タイ王国
内務省災害軽減局
教育省

タイ国
防災能力向上プロジェクト
（フェーズ２）

ファイナルレポート

ANNEXES (2/2)

平成 26 年 4 月
(2014 年)

独立行政法人
国際協力機構 (JICA)

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株式会社 地球システム科学

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ANNEXES (1/2)

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ANNEX 7

Manuals for Hydrology/Hydraulics, Flood Analysis and Hazard Map

The Project on Capacity Development in Disaster Management in Thailand (Phase-2)

MANUAL FOR HYDROLOGY / HYDRAULICS, FLOOD ANALYSIS AND HAZARD MAP

Japan International Cooperation Agency
IDEA Consultants, Inc.
Earth System Science Co., Ltd.

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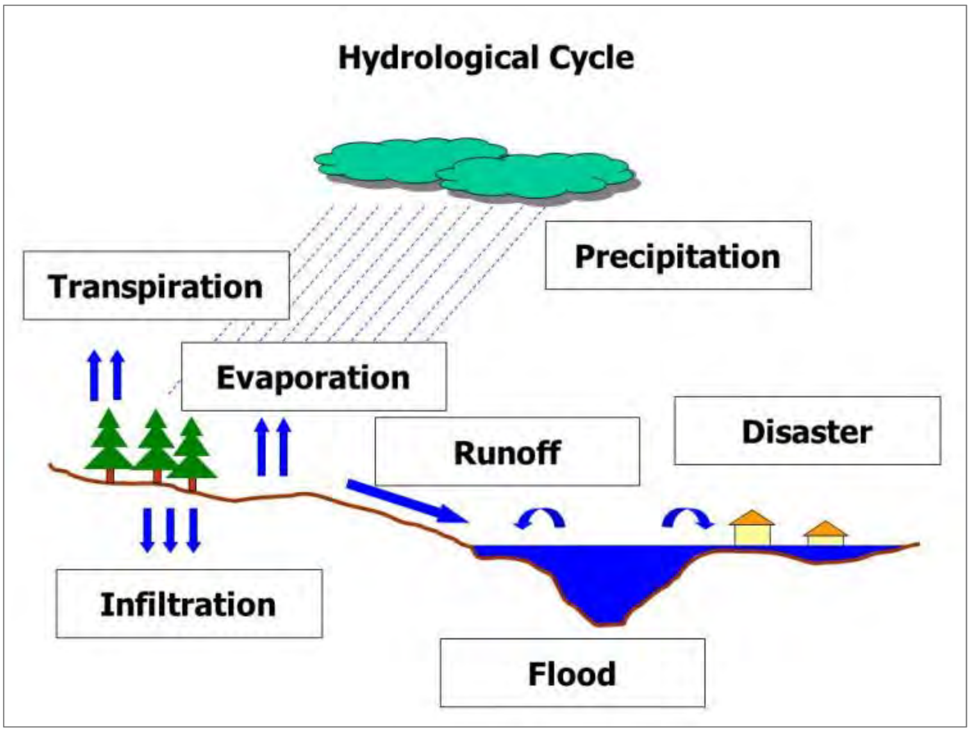
[Hydrology / Hydraulics]

[Flood Analysis / Hazard Map]

[Hydrology / Hydraulics]

1. General

1-1 Hydrological Cycle



It indicates hydrological cycle on the earth. Precipitation occurs. Precipitation is water dropping from the sky. It's sometimes rainfall and sometimes snow. Rainfall drops on the ground, leaf, roof, etc. Some water flow on the surface, drain into ditch or channel and into river, then finally into the sea. And some water infiltrates into the ground and become ground water. Ground water drains into the river taking so long period. Some water don't flow to the river, go back to the air by evaporation or transpiration. The water in the sea or lake goes back to the air, and it becomes cloud and drops on the ground as rainfall again. It is called hydrological cycle.

The hydrologic cycle is the central focus of hydrology. The cycle has no beginning or end, and its many processes occur continuously. As shown schematically in the figure, water evaporates from the oceans and the land surface to become part of the atmosphere; water vapor is transported and lifted in the atmosphere until it condenses and precipitates on the land or the oceans; precipitated water may be intercepted by vegetation, become overland flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow, and discharge into streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge groundwater, later emerging in springs or seeping into streams to form surface runoff, and finally flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continues.

1-2 Flood Control Measures

Flood Control Measures

Hard (structural measures)

Levee, bank protection, retarding basin, floodway, dam, groin, sluiceway, etc.

Soft (non-structural measures)

Hazard map, early warning system, land-use regulation, flood fighting, etc.

Flood control measures consist of hard (structural) measures and soft (non-structural) measures.

Hard (structural) measures:

1) Levee: Levee is constructed along the river to prevent overflowing of flood water from the river side into the land side when water level gets higher. Levee is made of soil basically, in terms of low cost, easy maintenance, easy acquisition of material, etc.

2) Bank protection: Bank protection is applied to protect river bank against erosion caused by flood flow. The work cost of bank protection occupies a large portion in the river improvement work, and therefore it is important to exercise ingenuity according to the characteristics of the river.

3) Retarding basin: Flood retarding basin is holding basin which temporarily store storm water to reduce downstream flow rates. Then stored water is drained to the river when water level in the river decreases.

4) Floodway: Floodway is a man-made water course constructed to divert flood water from the river.

5) Dam (flood control dam): Flood control dam stores flood water from upstream and then controls discharge to downstream.

6) Groin: Groins are applied to prevent scours caused by the suppression of the velocity at the riverbank or the front face of riverbank, to fix normal channel, and to guide river flow, etc.

7) Sluiceway: Sluiceway is located at the confluence of main stream and its tributary. It closes the gate during high water in main stream in order to prevent back flow from main stream to its tributary.

Soft (non-structural) measures:

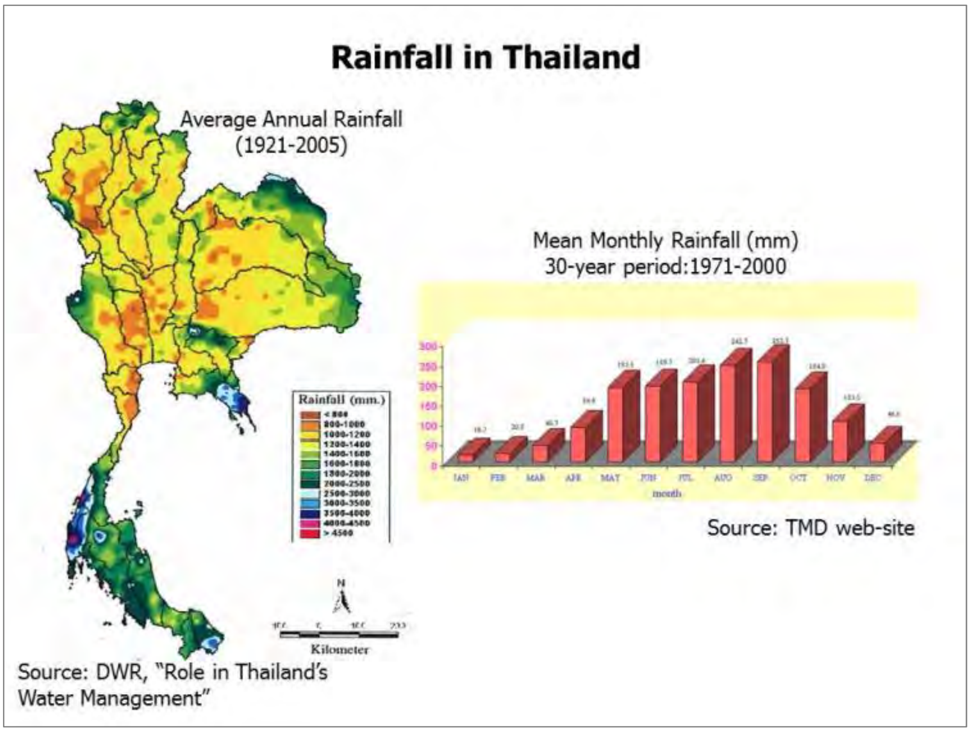
1) Flood hazard map: Flood hazard map is a map that graphically provides information on inundation (predicted inundation areas, inundation depth, etc.), as well as on evacuation (location of evacuation refuges, evacuation routes, dangerous spots o evacuation routes, etc.) in an easy-to-understand format. The goal is to quickly evacuate local residents in a safe and proper manner in the event of floods.

2) Early warning system: The objectives of early warning system is to reduce human vulnerability and flood damage by monitoring sources of floods, predicting where and when floods could possibly happen, issuing the warning about predicted situation.

3) Land use regulation: Hazardous areas for natural disaster are designated and classified as some risk levels. Land use and construction of buildings are restricted in the zone and relocation of existing houses is recommended.

4) Flood fighting: As an emergency measure to minimize flooding damage, flood fighting activities that have huge positive effects as small cost become very important along with structural measures. Flood fighting activities use soil, trees, and bamboo that are easily obtained on site.

1-3 Rainfall in Thailand

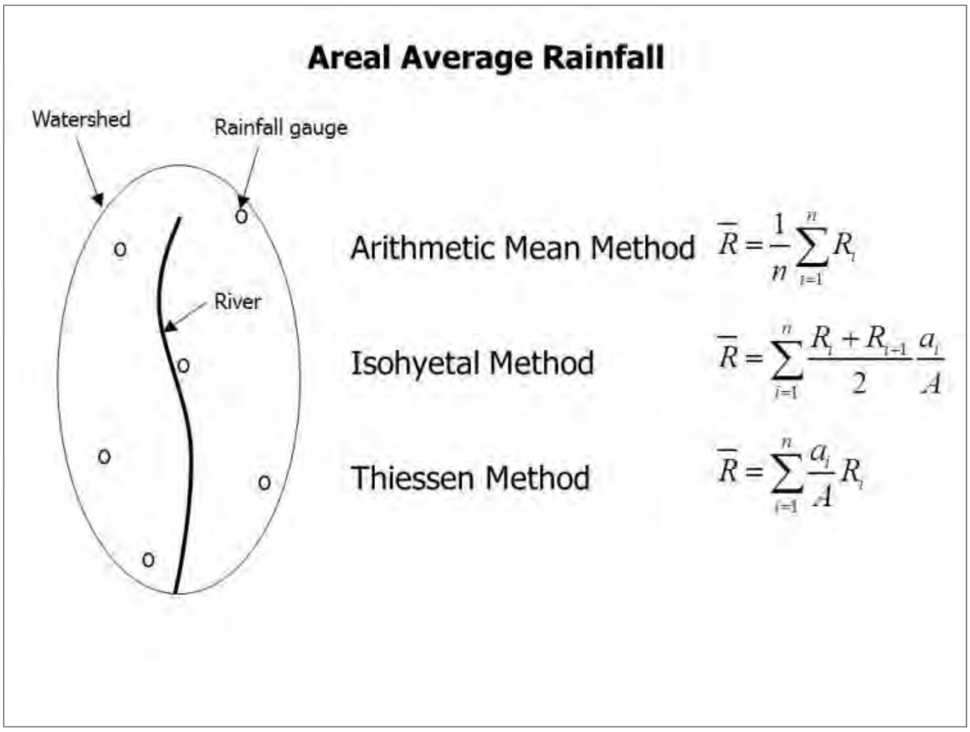


Climate condition in Thailand is influenced by the south western and north eastern monsoon storms. The south western monsoon brings heat stream from the Gulf of Thailand and Indian Ocean that becomes the rainfall while the north eastern monsoon bring cold and draught from China into Thailand. With the influence of both monsoons, Thailand has 3 seasons i.e. rainy season starting from May to mid-October, winter starting from mid-October to mid-February and summer starting from mid-February to mid-May.

Based on the average annual rainfall information within 30 years from 1976 to 2005 collected at the rainfall measure stations in each river basin as shown in figure (left), it shows that average annual rainfall in river basins of Thailand is equal to 1,426 mm with rainfall variation between 800 – 4,400 mm. The heavy rain always falls in the southern river basins especially in the western south river basin where the annual rainfall is higher than 2,400 mm.

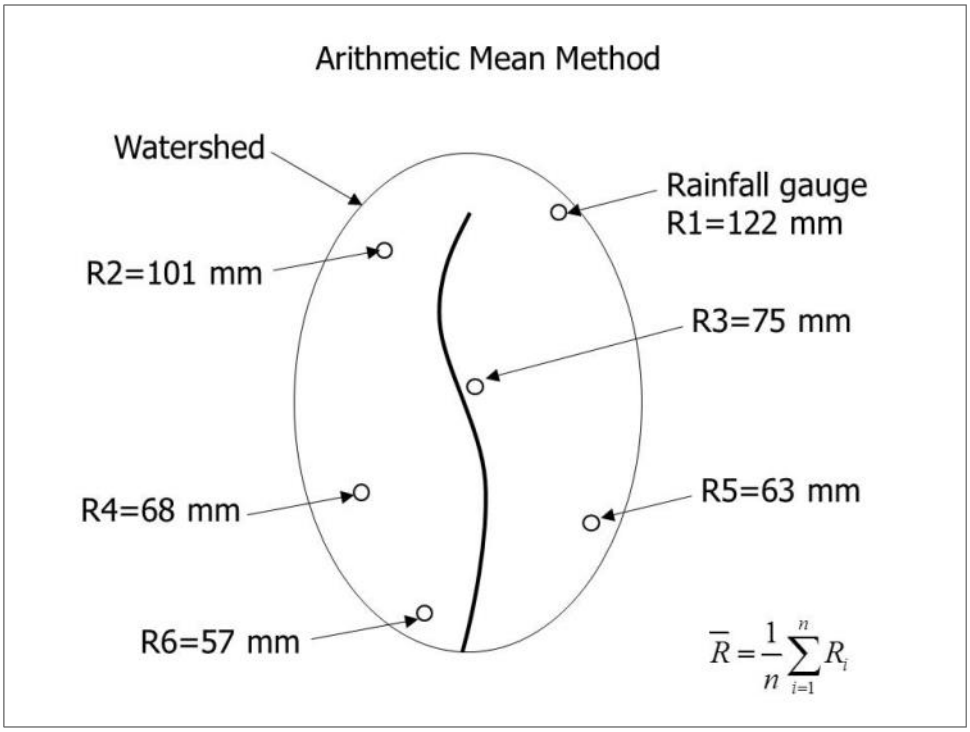
1-4 Areal Average Rainfall

The areal average rainfall in a river basin should be calculated by Arithmetic mean method, Thiessen polygon method or isohyetal method. Various methods are available for calculating the areal average rainfall in a river basin from rainfall data recorded within the river basin, but generally the arithmetic mean method, Thiessen plygon method, isohyetal method are employed.



(1) Arithmetic Mean Method

The arithmetic mean method is the simplest method of determining areal average rainfall. It involves averaging the rainfall depths recorded at a number of gages. This method is satisfactory if the gages are uniformly distributed over the area and the individual gage measurements do not vary greatly about the mean.



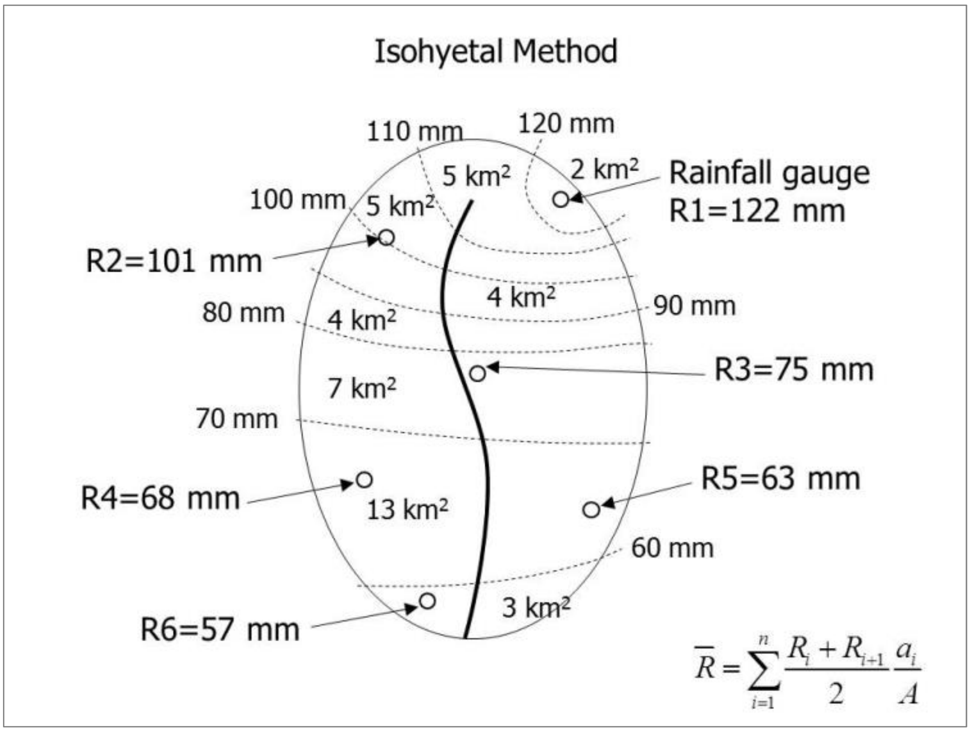
[Answer]

$$\bar{R}=\frac{1}{n}\sum_{i=1}^{n}R_i=\frac{122+101+75+68+63+57}{6}=81\,mm$$

(2) Isohyetal Method

The isohyetal method calculates areal average rainfall by constructing isohyets, using observed depths at rain gages and interpolation between adjacent gages.

Once the isohyetal map is constructed, the area Aj between each pair of isohyets, within the watershed, is measured and multiplied by the average Pj of the rainfall depths of the two boundary isohyets. The isohyetal method is flexible, and knowledge of the rainfall pattern can influence the drawing of the isohyets.



[Answer]

i	R_i	R_{i+1}	$(R_i + R_{i+1})/2$	a_i	$(R_i + R_{i+1})/2 * a_i /A$
1	130	120	125	2	6
2	120	110	115	5	13
3	110	100	105	5	12
4	100	90	95	4	9
5	90	80	85	4	8
6	80	70	75	7	12
7	70	60	65	13	20
8	60	50	55	3	4
Total				43	84

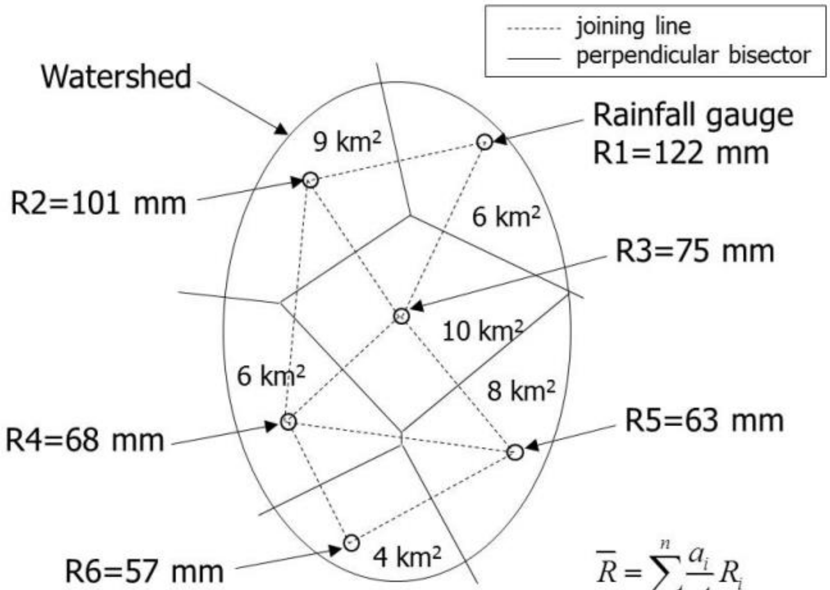
$$\bar{R} = \sum_{i=1}^{n} \frac{R_i + R_{i+1}}{2} \frac{a_i}{A} = 84\ mm$$

(3) Thiessen Method

The Thiessen method assumes that at any point in the watershed the rainfall is the same as that at the nearest gage so the depth recorded at a given gage is applied out to a distance halfway to the next station in any direction.

The relative weights for each gage are determined from the corresponding areas of application in a Thiessen polygon network, the boundaries of the polygons being formed by the perpendicular bisectors of the lines joining adjacent gages.

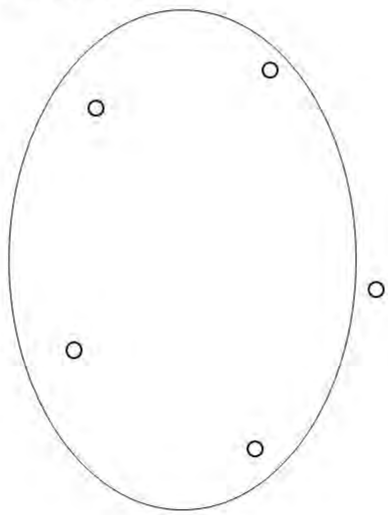
Thiessen Method

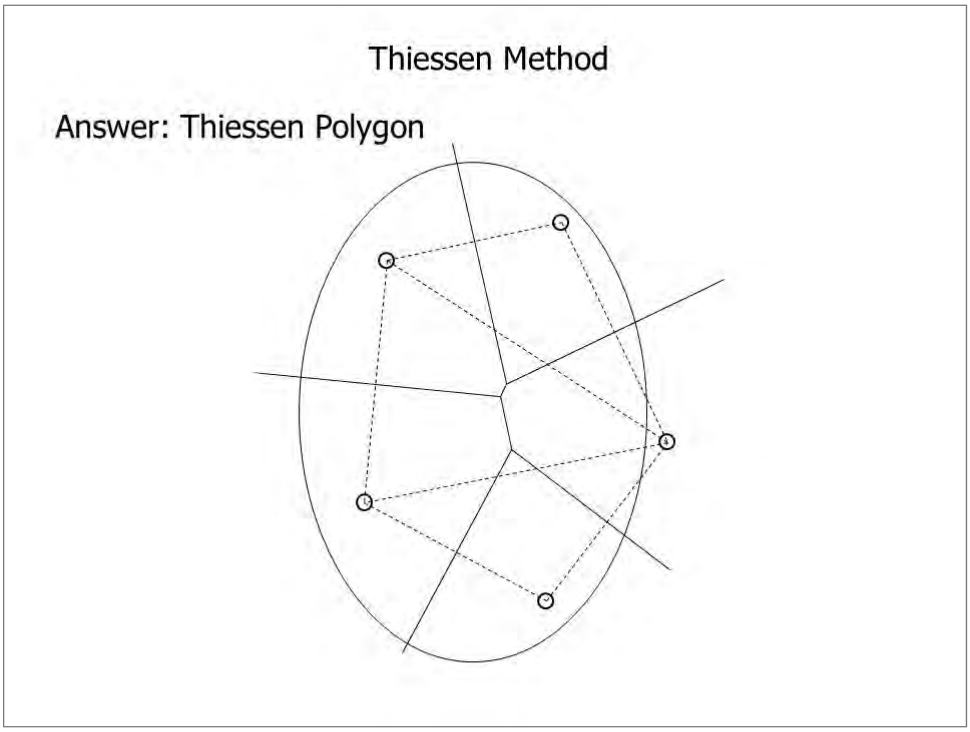


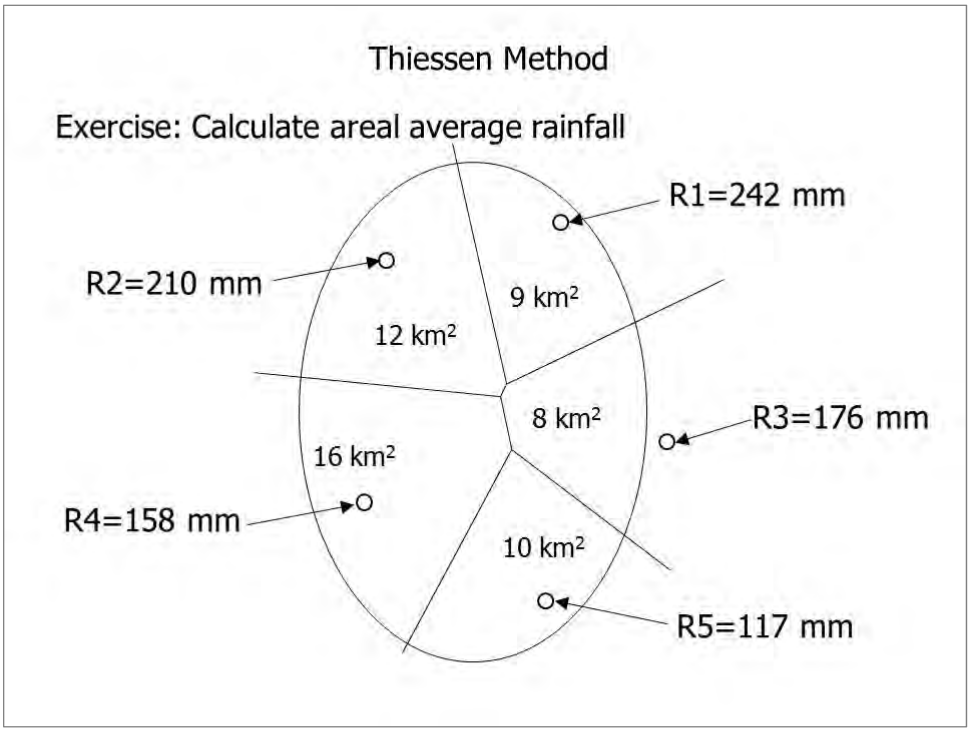
$$\overline{R} = \sum_{i=1}^{n} \frac{a_i}{A} R_i$$

Thiessen Method

Exercise: Draw Thiessen Polygon




Thiessen Method
Answer: Thiessen Polygon

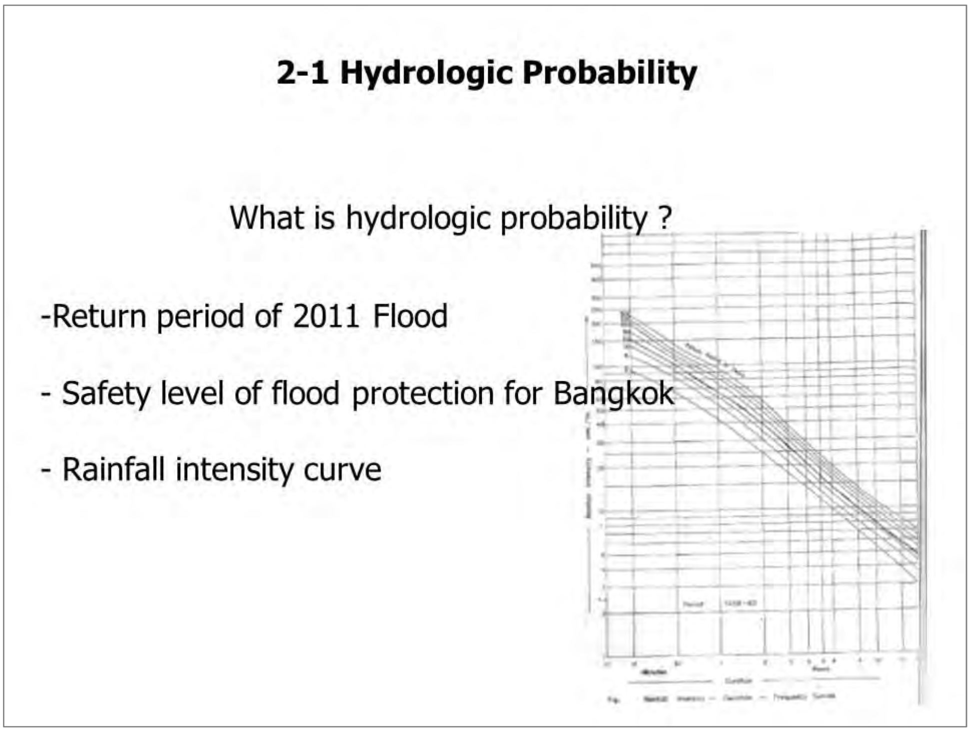

Thiessen Method
Exercise: Calculate areal average rainfall
R1=242 mm
R2=210 mm
9 km²
12 km²
8 km²
R3=176 mm
16 km²
R4=158 mm
10 km²
R5=117 mm

[Answer]

Station	Rainfall (mm)	Area (km^2)	Weight	Weighted Rainfall (mm)
R1	242	9	0.16	38.7
R2	210	12	0.22	46.2
R3	176	8	0.15	26.4
R4	158	16	0.29	45.8
R5	117	10	0.18	21.1
Total		55	1.00	178.2

2. Rainfall

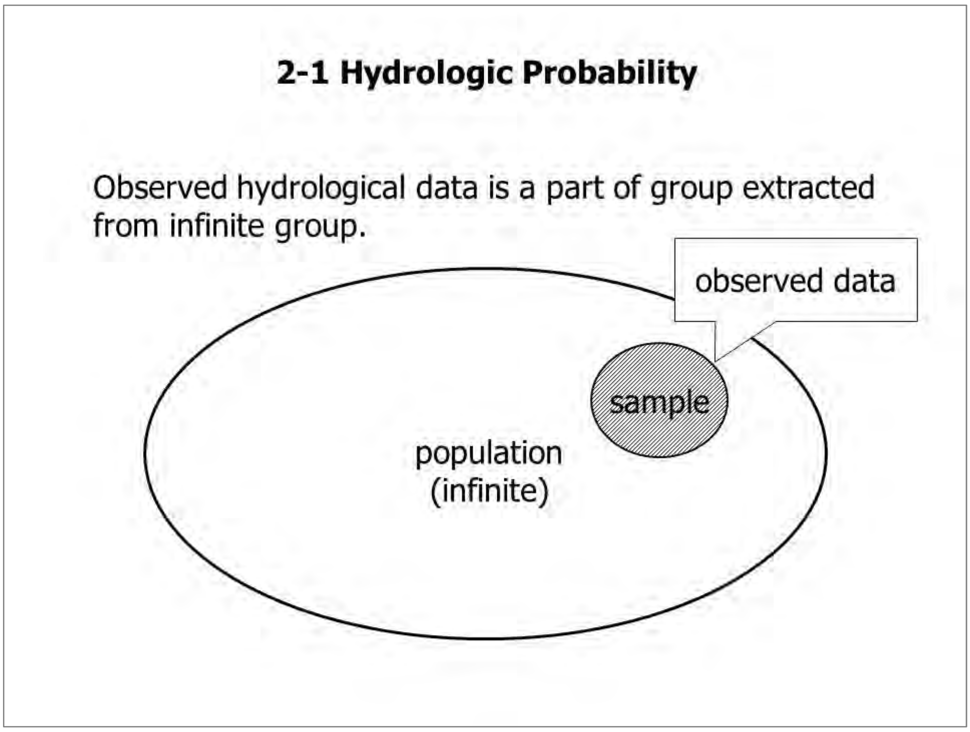
2-1 Hydrologic Probability

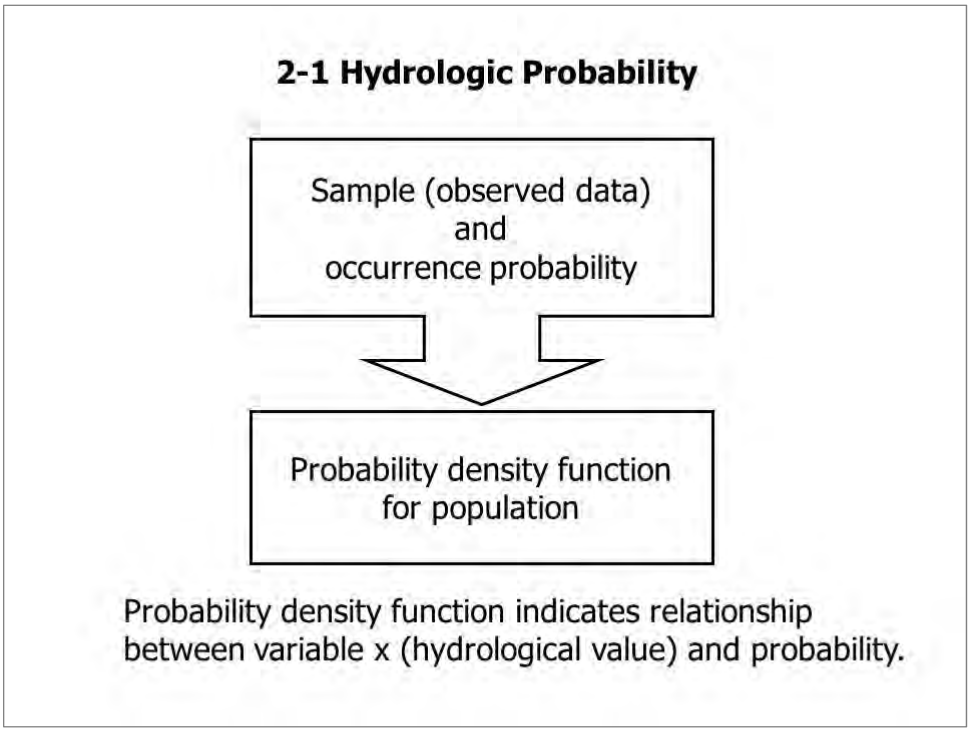


This chapter describes the statistical methods for the relationship between various hydrological quantities and frequency of their occurrence which are often examined for planning river works and so on.

Hydrological phenomena are primarily considered to be natural phenomena and will occur in conformity with the physical laws of nature, but for understanding the characteristics of these phenomena, it is often required to have analyses utilizing statistical laws in addition to physical laws. In this case, the statistical laws are of course considered to be closely related to the physical laws already known. Therefore overall knowledge of the physical characteristics of hydrological phenomena will also be required when making a statistical analysis.

Data of rainfall, water level, flow discharge, etc. which is acquired by observation is a part of infinite data. Observed data is called “sample” and infinite data is called “population”





Occurrence probability of rainfall, flow discharge, etc. is based on probability density function.

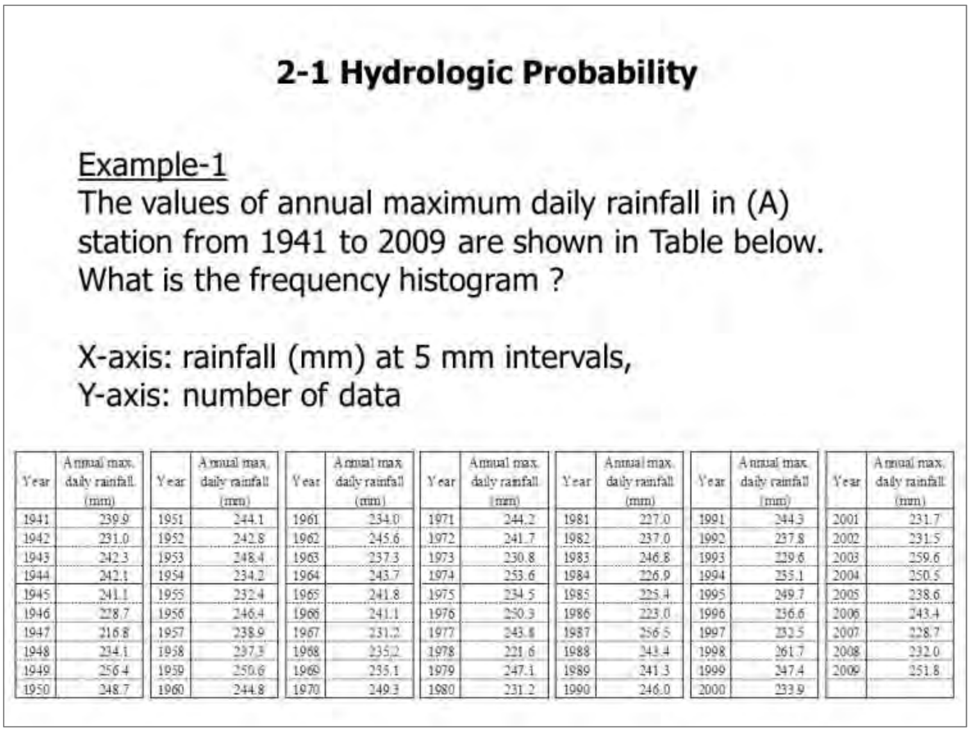
A random variable X is a variable described by a probability distribution. The distribution specifies the chance that an observation x of the variable will fall in a specified range of X. For example, if X is annual precipitation at a specified location, then the probability distribution of X specifies the chance that the observed annual precipitation in a given year will lie in a defined range, such as less than 1400 mm, or 1400-1600 mm, etc.

A set of observation x_1, x_2, …, x_n of the random variable is called a "sample". It is assumed that samples are drawn from a hypothetical infinite population possessing constant statistical properties, while the properties of a sample may vary from one sample to another. The set of all possible samples that could be drawn from the population is called the sample space, and an event is a subset of the sample space.

[Exercise]

There are annual maximum daily rainfall data for 69 years from 1941 to 2009 as shown in the table. Make a frequency histogram based on these data.

X-axis of the graph indicates rainfall (mm) at 5 mm intervals and Y-axis indicates number of data.



2-1 Hydrologic Probability

Example-1

The values of annual maximum daily rainfall in (A) station from 1941 to 2009 are shown in Table below. What is the frequency histogram ?

X-axis: rainfall (mm) at 5 mm intervals,
Y-axis: number of data

Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)
1941	239.9	1951	244.1	1961	234.0	1971	244.2	1981	227.0	1991	244.3	2001	231.7
1942	231.0	1952	242.8	1962	245.6	1972	241.7	1982	237.0	1992	237.8	2002	231.5
1943	242.3	1953	248.4	1963	237.3	1973	230.8	1983	246.8	1993	229.6	2003	259.6
1944	242.1	1954	234.2	1964	243.7	1974	253.6	1984	226.9	1994	255.1	2004	250.5
1945	241.1	1955	232.4	1965	241.8	1975	234.5	1985	225.4	1995	249.7	2005	238.6
1946	228.7	1956	246.4	1966	241.1	1976	250.3	1986	223.0	1996	236.6	2006	243.4
1947	216.8	1957	238.9	1967	231.2	1977	243.8	1987	256.5	1997	232.5	2007	228.7
1948	234.1	1958	237.3	1968	235.2	1978	221.6	1988	243.4	1998	261.7	2008	232.0
1949	256.4	1959	250.6	1969	235.1	1979	247.1	1989	241.3	1999	247.4	2009	251.8
1950	248.7	1960	244.8	1970	249.3	1980	231.2	1990	246.0	2000	233.9		

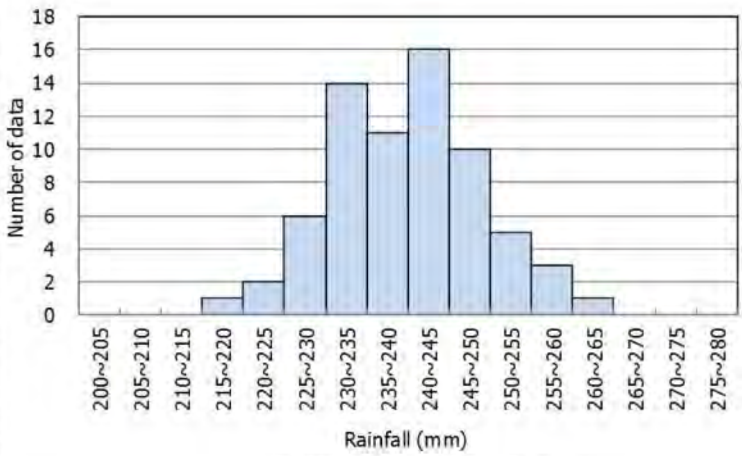
[Answer]

1) Make a left table, which shows number of data at 5 mm rainfall amount intervals as shown in the table.
2) Based on the above table, make a histogram as shown in the figure.

2-1 Hydrologic Probability

Answer-1

Rainfal (mm)	Number of data
200~205	0
205~210	0
210~215	0
215~220	1
220~225	2
225~230	6
230~235	14
235~240	11
240~245	16
245~250	10
250~255	5
255~260	3
260~265	1
265~270	0
270~275	0
275~280	0
Total	69



Frequency histogram

[Exercise]

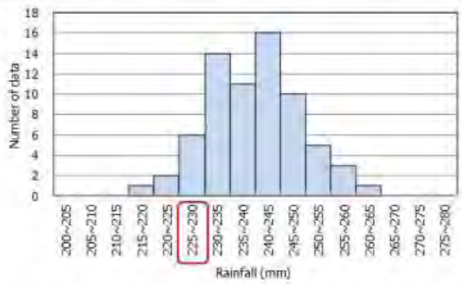
What is the probability that rainfall between 225~230 mm occur?

[Answer]

P = Number of data for 225~230 mm / total number of data = 6/69 = 0.087 => 9 %

2-1 Hydrologic Probability

Rainfal (mm)	Number of data
200~205	0
205~210	0
210~215	0
215~220	1
220~225	2
225~230	6
230~235	14
235~240	11
240~245	16
245~250	10
250~255	5
255~260	3
260~265	1
265~270	0
270~275	0
275~280	0
Total	69

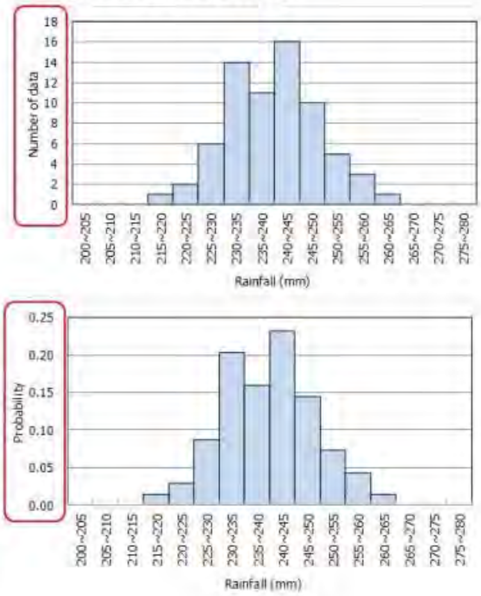


Q. What is the probability that rainfall between 225~230 mm occur ?

P = (number of data)/(total number of data)
= 6 / 69
= 0.087 => 9 %

2-1 Hydrologic Probability

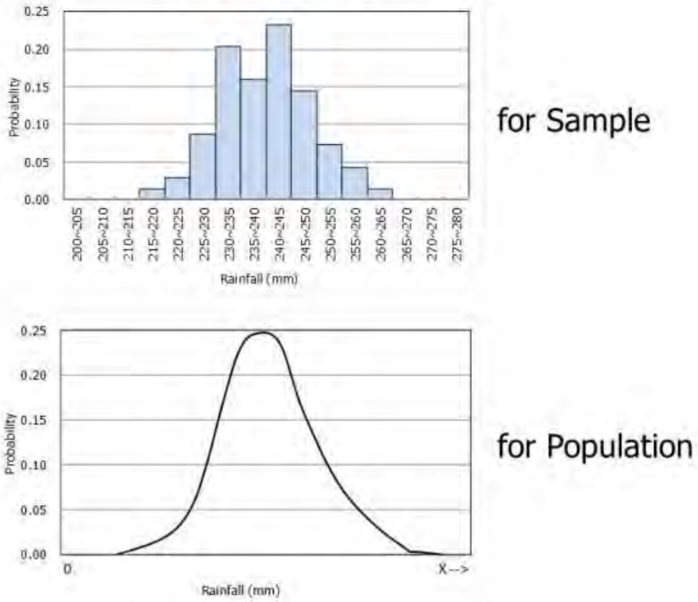
Rainfall (mm)	Number of data	Probability
200~205	0	0.0000
205~210	0	0.0000
210~215	0	0.0000
215~220	1	0.0145
220~225	2	0.0290
225~230	6	0.0870
230~235	14	0.2029
235~240	11	0.1594
240~245	16	0.2319
245~250	10	0.1449
250~255	5	0.0725
255~260	3	0.0435
260~265	1	0.0145
265~270	0	0.0000
270~275	0	0.0000
275~280	0	0.0000
Total	69	1

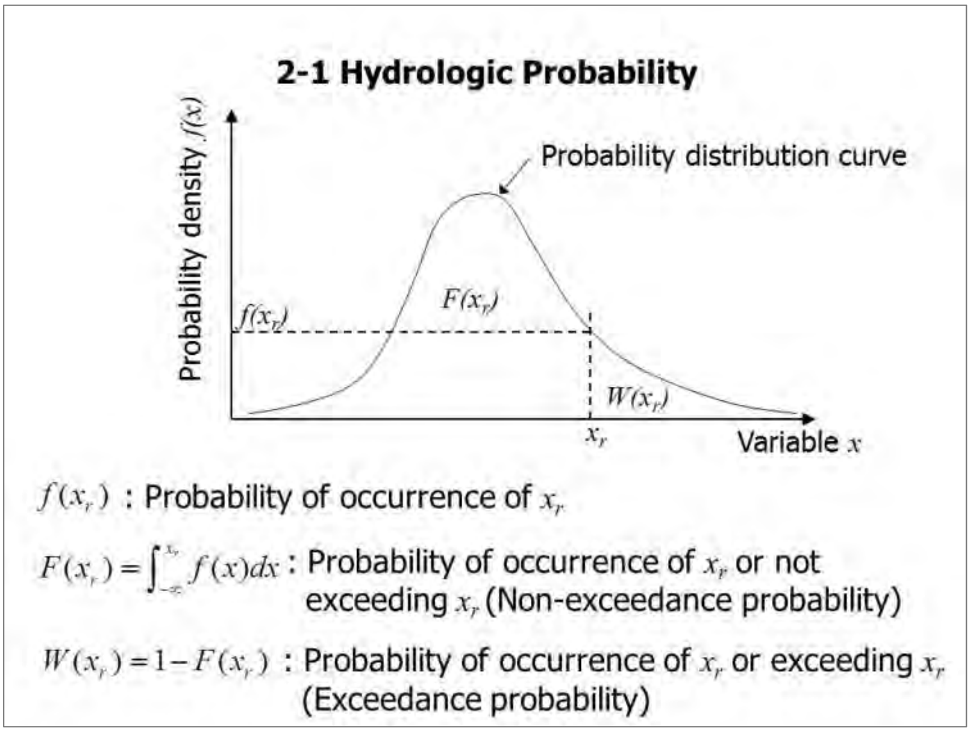


Number of other rainfall ranges is converted into probabilities. And then histogram with Y-axis with probability is figured.

This histogram is made using finite data, "sample". If using infinite data, "population", probability for variables (x) is shown as the next figure (below).

2-1 Hydrologic Probability





Hydrological values, i.e. rainfall, flow discharge, etc. tend to fit into non-symmetrically shaped probability distribution functions i.e. Gumbel distribution, lognormal distribution, Pearson type-III distribution, etc. better than symmetrically shaped normal distribution.

In above figure, f(xr) indicates probability of occurrence of certain value (xr). F(xr) is probability of occurrence of (xr) or not exceeding (xr), which is called non-exceedance probability. W(xr) is equal to 1- F(xr) and probability of occurrence of (xr) or exceeding (xr), which is called exceedance probability.

2-1 Hydrologic Probability

Exceedance probability				Return period
0.1 (10%)	=	1/10	=	10-year
0.05 (5%)	=	1/20	=	20-year
0.02 (2%)	=	1/50	=	50-year
0.01 (1%)	=	1/100	=	100-year

Return period (T) is expressed as 1/ F(xr) or 1/ W(xr). This equation means that the occurrence of a hydrological quantity equal to or larger than (xr) is expected at a rate of once in T years on average, or the occurrence of a hydrological quantity equal to or smaller than (xr) is expected at a rate of once in T years.

2-2 Estimation of Probability

2-2 Estimation of Probability

Hydrological probability is estimated by following two methods.

- Graphical method
  > Weibull plot
  > Hazen plot

- Probability distribution function formula
  > Lognormal distribution
  > Log-Pearson Type III distribution
  > Extreme value distribution (Gumbel distribution)

2-2 Estimation of Probability

Example-2

The values of annual maximum daily rainfall in YY station from 1991 to 2010 are shown in Table below.
Estimate probable rainfall for 10-year, 50-year, 100-year by graphical method.

Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)
1991	172	2001	55
1992	78	2002	140
1993	60	2003	97
1994	131	2004	220
1995	104	2005	153
1996	85	2006	90
1997	110	2007	160
1998	80	2008	118
1999	205	2009	180
2000	48	2010	68

2-2 Estimation of Probability

Answer-2

Step-1: Arrange the values in descending order.

Step-2: Estimate the exceedance probability of xj following equation.

Weibull plot $P(xj) = \frac{j}{N+1}$

Hazen plot $P(xj) = \frac{2j-1}{2N}$

Where,

P(xj): exceedance probability of xj,

j : the rank of a value in descending order, and

N : the total number of values.

2-2 Estimation of Probability

Step-3: Plot each probability of variable, x on the probability paper.

The cumulative probability of a theoretical distribution may be represented graphically on probability paper designed for the distribution. On such paper the ordinate usually represents the value of x in a certain scale and the abscissa represents the probability $P(X >= x)$ or $P(X < x)$, the return period T, or the reduced variety T. The ordinate and abscissa scales are so designed that the data to be fitted are expected to appear close to a straight line. The purpose of using the probability paper is to linearize the probability relationship so that the plotted data can be easily used for interpolation, extrapolation, or comparison purposes. In the case of extrapolation, however, the effect of various errors is often magnified; therefore, hydrologists should be warned against such practice if no consideration is given to this effect.

2-2 Estimation of Probability

Probability distribution function formula

> Extreme value distribution (Gumbel distribution)

Basic formula for distribution

$P(x) = 1 - \exp(-e^{-y})$

$y = a\,(x - x_0)$ *or* $x = x_0 + 1/a\ y$

where,

x: probable hydrological value (annual max. value),

y: standard extreme variable transformation of x, and

x_0, a: constants.

2-2 Estimation of Probability

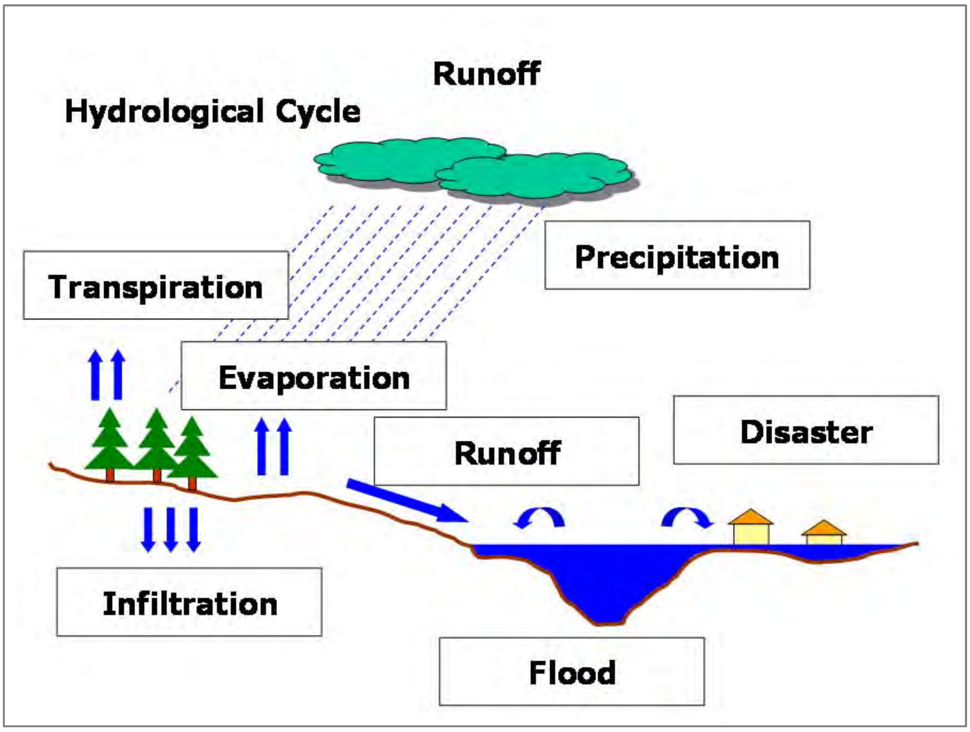
Example-3

The values of annual maximum daily rainfall in YY station from 1941 to 2009 are shown in Table below.
Estimate probable rainfall for 10-year, 50-year, 100-year by probability distribution function formula (Gumbell).

Year	Annual max. daily rainfall (mm)	Year	Annual max. daily rainfall (mm)
1991	172	2001	55
1992	78	2002	140
1993	60	2003	97
1994	131	2004	220
1995	104	2005	153
1996	85	2006	90
1997	110	2007	160
1998	80	2008	118
1999	205	2009	180
2000	48	2010	68

3. Runoff

3-1 Runoff



It indicates hydrological cycle on the earth. Precipitation occurs. Precipitation is water dropping from the sky. It's sometimes rainfall and sometimes snow. Rainfall drops on the ground, leaf, roof, etc. Some water flow on the surface, drain into ditch or channel and into river, then finally into the sea. And some water infiltrates into the ground and become ground water. Ground water drains into the river taking so long period. Some water doesn't flow to the river; go back to the air by evaporation or transpiration. The water in the sea or lake goes back to the air, and it becomes cloud and drops on the ground as rainfall again. It is called hydrological cycle.

The hydrologic cycle is the central focus of hydrology. The cycle has no beginning or end, and its many processes occur continuously. As shown schematically in the figure, water evaporates from the oceans and the land surface to become part of the atmosphere; water vapor is transported and lifted in the atmosphere until it condenses and precipitates on the land or the oceans; precipitated water may be intercepted by vegetation, become overland flow over the ground surface, infiltrate into the ground, flow through the soil as subsurface flow, and discharge into streams as surface runoff. Much of the intercepted water and surface runoff returns to the atmosphere through evaporation. The infiltrated water may percolate deeper to recharge groundwater, later emerging in springs or seeping into streams to form surface runoff, and finally flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continues.

Runoff

Run-off analysis:
to predict the volume of runoff of river from rainfall.

Runoff calculations are the techniques for calculating the volume of runoff of rivers from rainfall. It is common knowledge that the discharge of rivers generally increases whenever rain falls in the watershed but it is not easy to determine the volume of the runoff (Q) of a river due to rainfall (R).

Runoff

It is not easy to determine the volume of the runoff of the river from rainfall.

Because

- The measured rainfall is usually for a certain point only.

=> Areal average rainfall (ex. Thiessen method)

- Rainwater fallen on a watershed reaches a river through various courses, and part of rainwater is stored, infiltrate into underground, evaporate into the air.

=> Runoff model appropriate to the purpose

When calculating the volume of runoff from certain rainfall, it is required to know the amount of rainfall which has fallen in the river basin. Specific problems involved in this are as follows:

“ The measured rainfall is usually for a certain point only. ”

⇨ Areal average rainfall calculated based on measured rainfall is used for calculation.

“ Rainfall fallen on a watershed reaches a river through various courses, and part of rainwater is stored underground or evaporated on the way so it is not easy to know the phenomena accurately. ”

⇨ Appropriate runoff model is selected in accordance with the purpose of calculation and runoff characteristics.

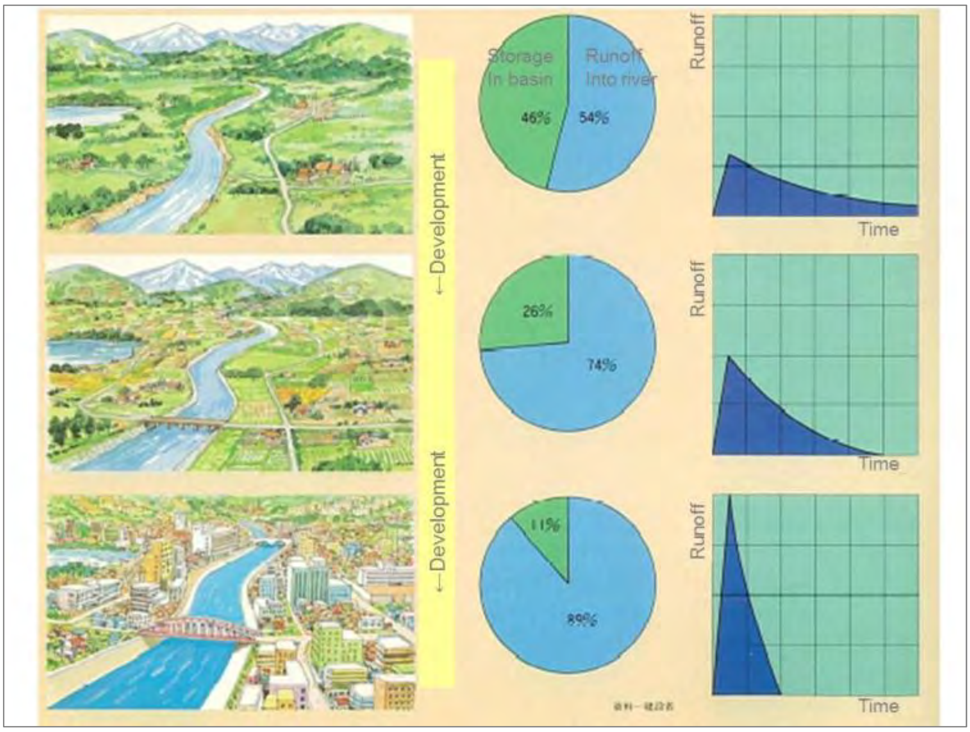
Runoff

Points to remember for runoff analysis

1. Rainfall depth must represent the watershed.
2. If any watershed conditions change, a detailed survey should be made into the relationship between the rainfall and runoff.

Rainfall depth must represent the watershed. Therefore, areal average rainfall calculated by “Arithmetic Mean Method”, “Isohyetal Method” or “Thiessen Method” is adopted.

If any conditions of watershed change, a detailed survey should be made into the relationship between the rainfall and runoff. Before development of watershed, most of the rainfall infiltrate into underground or is stored in paddy field or irrigation pond for example. After development of basin, surface runoff water flowing to lower land become bigger and flood damage becomes severer, because of covering of ground surface with concrete or asphalt, deforestation, or reclamation of irrigation pond. As the basin is developed more, storage volume in basin become less and volume of runoff into the river become more; moreover duration of runoff become shorter and peak runoff becomes greater.



Runoff

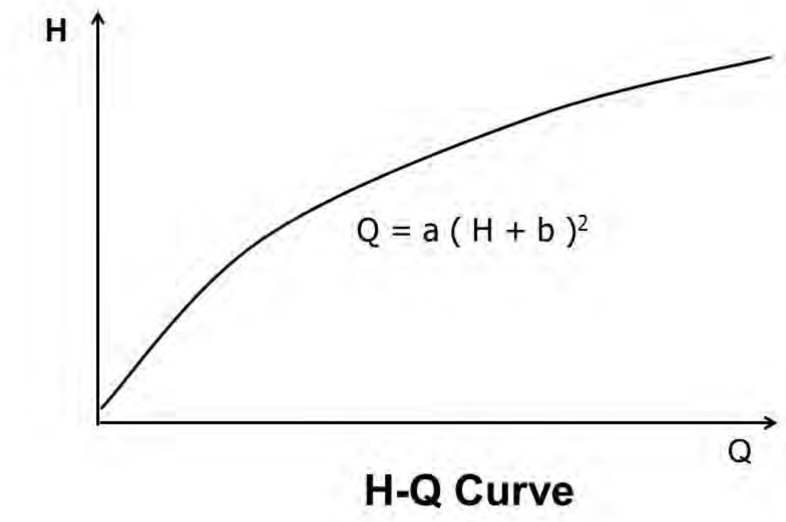
Points to remember for runoff analysis

1. Rainfall depth must represent the watershed.

2. If any watershed conditions change, a detailed survey should be made into the relationship between the rainfall and runoff.

3. Discharge can be obtain from the observed water level based on the relationship between water level and discharge (H-Q curve). If the river condition is changed due to river improvement, riverbed fluctuation, etc., the relationship should be revised.

Discharge can be obtained from the observed water level based on the relationship between water level and discharge, which is called H-Q curve. If the river condition is changed due to river improvement, riverbed fluctuation, etc., the relationship should be revised.



Runoff

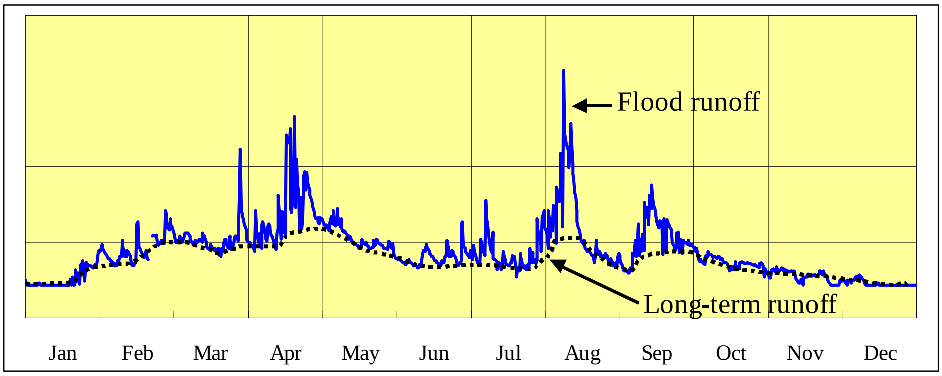
Points to remember for runoff analysis

1. Rainfall depth must represent the watershed.
2. If any watershed conditions change, a detailed survey should be made into the relationship between the rainfall and runoff.
3. Discharge can be obtain from the observed water level based on the relationship between water level and discharge (H-Q curve). If the river condition is changed due to river improvement, riverbed fluctuation, etc., the relationship should be revised.
4. Validity of runoff model should be verified using past rainfall and discharge data causing flood.

Validity of runoff model should be verified using measured rainfall and discharge data during past floods.

Runoff

Long-term runoff :
Mainly for studies of water resources development projects
Short-term runoff (flood runoff) :
Mainly for studies of disaster prevention projects

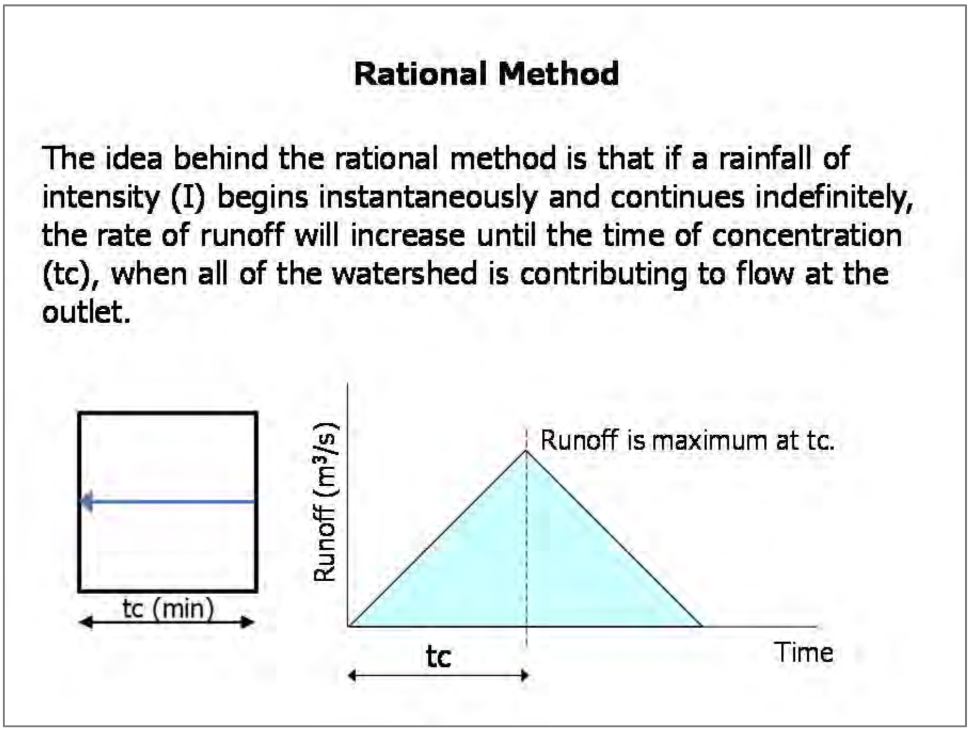


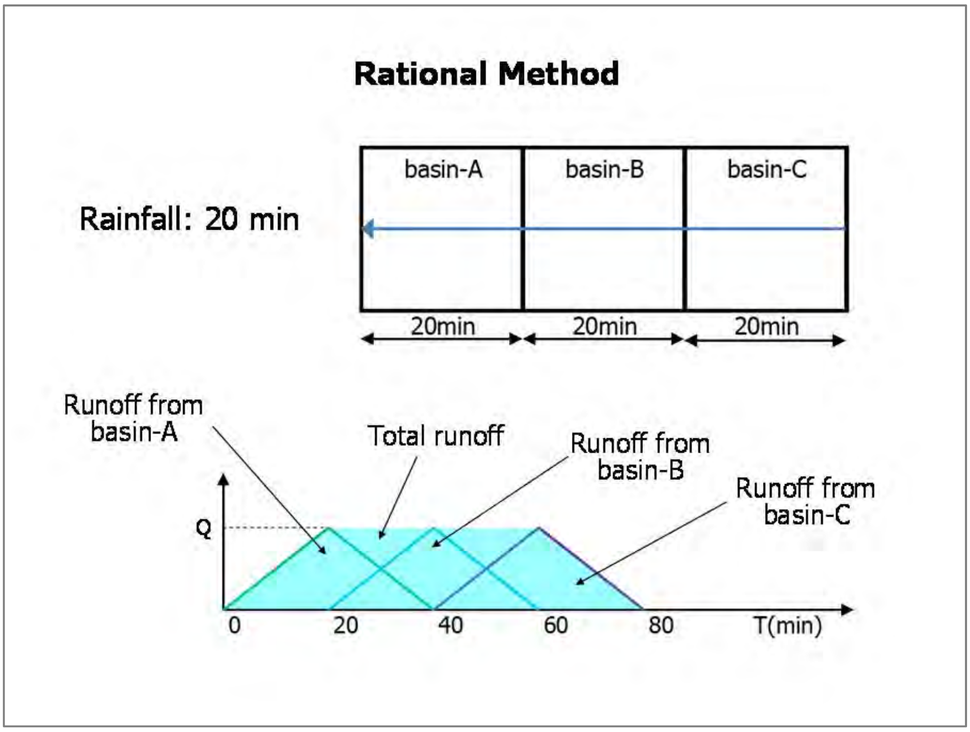
Runoff can be classified two types, i.e. long-term runoff and flood runoff. Dotted black line in the figure shows long-term runoff and blue solid line shows flood runoff.

