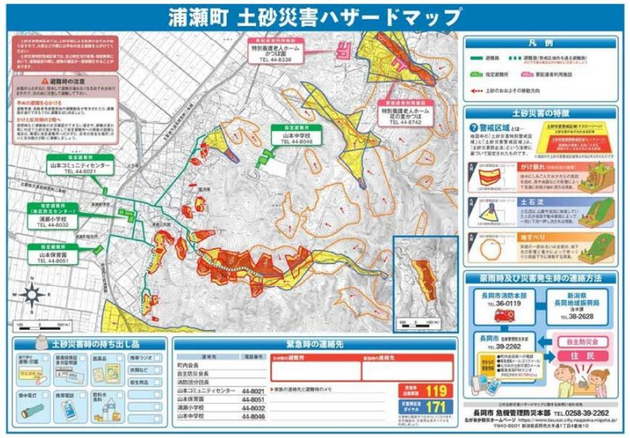
"Visual judgment with topographic map", "Interpretation of aerial photographs" and "Field investigation / Cross-section analysis with high resolution DEM and GIS" are the major methods for sediment disaster hazard assessment. Characteristics of each method are shown in Table 1-1 and Figure 1-3.

Table 1-1 Methods of Sediment Disaster Hazard Assessment

Sediment Disaster Hazard	Simplified	➡	Detailed
Method	**(1) Visual judgment with topographic map**	**(2) Interpretation of aerial photographs**	**(3) Field investigation / Cross-section analysis with high resolution DEM and GIS**
Items can be assessed	Narrowing / screening of hazard areas for detailed (3) Field investigation ➢ Hazard area of sediment disaster ➢ Reaching area / distance of soil mass / sediment ➢ (Areas where serious danger can occur [i.e. assumed yellow / red zones])	Same as left-mentioned method, narrowing / screening of hazard areas for detailed (3) Field investigation ➢ Hazard area of sediment disaster ➢ Reaching area / distance of soil mass / sediment ➢ (Areas where serious danger can occur [i.e. assumed yellow / red zones])	Assessment result will be more accurate than the left-mentioned methods ➢ Hazard area of sediment disaster ➢ Reaching area / distance of soil mass / sediment ➢ Yellow / red zones (designated dangerous area)
Major Necessary Data	➢ Topographic map (1/2,500 - 1:25000) ➢ Geological map ➢ Past disasters record	➢ Aerial photograph (Optical satellite image) or DEM ➢ Stereoscope (equipment)	➢ Survey results by the left mentioned methods ➢ High resolution DEM (Such as 5m-DEM)
Characteristics (●Pros, ×Cons)	● Simple method only by basic data (topographic map) and disaster record ● Inexpensive × Local-scale visual judgment is required × Credibility and accuracy of the data affect the assessment result × Field investigation is required for accurate evaluation / setting of dangerous spot (yellow and red zones)	● Simple method only by easily obtainable simple aerial images ● It can read / extract a lot of dangerous spots spread through a wide area × It requires some experience / expertise and assessment result depends on interpretation skill × Field investigation is required for accurate evaluation / setting of dangerous spot (yellow and red zones)	● Field investigation contributes detailed / precious assessment for various scales ● High resolution DEM enables to interpret dangerous spots, which cannot be detected by topographic map × It requires actual field investigation × Since filed investigation shall be basically conducted at the extracted sites by the left-hand methods, there is a risk to be exempt from the target site depending on the accuracy of the extraction (Field investigation) × Even though 5m-DEM is used for the analysis, it is not always the actual dangerous sites can be detected
Deference from Japanese methods	➢ This approach is used for extracting the dangerous sites especially for (3) Filed investigation. Also, it has been adopted by World Meteorological Organization	➢ Same as the left method, this approach is used for extracting the dangerous sites especially for (3) Filed investigation.	➢ Filed survey is conducted to designate the Yellow / Red zones
Example／Countries	➢ Japan ➢ Indonesia (Central Sulawesi) ➢ USA (Washington) etc.	➢ Japan ➢ Mexico, Italy and etc.	➢ Japan ➢ China ➢ All over the world

"Visual judgment / field investigation by expert / specialist" is the fundamental and major methods to conduct hazard assessment for sediment disaster, and it takes "steady work". However, there is a primary method of sediment disaster hazard assessment using DEM data, especially for "debris flow" and "steep slope collapse" (Hazard assessment for landslide requires a professional judgement by expert / specialist). Therefore, Chapter 3 and Chapter 4 explain how to conduct the primary hazard assessment for debris flow and steep slope collapse.

The simplified hazard assessment conducted in this project is based on topographical data, and geological conditions are not used. Therefore, the locations assessed for hazards will require validation through field surveys in the future, as well as re-evaluation / review considering items not included in the assessment conditions of this simplified method, such as geological conditions.

Sediment Disaster		Simplified	➡	Detailed
Methods of Hazard Assessment		(1) Visual judgment with topo-graphic map	(2) Interpretation of aerial photographs (Sabo foundation map)	(3) Field investigation / Cross-section analysis with high resolution DEM and GIS
Images of the result of hazard assessment				
Level of Assessment		B Assumption by a topographic map and past disasters records	B Assumption by the aerial photographs (or etc.) and past disasters records	A Confirmation of the hazard areas which were narrowed / screened by the left-hand methods
Way to use		Damage assumption (simplified / in a single uniform way), Planning of countermeasures	Damage assumption (simplified / in a single uniform way), Planning of countermeasures	Damage assumption (designation of hazard area), Planning of countermeasures and Evaluation of its effects
Assessable Items	Hazard area	C Adequate / Less accurate	B Adequate / Sort of accurate	A Adequate / Relatively accurate
	Sediment foot print	C Adequate / Less accurate	B Adequate / Sort of accurate	A Adequate / Relatively accurate
	Designation of hazard area	-	-	A Adequate
	Other basic information	-	-	A Adequate [Land use, building / household info., detailed landform, past sediment movement]
Conditions & Characteristics of the methods	Required data [Major data]	A Not many (Basic information) [Topographic / Geological map and Past disasters records]	B Not Many (Utilization of aerial imagery / DEM) [Aerial photograph (Optical satellite image) or DEM, Stereoscope (equipment)]	B Not many (High resolution data) [Survey results by the left mentioned methods, High resolution DEM (5m-grid)]
	Required techniques	A Not difficult – Need some experience / expertise	B Little difficult – Need some experience / expertise	A Not difficult – Need some experience / expertise
	Cost / Effort(Work)	Cost: A, Work: B Cost: Not much Work: Takes time and effort	Cost: B, Work: B Cost: Depends on the aerial imagery Work: Takes time and effort	Cost: C, Work: C Cost: Needs survey to confirm hazard areas Work: Needs survey to confirm hazard areas
	Accuracy	C Relatively inaccurate (Depends on the accuracy of the topographic map and interpretation skill)	B Sort of accurate (Mostly depends on interpretation skill)	A Relatively accurate
	Other major characteristics	× Credibility and accuracy of the data affect the assessment result	● It can read / extract a lot of dangerous spots spread through a wide area	× Since filed investigation shall be conducted at the extracted sites by the left-hand methods, there is a risk to be exempt from the target site depending on the accuracy of the extraction. Also, even though DEM is used for the analysis, it is not always the actual dangerous sites can be detected.

A: Good, B: Average, C: Poor

Figure 1-3 Summary of the major methods on sediment disaster hazard assessment

Chapter 2. Preparation of a Fundamental Data

DEM data is used to calculate a flow direction, flow accumulation and slope and so on. There are many options of free DEM data, such as ASTER GDEM, HydroSHEDS, SRTM3 and the GTOPO30 as mentioned below (refer to 2.1 4)). If you already have a DEM data, you can also use it.

How to download and prepare a DEM, flow direction / accumulation and slope using ASTER GDEM (section 2.1) **is explained hereafter.** If you have some available DEM data, you can skip some of the instructions below.

Major preparation steps are as shown below. **The detailed instruction of each step is shown in the following sections, especially "With ASTER GDEM"** and "With HydroSHEDS" (depending on the data).

1) **"Mosaic"** [Merge the downloaded DEMs]

2) **"Create a rectangle polygon to 'Extract / Clip' the above mosaic DEM"** [Rectangle polygon to cover all the area, Viti Levu Island / each river basin, including the river mouths and alluvial fans based on the HydroSHEDS' watersheds or any shape files]

3) **"Extract / Clip by mask"** [Extract "1) Mosaic DEM" by mask, "rectangle polygon"]

4) **"Fill"** [Fill ("ArcHydro > Fill") the above extracted DEM]

   [In case of the QGIS, "Click on Processing > Toolbox > SAGA > Terrain Analysis > preprocessing > Fill Sinks"]

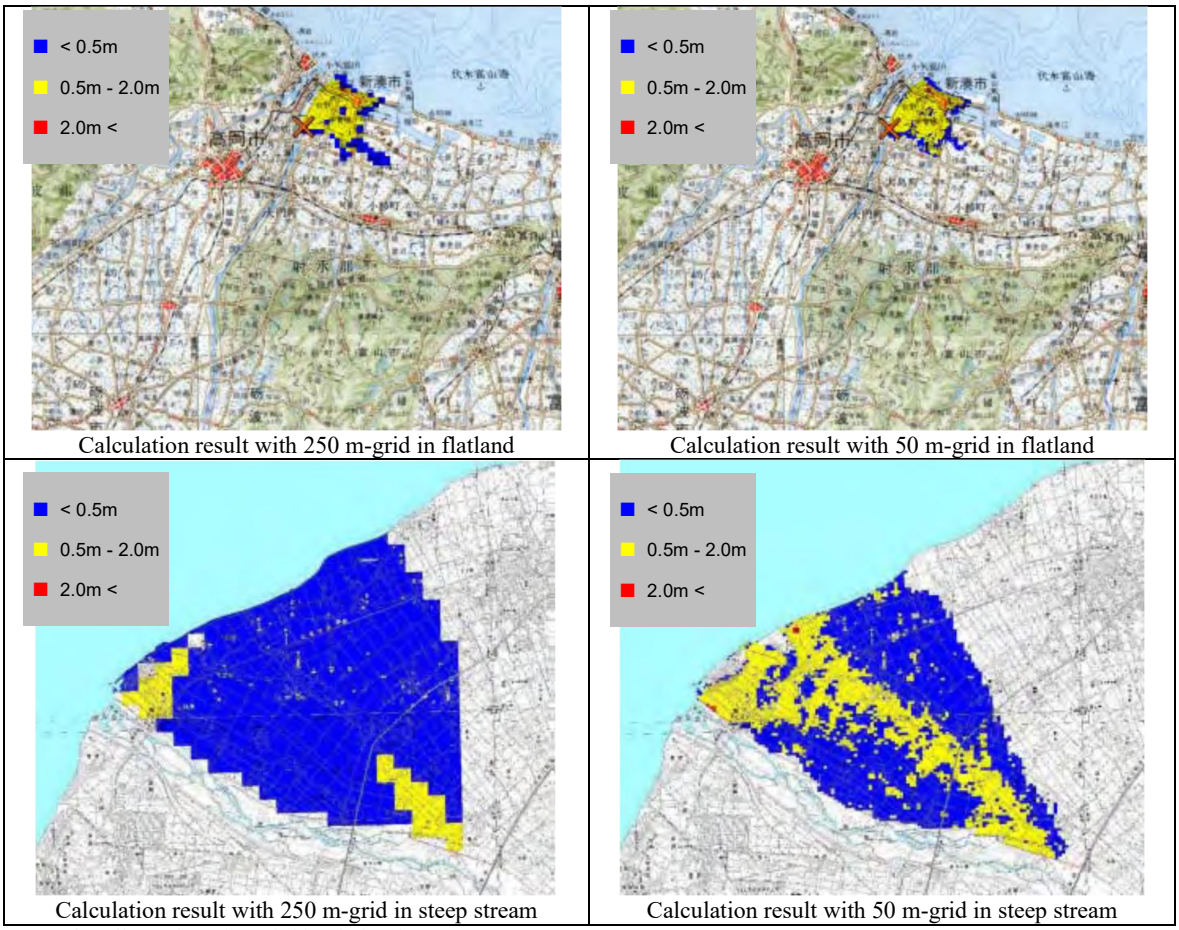
5) **"Flow direction"** [Make a Flow direction ("ArcHydro > Flow direction") using the above filled DEM]

6) **"Flow accumulation"** [Make a Flow accumulation ("ArcHydro > Flow accumulation") using the above filled DEM and flow direction]

7) **"Con"** [Convert Flow accumulation to stream ("Spatial analyst > condition > con") using the above flow accumulation]

Consideration: DEM / Calculation Grid Size

Calculation grid size shall be set appropriately in order to reproduce the actual phenomenon considering gradient in the flood plain. Figure 2-1 shows the difference in the calculation results with 250 m-grid and 50 m-grid.



Source: http://www.hrr.mlit.go.jp/river/gsiryo/

Figure 2-1 Comparison of the difference in the calculation results with 250 m and 50 m-grids

Finer grid size shall be applied in case that the flood plain is steep, since elevation difference among adjacent grids will be higher if the grid size is wide. Advisable elevation difference among adjacent grids is less than 50 cm.

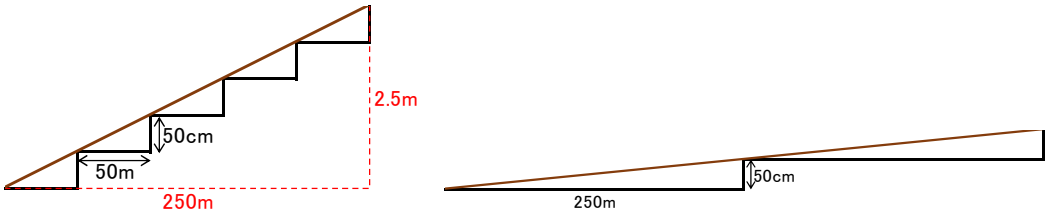
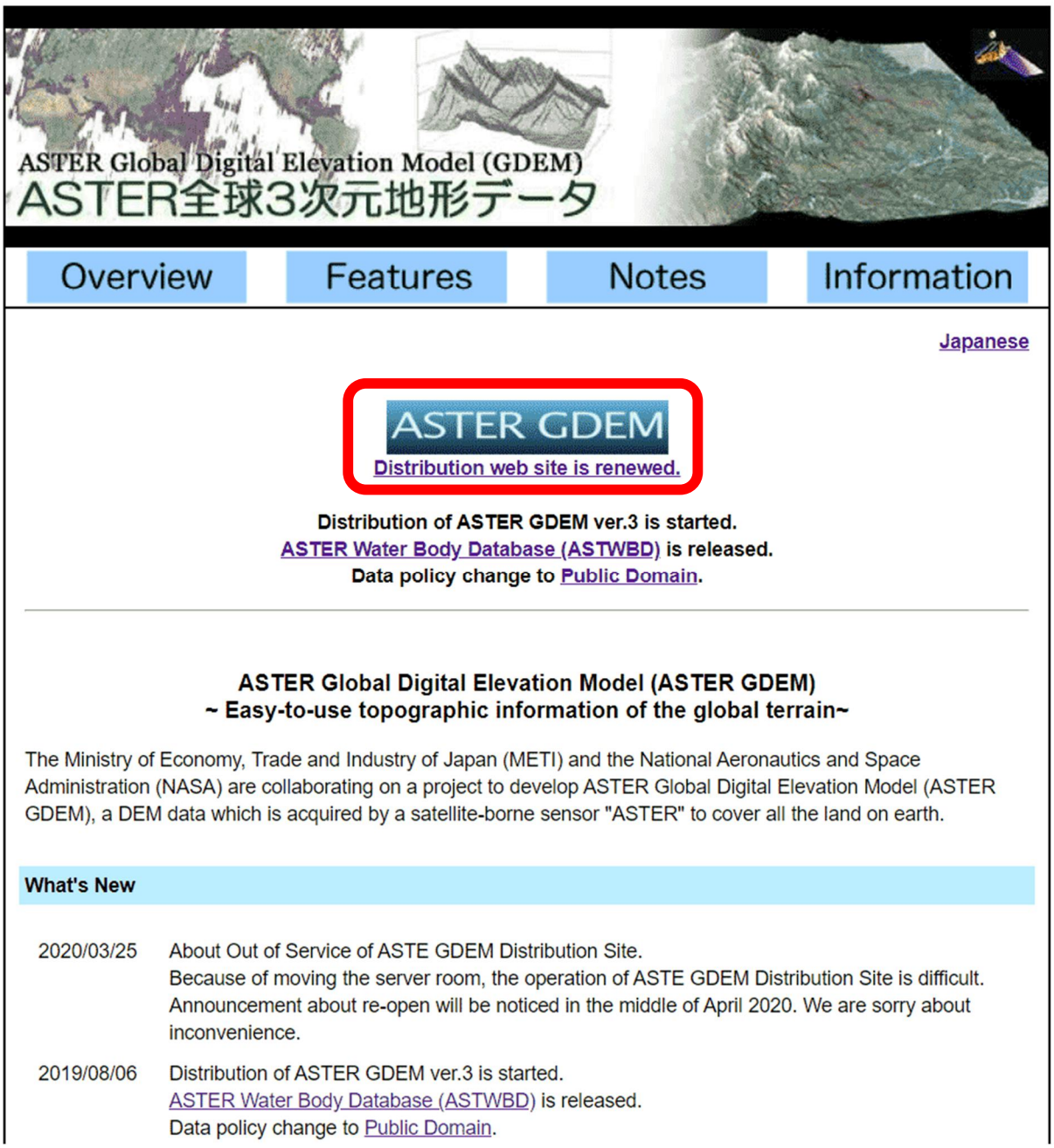


Figure 2-2 Schematic diagram of relation between grid size and elevation difference

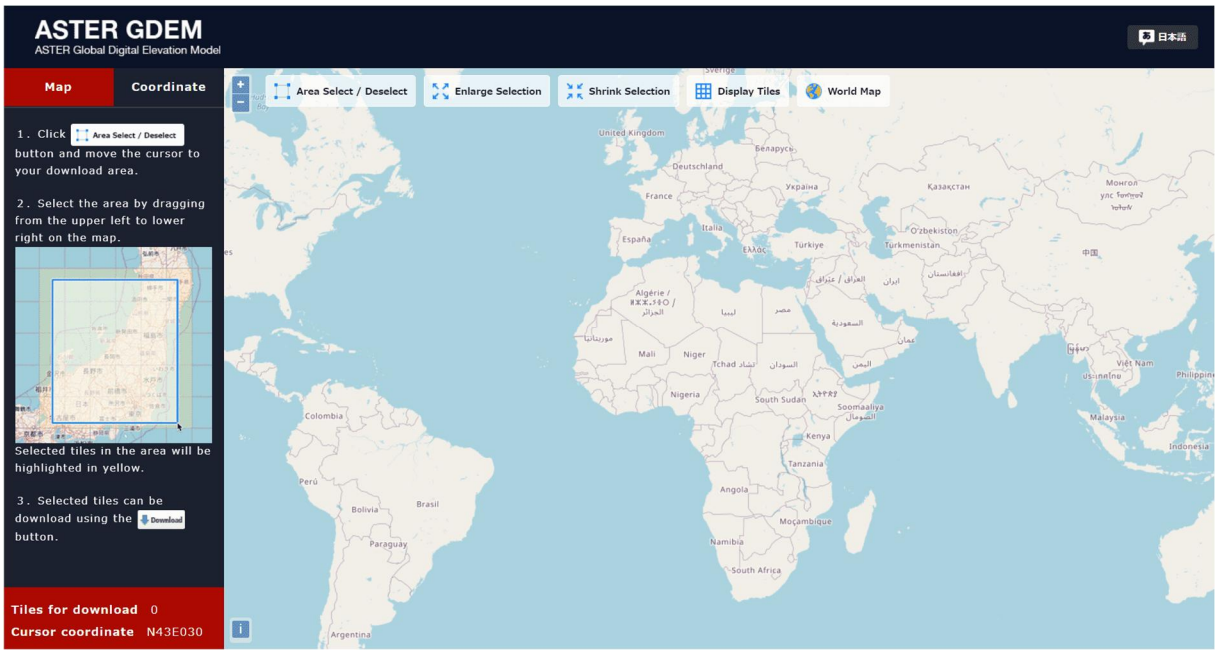
2.1 Preparation of DEM (ASTER GDEM), Flow Direction / Accumulation and Stream

1) Free digital elevation model (DEM) data is available on the website below.

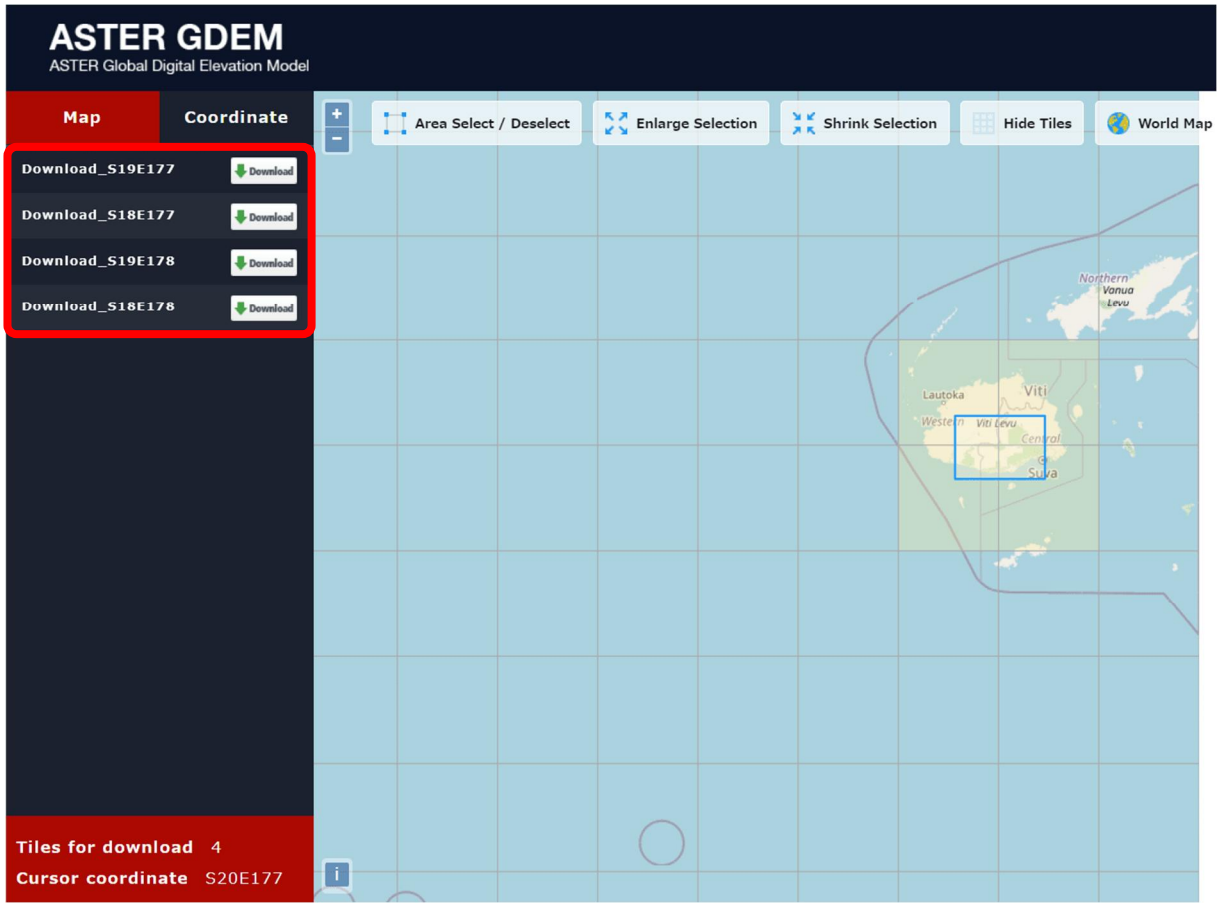
https://ssl.jspacesystems.or.jp/ersdac/GDEM/E/index.html



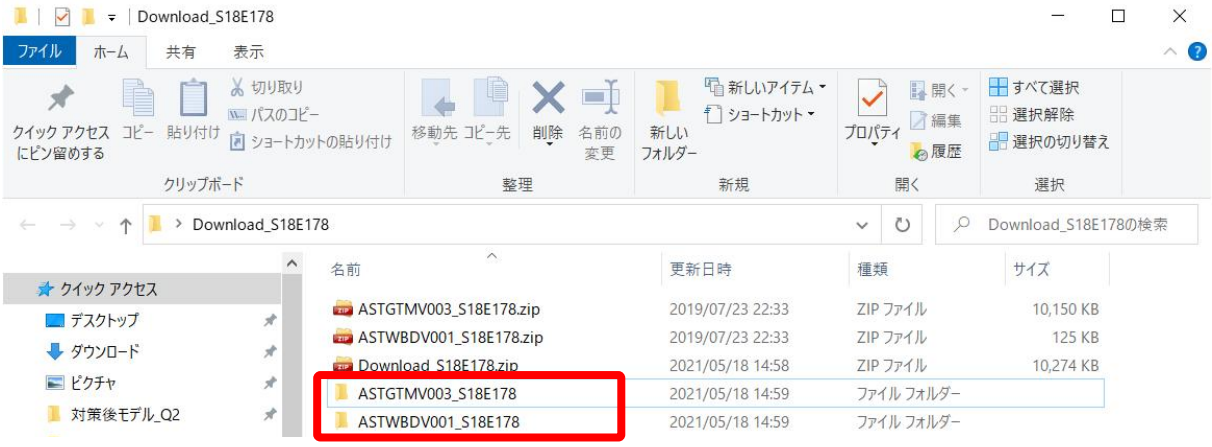
2) You'll find the world map as below. Then, zoom in on Fiji.



3) Select / highlight the target area. Then you can download the DEM data.

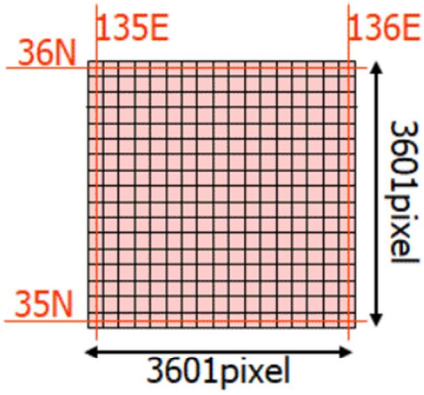
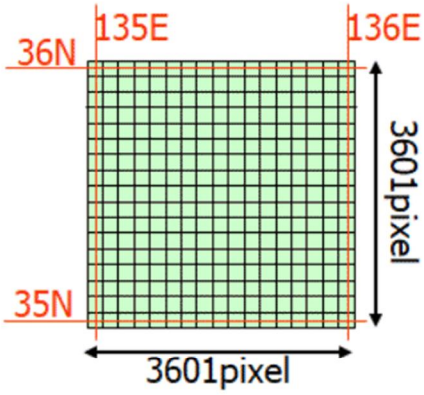


4) Unzip the downloaded DEM data. DEM data has 2 types of data, “ASTGTM (Aster GDEM) and ASTWBD (ASTER Water Body Database)”.



Both ASTGTM and ASTWBD consist 2 files. Formats of both data are as follows. Basically, we will use “ASTGTM…._dem.tif” data.

Format of ASTER DEM

File Name(Example of N35~36,E135~136)	ASTGTMV003_ N35E135_dem.tif	ASTGTMV003_ N35E135_num.tif
	DEM data	QA plane data
		
Output format	GeoTIFF, signed 16 bits	GeoTIFF, unsigned 8 bits
Geographic coordinates	Geographic latitude and longitude	
Tile Size	3601-by-3601 pixels (1-by-1 degree)	
Posting interval	1 arc-second	
DN values	1m/DN referenced to the WGS84/EGM96 geoid-9999 for void pixels, and 0 for sea water body	Stacking number or reference DEM (Refer to Table3 in User Guide)
Coverage	North 83 degrees to south 83 degrees, 22,912 tiles (1-by-1 degree) without tile shows ocean area	

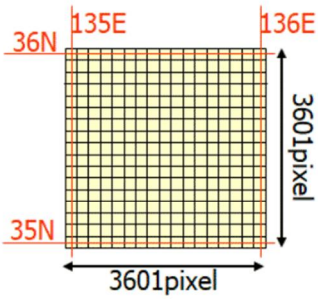
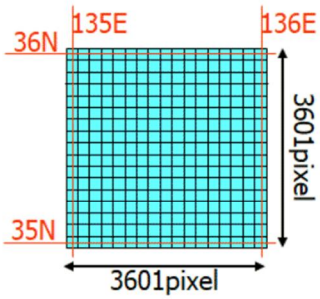
*The detail is described in User Guide.

*Here is the ASTWBD format.

Outline of ASTWBD

* ASTWBD shows the water area and its elevation with the same area and format as GDEM.
* The water area are classified to sea, lake and river.

Format of ASTWBD

File Name(Example of N35~36,E135~136)	ASTWBDV001_N35E135_dem.tif	ASTWBDV001_N35E135_att.tif
	Elevation of waterbody	Classification of waterbody
		
Output format	GeoTIFF, signed 16 bits	GeoTIFF, unsigned 8 bits
Geographic coordinates	Geographic latitude and longitude	
Tile Size	3601-by-3601 pixels (1-by-1 degree)	
Posting interval	1 arc-second	
DN values	1m/DN referenced to the WGS84/EGM96 geoid-9999 for land and void pixels, and 0 for sea water body	Land:0, Sea:1, River:2, Lake:3
Coverage	North 83 degrees to south 83 degrees, 22,886 tiles (1-by-1 degree) without tile shows ocean area	

*The detail is described in User Guide.

Even though there are some other free available DEM data, Aster GDEM is the latest and the posting interval is finer than other free DEM data, such as SRTM3 and the GTOPO30. *The DEM data might be updated. SRTM3 provides free 30m-posting-interval data as of 2022.

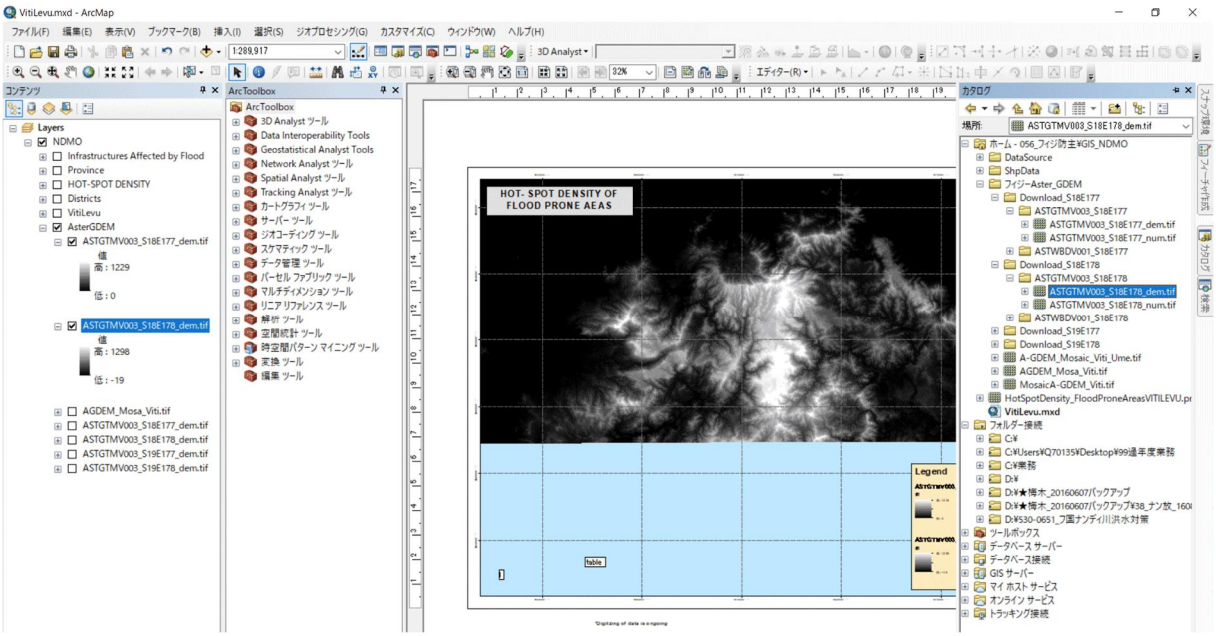
Comparison with other DEMs

	ASTER GDEM	SRTM3*	GTOPO30**	10 m mesh digital elevation data
Data source	ASTER	Space shuttle radar	From organizations around the world that have DEM data	1:25,000 topographic map
Generation and distribution	METI/NASA	NASA/USGS	USGS	GSI
Release year	2009 ~	2003 ~	1996 ~	2008~
Data acquisition period	2000 ~ ongoing	11 days (in 2000)		
Posting interval	30m	90m	1000m	about 10m
DEM accuracy (stdev.)	7~14m	10m	30m	5m
DEM coverage	83 degrees north ~ 83 degrees south	60 degrees north ~ 56 degrees south	Global	Japan only
Area of missing data	Areas with no ASTER data due to constant cloud cover (supplied by other DEM)	Topographically steep area (due to radar characteristics)	None	None

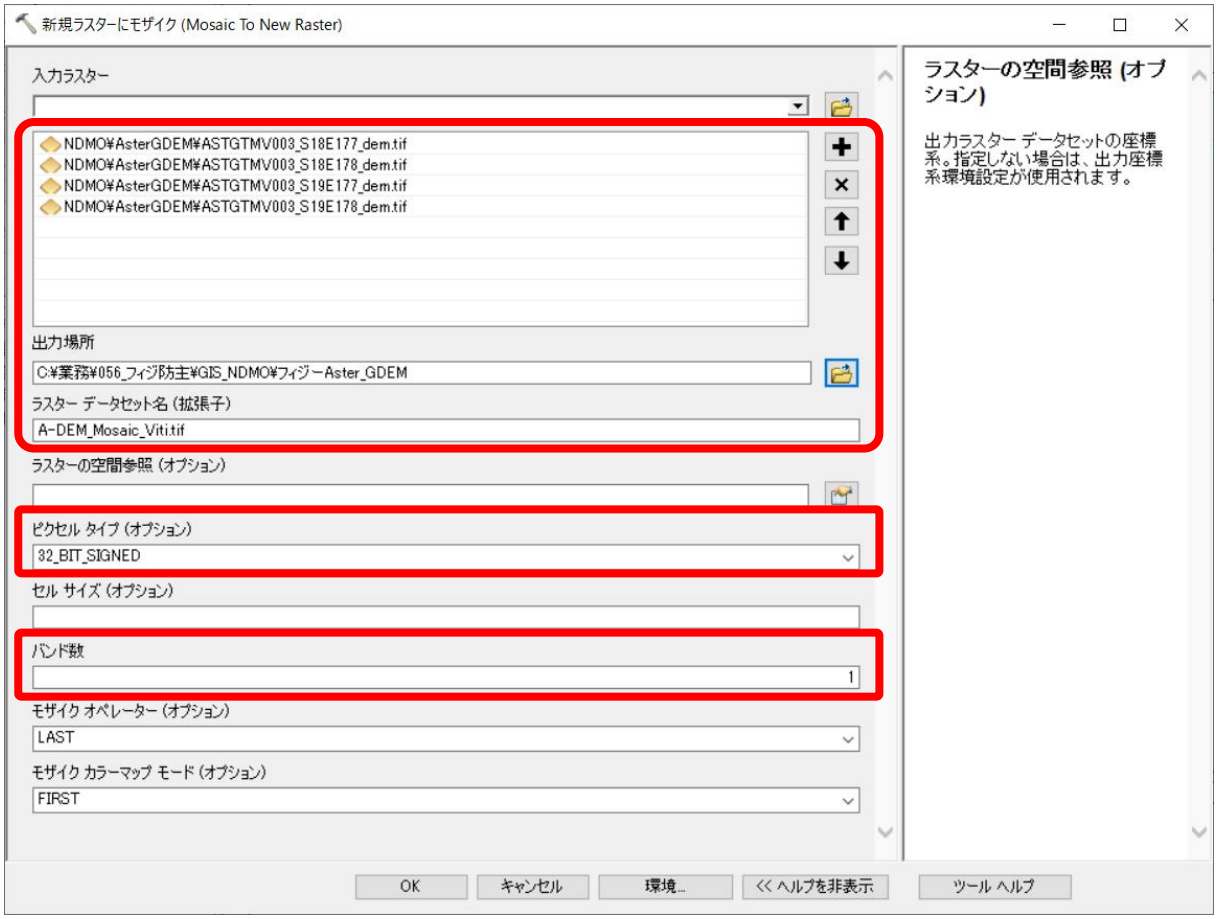
in 2009

*SRTM3: Shuttle Radar Topography Mission Data at 3 Arc-Seconds
**GTOPO30: Global 30 Arc-Second Elevation Data Set

5) Now, we will move to the GIS. Place the downloaded DEM data in your GIS folder. And add the "….dem.tif" data in the ToC (Table of Contents) of the GIS.

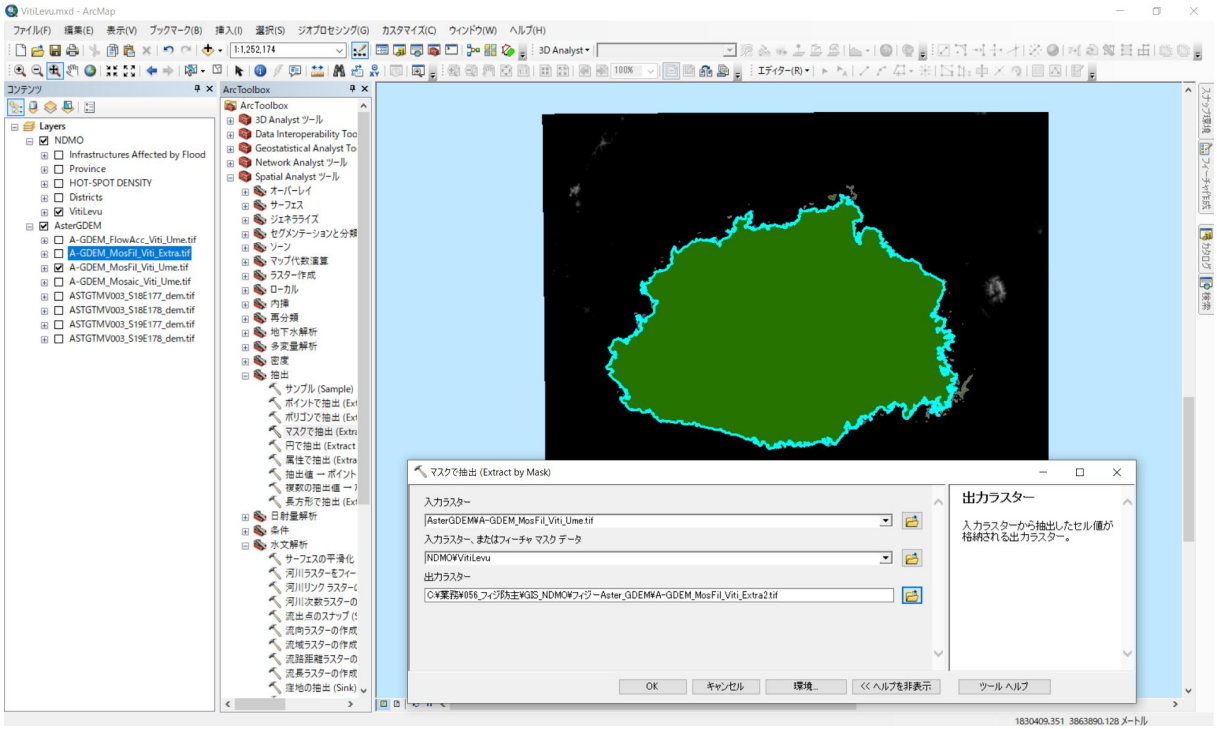


6) Viti Levu are consists of 4 dem.tif data, S18E177 & 178, S19E177 & 178. Therefore, now we combine / merge them into one Raster data set. Search a command, "**Mosaic** to New Raster" on the ArcGIS, then set the parameters as below. Pixel type can be "signed 32 bit".