Long-term runoff consists of groundwater runoff and is used mainly for studies of water resources development projects. On the other hand, flood runoff caused by rainfall is used mainly for studies of flood control projects.

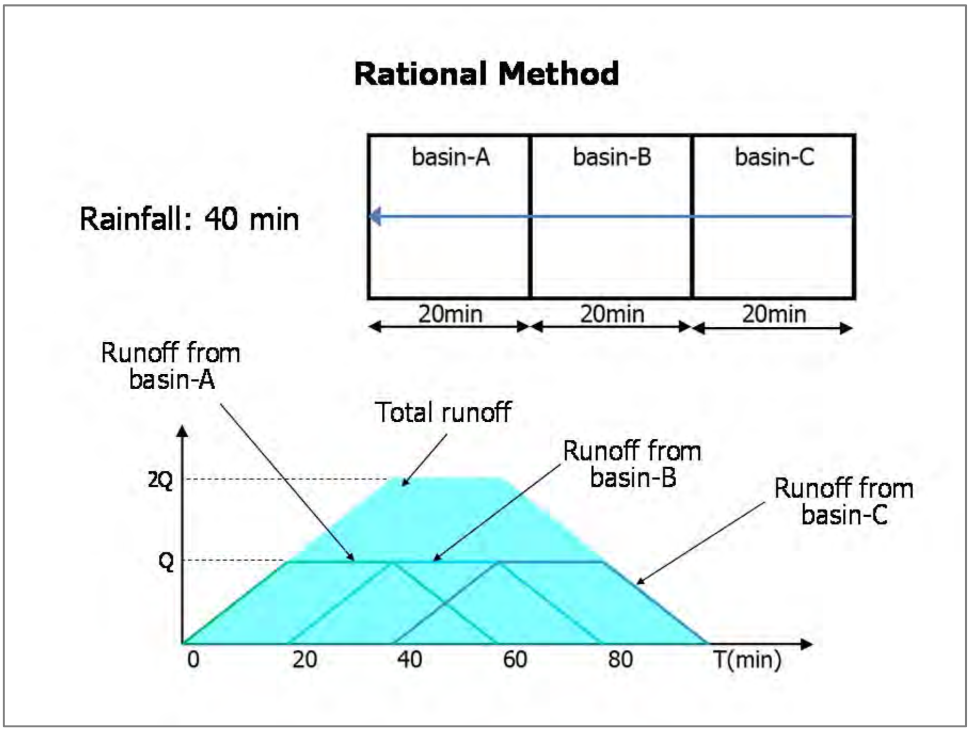
3-2 Rational Method

The rational method is a convenient method for estimating the peak discharge of a flood. It is widely utilized in rivers for that there is no need to consider the storage phenomena. Various formulas for estimating the maximum volume of flood have been generally treated as a function of the catchment area. The maximum discharge is not a function of only the catchment area, and so the run-off calculation methods must take account of other various elements such as intensity of rainfall, vegetation in the catchment, and gradient. Moreover, it is desirable for the planning purpose to include the flood frequency in the elements if possible. One simple run-off calculation method which has overcome various difficulties in the performance of calculations is the rational formula. This method considers the shape of a catchment as a rectangle which is symmetrical about the river course, and considers that the rainwater flows down the slope of the catchment at a constant speed to flow into the river course. The time required until the rain falling at the furthermost point reaches the exit of watercourse is called the flood concentration time. The volume of run-off is calculated by the rainfall intensity within the time multiplied by the run-off coefficient which expresses the physical state of the catchment.

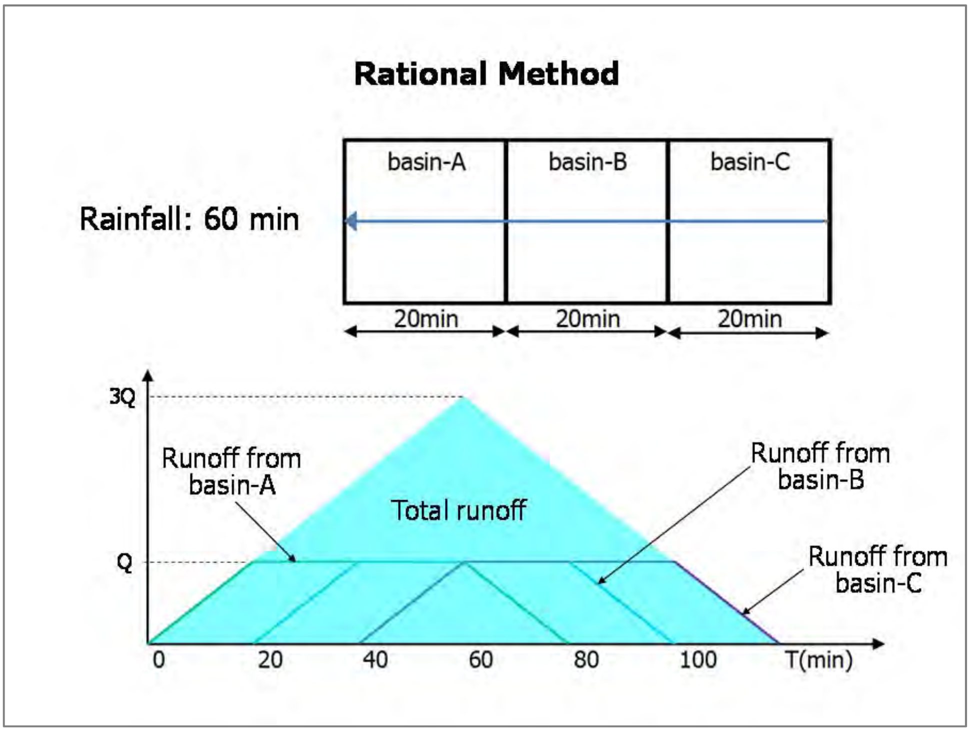




If rainfall continues for 20 minutes in the basin, which consists of basin-A, B and C shown in the upper figurer, firstly runoff from basin-A appears at the outlet and after 20 minutes runoff from basin-B appears and after 20 minutes runoff from basin-C appears.
Hydrograph at outlet is shown in the lower figure.



If rainfall continues for 40 minutes, runoff at the outlet is shown in the figure.



If rainfall continues for 60 minutes, runoff at the outlet is shown in the figure.

Rational Method

Rational Method

$$Q = 1/3.6 * frA$$

where,

Qp : Peak runoff (m^3/s)
A : Basin area (km^2)
r : Average rainfall intensity (mm/hr) during the time of concentration
f : Runoff coefficient

Since the rational formula was formulated based on the assumptions stated below, this formula should be applied to the catchments having the runoff characteristics as close as possible to these assumptions.

The runoff Q due to a rainfall with an intensity R becomes the greatest when said rainfall continues longer than its time of flood concentration.

Maximum value of runoff Qp due to a rainfall with an intensity R having a duration of rainfall equal to or longer than the time of flood concentration, has a linear relation with the rainfall intensity R.

Occurrence probability of peak runoff is equal to the occurrence probability of the rainfall intensity for a given time of flood concentration.

The runoff coefficient is the same for all the rainfalls regardless of their value of probability.

The runoff coefficient is the same for all the rainfalls falling in a given catchment.

According to the results of investigations and field experiments which have been so far carried out, the urbanized catchments where the rainfall is little infiltrated or stored in depressions tend to have the runoff characteristics relatively close to the preconditions stated above. Generally, the storage effect becomes more remarkable when the catchment area increases, by which the assumption of linearity of the catchments, to which the rational formula is applied, is smaller than 100 km2 in many cases.

Rational Method

Runoff coefficient (f)

The runoff coefficient is the most difficult element to determine when applying the rational formula. Various values have been proposed for the runoff coefficient.

1) Runoff coefficient of rivers in Japan

Steep mountainous region	0.75 – 0.90
Mountains of Tertiary strata	0.70 – 0.80
Rugged land and forests	0.50 – 0.75
Flat arable land	0.45 – 0.60
Irrigated paddy fields	0.70 – 0.80
Rivers in mountainous regions	0.75 – 0.85
Small rivers in level land	0.45 – 0.75
Large rivers with over half of the catchment in flat land	0.50 – 0.75

Rational Method

2) Runoff coefficient as a standard for sewage facilities

Commercial zone	0.7 – 0.9
Industrial zone	0.4 – 0.6
Residential zone	0.3 – 0.5
Park areas	0.1 – 0.2

Rational Method

3) Runoff coefficient in a standard for small scale sewerage facilities

3-1) Standard Values of Basic Runoff Coefficients Classified by Type of Works

Roof	0.90
Roads	0.85
Other impermeable surface	0.80
Water surfaces	1.00
Vacant lots	0.20
Parks with much grass and many trees	0.21
Mountainous regions with gentle slopes	0.30
Mountainous regions with steep slopes	0.50

Rational Method

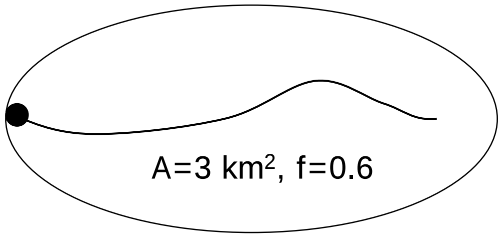
3-2) Standard Values of Overall Runoff Coefficients Classified by Land Use

Regions having very few vacant lots or similar residential areas	0.80
Industrial zone having several vacant lots such as outdoor working areas on infiltration surfaces and housing lots with small gardens	0.65
Residential quarters with intermediate-rise apartment buildings such as those built by the Japan Housing Corporation, or single-family residences	0.50
High-class residential areas having many trees, and areas with many farms	0.35

Rational Method

Example-1

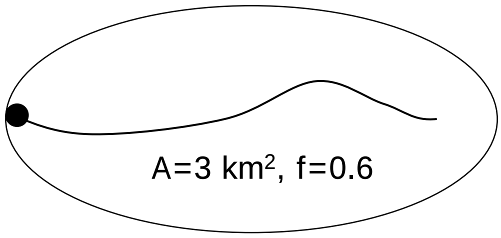
Estimate peak runoff discharge of the following basin when rainfall intensity of 20mm/hr occurred for 2hr. This basin has a catchment area of 3 km^2, runoff coefficient of 0.6, and concentration time of 40 minutes.



Rational Method

Answer-1

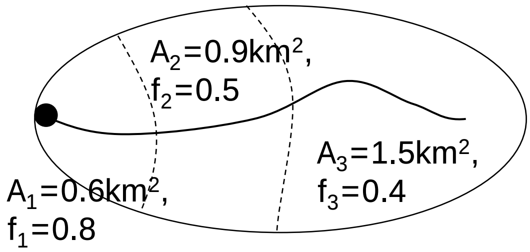
Q = 1/3.6 x frA
 = 1/3.6 x 0.6 x 20 x 3
 = 10 m^3/s



Rational Method

Example-2

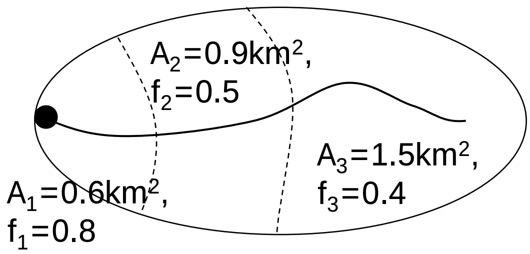
Estimate peak runoff discharge of the following basin when rainfall intensity of 20mm/hr occurred for 2hr. This basin has a catchment area of 3 km^2, runoff coefficient of 0.4, 0.5 and 0.8, and concentration time of 40 minutes.



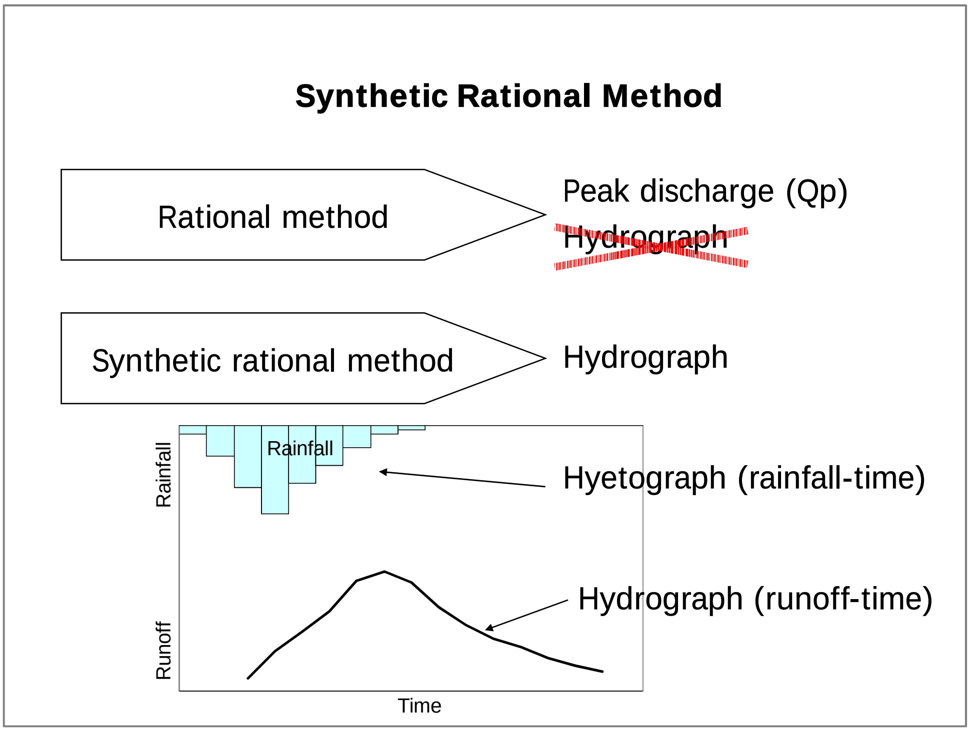
Rational Method

Answer-2

$Q = 1/3.6 \times r \times \Sigma f_i a_i$
$= 1/3.6 \times 20 \times (0.8 \times 0.6 + 0.5 \times 0.9 + 0.4 \times 1.5)$
$= 8.5\ m^3/s$



3-3 Synthetic Rational Method



Rational method can provide just peak discharge.   But discharge hydrograph is needed for a study/project with flow regulation.   Synthetic Rational Method is one of runoff analysis method, which can give hydrograph.

Synthetic Rational Method is:

to make hyetograph for each flood concentration time (tc),
to calculate peak discharges for each tc,
to combine these peak discharges and make a hydrograph.

Synthetic Rational Method

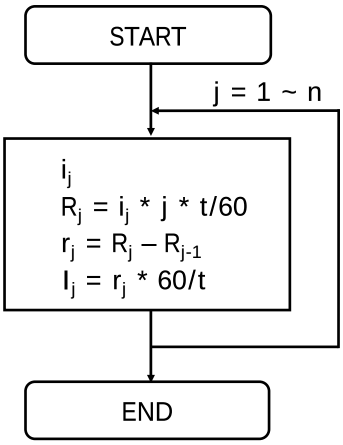
Hydrograph can be obtained by synthetic rational method as follows.

(1) Model hyetograph
- to calculate rainfall intensity ($I_1 \sim I_n$) for each flood concentration time
- to arrange these rainfall intensities on a graph => model hyetograph

(2) Model hydrograph
- to calculate discharge for each I_j using rational method
- to make model hydrograph connecting neighboring peak discharges on the graph

Synthetic Rational Method

(1) Model hyetograph
- Calculate rainfall intensity for each flood concentration time according to the following procedure.



t: flood concentration time (min)
n: number of I
j: number
i: mean rainfall intensity for duration of rainfall, jt (mm/hr)
R: accumulated rainfall (mm)
r: rainfall for each flood concentration time (mm)
I: rainfall intensity for each flood concentration time (mm/hr)

[Step 1] j = 1

T = j * t = 1 * t = t

i1 for t is obtained from rainfall intensity – duration curve

R1 = i1 * j * t/60 = i1 * t/60

r1 = R1 – 0 = R1

I1 = r1 * 60/t

[Step 2] j = 2

T = j * t = 2 * t = 2t

i2 for t is obtained from rainfall intensity – duration curve

R2 = i2 * j * t/60 = i2 * 2t/60

r2 = R2 – R1

I2 = r2 * 60/t

[Step 3] j = 3

T = j * t = 3 * t = 3t

i3 for t is obtained from rainfall intensity – duration curve

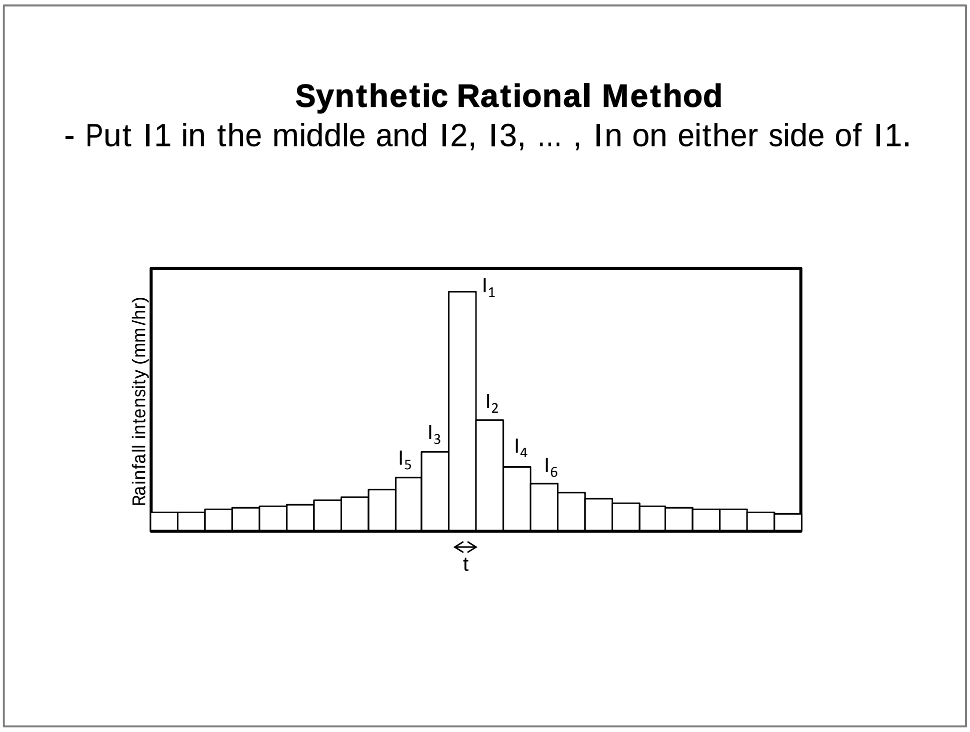
R3 = i3 * j * t/60 = i3 * 2t/60

r3 = R3 – R2

I3 = r3 * 60/t

(Repeat from Step 1 to Step n)

Rainfall intensities for j = 1 to n, which are obtained in the way described above, are divided into right and left putting I1 in the middle.



Peak discharge (Qj) for each Ij is calculated by Rational Formula.

Qj = 1/3.6 * f * A * Ij (m3/sec)

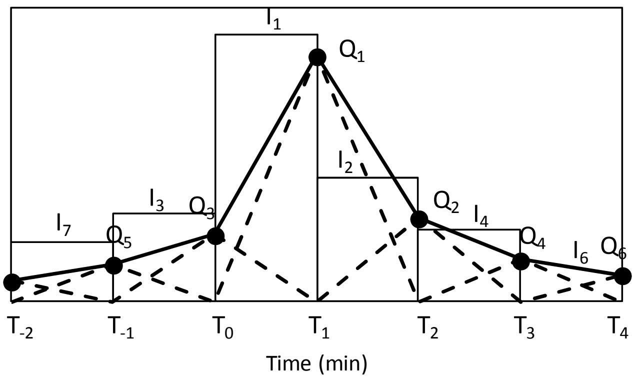
j = 1~n

Hydrograph is prepared by composing Qj as shown below.

Synthetic Rational Method

(2) Model hydrograph

- Calculate the discharge for each I by Rational formula.
- Synthesize each discharge to form hydrograph.



Synthetic Rational Method

Example-3

Make a hydrograph for following rainfall using synthetic rational formula.

- Rainfall intensity curve: Pilot site (Lampang or Lamphun)
- Time of flood concentration: 120 min.

3-4 Unit Hydrograph

Basic concept of the unit hydrograph method was proposed by Sherman in 1932. Main point of this method is discharge curve at a certain point of a river by the unit effective rainfall which had fallen in a unit time, has always the same form. The discharge curve obtained at that time is called the unit hydrograph.

The main problems with the application of this method is as follows: In the first place, the resulting unit hydrographs are often different between the major floods and medium or small floods, if the duration of rainfall is equal, the duration of hydrographs is also considered to be all the same. However, the time required until the surface run-off recesses to a certain discharge will vary depending upon the initial discharge. In other words, the relation between the rainfall and run-off will not be linear. These are the problems included in the preconditions of this method.

However, compared to other various methods, the unit hydrograph method has many advantages. At present, much research has been performed in many countries for this unit hydrograph method in which the run-off calculations are started after determining the unit hydrograph of the object river basin.

The unit hydrograph is a simple linear model that can be used to derive the hydrograph resulting from any amount of excess rainfall. The following basic assumptions are inherent in this model.

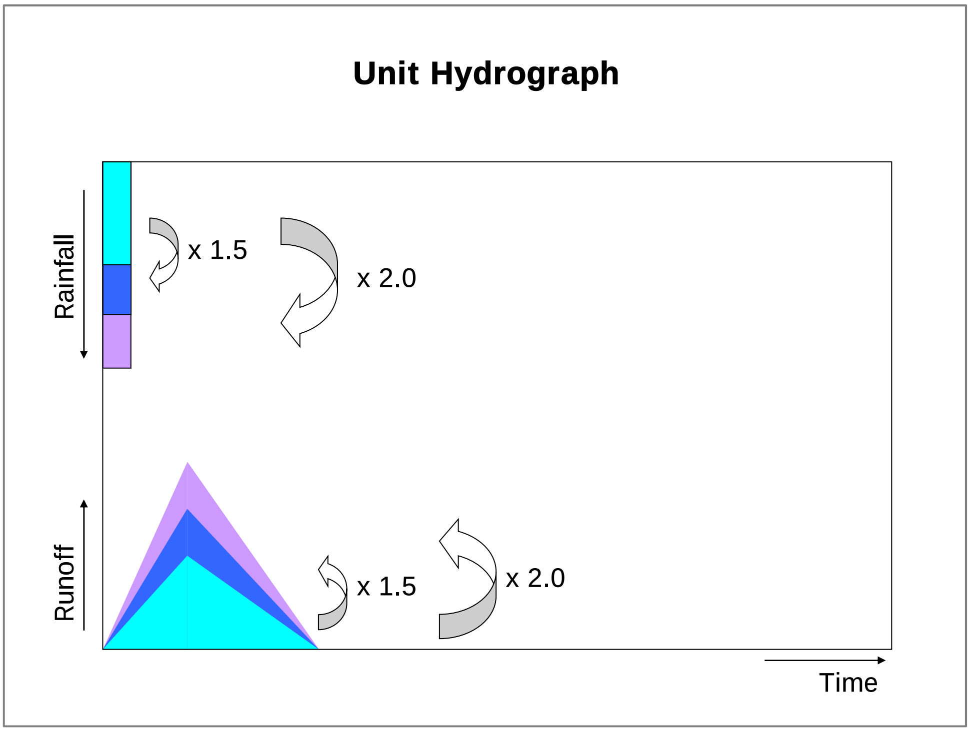
Unit Hydrograph

Fundamental assumptions of unit hydrograph method

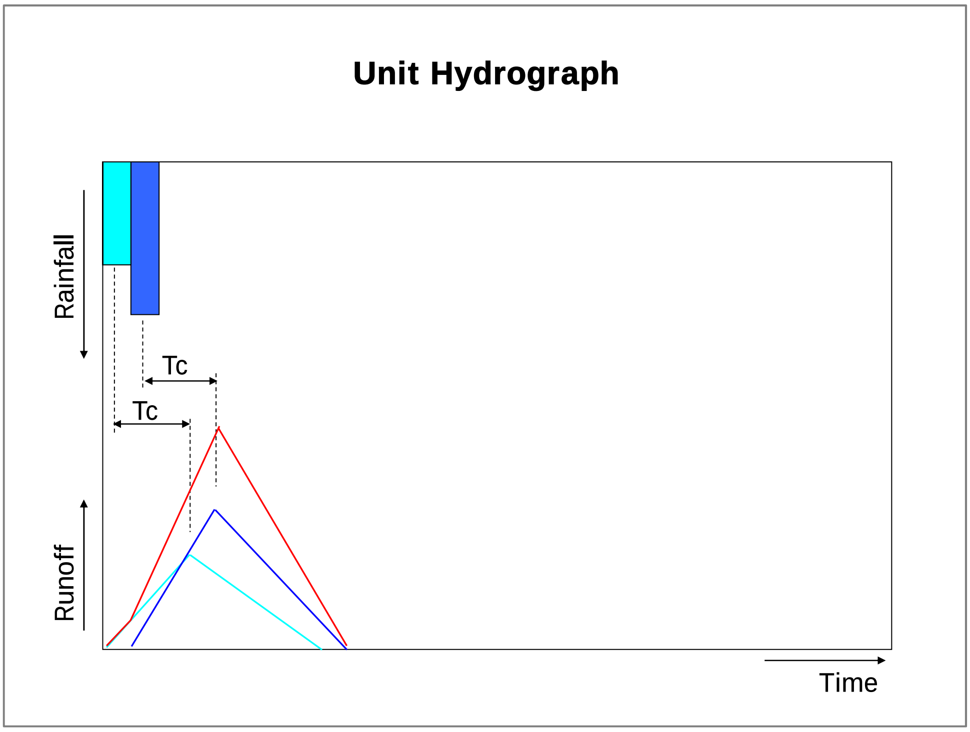
1) The excess rainfall which has a constant intensity within the effective duration, causes a constant runoff.

2) Volume of direct runoff is in direct proportion to the intensity of rainfall.

3) Volume of runoff is to be determined by adding together the runoff components of each rainfall.



It is assumed that runoff shown in below figure appears in accordance with unit rainfall per unit time shown in upper figure.
If rainfall becomes 1.5 times, runoff should be also 1.5 times.
And, if rainfall becomes 2.0 times, runoff should be also 2.0 times.

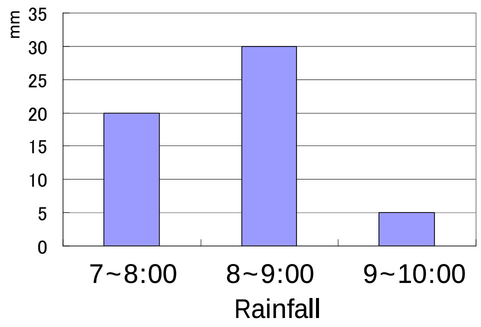


When there are two rainfalls per unit time continuously as shown in figure, the total runoff hydrograph is acquired by adding up two runoffs according with each rainfall.

Unit Hydrograph

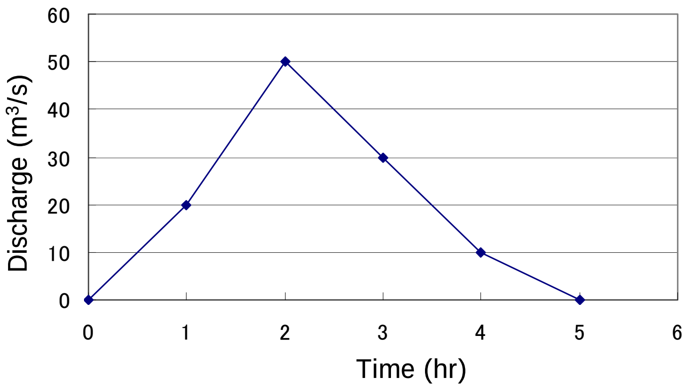
Example-4

Make a hydrograph for following rainfall using unit hydrograph shown in next figure.

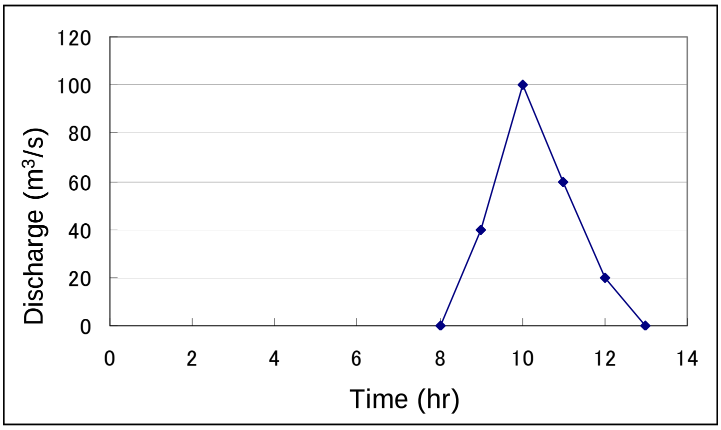


Unit Hydrograph

This unit graph shows discharge corresponding to rainfall of 10 mm for 1 hr.

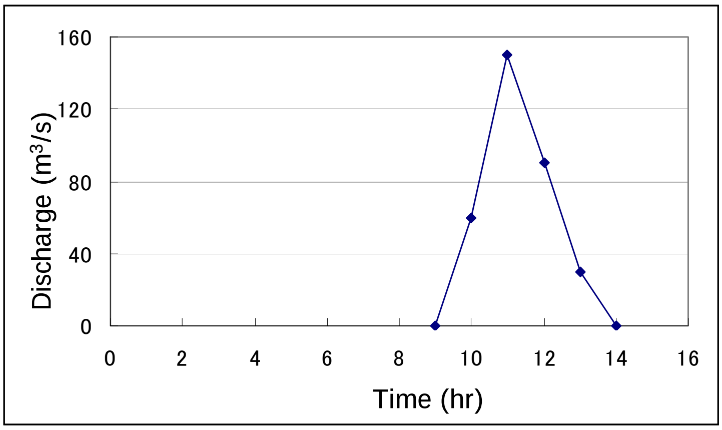


Unit Hydrograph



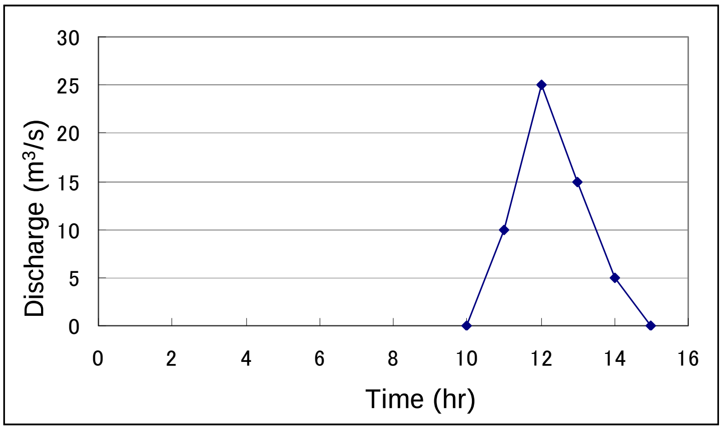
Discharge for 20 mm of rainfall from 7:00 to 8:00

Unit Hydrograph



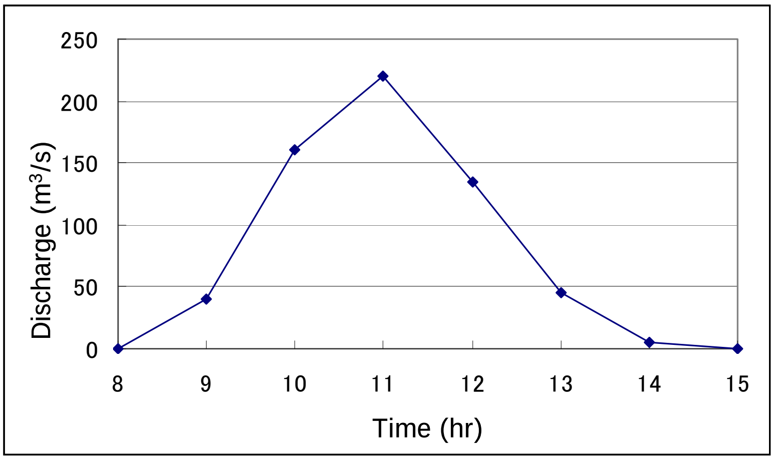
Discharge for 30 mm of rainfall from 8:00 to 9:00

Unit Hydrograph



Discharge for 5 mm of rainfall from 9:00 to 10:00

Unit Hydrograph

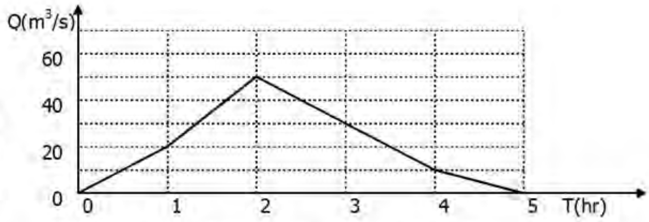


Unit Hydrograph

Example-1

Make a hydrograph for following rainfall using unit hydrograph.

Rainfall
10-11:00 15mm
11-12:00 30mm
12-13:00 35mm
13-14:00 20mm

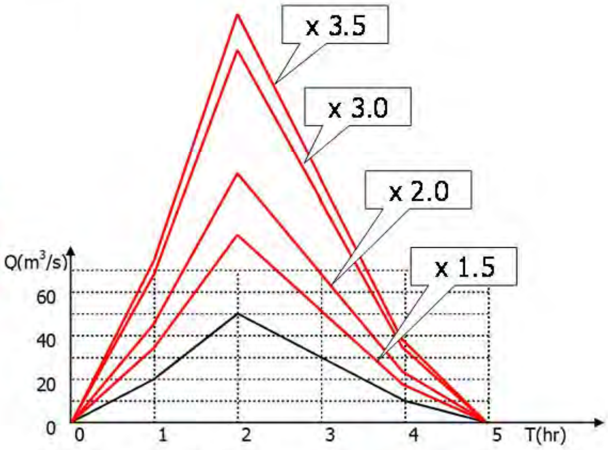


(*) This unit graph shows discharge corresponding to rainfall of 10 mm for 1 hr.

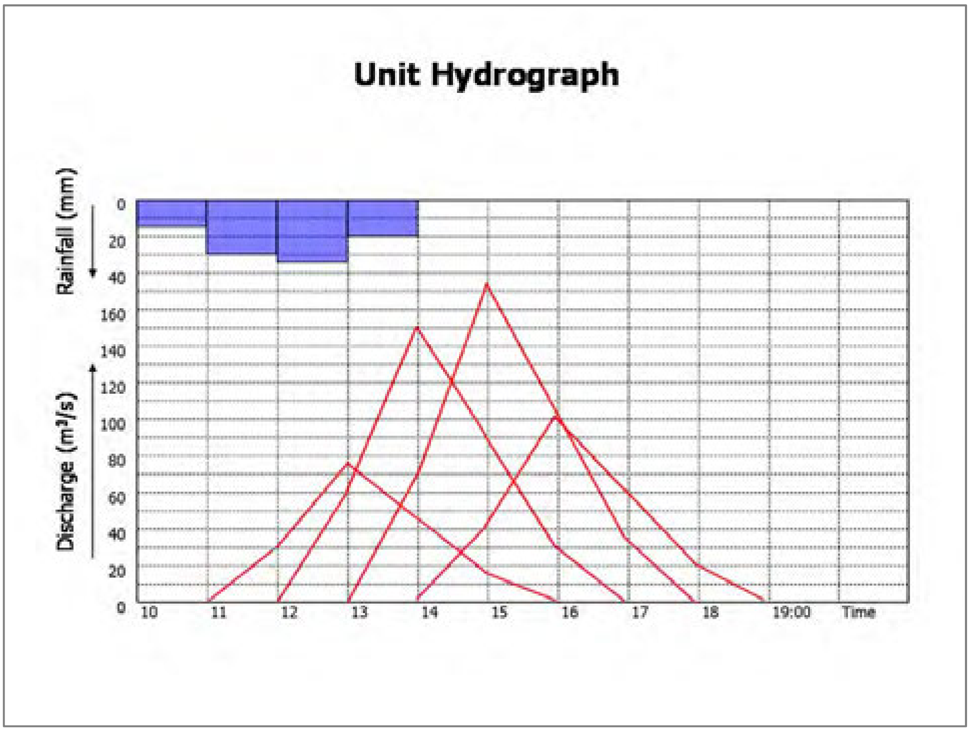
Unit Hydrograph

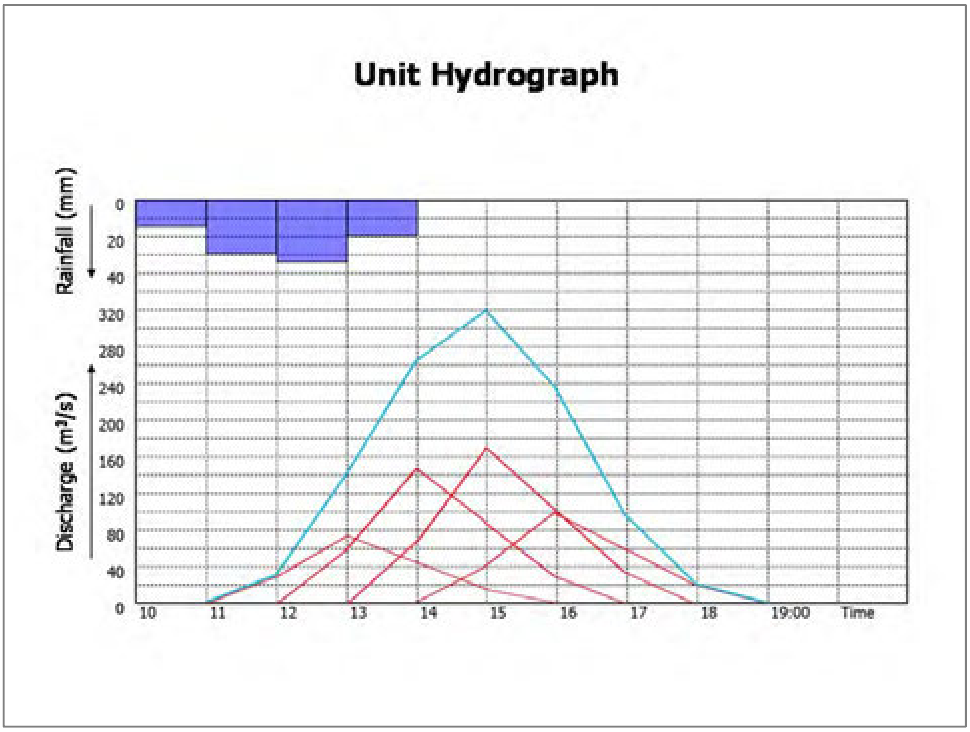
Answer-1

Rainfall
10-11:00 15mm=> x 1.5
11-12:00 30mm=> x 3.0
12-13:00 35mm=> x 3.5
13-14:00 20mm=> x 2.0

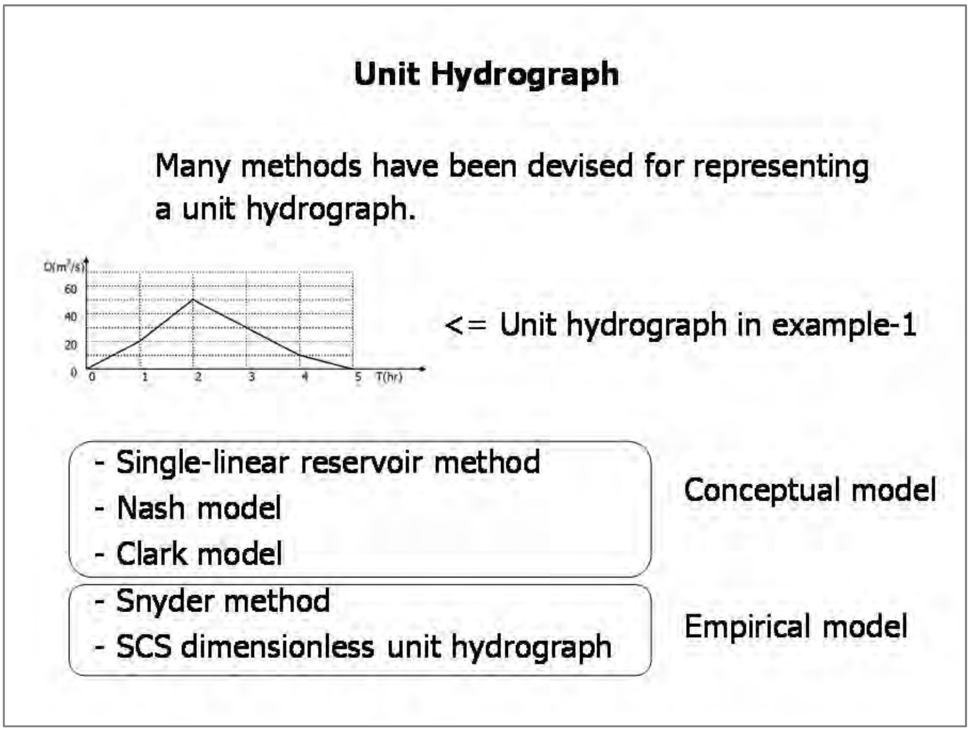


(*) This unit graph shows discharge corresponding to rainfall of 10 mm for 1 hr.


Unit Hydrograph
Rainfall (mm)
0
20
40
Discharge (m³/s)
160
140
120
100
80
60
40
20
0
10
11
12
13
14
15
16
17
18
19:00
Time


Unit Hydrograph
Rainfall (mm)
0
20
40
Discharge (m³/s)
320
280
240
200
160
120
80
40
0
10
11
12
13
14
15
16
17
18
19:00
Time

Various methods are proposed for unit hydrograph. There are single-linear reservoir method, Nash model, Clark mode, etc. as conceptual model and Snyder method, SCS dimensionless unit hydrograph as empirical model.

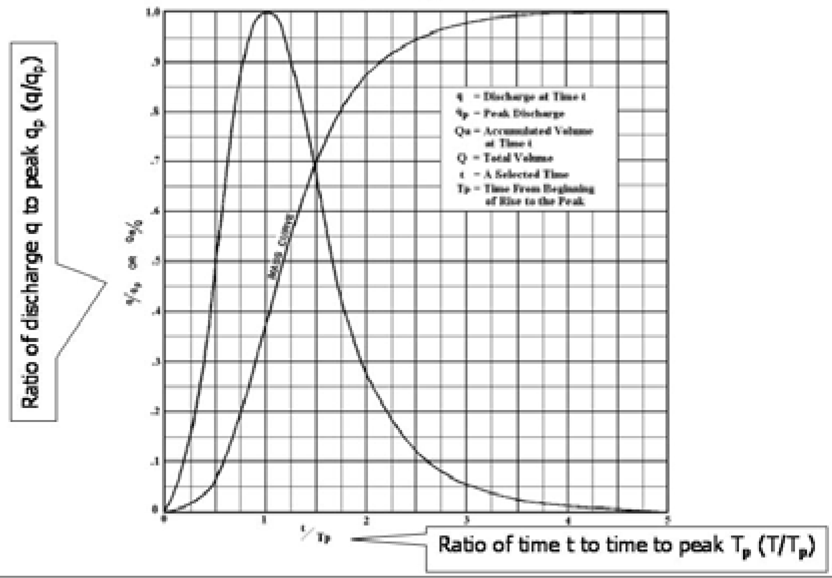


(1) SCS Dimensionless Hydrograph

The SCS dimensionless hydrograph is a synthetic unit hydrograph in which the discharge is expressed by the ratio of discharge q to peak discharge qp and the time by the ratio of time t to the time of rise of the unit hydrograph, Tp. Given the peak discharge and lag time for the duration of excess rainfall, the unit hydrograph can be estimated from the synthetic dimensionless hydrograph for the basin.

Unit Hydrograph

(1) SCS dimensionless unit hydrograph



Unit Hydrograph

SCS Dimensionless Hydrograph

$$q_p = CA/T_p$$

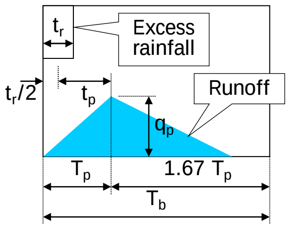
where

- q_p : peak discharge of unit hydrograph (m^3/s)
- C : 2.08
- A : drainage area (km^2)
- T_p : time-to-peak of unit hydrograph (hr)

$$T_p = t_r/2 + t_p$$

where

- t_r : duration of effective rainfall (hr)
- t_p : lag time (hr)
  = $0.6T_c$: T_c is the time of concentration



(2) Snyder's Synthetic Unit Hydrograph

Snyder defined a standard unit hydrograph as one whose rainfall duration t_r is related to the basin lag t_p by

$$t_r = 5.5\ t_p$$

The basin lag is

$$t_p = C_1 C_t (L L_c)^{0.3}$$

where t_p is in hours, L is the length of the main stream in kilometers from the outlet to the upstream divide, L_c is the distance in kilometers from the outlet to a point on the stream nearest the centroid of the watershed area, C_1=0.75, and C_t is a coefficient derived from gaged watersheds in the same region.

Unit Hydrograph

(2) Snyder's synthetic unit hydrograph

$$t_p = 5.5\ t_r$$

$$t_p = C_1 C_t (L L_c)^{0.3}$$

where,

L: The length of main stream (km) from the outlet to the upstream divide

L_c: The distance (km) from the outlet to a point on the stream nearest the centroid of the watershed area.

4. Channel Flow

The following flow classifications are based on how the flow velocity varies with respect to space and time. Each types of open channel flow that occurs in rivers. Each type of flow must be analyzed using methods that are appropriate for that flow.

1) Uniform flow

Uniform flow rarely occurs in natural rivers because, by definition, uniform flow implies that the depth, water area, velocity, and discharge do not change with distance along the channel. This also implies that the energy grade line, water surface, and channel bottom are all parallel for uniform flow. The depth associated with uniform flow is termed “normal depth.” Uniform flow is considered to be steady flow only, since unsteady uniform flow is practically nonexistent. Only in a long reach of prismatic channel of uniform roughness carrying a flow that has been undisturbed at the reach boundaries for a long time will the flow e uniform.

(2) Non-uniform flow

Most flow in natural rivers and channels is non-uniform, or spatially varied flow. Here, the term “spatially varied” is to be taken in the one-dimensional sense; i.e. hydraulic variables vary only along the length of the river. Even if the flow is steady, spatial variation can result from changes occurring along the channel boundaries (e.g., channel geometry changes), from lateral inflows to the channel, or both.

(3) Unsteady flow

If the velocity at a point changes with time, the flow is unsteady. Methods for analyzing unsteady flow problems account for time explicitly as a variable, while steady flow methods neglect time all together.

Hydraulics

The flow in channel or river can be classified into below three types.

1) Uniform flow: The depth and discharge of flow is the same at every section of the channel.

2) Non-uniform flow: The discharge of flow is constant but velocity is varied.

3) Unsteady flow: The depth of flow changes with time.

Hydraulics

		time	
		constant	non-constant
spatial	constant	uniform flow	
	non-constant	non-uniform flow	unsteady flow

Hydraulics

Uniform Flow

If a constant discharge flows through a channel with unchanging shape of cross section and gradient, the hydraulic quantities should be determined by uniform flow calculations as a rule.

If three quantities out of velocity, roughness coefficient, hydraulic mean depth and water surface slope are known, the remaining quantity can be calculated by the uniform flow calculations. The uniform flow appears then a constant discharge flows through an infinitely long water channel with unchanging gradient and shape of section. Therefore, each hydraulic quantity stated above will not change with time and location. Relations between hydraulic quantities can be given by Manning's Formula shown next figure.

Hydraulics

Manning's Formula

$$Q = \frac{1}{n} A R^{2/3} I^{1/2}$$

where,

Q: discharge (m^3/s)
n: roughness coefficient
A: cross-sectional area of flow (m^2)
R: hydraulic radius (m)
(R=A/P, P: wetted perimeter)
I: slope of energy line

Hydraulics

Typical values of roughness coefficient

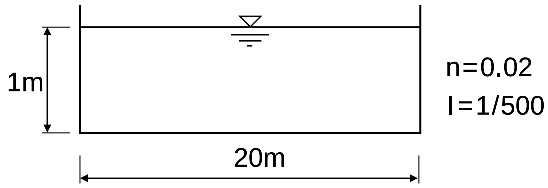
River and channel condition	Manning's "n"
Small channel in plain without weeds	0.025 – 0.033
Small channel in plain with weeds & shrubs	0.030 – 0.040
Small channel in plain with many weeds and cobble on bed	0.040 – 0.055
Watercourse in mountainous region with gravel & cobble	0.030 – 0.050
Watercourse in mountainous region with cobble & boulder	Over 0.040
Large watercourse with clay, sandy bed, slightly meandering	0.018 – 0.035
Large watercourse with cobble on bed	0.025 – 0.040

Roughness coefficient expressing the degree of resistance of river course is one of basic numerical values needed when making various hydraulic calculations for rivers.
Typical values of roughness coefficient for rivers or channels are approximately in the range stated in the table.

Hydraulics

Example-1

Calculate flow velocity and discharge of below channel using Manning's Formula.



[Answer]

Roughness coefficient (n) = 0.02

Slope of energy line (I) = 1/500

Hydraulic radius (R) = A/P = (1x20)/(1+20+1) = 0.91 (m)

Cross-sectional area = 1x20 = 20 (m^2)

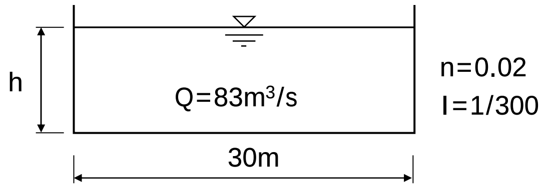
$$Q = \frac{1}{n} I^{1/2} R^{2/3} A$$

$$= \frac{1}{0.02} \times \left(\frac{1}{500}\right)^{1/2} \times 0.92^{2/3} \times 20 = 42.3\ (m^3/s)$$

Hydraulics

Example-2

Calculate water depth of below channel using Manning's Formula.



[Answer]

(i) Assuming h=1.0 (m)

Roughness coefficient (n) = 0.02

Slope of energy line (I) = 1/300

Hydraulic radius (R) = A/P = (1x30)/(1+30+1) = 0.94 (m)

Cross-sectional area = 1x30 = 30 (m^2)

$$Q = \frac{1}{n} I^{1/2} R^{2/3} A$$

$$= \frac{1}{0.02} \times \left(\frac{1}{300}\right)^{1/2} \times 0.94^{2/3} \times 30 = 81.3\ (m^3/s)$$

(ii) Assuming h=0.9 (m)

Hydraulic radius (R) = A/P = (0.9x30)/(0.9+30+0.9) = 0.85 (m)

Cross-sectional area = 0.9x30 = 27 (m^2)

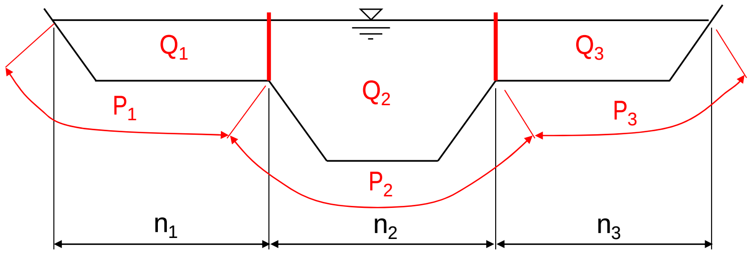
$$Q = \frac{1}{n} I^{1/2} R^{2/3} A$$

$$= \frac{1}{0.02} \times \left(\frac{1}{300}\right)^{1/2} \times 0.85^{2/3} \times 27 = 69.9\ (m^3/s)$$

Therefore, h = 1.0 (m)

Uniform Flow

Flow in compound section



$$Q = Q_1 + Q_2 + Q_3$$

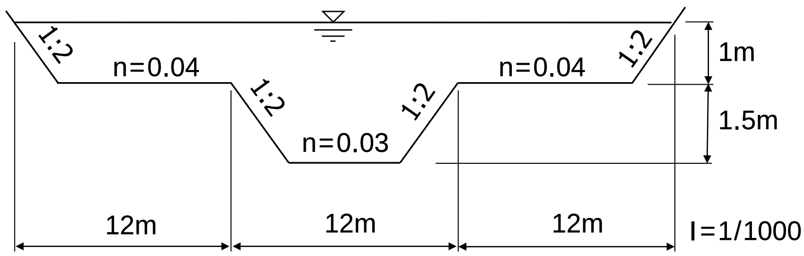
$$= \frac{1}{n_1} A_1 R_1^{2/3} I^{1/2} + \frac{1}{n_2} A_2 R_2^{2/3} I^{1/2} + \frac{1}{n_3} A_3 R_3^{2/3} I^{1/2}$$

where, $R_1 = A_1/P_1$, $R_2 = A_2/P_2$, $R_3 = A_3/P_3$

Uniform Flow

Example-4

Calculate flow velocity and discharge of below channel using Manning's Formula.



[Answer]

(i) Left Q_1

Roughness coefficient (n_1) = 0.04

Slope of energy line (I) = 1/1000

Cross-sectional area (A_1) = (12+10)/2*1.0 = 11.0 (m^2)

Wetted perimeter (P_1) = $\sqrt{5}$+10 = 12.24 (m)

Hydraulic radius (R) = A/P = 11.0/12.24 = 0.90 (m)

$$Q_1 = \frac{1}{0.04} \times \left(\frac{1}{1000}\right)^{1/2} \times 0.90^{2/3} \times 11 = 8.11\ (m^3/\mathrm{s})$$

(ii) Center Q_2

Roughness coefficient (n_2) = 0.03

Slope of energy line (I) = 1/1000

Cross-sectional area (A_2) = 12*1.0+(12+6)/2*1.5 = 25.5 (m^2)

Wetted perimeter (P_2) = 2*1.5*$\sqrt{5}$+6 = 12.71 (m)

Hydraulic radius (R) = A/P = 25.5/12.71 = 2.01 (m)

$$Q_2 = \frac{1}{0.03} \times \left(\frac{1}{1000}\right)^{1/2} \times 2.01^{2/3} \times 25.5 = 42.81\ (m^3/\mathrm{s})$$

(iii) Center Q_3

$Q_3 = Q_1$ = 8.11 (m^3/s)

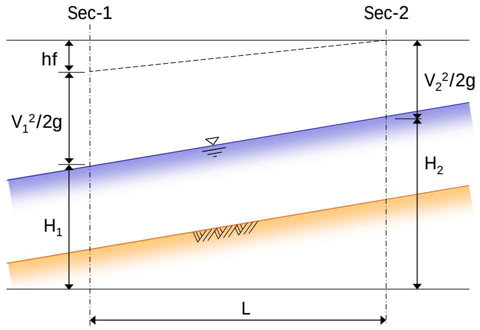
Therefore,

$\Sigma Q = Q_1 + Q_2 + Q_3$ = 8.11+42.81+8.11 = 59.0 (m^3/s)

v = Q/A = 59.0 / (11.0+25.5+11.0) = 1.24 (m/s)

Hydraulics

Non-uniform flow



Bernoulli's theorem

$$H_1 + \frac{v_1^2}{2g} + hf = H_2 + \frac{v_2^2}{2g}$$

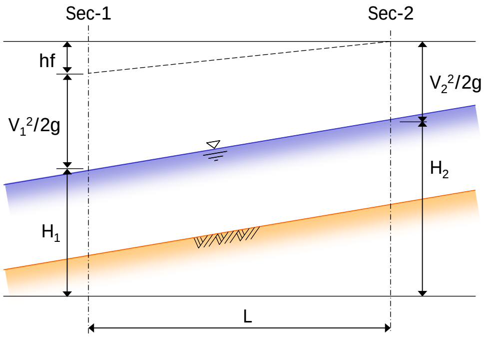
elevation head　velocity head　friction head loss

When a constant discharge flows through a channel with longitudinally changing shape of section and gradient, the hydraulic quantities should be determined by non-uniform flow calculations as a rule.

For making non-uniform flow calculations, it is required to investigate the characteristics of river sections. In addition, it is required to check the location of water level controlling facilities such as weirs, groundsills, bridge piers, etc. and also to know whether a control section may occur at points where the gradient or section changes suddenly.

Hydraulics

Non-uniform flow



$$H_1 + \frac{v_1^2}{2g} + hf = H_2 + \frac{v_2^2}{2g}$$

(Bernoulli's theoram)

$$H_2 = H_1 + \frac{v_1^2 - v_2^2}{2g} + hf$$

$$= H_1 + \frac{v_1^2 - v_2^2}{2g} + \frac{v^2 L n^2}{R^{4/3}}$$

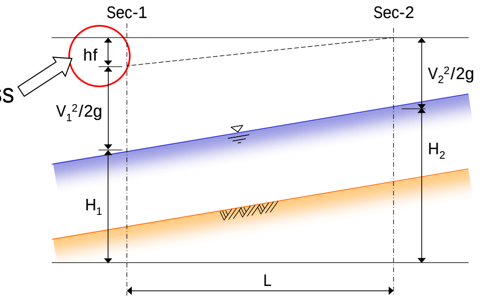
$$= H_1 + \frac{Q^2}{2g}\left(\frac{1}{A_1^2} - \frac{1}{A_2^2}\right) + \frac{Q^2 L n^2}{2}\left(\frac{1}{A_1^2 R_1^{4/3})} + \frac{1}{A_2^2 R_2^{4/3})}\right)$$

The mathematical statement of energy conservation for steady open channel flow is the modified Bernoulli energy equation. It states that the sum of the kinetic (due to motion) energy plus the potential energy (due to height) at a particular location is equal to the sum of the kinetic and potential energies at any other location plus or minus energy losses or gains between those locations. This equation and figure illustrate the conservation of energy principle for steady open channel flow.

Hydraulics

Non-uniform flow

Friction head loss



Friction head loss

$$v = \frac{1}{n} R^{2/3} I^{1/2} \text{ ------ Manning's formula}$$

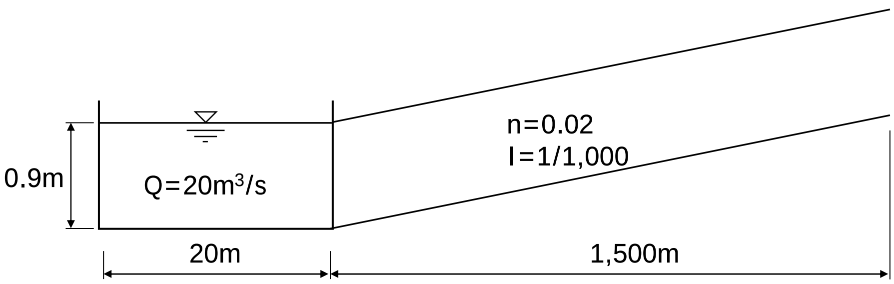
$$v^2 = \frac{1}{n^2} R^{4/3} \frac{hf}{L}$$

$$hf = \frac{v^2 L n^2}{R^{4/3}}$$

Hydraulics

<u>Example-3</u>

When discharge in a channel shown below is $20m^3/s$, determine the water surface profile. Water depth at downstream end is 0.9m, elevation of riverbed is 0m,msl, section interval is 50m.



Hydraulics

Q (m^3/s)	20
g (m/s^2)	9.8
n	0.02

		Sec-1	Sec-2
H_w (m,MSL)	(A)	1.6	
L (m)		0	50
H_B (m,MSL)		0	0.05
W_B (m)		10	10
h ($=H_w-H_b$, m)			
A ($=W_B*h$, m^2)			
P ($=W_B+2h$, m)			
R (=A/P)			
$\frac{Q^2}{2g}\left(\frac{1}{A_1^2}-\frac{1}{A_2^2}\right)$	(B)		
$hf=\frac{n^2LQ^2}{2}\left(\frac{1}{A_1^2R_1^{4/3}}+\frac{1}{A_2^2R_2^{4/3}}\right)$	(C)		
H_w'(check)	(A)+(B)+(C)		
H_w-H_w'			

If $H_w = H_w'$ ($H_w-H_w'=0$), OK.
If not,
assume another H_w and calculate again.

[Flood Analysis / Hazard Map]

Technical Tutorial Manual For Flood Hazard Mapping

Task Force – Flood Risk Management

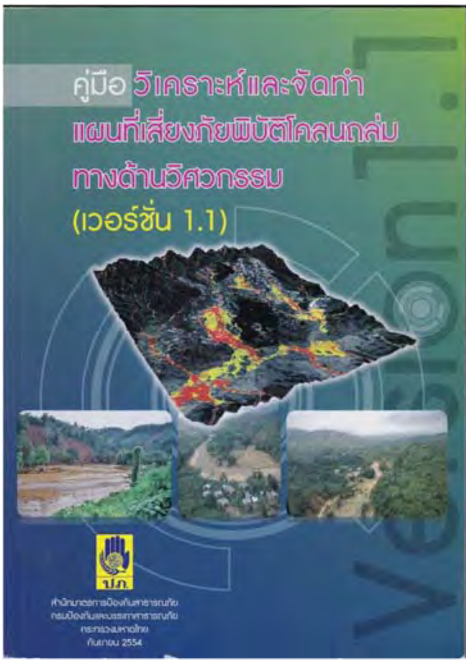
Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Introduction

Background

DDPM has prepared provincial scale flood risk map that was developed during the project of Phase-1.

The manuals have been updated by DDPM, and the trainings to the provincial DPM offices were also conducted with provision of necessary topo-sheet maps and high resolution aerial photographs that was provided based on MOU between DDPM and Land Development Department. The map set is now available from official web-site of DDPM.



Manual for Risk Map after Phase-1

Introduction

Background

The provincial flood risk map developed Phase-1 aims to be used for provincial disaster management, basic planning of structural/nonstructural measures and reporting of disaster information. However more accuracy based on hydro-meteorological analysis was required to apply the risk maps into the community activities of CBDRM.

Objective

According to the above background, the technical tutorial manual was prepared by TF-FRM in Phase-2 project. The objective of the manuals is as follow;

- **The manual shall provide technical procedure to prepare hazard map, not for conceptual manners.**
- **The manual shall be used for trainings to regional and provincial DPM officers after the project as a training text book.**
- **The manual shall be updated and revised by DDPM after the project.**

Contents

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Lesson 1
Runoff Analysis

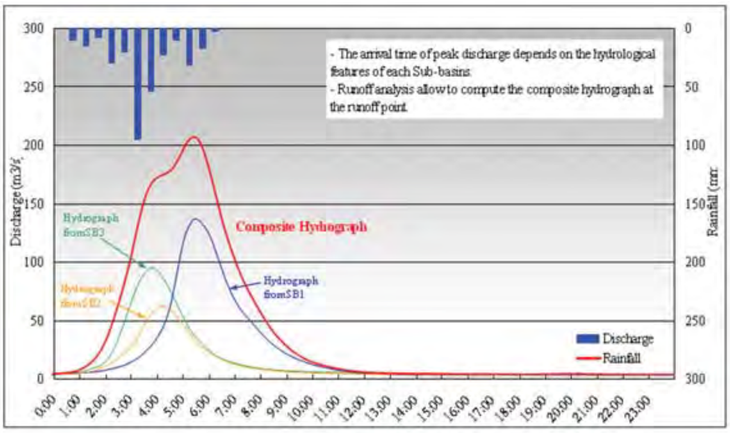
Basic Procedure of HEC-HMS

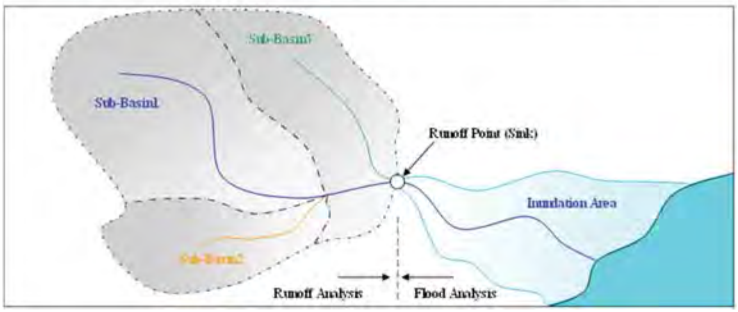
Task Force – Flood Risk Management

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

General

- Flood simulation can be divided into 2 processes of "**Runoff Analysis**" and "**Flood Analysis**".
- Runoff Analysis is to obtain "**Hydrograph**" that is a time series data of discharge amount (m^3/s), which is generated by certain rainfall into the watershed.
- The character of hydrograph and its peak time is highly affected by the geographical and geological condition of each sub- basin.
- The each sub-basin generates different hydrographs at the runoff point . The total hydrograph of the watershed at the runoff point is, therefore, accumulated hydrograph from all sub-basins.