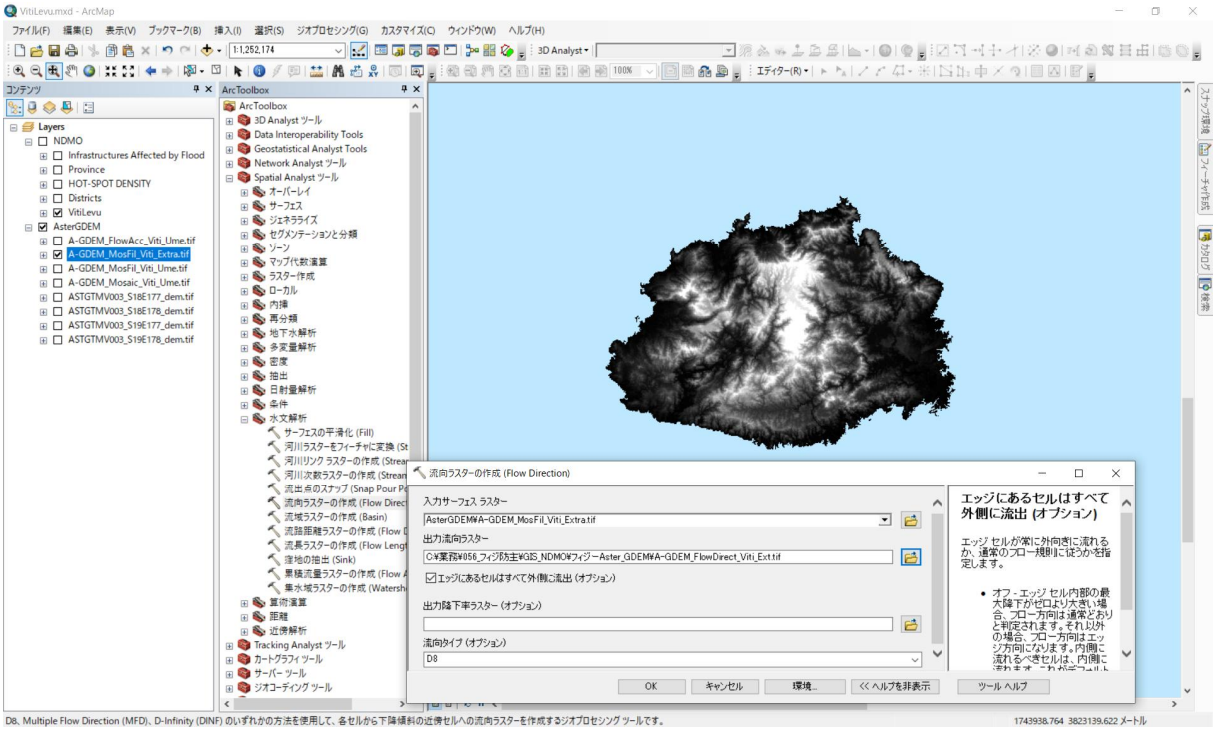
*If the ArcGIS shows any errors on processing commands, **it is better to do on a new map (simpler ToC)** / simpler directory / file name / coherent coordination.

7) Extract only the Viti Levu Island from the combined raster. Search a command, “Extract by Mask” on the ArcGIS, then set the parameters as below. *Caution: Shape files of “Viti Levu” or “coastal line” might not be suitable to use as a mask, since the some river mouths and alluvial fans might not be covered. In that case, you might create a rectangle polygon.

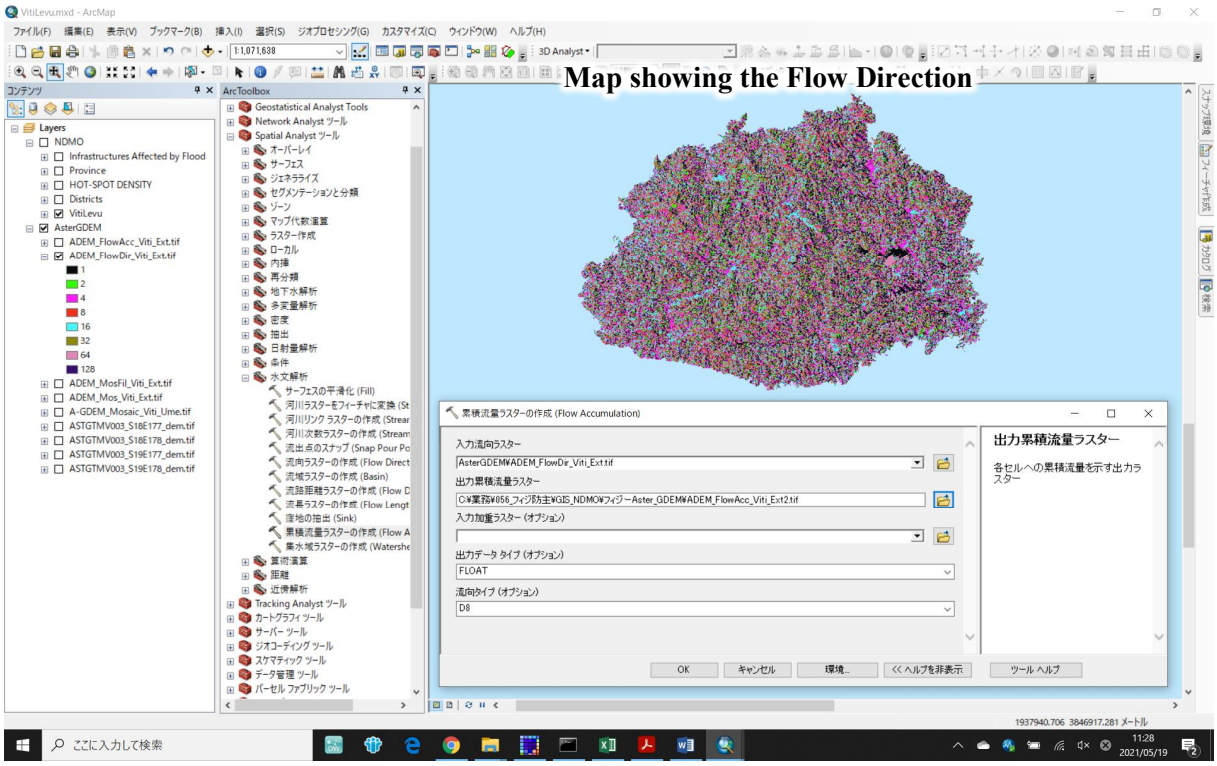


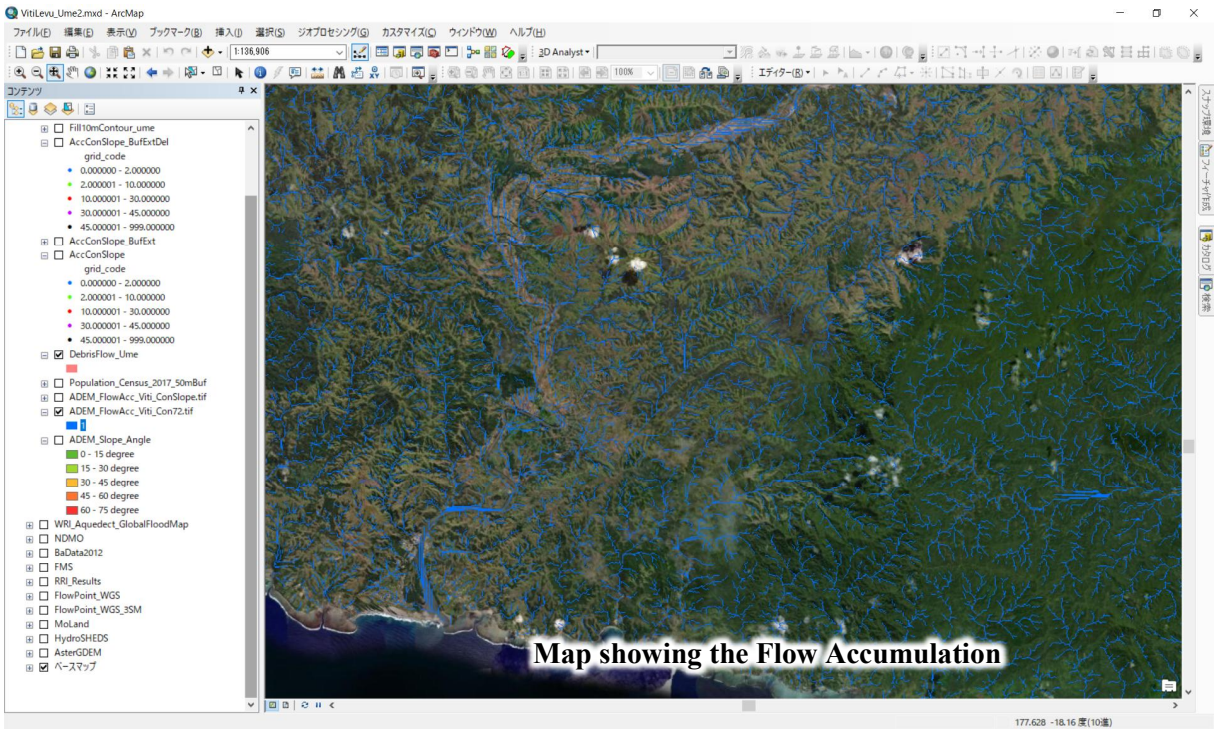
8) Fill the “low-lying depression” points. If there are low-lying depression points, flow direction gathers towards those points and there is no way out of the flow. It will cause a calculational error. Search a command, “Fill” on the ArcGIS, then just set the input raster data (in this case, above extracted DEM raster data) and output raster data.

9) Create “Flow Direction” raster. Search a command, “Flow Direction” on the ArcGIS, then set the parameters as below using the “filled + extracted DEM raster data” created in 8).



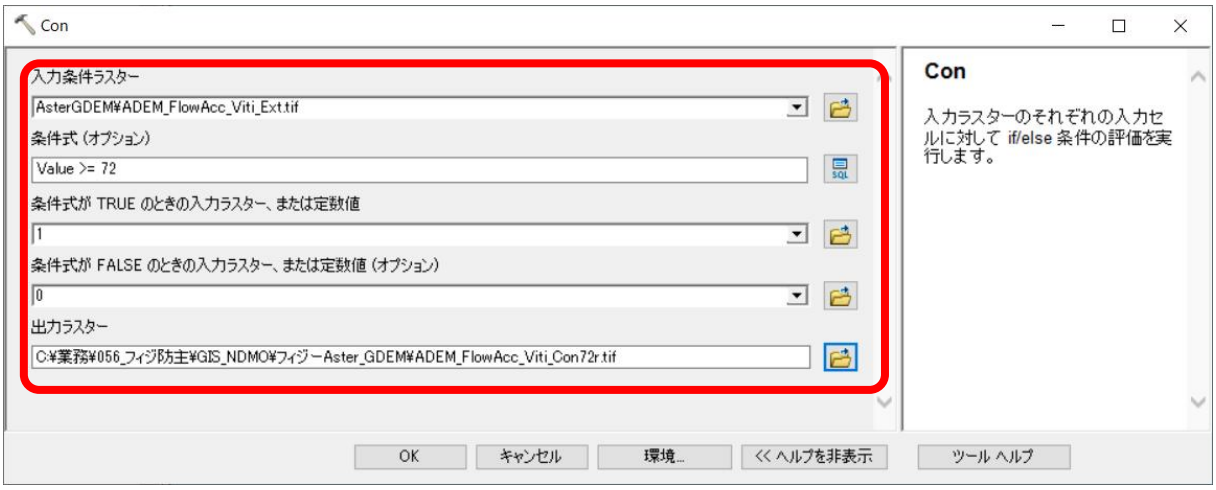
10) Create “Flow Accumulation” raster. Search a command, “Flow Accumulation” on the ArcGIS, then set the parameters as below using the “Flow Direction raster” created in 9).

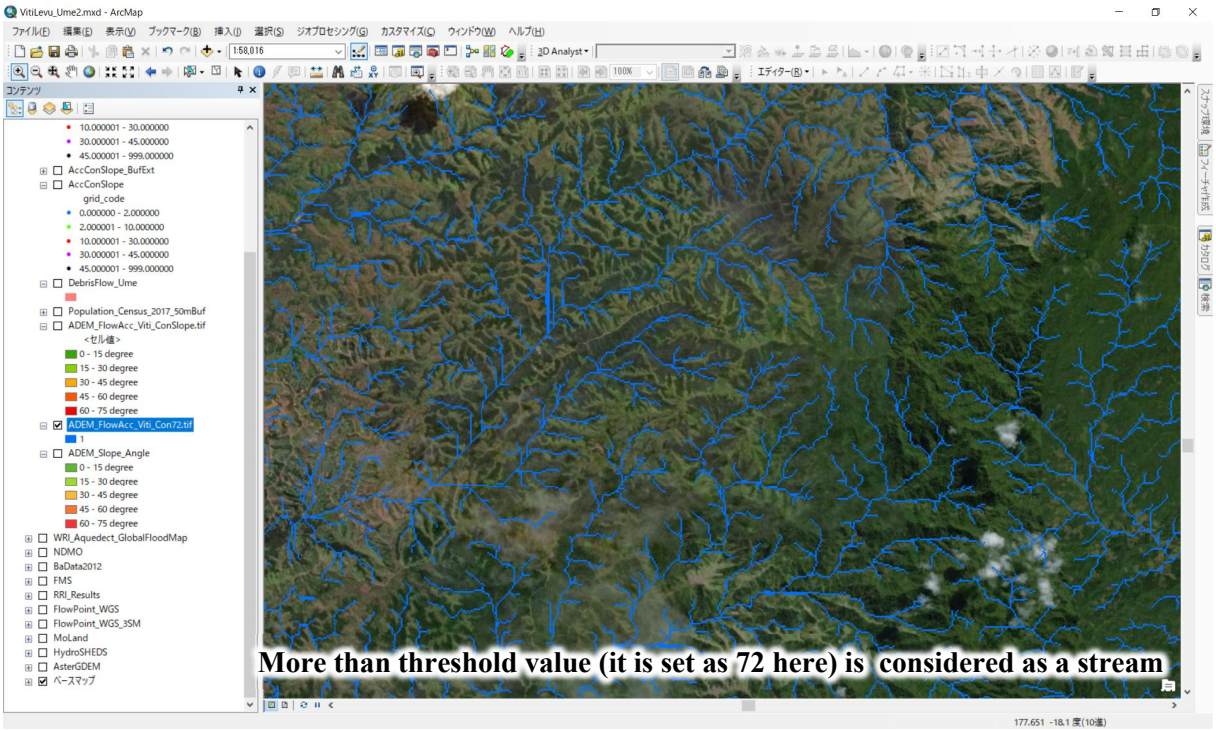




11) As you can imagine, smaller value of flow accumulation indicates small stream and bigger value indicates bigger stream. Here, **any streams above threshold value / level will be considered as a stream in order to conduct debris flow hazard assessment**. The threshold value is set as "72" here (in case of the 30m DEM*). Search a command, "Con" on the ArcGIS or Spatial analyst > Condition > Con. Set the condition as below. Optional condition expression is used here. Directly type the formula, such as **Value >= 72**. Flow accumulation data will be the input raster.

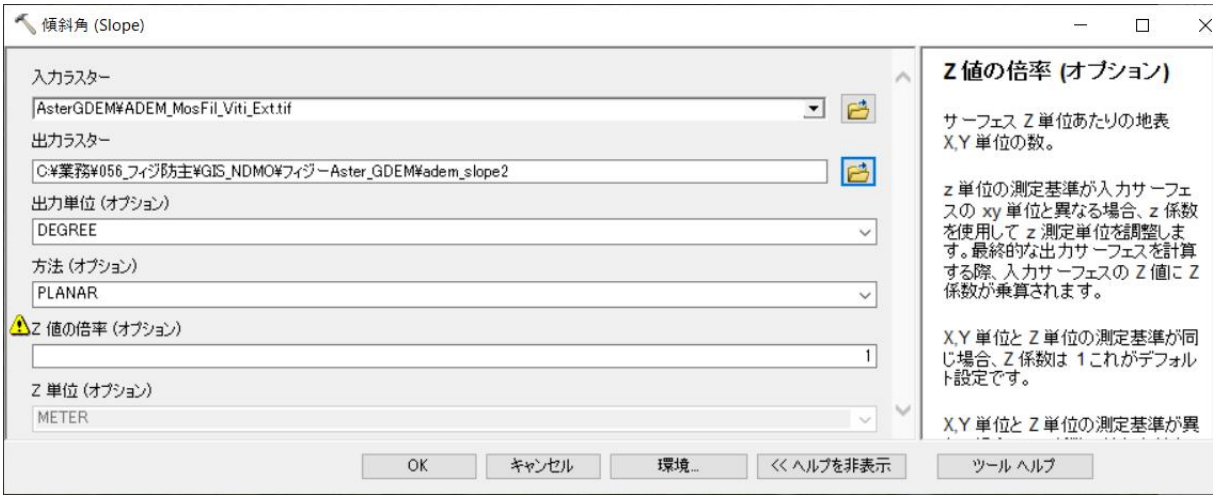
***IMPORTANT:** The threshold value shall be changed depending on the value of flow accumulation. Especially if the finer / much higher resolution DEM is used, it will result many streams will be identified / created than the ones created using rougher DEM. Along with that, the values of flow accumulation will increase. So, if 72 is used for the condition expression for "Con" in this case, so many tiny streams will be created and it won't be appropriate. Therefore, bigger value shall be used for the condition expression determining the value by trial-and-error. In case of the AW3D 0.5m for Suva area, condition expression can be set as "Value >= 30000" based on the trial-and-error calculation.

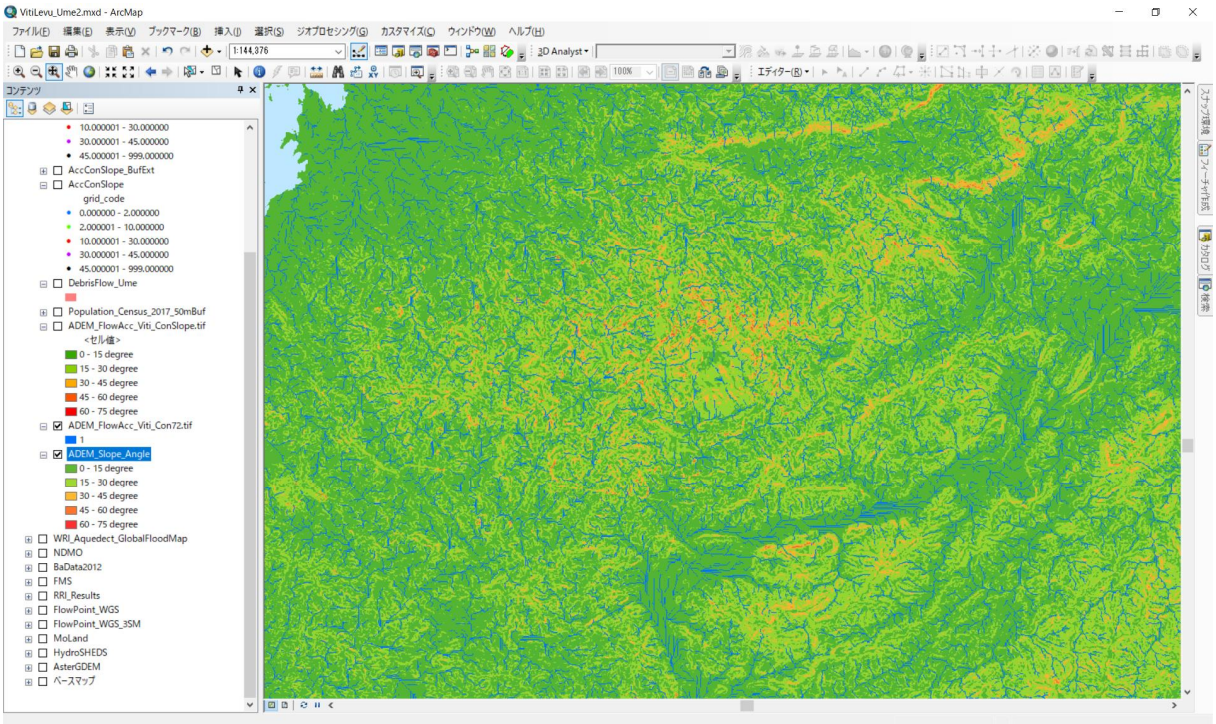




Chapter 3. Primary Hazard Assessment of Steep Slope Collapse

1) As mentioned in the 1.2, steep slope collapse often occurs on slope of ≥30° and the height of ≥5m. Therefore, slope / gradient shall be checked using the GIS. Search a command "Slope" on the ArcGIS or Spatial analyst > Surface > Slope. Set the condition as below. The symbol of the slope shall be adjusted as below (classification / gradation, 5 classes). Here, warm colors (orange, dark orange and red) indicate the more than 30-degree slope and it is considered as a hazardous area of steep slope collapse.