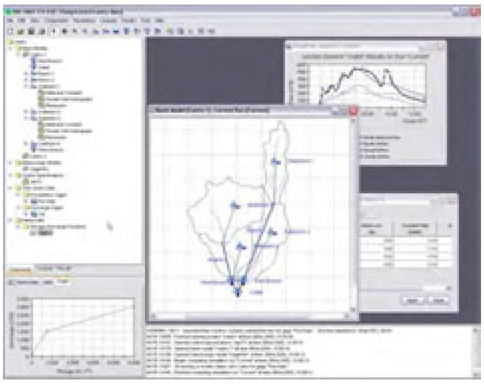


General

➢ **HEC-HMS** (Hydrologic Modeling System) is developed by US Army Corps of Engineer as well as HEC-RAS.

➢ **HEC-HMS** is designed to simulate the precipitation-runoff processes.

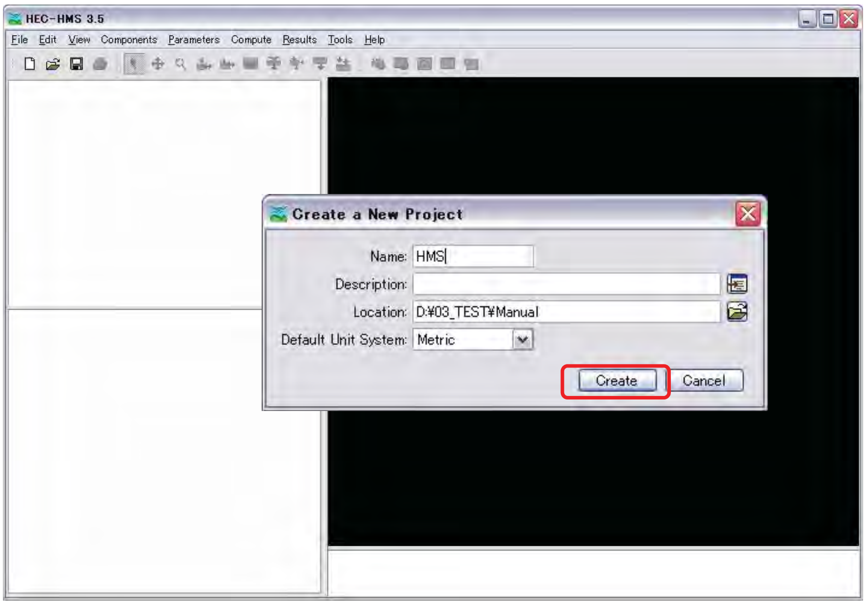
➢ Hydrographs produced by the program are used directly or in conjunction with other software.



<REQUIRED INPUT>

Basin Model:	**- Sub-Basin (Area, Loss, Transform, Base flow etc.)** **- Reach (Routing, Loss/Gain)**
Meteorological Model:	**- Precipitation (Frequency Storm, Specified Hyetograph)** **- Evapo/Transpiration**
Control Specification:	**- Simulation Time Intervals**
Time Series Data:	**- Observed Data**

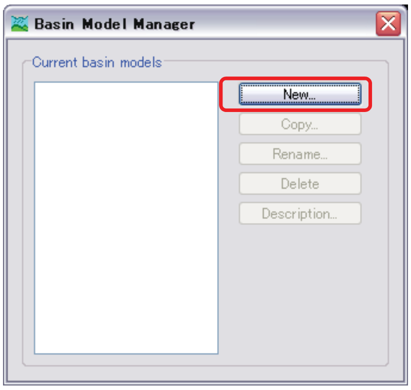
Getting Start

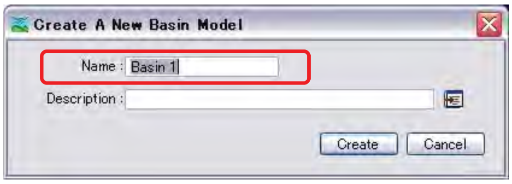


➢ Start HEC-HMS. Select [**File**] – [**New**].

➢ Enter project name of "**HMS**" for [Name] and select working directory in your computer. If necessary, enter [Description] as you like. Make sure the [Default Unit System] is "**Metric**". Then click [Create].

Setup Basin Model





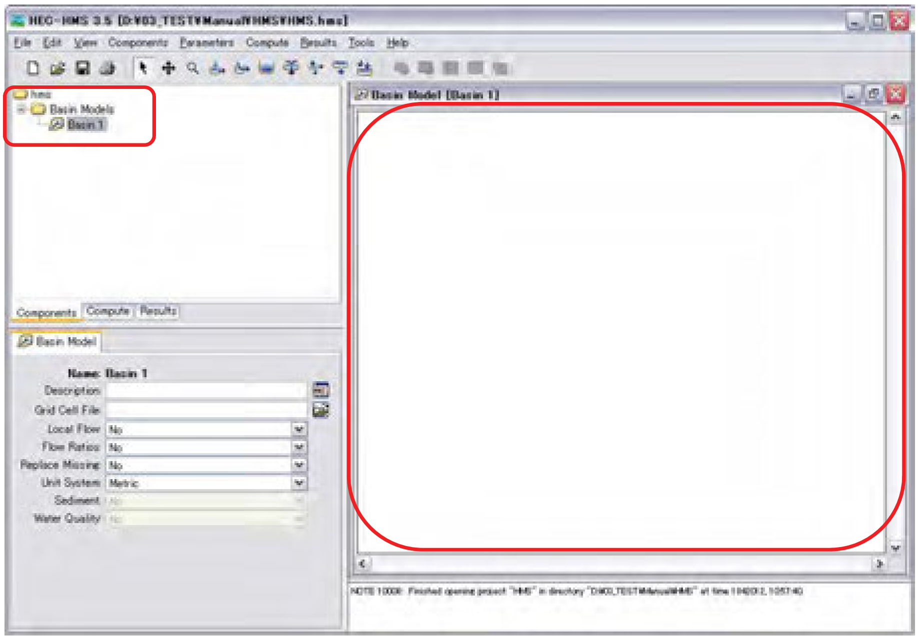
➢ You need to prepare **Basin Model**, **Meteorological Model** and **Control Specification** for calculation at least. Firstly, create [**Basin Model**].

➢ Select [**Components**] – [**Basin Model Manager**].

➢ In the following dialog, click [**New**].

➢ Enter the name of Basin Model as you like. Here use the default name of "**Basin 1**". Then click [**Create**].

Setup Basin Model



➢ When you click [Basin Model] – [Basin 1] in the left window, the map view window will appear in the right. Now you will start to create basin model in this window.

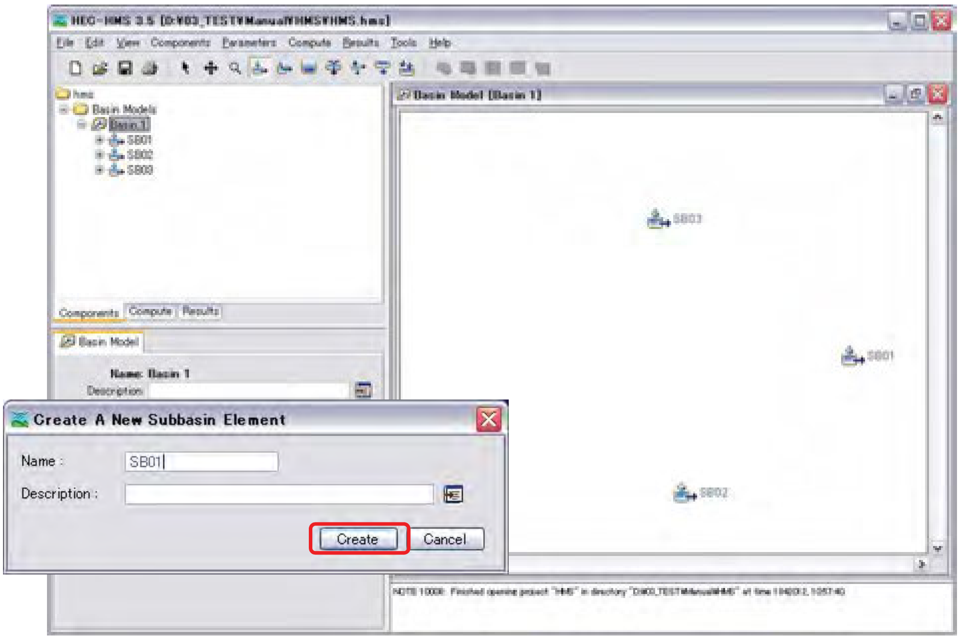
Setup Basin Model

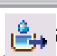
On the menu bar at the top, you can find several hydrological elements.

From the left to right:

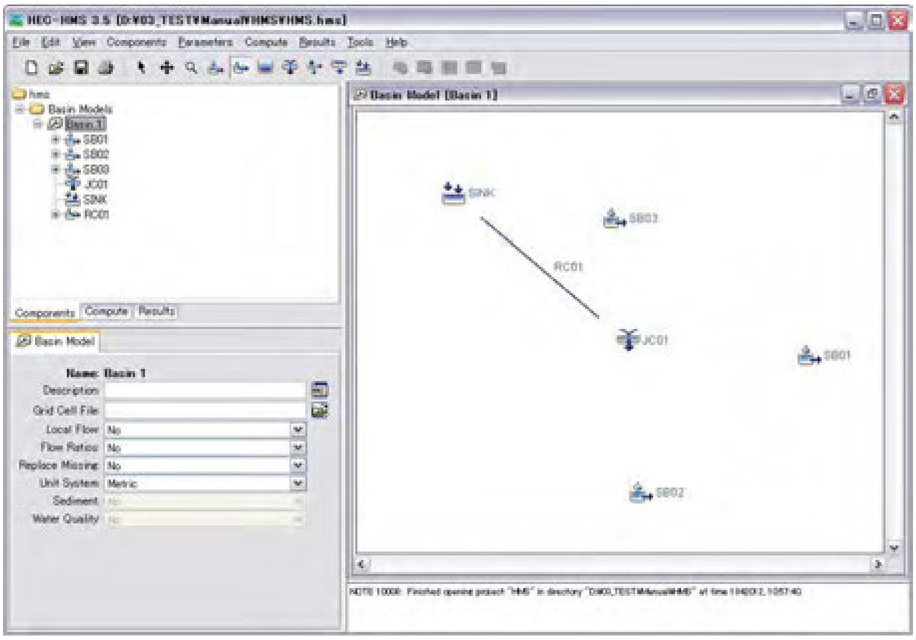
- **Subbasin** Rainfall-runoff computation on a watershed.
- **Reach** Convey (route) stream flow downstream in the basin model.
- **Reservoir** Model the detention and attenuation of a hydrograph caused by a reservoir or detention pond.
- **Junction** Combine flows from upstream reaches and sub-basins.
- **Diversion** Model abstraction of flow from the main channel.
- **Source** Introduce flow into the basin model (from a stream crossing the boundary of the modeled region). Source has no inflow.
- **Sink** Represent the outlet of the physical watershed. Sink has no outflow.

Setup Basin Model



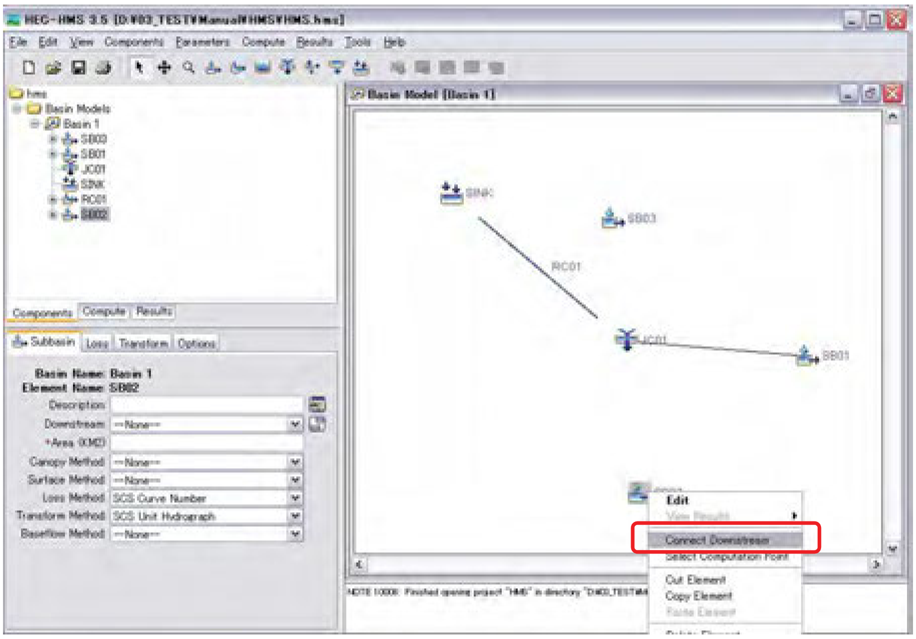
- Click the subbasin Icon  and click on where you want to put it the map view dialog. In HEC-HMS, the location of hydrological elements is not important, because the connecting relation between each element is defined by the element description. You can put it on any place.
- Add 3 Subbasin as above. When you click in the map view, . So please define each Subbasin as "**SB01**", "**SB02**" and "**SB03**".

Setup Basin Model



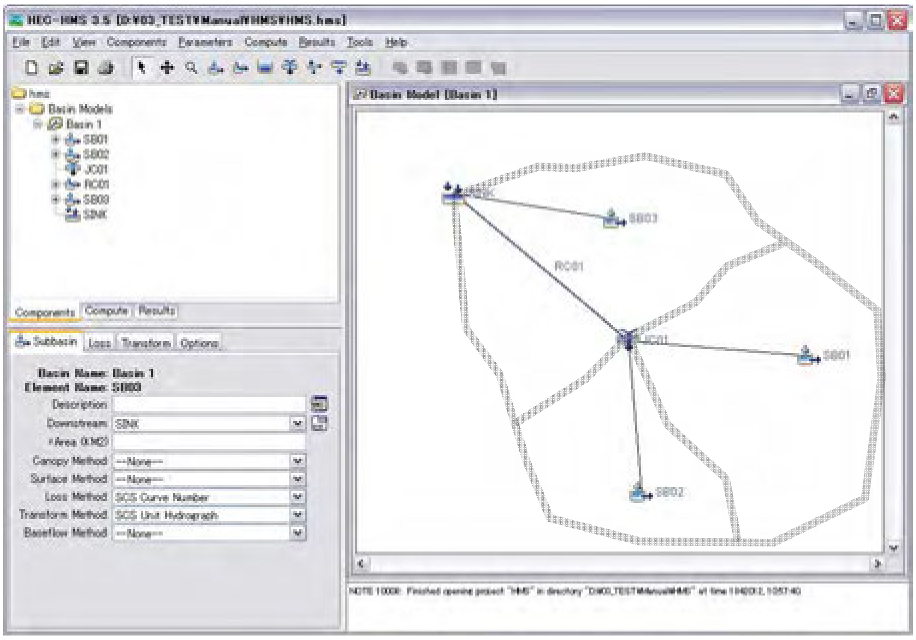
- Likewise, add “**SINK**” as a Sink  (means runoff point)
- Add “**JC01**” as a Junction  between [SB01] and [SB02].
- Add “**RC01**” as a Reach  between [JC01] and [SINK] as bellow.

Setup Basin Model



- Currently, all elements are isolated each other. You need to connect the each element.
- Right click on [**SB01**] and select [**Connect Downstream**]. Then click an element that you want to connect to. In this case click on [**JC01**]. Likewise, connect [**SB02**] to [**JC01**].
- Make sure that [SB01] and [SB02] are connected.

Setup Basin Model



➢ Likewise, connect all of the elements as above.

➢ The thick gray line shows assumed subbasin boundary (it is not created). Rainfall into the subbasin [SB01] and [SB02] flows into [JC01]. Then, it flows down through [RC01] toward [SINK]. On the other hand, rainfall into subbasin [SB03] flows into [SINK] directory.

Setup Basin Model

➢ Subbasin elemets requires several parameter to compute hydrograph.

➢ In this training, we use "**SCS Curve Number**" method for [Loss Method] and "**SCS Unit Hydrograph**" for [Transform Method] of the subbasins.

➢ The other parameters must be "—None—".

➢The loss method specifies the actual amount of incoming precipitation that will be infiltrated stored in the watershed before surface runoff begins. The "**SCS Curve Number**" is defined as the right table.

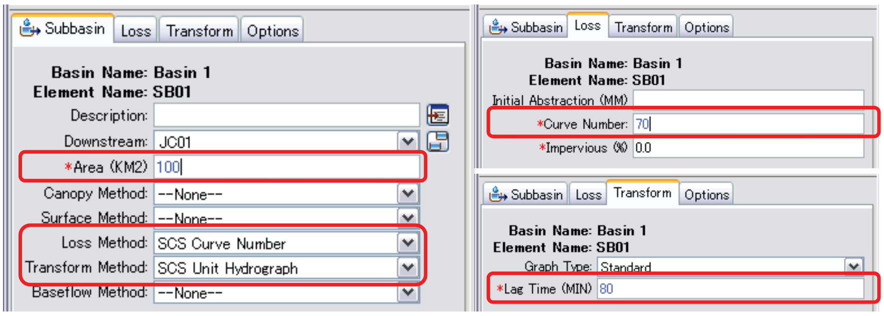
➢ The transform method performs the actual surface runoff calculation from subbasin. The "**SCS Unit Hydrograph**" is one of the unit hydrograph method, which requires only one parameter of "**Lag Time**" for each sub-basin.

Table of Runoff Curve Numbers (SCS, 1986)

Description of Land Use		Hydrologic Soil Group			
		A	B	C	D
Paved parking lots, roofs, driveways		98	98	98	98
Streets and Roads	Paved with curbs and storm sewers	98	98	98	98
	Gravel	76	85	89	91
	Dirt	72	82	87	89
Cultivated Land	Without conservation treatment (no terraces)	72	81	88	91
	With conservation treatment (terraces, contours)	62	71	78	81
Pasture or Range Land	Poor (<50% ground cover or heavily grazed)	68	79	86	89
	Good (50-76% ground cover; not heavily grazed)	39	61	74	80
Meadow (grass, no grazing, mowed for hay)		30	58	71	78
Brush (good, >75% ground cover)		30	48	65	73
Woods and Forests	Poor (small trees/brush destroyed by over-grazing or burning)	45	66	77	83
	Fair (grazing but not burned; some brush)	36	60	73	79
	Good (no grazing; brush covers ground)	30	55	70	77
Open Spaces (lawns, parks, golf courses, cemeteries, etc.)	Fair (grass covers 50-75% of area)	49	69	79	84
	Good (grass covers >75% of area)	39	61	74	80
Commercial and Business Districts (85% impervious)		89	92	94	95
Industrial Districts (72% impervious)		81	88	91	93
Residential Areas	1/8 Acre lots, about 65% impervious	77	85	90	92
	1/4 Acre lots, about 38% impervious	61	75	83	87
	1/2 Acre lots, about 25% impervious	54	70	80	85
	1 Acre lots, about 20% impervious	51	68	79	84

Group A Soils:	High infiltration (low runoff). Sand, loamy sand, or sandy loam. Infiltration rate > 0.3 inch/hr when wet.
Group B Soils:	Moderate infiltration (moderate runoff). Silt loam or loam. Infiltration rate 0.15 to 0.3 inch/hr when wet.
Group C Soils:	Low infiltration (moderate to high runoff). Sandy clay loam. Infiltration rate 0.05 to 0.15 inch/hr when wet.
Group D Soils:	Very low infiltration (high runoff). Clay loam, silty clay loam, sandy clay, silty clay, or clay. Infiltration rate 0 to 0.05 inch/hr when wet.

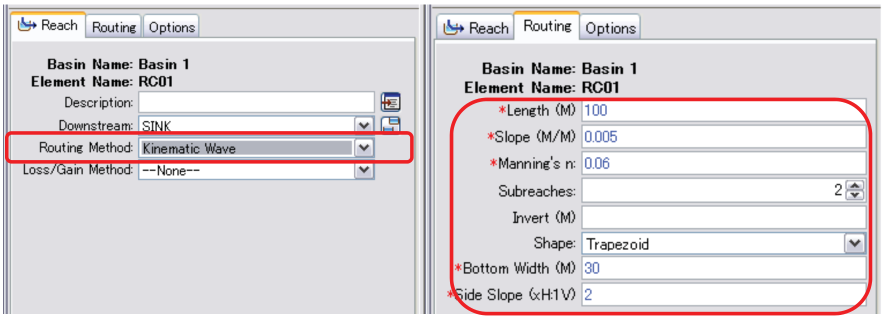
Setup Basin Model



Subbasin Name	Area (KM2)	SCS Curve Number (Curve Number)	SCS Unit Hydrograph Lag Time (min)
SB01	100	70	180
SB02	80	70	160
SB03	120	75	200

- In this training, you use the above parameters for each subbasin.
- Enter the necessary values (highlighted by read line) into each Tab of [**Loss**] and [**Transform**] .

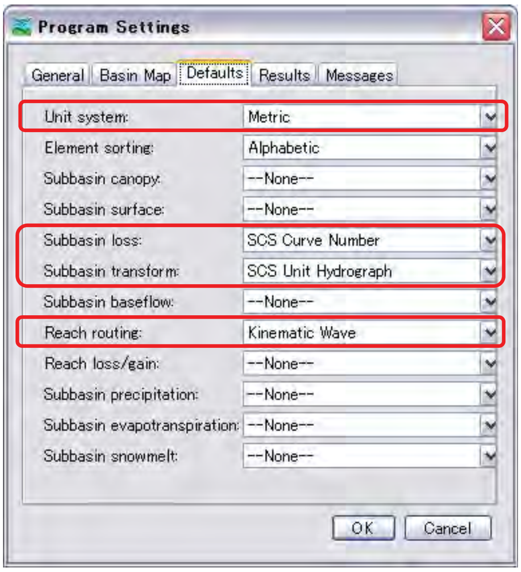
Setup Basin Model



Reach Name	Length (M)	Slope (M/M)	Manning's n	Shape	Bottom Width (M)	Side Slope (xH:1V)
RC01	1000	0.005	0.06	Trapezoid	30	2

- For reach elements of [**RC01**], you will use "**Kinematic Wave**" method for the Routing Method, which approximates the full unsteady flow equations by ignoring internal and pressure forces. It also is assumed that the energy slope is equal to the bed slope.
- Select "**Kinematic Wave**" and enter the necessary values into each Routing Tab as above parameter.
- Now all necessary data for Basin Model were completed. Save the file from [**File**] – [**Save**].

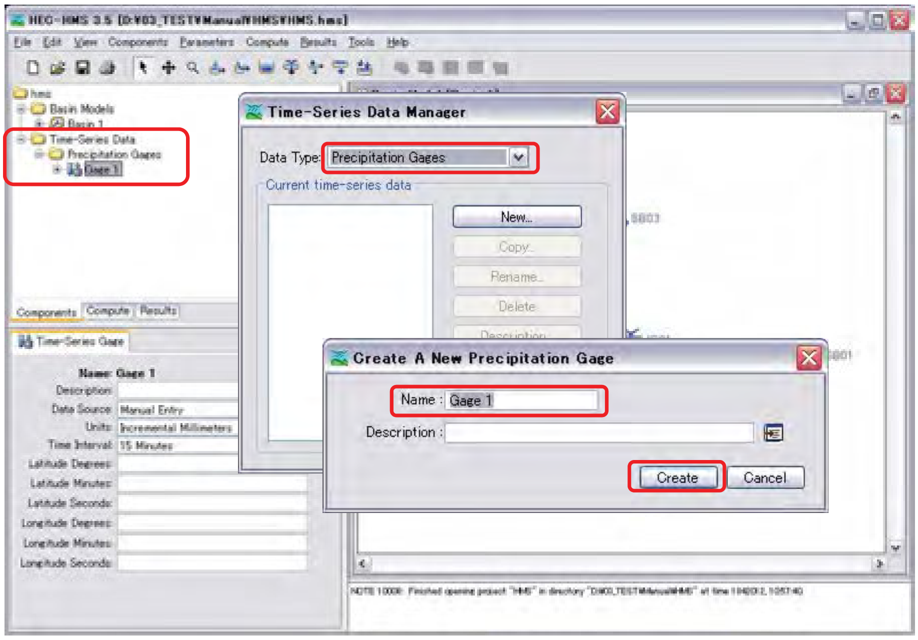
Setup Basin Model



➢The method of “**SNS Curve Number**”, “**SNS Unit Hydrograph**” and “**Kinematic Wave**” are basically used in this manual.

➢ Therefore, It is highly recommend setting these methods as default in HEC-HMS. Click [**Tools**] – [**Program Setting**], and select [**Default**] Tab. Select each default method as above.

Setup Meteorologic Model



➢ Firstly, you need to prepare rainfall data that may be observed by automatic rain gage.

➢ Select [**Components**] – [**Time-Series Data Manager**]. In the following dialog, click [**New**]. Enter the name of Precipitation Gage as you like. Here use the default name of “**Gage 1**”. Then click [**Create**].

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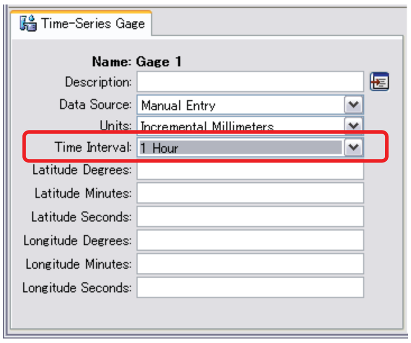
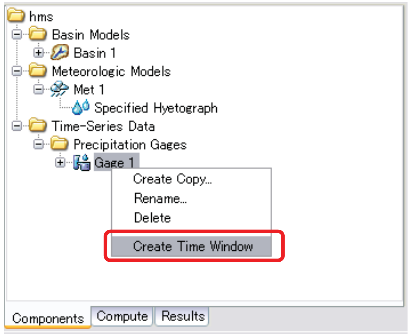
Setup Meteorologic Model





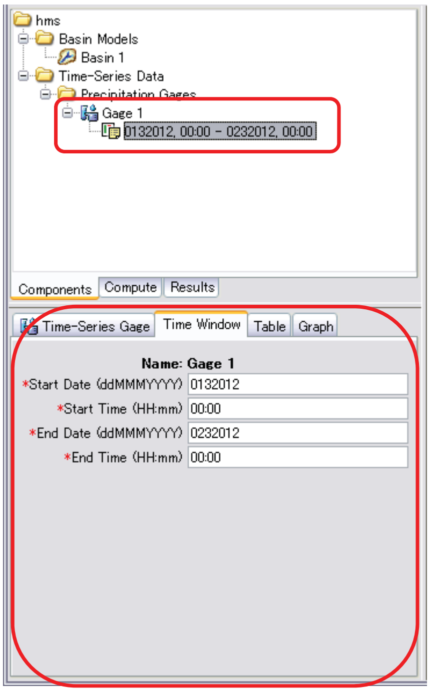
➢ In the parameter dialog at the left bottom, select [**Time Interval**] as “**1 Hour**”.

➢ Right click on [**Gage 1**] and select [**Create Time Windows**].

Setup Meteorologic Model

➢ In the dialog of [Add Time-Series Data Time Window, enter the period of observed rainfall.

➢ Tentatively, set “**00:00**” on “**01MAR2012**” for [Start Date / Time] and “**00:00**” on “**02MAR2012**” for [End Date /Time], so that this series can have 24 hours rainfall data.



➢ Open [**Gage 1**]. When you select time-series data of “**01032012, 00:00 - 02032011, 00:00**”, several Tabs will appear at the bottom.

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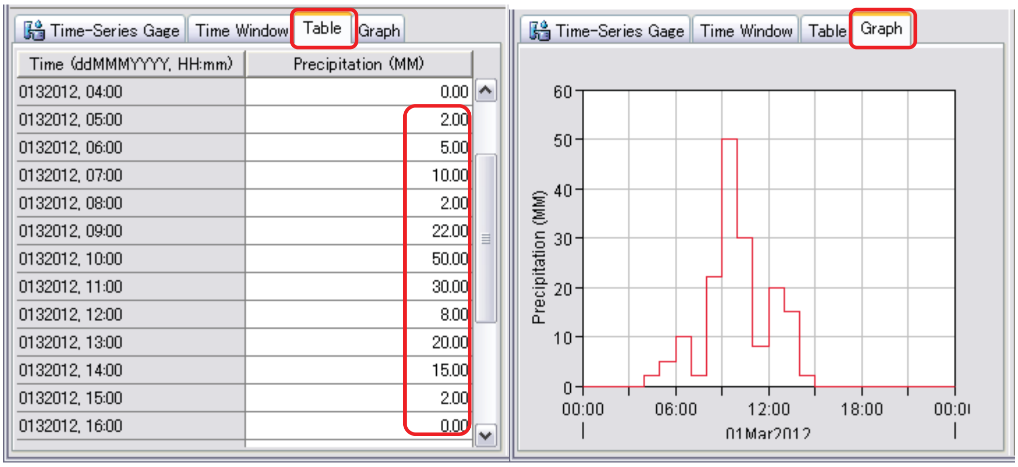
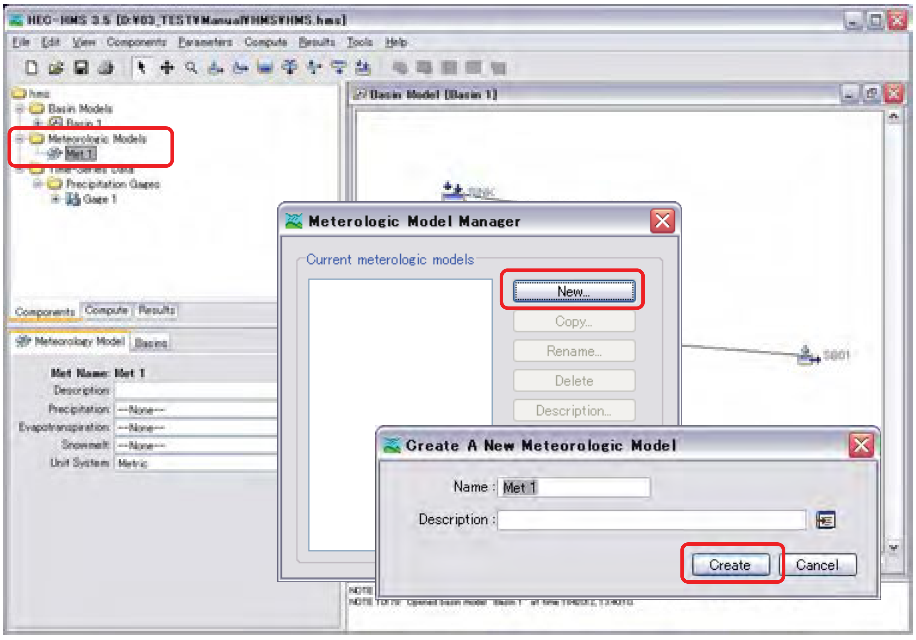
Setup Meteorologic Model



➢ Select [**Table**] Tab, and fill hourly rainfall data in 05:00 – 15:00 as above. If you have an actural data set of hourly rainfall, you can enter the data.

➢ Check the input rainfall data in the [**Graph**] Tab. Save the project by [**File**] – [**Save**].

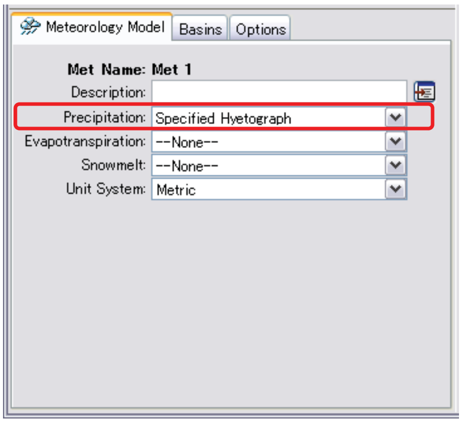
Setup Meteorologic Model

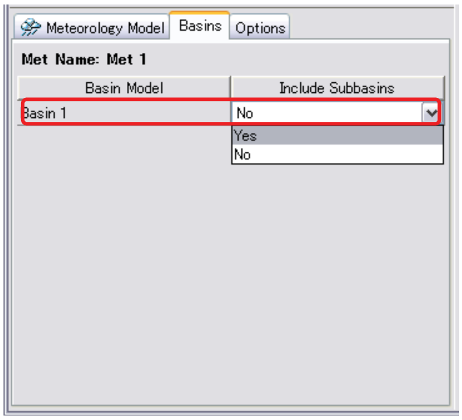


➢ Now you are ready to prepare the Meteorologic Model for your project.

➢ Select [**Components**] – [**Meteorologic Model Manager**]. In the following dialog, click [**New**]. Enter the name of Basin Model as you like. Here use the default name of "**Met 1**". Then click [**Create**].

Setup Meteorologic Model

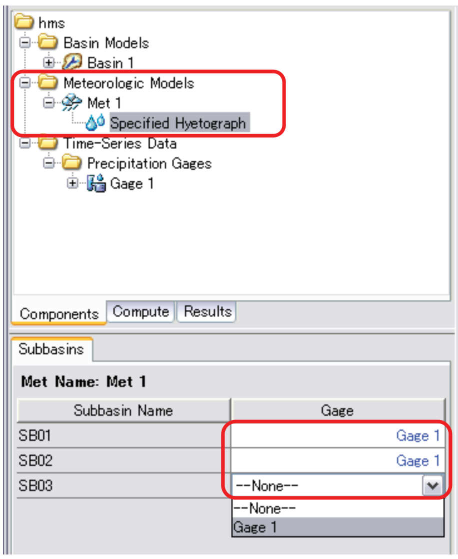




➢ Select [**Meteorology Model**] Tab in the bottom, and select "Specified Hyetograph".

➢ Select [**Basin**], and select "**Yes**". This means the Meteorologic Model of "**Met 1**" will be applied to Basin Model of "**Basin 1**".

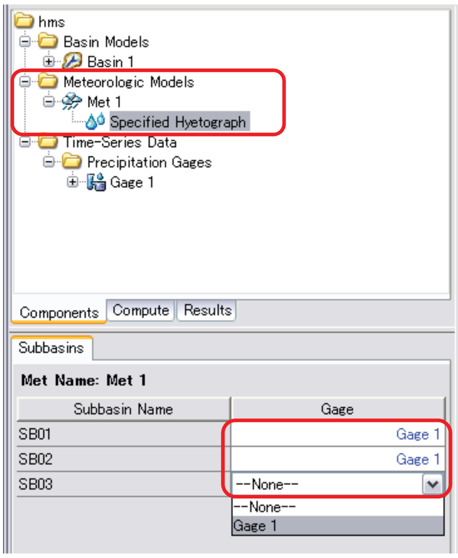
Setup Meteorologic Model



➢ Select [**Meteorologic Model**] – [**Specified Hyetograph**] in the component window . Then select "**Gage 1**" for each subbasin. Now the time-series data of "**Gage 1**" is applied to all of the subbasins.

➢ Save the file from [**File**] – [**Save**].

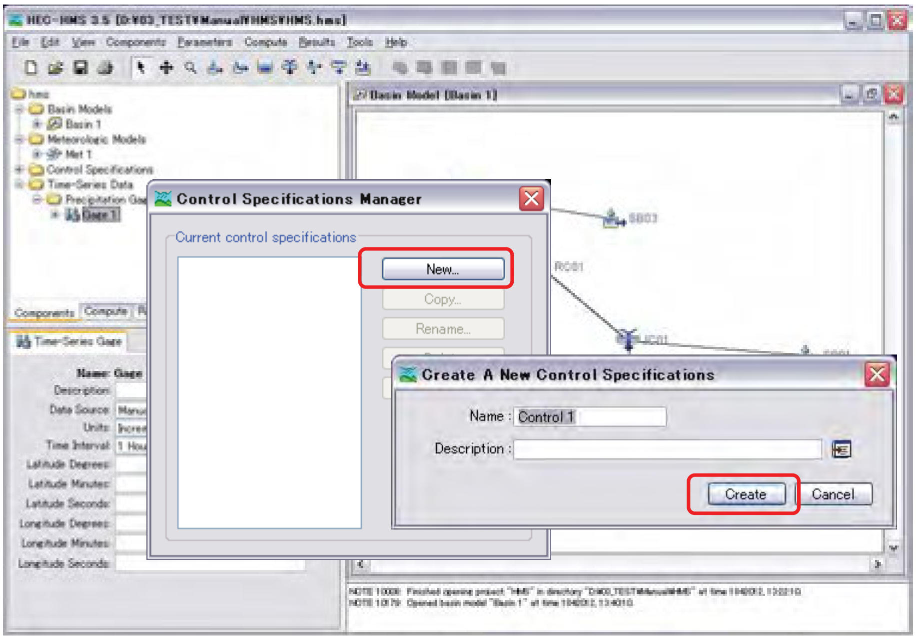
Setup Meteorologic Model



➤ Select [**Meteorologic Model**] – [**Specified Hyetograph**] in the component window . Then select "**Gage 1**" for each subbasin. Now the time-series data of "**Gage 1**" is applied to all of the subbasins.

➤ Save the file from [**File**] – [**Save**].

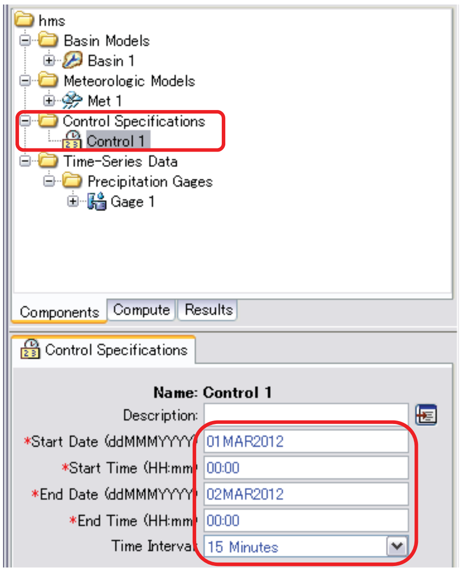
Setup Control Specification



➤ Control Specification is for computation setting such as time interval.

➤ Select [**Components**] – [**Control Specifications Manager**]. In the following dialog, click [**New**]. Enter the name of Basin Model as you like. Here use the default name of "**Control 1**". Then click [**Create**].

Setup Control Specification



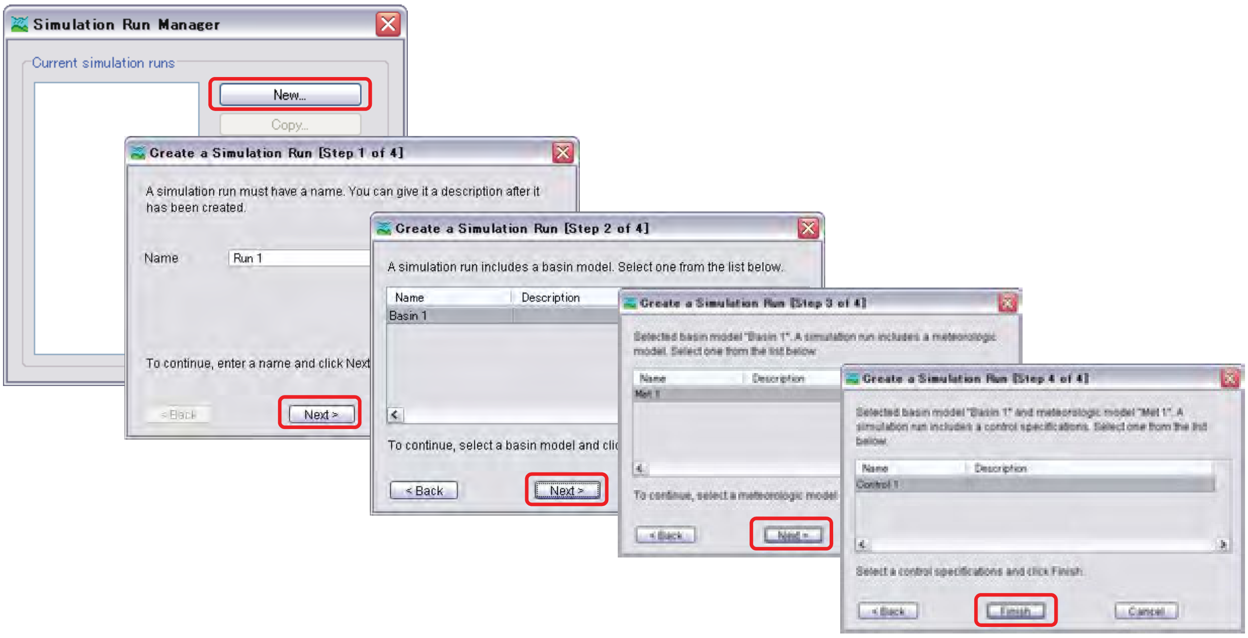
➢ Select [**Control Specifications**] – [**Control 1**] in the left window.

➢ Enter time and date for the computation. The computation time must be in the period of [Hyetograph (Specified Precipitation)].

➢ Select the [Time Interval] as “**15 Munities**”.

➢ Now all of necessary components have been completed, Save the project.

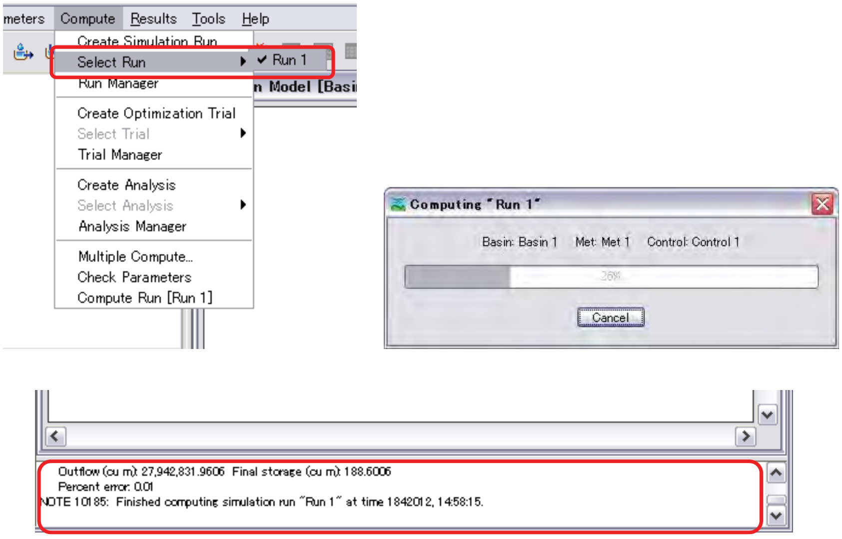
Run Model



➢ Select [**Compute**] – [**Run Manager**]. In the following dialog, click [**New**]. Enter the name of simulation. Here use default name of “**Run**”. Then, click [Next].

➢ In the following dialogs, check the component of [**Basin**], [**Meteorology**] and [**Control Specification**] and click [**Next**]. If you have several components, you can select it in the list.

Run Model

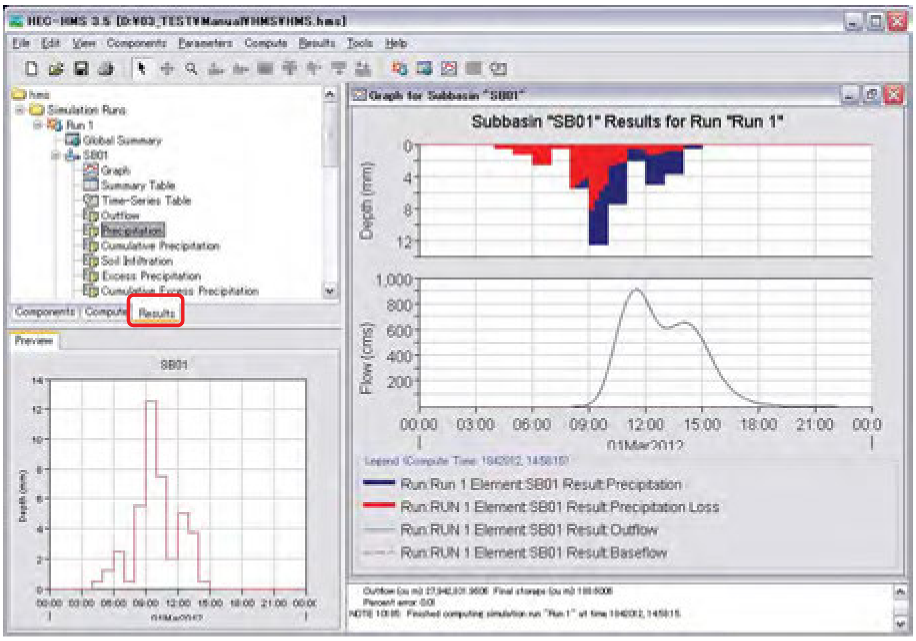


➢ Select [**Compute**] – [**Select Run**] – [**Run 1**]. If you have other combination of run condition, you can find “Run 1”, “Run 2”, “Run 3” … Here “**Run 1**” is only selectable.

➢ Then, select [**Compute]** – [**Compute Run [Run1]**]. Or you can just click  .

➢ Immediately computation will be finished. When the simulation is stopped before completion, there must be insufficient input data. Refer the message line at the bottom of window.

Run Model



➢ You can look at the result of computation in the [**Result**] Tab at the left.

➢ When you select any subbasin elements, you can see the hyetograph and hydrograph. The red part of hyetograph is precipitation loss computed by SCS curve number method. The actual effective rainfall is only blue part.

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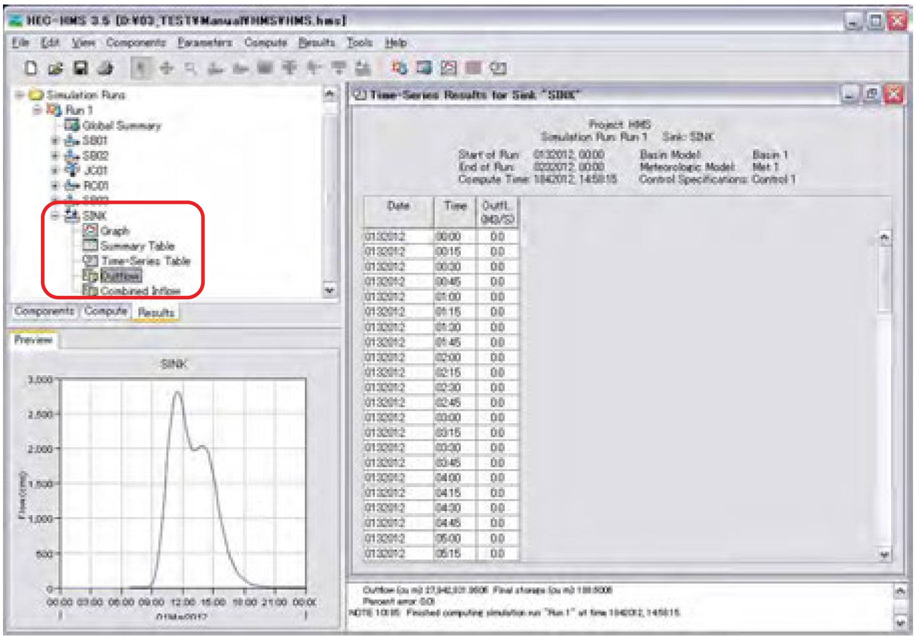
Run Model



- In the result of [SINK], you can find a graph, summary table, time-series table and so on.
- The time-series table can be used as “Input Hydrograph” for the later flood analysis.

END

Lesson 2
Runoff Analysis

Geometry Data Extraction for HEC-HMS

Task Force – Flood Risk Management

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Necessary Parameters for Runoff Model

Sub-basin element

- Area: KM2
- Canopy Method: none
- Surface Method: none
- Loss Method: SCS Curve Number
- Transform Method: SCS Unit Hydrograph
- Baseflow Method: none

※SCS Unit Hydrograph ← Lag Time = Tc x 0.6

$$Tc = 0.663 \times \left(\frac{L}{\sqrt{S}}\right)^{0.77}$$

Reach element

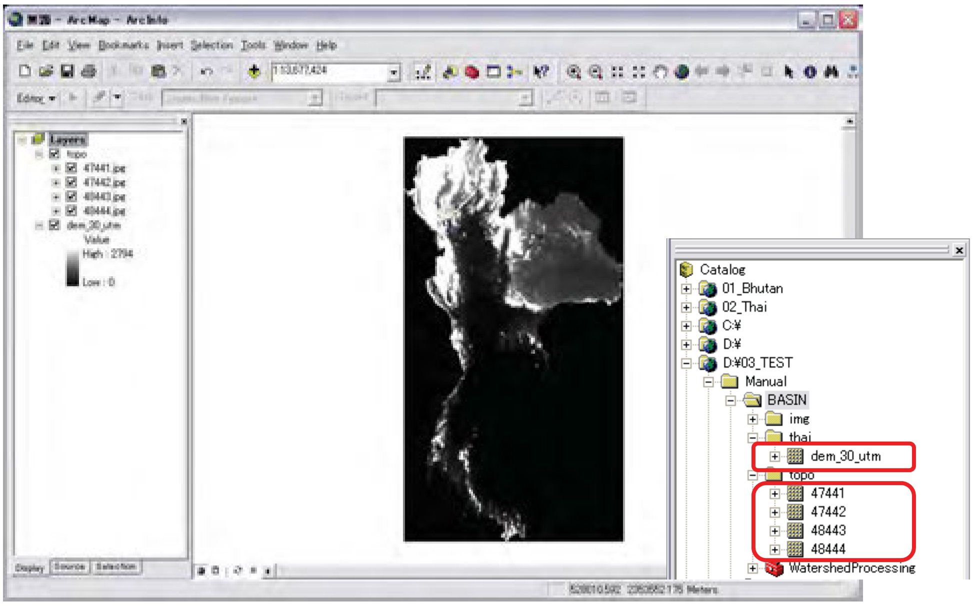
- Routing Method: Kinematic Wave
- Loss/Gain Method: none

※Kinematic Wave ← Manning Formula
L, S, Manning's N,
Channel Shape, Width

➢ In this manual, **SCS Curve Number** and **SCS Unit Hydrograph** methods are employed for the parameter of Sub-basin's direct runoff, and **Kinematic Wave** method is used for the parameter of Reach routing.

➢ The most of parameters can be obtained from elevation model (DEM). In this session, therefore, you will learn how to extract the geometrical parameters from DEM.

Preparation of Digital Elevation Model (DEM)

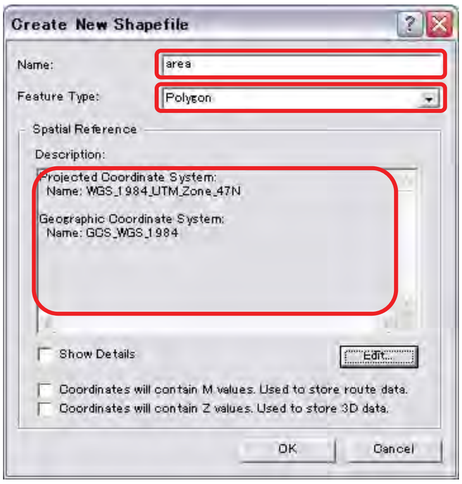


➢ Open ArcMap and ArcCatalog. Add [**dem_30_utm**], which covers whole of Thailand, into ArcMap.

➢ Add fore (4) sets of topo-sheet maps, which can be obtained from DDPM Headquarters.

➢ Our model site of "**Muang Sam Pee**" village is located at southeast end of toposheet [**47441**].

Preparation of Digital Elevation Model (DEM)

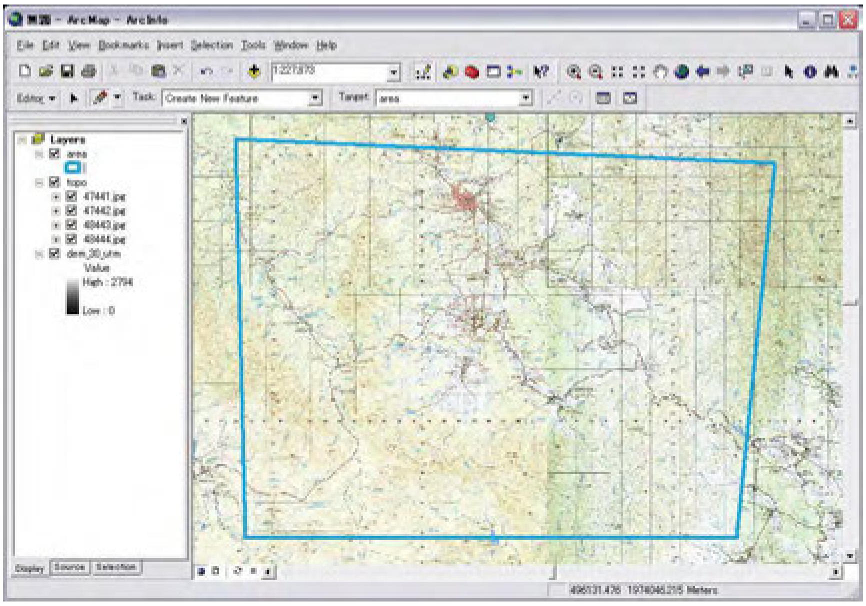


➢ The file size of DEM (dem_30_utm) elevation is too large for analysis. Firstly you need to clip it and generate smaller size of DEM.

➢ Go back to ArcCatalog. Create a new folder "**Shape**" in the [**BASIN**] folder. Add a new polygon in the [Shapes] folder. The [Name] is "**area**", [Feature Type] is "**Polygon**" and [Spatial Reference] is same as "**dem_30_utm**".

➢ Add the newly created "**area.shp**" to Arc Map.

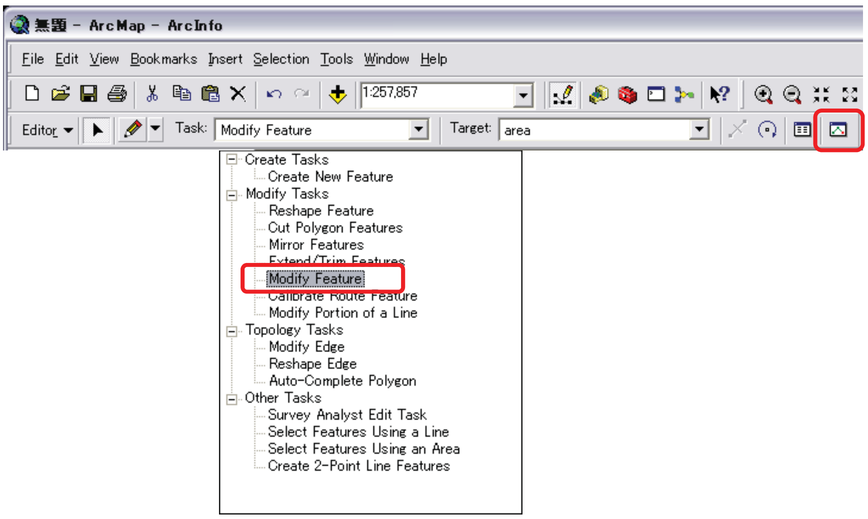
Preparation of Digital Elevation Model (DEM)



➢ Edit “**area.shp**” using [Editor] tool.

➢ Draw analysis area that cover the whole target basin area (blue line). In this step, it is not necessary to draw exactly rectangular.

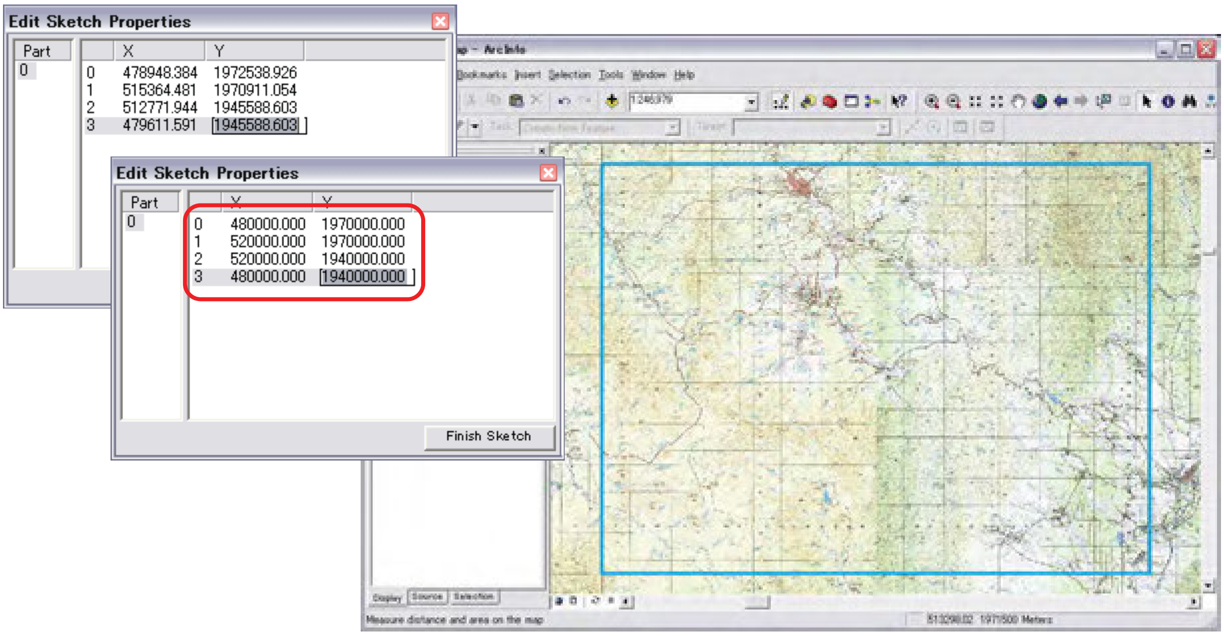
Preparation of Digital Elevation Model (DEM)



➢ Select the drawn “**area.shp**”, and select [**Modify Feature**] from [**Task**] in Editor Toolbar. Each vertexes will turn to red.

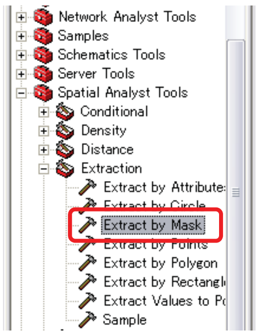
➢ And click [**Sketch Propaties**] in the Toolbar.

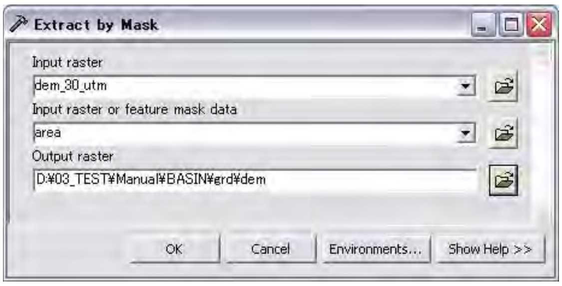
Preparation of Digital Elevation Model (DEM)



- Edit X, Y values of vertexes of “**area.shp**” to be rectangular shape as shown in above.
- When you complete editing, stop editing.

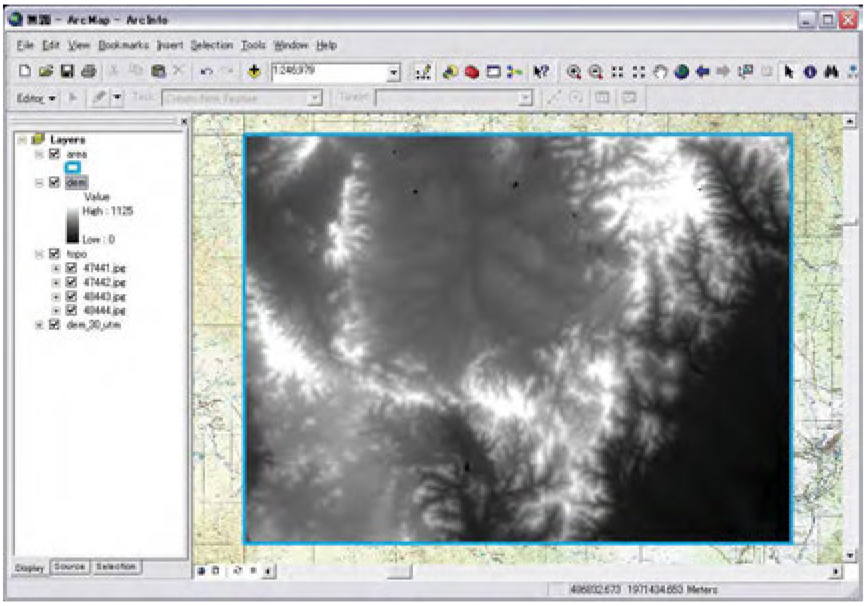
Preparation of Digital Elevation Model (DEM)





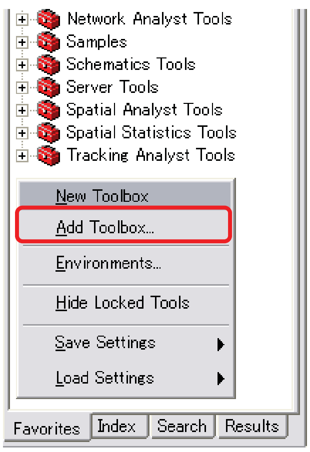
- Open [**ArcToolbox**]. Select [**Spatial Analyst Tools**] – [**Extraction**] – [**Extract by Mask**].
- Select “**dem_30_utm**” for [Input raster], “**area**” for [Input raster or feature mask data].
- Create [**Grid**] folder under the [**BASIN**] folder and save as “**dem**”. Then click [**OK**].

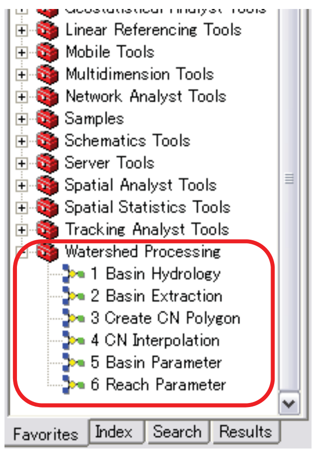
Preparation of Digital Elevation Model (DEM)



➢ Now you have obtained a digital elevation model (DEM) for your project site. This will be used in the following geometry analysis by GIS

Basin Preparation





➢ To simplify the geometric analysis, [**Watershed Processing**] tool that was developed to prepare the necessary data-set for runoff analysis, will be used in this manual.

➢Open [**Arc Toolbox**]. Right click on the blank area and select [**Add Toolbox**].

➢ Browse [**Watershed Processing**] tool from your [BASIN] folder.

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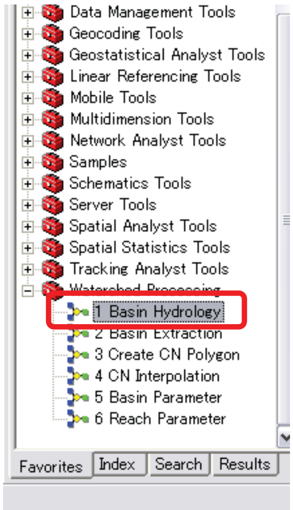
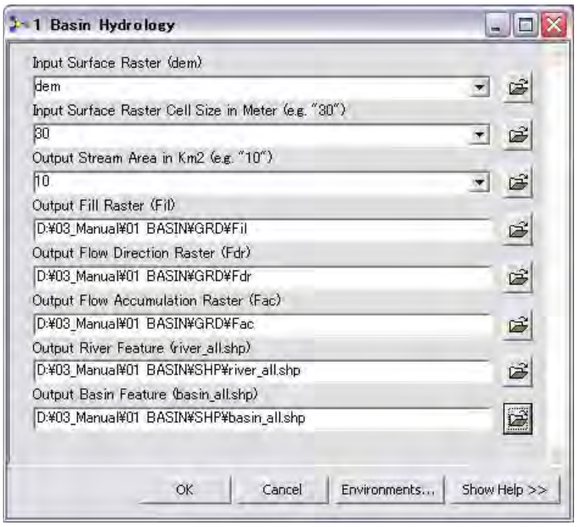
Basin Preparation



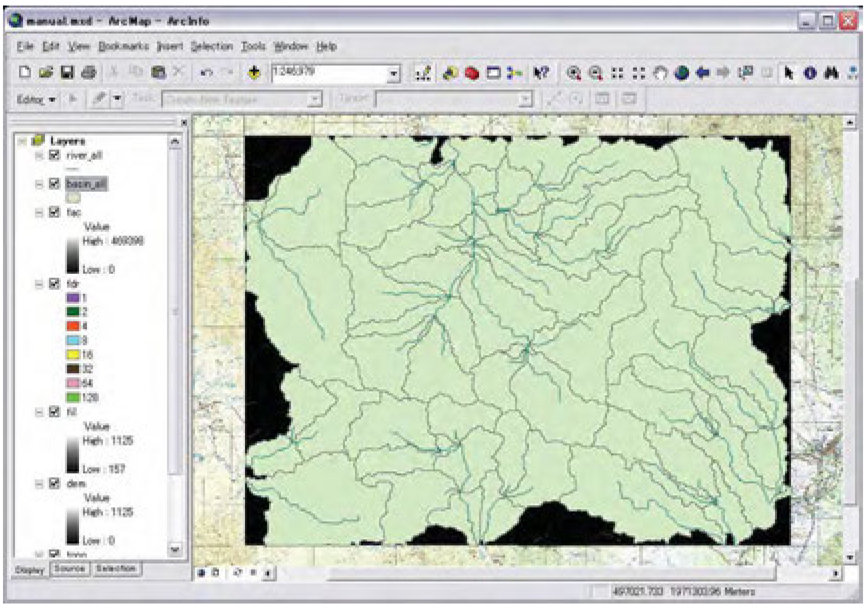


➢ Select [**Watershed Processing**] – [**1 Basin Hydrology**]. Enter "**30**" for Raster Cell Size since your DEM is 30m mesh. When you enter "**10**" for Stream Area, the tool will extract sub-basins that have more than 10 km^2 in area. If your target basin is smaller, this value must be smaller as 5km^2, or 2km^2.

➢ "( )" in the dialog box is recommended file names for output. It is recommended that save "**river_all.shp**" and "**basin_all.shp**" in a new folder of [**Shape**] to distinguish from grid files.

➢ After selecting or entering all of input and output file names, click [**OK**].

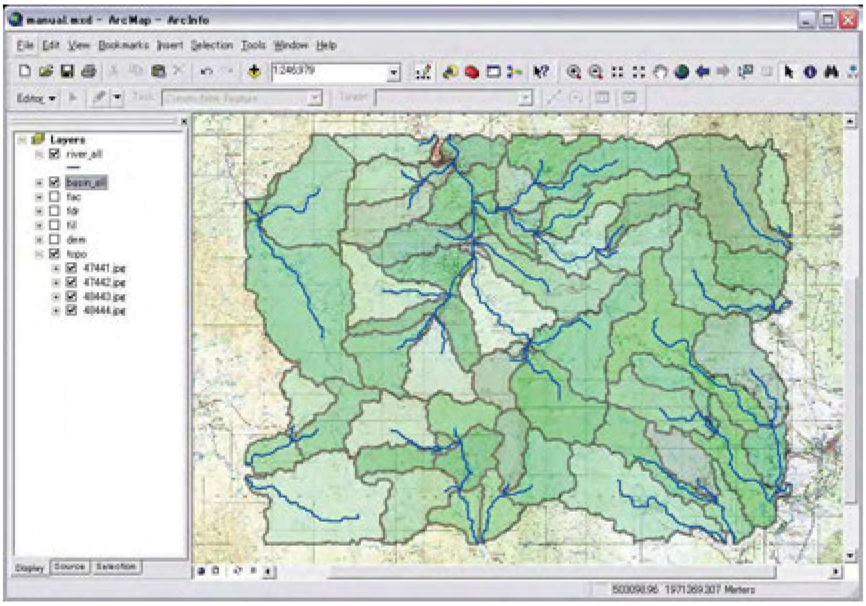
Basin Preparation



➢ The rivers and the sub-basins, which have the area more than 10 km^2, were extracted.

➢ Note that it contains unnecessary area for your analysis. You have to extract only the project basin from "**river_all**" and "**basin_all**" in the next step.

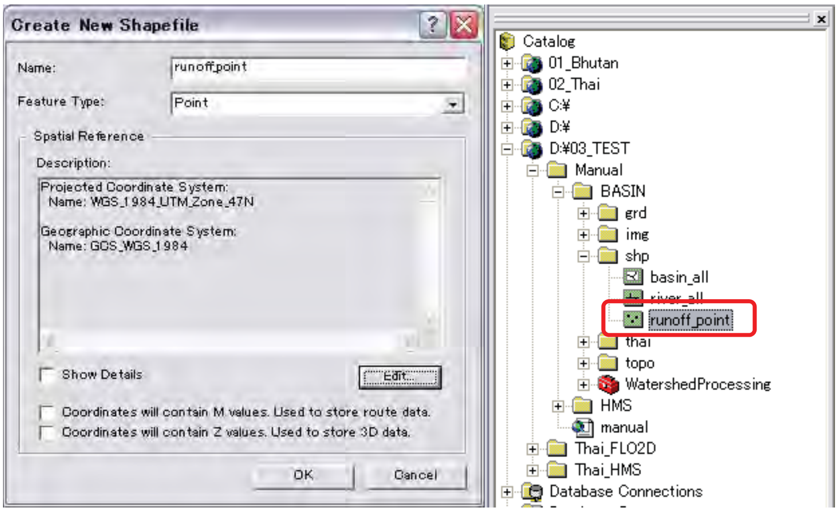
Basin Extraction



➤ Firstly you need define the location where you want to know the runoff (hydrograph).

➤ Change the symbol and transparency of "**river_all**" and "**basin_all**" as you can see the underlying topo-sheet map to define the runoff point.

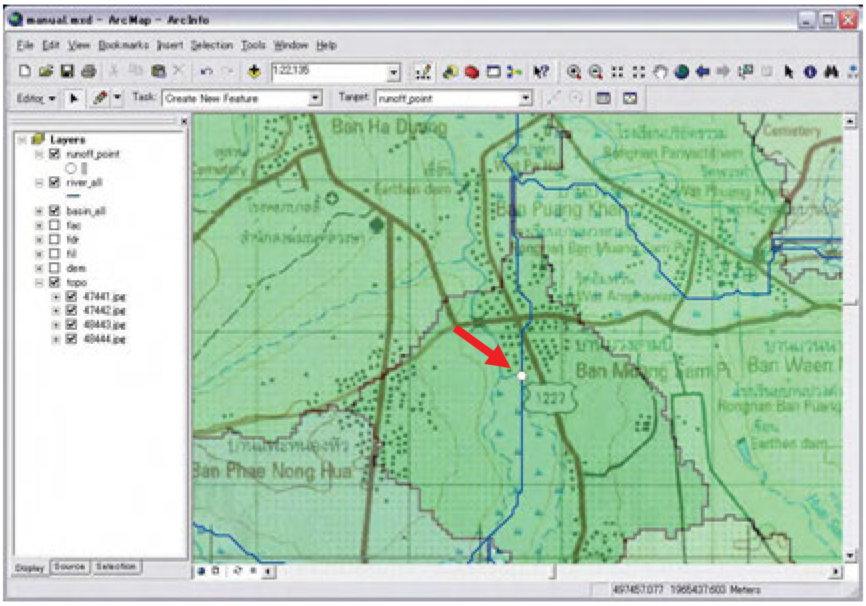
Basin Extraction



➤ Open [**ArcCatalog**] and create point feature of "**runoff_point.shp**" in [**Shape**] folder.

➤ Add the "**runoff_point.shp**" to the ArcMap.

Basin Extraction

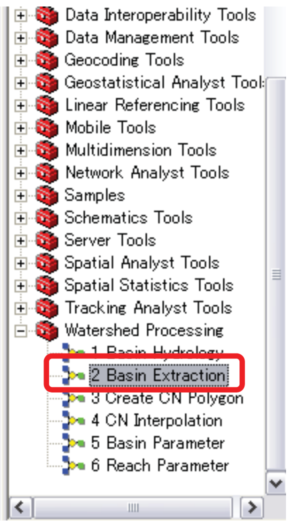


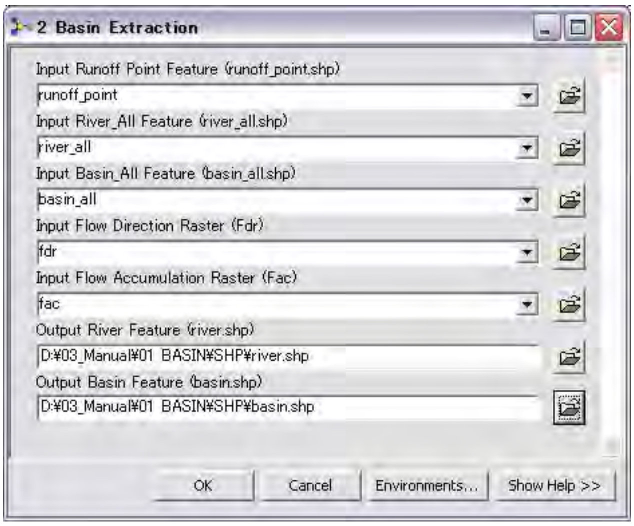
➤ Start editing of "**runoff_point.shp**" by [Editor].

➤ Find out "**Muang Sam Pee**" village in the map, and add a point on the map. The point must be near the "**river_all**" shape, but not necessary to be exactly on the line.

➤ Then stop editing.

Basin Extraction



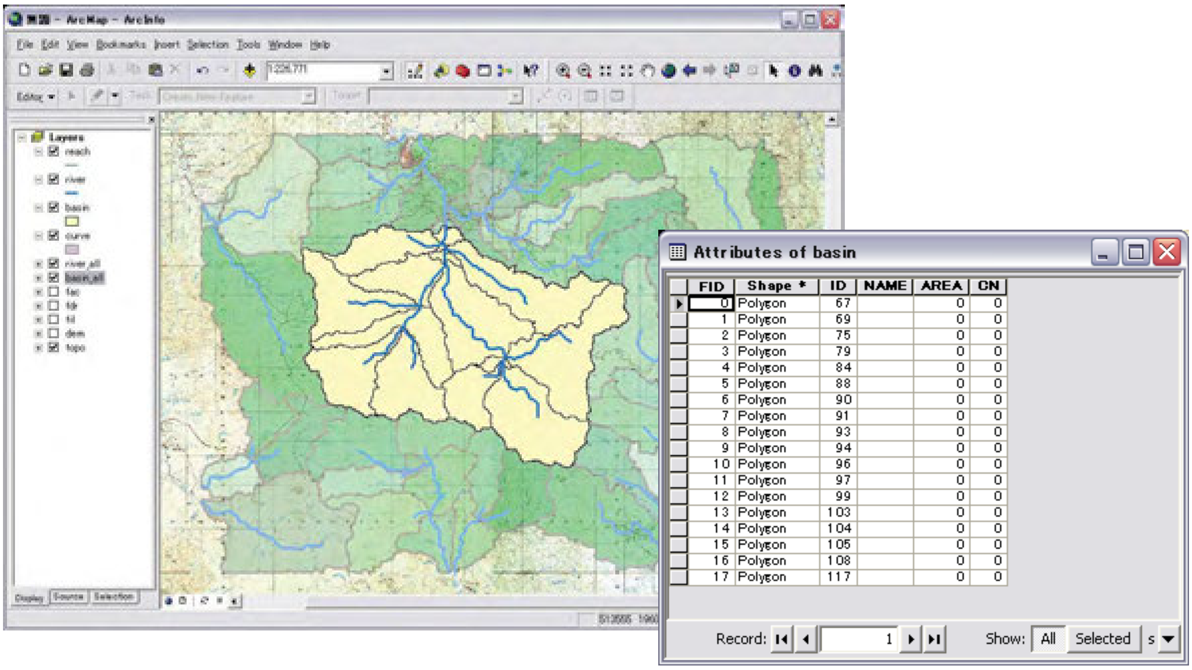


➤ Select [**Watershed Processing**] – [**2 Basin Extraction**] in the toolbox.

➤ In the dialog, enter the necessary information as above. Output River Feature is "**river.shp**" and Output Basin Feature is "**basin.shp**".

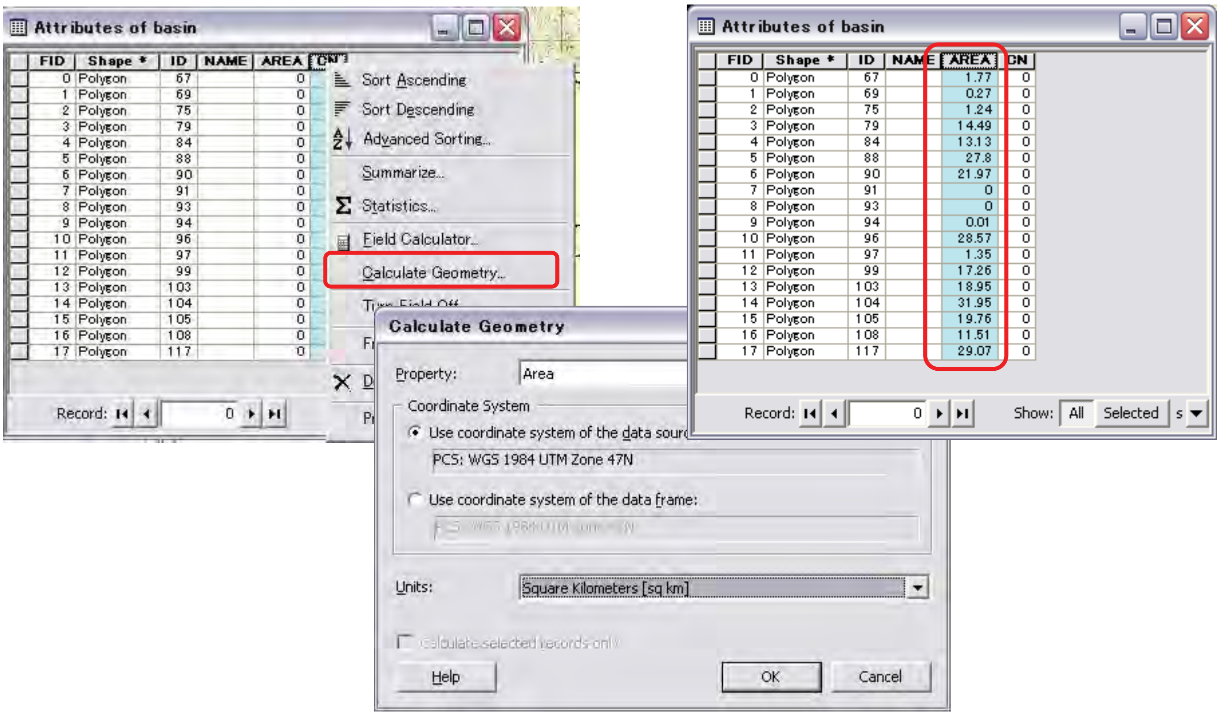
➤ Then click [**OK**].

Basin Extraction



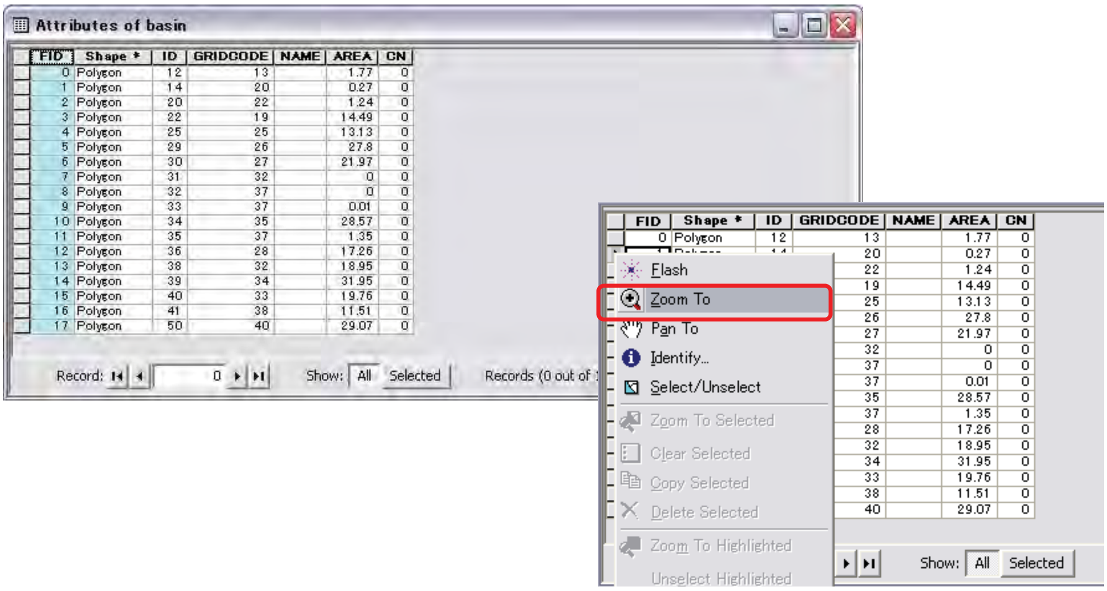
- Make sure that your target basin area was successfully extracted.
- Open the attribution table of “**basin.shp**”. Now you can find seventeen (**17**) polygons in it.
- You can remove unnecessary layers of “basin_all”, “river_all” and “runoff_point”.

Basin Modification



- Right click on the field of [**AREA**], and select [**Calculate Geometry**]. In the following dialog, select units as “**Square Kilometers [sq km]**”, and click [**OK**].
- You will obtain the area of each sub basins as above.

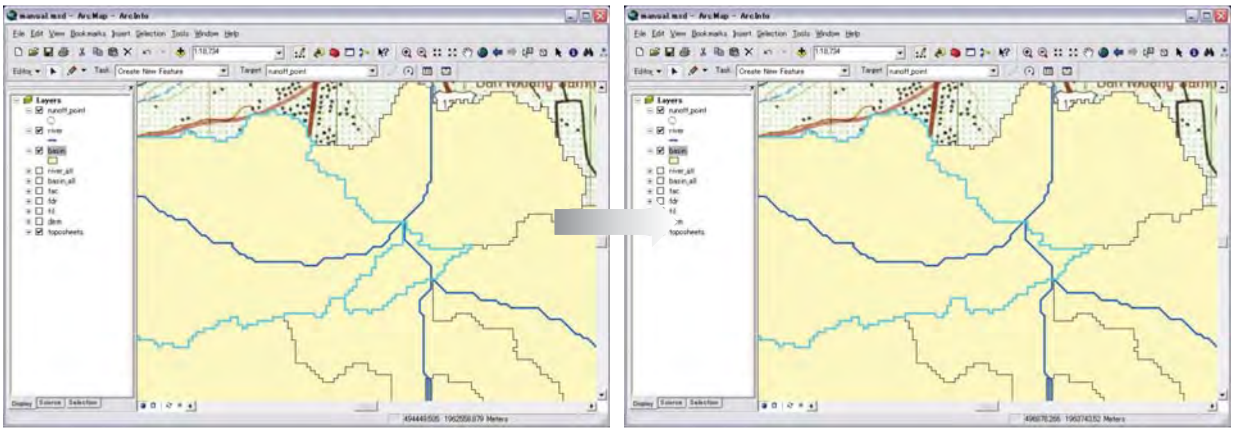
Basin Modification



➢ You may notice that there are several "**0**" km^2 sub-basins or too small sub-basins in the table. You have to manually modify these sub-basins as to be suitable for calculation.

➢ Right click at the left-end of record of a small sub-basin (e.g. FID = 1) and click [**Zoom To**].

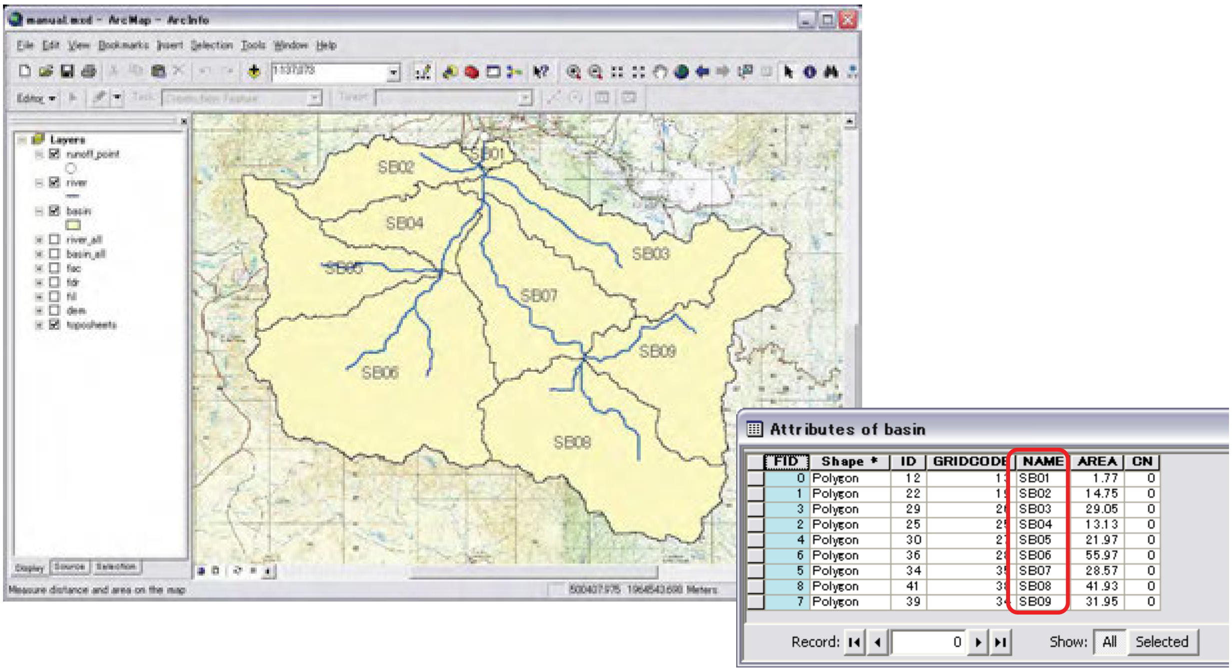
Basin Modification



➢ Start editing of "**basin.shp**".

➢ Select two (2) polygons which you want to merge. In this case, select [FID] = 2 and 4. Then ,select [**Editor**] – [**Merge**]. Make sure that the two sub-basins were merged as above.

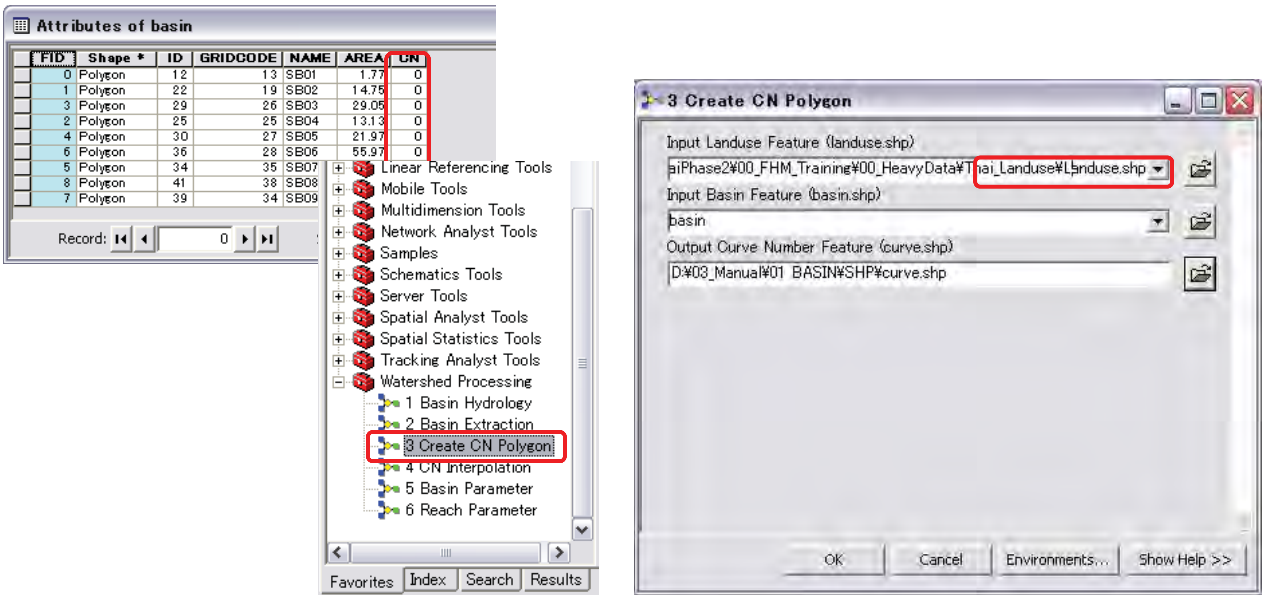
Basin Modification



➢ Likewise, merge the other sub-basins. Finally produce nine (9) sub-basins in the project area as above. And then edit the name of 9 sub-basin (**SB01**, **SB02**, **SB03** …) as above.

➢ **Make sure that re-calculate the area after modification of sub-basins!!**

Curve Number

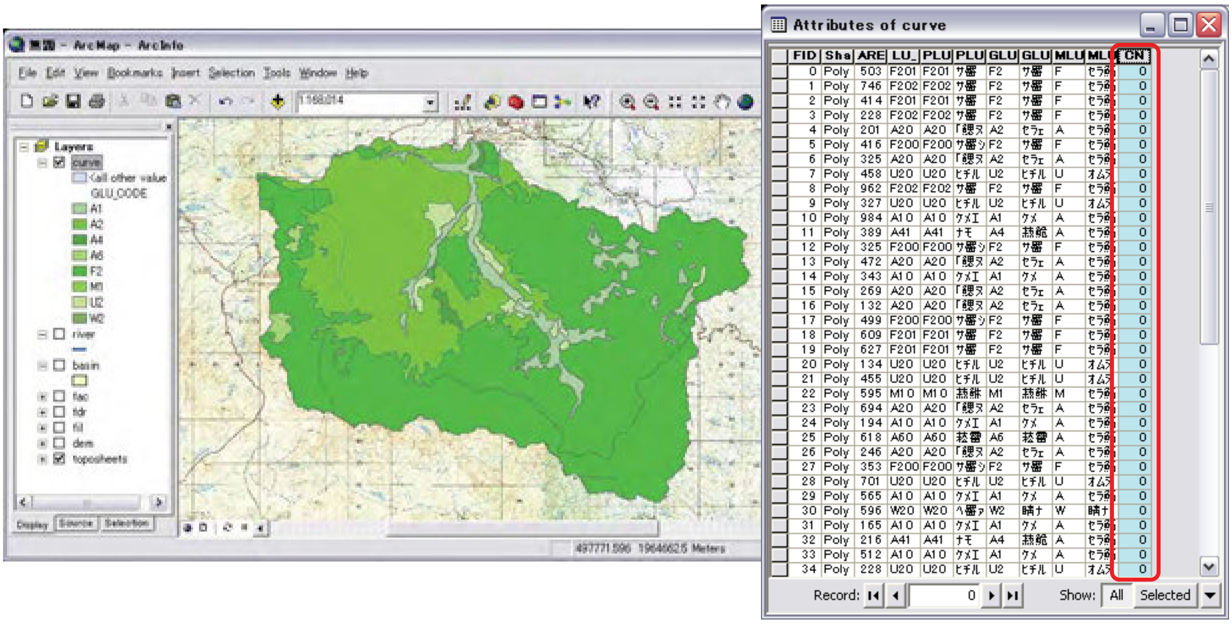


➢ The attribute table of "**basin.shp**" has a field of [**CN**] for "Curve Number". You can manually enter the curve number referring "Table of Runoff Curve Number" in the last session.

➢ In this manual, however, you will extract the [**CN**] from land use data "**Landuse.shp**" instead.

➢ Open [**3 Create CN Polygon**] from toolbox. In the dialog, select "**Landuse.shp**" and "**basin.shp**" for Input Feature, and named Output Feature as "**curve.shp**". Then click [**OK**].

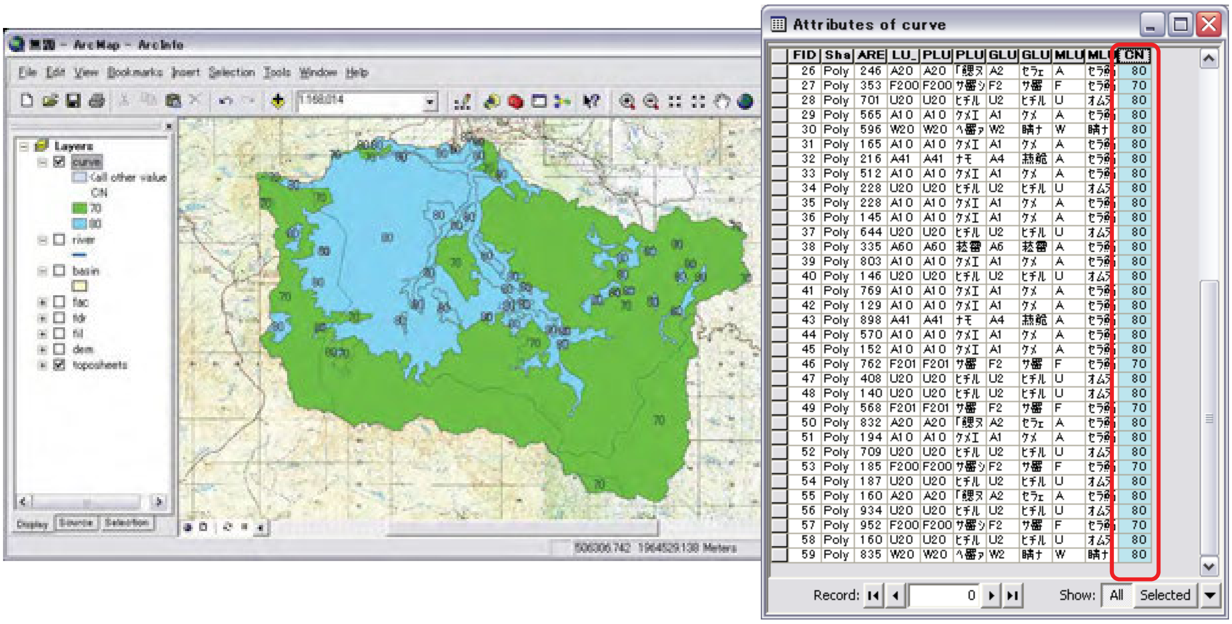
Curve Number



➢ The attribute table of the output “**landuse.shp**” has a column of [**CN**]. Now the value of each polygon is “**0**”.So please assign the adequate curve number value.

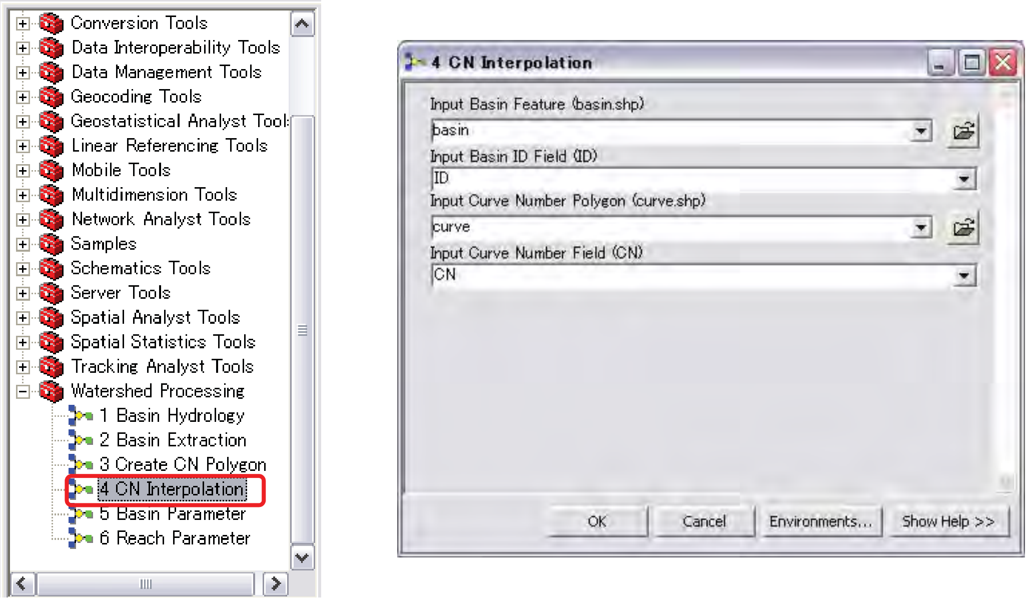
➢ In this manual, assign “**70**” for forest “F”, and assign “**80**” for the other land.

Curve Number



➢ Now the “**landuse.shp**” has curve number value in [**CN**] as above.

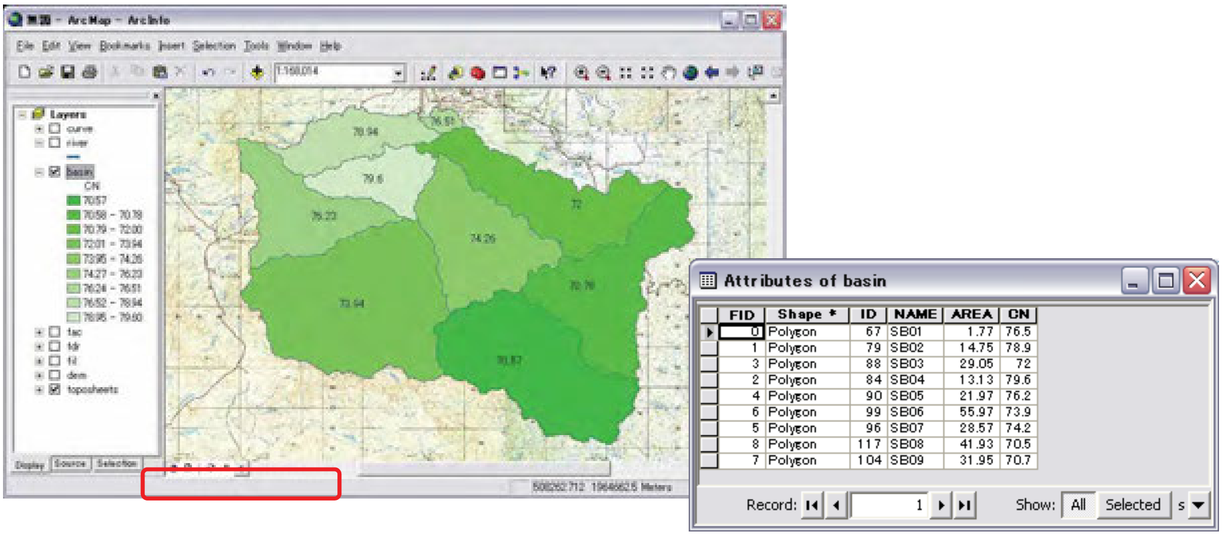
Curve Number



➢ Now you can interpolate the curve number into the "**basin.shp**".

➢ Open tool of [**4 CN Interpolation**]. In the dialog, select "**basin.shp**" and "**ID**" for Input Basin Feature and ID Field, and select "**curve.shp**" and "**CN**" for Input Curve Number. And then click [**OK**].

Curve Number

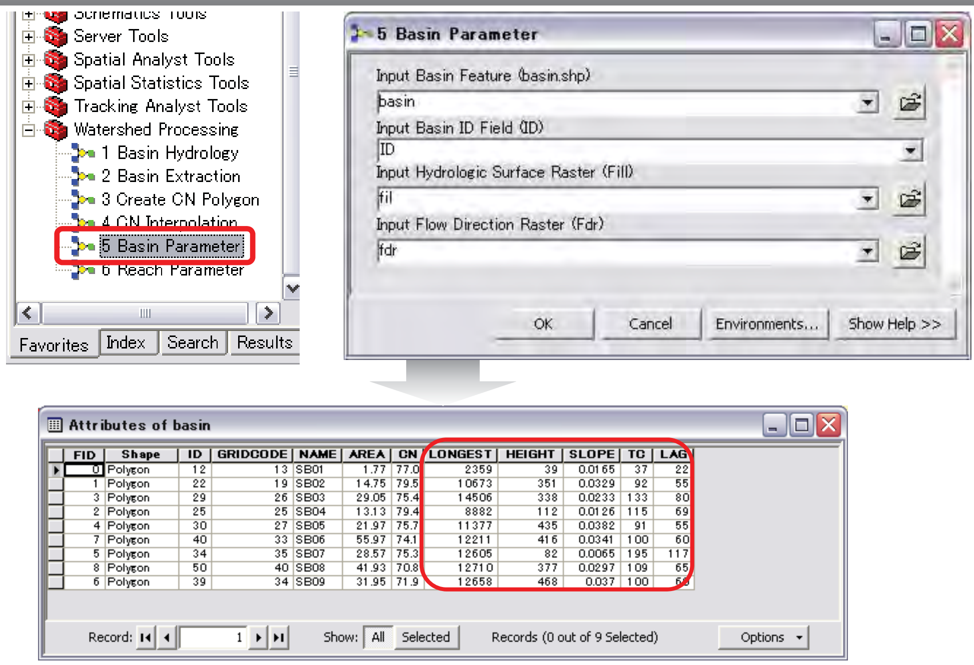


FID	Shape *	ID	NAME	AREA	CN
0	Polygon	67	SB01	1.77	76.5
1	Polygon	79	SB02	14.75	78.9
3	Polygon	88	SB03	29.05	72
2	Polygon	84	SB04	13.13	79.6
4	Polygon	90	SB05	21.97	76.2
6	Polygon	99	SB06	55.97	73.9
5	Polygon	96	SB07	28.57	74.2
8	Polygon	117	SB08	41.93	70.5
7	Polygon	104	SB09	31.95	70.7

➢ Confirm that the "**basin.shp**" has now curve number value in the field of [**CN**].

➢ If the most part of sub-basin area is occupied by forest, the curve number must be near to "**70**". If it contains large area of cultivation field, then the value must be near to "**80**".

Basin Parameter Extraction

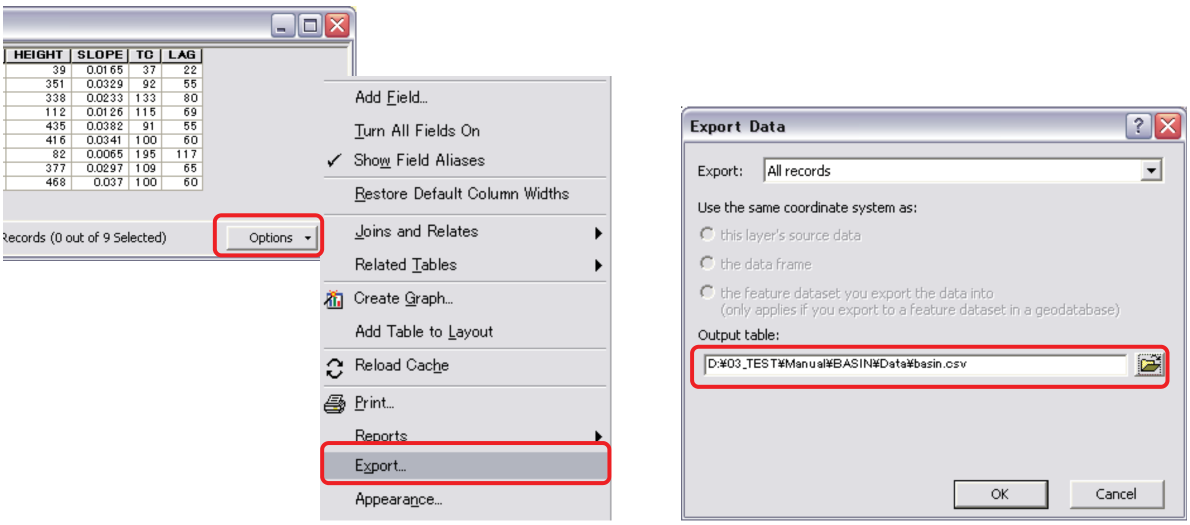


FID	Shape	ID	GRIDCODE	NAME	AREA	CN	LONGEST	HEIGHT	SLOPE	TC	LAG
0	Polygon	12	13	SB01	1.77	77.0	2359	39	0.0165	37	22
1	Polygon	22	19	SB02	14.75	79.5	10673	351	0.0329	92	55
3	Polygon	29	26	SB03	29.05	75.4	14506	338	0.0233	133	80
2	Polygon	25	25	SB04	13.13	79.4	8882	112	0.0126	115	69
4	Polygon	30	27	SB05	21.97	75.7	11377	435	0.0382	91	55
7	Polygon	40	33	SB06	55.97	74.1	12211	416	0.0341	100	60
5	Polygon	34	35	SB07	28.57	75.3	12605	82	0.0065	195	117
8	Polygon	50	40	SB08	41.93	70.8	12710	377	0.0297	109	65
6	Polygon	39	34	SB09	31.95	71.9	12658	468	0.037	100	60

➢ In this manual, “**Krippen Formula**” will be employed to calculate Time of Concentration (TC) and Lag Time (LAG).

➢ Select [**Watershed Processing**] – [**5 Basin Parameter**] in the toolbox. Select the necessary items as above figure. If you cannot select “ID” from pull-down menu, enter “ID” manually. Then click [**OK**].

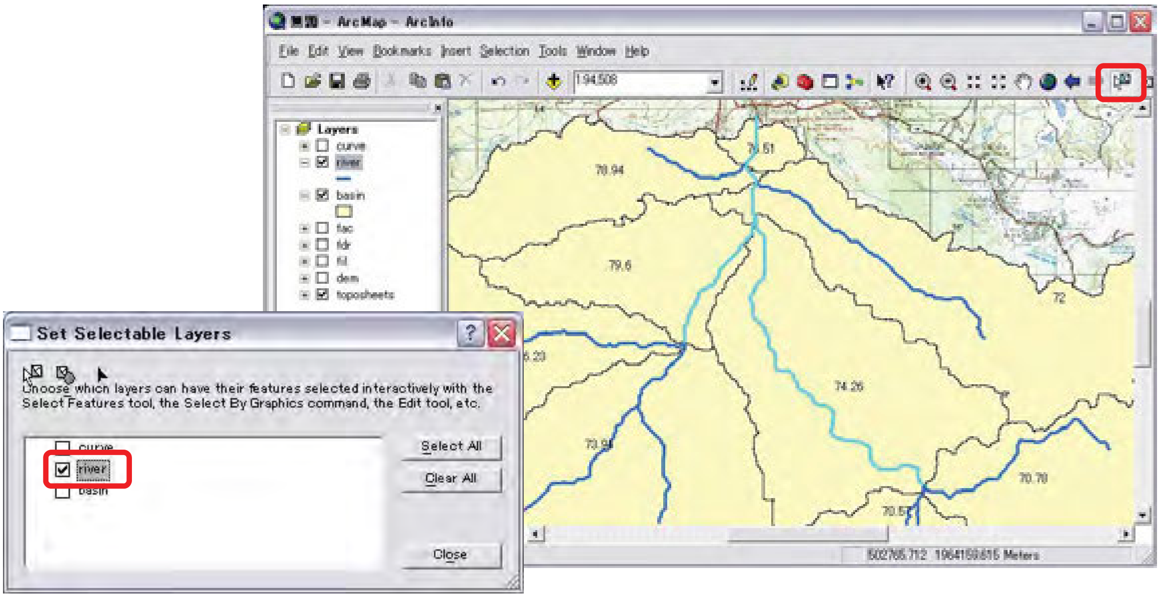
Basin Parameter Extraction



➢ Select [**Options**] in the attribute table, and select [**Export**].

➢ In the dialog, save the exporting table as “**basin.dbf**”. It is recommended to create a new folder of [**data**] in [**BASIN**], and save in it.

Reach Preparation

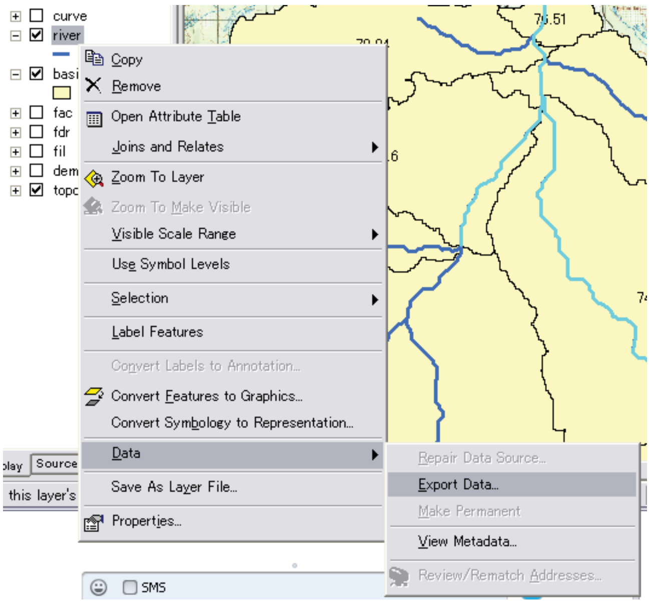


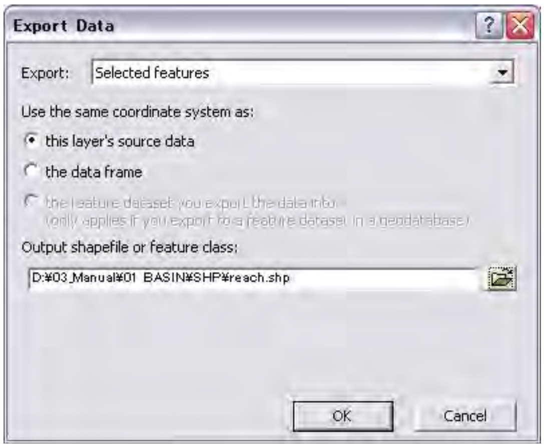
➢ Now you need to extract “**reach.shp**”.

➢ Select only reach segments from the “**river.shp**” by [**Select Features**] Tool. Here you can find 5 reach segments as above.

➢ To avoid miss-selection, it is recommend to set selectable layers only “**river.shp**” by [**Selection**] – [**Set Selectable Layers**].

Reach Preparation

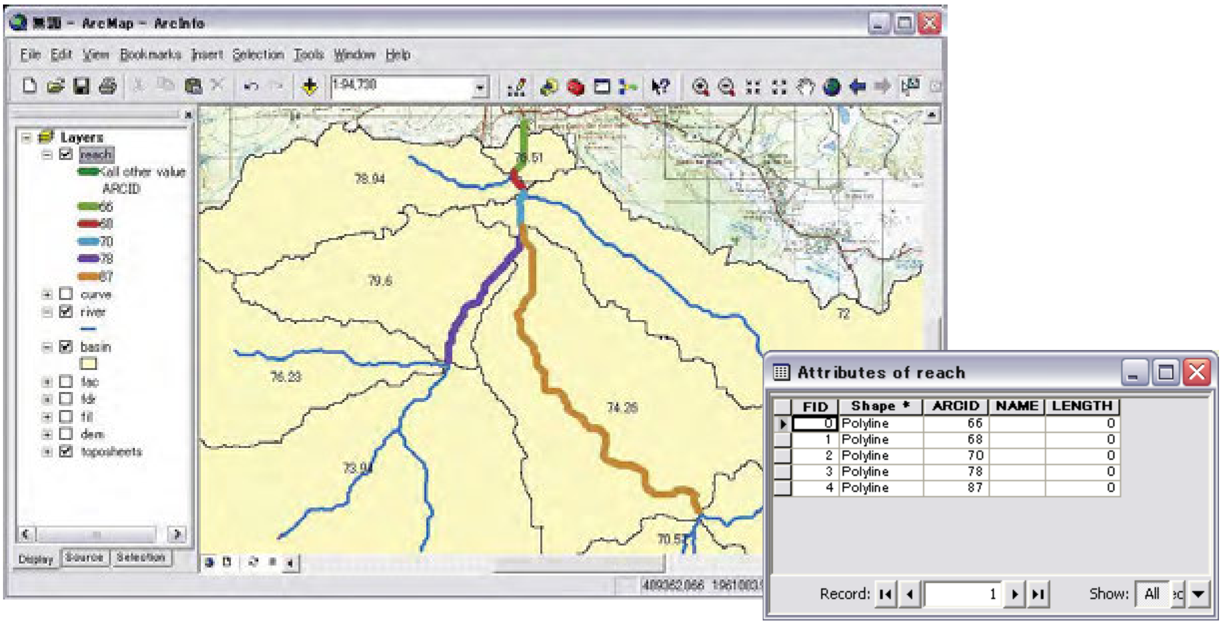




➢ Keep the selection, and right click on “**river.shp**”. Select [**Data**] – [**Export Data**].

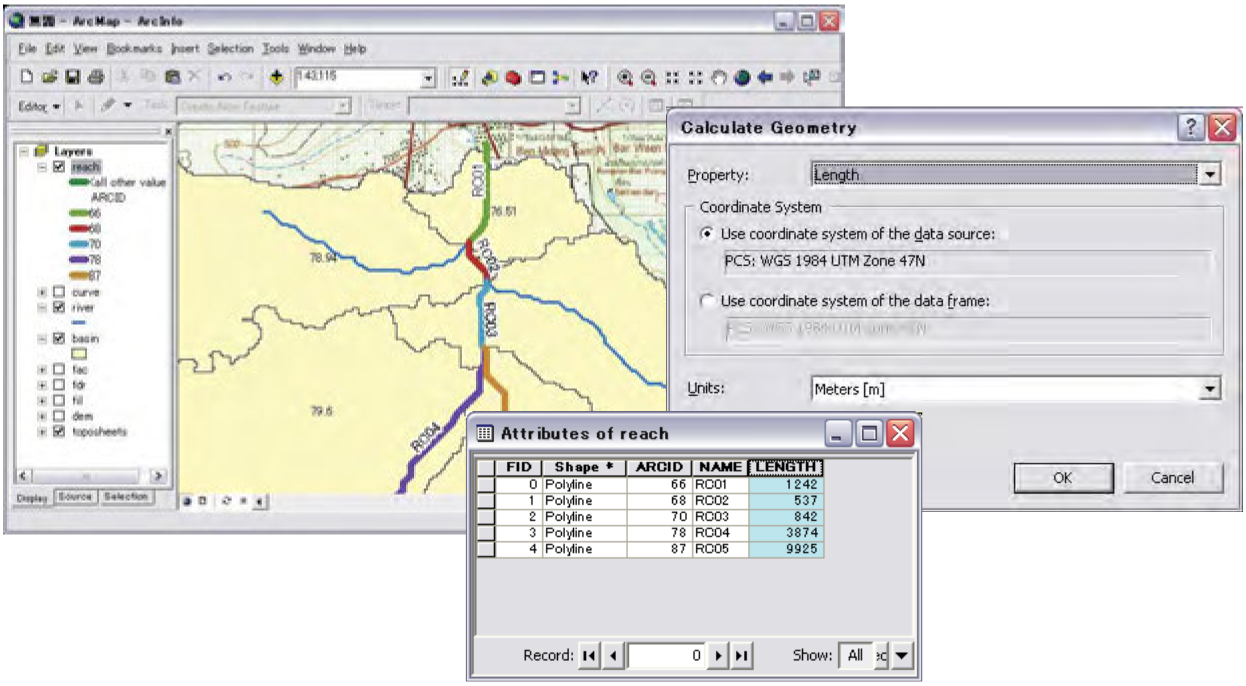
➢ In the dialog, confirm the “**Selected features**” are selected as [**Export**]. Click [**OK**].

Reach Preparation



➢ Now you have obtained "**reach.shp**" as above.

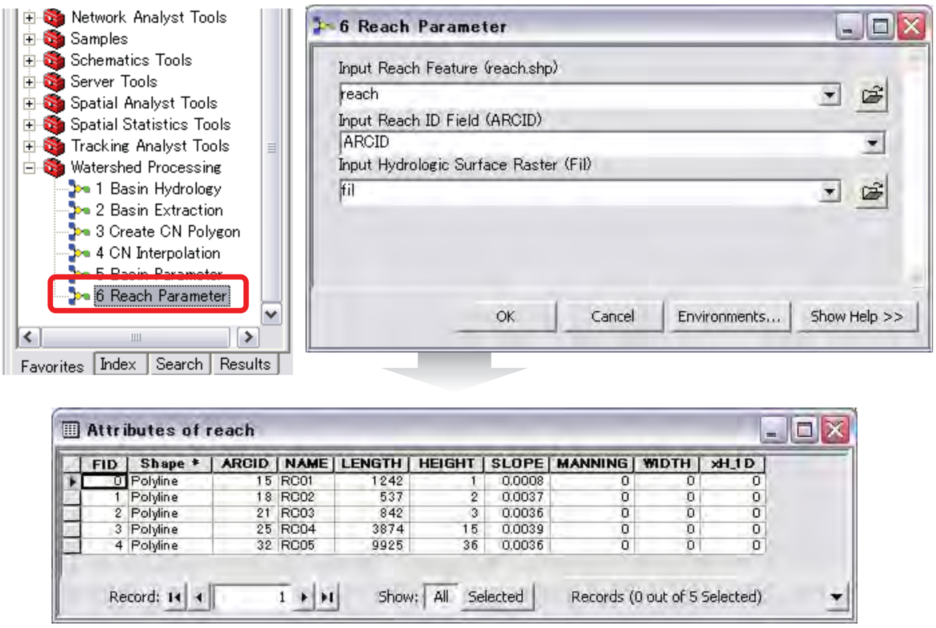
Reach Preparation



➢ Using Editor, assign the name of reaches "**RC01**", "**RC02**", "**RC03**", "**RC04**" and "**RC05**" from downstream to upstream.

➢ Calculate [**LENGTH**] in meter [m] by using [**Calculate Geometry**].

Reach Parameter Extraction



FID	Shape *	ARCID	NAME	LENGTH	HEIGHT	SLOPE	MANNING	WIDTH	xH_1D
0	Polyline	15	RC01	1242	1	0.0008	0	0	0
1	Polyline	18	RC02	537	2	0.0037	0	0	0
2	Polyline	21	RC03	842	3	0.0036	0	0	0
3	Polyline	25	RC04	3874	15	0.0039	0	0	0
4	Polyline	32	RC05	9925	36	0.0036	0	0	0

➢ Select [**Watershed Processing**] – [**6 Reach Parameter**] in the toolbox.

➢ Select "**reach.shp**" for [Input Reach Feature], "**ARCID**" for [Input Reach ID] and "**Fil**" for [Input Hydrologic Surface Raster]. Then click [**OK**].

➢ [**HEIGHT**] and [**SLOPE**] will be automatically calculated as above.

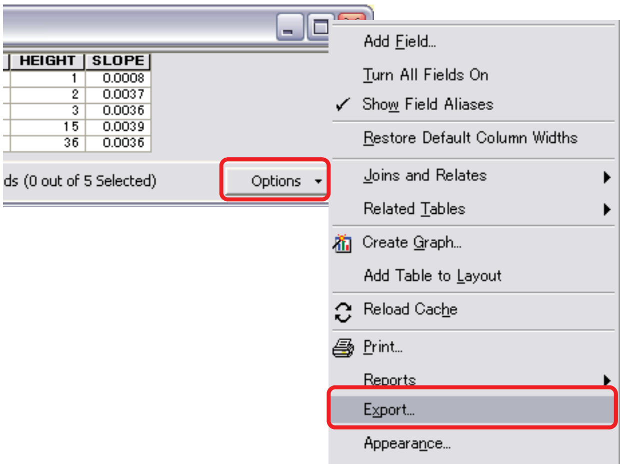
Reach Parameter Extraction

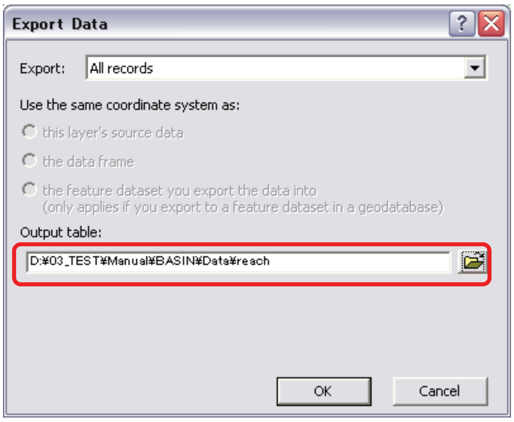
FID	Shape *	ARCID	NAME	LENGTH	HEIGHT	SLOPE	MANNING	WIDTH	xH_1D
0	Polyline	15	RC01	1242	1	0.0008	0	0	0
1	Polyline	18	RC02	537	2	0.0037	0	0	0
2	Polyline	21	RC03	842	3	0.0036	0	0	0
3	Polyline	25	RC04	3874	15	0.0039	0	0	0
4	Polyline	32	RC05	9925	36	0.0036	0	0	0

FID	Shape *	ARCID	NAME	LENGTH	HEIGHT	SLOPE	MANNING	WIDTH	xH_1D
0	Polyline	15	RC01	1242	1	0.0008	0.06	20	2
1	Polyline	18	RC02	537	2	0.0037	0.06	20	2
2	Polyline	21	RC03	842	3	0.0036	0.06	20	2
3	Polyline	25	RC04	3874	15	0.0039	0.06	15	2
4	Polyline	32	RC05	9925	36	0.0036	0.06	15	2

➢ Edit "**reach.shp**" and manually fill the blank items of [**MANNING**], [**WIDTH**] and [**xH_1D**] as above. The [**xH_1D**] that is the arc cotangent of channel bank slope.

Reach Parameter Extraction





- Select [**Options**] in the attribute table of “**reach.shp**”, and select [**Export**].
- In the dialog, save the exporting table as “**river.dbf**” in the folder of [**data**] in [**BASIN**].

Output Parameters

Sub-basin Parameters

	A	B	C	D	E	F	G	H	I	J	K
1	ID	GRIDCODE	NAME	AREA	CN	LONGEST	HEIGH	SLOPE	TC	LAG	
2	12	13	SB01	1.77	77.11	2359	39	0.0165	37	22	
3	22	19	SB02	14.75	79.36	10673	351	0.0329	92	55	
4	25	25	SB04	13.13	79.44	8882	112	0.0126	115	69	
5	29	26	SB03	29.05	75.53	14506	338	0.0233	133	80	
6	30	27	SB05	21.97	75.68	11377	435	0.0382	91	55	
7	34	35	SB07	28.57	75.42	12605	82	0.0065	195	117	
8	35	37	SB08	41.93	70.92	12710	377	0.0297	109	65	
9	36	28	SB06	55.97	74.15	12211	416	0.0341	100	60	
10	39	34	SB09	31.95	71.97	12658	468	0.0370	100	60	
11											

Reach Parameters

	A	B	C	D	E	F	G	H	I	J
1	ARCID	NAME	LENGTH	HEIGHT	SLOPE	MANNING	WIDTH	xH_1D		
2	15	RC01	1242	1.0	0.0008	0.0600	20.00	2.00		
3	18	RC02	537	2.0	0.0037	0.0600	20.00	2.00		
4	21	RC03	842	3.0	0.0036	0.0600	20.00	2.00		
5	25	RC04	3874	15.0	0.0039	0.0600	15.00	2.00		
6	32	RC05	9925	36.0	0.0036	0.0600	15.00	2.00		

- Finally, you have obtained all parameters of Sub-basins and Reaches.
- These parameters will be input into the HEC-HMS Runoff Model in the next session.

END

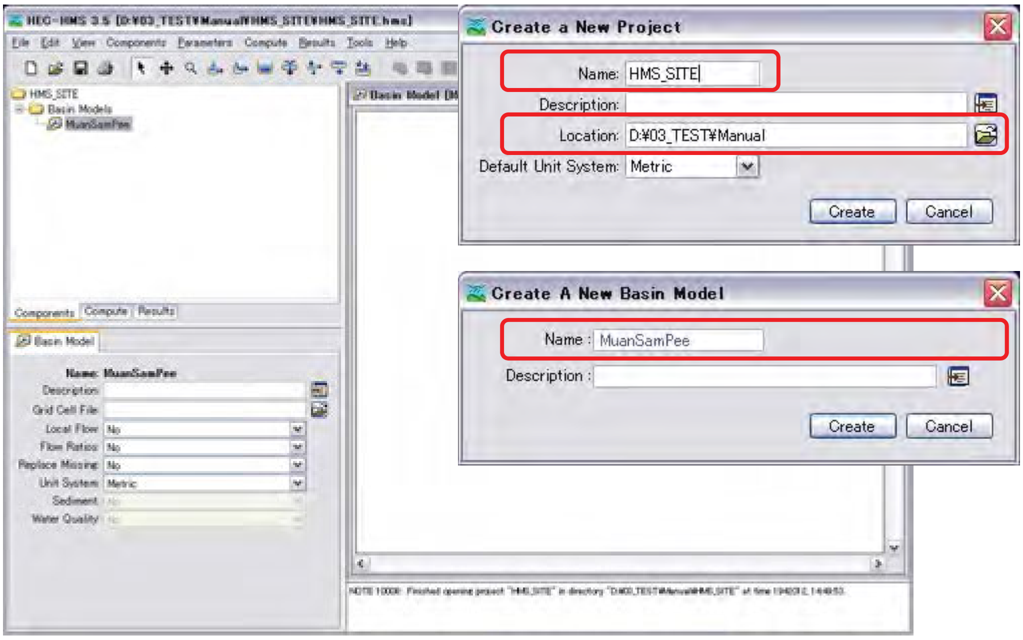
Lesson 3
Runoff Analysis

Runoff Modeling by HEC-HMS

Task Force – Flood Risk Management

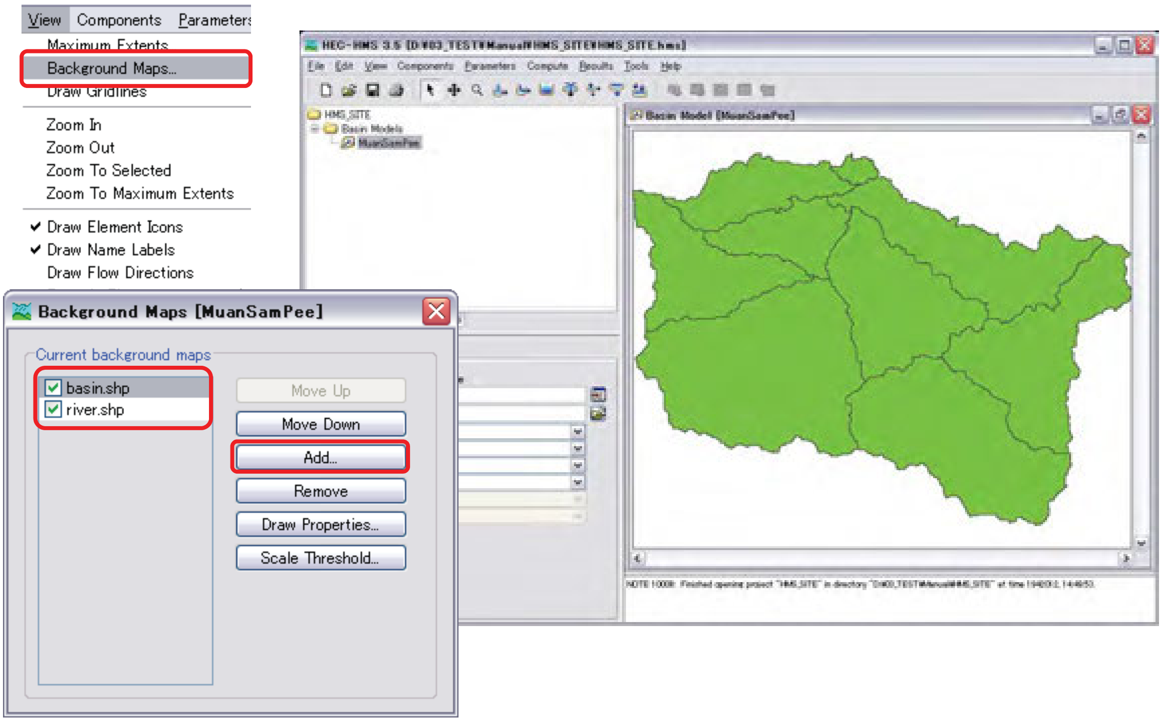
Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Setup Basin Model



- Open HEC-HMS. Create new project "**HMS_SITE**".
- Create a new basin model of "**MuanSamPee**".

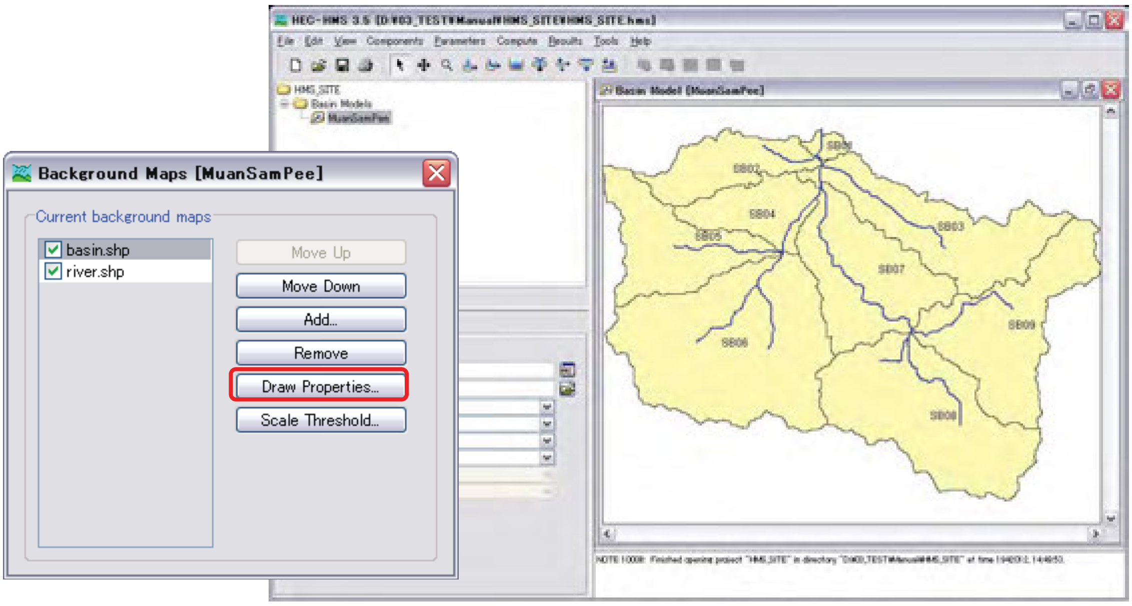
Setup Basin Model



➢ Select [**View**] – [**Background Maps**]. In the dialog, click [**Add**].

➢ Browse "**basin.shp**" and "**river.shp**" in the folder of [**BASIN**] – [**shp**]. Then click [**Select**].