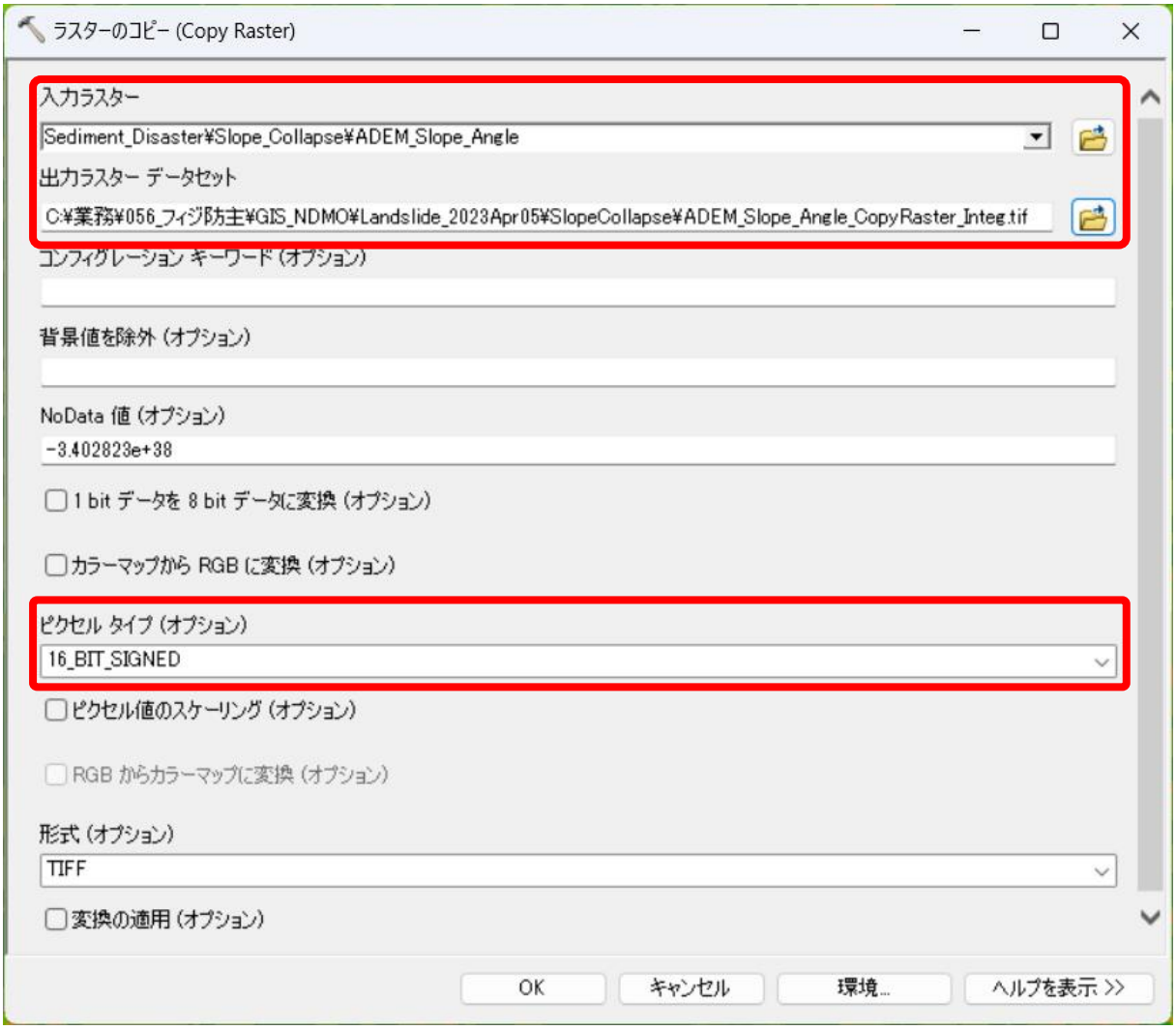




2) To do the procedures below, you need to convert the raster data (slope) to the vector data (here, convert to a polygon). But, the command of "Raster to Polygon" works for the cells whose values are integer type. Since the slope raster is composed of the real numeric type, you need to convert the real numeric type raster to integer type one.

3) **Option 1. If you cannot use Spatial Analyst or 3D Analyst – After the decimal point might be ignored / rounded**

Search a command, “Copy Raster” on the ArcGIS or Data Management Tool > Raster > Raster Data Set > Copy Raster. Set the input raster as the “Slope” raster, and set the place / folder to output the converted raster data. You need to select the pixel type.



ピクセルタイプ	ビット深度	各セルに格納できる値の範囲
符号なし整数	1 BIT	0 ～ 1
符号なし整数	2 BIT	0 ～ 3
符号なし整数	4 BIT	0 ～ 15
符号なし整数	8 BIT unsigned	0 ～ 255
符号付き整数	8BIT signed	-128 ～ 127
符号なし整数	16 Bit unsigned	0 ～ 65535
符号付き整数	16 Bit signed	-32768 ～ 32767
符号なし整数	32 Bit unsigned	0 ～ 4294967295
符号付き整数	32 Bit signed	-2147483648 ～ 2147483647
浮動小数点数	32 ビット	-3.402823466e+38 ～ 3.402823466e+38
浮動小数点数	64 ビット	負の値は -1.79769313486231570E+308 ～ -4.94065645841246544E-324、 正の値は 4.94065645841246544E-324 ～ 1.79769313486231570E+308

Integer type

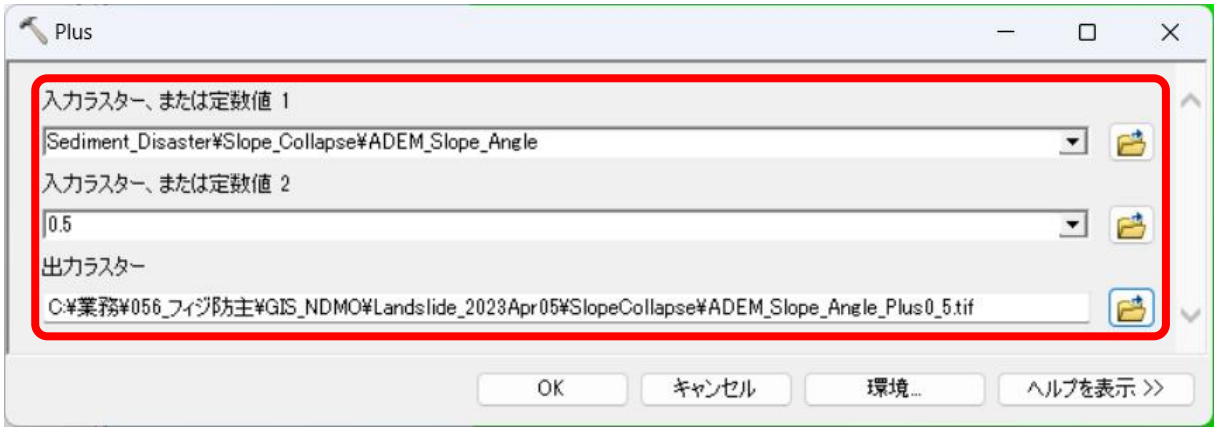
属性テーブル作成可能

Float / Real numeric type

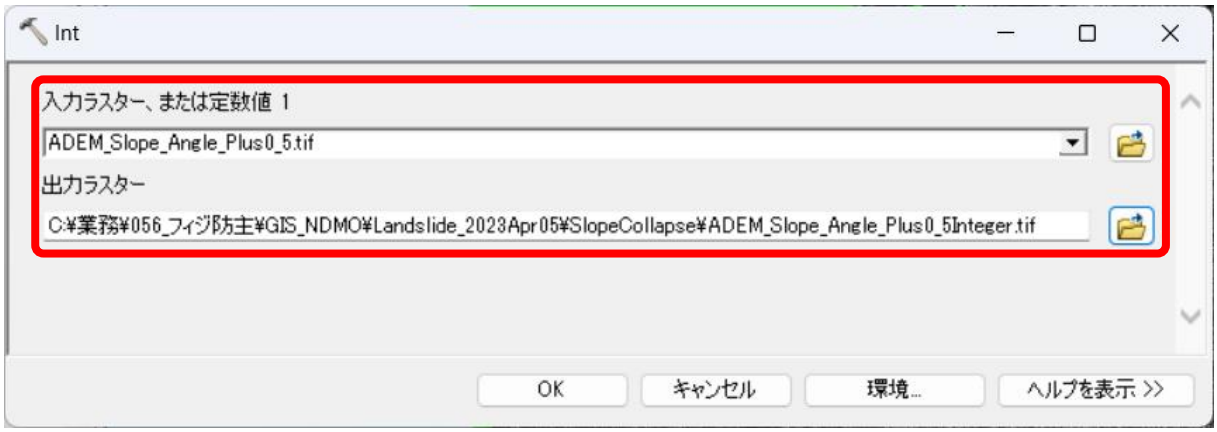
変換が必要

4) **Option 2. If you can use Spatial Analyst or 3D Analyst – Rounding off the decimal point**

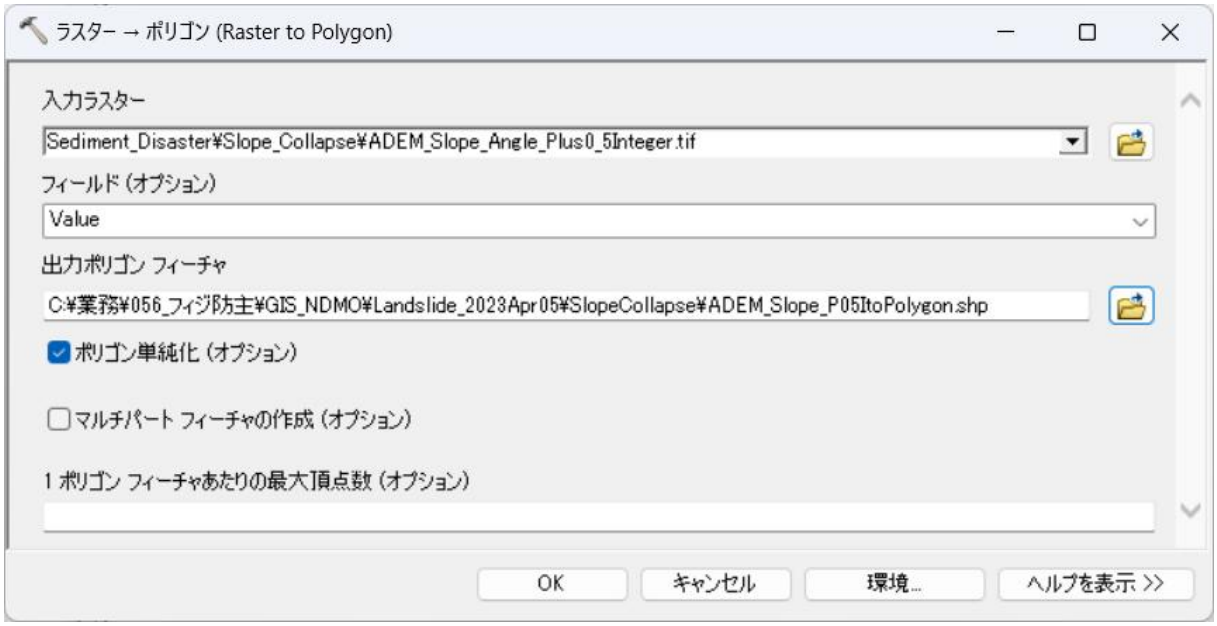
Search a command, “Plus” on the ArcGIS or Spatial Analyst > Numerical Operation > Plus.

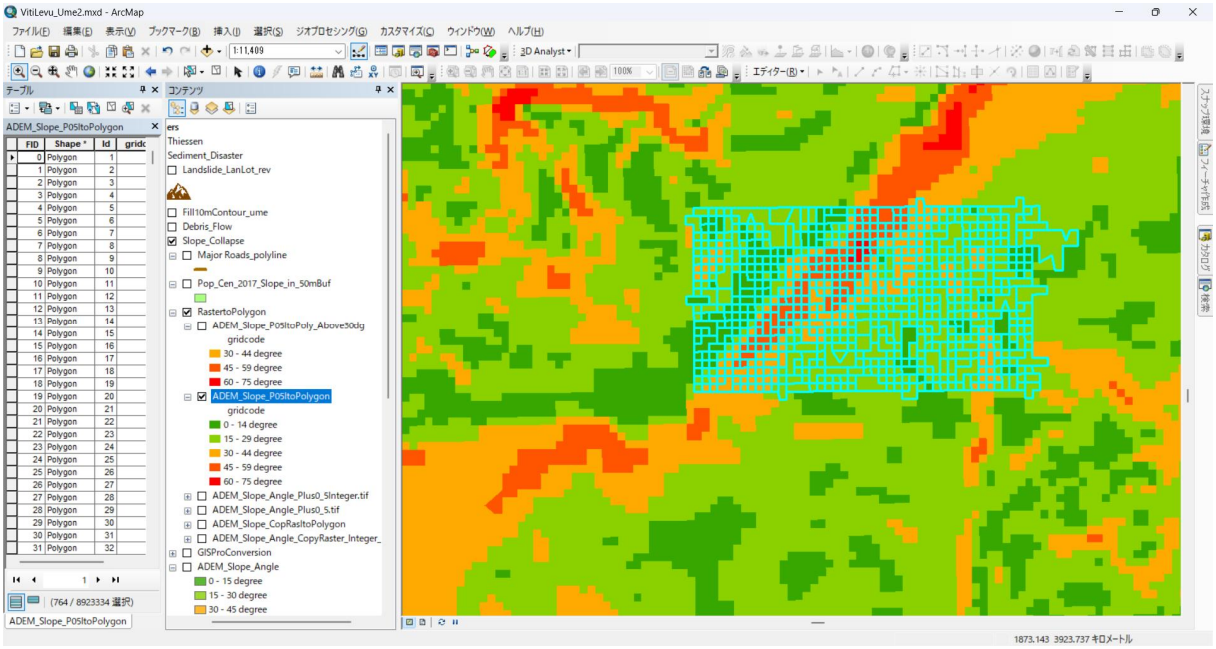


Then, search a command, “Int” on the ArcGIS or Spatial Analyst > Numerical Operation > Int. Set an input raster as the one created above by the Plus command.

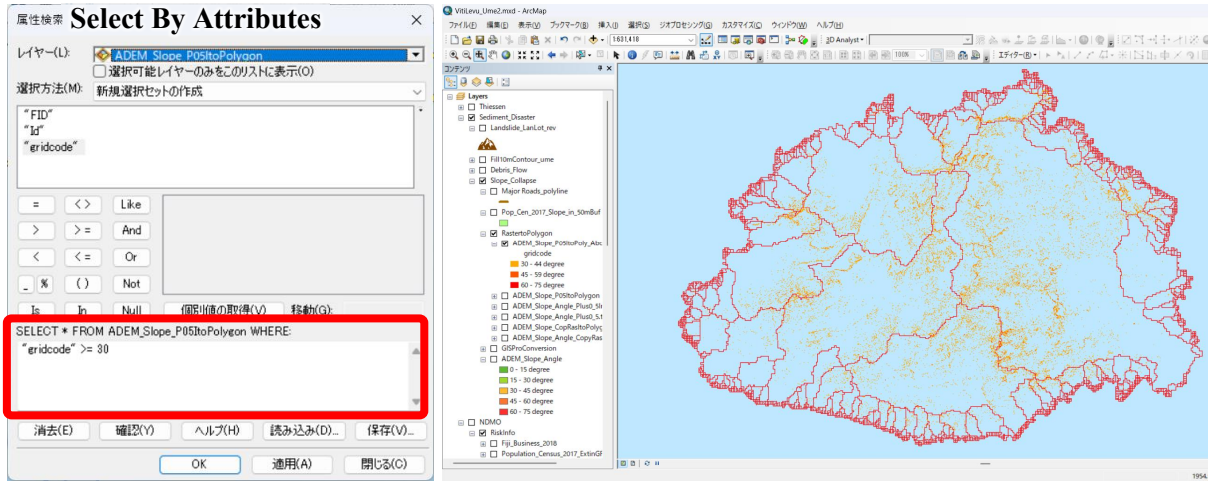


5) For both options. Now the Slope raster is converted as the Integer type, so you can convert the Raster to Polygon. Search a command, “Raster to Polygon” on the ArcGIS or Data Conversion Tool > Conversion from Raster > Raster to Polygon.

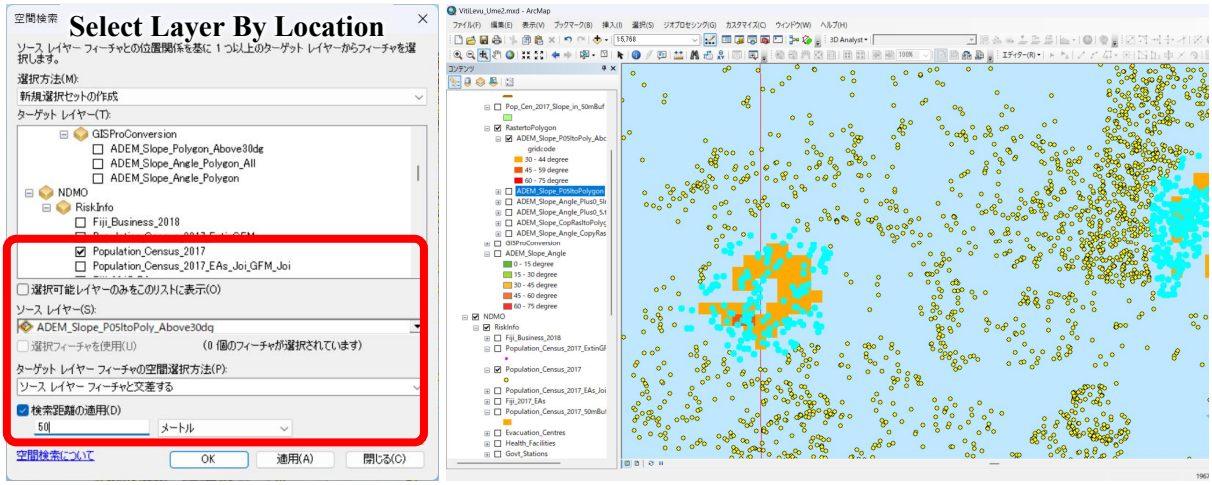




6) Extract the slope of ≥30° by "Select By Attributes". Then, right click on the polygon data and Data > Data Export > Export Selected Features.



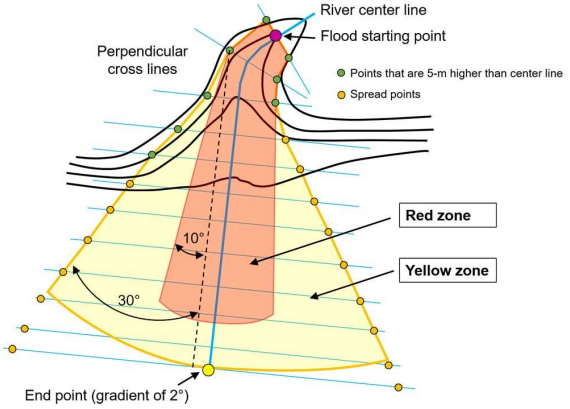
7) Extract the household / building with in 50m buffer of the slope of ≥30° by "Select Layer By Location". The target layer should be "Population Census" and the source layer should be the above extracted slope polygon. You need to set the "search distance" as 50m. Then, right click on the Population Census data and Data > Data Export > Export Selected Features.



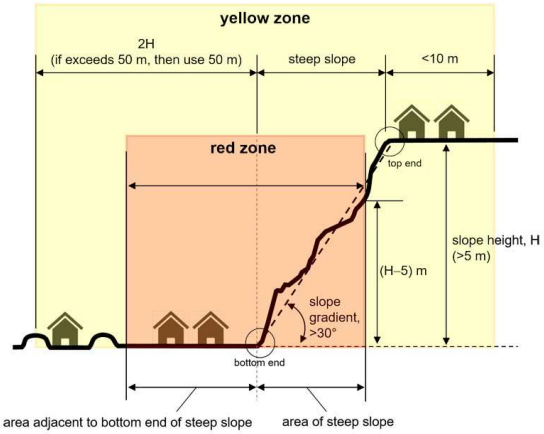
Below mentioned areas can be assessed as sediment disaster hazard and be set / designated as Yellow / Red zones in Japan. This basic method of visual judgment for debris flow and steep slope collapse hazard evaluation is adopted by WMO and published as a guideline[5].