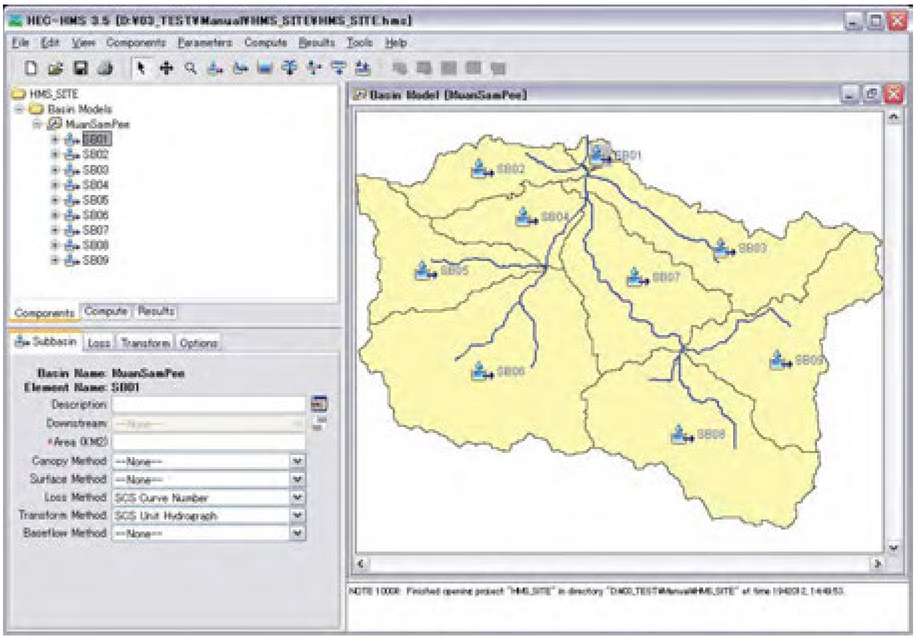
Setup Basin Model



➢ Select [**View**] – [**Background Maps**], and click [**Draw Properties**].

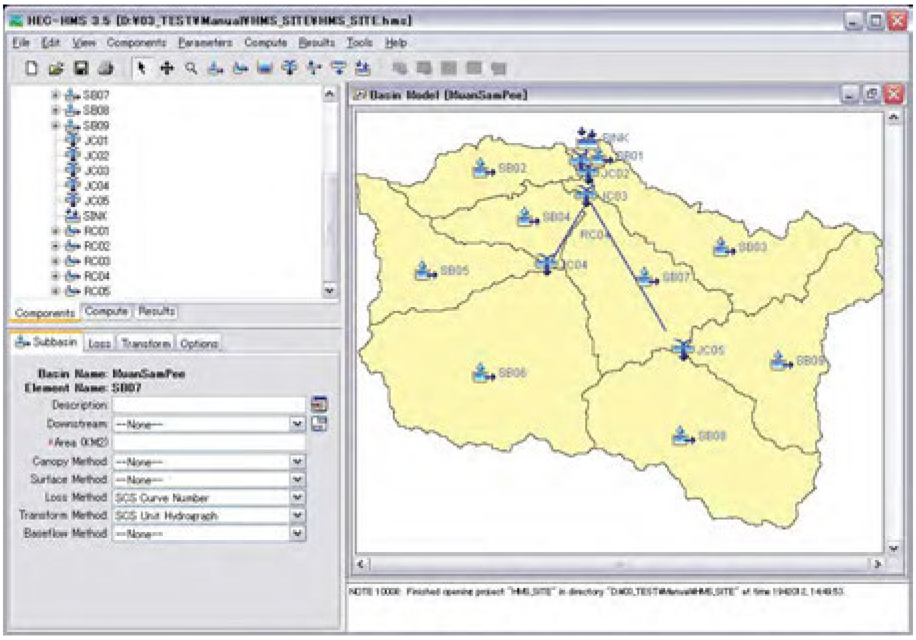
➢ In the dialog, you can change the symbols and transparency as well as labeling.

Setup Basin Model



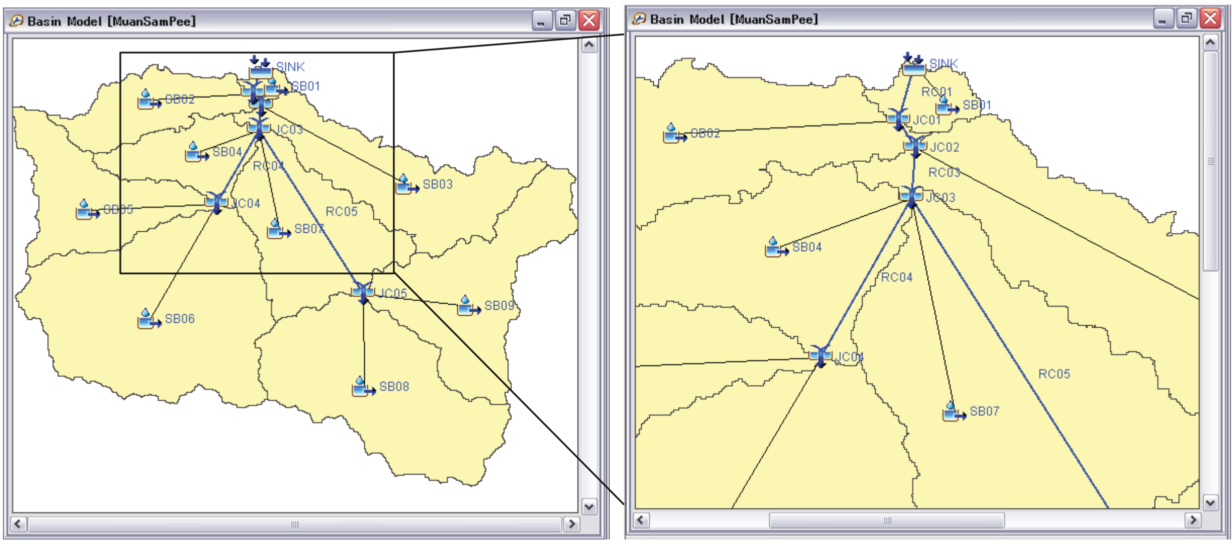
➢ Put [**Subbasin**] elements of **SB01 – SB09** on the map.

Setup Basin Model



➢ Likewise, put [**Junction**] elements of "**JC01 – JC05**", [**Reach**] elements of "**RC01 – RC05**" and [**Sink**] element of "**SINK**".

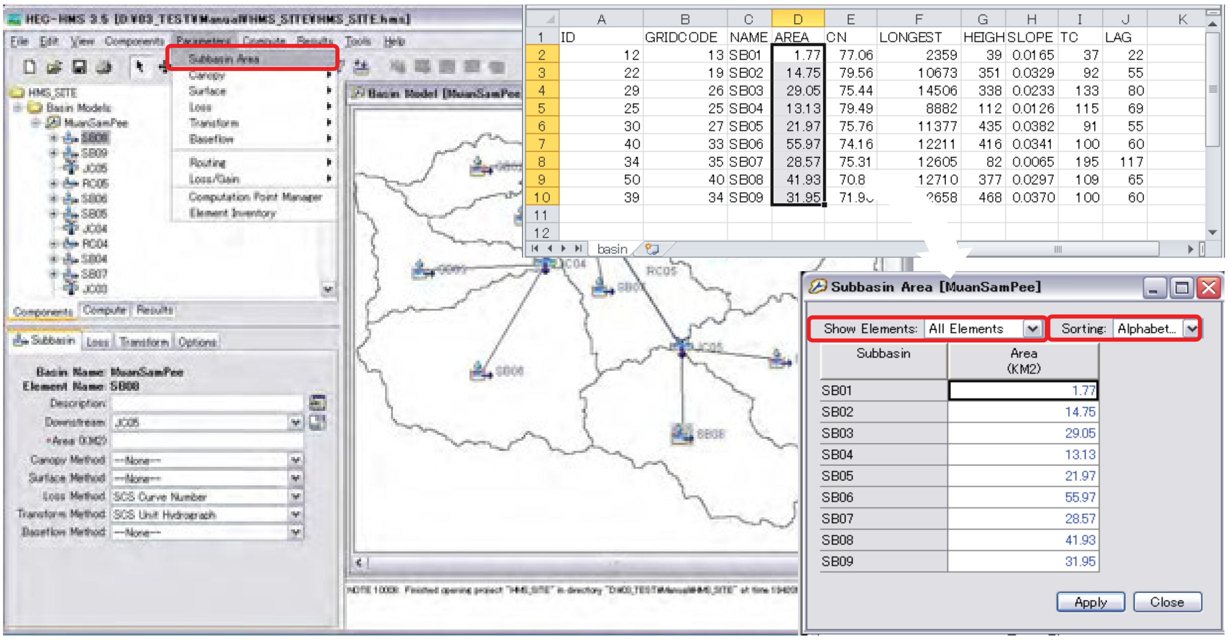
Setup Basin Model



➢ Connect each element by right clicking on the element and select [**Connect Downstream**].

➢ Make sure that all elements have connected properly.

Setup Basin Model

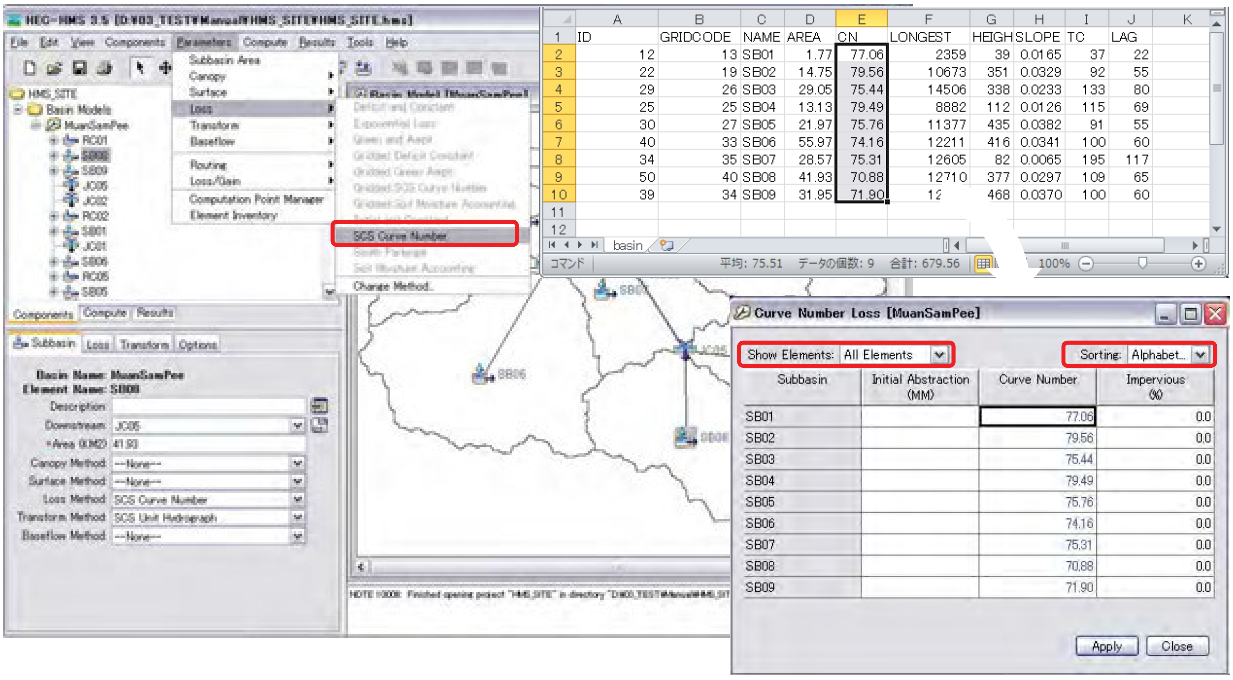


➢ Select any sub-basin elements. Then, select [**Parameters**] – [**Subbasin Area**].

➢ Open data file of “**basin.dbf**” by Excel, and copy [**AREA**] into [**Area (KM2)**] of basin model.

➢ **Caution!!** Don’t forget to sort data on Excel and HEC-HMS (you can sort by select [Sorting] on the up-right corner.

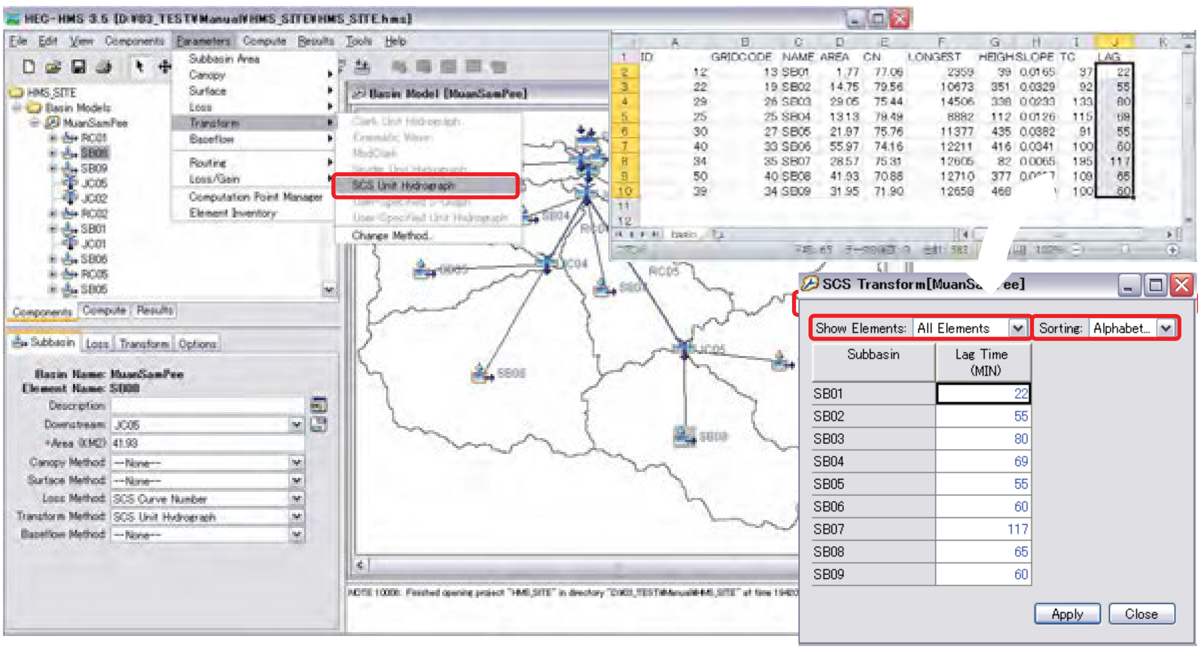
Setup Basin Model



➢ Select [**Parameters**] – [**Loss**] – [**SCS Curve Number**].

➢ Open data file of "**basin.dbf**" by Excel, and copy [**CN**] into [**Curve Number**] of basin model.

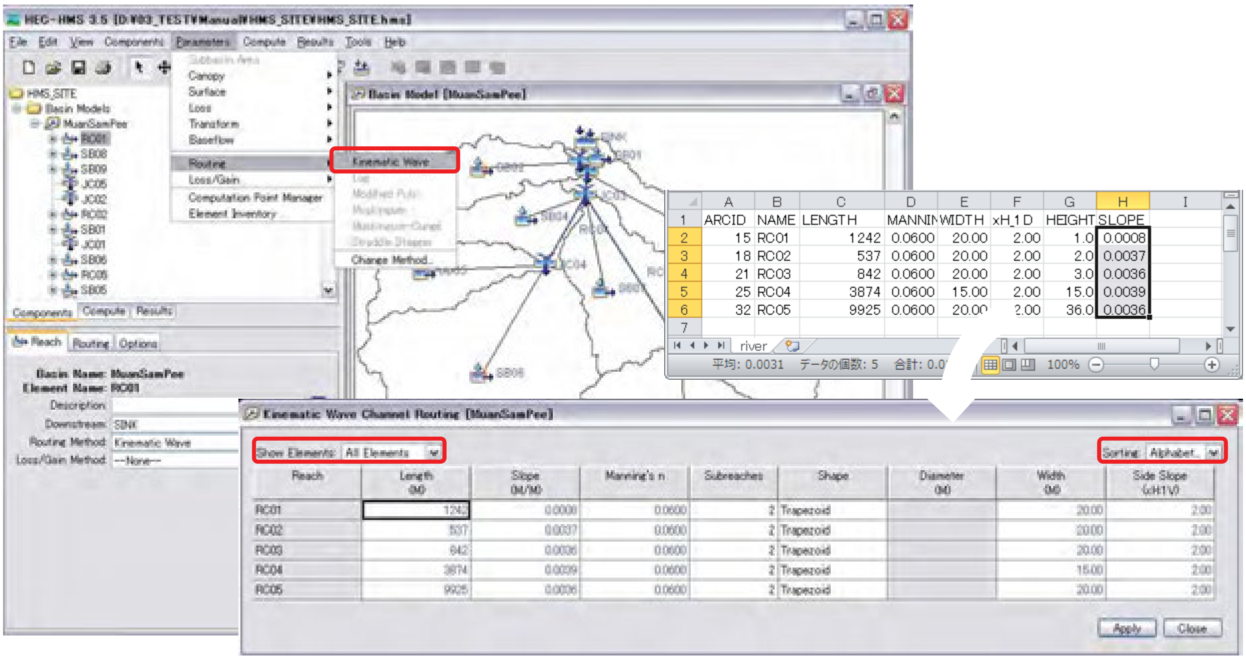
Setup Basin Model



➢ Select [**Parameters**] – [**Transform**] – [**SCS Unit Hydrograph**].

➢ Open data file of "**basin.dbf**" by Excel, and copy [**LAG**] into [**Lag Time (MIN)**] of basin model.

Setup Basin Model

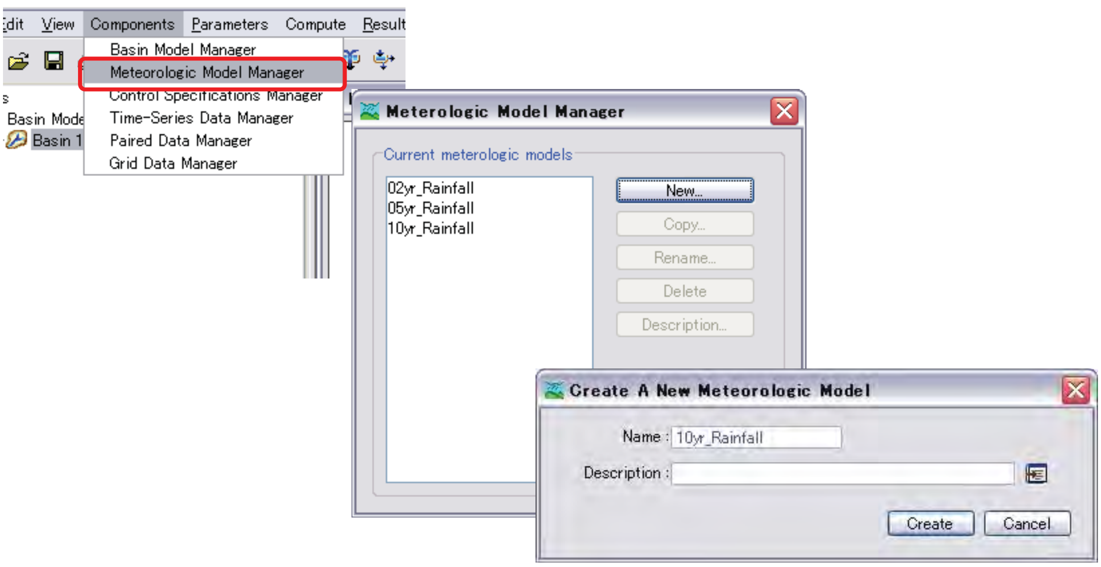


➢ Select any reach elements. Then, select [**Parameters**] – [**Routing**] – [**Kinematic Wave**].

➢Open data file of "**river.dbf**" by Excel, and copy [**LENGTH**], [**MANNING**], [**WIDTH**], [**xH_1D**] and [**SLOPE**] into the fields of reach elements as above.

➢ Now all parameters for the basin model have been completed. Save the project.

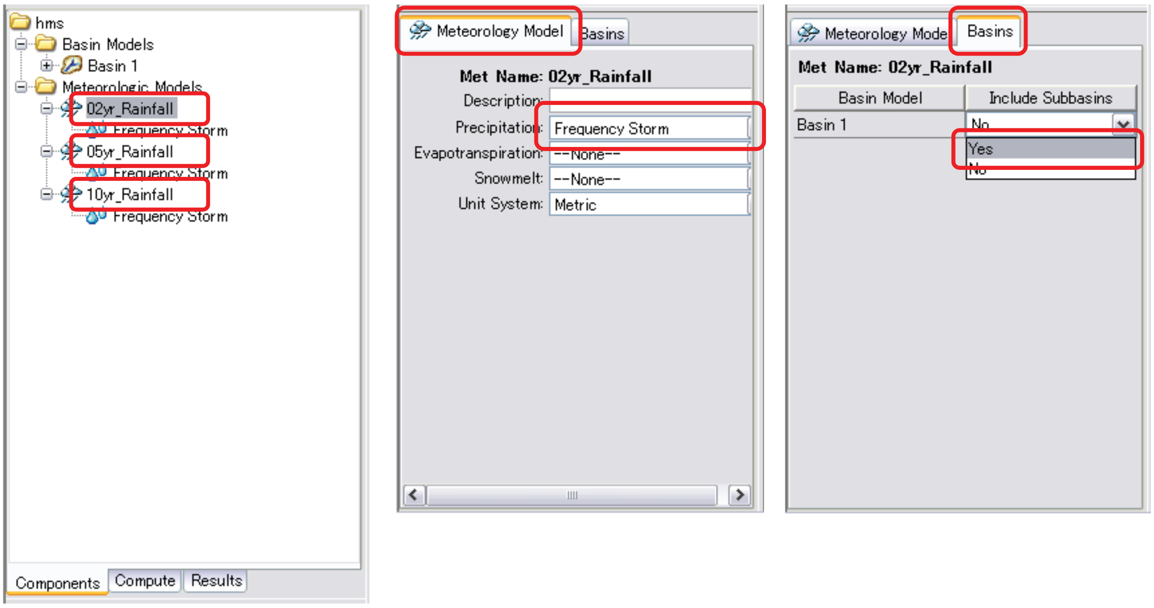
Setup Meteorologic Model



➢ Select [**Components**] – [**Meteorologic Model Manager**]. In the following dialog, click [**New**] and input name.

➢ Here, you will produce hydrographs of 2-yr, 5-yr and 10-yr probable. So, create five (5) meteorologic models named "**02yr_Rainfall**", "**05yr_Rainfall**" and "**10yr_Rainfall**".

Setup Meteorologic Model



➢Before entering rainfall data in your model, open [**Meteorology Model**] Tab, and select "**Frequency Storm**" for [**Precipitation**].

➢ Change to [**Basins**] Tab, and select "**Yes**" to include sub-basins. This means that the rainfall will be applied to the "**Basin 1**" model.

Setup Meteorologic Model

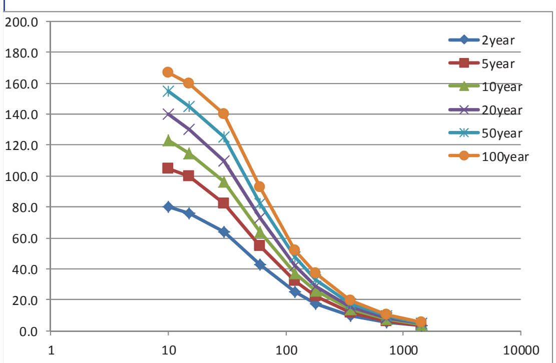
Bhumibol Dam, Tak

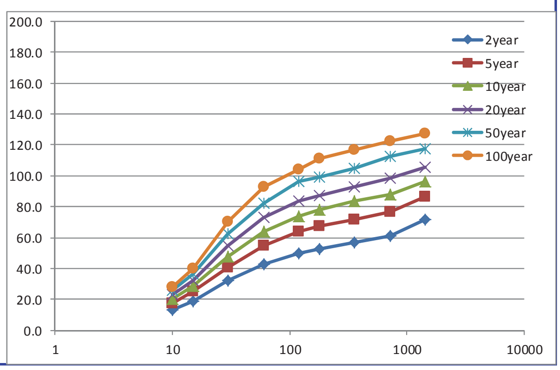
Rainfall Intensity (mm/hr)

	2year	5year	10year	20year	50year	100year
5						
10	80.0	105.0	123.0	140.0	155.0	167.0
15	76.0	100.0	115.0	130.0	145.0	160.0
30	64.0	82.0	96.0	110.0	125.0	140.0
60	43.0	55.0	64.0	73.0	82.0	93.0
120	25.0	32.0	37.0	42.0	48.0	52.0
180	17.5	22.5	26.0	29.0	33.0	37.0
360	9.5	12.0	14.0	15.5	17.5	19.5
720	5.1	6.4	7.3	8.2	9.4	10.2
1440	3.0	3.6	4.0	4.4	4.9	5.3

Rainfall Depth (mm)

	2year	5year	10year	20year	50year	100year
5						
10	13.3	17.5	20.5	23.3	25.8	27.8
15	19.0	25.0	28.8	32.5	36.3	40.0
30	32.0	41.0	48.0	55.0	62.5	70.0
60	43.0	55.0	64.0	73.0	82.0	93.0
120	50.0	64.0	74.0	84.0	96.0	104.0
180	52.5	67.5	78.0	87.0	99.0	111.0
360	57.0	72.0	84.0	93.0	105.0	117.0
720	61.2	76.8	87.6	98.4	112.8	122.4
1440	72.0	86.4	96.0	105.6	117.6	127.2

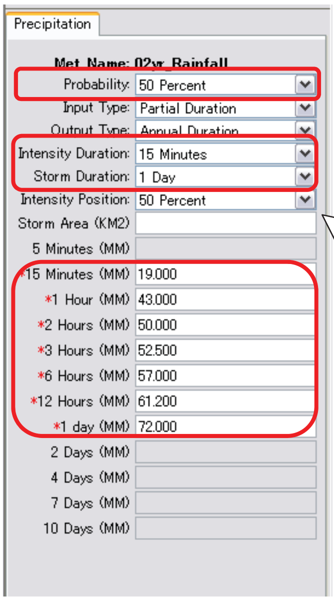




➢ The nearest rain gage station of Muan Sam Pee village is located at Bhumibol Dam. Open excel file of "Intensity Curve", and see the data of [**Bhumibol Dam, Tak**].

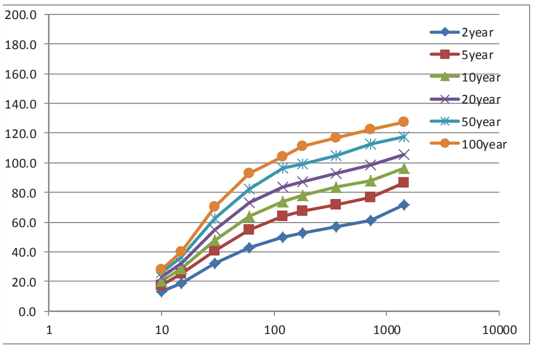
➢ In HEC-HMS, Rainfall Depth (mm) is used for frequency storm.

Setup Meteorologic Model



Rainfall Depth (mm)

	2year	5year	10year	20year	50year	100year
5						
10	13.3	17.5	20.5	23.3	25.8	27.8
15	19.0	25.0	28.8	32.5	36.3	40.0
30	32.0	41.0	48.0	55.0	62.5	70.0
60	43.0	55.0	64.0	73.0	82.0	93.0
120	50.0	64.0	74.0	84.0	96.0	104.0
180	52.5	67.5	78.0	87.0	99.0	111.0
360	57.0	72.0	84.0	93.0	105.0	117.0
720	61.2	76.8	87.6	98.4	112.8	122.4
1440	72.0	86.4	96.0	105.6	117.6	127.2

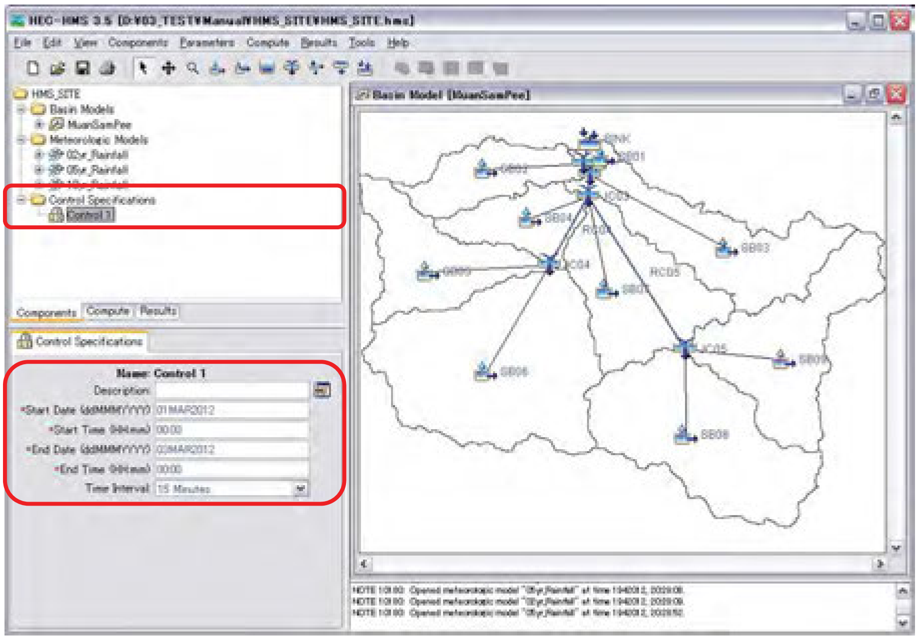


➢ Select [02yr_Rainfall] – [Frequency Storm] in the left.

➢ In the [**Precipitation**] Tag, select “**50 Percent**” for [Probability], “**15 Minutes**” for [Intensity Duration] and “**1 Day**” for [Storm Duration]. ※ 2-year probable = 50%

➢ Enter rainfall depth (mm) from Intensity Curve. Likewise, enter rainfall data for 5yr and 10yr.

Setup Control Specification

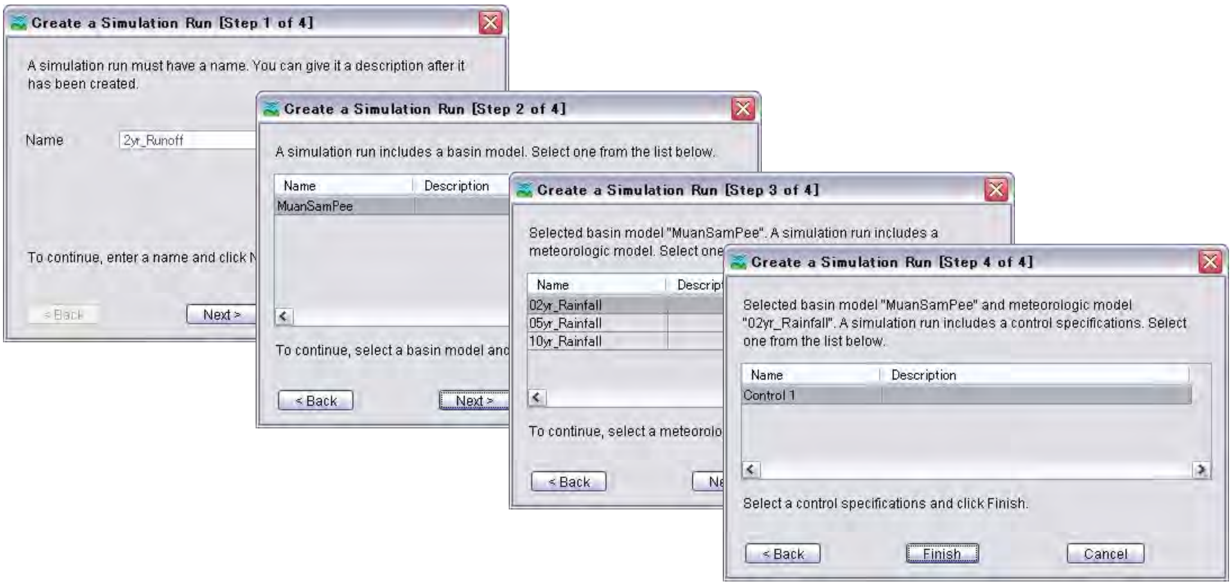


➢ Select [**Component**] – [**Control Specifications Manager**], and add “**Control 1**”.

➢ Enter the date and time: “**00:00 on 01MAR 2012**” for [Start Time/Date] and “**00:00 on 03 MAR 2012**” for [End Time/Date] (48 hours).

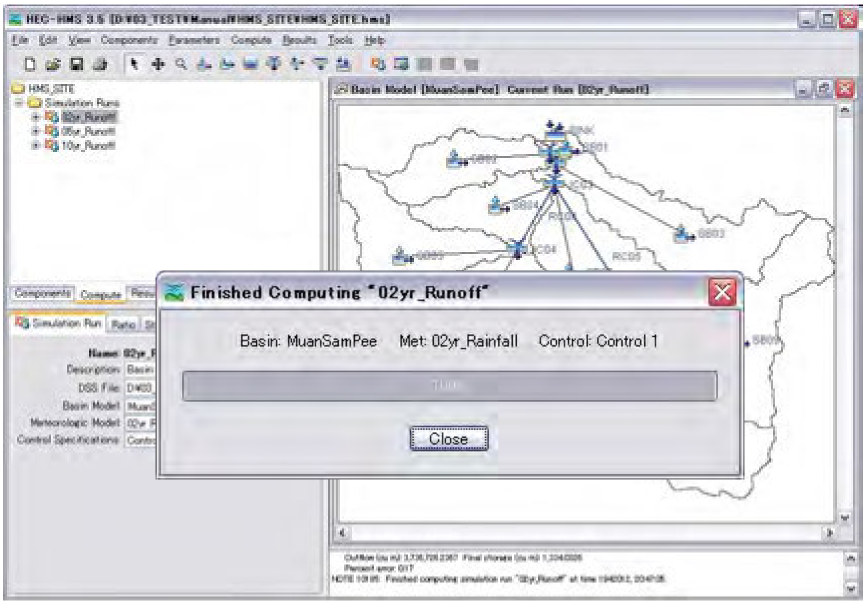
➢ Select “**15 Minutes (0.25 Hour)**” for [Time Interval].

Run Model



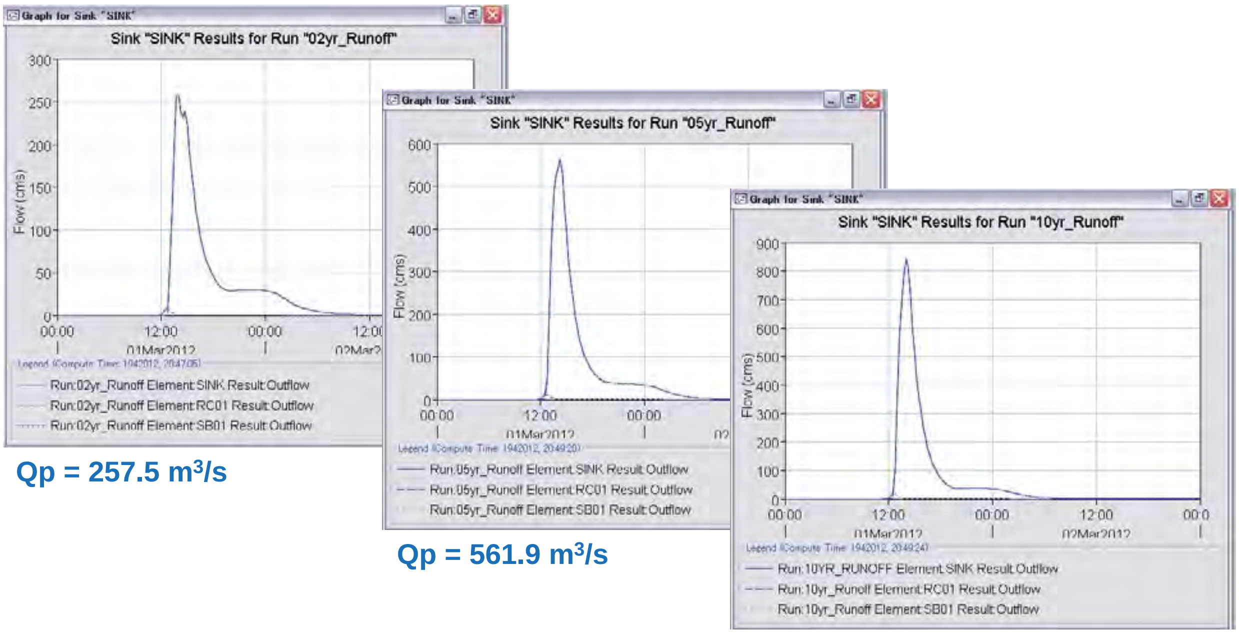
- Select [**Compute**] – [**Create Simulation Run**], and name “**02yr_Runoff**” for [Run Name].
- Select “**02yr_Rainfall”** for [Meteorologic Model]. Finally crick [**Finish**].
- Likewise, do the same for “**05_Runoff**” and “**10yr_Runoff**” as well.

Run Model



- Run all of simulation of “**02yr_Runoff**”, “**05yr_Runoff**” and “**10yr_Runoff**”.

Result



Qp = 257.5 m^3/s

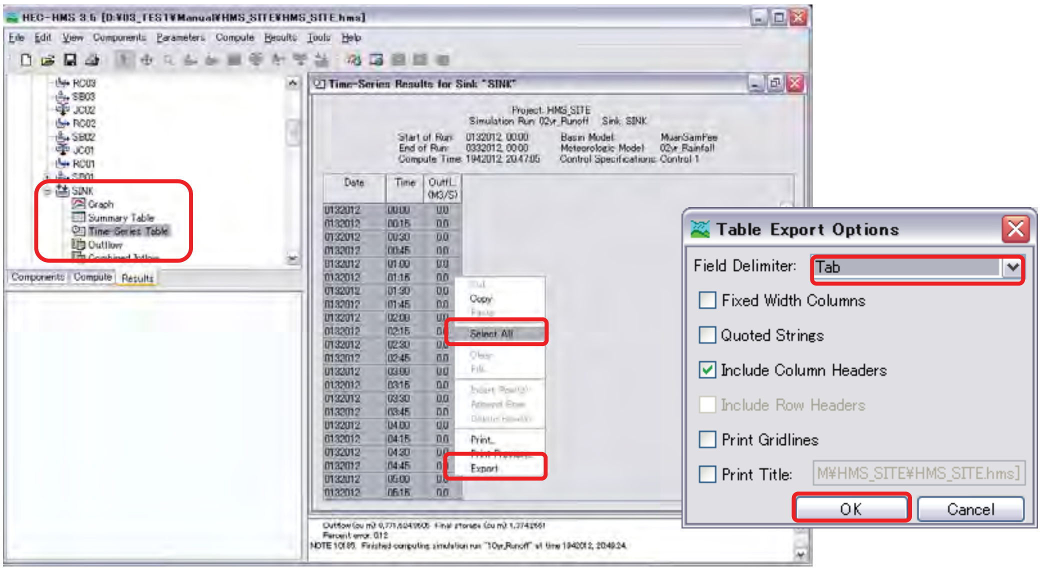
Qp = 561.9 m^3/s

Qp = 841.6 m^3/s

➢ Check the [**Graph**] of [**SINK**] for each simulation of 2yr, 5yr and 10yr Runoff.

➢ Run all of simulation of "**02yr_Runoff**", "**05yr_Runoff**" and "**10yr_Runoff**".

Result



➢ The output hydrograph will be used for flood analysis in the next section, you have to export it as versatile format.

➢ Select [**SINK**] – [**Time-Series Table**] in the left. Right click on the time-series table in the right and click [**Select All**] and [**Export**].

➢ In the dialog, select "**Tab**" for [**Field Delimiter**] and click [**OK**]. Save the output files as "**02yr_Runoff**", "**05yr_Runoff**" and "**10yr_Runoff**" in newly created [**Hydrograph**] folder.

END

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

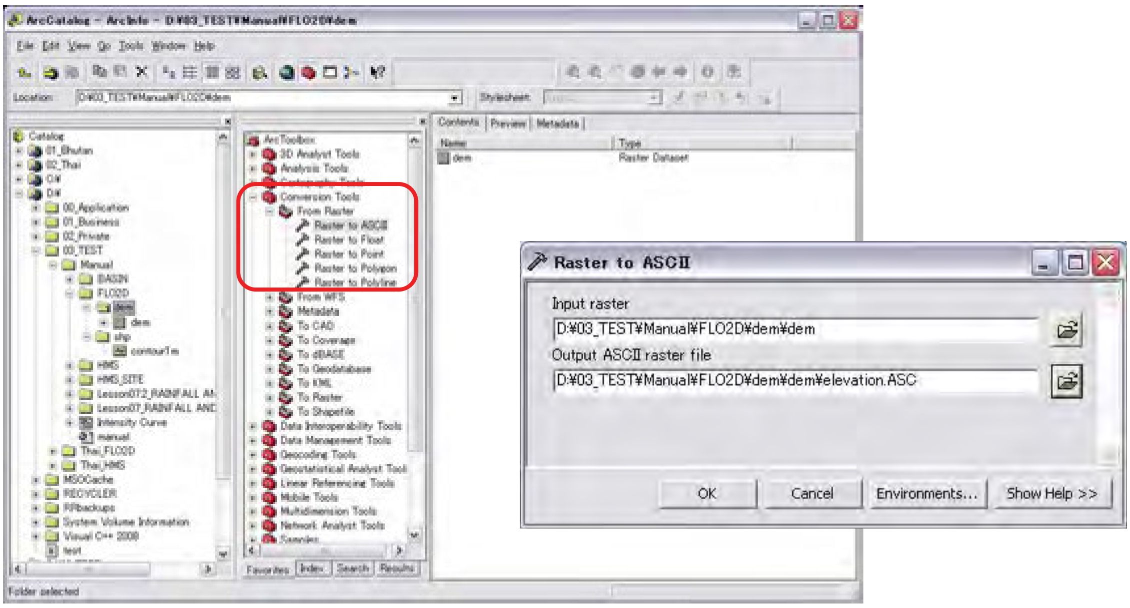
Lesson 4
Flood Simulation

Basic Procedure of FLO-2D Model

Task Force – Flood Risk Management

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Grid System Development

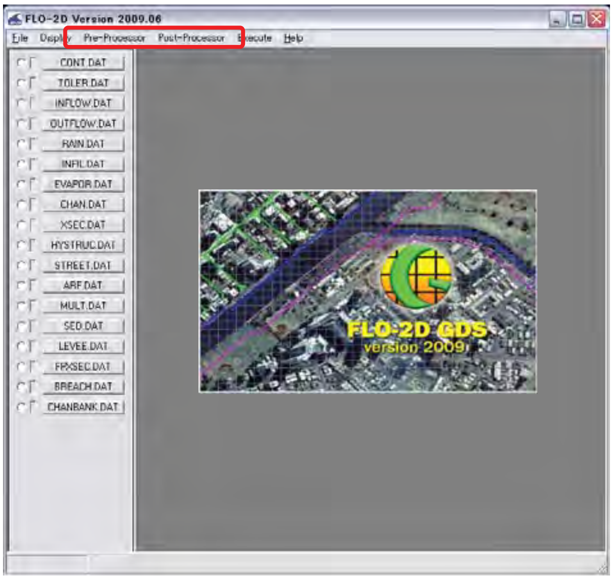


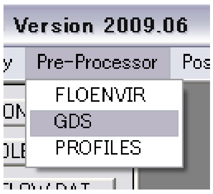
➢ Firstly, you have to covert DEM into **ASCII** file that you can import into FLO-2D.

➢ Open **ArcCatalog** and **ArcToolbox**. From the Toolbox, click [**Conversion Tools**] – [**From Raster**] – [**Raster to ASCII**].

➢ In the dialog, select "**dem** (5m mesh)" in the folder of [FLO2D] – [dem] for Input Raster, and save as "**elevation.asc**". Make sure that it must be saved as **ASCII format**. Then click [**OK**].

Grid System Development

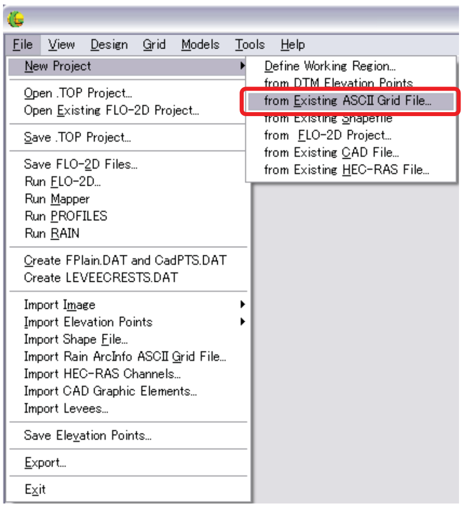


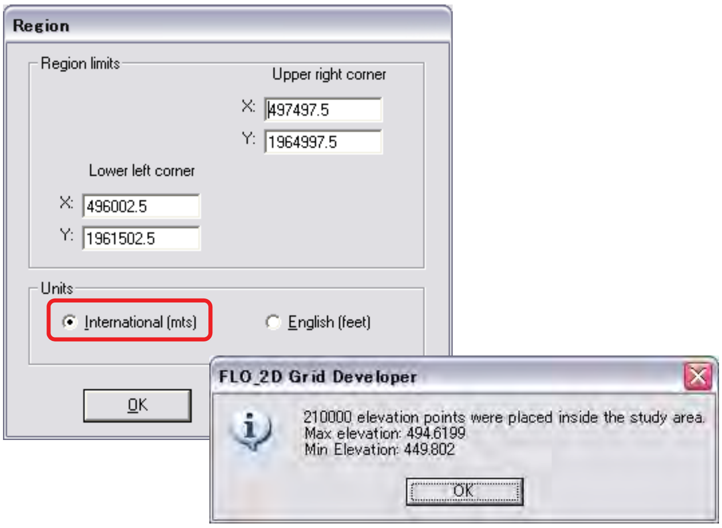


➢ Open FLO-2D. FLO-2D is composed of several components such as **GUI** (Graphical User Interface : above figure), **GDS** (Grid Developer System) and **MAPPER**.

➢ Basically, you can edit and run a model by only **GUI**. However **GDS** allow you to setup the model easily and visually. So firstly launch GDS from [**Pre-Processer**] – [**GDS**].

Grid System Development

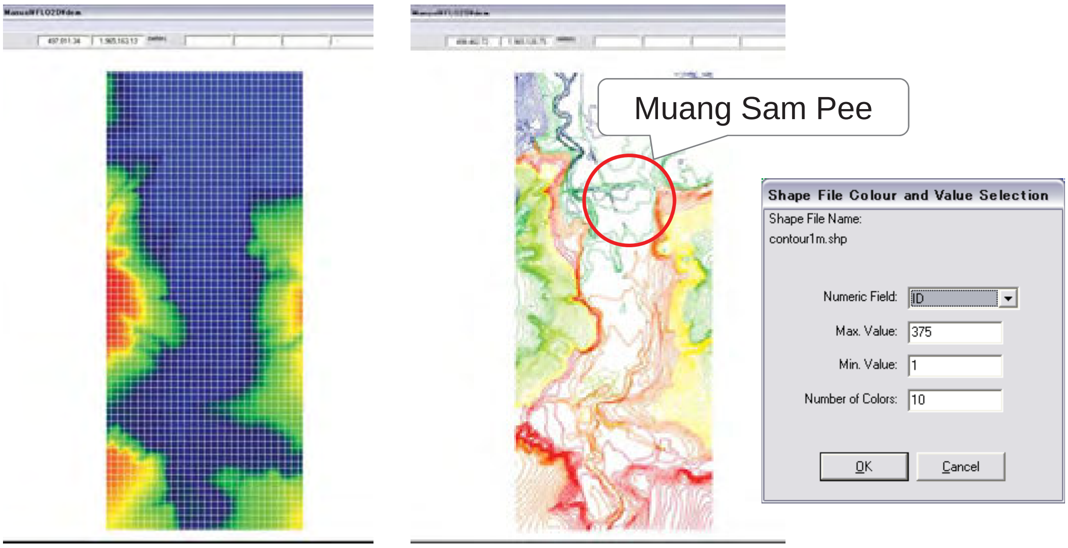




➢ In GDS, select [**File**] – [**New Project**] – [**from Existing ASCII Grid File**]. Select "**elevation.asc**" that you have generated from DEM (5m mesh size).

➢ In the following dialog, check "**International (mts)**" for Units, and click [**OK**].

Grid System Development

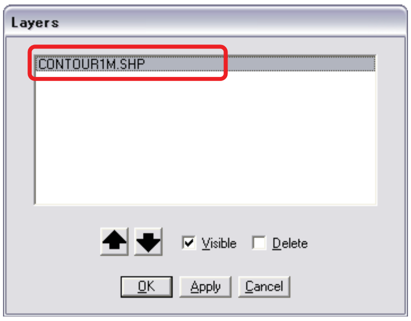


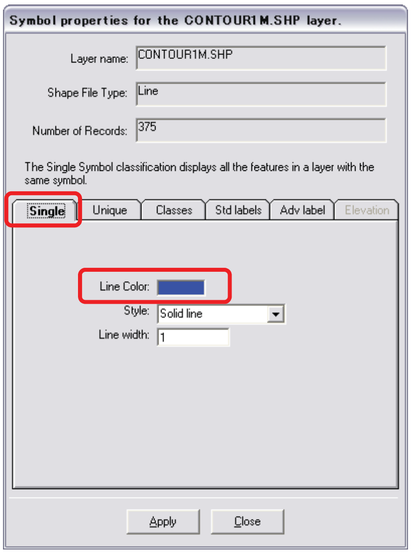
➢ The elevation points is sometimes very heavy to draw. So it is recommend to hide it by checking off [**View**] – [**Elevation Points**].

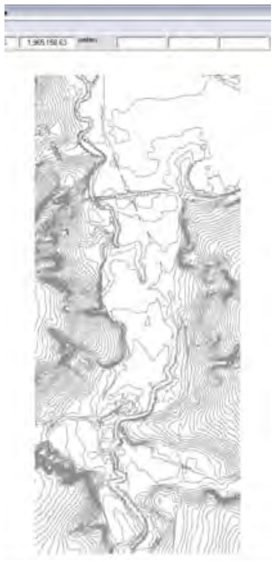
➢ Instead of elevation points, import shape file of contour line.

➢ Click [**File**] – [**Import Shale File**]. Then browse “**contour1m.shp**” in [shp] folder. In the next dialog, just click [**OK**].

Grid System Development





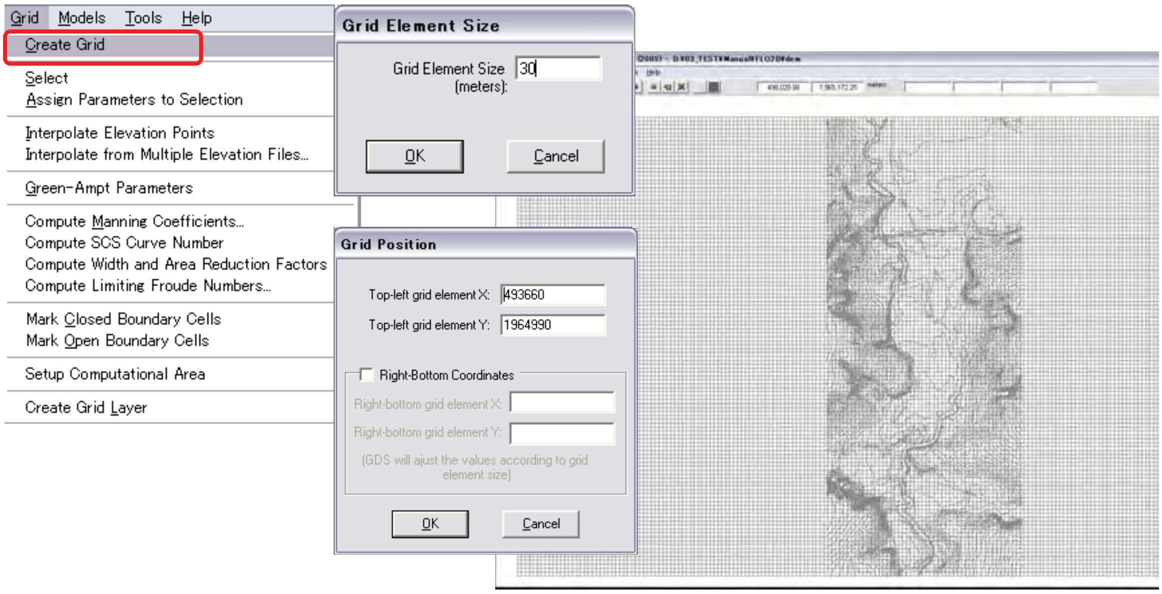


➢ If you want to change the symbol of shape file “**contour1m**”, click [**View**] – [**Layers List**]. In the dialog, double click the item that you want to change the symbol.

➢ Select [**Single**] Tab, and change the [**Line Color**] into grey. Then, click [**Apply**]. Of course, you can use multiple symbol as same as ArcGIS.

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

Grid System Development

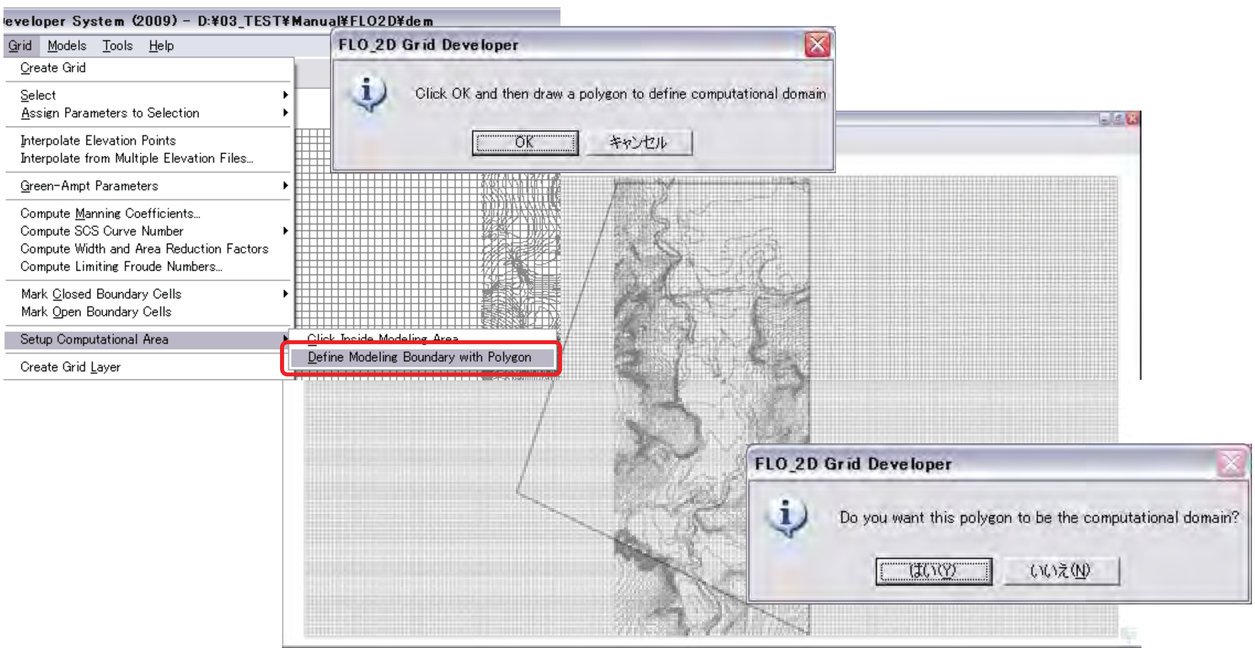


➢ First you need to setup Grid. Click [**Grid**] – [**Create Grid**]. In the dialog, enter “**30**” and click [**OK**]. This means simulation grid element size in your model will be 30m mesh.

➢ In the following dialog, check the Grid Position, and just click [**OK**].

➢ Now Grid was generated in the GDS.

Grid System Development

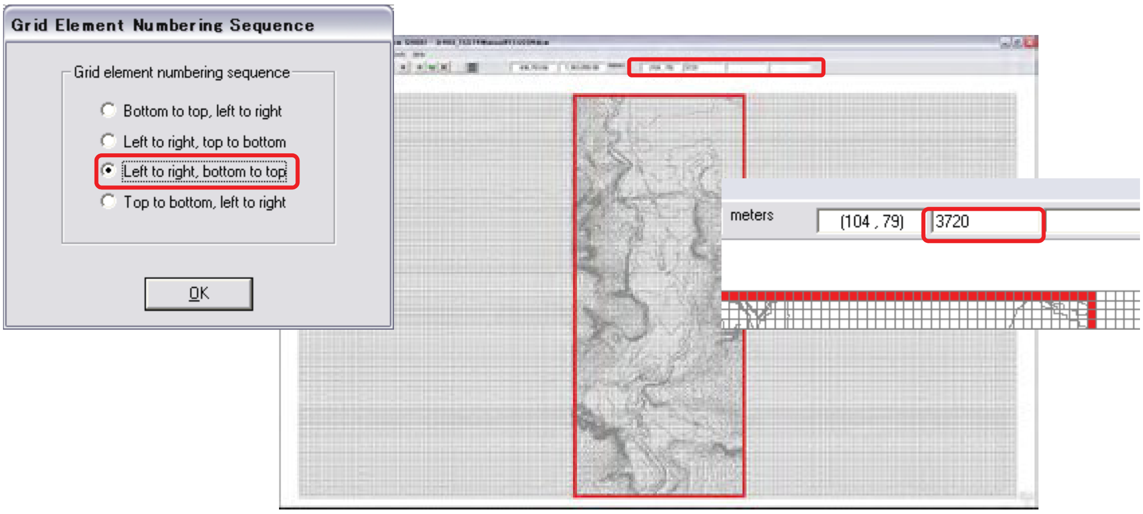


➢ Next, you have to define a computation area.

➢ Click [**Grid**] – [**Setup Computational Area**] – [**Define Modeling Boundary with Polygon**]. In the dialog, just click [**OK**]. Then start drawing computation area that cover all contour line area.

➢ When you reach to the final vertex of the polygon, double click and click [**Yes**].

Grid System Development



➢ After creating the computation area, you will be asked of [**Grid Element Numbering Sequence**]. In this dialog, you have to define the numbering sequence in the area.

➢ The numbering sequence is better to be the same direction of actual flow, so that the simulation will be faster. In this case, flow is from the bottom to the top direction (south to north). "**Left to right, bottom to top**" is recommended for numbering sequence.

➢ After define the numbering sequence, you can check the **Grid Element Number** of each grid of the computation area. Mouse on any grid, then see on the toolbar. The number is unique in your computation area such as "ID number".

Grid System Development

➢ When you check [**View**] – [**Grid Element Numbers**], you can see the grid numbers in the computation area.

➢ In this case, the sequence starts from left-bottom corner toward right. And then the next number starts from left end of the second lowest row.

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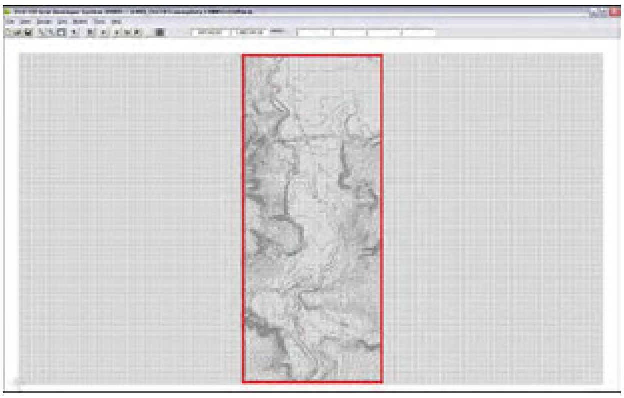
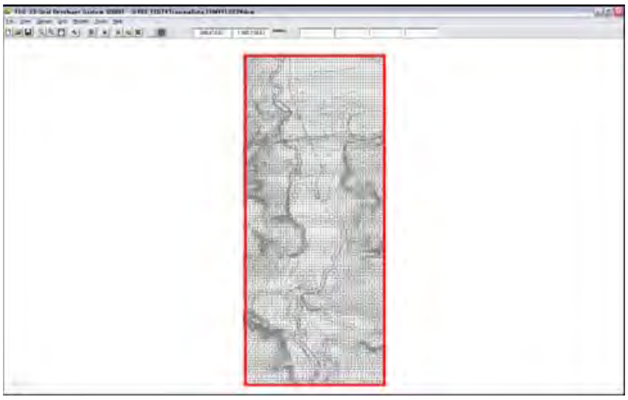
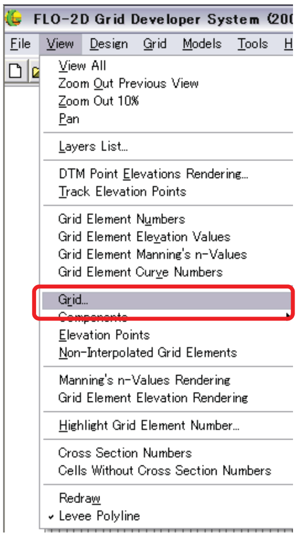
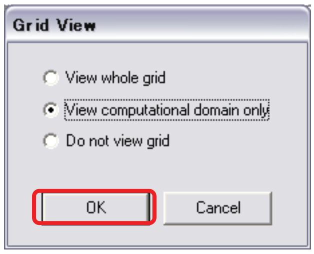
Grid System Development



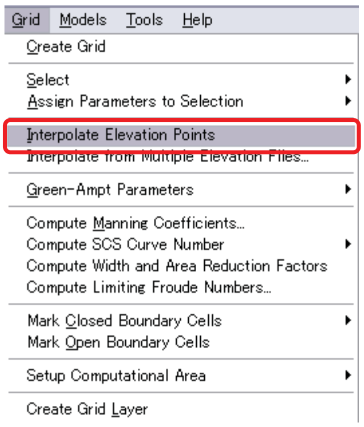


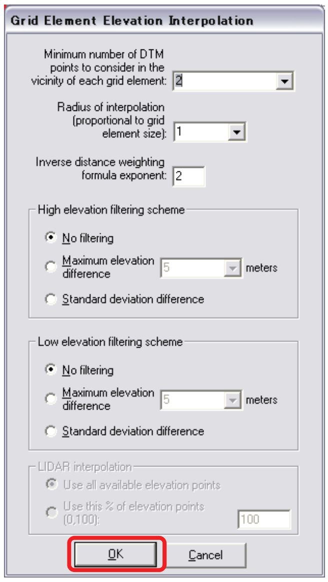




- If you don't want to show the grid, select [**View**] – [**Grid**], and check [**View computation domain only**].
- Then grids outside of computation area disappears.

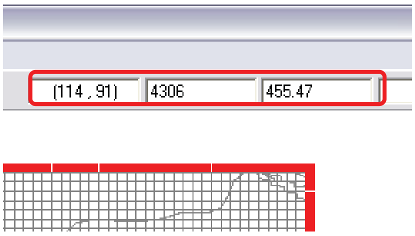
Grid System Development

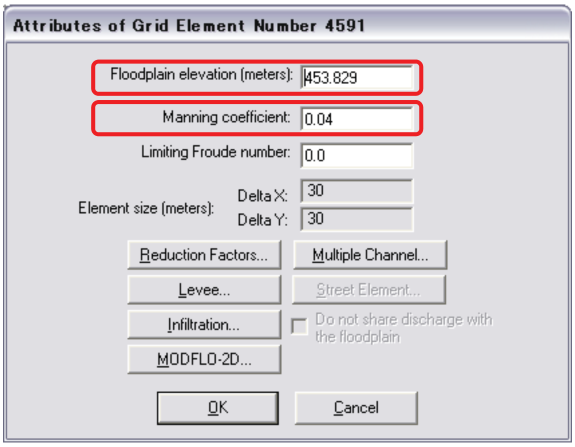




- Next, you have to assign elevation value for each element in the computation area.
- Click [**Grid**] – [**Interpolate Elevation Points**]. In the dialog, you can see several option to interpolate elevation value for grids. Since you have enough small size mesh data from 5m DEM, you can use the <u>default setting</u>. If not, you need to adjust [**Minimum number of DTM points**] and [**Radius of interpolation**].
- Just click [**OK**].

Grid System Development

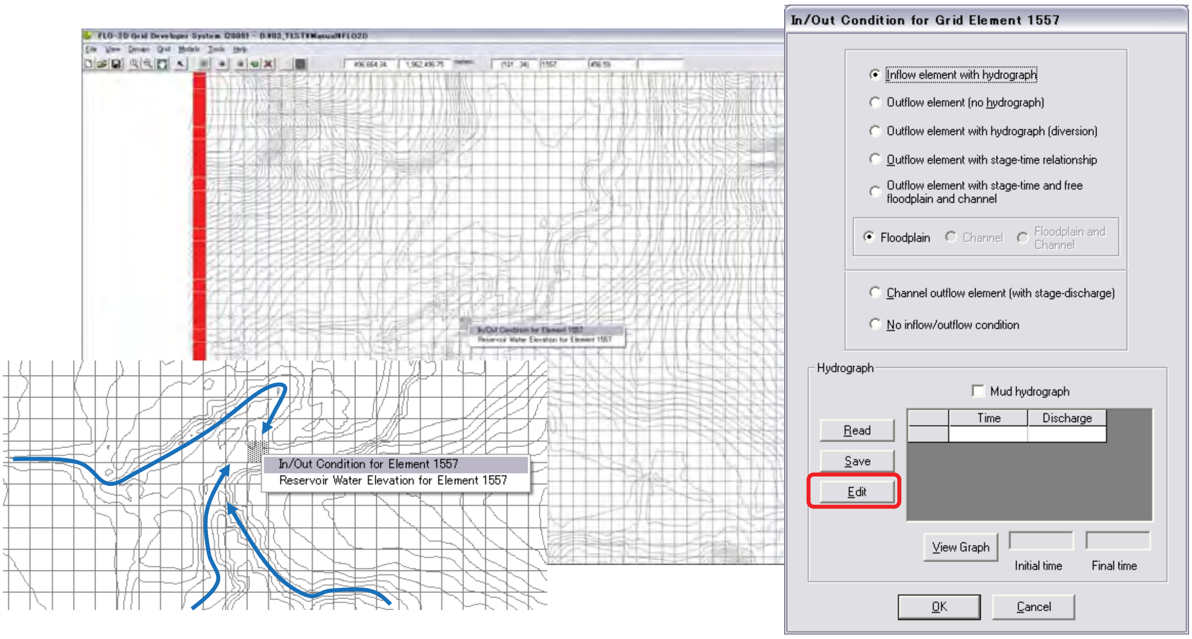




➢ After interpolation of elevation points, you can see the elevation values for every grids in the toolbar by mouse-on any grids in the computation area. Or, you can see it when you double click on a grid.