Since the assumed affected area (= yellow zone and red zone) of steep slope collapse are considered as "within 50m at the bottom end of the slope" and "within 10m at the top end of the slope", the above buffer area of the slope as set as 50 m. In the case of a debris flow, the flow direction of the debris flow will form a fan-shaped area with an angle of approximately 30 degrees centered on the valley exit. However, this project does not take that into consideration.

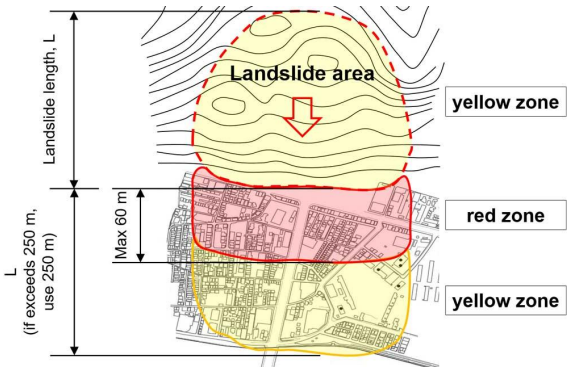
Debris flow



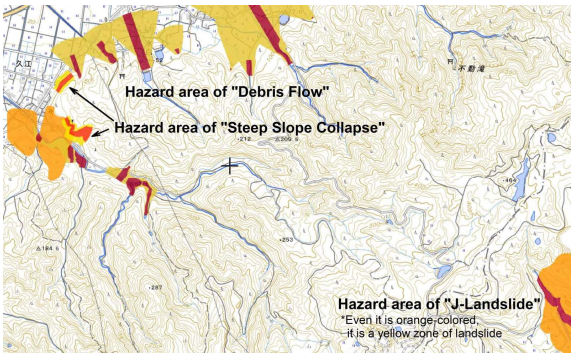
Steep slope collapse



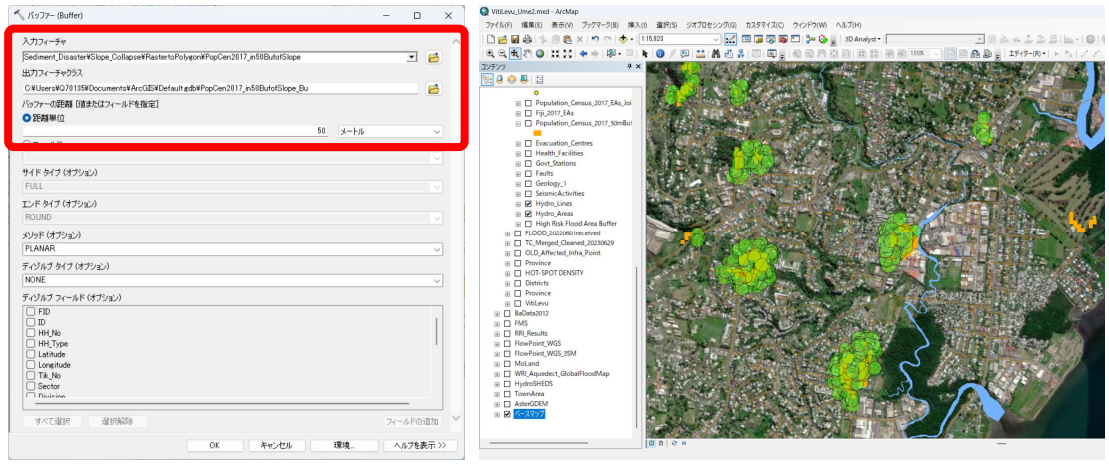
Landslide



Example of sediment disaster hazard map in Japan



8) For making buffer, search a command, "Buffer" on the ArcGIS. Set the input / output features and the **distance of buffer as 50m**.

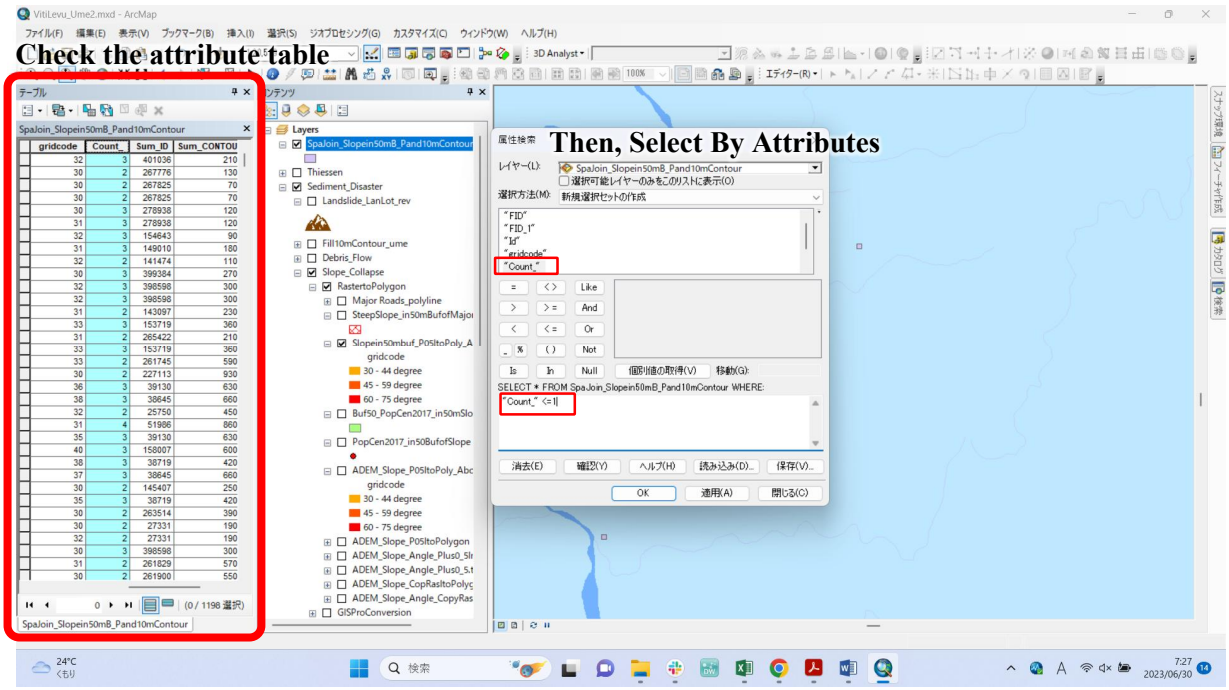


[5] Integrated Flood Management Tools Series No.12 – Management of Sediment-Related Risks, 2011, World Meteorological Organization, https://www.floodmanagement.info/publications/tools/APFM_Tool_12.pdf

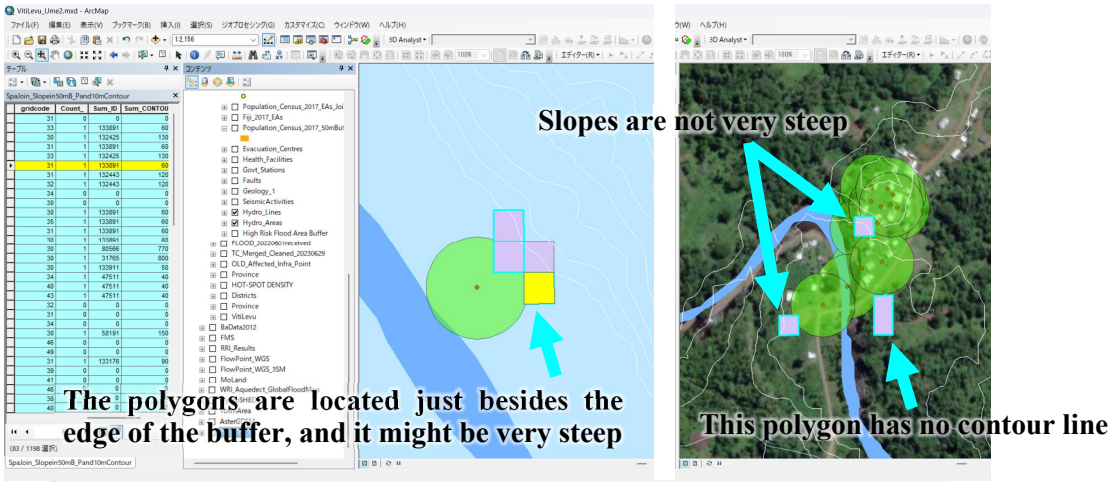
9) Now you will check the slope is more than 5m in height. You can count how many contour lines are in the each slope polygon. Here, you can use the “10m Contour line”. First, you need to do “Select Layer By Location” and search the slopes in the 50m buffer of the households / buildings. Then, right click on the slope polygon data, which is set as the target layer, and Data > Data Export > Export Selected Features.

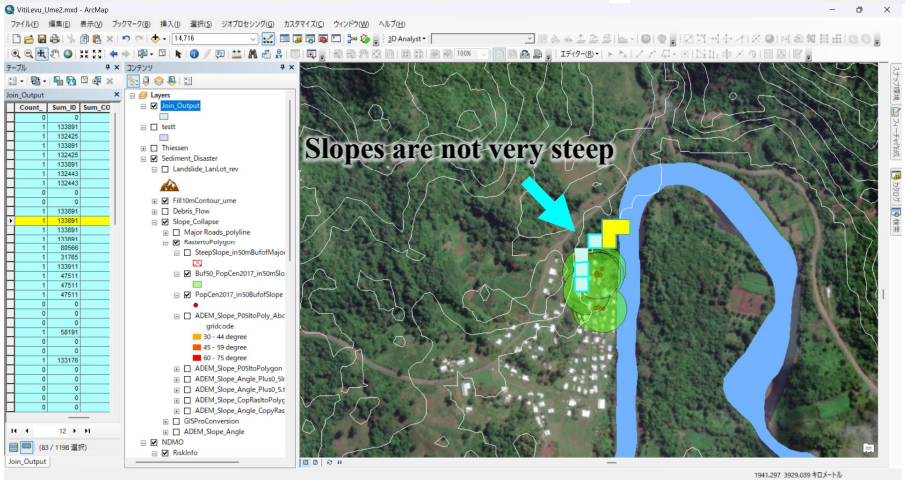
10) To count the contour lines in the each polygon, you do “Spatial Join”. Right click on the above extracted / exported slope polygon (within 50m buffer of the households / buildings) > Joint and Relate > Joint > Spatial Join. Set the joint layer as the 10m contour line, and set the counting measure as “sum”.

11) After the Spatial Join, you can check how many contour lines are in the each polygon by checking the attribute table. “Count_” shows the number of the contour lines in the polygon. Then, you do “Select By Attributes” and select the polygons which has less than 1 contour line.

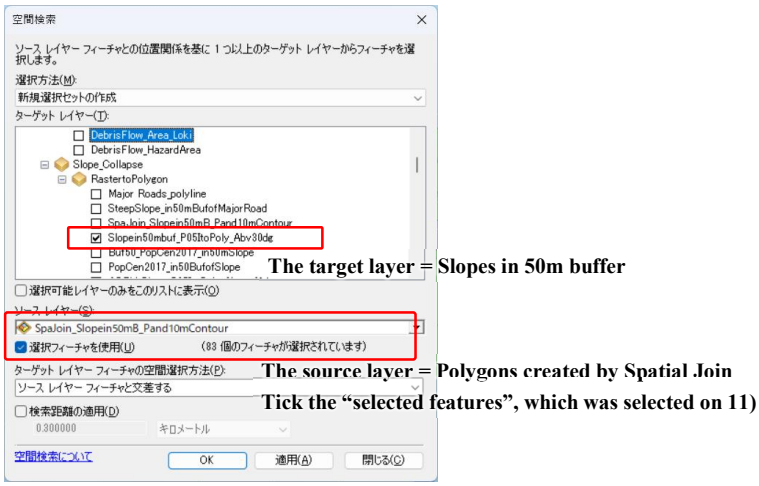


12) Even though the height of the polygons which have only 1 contour line can be more than 5m, we will exclude those polygons. Or maybe you can check whether we should exclude the polygon, which have 1 contour line, one by one. The figures below shows some of the examples of the polygon which can be excluded.

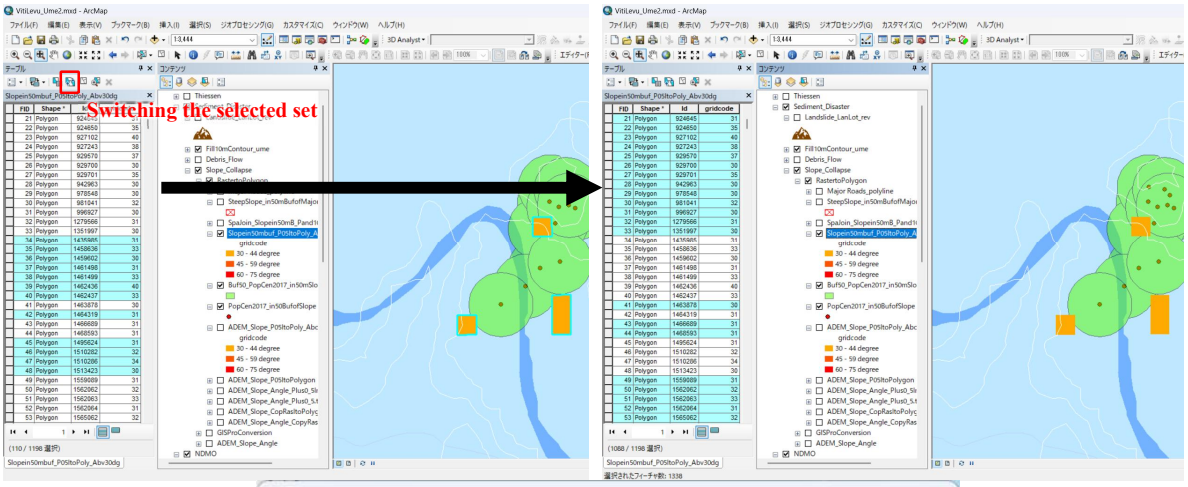


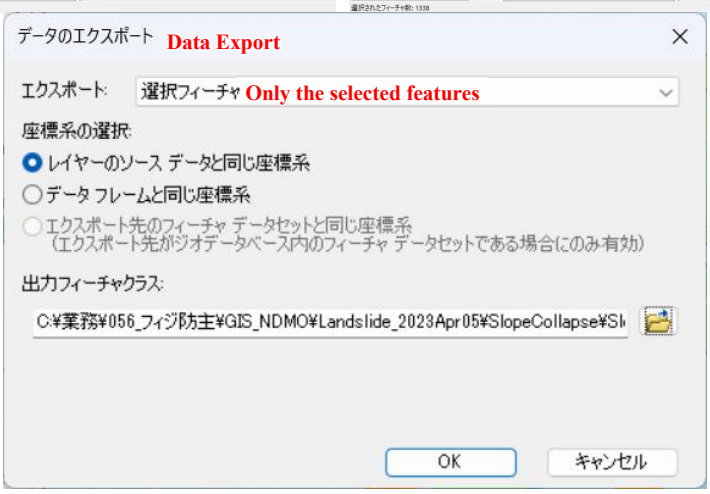


13) After selecting the polygons which has less than 1 contour line, "Select Layer By Location" again and search the slopes which overlap with the slopes selected by "Select By Attributes" on 11). The target layer should be the polygon created on 7), "Polygons / slopes in 50m buffer of the building", and the source layer should be the polygon created on 10), "Spatial Join". Make sure to tick the "selected features".



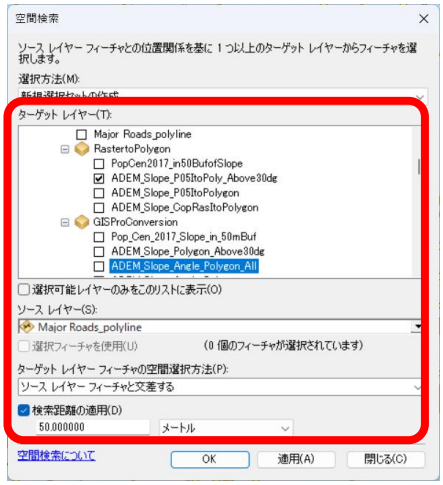
14) Open the attribute table of the polygon created on 7), “Polygons / slopes in 50m buffer of the building”. The polygons selected by “Select Layer By Location” are highlighted. Now click the “switching the selected set” on the attribute table, then right click on the slope polygon data, and Data > Data Export > Export Selected Features.

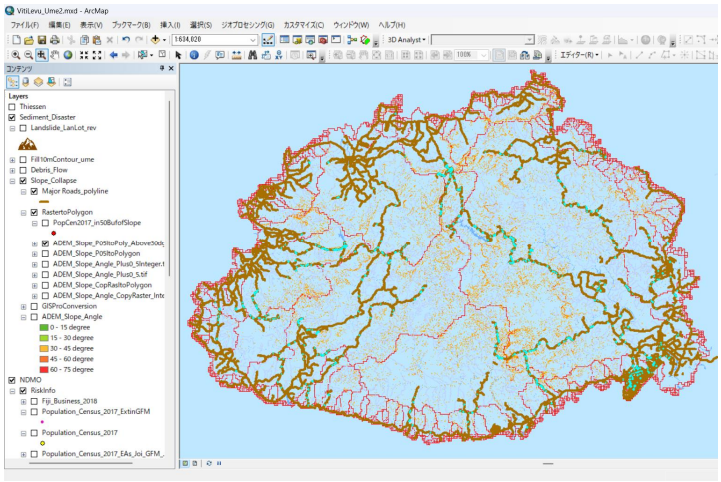




15) Continue the procedures 7) and 8). Then, now you have the households / buildings within 50m distance of the slope of ≥30° and the height of ≥5m.

16) Same as the household / building, check the major roads or infrastructures within 50m buffer of the slope. Regarding the major roads, the slope within the 50m buffer of the major roads will be extracted. Light blue highlighted parts in the below right figure are the steep slope adjacent to the major roads.