➢ In this dialog of [**Attributes of Grid Element Number ****], you can also find the [**Manning coefficient**]. The "**0.04**" is default value for Manning coefficient. If you want to change the individual elevation and Manning coefficient, you can manually edit the value. Here you can leave it.

In / Out Boundary Condition (Inflow)



➢ Find confluence of three rivers upstream of Muang Sam Pee. Right click on the confluence grid and select [**In/Out Condition for Element *****].

➢ In the dialog, select [**inflow element with hydrograph**].

➢ Then click [**Edit**] in [**Hydrograph**].

Project on Capacity Development
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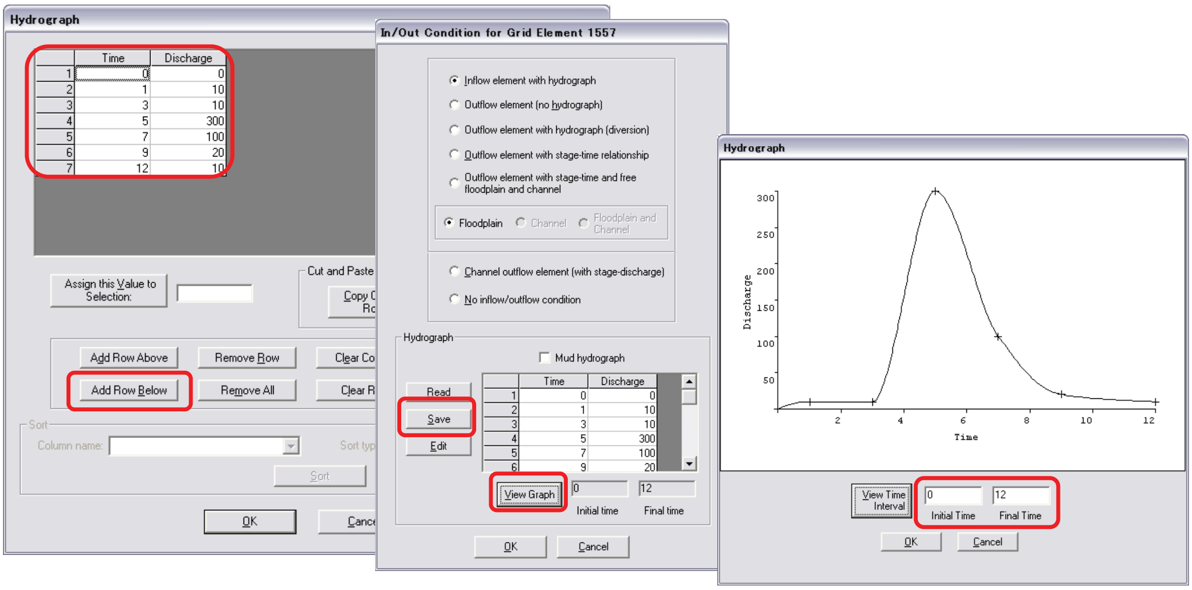
In / Out Boundary Condition (Inflow)

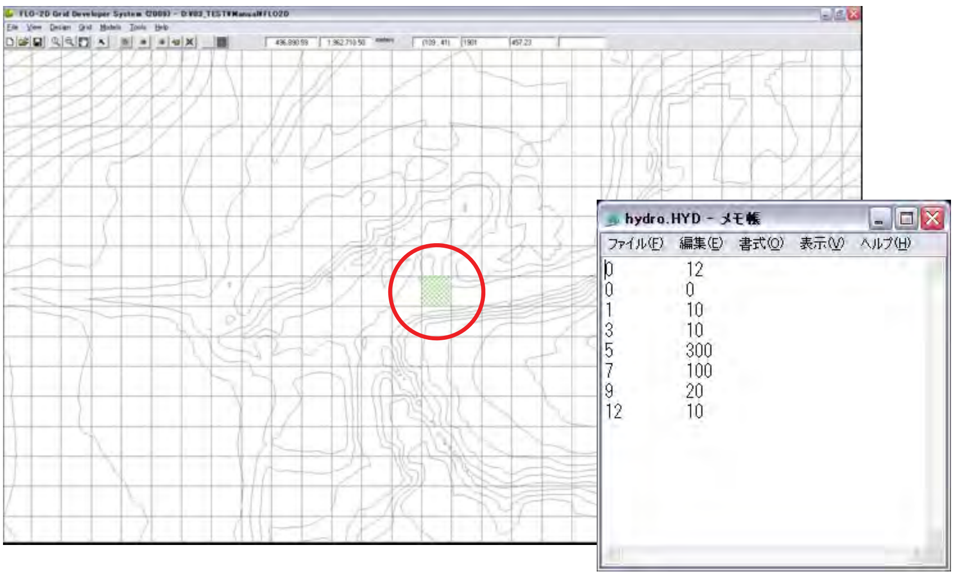


➢ In the dialog of [**Hydrograph**], add rows using [**Add Row Below**], then fill the Time and Discharge as above figure. After editing, click [**OK**].

➢ Click [**View Graph**]. In the graph window, enter [**Initial Time**] and [**Final Time**] as “**0**” and “**12**”.

➢ Save the edited hydrograph as “**hydro,HYD**” in [**FLO2D**] folder.

In / Out Boundary Condition (Inflow)

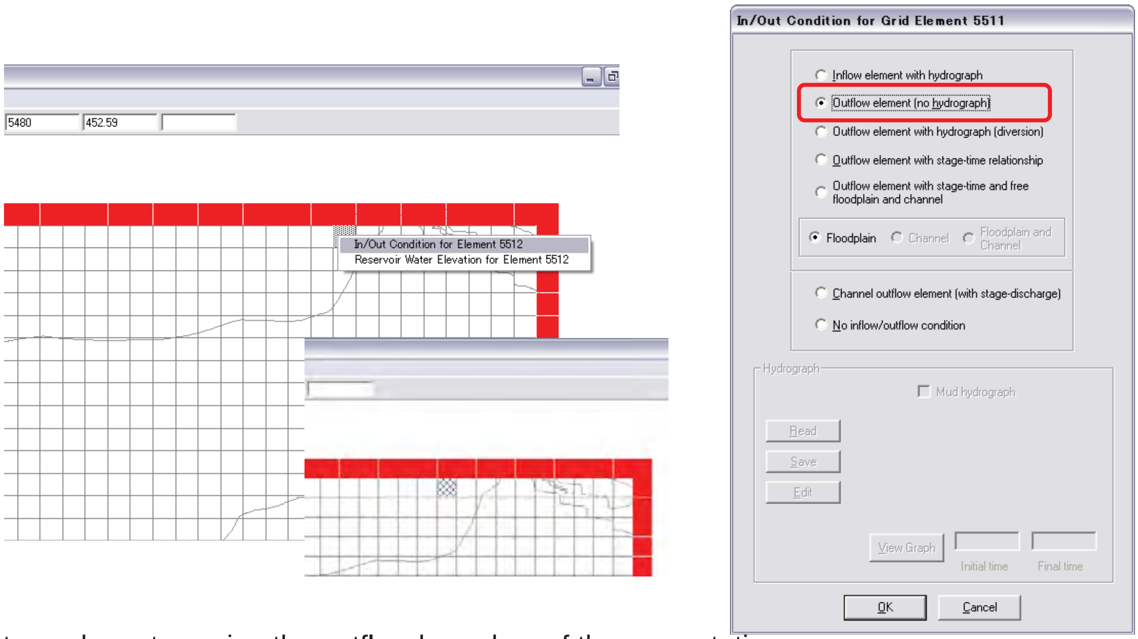


➢ Now the gird where the hydrograph was assigned is filled by red color as above.

➢ Check “**hydro.HYD**” file opened by text editor. This is the one you have saved as a hydrograph for inflow. The first row represents “Initial Time” and “Final Time”.

➢ When you want to use a hydrograph generated by HEC-HMS, you have to save the data as the same format (Space delimited formatted text).

In / Out Boundary Condition (Outflow)

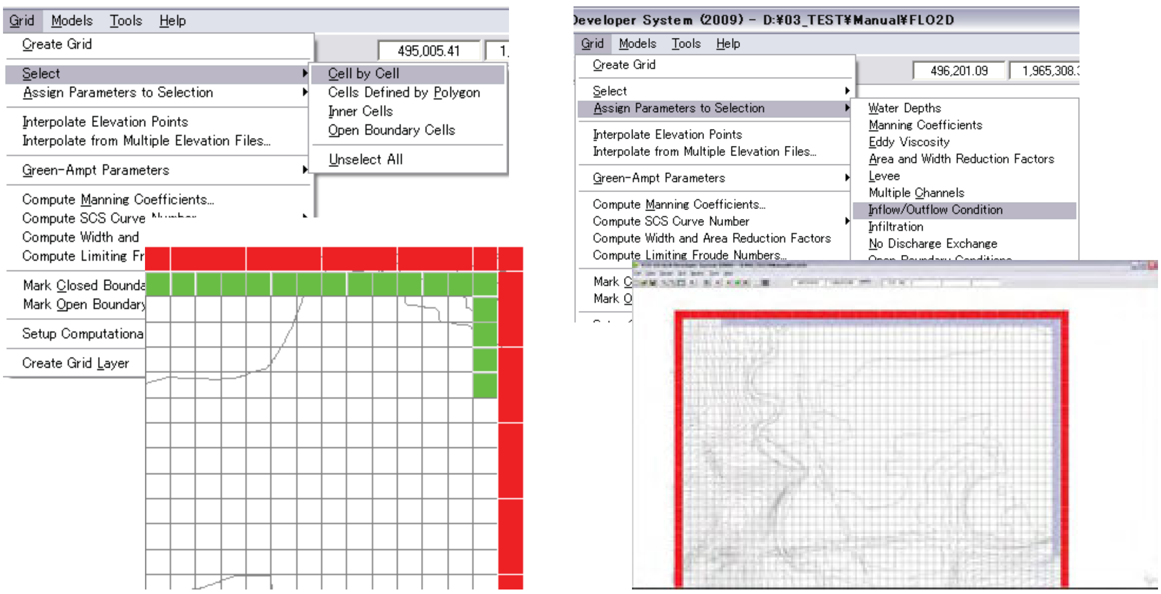


➢ Next, you have to assign the outflow boundary of the computation area.

➢ Right click at the merge of computation area, and select [**In/Out Condition For Element *****]. In the dialog, check [**Outflow element (no hydrograph)]**, then click [**OK**]. The grid was filled by blue color.

➢ However, it may take time. You can do this by another method as the next page.

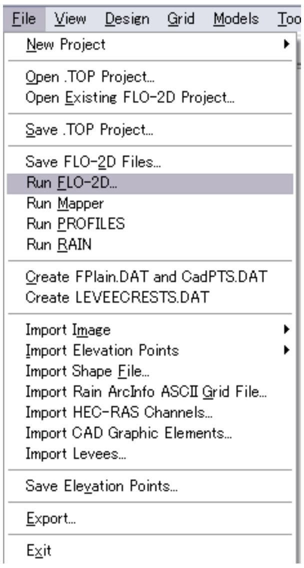
In / Out Boundary Condition (Outflow)

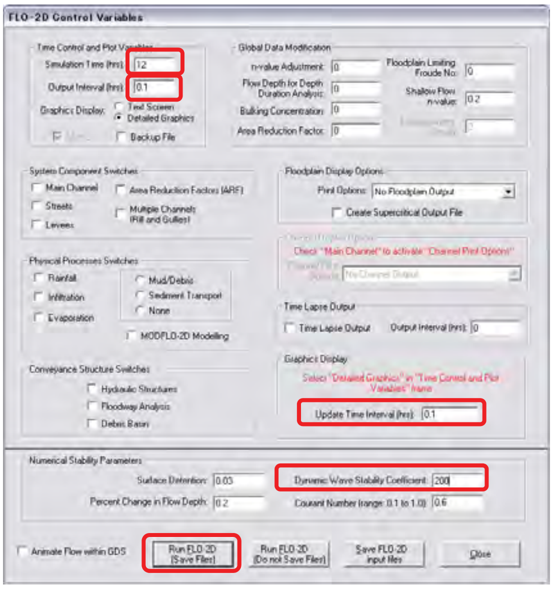


➢ Click [**Grid**] – [**Select**] – [**Cell by Cell**]. Then select merge grids of the computation area. The grids will be filled by green color. If you click SHIFT key and drag the mouse, you can select grids continuously.

➢ After selection, click [**Grid**] – [**Assign Parameters to Selection**] – [**Inflow / Outflow Condition**]. In the dialog, check [**Outflow element (no hydrograph)**] and [**OK**]. Now all of merge grids were assigned as outflow cell (blue colored).

Run FLO-2D Model



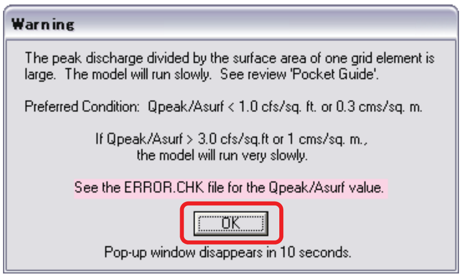


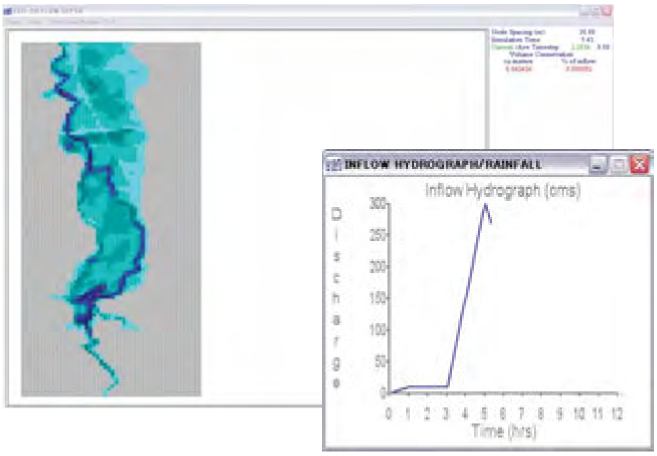
➢ Now ready to run the model. Select [**File**] – [**Run FLO-2D**]. In the dialog of [**Control Variables**], enter "**12**" for simulation time and "**0.1**" for output interval, and check [**Detailed Graphics**].

➢ Tentatively all parameters must be default. However, please enter "**200**" for [**Dynamic Wave Stability Coefficient**], which control the computation stability. If you use this, the computation will be slow. The value more than "100" means you don't use it.

➢ Click [**Run FLO-2D (Save Files)**] and save "**FPLAIN.DAT**" in the new folder named "**test01**".

Run FLO-2D Model



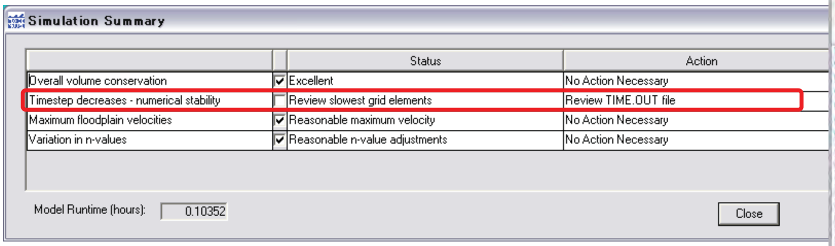


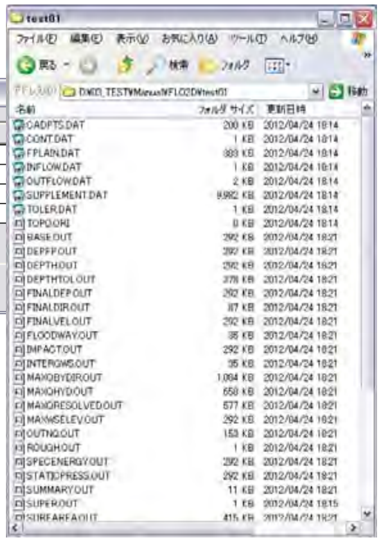
➢ When you start run, the above [Warning] dialog may appear. FLO2D recommends input peak discharge less than **0.3 m^3/s in 1.0 m^2 grid**. Otherwise, the model will run slowly.

➢ In this case, Qp = 300 m^3/s in 900 m^2(30m x 30m), which means 0.33 m^3/s in 1.0 m^2 grid. But you can ignore this warning because it is not very large value.

➢ You can look the progressing computation in the window, because you have checked [**Detailed Graphics**] for [**Graphic Display**] before.

Run FLO-2D Model





➢ After finishing run, dialog of [**Simulation Summary**] will appear. You can check the status of your model. If necessary, you need to modify your model. In this case, "**Review TIME.OUT file**" is suggested. This may be because of too large inflow discharge.

➢ You can also check all of input / output files in your folder "**test01**".

➢ The [*.DAT] are input files. All files can be opened by text editor. You can check / modify this DAT files manually, and run the model without GDS program.

➢ The [*.OUT] are output files.

Run FLO-2D Model

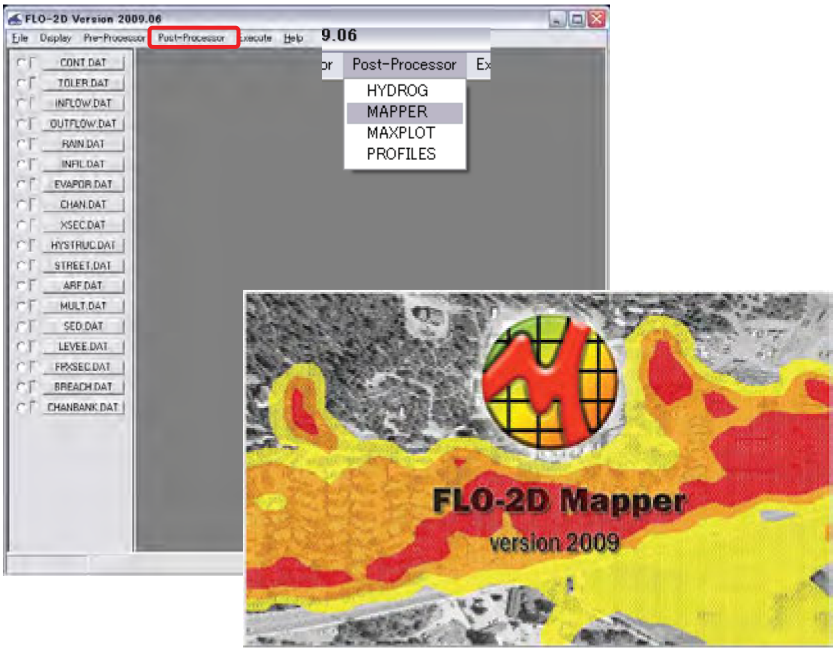
<u>The following DAT files are essential for computation.</u>

➢ **CADPTS.DAT**:	Grid number and the location (X, Y)
➢ **CONT.DAT**:	Control specification such as simulation time and output interval
➢ **FPLAIN.DAT**:	Positional relation of each grid, manning's N and elevation
➢ **INFLOW.DAT**:	Inflow condition (inflow cell and hydrograph)
➢ **OUTFLOW.DAT**:	Outflow condition (outflow cell and hydrograph)
➢ **SUPPLEMENT.DAT**:	Background shape files and so on
➢ **TOLER.DAT**:	Parameters for numerical stability of computation

<u>The following DAT files are optionally added for computation.</u>

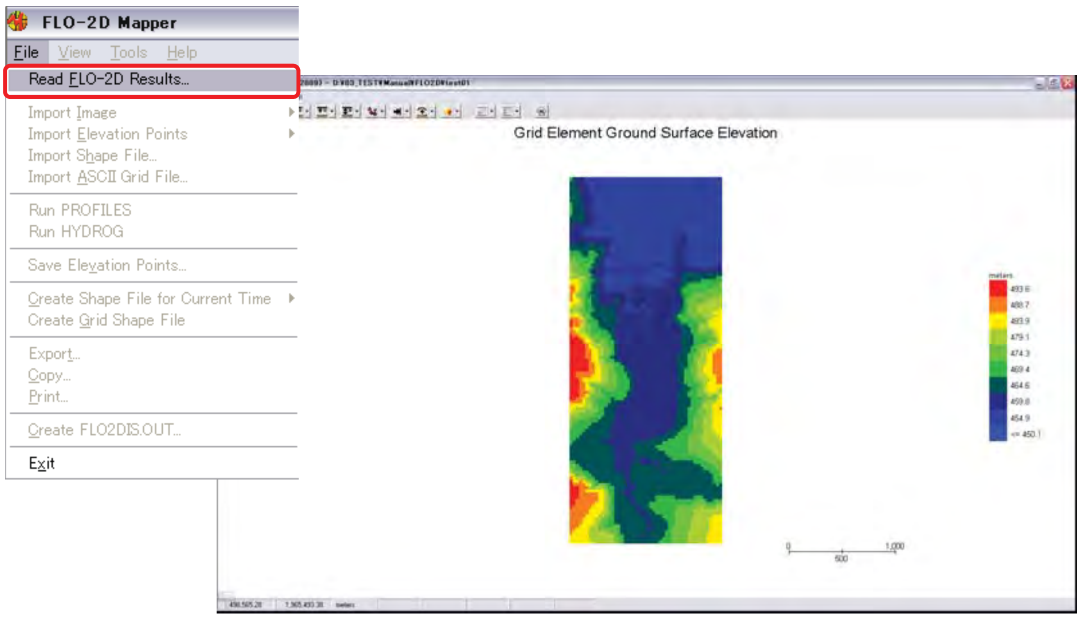
➢ **CHAN.DAT**:	Channel shape, grid number, elevation, etc.
➢ **CHANBANK.DAT**:	Channel left / right bank grid number
➢ **XSEC. DAT**:	Cross-section profile data
➢ **LEVEE.DAT**:	Levee grid number, height, direction, etc.
➢ **RAIN.DAT**:	Rainfall into the flood plain area

Flood Mapping



➢ Open FLO-2D. Launch Mapper from [**Post-Processer**] – [**MAPPER**].

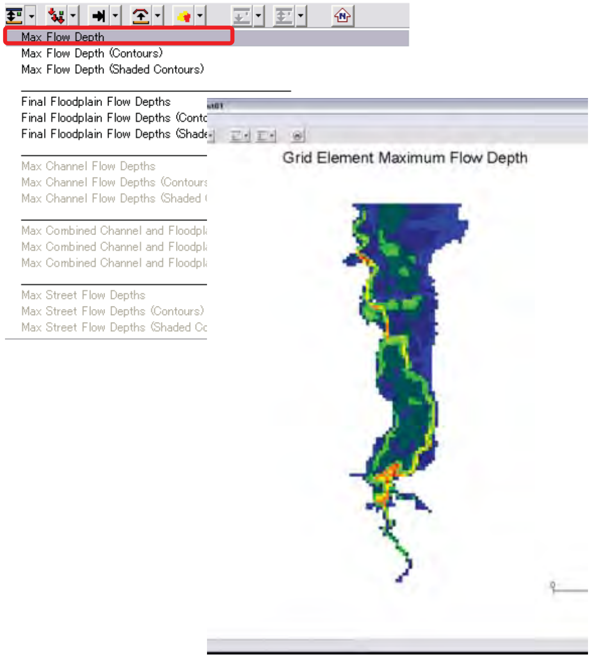
Flood Mapping

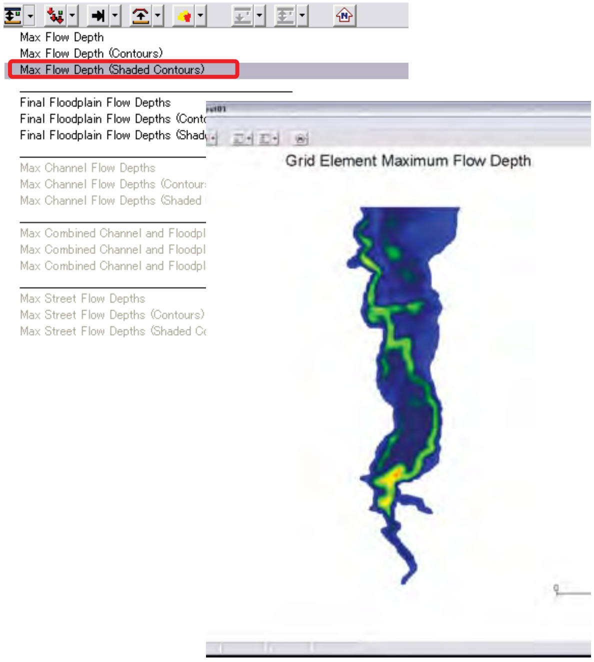


➢ Click [**File**] – [**Read FLO-2D Results**]. Select "**FPLAIN.DAT**" in your [**test01**] folder.

➢ Ground Surface Elevation will appear. This

Flood Mapping

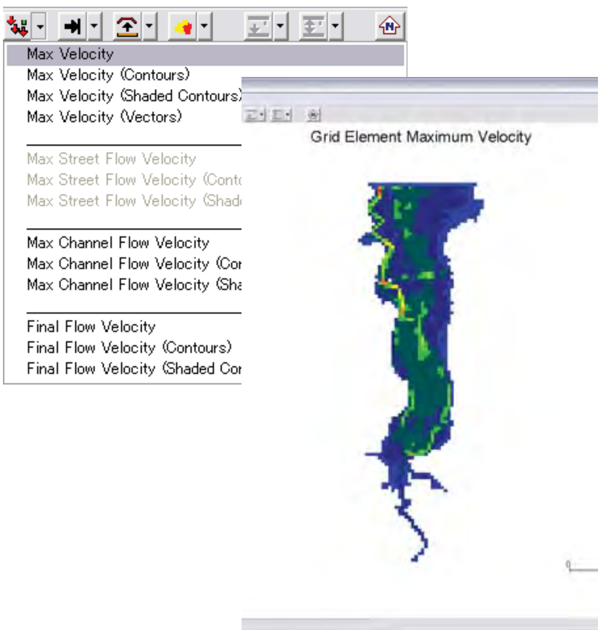


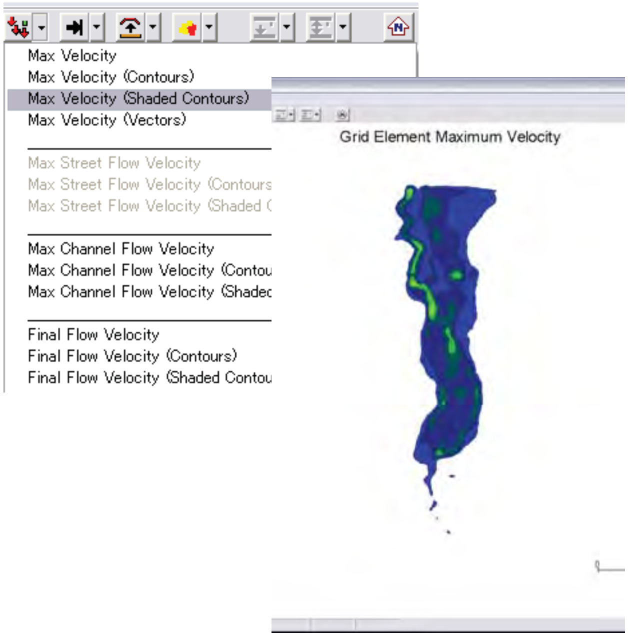


- In most case, you need to know the maximum inundation depth for flood hazard map. Click [**Flow Depth**] icon on the toolbar, and select [**Max Flow Depth**]. You can see the maximum depth as left figure.
- When you select [**Max Flow Depth (Shaded Contours)**], you can see as right figure.

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Flood Mapping

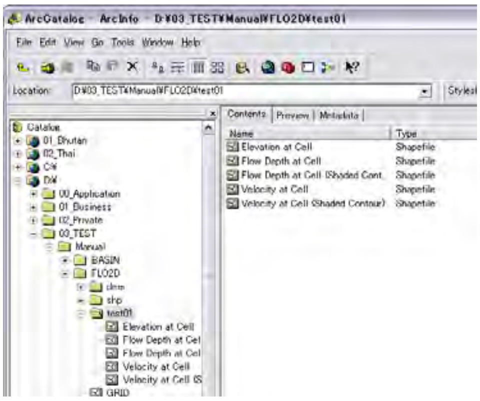


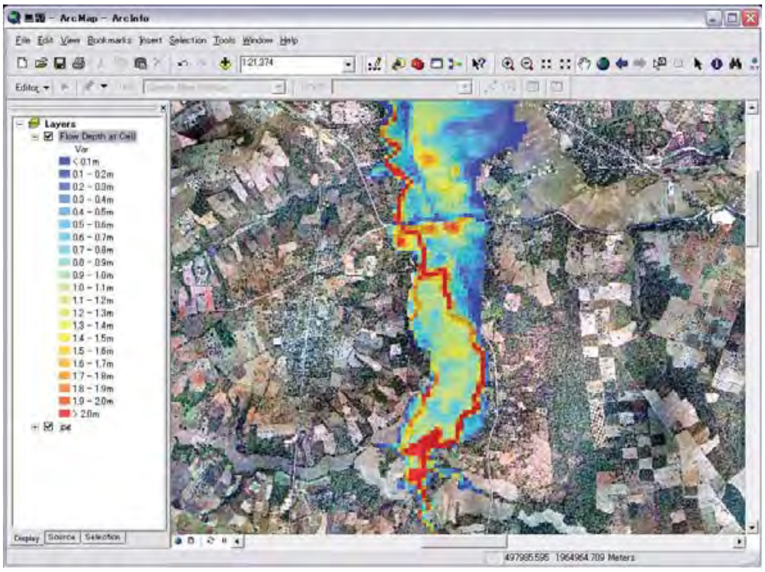


- Likewise, when you select [**Max Velocity**] and [**Max Velocity (Shaded Contours)**], you can see the maximum velocity of flood, which is also very important to represent hazard level.

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Flood Mapping





➢ Once you create any kind of mapping either depth or velocity in MAPPER, shape files (polygon) will be automatically created in the same folder. You can check the shape files in ArcGIS.

➢ You can add the shape files into ArcGIS and show it with aerial photo as the right figure. <u>Note that the shape files have no coordinate system.</u>

END

Lesson 5
Flood Simulation

Modification of Manning's N & Inflow Hydrograph

Task Force – Flood Risk Management

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

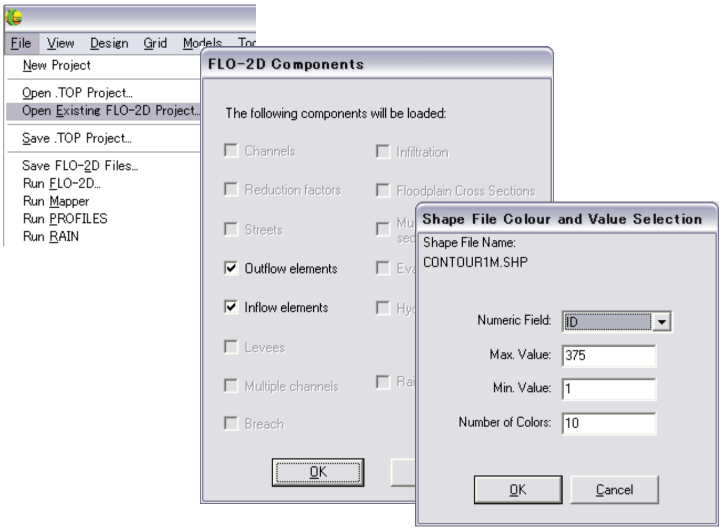
Preparation of New Project

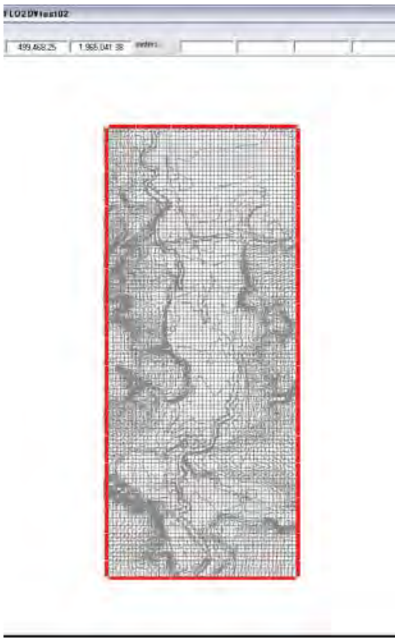
➢ In this lesson, you will learn how to modify Manning's N of flood plain and how to import hydrograph generated by HEC-HMS.

➢ Firstly, copy the folder of "**test01**", and past as "**test02**".

➢ Erase all files excepting **"***.DAT**" files. As explained in the last lesson, FLO2D requires only DAT files for computation.

Preparation of New Project



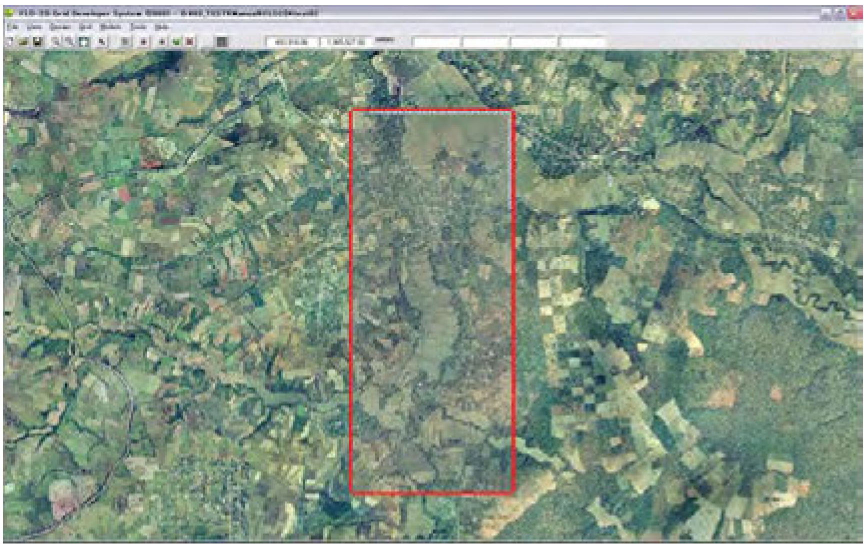


➢ Open the project in the "**test02**". Start GDS, and click [**File**] – [**Open Existing FLO-2D Project**].

➢ Select "**FPLAIN.DAT**" in the "**test02**". In the following 2 dialogs, just click [**OK**].

➢ As same as the before lesson, make elevation points invisible, and change symbol of contour line.

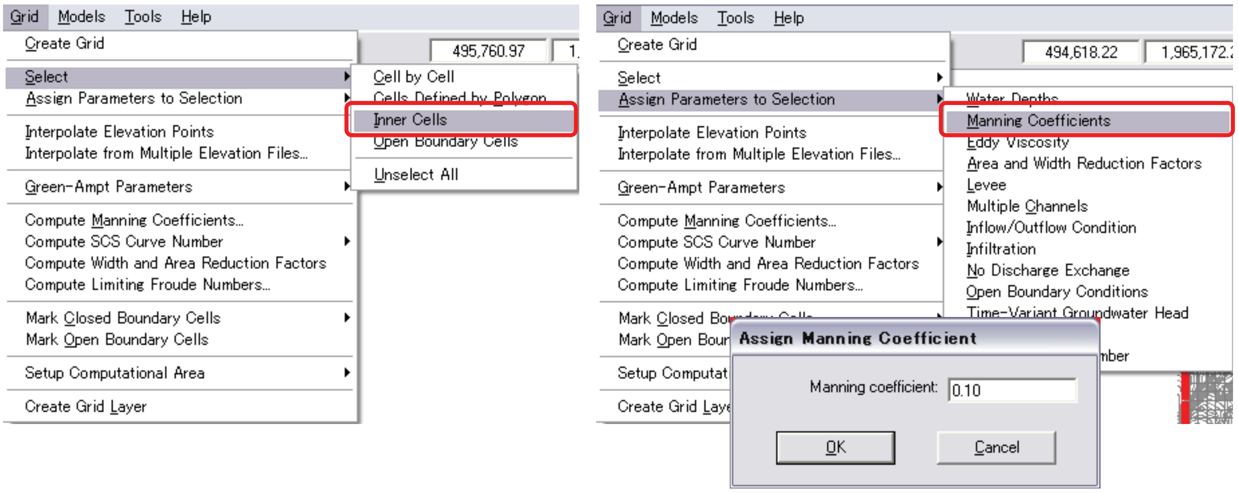
Modification of Manning's N



➢ Click [**File**] – [**Import Image**] – [**Individual Image**]. Select "aerial.jpg" in [**BASIN**] – [**img**] folder.

➢ In this manual, you will assign the Manning's N as "**0.08**" for the paddy field and "**0.10**" for the other.

Modification of Manning's N

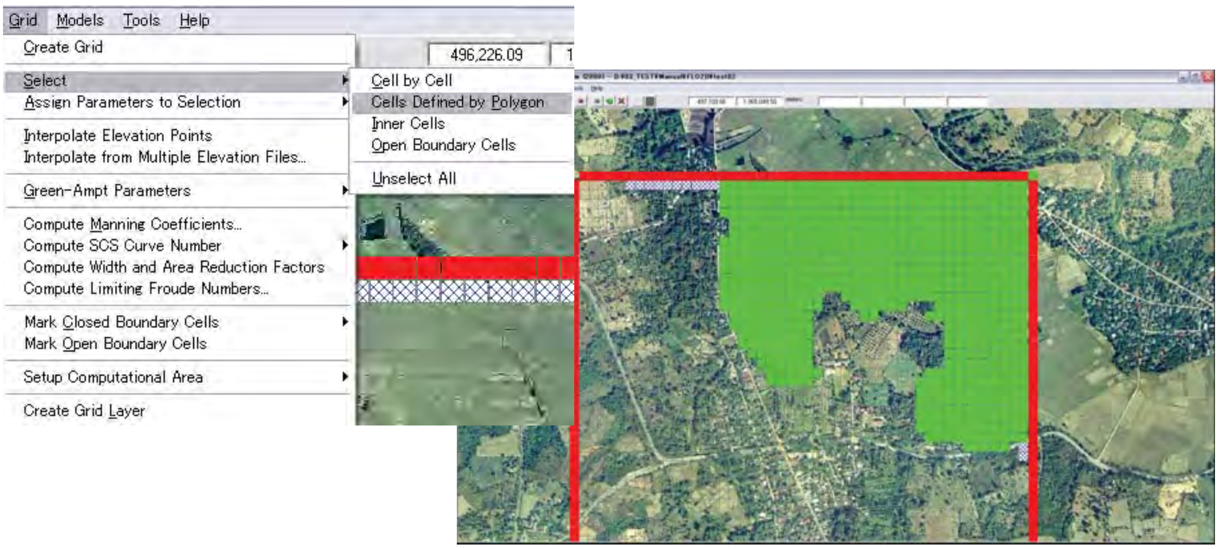


➢ Firstly enter "**0.10**" for all computation area.

➢ Click [**Grid**] – [**Select**] – [**Inner Cells**] to select grids in the computation area, then click [**Grid**] – [**Assign Parameters to Selection**] – [**Manning Coefficients**]. In the dialog, enter "**0.10**".

➢ You can check the manning coefficient of each grid by double clicking on the grid. Or click [**View**] – [**Manning's n-value rendering**].

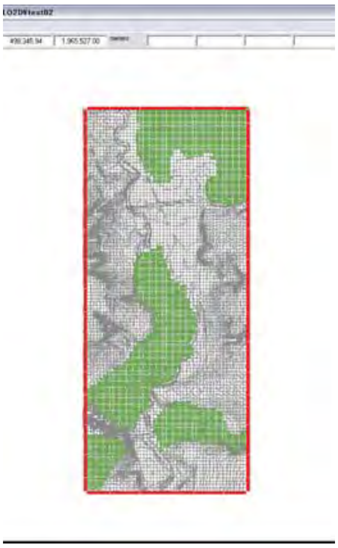
Modification of Manning's N

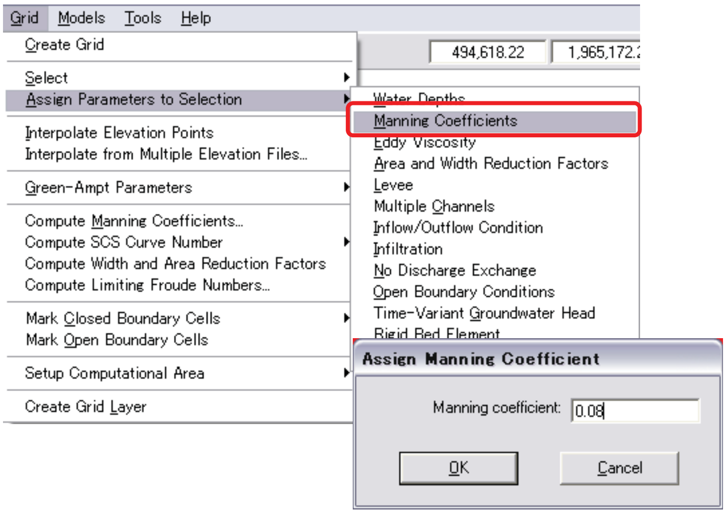


➢ Next enter "**0.08**" for paddy field.

➢ Click [**Grid**] – [**Select**] – [**Cells Defined by Polygon**] . Then draw polygon to cover the area of paddy field as above figure.

Modification of Manning’s N

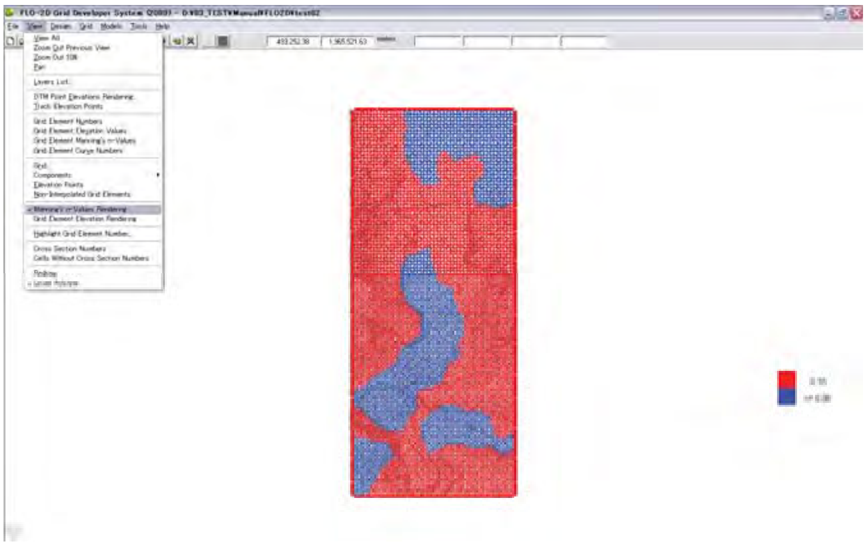




➢ After selection, click [**Grid**] – [**Assign Parameters to Selection**] – [**Manning Coefficients**].

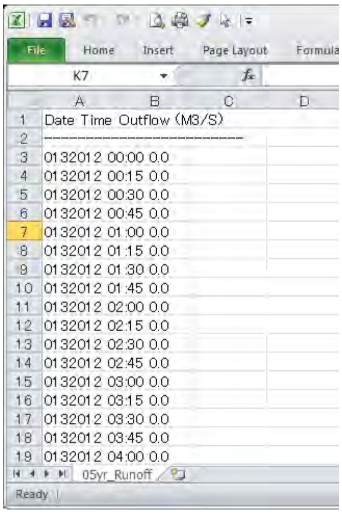
➢ In the dialog, enter “**0.08**” for Manning’s N.

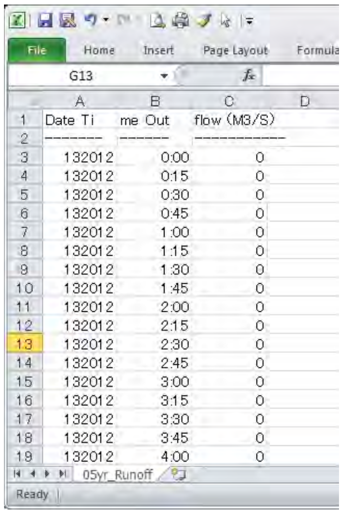
Modification of Manning’s N



➢ When you check [**View**] – [**Manning’s n-values Rendering**], you can see the distribution of Manning coefficient as above.

Input Hydrograph





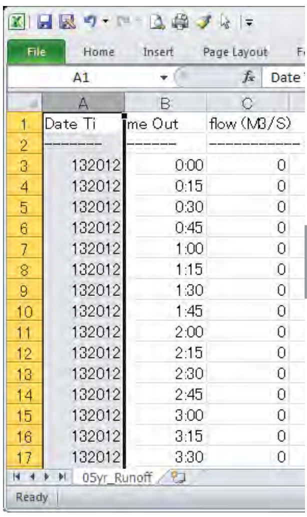
➢ Before importing of hydrograph generated by HEC-HMS, you need to prepare [*****.HYD**] file.

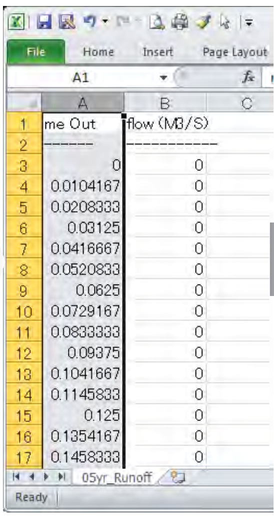
➢ As explained in the last lessen, HYD file must be "**space delimited formatted text**". The first row represents "Initial Time" and "Final Time" of hydrograph. Rows after the second row represents discharge (m^3/s) in each time (hour).

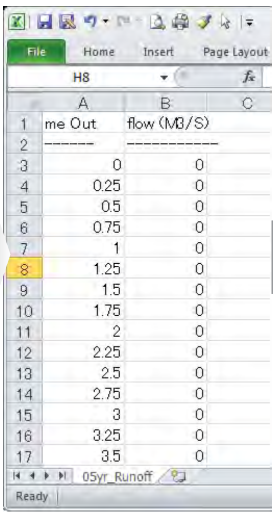
➢ Open "**05yr_Runoff**", which was generated in Lesson03, by Excel.

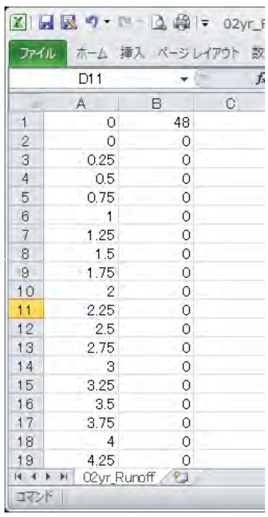
➢ The data may be automatically separated for each columns. If not, separate by use of [**Data**] – [**Text to Columns**].

Input Hydrograph







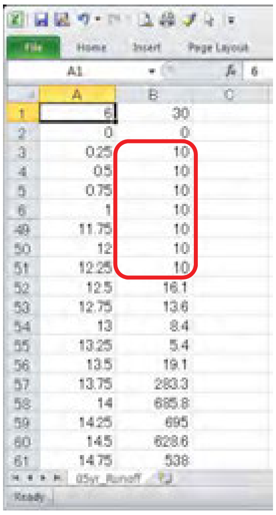


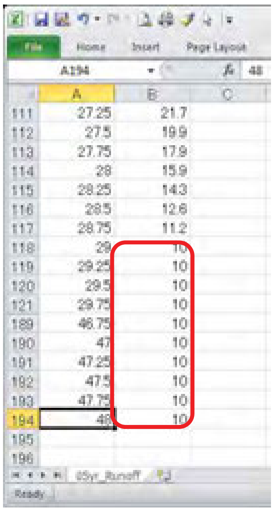
➢ Erase the first column. Change the format of cells in the second column as "**General**".

➢ Change the values of the first column (hour) as "**0, 0.25, 0.5, 0.75, 1, ・・・**" because the time interval is 15 minutes (= 0.25).

➢ Erase the first row, and enter the value of "**6**" and "**30**" at the second row. These two values represent "Initial Time" and "Final Time" of the hydrograph.

Input Hydrograph





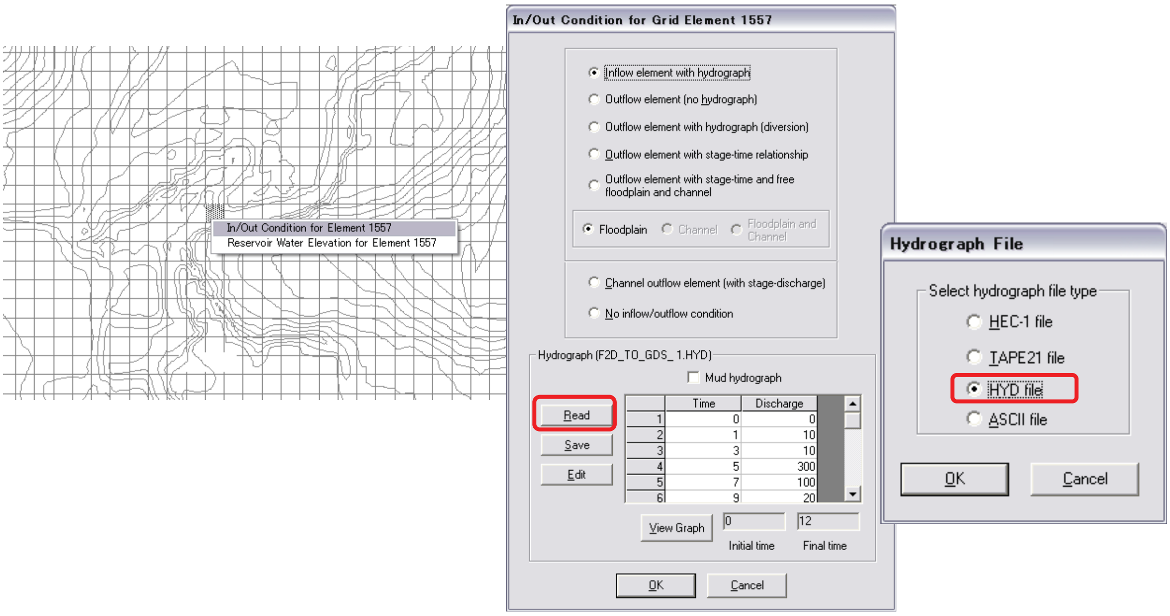
➢ Now the format was corrected to import FLO-2D. However the hydrograph has no base flow of the river. For computation purpose, it is recommended to enter a certain amount of base flow.

➢ Enter 10 m^3/s at both before and after of peak inflow as above. Note that the flow of the first time step (0 hour) must be 0 m^3/s

➢ Now, save as "**05yr_Runoff.HYD**" by the same format (**space delimited formatted text**).

➢ Check the produced "**05yr_Runoff.HYD**" by text editor.

Input Hydrograph

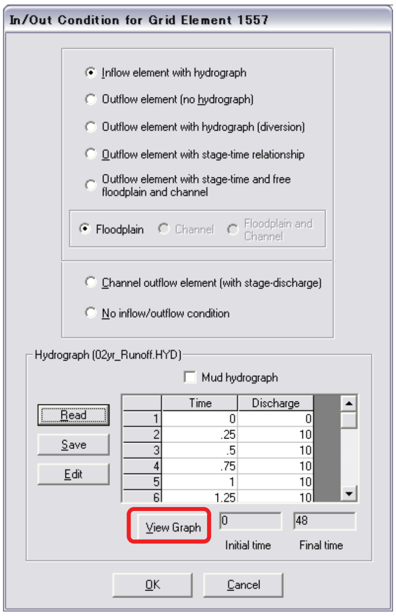


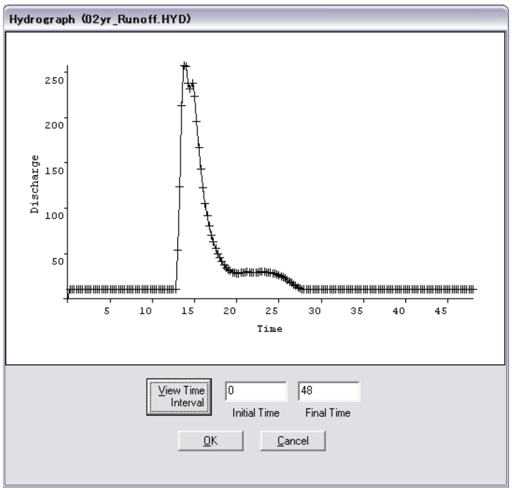
➢ Now, bask to FLO-2D GDS.

➢ Right click on inflow grid, and select [**In/Out Condition for Element *****].

➢ In the dialog, click [**Read**]. Select [**HYD.file**] and click [**OK**]. Select "**02yr_Runoff.HYD**".

Input Hydrograph

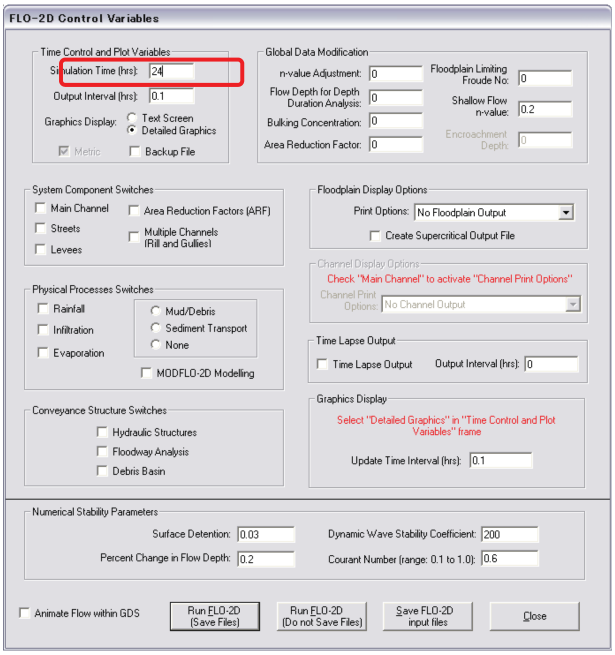


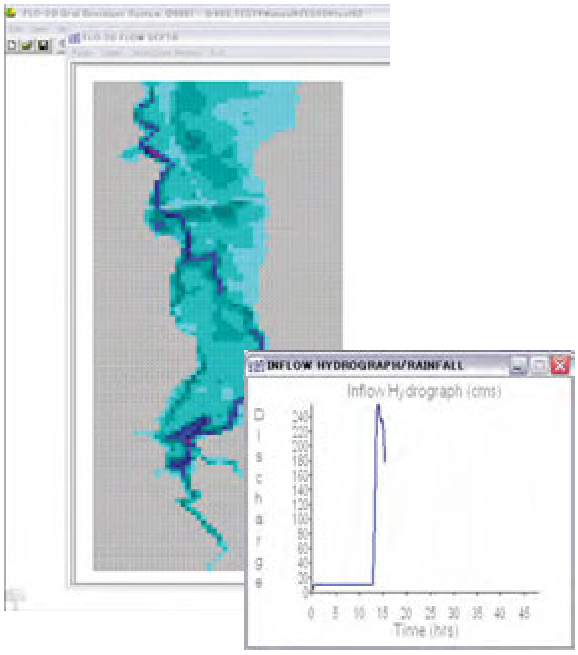


➤ When you click [**View Graph**], you can see the hydrograph.

➤ The hydrograph has base flow of 10 m^3/s.

Run Model



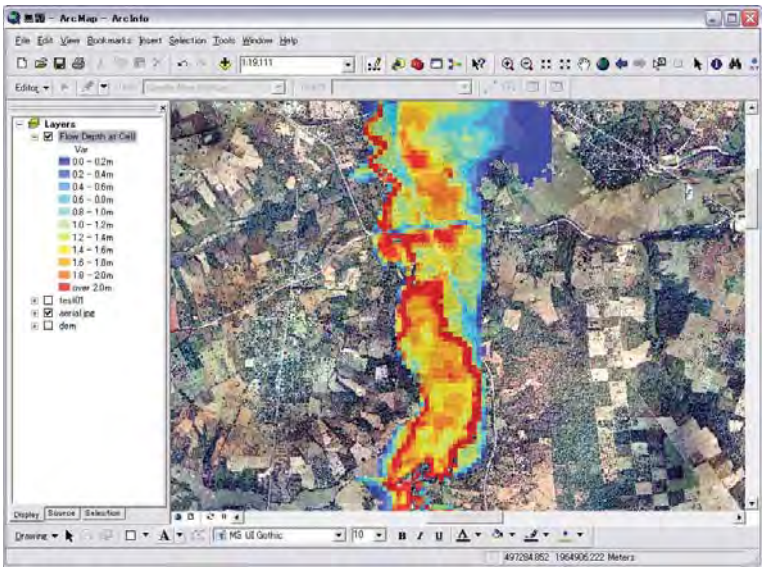


➤ Click [**File**] – [**Run FLO-2D**].

➤ Change the [**Simulation Time (hrs)**] into “**24**”(6-30). Then click [**Run FLO-2D (Save Files)**].

➤ Save the “**FPLAIN.DAT**” in [**test02**] folder.

Run Model



- ➢ Check the maximum water depth by 5-years probable rainfall.
- ➢ The drawn inundation area may be larger than the actual. Further, the river is flooded even in normal base flow of 10 m^3/s. This is because of that the model has no channel element. The channel must have certain flow capacity. If the flow increases beyond the channel capacity, then flood will occur.
- ➢ In the next lesson, therefore, you will input channel element in the model.

END

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

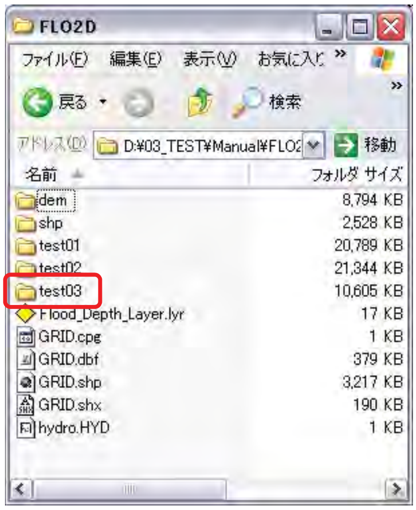
Lesson 6
Flood Simulation

Simple Chanel Element Development

Task Force – Flood Risk Management

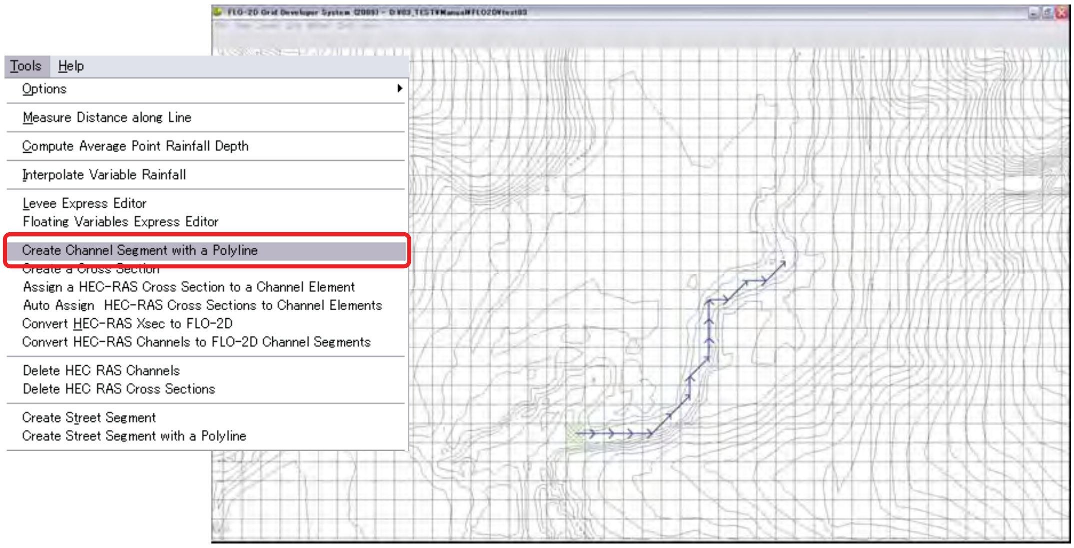
Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Preparation of New Project



- In this lesson, you will learn how to develop channel element in the model.
- Copy the folder of “**test02**”, and past as “**test03**”. And erase all files excepting **“***.DAT**” files.

Create Channel Segment

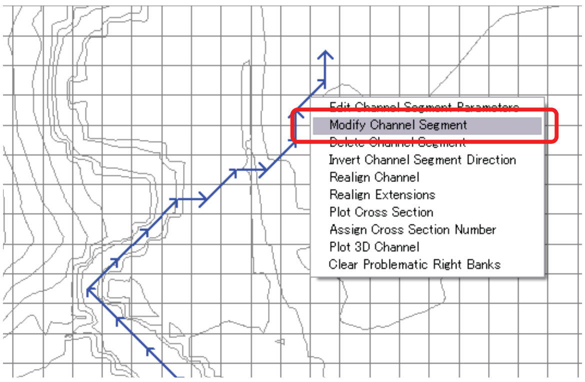


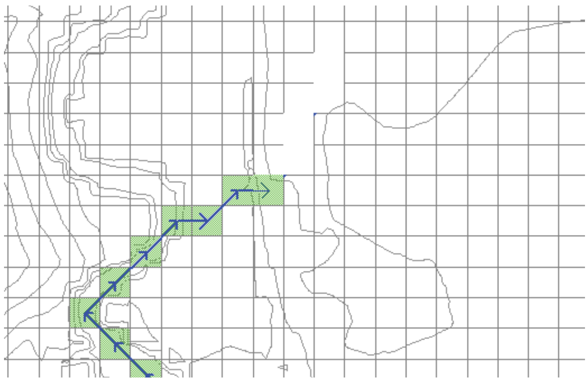
➢ Start GDS, and click [**File**] – [**Open Existing FLO-2D Project**]. Select "**FPLAIN.DAT**" in the "**test03**". Arrange view layers from [**View**] – [**Layers List**]. Hide aerial photo and elevation point, if there is.

➢ Zoom to the inflow grid (red hatch). And click [**Tools**] – [**Create Channel Segment with Polyline**]. Click on the "inflow grid", then start to draw polyline along the river.

➢ It may be difficult to draw the polyline exactly on the river line. You can draw it roughly because you are able to modify the line later.

Create Channel Segment



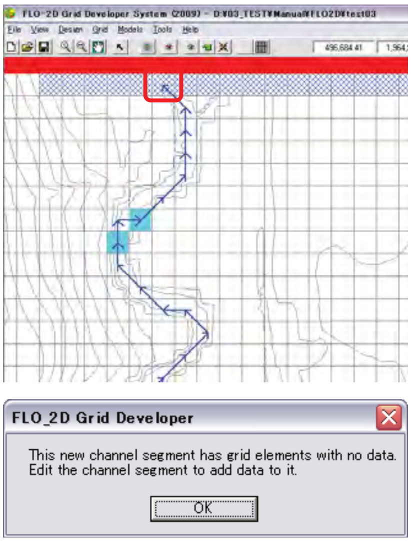


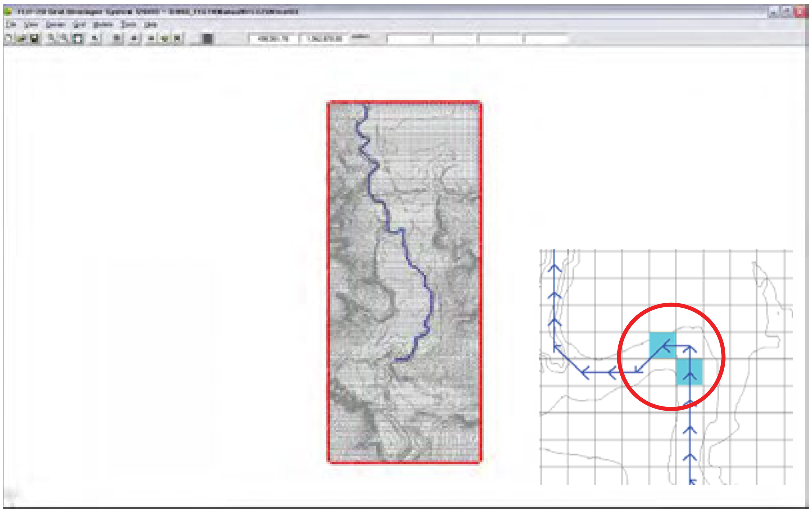
➢ If you make a big mistake to align the channel segment, stop to draw channel segment by double click on any cell.