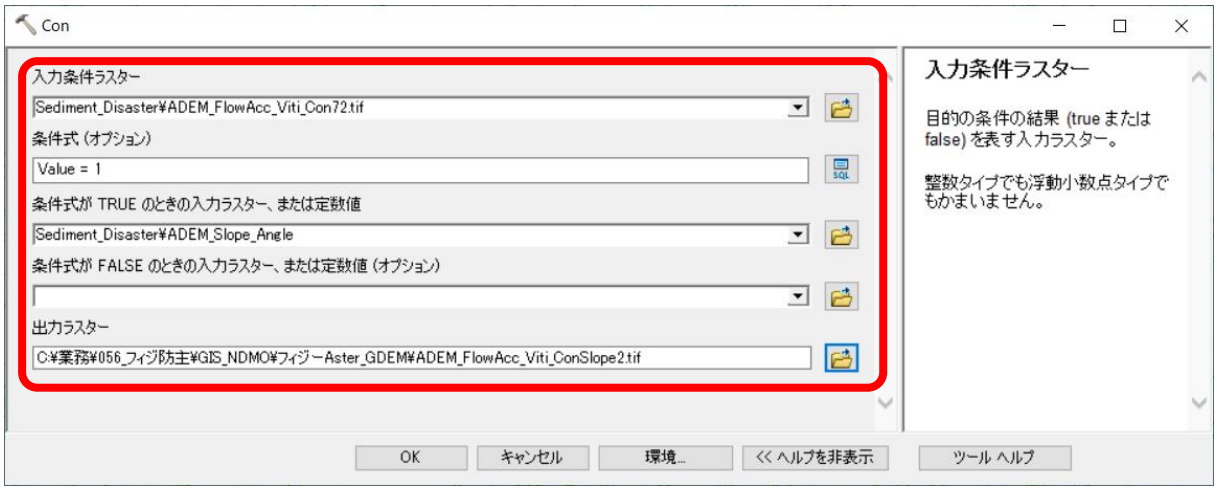


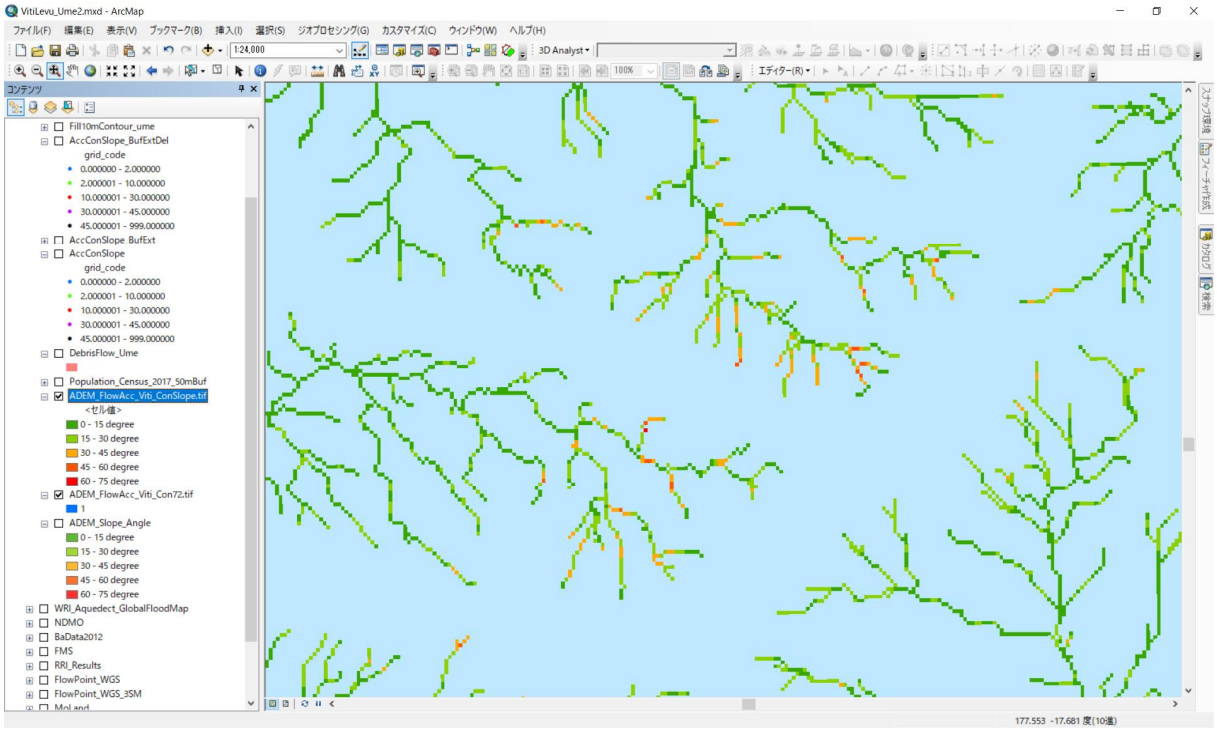
17) You can do the same procedure to check the slopes near the important infrastructures, such as health facilities, evacuation centers, and lifeline facilities and so on.

Chapter 4. Primary Hazard Assessment of Debris Flow

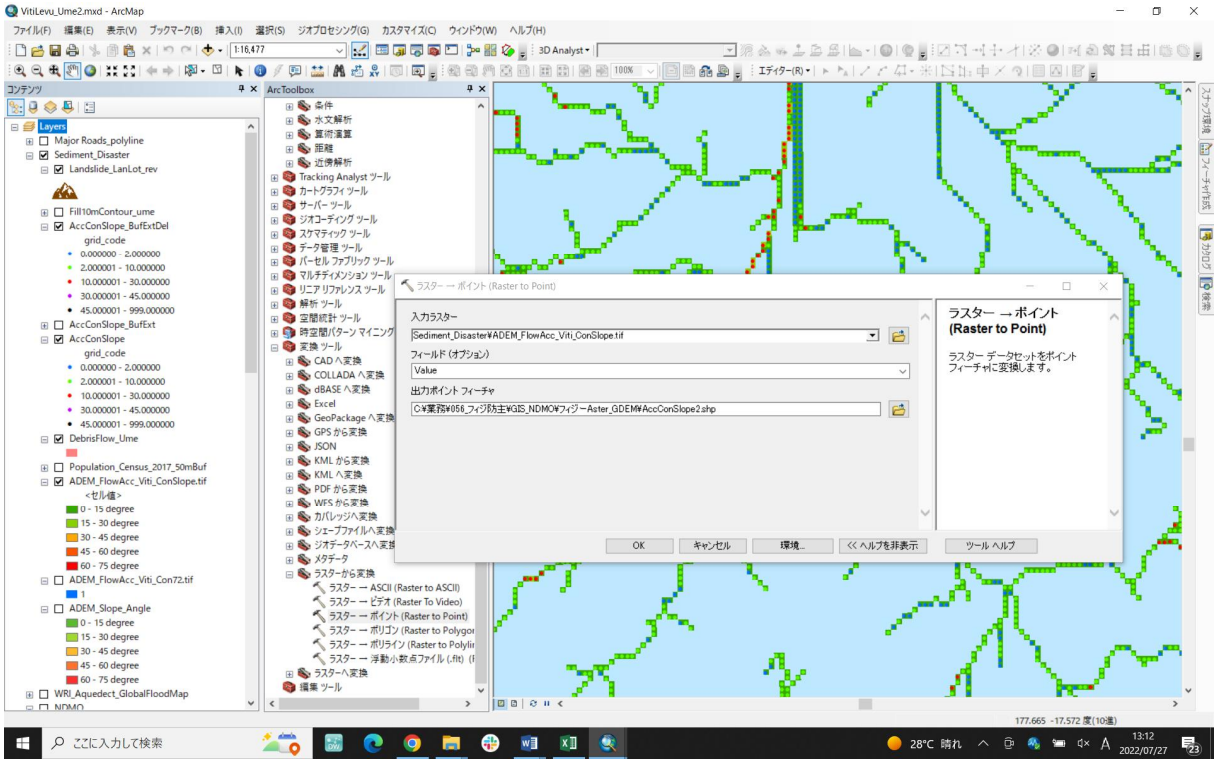
1) Debris flows are phenomena in which sediments on mountain streams and mountainside slopes become unstable during heavy rains or earthquakes, and flow down as turbid flows. Generation source of debris flow can be around / more than 10-degree slope (it can be 15 - 20°), even though it depends on the condition of the sediment.

2) Therefore, more than 10-degree slope will be extracted as a potential generation source of debris flow utilizing the above prepared data. Add the attribute of slope (prepared in the Chapter 3) to the stream prepared in "2.1 11)". Search a command, "Con" on the ArcGIS or Spatial analyst > Condition > Con. Set the condition as below [replace the indicator of the stream "1" with slope (prepared in the Chapter 3)]. The symbol of the slope shall be adjusted as below (classification / gradation, 5 classes).

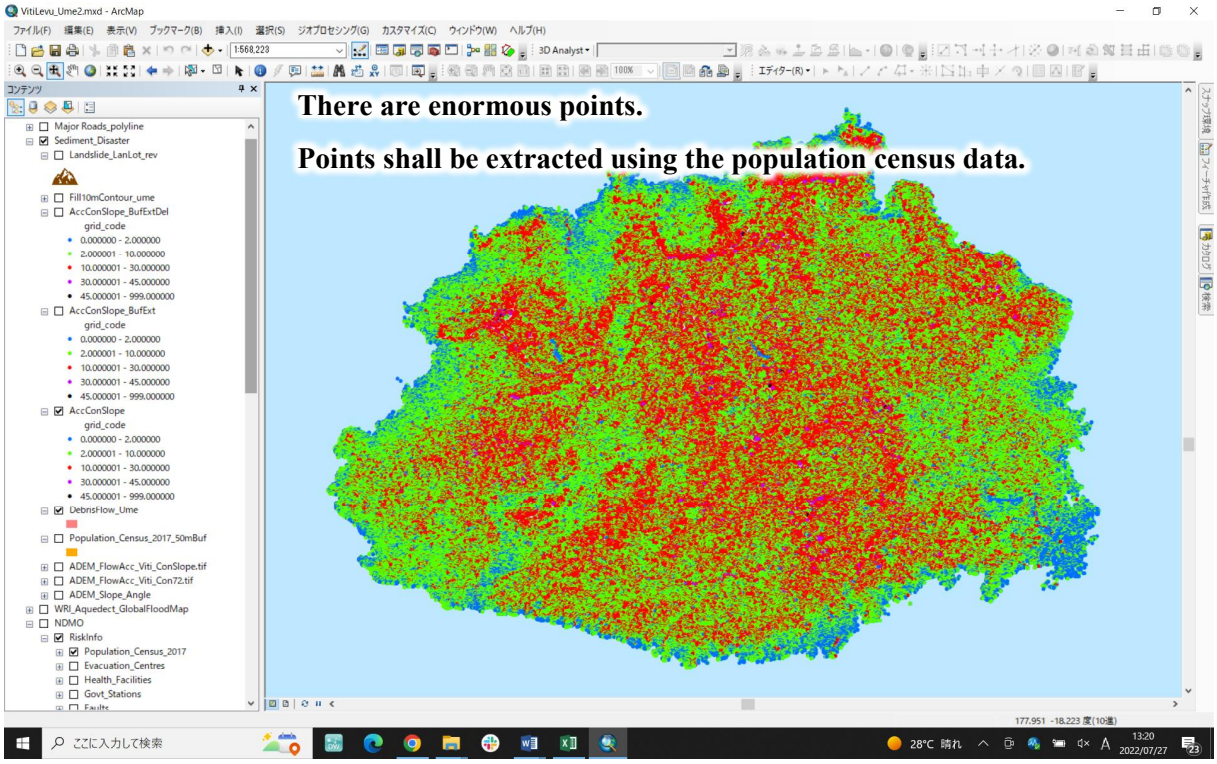




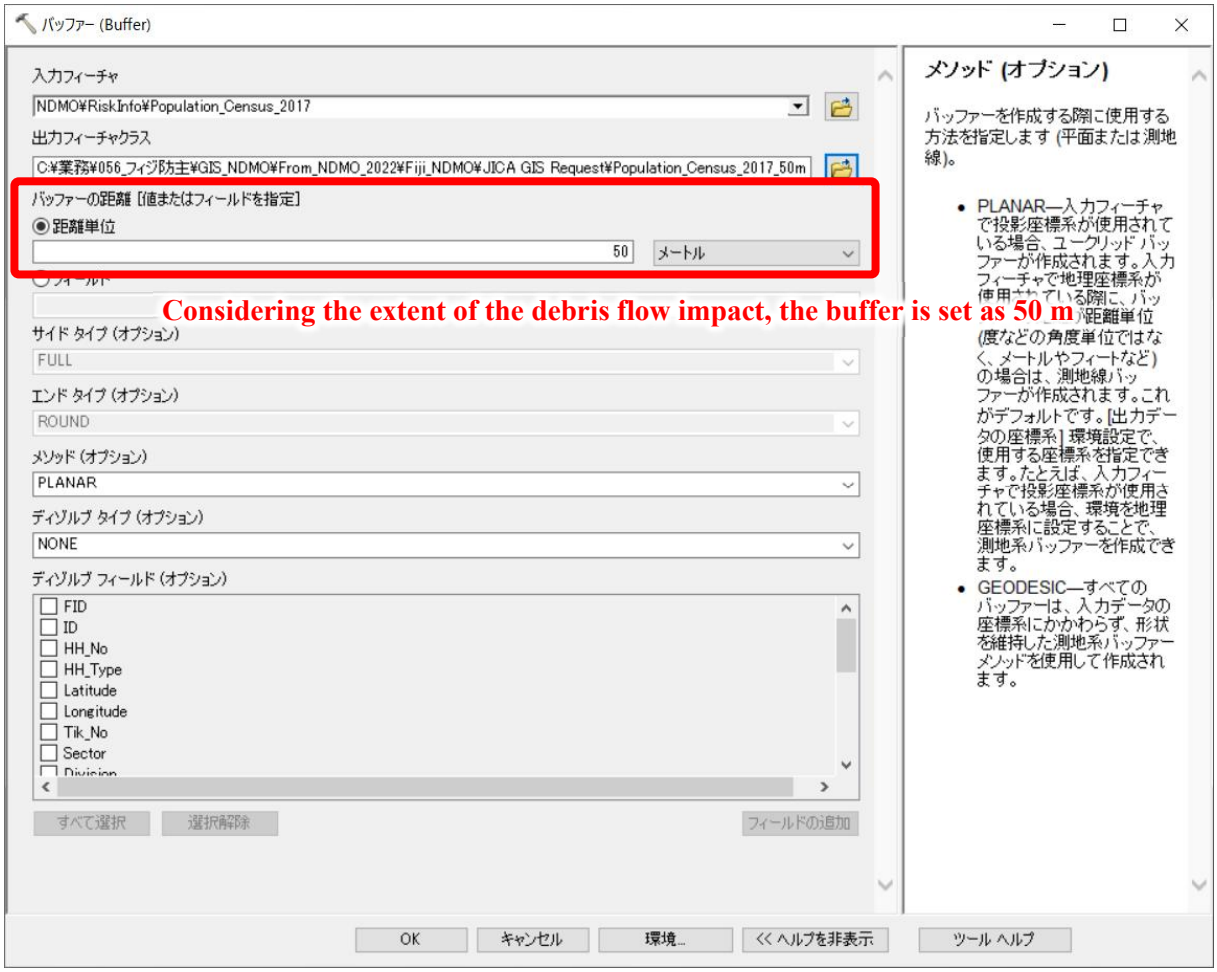
3) Streams with slope-attribute are needed to be converted to a point data to identify the potential generation source of debris flow. Search a command, “Raster to Point” on the ArcGIS or Conversion Tool > Conversion from Raster > Raster to Point. The symbol of the slope shall be adjusted as below (classification / gradation, 5 classes) again. You might utilize the layer data, “AccConSlope.lyr” by importing the layer for adjusting the color (property of the shape file > Symbol > import).



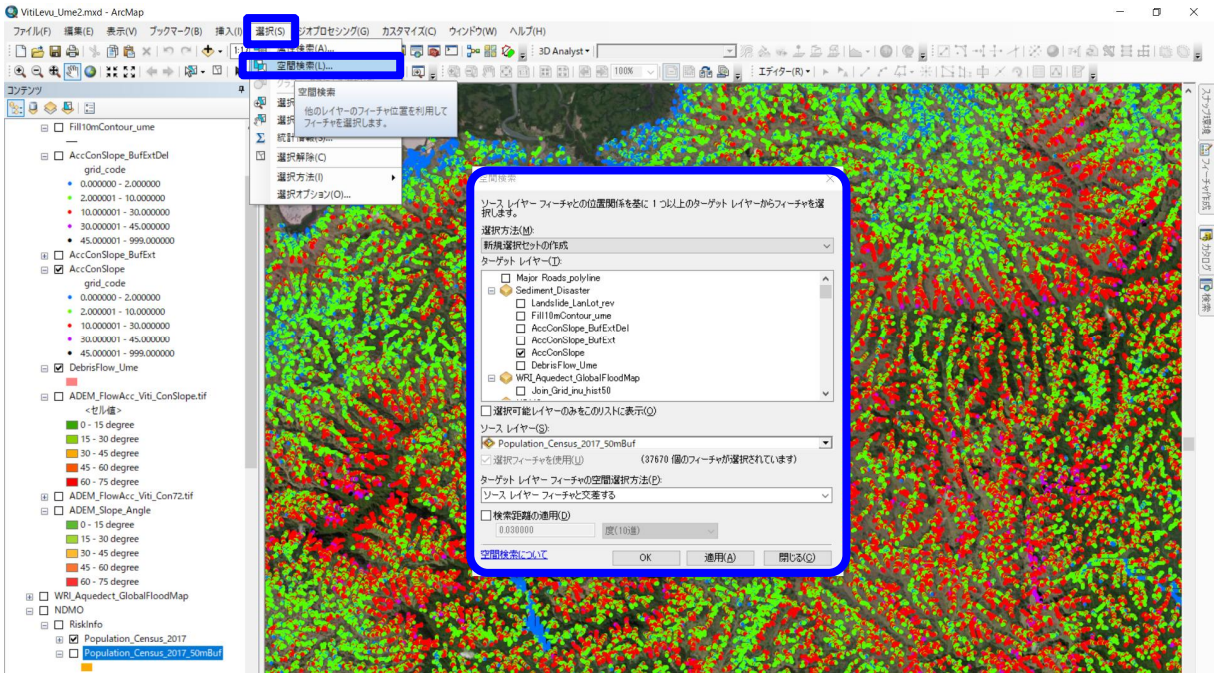
4) Streams which are close to houses / residence shall be extracted since there are enormous streams in the country.



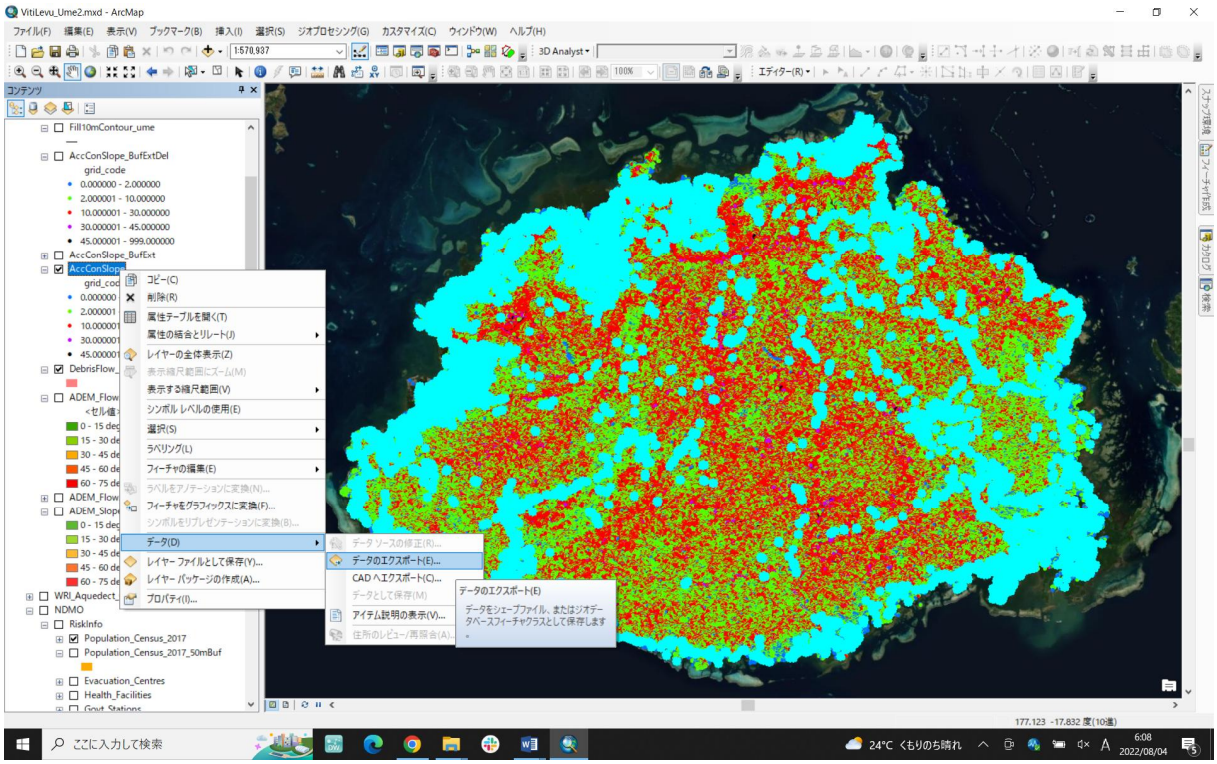
5) Streams are extracted utilizing the “Population_Census_2017 (GIS point data)”. First of all, make the 50m-buffer of the population census 2017. Search a command, “buffer” on the ArcGIS and set the condition as below.

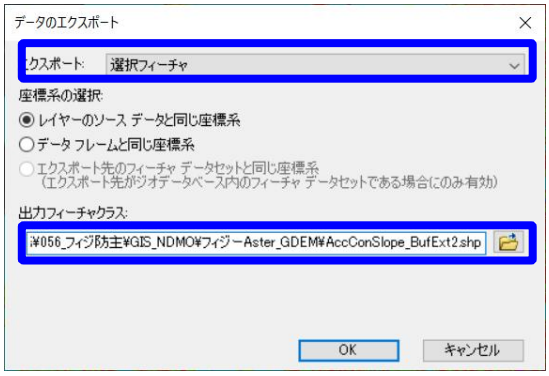


6) Secondly, conduct spatial search with the above created 50m-buffer. Target layer shall be set as “AccConSlope” and the source layer shall be set as “Population_Census_2017_50mBuf (above created buffer shape file).