➢ Then right click on any channel segments, and click [**Modify Channel Segment**]. This option allows you to modify the channel by dragging of mouse.

➢ When you correct it, again double-click on the segments.

Create Channel Segment



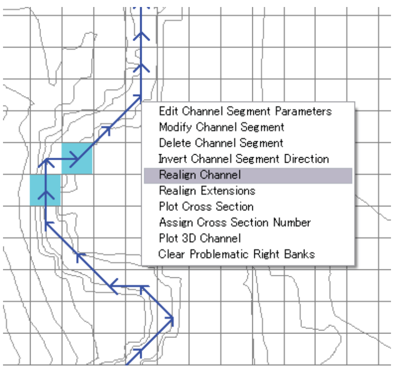


➢ When you reach to the outflow element (blue hatch), double click on the last grid. In the next dialog, just click [**OK**].

➢ You may see some light-blue colored grids along the channel. There are called “**NOFLOCS**”. In FLO-2D model, each channel element searches all eight (8) flow directions for potential contiguous elements. A pair of **NOFLOS** means there is no flow exchange between the two cells.

➢ Basically, NOFLOCS will be automatically created at the perpendicular alignment of channel.

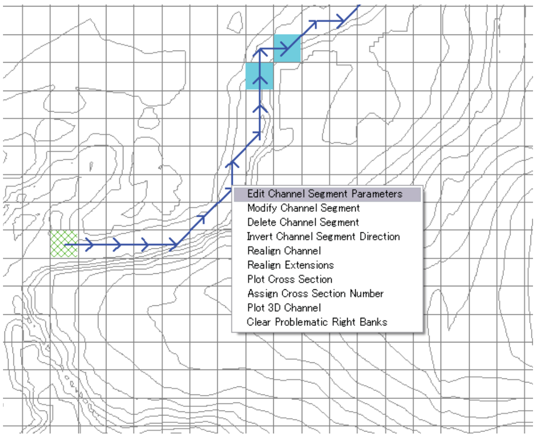
Create Channel Segment

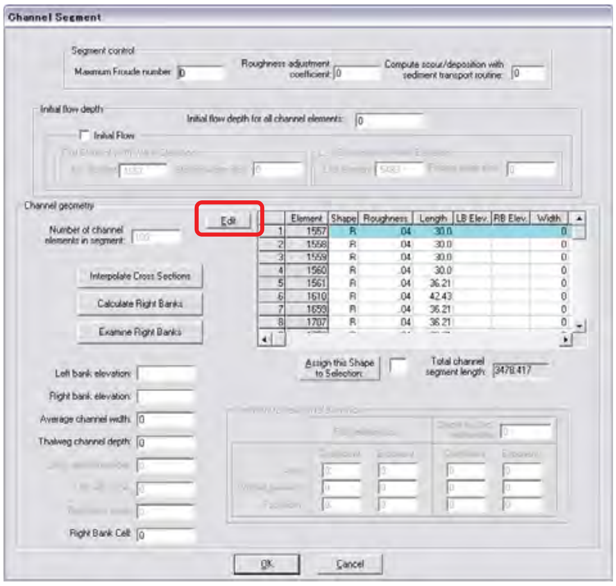


➢ If you want to change the channel alignment, click on any channel segment and select [**Realign Channel**].

➢ The vertex of channel segment will turn to circles. Then move the vertex where you want to move to. After modification, click [**Apply**].

Create Channel Segment

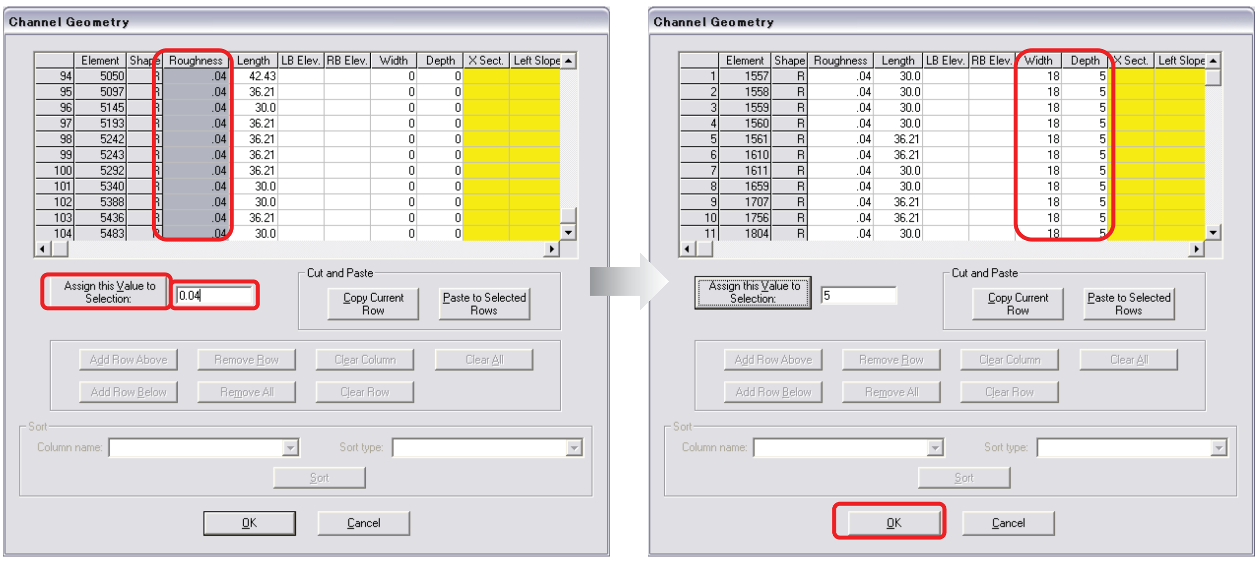




➢ When you create the channel alignment, then click at any channel segments, and select [**Edit Channel Segment Parameters**].

➢ Dialog of [**Channel Segment**] will appear. You will manage the channel segment in this dialog. Click [**Edit**] at the middle of the dialog.

Create Channel Segment

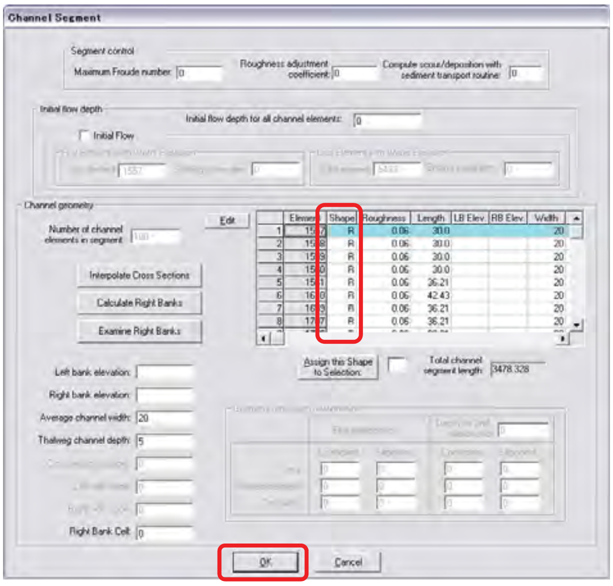


➢ In the following [**Channel Geometry**] dialog, select all column of [**Roughness**]. Enter the value of “**0.04**” (maybe default) and click [**Assign this Value to Selection**]. The roughness (Manning’s N) of 0.04 will be assigned all of channel element.

➢ Likewise, enter [**Width**] as “**18**” and [**Depth**] as “**5**”.

➢ Then click [**OK**].

Create Channel Segment

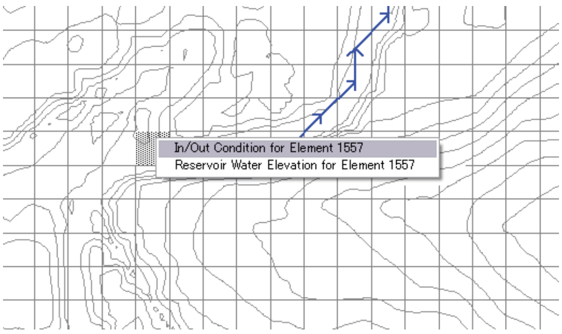


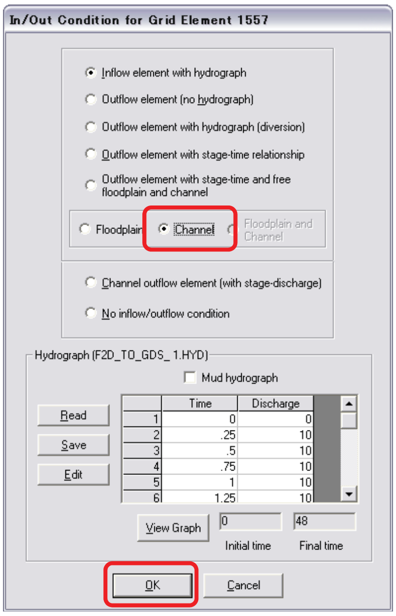
➢ The [**Shape**] at the left end of table represents cross section shape of the channel. When you put "**R**", it means rectangular shape. "**T**" is trapezoidal shape and "**V**" is V shape.

➢ When you want to use specific measured cross section data, you have to put "**N**".

➢ Now you will use "**R**" (rectangular shape). Click [**OK**].

Modification of Inflow / Outflow Condition



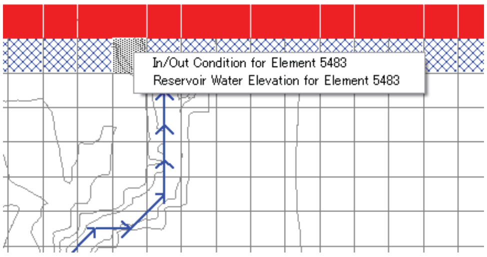


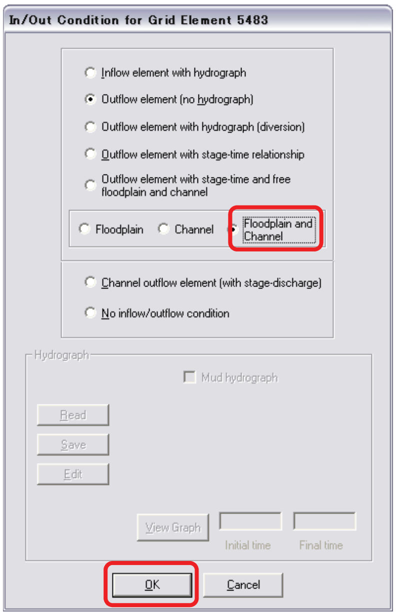
➢ When you use channel segments, you are required to change the boundary condition of inflow and outflow grids.

➢ Right click on the Inflow Grid, and select [**In/Out Condition for Element *****].

➢ In the dialog, check [**Channel**] instead of [**Floodplain**]. Then click [**OK**].

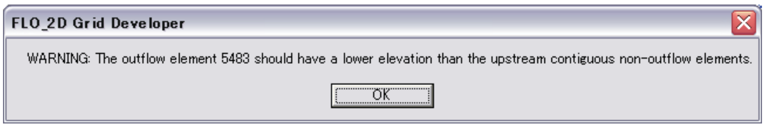
Modification of Inflow / Outflow Condition

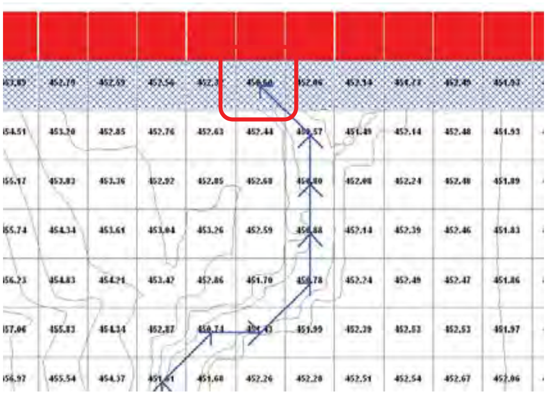


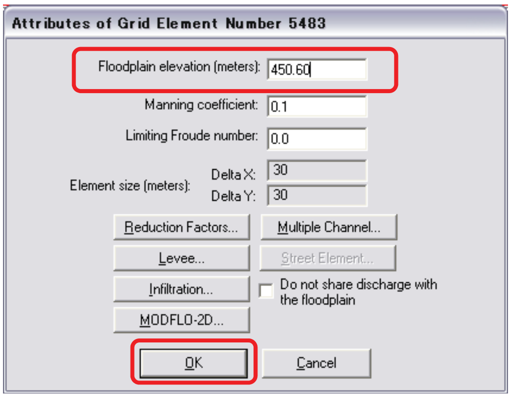


- ➢ Likewise, right click on the Outflow Grid, and select [**In/Out Condition for Element *****].
- ➢ In the dialog, check [**Floodplain and Channel**] instead of [**Floodplain**]. Then click [**OK**].

Modification of Inflow / Outflow Condition





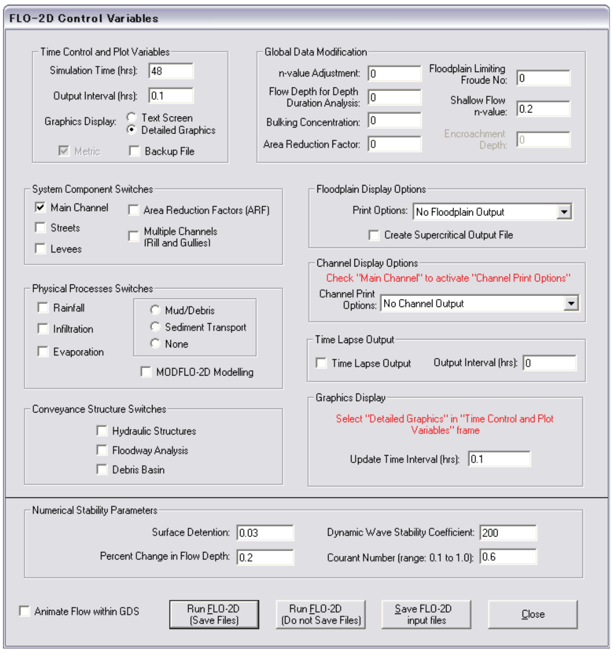


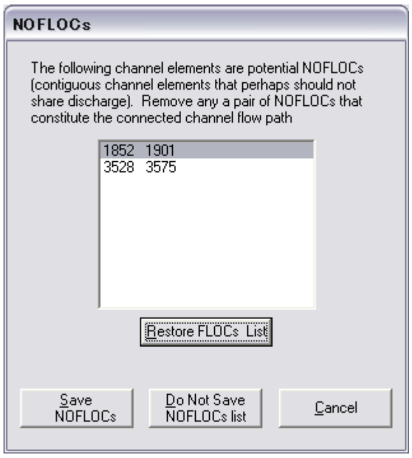
➢ You may be asked as above warning. In channel segment, elevation of the last channel element have to be lower than the upstream contiguous channel element.

➢ Zoom up at the end of channel segment, and click [**View**] – [**Grid Element Elevation Values**].

➢ If the end element is higher than upstream element, double click at the end, and directory modify the [**Floodplain elevation (meters)**] into lower value. In this case, you can modify “**450.92**” to “**450.50**”.

Run Model



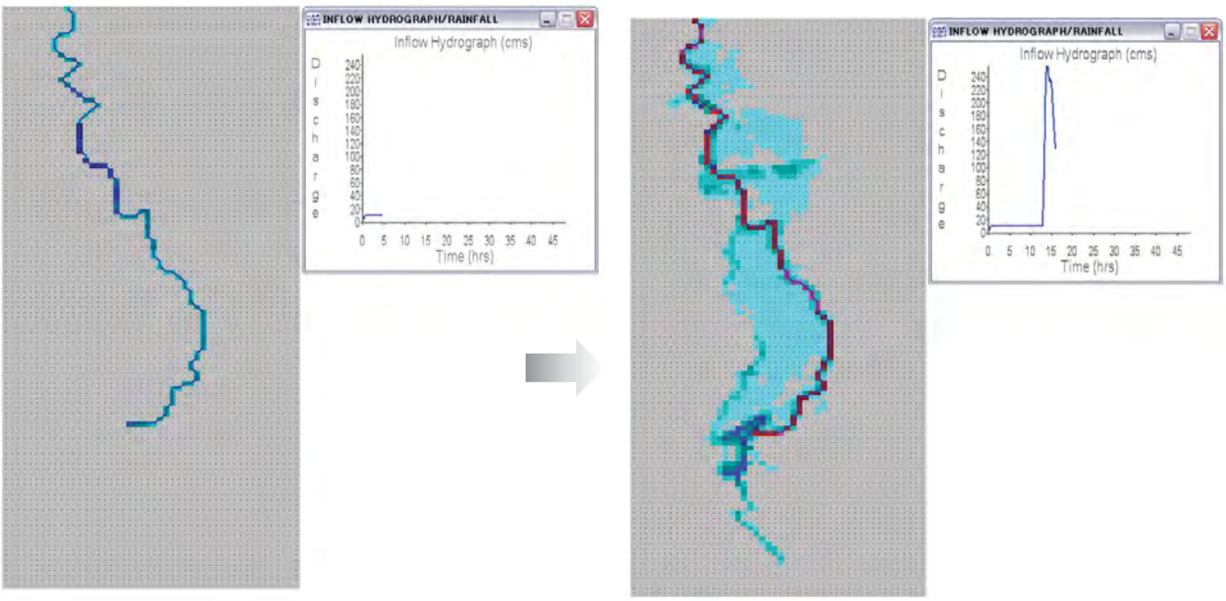


➢ Now, you are ready to run the simple channel model. Select [**File**] – [**Run FLO-2D**].

➢ In the dialog of [**FLO-2D Control Variables**], make sure that [**Main Channel**] was checked. If not, check it. Click [**Run FLO-2D (Save Files)**].

➢ A dialog of [**NOFLOCs**] will appear. Click [**Save NOFLOCs**].

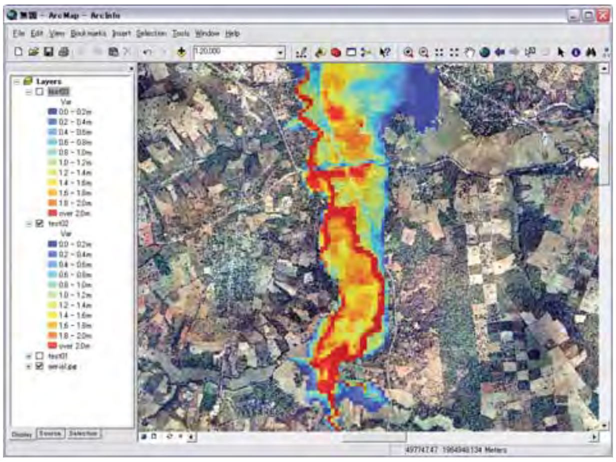
Run Model



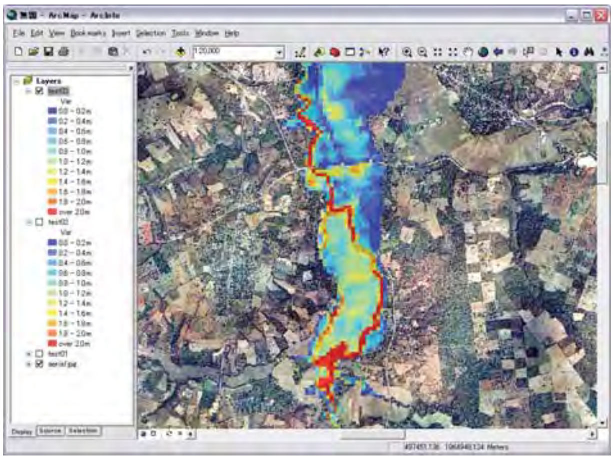
➢ You may notice that the difference from the last lesson.

➢ Since the channel has certain flow capacity, flood doesn’t occur by base flow of only 10 m^3/s. When discharge starts rising, firstly the upstream will be flooded. At the same time, several locations along the channel is also flooded.

Run Model



No Channel Segments



With Channel Segments

➢ Compare between the output of lesson 5 and lesson6. The flood area and water depth are obviously different. This is because of channel flow capacity.

➢ But still you need some modifications of the model as bellow.

1) The channel bed slope is not smooth because it was just generated from interpolated surface elevation.

2) The highway running east – west direction at Muang Sam Pee village must behave as a levee or an embankment for flood. You need add such structure in the model.

END

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

Lesson 7
Flood Simulation

Chanel Profile Modification
& Levee Element

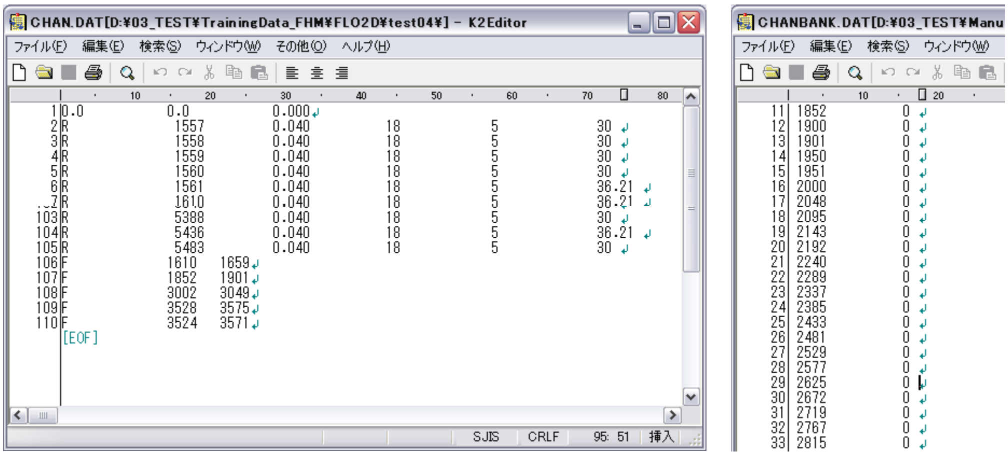
Task Force – Flood Risk Management

Project on Capacity Development in Disaster Management
in Thailand – Phase 2 –

Review DAT Files

- In this lesson, you will learn how to modify the channel element profile (channel bed slope) and how to add a levee in the model.
- Copy the folder of “**test03**”, and past as “**test04**”. And erase all files excepting **“***.DAT”** files. You may notice that there are additional two (2) DAT files of “**CHAN.DAT**” and “**CHANBANK.DAT**”.

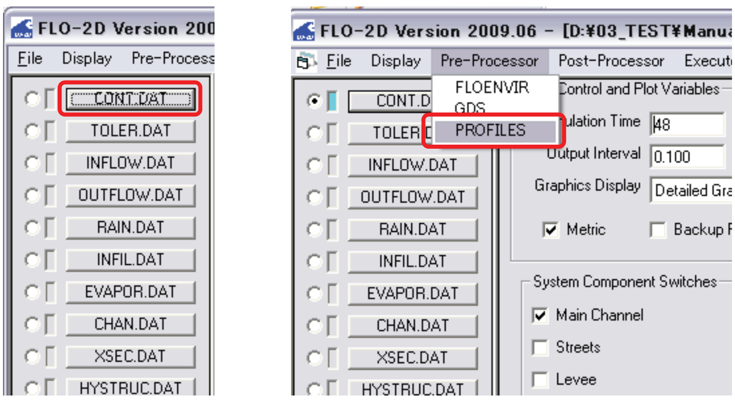
Review DAT Files



➢ In the "**CHAN.DAT**", there are parameters of every grid elements, where channel segment were assigned. The final 5 lines represent **NOFLOC** in the channel segment.

➢ In the "**CHANBANK.DAT**", the left column is left bank grid number and the right column is right bank grid number. But the right bank is now empty because the channel width is less than the grid element size (30m).

Channel Profile Modification



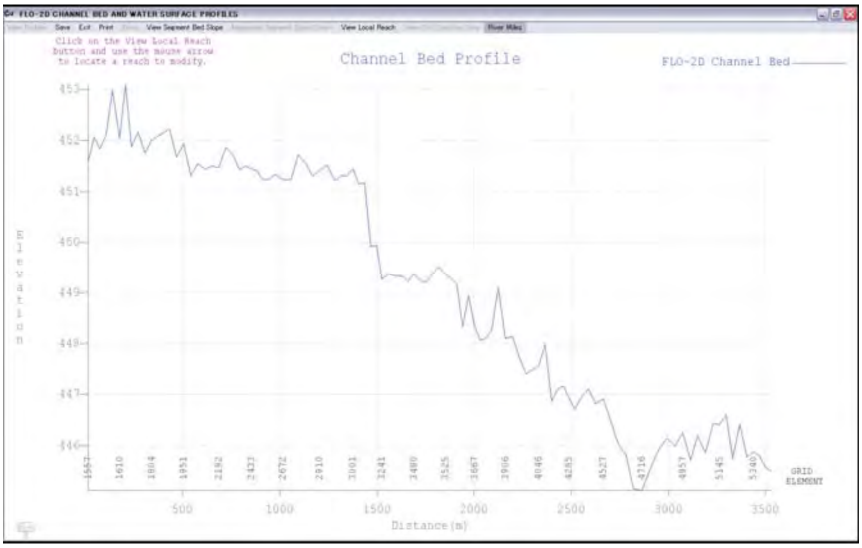
➢ In the last lesson, the channel bed elevation was extracted from the surface elevation of each grid (**FPLAIN.DAT**) where the channel segment s were assigned. For instance, if the surface grid elevation is "**485.23m**", the channel bed elevation is "**480.23**m (= surface – 5m)".

➢ Because the surface grid elevation is not always smooth due to the interpolated large grid size, the channel bed elevation is also undulated.

➢ To modify the channel bed slope, you will use [**PROFILES**] module in FLO-2D. When you modify the river bed in PROFILES, the original FPLAIN.DAT will be replaced. But if you are opening GDS, it will be over write by previous FPLAIN.DAT again. So please make sure to close GDS at this moment.

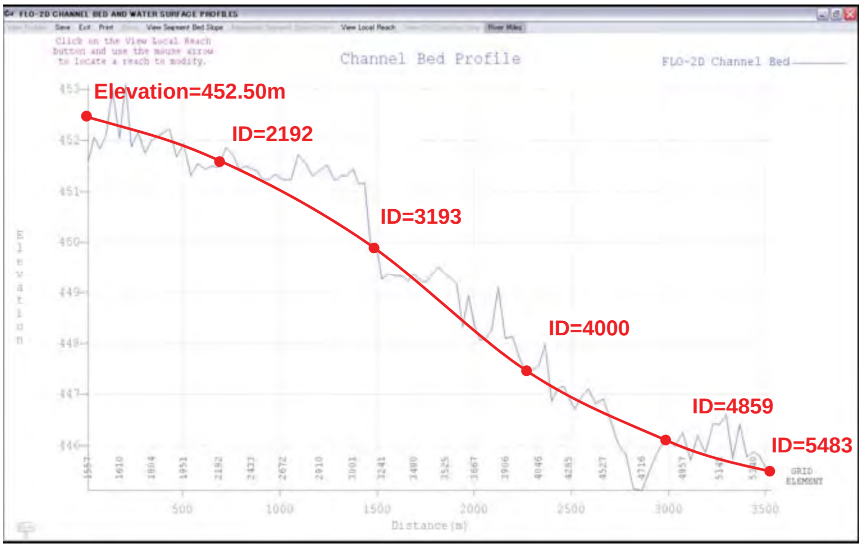
➢ Start FLO-2D. Click [**CONT.DAT**] button and then select "**CONT.DAT**" in "**test04**" folder. Then click [**Pre-Processer**] – [**PROFILES**].

Channel Profile Modification



➢ In the dialog of [**FLO-2D CHANNEL BED AND WATER SURFACE PROFILES**], click [**View Segment Bed Slope**]. You can see the current profile of channel bed slope, that must be highly undulated as above.

Channel Profile Modification



➢ In this lesson, you will manually modify and simplify the channel bed slope as above figure.

➢ Red dots shows vertexes of modified channel bed profile. If the grid number is not same as above, you can select any vertexes to modify the profile.

Channel Profile Modification

➢ Click [**View Local Reach**].

➢ The mouse cursor will change to ↑arrow. Then click near the most upstream profile.

➢ The target location of the profile will be zoomed up. You can modify the channel bed elevation at this triangle arrow, which can be moved by Up and Down button of the keyboard.

➢ Move the arrow to the most upstream element.

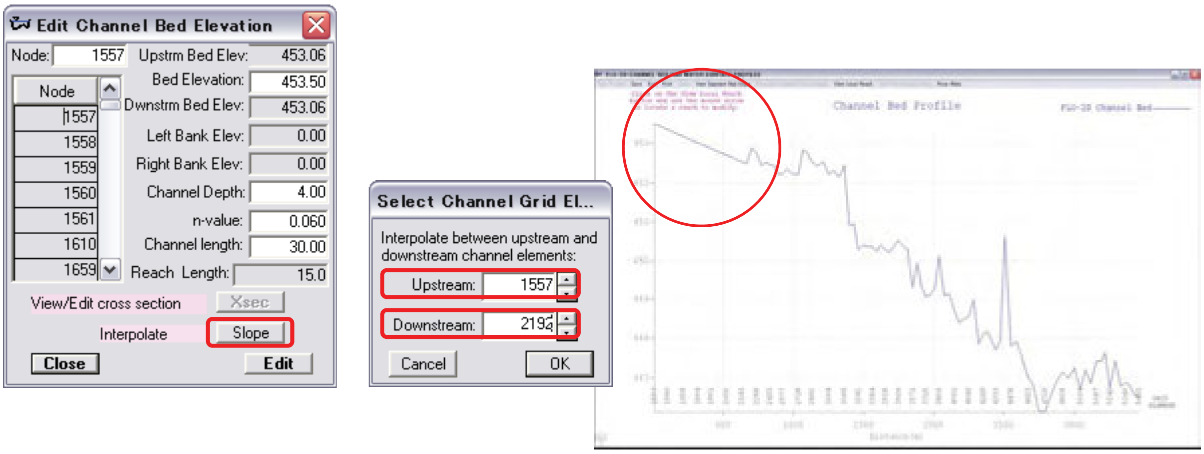
Channel Profile Modification

➢ When you click [**View/Edit Xsection Data**],

➢ In the dialog of [**Edit Channel Bed Elevation**], change the [Bed Elevation] from “451.59” into “452.50” and click [**Edit**].

➢ Now the channel bed elevation was changed.

Channel Profile Modification

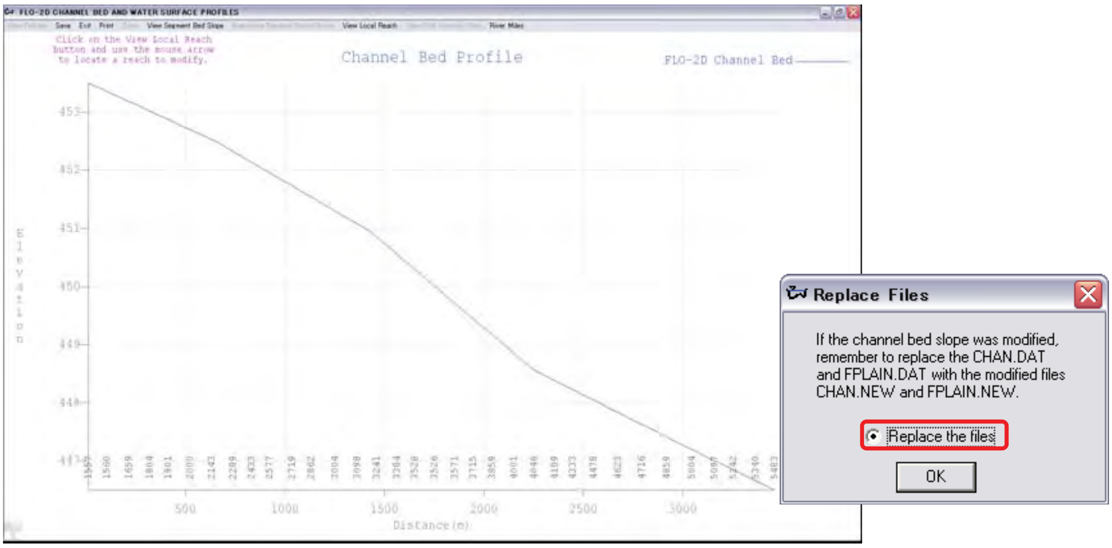


➢ Next, click [**View/Edit Xsection Data**] and [**Slope**].

➢ In the following dialog, enter the channel element grid number of "**1557**" and "**2192**" respectively. Then click [**OK**].

➢ Make sure that the profile between "1557" and "2192" was interpolated as above figure.

Channel Profile Modification



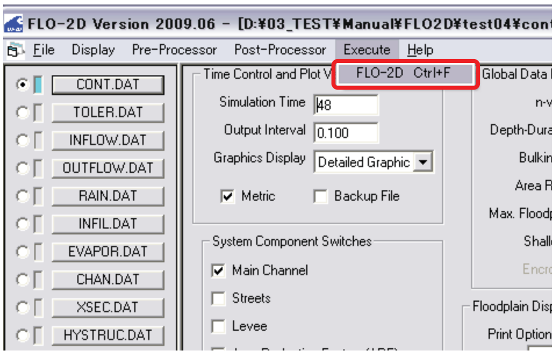
➢ Likewise, interpolate other vertexes as above figure.

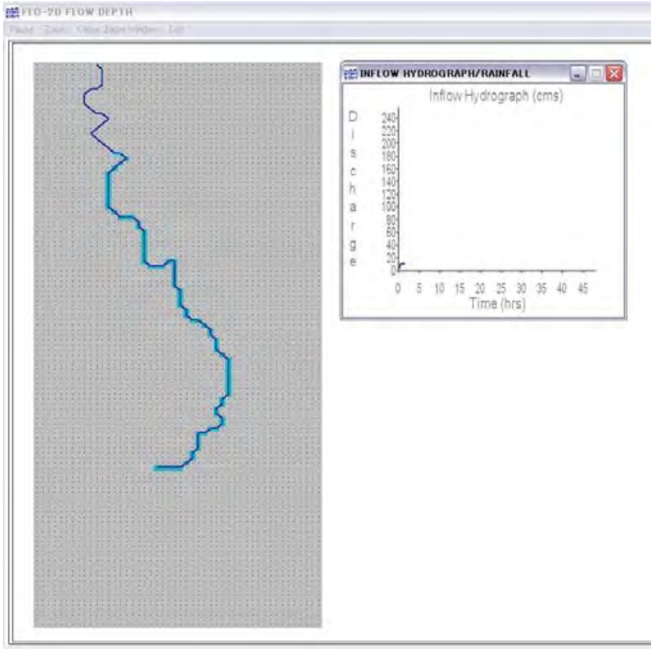
➢ After modification and smoothing, click [**Save**]. You will be asked if you want to update **CHAN.DAT** and **FPLAIN.DAT**.

➢ When you just click [**OK**], those will be not replaced, but **CHAN.NEW** and **FPLAIN.NEW** will be created in the folder. When you check the [**Replace the files**], **CHAN.DAT** and **FPLAIN.DAT** will be replaced. Here please check it, and click [**OK**].

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

Run Model



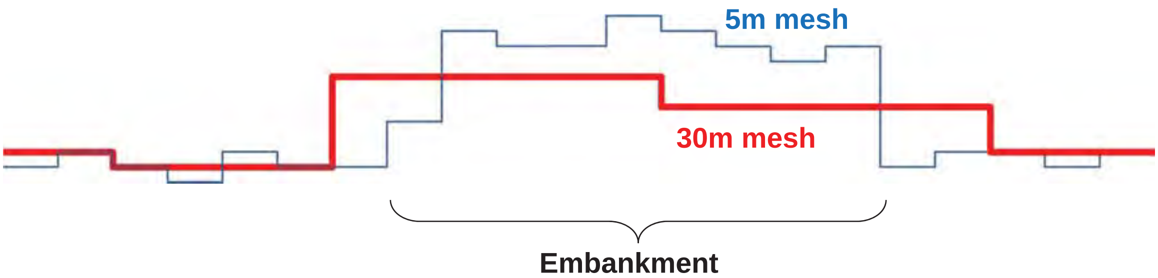


➢ Close [**PROFILES**].

➢ You can run the FLO-2D model without GDS. Just click [**Execute**] – [**FLO-2D**]. Then computation will starts.

➢ Make sure that the flow depth in the channel is smoother than before.

Levee Component



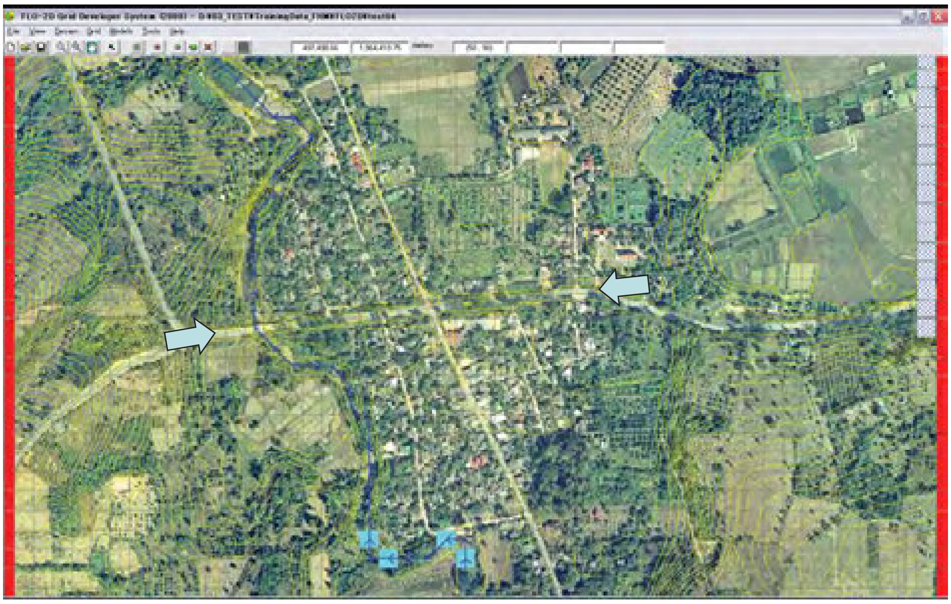
➢ Now you are working on 30m mesh grids generated (interpolated) from 5m mesh DEM.

➢ Due to the interpolation, the surface elevation tend to be higher or lower than actual elevation. For example, as shown in above figure, there might be highly elevated object such as Embankment. But after interpolation, the height will be reduced.

➢ Thus, in the next step, you will create "**LEVEE**" at the location of embankment instead of modification of grid elevation.

➢ Open **GDS** and click [File] – [Open Existing FLO-2D Projects]. Then open **FPLAIN.DAT** from the [**test04**] folder.

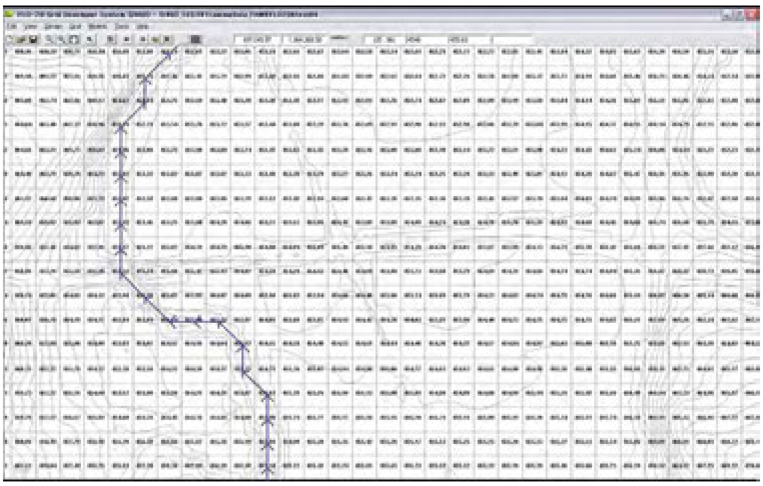
Levee Component

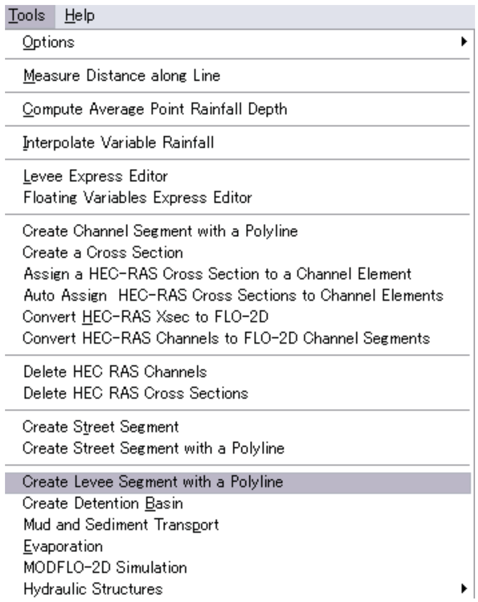


➢ There is a highway in the Muang Sam Pee village (arrows in above figure). This highway contribute very important effect to the flood behavior. Because the highway is embanked about 2m from the flood plain, water flow from upstream is blocked.

➢ In you model, the elevation of highway may be about **454m – 455m**. But the actual elevation is about **456m**. So you need to create **LEVEE** with elevation of **456m**.

Levee Component



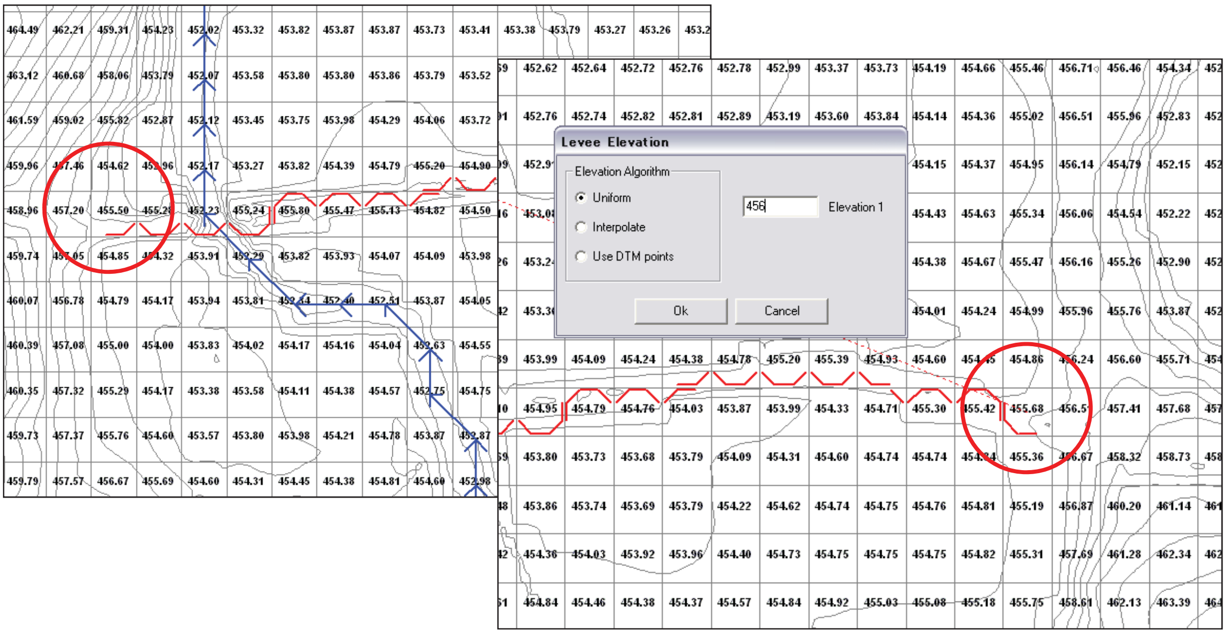


➢ Firstly, show grid elevation values by click [**View**] – [**Grid Element Elevation Values**].

➢ Then click [**Tool**] – [**Create Levee Segment with a Polygon**]

➢ You can start drawing at a grid which has elevation less than **456m**.

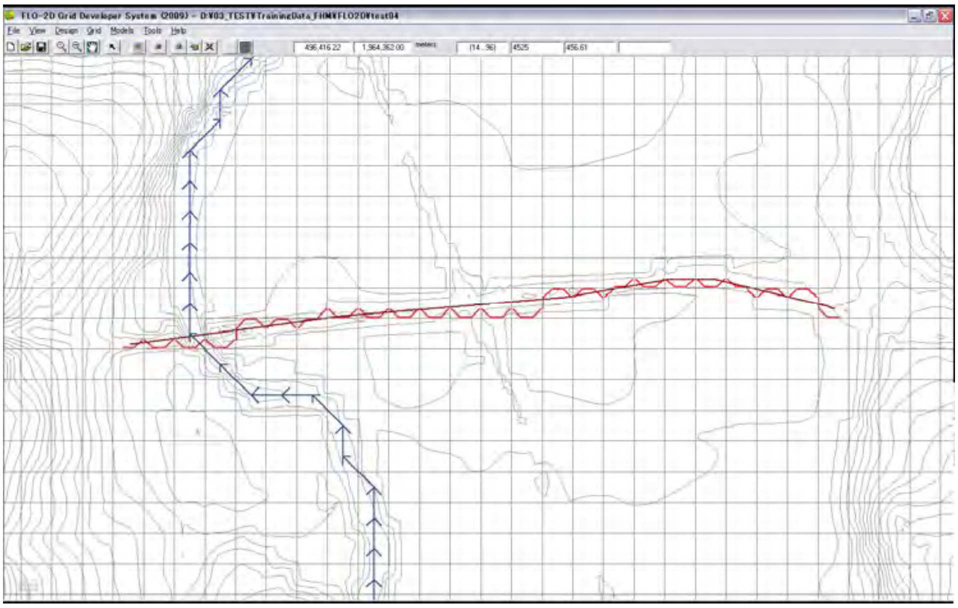
Levee Component



➢ In this case, start drawing at grid number “**4091**” and end at “**4162**”. When you draw until the end, click [**Apply**].

➢ The dialog of [**Levee Elevation**] will appear, then enter “**456**” for uniform elevation and click [**OK**]..

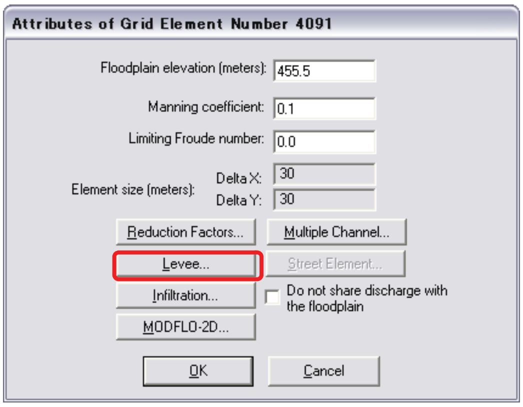
Levee Component

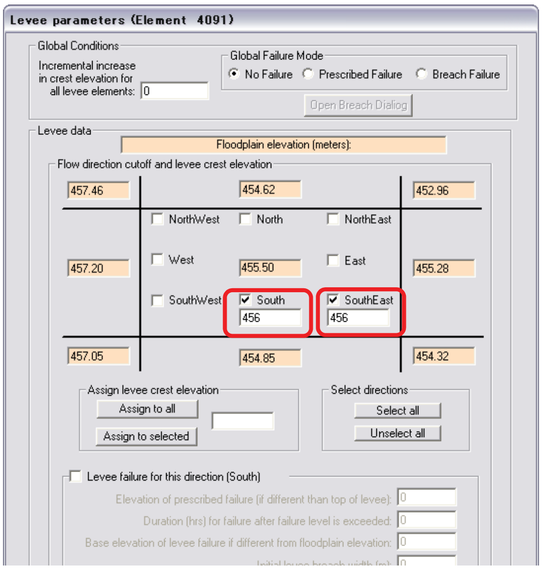


➢ Now you created a Levee as above figure. This levee has elevation of **456m** for each segment.

➢ But still you need modify the elevation at the starting point and ending point.

Levee Component



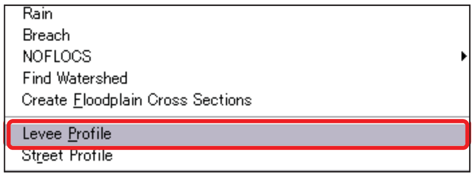


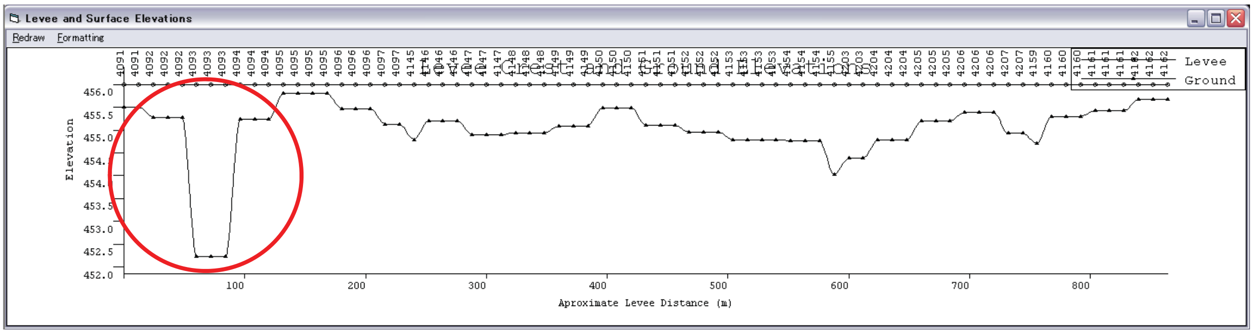
➢ Double-click on the starting cell of “**4092**”. And click [**Levee**] in the dialog.

➢ The element has levee (wall) in the direction of South and South East. However there is no wall in the direction of South West. Because there is higher grid in the direction of South West, water flow cannot pass this Levee element. In case there is any lower elevation where water can flow down to the downstream, you need to check on the small box and input elevation value “**456**”.

➢ In this case, you don’t need to modify anything. Please check at the ending cell of “**4162**”.

Levee Component





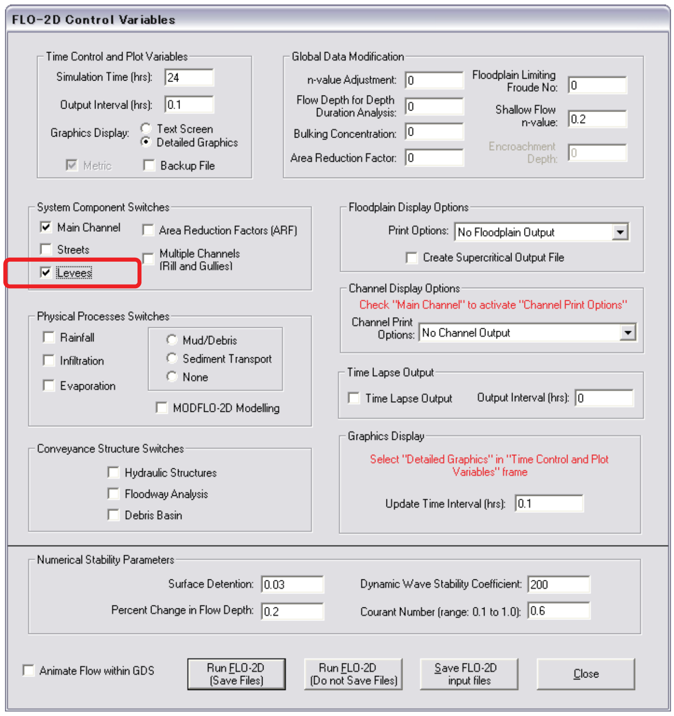
➢ You can also check the Levee’s profile.

➢ Select [**Tool**] – [**Levee Profile**], and click on the any Levee elements.

➢ In the view of [**Levee and Surface Elevation**], you can notice that there is river channel at cell number of “**4093**”.

➢ Close the view window.

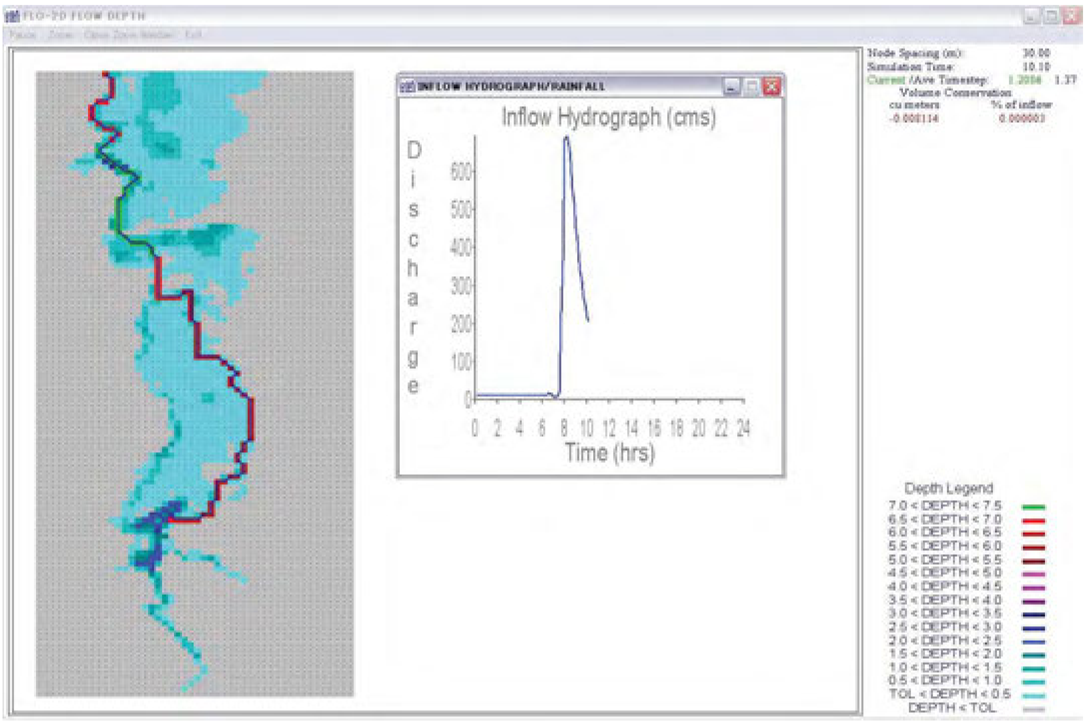
Levee Component



➢ Now you are ready to run the model. Please do not forget to check on [**Levees**] in [**Segment Component Switches**].

➢ Then click [**Run FLO-2D (Save File)**].

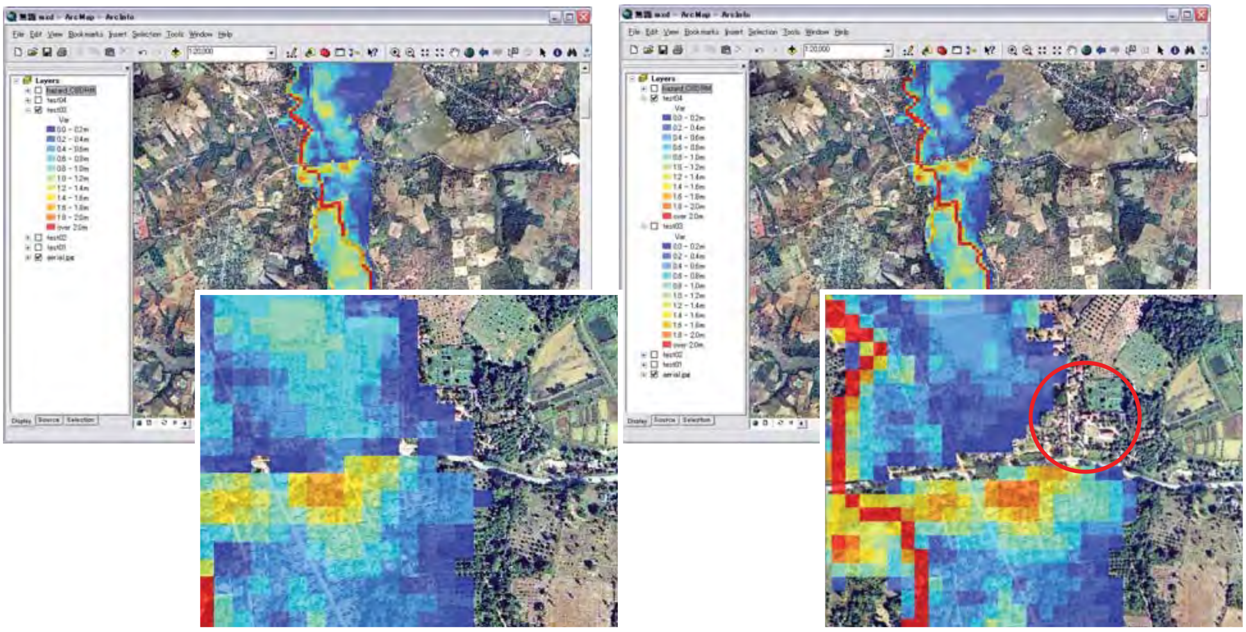
Levee Component



➢ You can notice that the highway behave has an obstruction for flood flow. The downstream area of the highway is flooded by water from river not from southern part of the highway.

➢ Indeed, this is the actual phenomenon that villagers have experienced.

Levee Component



- ➢ You can look at the difference between without Levee (left) and with Levee (right).
- ➢ The red circle is a temple that residents identified as a safe place for evacuation in their CBDRM. On the other hand, the south part of the highway is deeply inundated by the obstruction of the highway.

END

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

Lesson 8
Flood Simulation

Add Tributaries
& Multi-Hydrograph Input

Task Force – Flood Risk Management

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

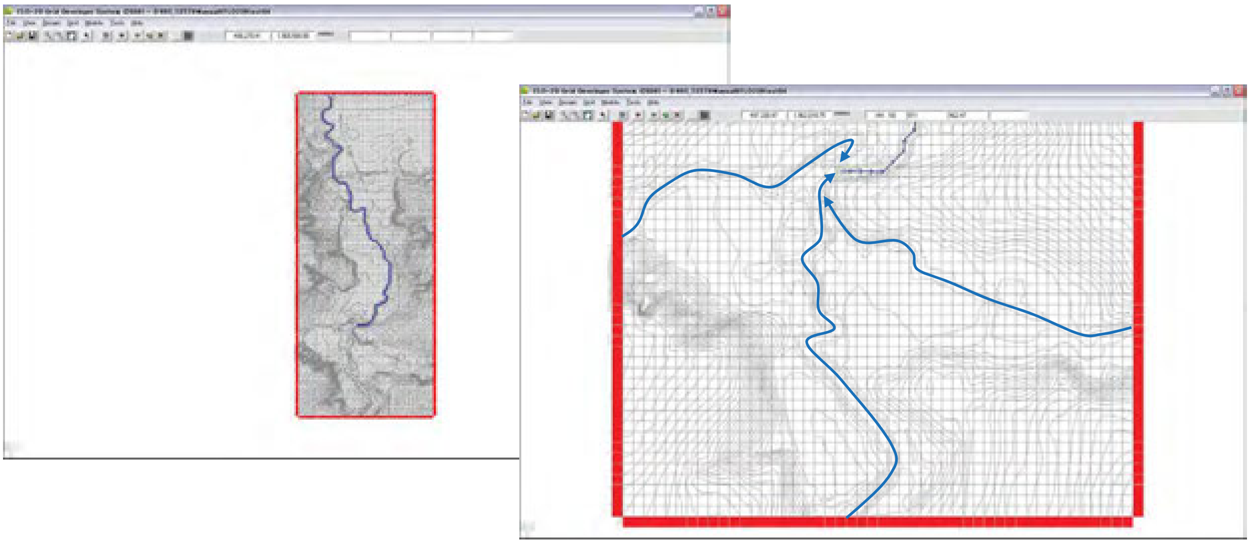
Review DAT Files

➢ In the previous lessons, you input only one hydrograph into the model. However, you may need to input multiple hydrograph because some villages are not located in the downstream area but also scattered in the upstream.

➢ Firstly you will create some additional tributaries, and then input hydrographs from HEC-HMS.

➢Copy the folder of “**test04**”, and past as “**test05**”. And erase all files excepting **“***.DAT**” files. You may notice that there are a new DAT files of “**LEVEE.DAT**” that is created in the last lesson.

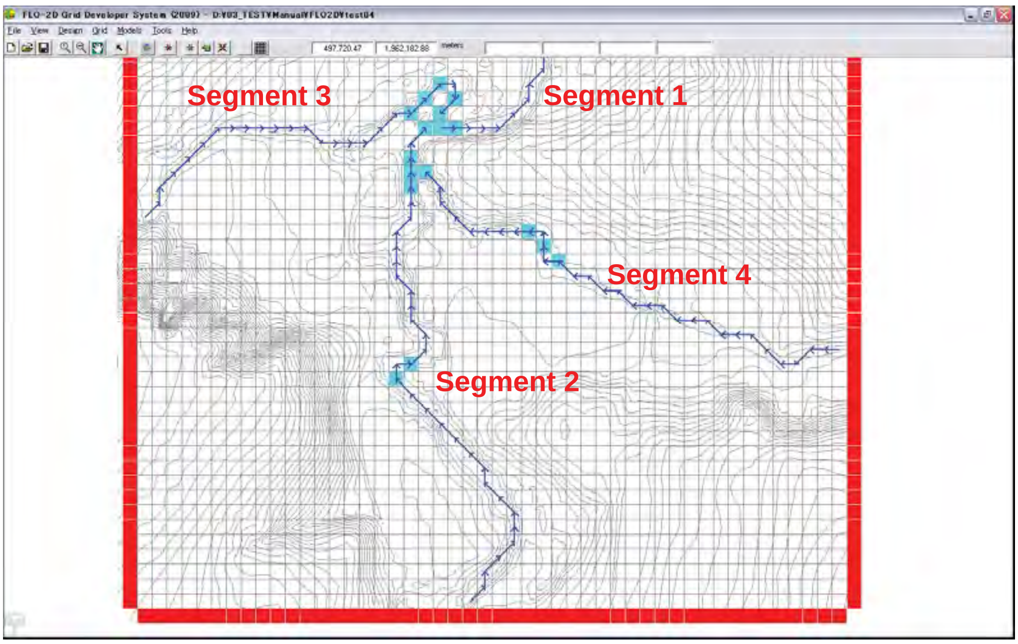
Add Channel Segments



➢ Start GDS and open “**FPLAIN.DAT**” in the “**test05**” folder.

➢ Zoom to the upstream of the current channel segment. There are three (3) tributaries from each sub-basin. Now you will generate 3 tributaries.

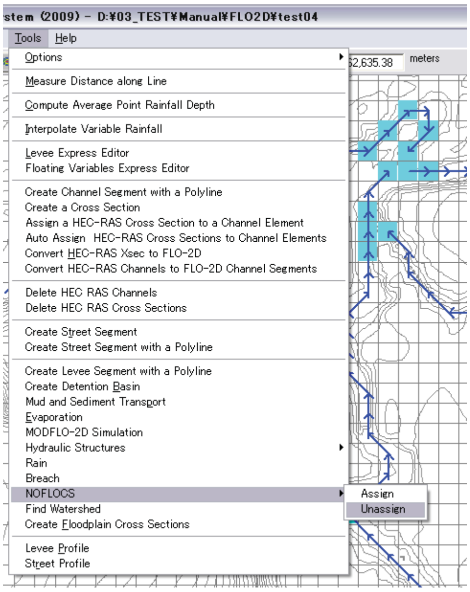
Add Channel Segments

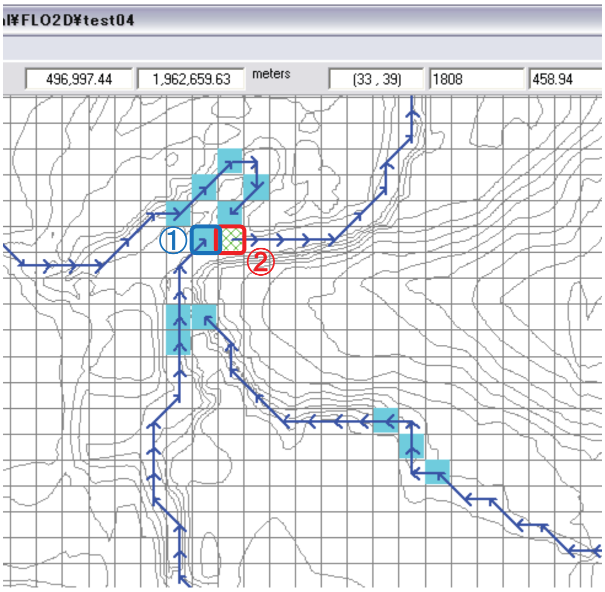


➢ Click [**Tools**] – [**Create Channel Segment with a Polyline**].

➢ Draw three (3) channel segments along the rivers as above figure.

Add Channel Segments

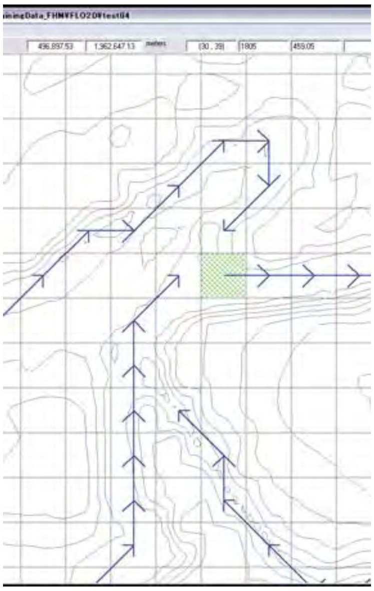


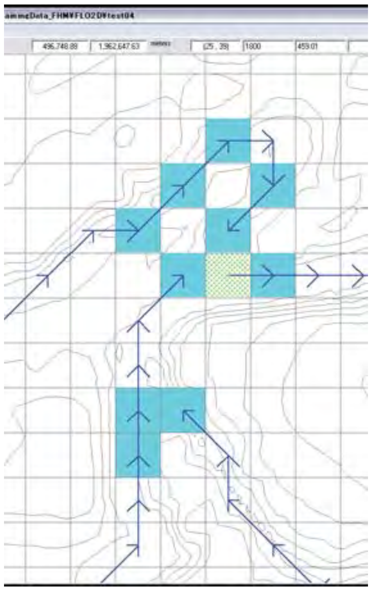


➢ The lite-blue colored cells are **NOFLOCS**, which means there are no flow exchanges between the two cells. You need to unassign the NOFLOCS between the end of a tributary and the head of main channel.