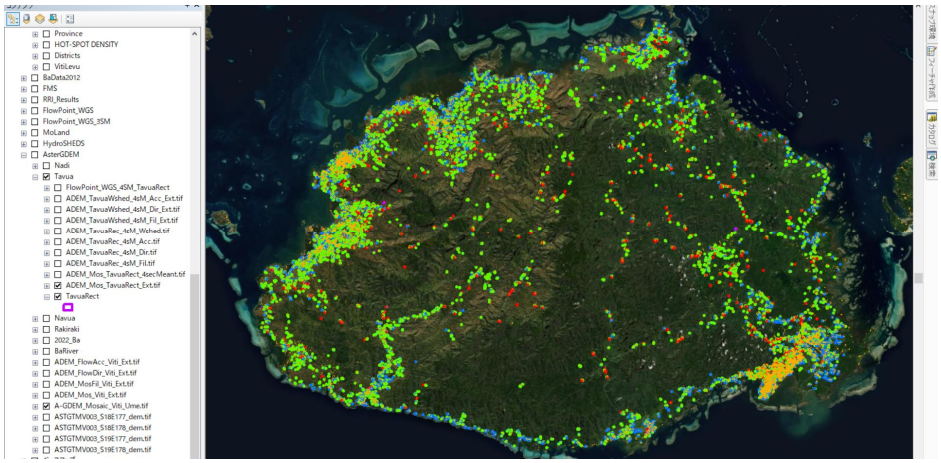


7) Selected stream points are the streams within 50m-buffer of the residence. Therefore, export the selected features right-clicking on the “AccConSlope” (right-click > data > data export > export only the selected features).

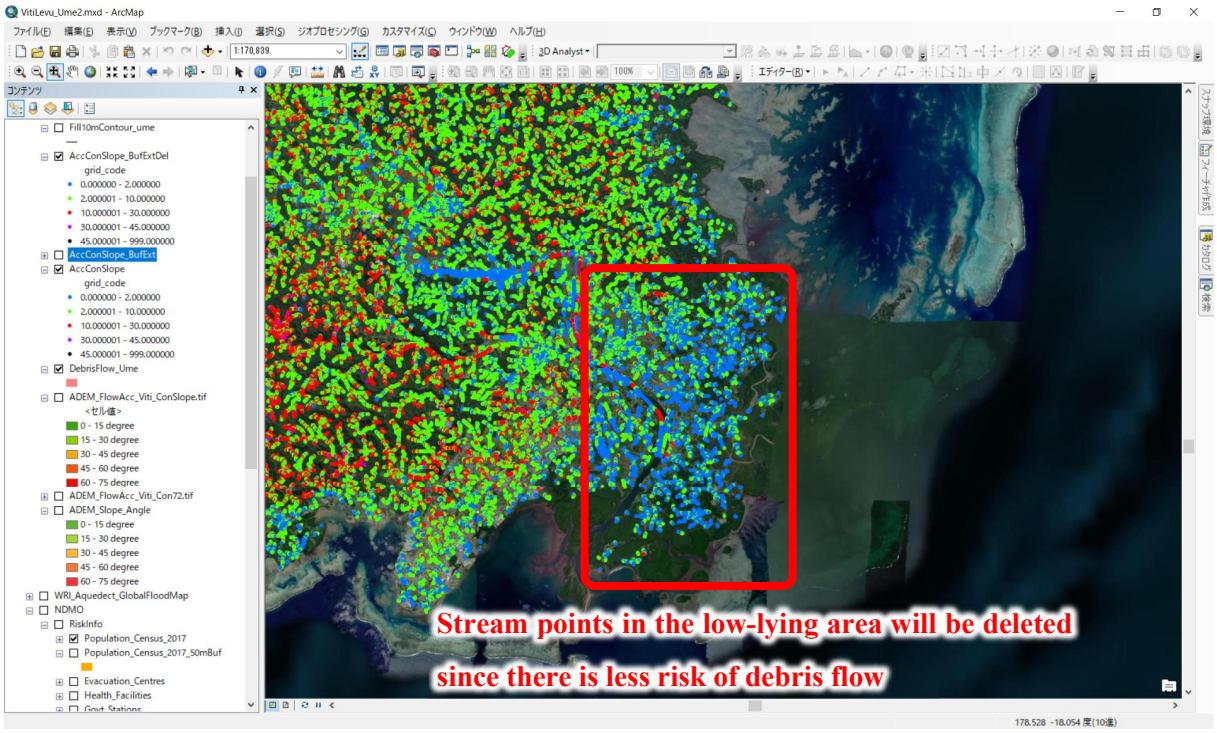




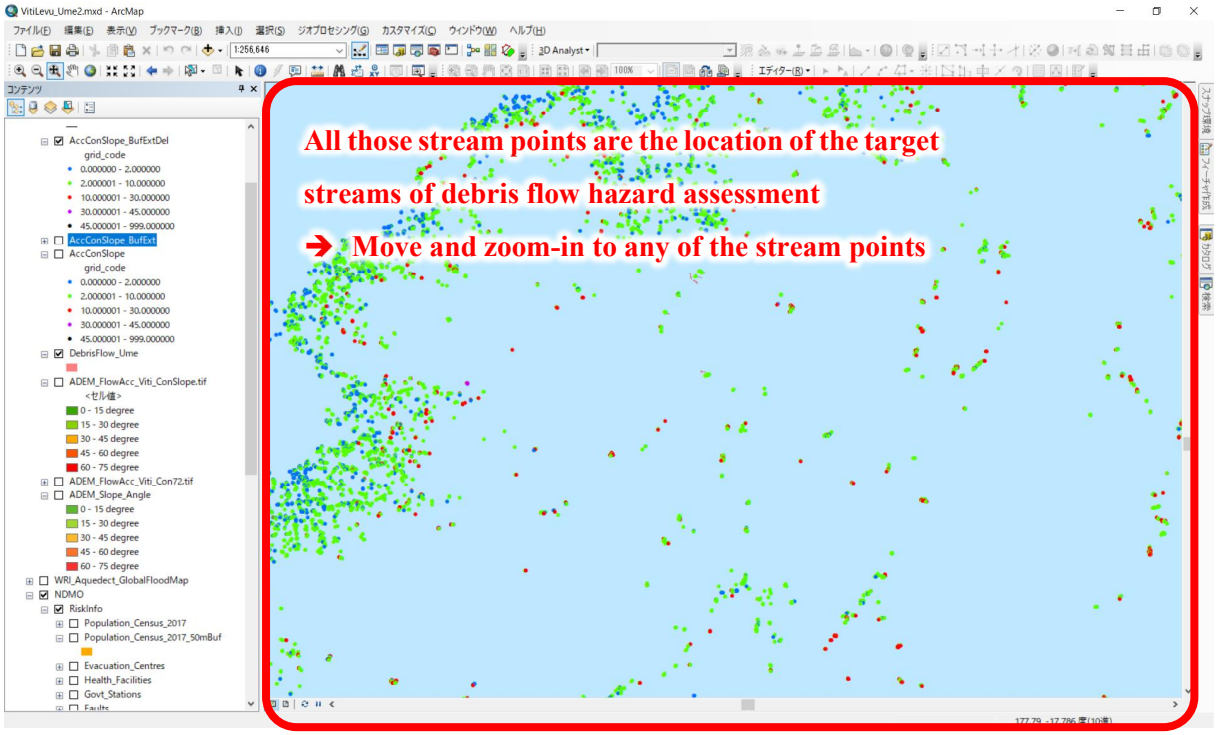
8) It will be like as the figure below after export the selected steam points. *Extracted stream points just INDICATE “they are the target streams” (some stream points where there is no resident were eliminated). However, “AccConSlope” shall be still used for identification of potential generation sources of debris flow.

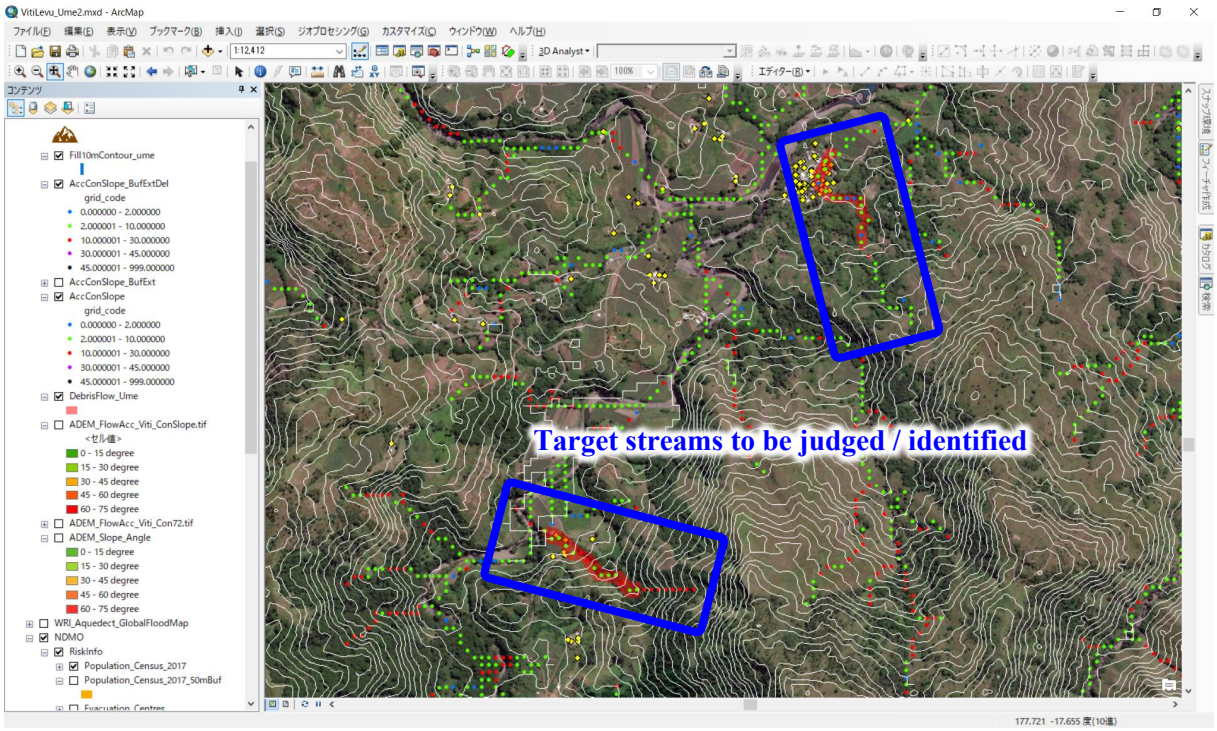


9) You might delete some more stream points by “Editor” especially in the low-lying areas, where there is less risk of debris flow, before identifying the potential generation sources.



10) Now we'll move to a manual identification / judgement. *Once again, the extracted streams prepared in "Chapter 4 7)" is used only for checking location of the target streams. And the whole stream points, "AccConSlope", shall be used for identification of potential generation sources of debris flow.

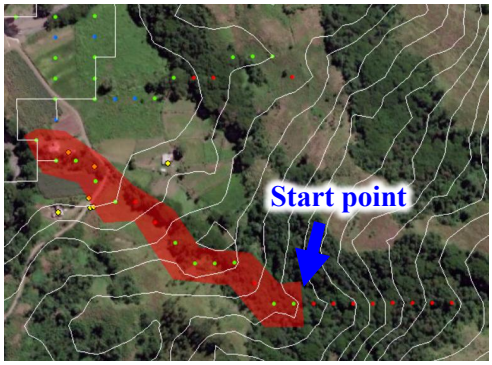


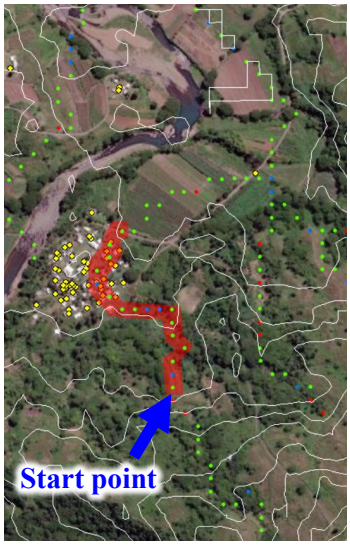


11) We need to identify "potential generation sources, start point of debris flow" and "end point of debris flow". There are criteria for both points.

Start point

A) *Changing point of the slope / gradient, "More than 10 degree (red points)" to "Less than 10 degree (green points)".* ***Starting from the upstream green point.***

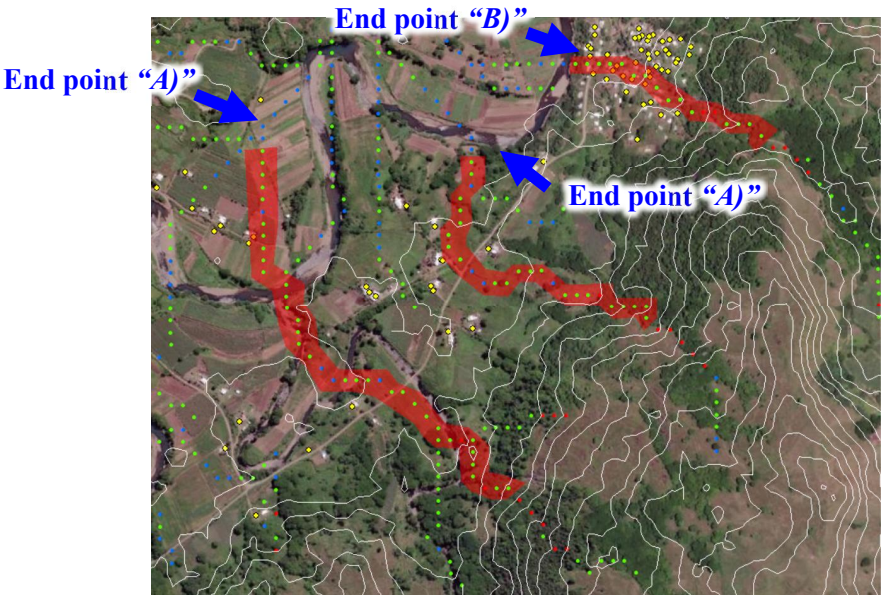




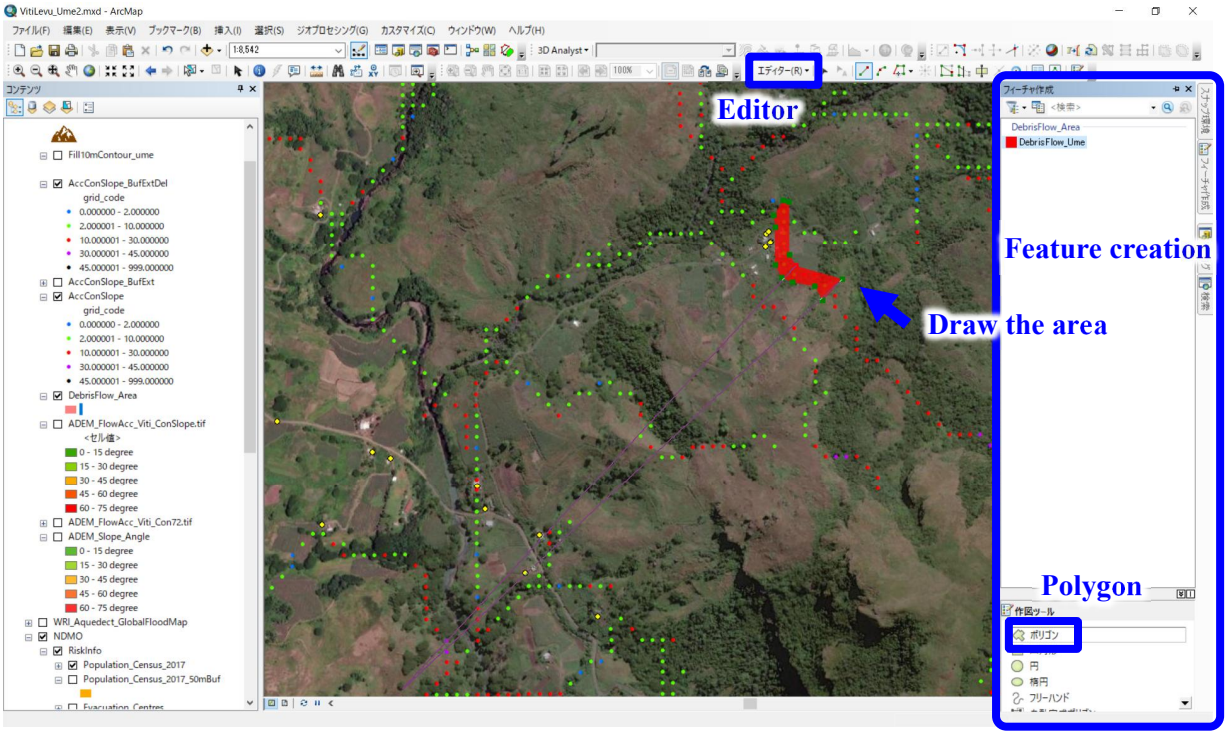
End point

A) *Changing point of the slope / gradient, "More than 2 degree (green points)" to "Less than 2 degree (blue points), and* ***it needs to be 3-consecutive blue points****". And it needs to be Starting from the upstream green point.*

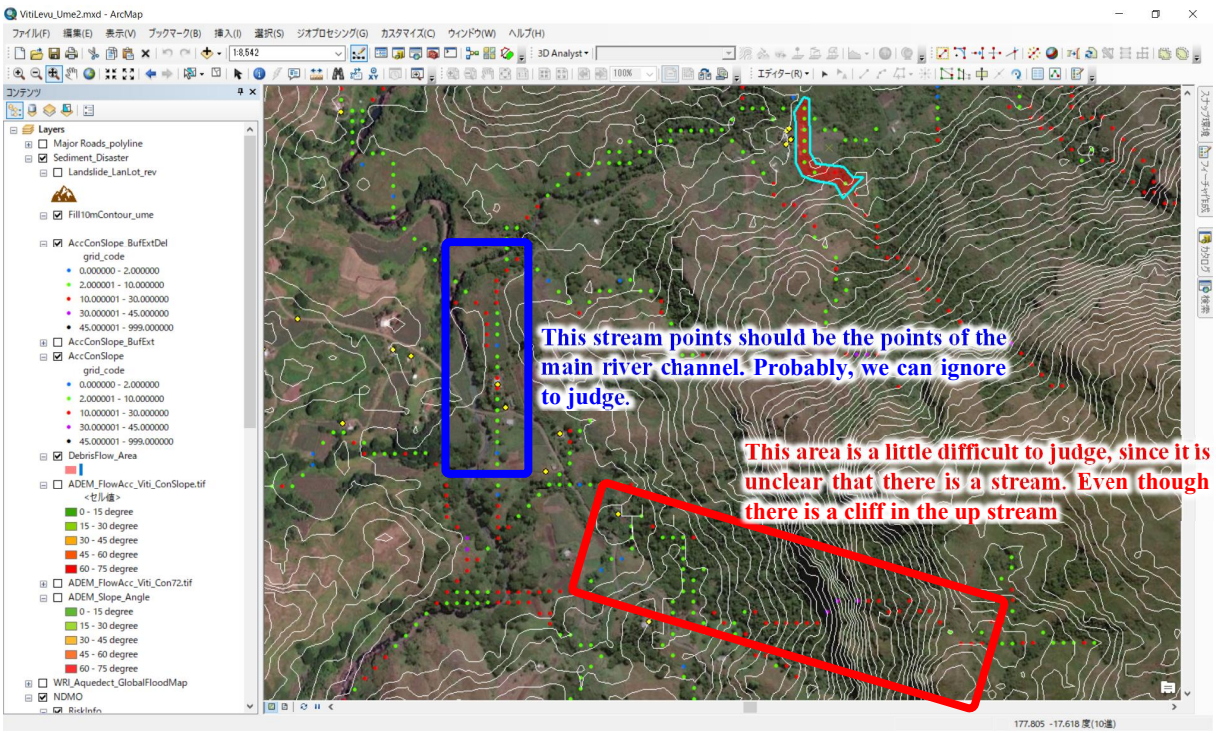
B) ***End of the community / residence*** *(if there is no more residences in the down-stream) or at the* ***confluence point of a major river / main river channel***



12) Area / polygon to cover the all the stream points starting from the above identified start point to the end point shall be drawn by “Editor”. “DebrisFlow_Area.shp” is used for drawing the area. You need to start editing and create features. Save the edit once you finish drawing the debris flow areas. Save the edit often to avoid lost production time by forced termination.



13) You will often find unclear areas to identify the debris flow hazardous area like as below. You should refer to the “Creeks / Streams / Rivers polyline data”, “contour lines” and the “base map / satellite image”, and “topographic condition”. Some streams DO NOT match the base map / satellite image because the streams are created based on the 30-m DEM data. It is left to the judgment of the individual.

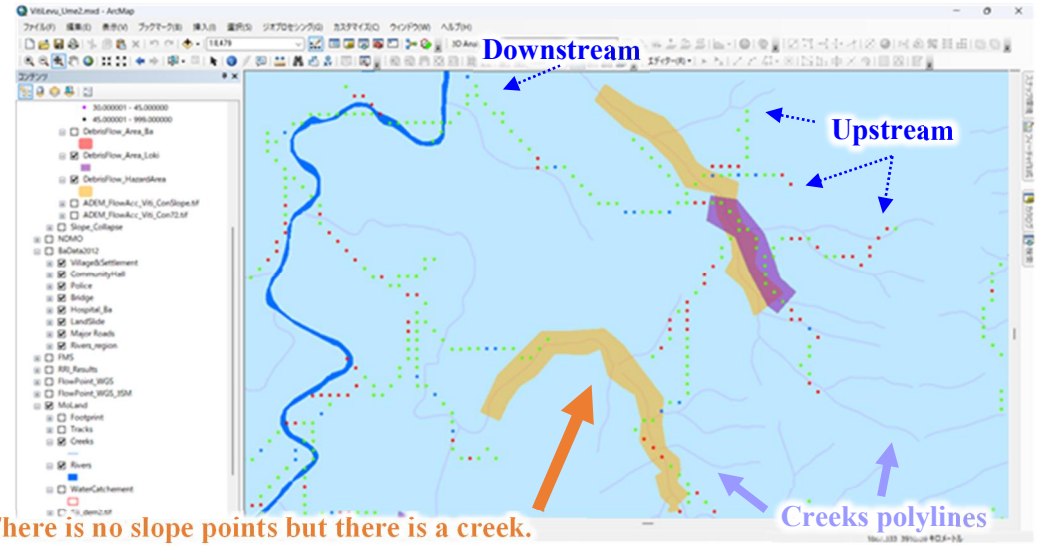


IMPORTANT Tips / Point to be checked

1) Check which side will be upstream / downstream (Higher elevation to lower elevation).

2) Check whether the source / start point of the debris flow is mountain / hilly or flat area. When you find the red points in the upstream and if it's in the flat area, you should NOT consider those points as the start point.

3) Compare / check the slope points and creeks / river polylines with the base map / the satellite image.

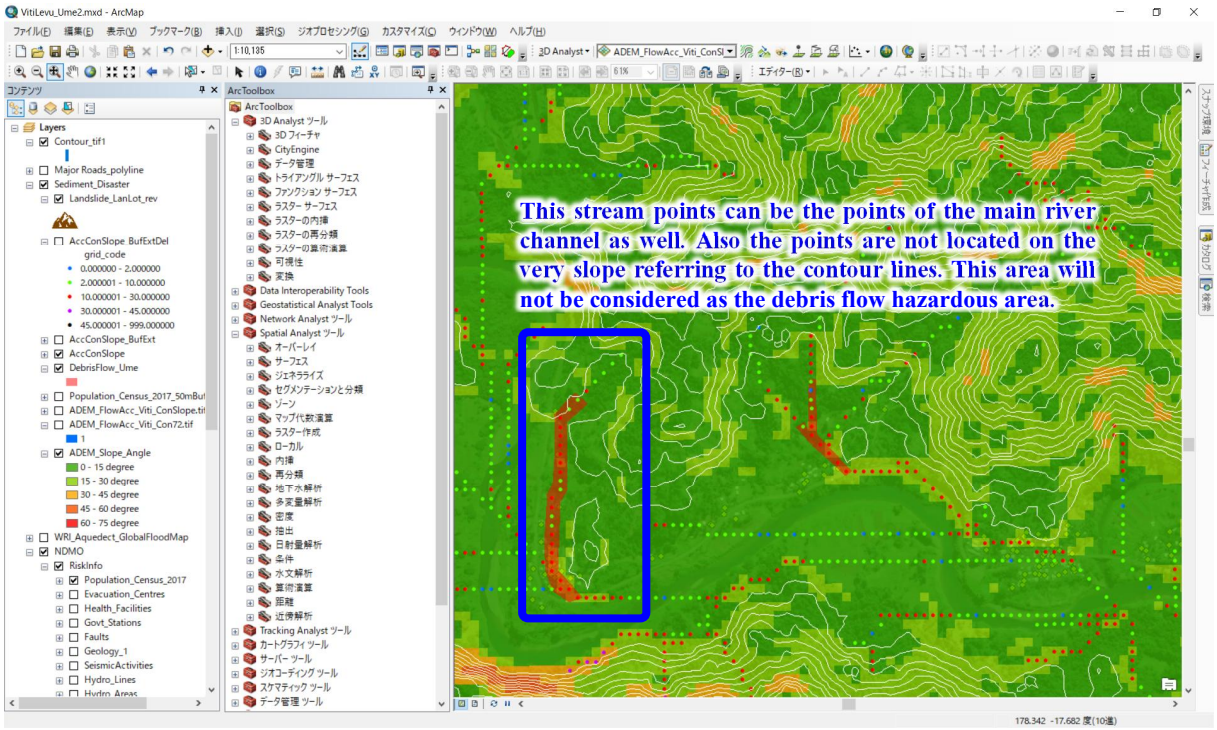


There is no slope points but there is a creek.
You can refer to the slope gradient to judge the start point of the debris flow, however you need to draw the area following the creeks polyline and checking the base map / the satellite image.

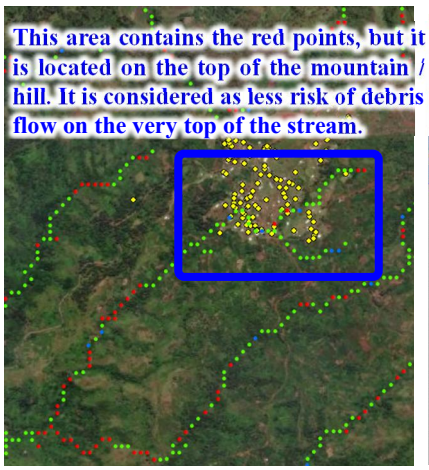
Some points (streams) DO NOT match the base map / satellite image or the creeks polylines because the streams are created based on the 30-m DEM data.
You need to create the area based on the base map / satellite image or the creeks.

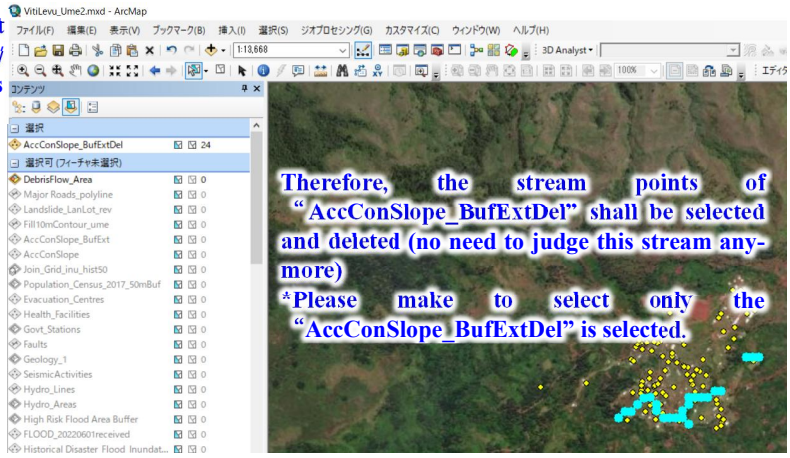
4) Check whether the building along the creeks seems a residence building or a shed.

5) Basically targeting the creeks which the headstream is located in the mountain / hilly areas.



14) You should delete the stream points where you judged / decided not to set as a hazardous area on the shape file, “AccConSlope_BufExtDel”, by Editor (Editor > select the stream points you’ll delete, then delete).



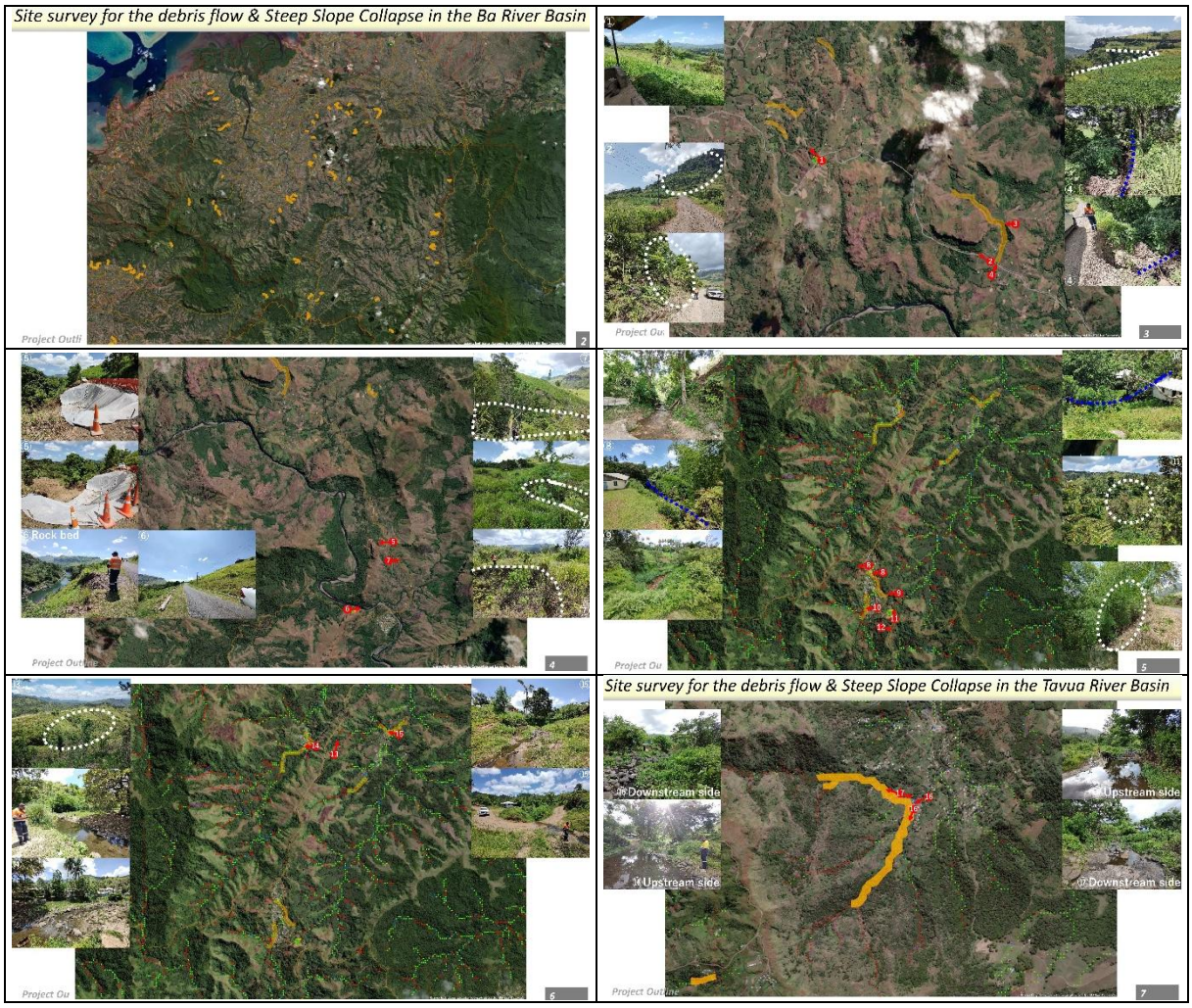


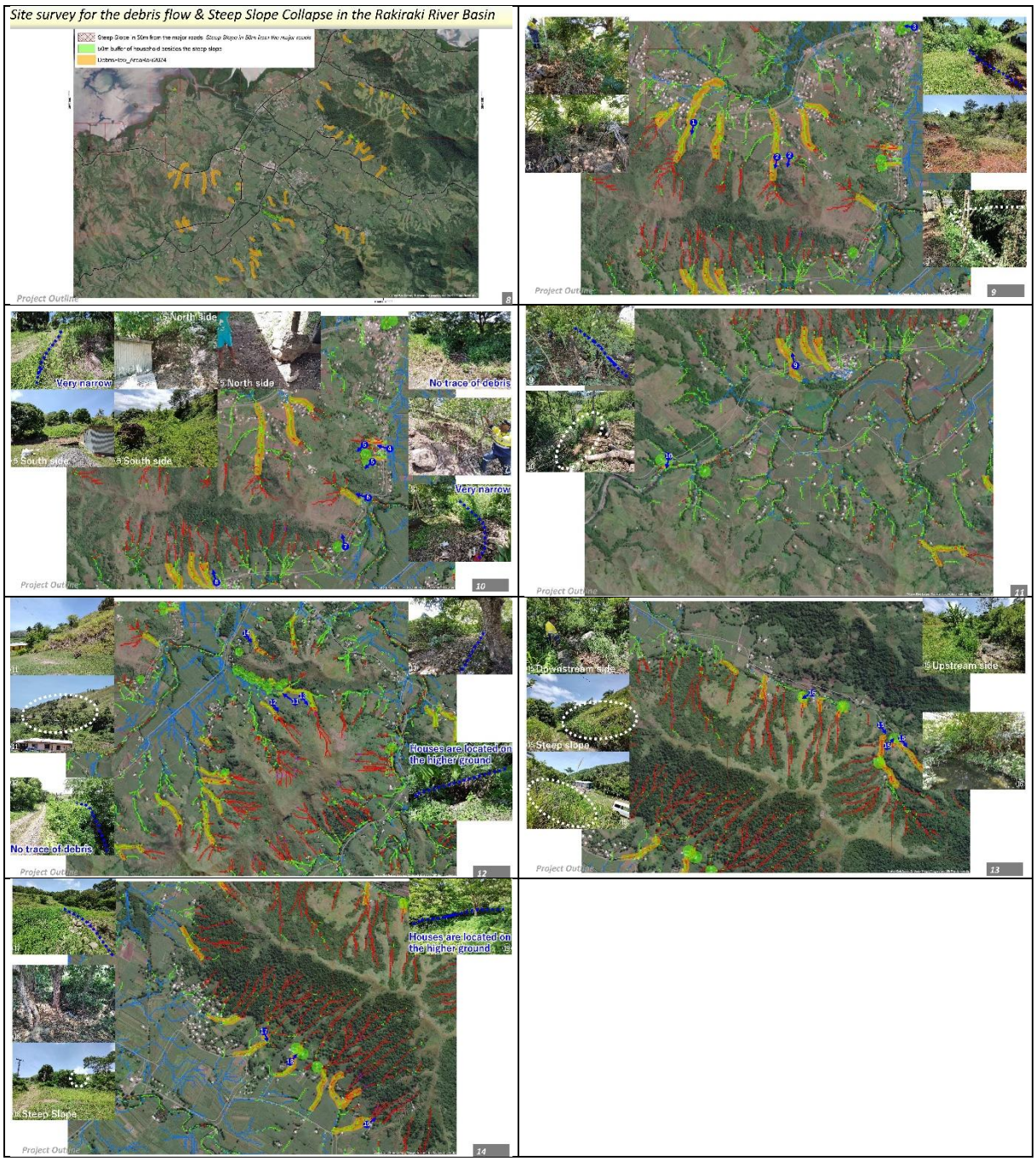
Chapter 5. On-Site Validation

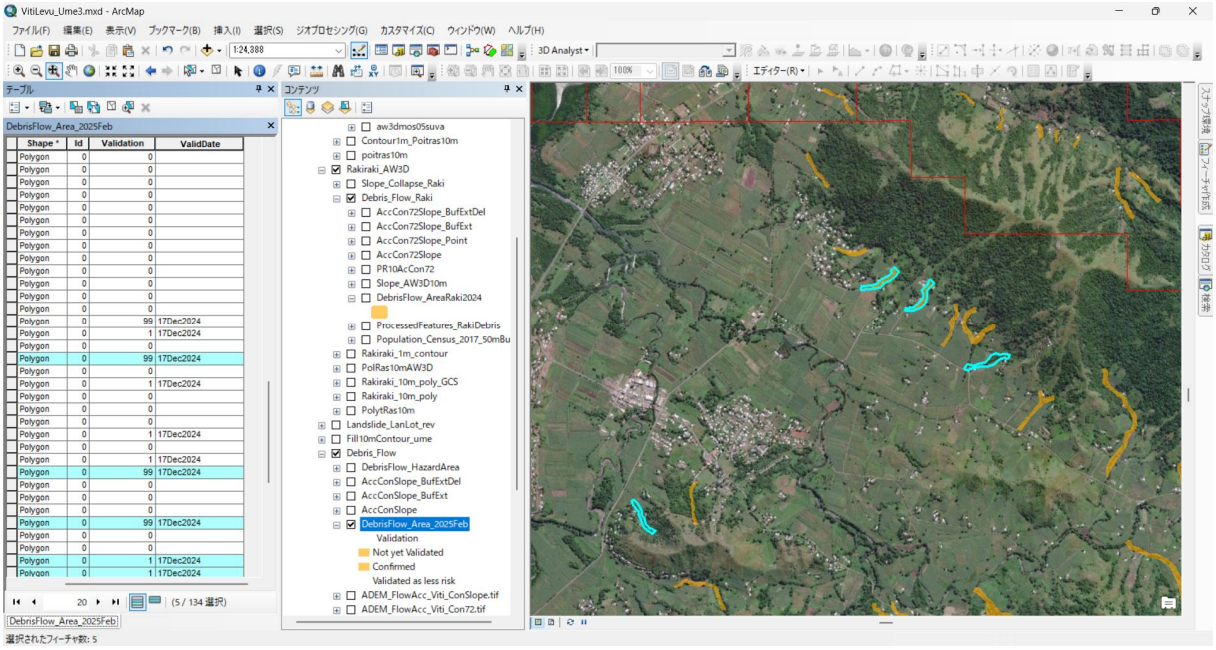
1) As mentioned in the "Chapter 1 Introduction", since the simplified hazard assessment conducted in this project is based on topographical data 'geological conditions are not used), on-site validation is important. The followings are the examples of the site survey result. You should take pictures, review the results of the desk study and finally organize the information like the example.

2) Examples of tips / points to check are followings. You might interview to the residents about the past landslide situation. It is important to note that just because there have been no disasters in the past does not mean that disasters will not occur in the future. Also you might give them a heads-up about landslides.

For Steep Slope Collapse			
✧ Geological conditions	✧ Ground surface conditions	✧ Thickness of surface soil	✧ Passed record of the disaster occurrence
✧ Existence of overhang	✧ Existence of spring water	✧ Distance from human activity areas	
For Debris Flow			
✧ Trace of the debris, such as stones / rocks / cobbles, drift woods	✧ Width of the streams	✧ Relative height of the adjacent buildings	✧ Distance from human activity areas




Site survey for the debris flow & Steep Slope Collapse in the Rakiraki River Basin
Project Outline
8
9
North side
Very narrow
North side
No trace of debris
South side
South side
Very narrow
10
11
Houses are located on the higher ground
No trace of debris
12
Downstream side
Upstream side
Steep slope
13
Houses are located on the higher ground
Steep Slope
14

3) After the on-site validation, the reviewed results should be reflected on the GIS information like below. You can add the fields of “Validation” to distinguish between places that have been confirmed and those that have not (Here, the confirmed locations were distinguished by entering numbers: “1” indicates the confirmed as hazard area, “99” indicates the confirmed as no / less risk area*, “0” indicates the area is not validated yet), as well as places that are dangerous and those that are not. You can also add the field for the “Validation date”.

   * To distinguish whether it was a previously judged area or an oversight, it would be better to make the data invisible rather than deleting it.