➢ Click [**Tools**] – [**NOFLOCS**] – [**Unassign**]. Click at the blue colored grid ①, and then click at the red colored grid ② in above figure. The light-blue color will be disappeared. This means NOFLOCS was unassigned.

Add Channel Segments



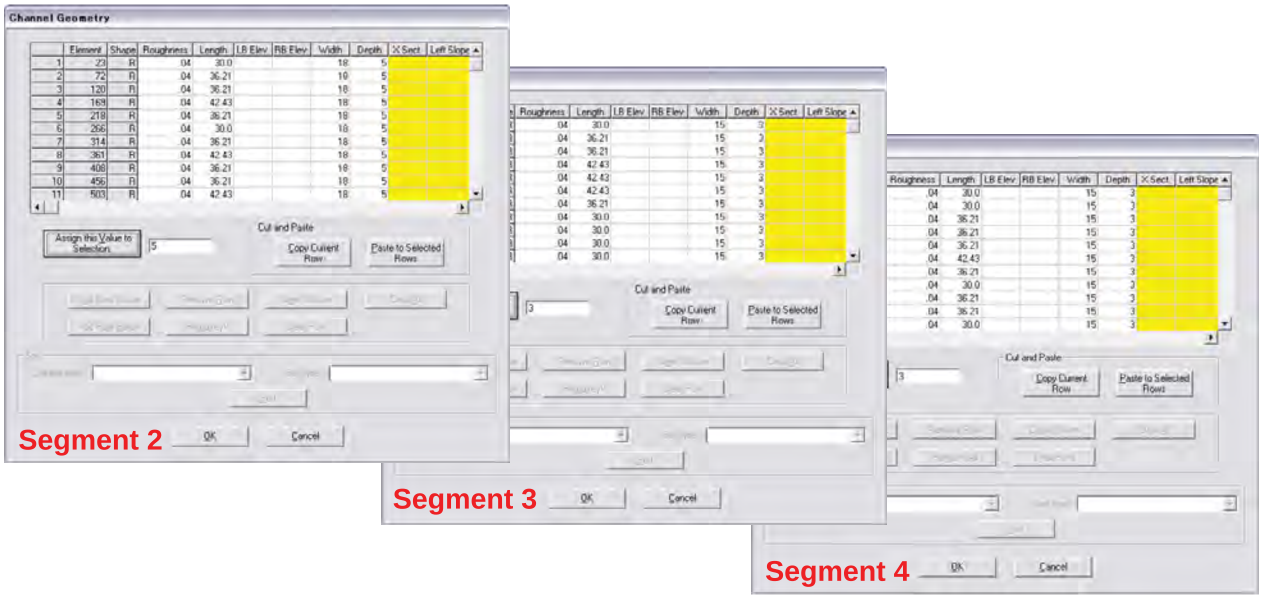



➢ If you encounter any problem to assign and unassign NOFLOCS, please erase all NOFOCS near the confluence by [**Tool**] – [**NOFLOCS**] – [**Unassign**] as above left figure.

➢ Then assign NOFLOCS as above center figure. Here the black arrows must be NOFLOCS. Select [**Tool**] – [**NOFLOCS**] – [**Assign**], then click each pairs of cells to assign NOFLOCS.

➢ Finally you will obtain as the above right figure.

Add Channel Segments

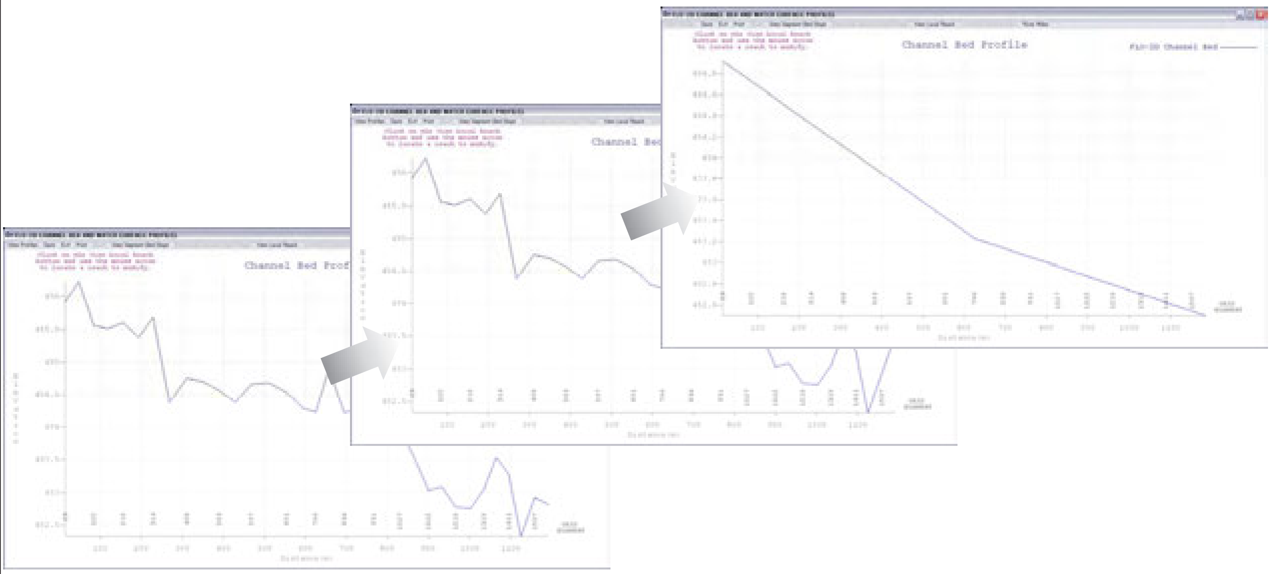


➢ Click on any channel segments in each tributary, and then select [**Edit Channel Segment Parameters**]. Click [**Edit**] in the dialog, and assign channel geometry as follows:

Roughness = **0.04**, Width = **18** and Depth = **5** for the Segment 2.
Roughness = **0.04**, Width = **15** and Depth = **3** for the Segment 3 & 4.

➢ Save FLO-2D file by [**File**] – [**Save FLO-2D Files**]. When you are asked where you save NOFLOCS or not, click [**Save NOFOCs**]. Then close GDS.

Channel Profile Modification

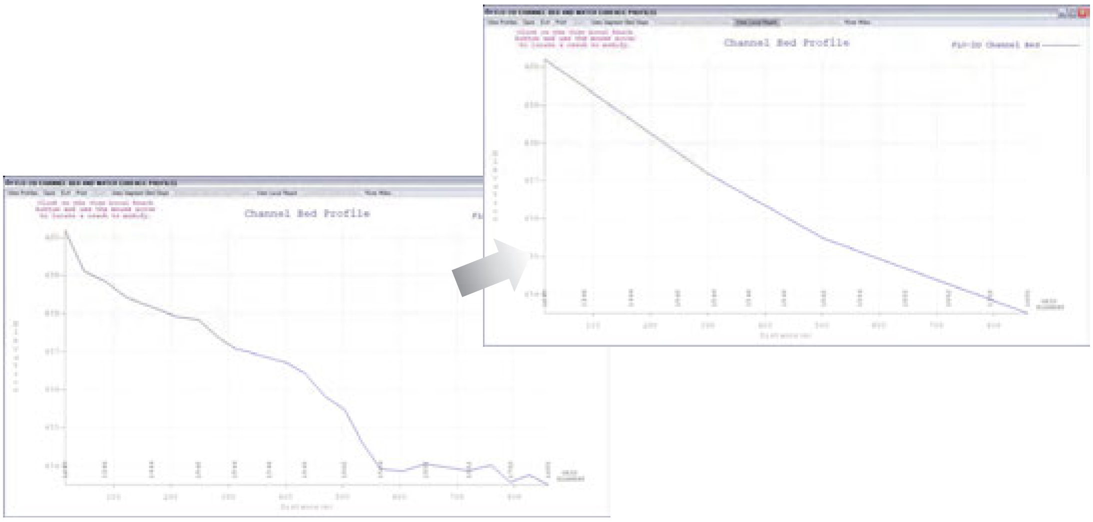


➢ Open [**PROFILES**]. Click [**View Segment Bed Slope**]. Check on "**Segment 2**", then click [**OK**].

➢ Click [View Local Reach]. Then, change elevation of downstream end of the channel into "**452.50m**" that is the elevation of upstream end of the "**Segment 1**".

➢ Then interpolate bed elevation between several locations. In this case, interpolate between **23**, **786** and **1556**.

Channel Profile Modification

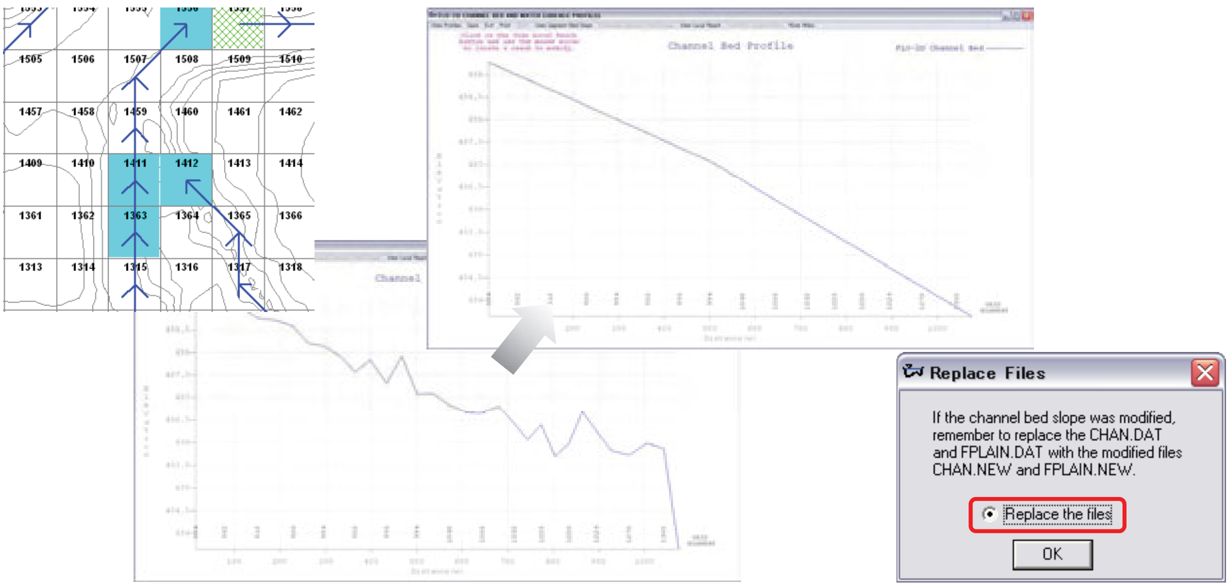


➢ Likewise, click [**View Segment Bed Slope**]. Check on "**Segment 3**", then click [**OK**].

➢ Change elevation of downstream end of the channel into "**452.50m**" that is the elevation of upstream end of the "**Segment 1**".

➢ Then interpolate bed elevation between several location. In this case, interpolate between **1249**, **1544**, **1502** and **1605**.

Channel Profile Modification

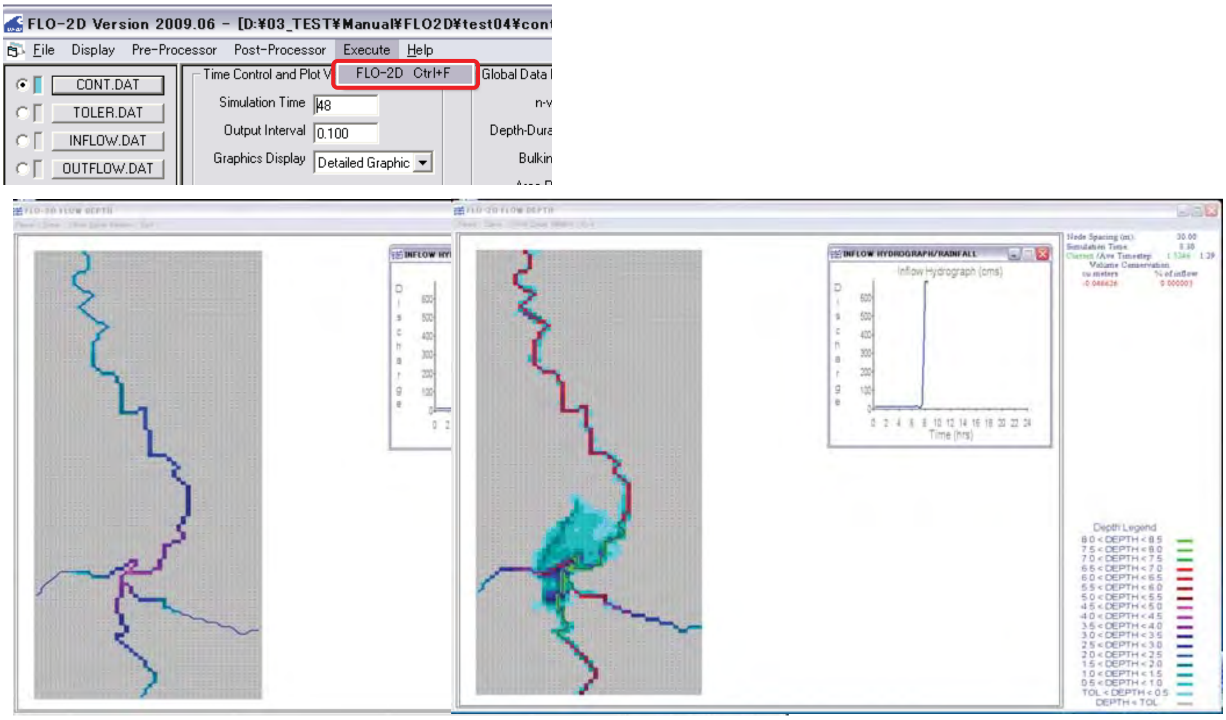


➢ Likewise, click [**View Segment Bed Slope**]. Check on "**Segment 4**", then click [**OK**].

➢ Change elevation of downstream end of the channel into "**452.59m**" that is the channel bed elevation of the confluence (Grid number: 1459) of "**Segment 2**". Then interpolate bed elevation between several location. In this case, interpolate between **864**, **994** and **1412**.

➢ After editing, save the PROFILES and replace **CHAN.DAT** and **FPLAIN.DAT**.

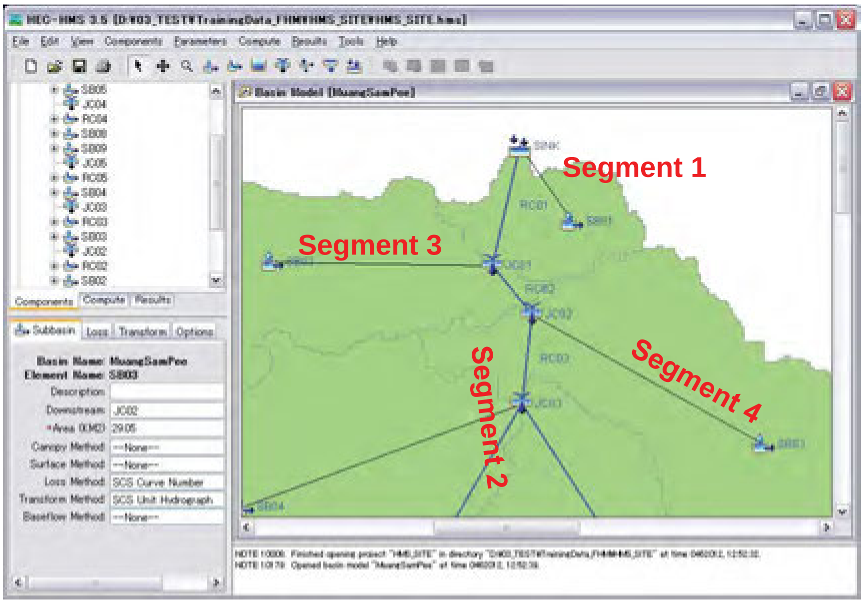
Run Model



➢ Close [**PROFILES**].

➢ Tentatively try to run the model to know what is different between before and after creating tributaries. Click [**Execute**] – [**FLO-2D**].

Preparation of Hydrographs

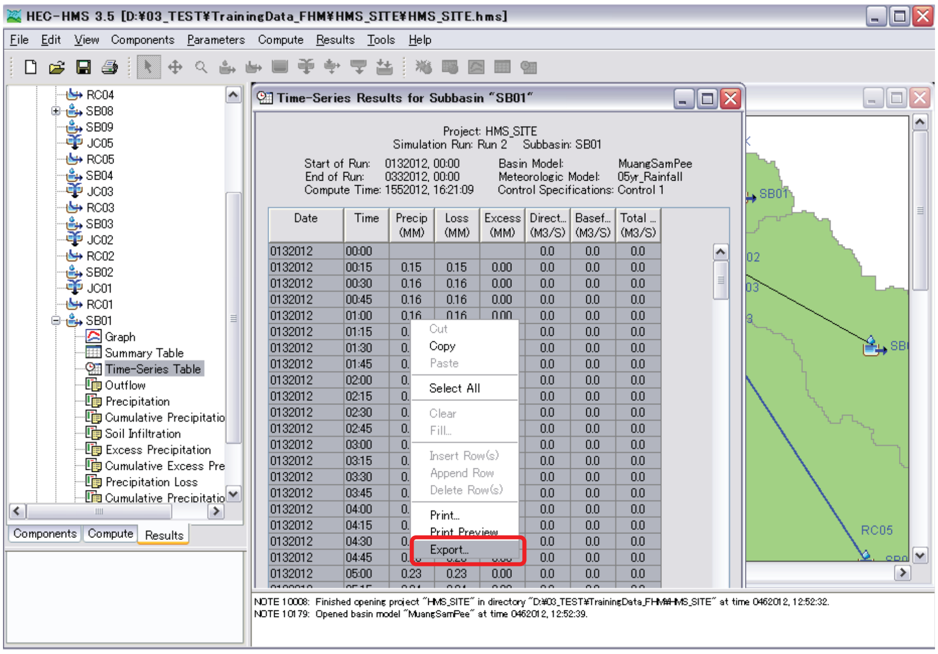


➢ Open HEC-HMS, then open the project of “**HMS_SITE**”.

➢ In the above figure, you need to extract hydrographs from following location:

Outflow from SB01	⇒	Inflow for Segment 1 in FLO-2D
Inflow to JC02	⇒	Inflow for Segment 2 in FLO-2D
Outflow from SB02	⇒	Inflow for Segment 3 in FLO-2D
Outflow from SB03	⇒	Inflow for Segment 4 in FLO-2D

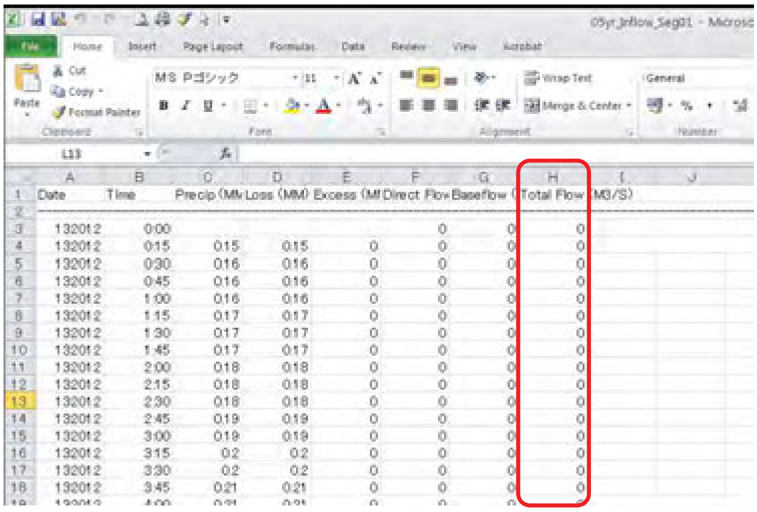
Preparation of Hydrographs



➢ Open the result of 5yr_Runoff. Open the [**Time-Series Table**] of [**SB01**]. Then select all records and export as **Tab Delimiter** named “**05yr_Inflow_Seg01**”.

➢ Likewise, export “**05yr_Inflow_Seg02**” from [**JC02**], “**05yr_Inflow_Seg03**” from [**SB02**] and “**05yr_Inflow_Seg04**” from [**SB03**], into the [**Hydrograph**] folder.

Preparation of Hydrographs

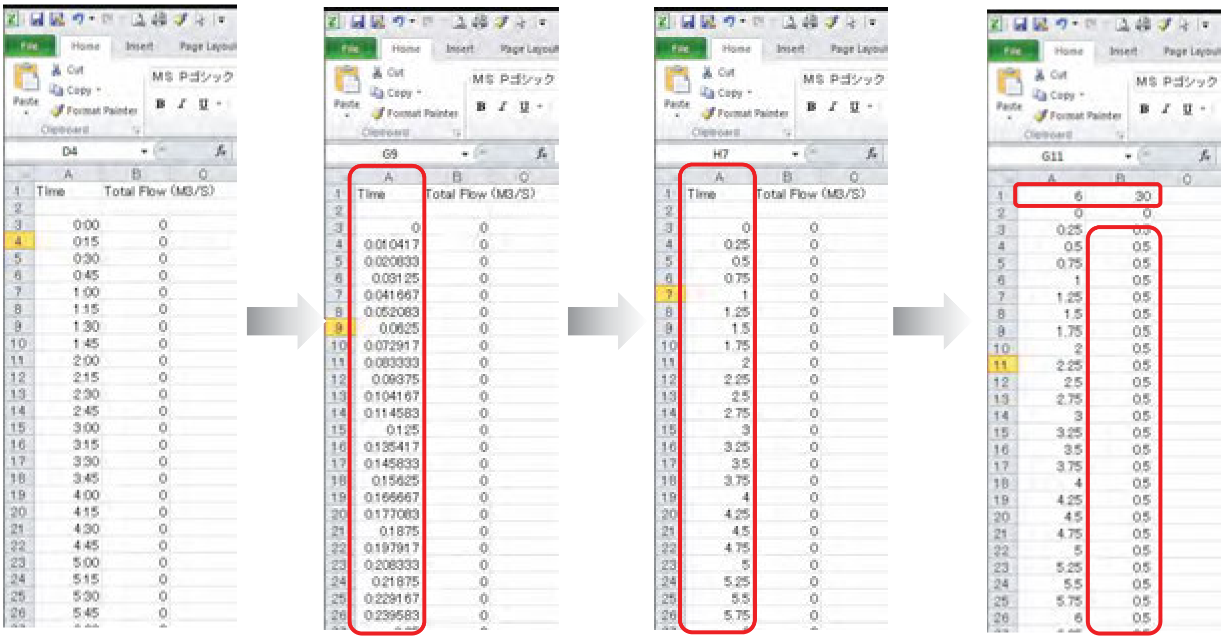


➢ Open “**05yr_Inflow_Seg01**” by Excel. The data may be automatically separated for each columns. If not, separate it by use of [**Data**] – [**Text to Columns**].

➢ The Sub-basin elements have several output such as Precipitation, Loss and Excess rainfall. But you need to use only [**Total Flow (M3/S)**] at the right end.

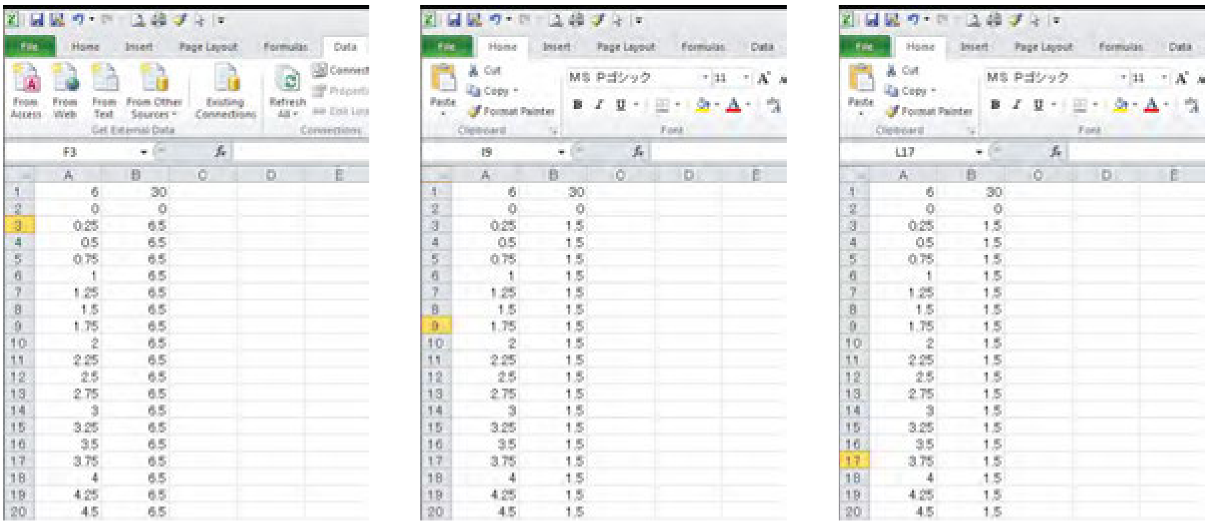
➢ Erase columns of A, C, D, E, F, G.

Preparation of Hydrographs



- Change format of Column A by [**Format Cells**] – [**Number**]. Replace as **0**, **0.25**, **0.5**, **0.75**…
- Input base flow of "**0.5**" as the right end figure.
- Erase the first row "**1**", and input starting time and ending time as "**6**" and "**30**".
- Save the file as [**Formatted Text (Space delimited) *.prn**].

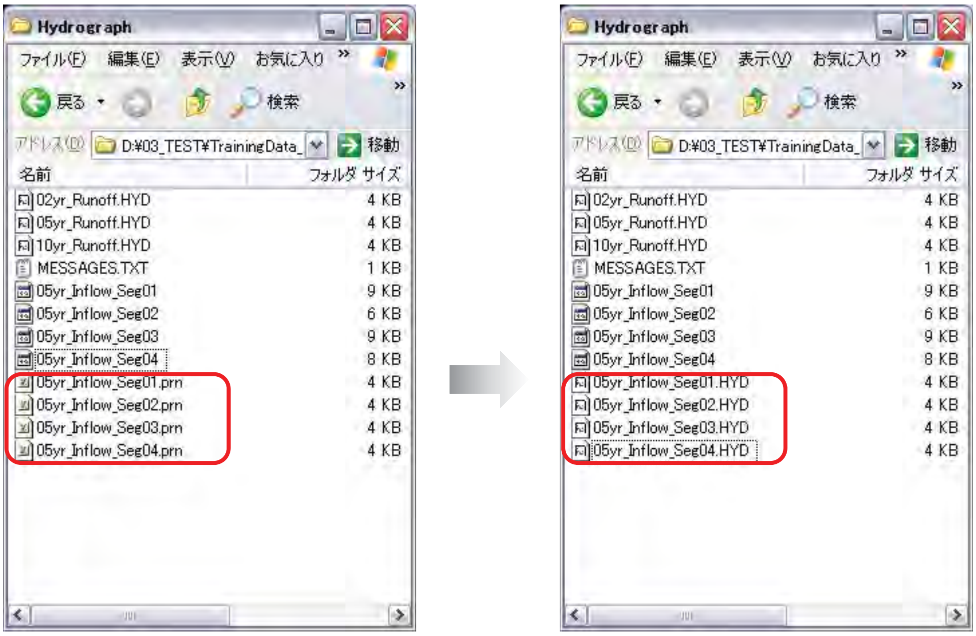
Preparation of Hydrographs



05yr_Inflow_Seg02 05yr_Inflow_Seg03 05yr_Inflow_Seg03

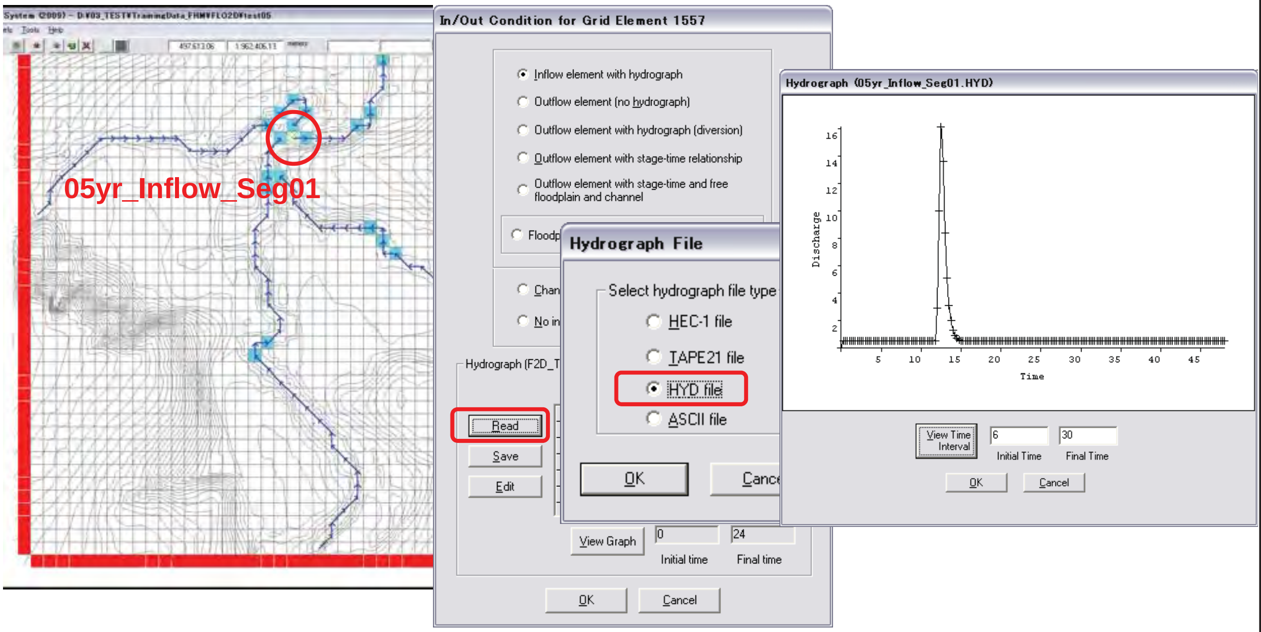
- Open "**05yr_Inflow_Seg02**" by Excel. This file has 3 columns of "**Inflow from RC03 (M3/S)**", "**Inflow from SB03 (M3/S)**" and "**Outflow (M3/S)**". Here you need to use "**Inflow from RC03 (M3/S)**" which is total inflow from upstream area.
- Erase columns of A, D, E. Then modify table as same as **05yr_Inflow_Seg01**. The base flow will be "**6.5**".
- Likewise do same work for Seg03 and Seg04. These two hydrographs have base flow of "**1.5**".

Preparation of Hydrographs



➢ Change the extension of “***.prn**” into “***.HYD**”, so that FLO-2D can read these hydrograph files.

Replace Hydrograph in FLO-2D

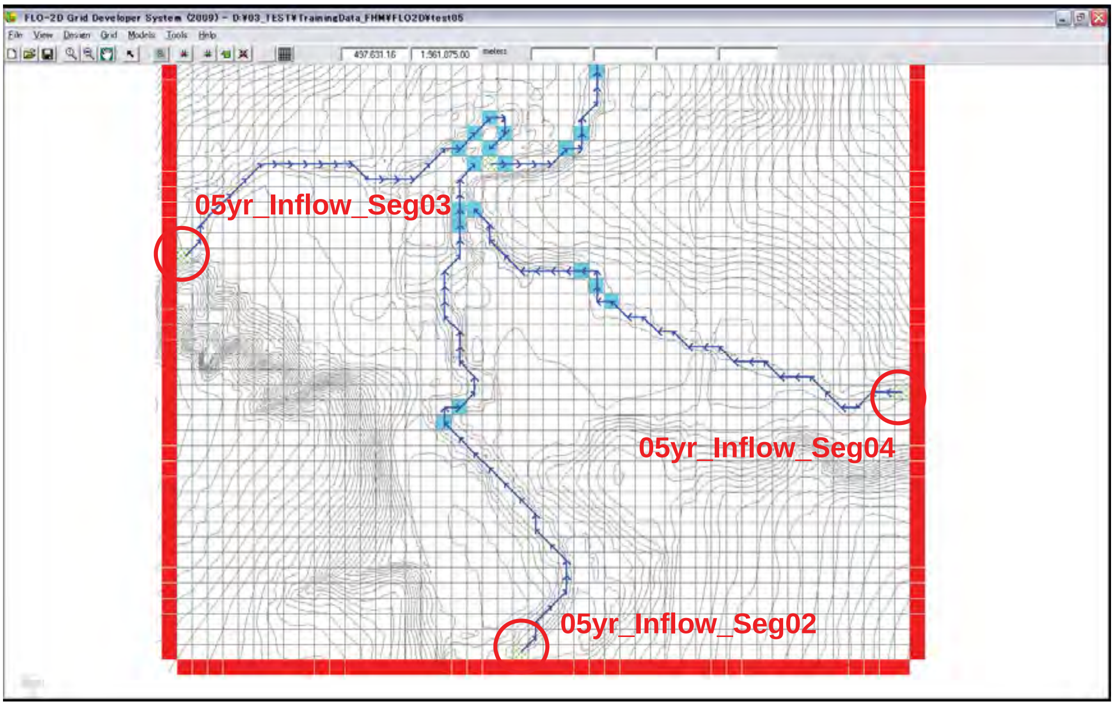


➢ Now go back to FLO-2D. Open **GDS** and open “**FPLAIN.DAT**” in [**test05**].

➢ Zoom to the upstream area. Right-click on the grid where you input hydrograph before. Click [**In/Out Condition for Element *****].

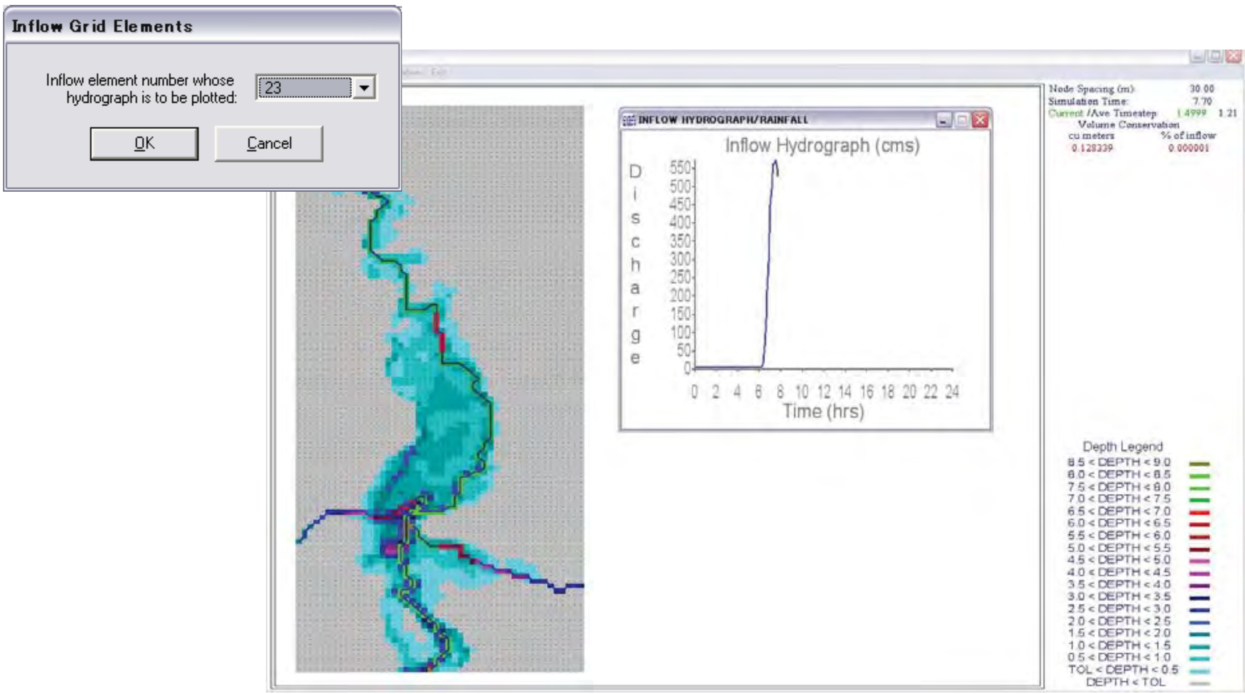
➢ In the dialog, click [**Read**] and check [**HYD file**]. Select “**05yr_Inflow_Seg01.HYD**”, and click [**OK**]. Now the hydrograph was replaced to a new hydrograph.

Replace Hydrograph in FLO-2D



➢ Likewise, assign hydrographs of "**05yr_Inflow_Seg02**", "**05yr_Inflow_Seg03**" and "**05yr_Inflow_Seg04**" at above locations.

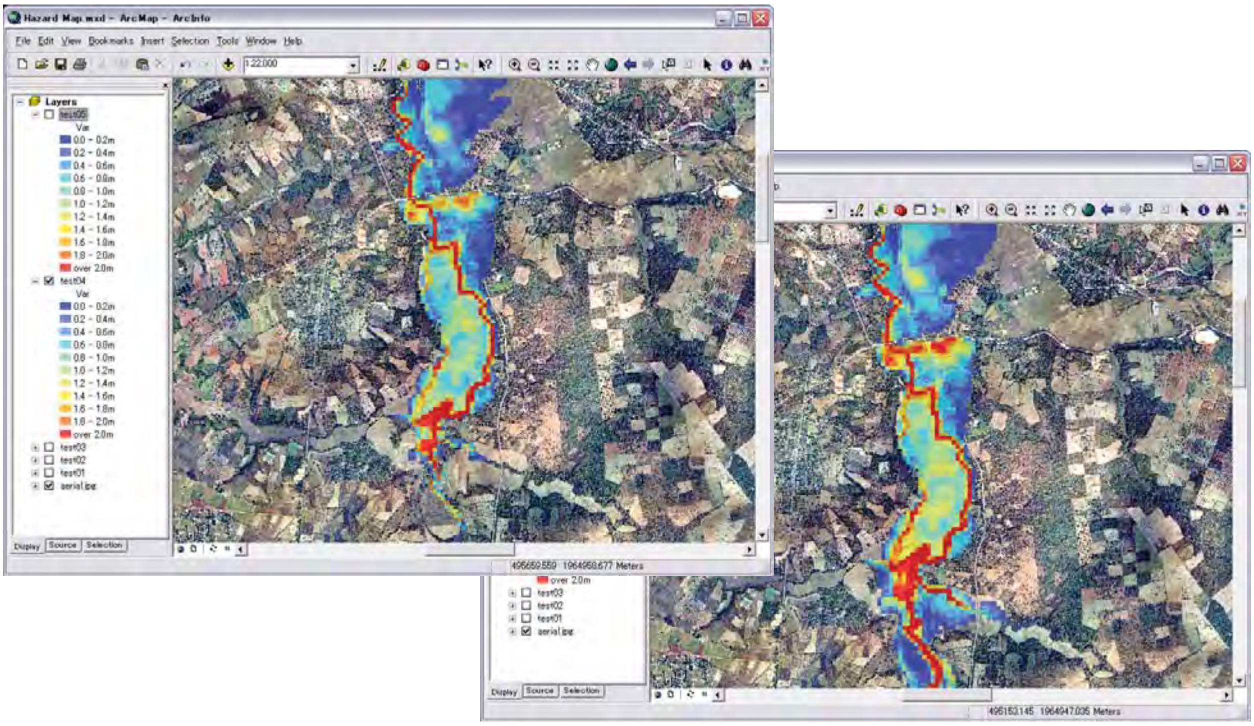
Run FLO-2D Model



➢ Now you are ready to run the new model. Select [**File**] – [**Run FLO2D**].

➢ Since you use multiple hydrographs for the model, you have to select which hydrograph will be displayed during the simulation. Just you can select "**23**".

Run FLO-2D Model



➢ Compare the outputs of Lesson 07 and Lesson 08. You can find the inundation area in the upstream.

END

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

ANNEX 8

Manuals for River Structure Plan and Early Warning System

The Project on Capacity Development in Disaster Management in Thailand (Phase-2)

MANUAL FOR RIVER STRUCTURE PLAN AND EARLY WARNING SYSTEM

Japan International Cooperation Agency
IDEA Consultants, Inc.
Earth System Science Co., Ltd.

Table of Contents

[River Structure Plan]

[Early Warning System]

[River Structure Plan]

1. Formulating of Channel Plan

1.1 Fundamental Policy of Formulating Channel Plan

The waterway shall be planned to allow the safe passage of discharge not more than the design flood discharge and also shall be planned considering of river utilization, natural environment conservation, the situation of land use at the riverside, etc.

The waterway refers to the land space through which the river water passes and the portion surrounded by levees or riverbanks and riverbed. The waterway must have sectional and plane forms necessary to allow the passage of design flood discharge. Since the river flow fluctuates continuously and the flowing water involves earth, sand and others, river channel must be designed to secure the function permanently and stably in consideration of maintenance.

In formulating the channel plan, the matters given in the text must be taken into consideration to sufficiently secure the function.

1.2 Procedure for Formulating Channel Plan

For the channel plan, the following steps of procedure shall be taken.

1. To decide the design flood discharge for the waterway
2. To decide the design section according to the reasons requiring the improvement
3. To decide the alignment of the design plan
4. To decide the longitudinal sectional form of the waterway
5. To decide the cross sectional form of the waterway
6. To verify the effects of improvement

Step 2 - 6 shall be repeated until the plan becomes appropriate for the requirements.

The channel plan must be worked out to sufficiently meet the purposes specified in the flood defense plan. As the procedure, the reasons and the section requiring the improvement shall be first investigated. Whether or not the discharge capacity is insufficient, whether or not any irrigation weirs, bridges, etc. form bottlenecks, whether or not the channel alignment is correct, what were the causes of the major disasters in the past, etc. must be investigated and analyzed, to establish the policy of improvement.

The plane form, longitudinal sectional form and cross sectional form of the waterway shall not be assumed independently, but in the actual procedure, they shall be set first temporarily, to finally decide the best channel plan for the river after checking the respective portions. To examine the effects of improvement, not only the relationship between construction cost and economical effect after the improvement but also various factors such as the importance of the disaster prevention zone and effects in the respective stages during improvement works shall be discussed.

1.3 Velocity Formula

The discharge capacity shall be calculated on the basis of the uniform flow or non-uniform flow according to the conditions of the waterway. As the average velocity formula, Manning's formula shall be used in general.

The flood flow is not steady because of temporal velocity changes, but it can be treated as steady flow for the ordinary channel plan.

If the change of velocity in longitudinal direction cannot be neglected because of the large change of the sectional form of waterway and river regime in the direction of flood flow, the flow capacity shall be calculated on the basis of the non-uniform flow in principle.

For small rivers with little changes in its sectional form and river regime, longitudinal velocity change can be neglected. In this case, the flow capacity shall be calculated based on the uniform flow in principle.

Non-uniform flow should be applied for flow calculation when backwater affects the water level in upper reach due to tidal level at river mouth, water level of main stream at the confluence or narrow section (bottleneck).

Many formulas for average velocity are provided. The Manning's formula is used very widely among them, because it suits the characteristics of rivers and is easy to use and convenient as a calculation formula.

Manning's formula:

$$V = \frac{1}{n} R^{2/3} I^{1/2}$$

Where,

- V: Average velocity of sectional forms of river flow (m/s)
- R: Hydraulic mean depth (m)
- I: Slope of water surface (Bed slope)
- n: Manning's coefficient of roughness

1.4 Coefficient of Roughness

Manning's coefficient of roughness shall be decided with emphasis on the analysis of past floods: Provided that, when the data of past floods are few or when the data are not accurate enough, the following values shall be used for calculating the flow capacity of a waterway.

General waterway:	0.030 – 0.035
Rapid river of wide and shallow river:	0.040 – 0.050
Temporary waterway excavated without timbering:	0.035
Three-side lined channel:	0.025
River tunnel:	0.023

Coefficient of roughness used for an actual channel plan should be decided with emphasis on t coefficient of roughness obtained by the analysis of past major floods. And when coefficient of roughness is determined, those of other rivers, which have similar characteristics, shall be referred.

In the analysis of past floods, flood mark values shall be investigated for verification.

In case that the channel conditions changed greatly or the data of past floods are few and not accurate enough, it is recommended to take the above values in the text.

In general, with medium to small rivers, the river channel conditions change entirely after improvement in most cases, and therefore no flood data is available in those cases. If so, the values of the text shall be taken.

2. Plane Form of Waterway

2.1 Route Selection of Waterway

In the planned section requiring improvement, the best route of channel improvement shall be selected with the examination centered on the route along the existing waterway, in comparison with the route incorporated with new river excavation, if necessary.

In general, the river improvement work is mostly executed along the existing river, taking the situation of topographic features, types of land use, difficulty of land acquisition, etc. into consideration.

For the existing river with extremely meandering waterway, or for the river with large scale congestion of houses along the existing waterway, etc., the route incorporated with new river excavation of flood ways, short cuts, etc. shall be discussed. In such a case, several routes shall be set by combining the portions of existing channel use and the portions of new river excavation, and for the respective routes, the topographic and geologic reasonableness, considerations for the current and future land use, administrative district, irrigation and drainage systems, influence to groundwater level, countermeasure against inner waters, influence to the upper and lower reaches of the planned sections, working expenses for improvement project, maintenance after improvement, etc. shall be taken into account, to select the best route.

For setting the improvement route, the following matters shall be mainly examined.

1. Alignment shall be set by as smooth curves as possible with less meanderings.
2. The channel shall be as far away from densely populated area as possible.
3. The embanked sections shall be a mountain connected levee as practically as possible.
4. The rapid river shall be provided with as many open levees as possible.

2.2 Alignment

The alignment shall be decided to be as smooth as possible, based on the examination as to the situation of land use, flow regime on the occasion of floods, present situation of the waterway, maintenance and construction expenses of the waterway in future, etc.

For deciding the alignment of a waterway, the following points must be comprehensively examined.

1. Even in the section with sufficient river width in the existing waterway, it is generally desirable to secure a width as large as possible in consideration of the retarding effect.
2. The direction of river flows and positions of water hammer zones on the occasions of floods shall be discussed, to decide the alignment so that the water may flow with as little resistance as possible. Generally, in most cases, rapid rivers are almost linear. Medium to small rivers shall avoid extreme S curves, to be generally smooth. In large rivers, since water hammer zones can be fixed to omit the revetments on the other side, and rivers themselves have the nature to meander, and so on, most designs are worked out with slow curves
3. The position of a water hammer zone shall be decided, in consideration of present waterway, topographic and geologic features in the hinterland, and situations of land use. House-congested areas and the closing places of old rivers, etc. shall be avoided as practically as possible.
4. At the point of a curve, it is desirable to recede the inside alignment of the curve and thus extend the river width and slacken the water hammer.

   As for the alignment of low flow channel, both banks are normally parallel in alignment if the alignment of the levees is linear or slightly curved. But, the alignment is not always parallel to those of the banks, as it is decided generally in consideration of the channel maintenance, river use, etc. It is necessary to arrange the banks as far away from the levees as possible.

4. Design Flood Level

4.1 Design Flood Level

The design flood level shall be decided in relation to the design flood discharge and the cross sectional form and longitudinal sectional form of the waterway, but shall be as low as possible above the ground height along the river. If possible, the level is desirable to be taken at not more than the maximum water level of experienced even when taking the conditions of the lower reach into consideration, in a river planned on a small scale, the design flood level shall be set at about the ground level.

To plan a waterway with levees, since the high design flood level involves difficult problems of inner waters, tributary disposal, etc., the level shall be taken as low as possible, and in an ordinary case, it shall be taken at not more than the maximum water level of experienced floods. If a high level must invariably be taken, then sufficient considerations must be made for it.

If the waterway can be artificially excavated due to the conditions in the upper and lower reaches, it should be positively examined if sufficient countermeasures are taken to secure the groundwater level on the occasion of low flow, to secure the intake water levels for various kinds of water use, and to maintain the normal function of river water.
This is because it allows the sufficient afflux of drainage from the hinterland into the waterway, and the avoidance of disasters such as the breaking of levees since there are no structures like levees. However, excavation essentially increases the flow capacity. In this case, the discharge more than designed flows, and also in the waterway with the levee section in the lower reach, the discharge more than designed flows, being not preferable in view of the safety of levees. Also from the point of the safety of the river system as a whole, excessive artificial excavation had best be avoided. Therefore, the most preferable design flood level is about the ground level.

4.2 Design Flood Level of Tributary in the Backwater Section of Main River

The foundation works for a revetment must have a structure which is able to support the slope protection works in consideration of scour in front of revetment. The most general case of damage to a revetment is that the foundation works or the slope protection works are collapsed because the foundation is exposed by local scour during flood.

In general, the foundation of revetment is installed 0.5–1.5 m deep from the deepest riverbed level. However, it should be determined considering the river scale, scour situation, estimated maximum scour depth, past damage, depth of footing surrounding structures, etc.

When the estimated maximum scour depth is deeper than the level of the foundation crown or when stabilization of the foundation works is required according to the past damage, installation of foot protection works is effective.

In refilling at the foundation, it is required sensitivity to the environment. For example, diversity at waterside is secured by utilizing surplus soil in riverbed.

For pile foundations, some measures, including gathered stones, are necessary to prevent scouring at the front and to ensure diversity at the water edge.

Underpinning works are introduced to protect the foundation when the foundations of an existing revetment are either exposed or damaged due to scouring or lowering of the bed and should not have a structure, which disturb the flood flow. Conservation of the water edge diversity should also be taken into consideration.

4.3 Design Flood Level at Curved Sections

In principle, the revetment should be covered with surplus soil. The covering of a revetment with soil secures the presence of soil for plant growth. As the major factors determining plant growth are light, water and soil, a porous soil cover to a revetment provides favorable conditions for plant growth as in the case of a natural bank. The cover thickness should be sufficient to hide the revetment and to facilitate thick vegetation.

Soil cover has such positive effects as an increase of the revetment strength, creation of favorable conditions for plant growth, restoration of the river’s character, improvement of the landscape and improved accessibility to the water edge. In view of conservation of the ecosystem and the effective utilization of resources, soil at the site is used for soil cover. The soil should be spread, not be compacted.

5. Longitudinal and Cross Sectional Forms of Waterway

5.1 Longitudinal Sectional Form of Waterway

5.1.1 Design Bed Slope

The design riverbed slope shall be decided in relation to the design riverbed level, with riverbed maintenance and construction cost taken into account, but generally with emphasis on the

present average riverbed slope. The slope of a generally with emphasis on the present average riverbed slope. The slope of general river shall change gradually from steep to gentle one in the descending course.

The design riverbed slope shall be obtained according to the present riverbed slope with an ordinary river, because it is the safest way for channel maintenance in future so far as no local change progresses in the present riverbed, and it requires only a reasonable construction cost in general.

However, this shall not apply when the present river regime is changed on purpose by a channel plan. Particularly when it is a local problem as in the case of short cut, etc., it shall be decided with the riverbed slopes before and after the short cut taken into consideration.

When the river regime is generally, not locally, changed, the longitudinal sectional form shall be decided in combination with the cross sectional form, etc., with future channel stability also taken into account.

The riverbed slope of a general river shall change gradually from steep to gentle one in the descending course. In general, it almost balances tractive force to keep the waterway free from the occurrences of scour and deposition.

Since the sudden change of riverbed slope often makes the riverbed unstable, it is generally desirable to keep the ratio of the slopes at before and after the change point of riverbed slope, less than 2.

5.1.2 Design Riverbed Level

The design riverbed level is decided in relation to the design riverbed slope, design cross sectional form, with inland ground level taken into consideration, but also the groundwater level, intake level for irrigation water, ground level of existing important structures, etc. shall be considered.

The design riverbed level shall be decided by trial decision of the riverbed slope and cross sectional design form. The trial calculation shall be made according to the following conditions.

1. The design flood level shall be as close to the inland ground level as possible.
2. The ground level of important structures, intake level for irrigation water, design riverbed level of main river at the confluence if with a tributary riverbed level at the point of bedrock exposure, peripheral groundwater level, etc. shall be fully taken into consideration.
3. The water depth to provide the average velocity of 2 to 3 m/s in a mild river and about 4 m/s

in a torrential river shall be obtained for the safety of levees, as a standard of design water depth.

If necessary, considering the situations, etc., of riverbed, a groundsill shall be provided to stabilize the riverbed. In this case, as regards the position and direction, the plane form of the river channel shall be taken into account.

5.2 Cross Sectional Form of Waterway

5.2.1 Design Cross Sectional Form

The design cross sectional form of a waterway shall be a compound cross section in general. However, for a torrential river or a river with small design flood discharge, it shall be decided upon consideration of the conditions of the waterway, the difficulty of maintenance, etc.

Since the ratio of maximum discharge to minimum discharge is large in an ordinary river, a compound cross section form is desirable to obtain stable river channel.

However, with a torrential river, if several watercourses are provided in a wide river width and change, it is often difficult to clearly set low flow channel and high water channel in view of the maintenance of the waterway.

The form is normally a single cross section in a river with a small design flood discharge.

5.2.2 River Width

The river width shall be decided according to the design flood discharge, considering the longitudinal slope, topographic and geologic features of the river, and the situation of land use along the river, etc.

The design river width is related to the design flood discharge, and is to be decided according to the regime and surrounding situations of the river. Even if the design flood discharge is the same, the difference in water depth, slope and riverbed roughness changes the proper river width. Furthermore, it depends upon the conditions of existing levees, the state of housing congestion in the coastal area, situations of land acquisition, etc. Therefore, it must be decided in the discussion of the river plan as a whole.

Fore making a river plan, it is recommended to make a discussion in reference to the following values:

Design flood discharge (m^3/sec)	River width (m)
300	40 – 60
500	60 – 80
1,000	90 – 120
2,000	160 – 220
5,000	350 - 450

5.2.3 Width of Low-Flow Channel and Height of High-Water Channel

The width of a low flow channel and the height of a high water channel shall be decided upon consideration of the maintenance of the waterway, the frequency of flooding on the high water channel, and the utilization of the high water channel.

The height of a high water channel is to be discussed together with the width of a low flow channel, and it is not preferable to have an excessively high velocity on the high water channel from the maintenance viewpoint, to secure the stability of high water channel on the occasion of a flood.

In most cases, the design velocity on the high water channel for medium and small rivers and newly provided rivers is about 2 m/sec.

If a large design velocity on high water channel is inevitable, then revetment work, etc. shall be executed.

The width of a low water channel is generally decided with emphasis on the present situation, and the height of a high water channel is, in most cases, decided by calculating the flow capacity for the frequency of three floods per year. However, in recent years, the demand for use of high water channel in rivers is strong, the river environment is positively assessed as an important function of rivers, and therefore the height of the high water channel must be decided with these taken into consideration.

5.2.4 Cross Sectional Form at Curve

Necessary measures such as enlargement of the river width shall be taken at a curve of waterway according to the condition of the curve and the condition of the waterway in the upper and lower reaches.

At a curve of waterway, the drift current is caused on the occasion of a flood, and the water level at the concaved side of the curve rises to cause high velocity locally, threatening to make the waterway unstable. Considering that dead water zone is caused inside the curve, and that the effective cross sectional area of river is decreased due to eddy current, any measure to enlarge the effective river width by about 10 to 20 % must be taken.

According to the plane form, drift current may be caused inside the curve, and sufficient discussion including the plane form is required to be made.

6. Levee

6.1 Definition of Complete Levee

The complete levee refers to the levee with the required height and sectional form for the design flood level and further with revetment, etc. (slope and foot protections, etc.) executed as required.
The difference between the crest height of a levee and the design flood level is called freeboard.

The height and section of a levee are decided against the design flood level, but since the levee is generally made of earth and sand, overflow and permeation must be fully taken into consideration.

Therefore, freeboard is necessary, and a stable sectional form to breakdown by erosion due to the flowing force, revetment is required or slope must be tamped and covered with sod, etc.

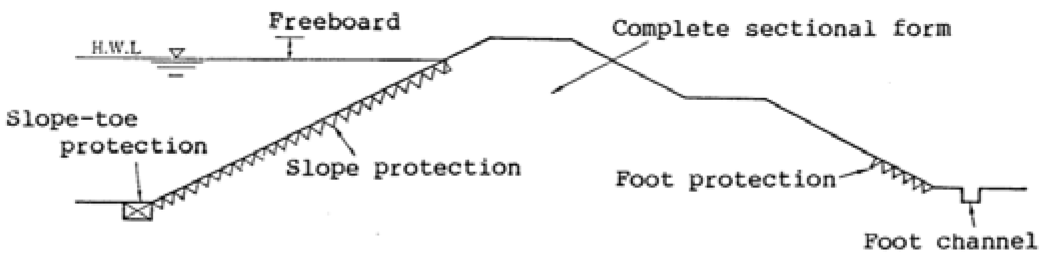


Figure 6.1 Typical Levee Section

The freeboard given here is a usual designation of the height to be added to the design flood level, and does not mean an allowance for design.
The complete levee in terms of structure must be surely provided with the safety normally considered against the river water of design flood level. Therefore, it will have the necessary sectional form and revetment, and further the slope protection, etc. as required. In the meantime, in the actual procedure of river improvement, work is sometimes executed in steps such as executing temporary work of levee section and leaving revetment unworked, or executing slope protection only for revetment and leaving foot protection for execution in later year, for a step-by –step increase of safety against flood or the height of levees at opposite bank

at upper and lower reaches, or for reasons such as the work cost, etc. The strength of the levee in this case cannot be expected to demonstrate the function as a complete structure against the river water of design flood level, but the method is considered proper as a method of improvement. The levee in this case is called a temporary levee, to distinguish it from a complete levee. The limit of stability of the temporary levee as a structure is naturally different from that of the complete levee.

The levee is built with earth and sand as mentioned above, but if a soil levee is very difficult or improper because of land problem, important facilities or the style of bank use, etc., the levee of special structure as the concrete retaining wall is provided, and it is generally called a special levee.

6.2 Style of Levees

1. When new levees are built, the place with unstable foundation ground such as weak subsoil shall be avoided as practically as possible.
2. When enlarging of old levees, the enlargement shall be made on the landside, but it may be made on the waterside, for the reason of levee alignment or when the high-water channel is wide with sufficient river width, etc.

The major styles of levees are new levees and old levee enlargement.

The new levees include the construction of new levees at sections without levees, and the backward displacement at narrow path. The place of weak subsoil should be avoided as practicably as possible.

In the case of enlarging old levees, whether enlargement is made on the landside or waterside is decided according to the position of design alignment, and in general it is desirable to enlarge the landside to leave the stable waterside slope as it is. When the land acquisition is very difficult or when the flood way is wide with sufficient cross sectional area, enlargement may inevitably be made on the waterside. However, when the toe of levee slope is close to the low-flow channel, it is desirable to avoid enlargement on the waterside even if there is sufficient river width.

6.3 Height

The height of a levee shall be the value obtained by adding the freeboard value, specified in 6.4 of this chapter, to the design flood level.

The height of a levee is obtained based on the “design flood level” with a required freeboard added to it.

The “design flood level” refers to the water level decided to allow the safe passage of the design flood discharge, based on the water level obtained by calculation which will be reached when the design flood discharge is made to flow in the planned waterway. The design flood discharge is made to flow in the planned waterway. The design of a levee is always based on the design flood level, and also the discussion as to stability to seepage is made for the design flood level.

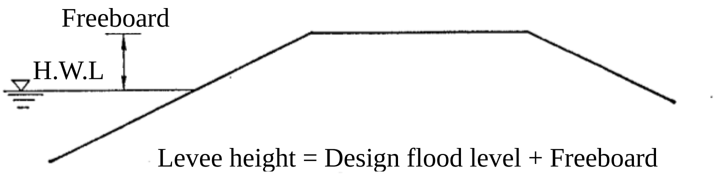


Figure 6.2 Levee Height

6.4 Freeboard

1. The freeboard of a levee shall not be less than the value given in the following able, according to the design flood discharge: Provided that, when the ground height in the inland adjacent to the levee concerned, is higher than the design flood level and when it is expected in view of topographic features that no trouble for flood control will occur, the freeboard can be 0.6 m or more even if the design flood discharge is 200 m^3/s or more.

Design Flood Discharge and Freeboard

Design flood discharge (m^3/s)	Freeboard (m)
Less than 200	0.6
200 and up to 500	0.8
500 and up to 2,000	1.0
2,000 and up to 5,000	1.2
5,000 and up to 10,000	1.5
10,000 and over	2.0

2. In the backwater section of a tributary, the height of levees shall be so decided that it is not lower than the levee height of the main river: Provided that the same shall not apply when reverse check facilities are provided.

Text 1 shows the freeboard values of levees, and as described in 6.3 in this chapter, the necessary levee height is obtained by adding any freeboard value to the design flood level. The proviso proscribes that the freeboard of 0.6 or more can be selected when the ground height in the inland is higher than the design flood level and when it is expected in view of topographic features that no trouble for flood control will occur.

Basically, freeboard is a margin of the height that does not allow overflow against the design flood level. In general, the levee is made of earth and sand is very weak to overflow. Therefore, it is provided in preparation for temporary rises of the water level caused by wind and waves on the occasion of a flood, swell and hydraulic jump, etc. on the occasion of a flood, so as to never allow overflow. It is also considered to cover various factors such as securing safety for patrolling against floods and executing flood prevention, countermeasures against drifts, and so on.

Strictly speaking, the freeboard should be decided for each river, section and structure of levee with the characteristics taken into account, but because it is very complicated for planning, and because it is not preferable for the stabilization of people's livelihood that the levee height is different according to place, the freeboard values are specified by degrees according to the scale of design flood discharge. Since it is practically impossible to uniformly change the freeboard at the change point of design flood discharge, it is generally changed at the point of interruption such as mountain-connected levee, bridge, etc.

The text 2 specifies the freeboard concerning a backwater section of tributary, and prescribes that it must be as high as the levee of the main river at the confluence so far as it has the function to prevent inundation in the same area in connection with the levees of the main river. In general, the levee height of the main river at the confluence is brought horizontally onto the own discharge levee height of the tributary.

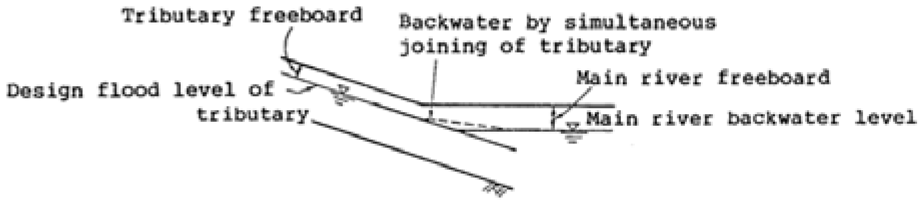
In the proviso, the case of providing reverse flow check facilities refers to the case of planning the so called semi-backwater levee system to downscale the structure of the tributary levee such as reducing freeboard by providing reverse flow check facilities such as gate, when the arrangement of complete backwater levee system along the tributary is improper since it involves the acquisition of much land and movement of houses, etc. for the levee ground. In this case, the value corresponding to the design flood discharge of the branch is generally employed for the freeboard.

In the river of inner water drainage not to be provided with backwater levees, the inner waters overflow the levees when the gate is down. When the levees are covered with concrete, etc. on the respective three faces, or when overflow levee is provided, the levee height must be discussed in view of topography, economic efficiency, etc.

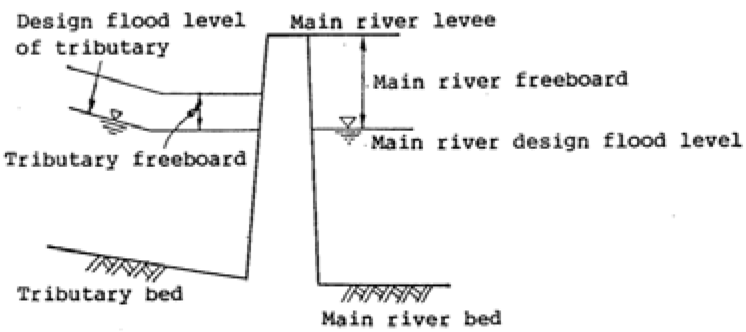
In the case of an excavated artificial waterway, the distinction between levee and control pathway is confusing, and care must be taken accordingly. As described in the commentary of 6.1 of this chapter, the embankment of less than 0.6 m above the inland ground is treated as a control pathway.

The height of the control pathway is not particularly specified, but when the levee portion exists. With the excavated artificial waterway, the height with the value of 0.6 m or more added to the design flood level is ordinarily taken as the crest height also in the control pathway portion, as with the levee portion, to make the height uniform. In the so called complete excavated artificial waterway with no levee portion in a series of section , the control pathway is not required to be the height with 0.6 m or more added to the design flood level.

In such a section, the crest width and the tree planting standards are also in accordance with those of the control pathway for river bank.



(Backwater section)



(Semi-backwater levee)

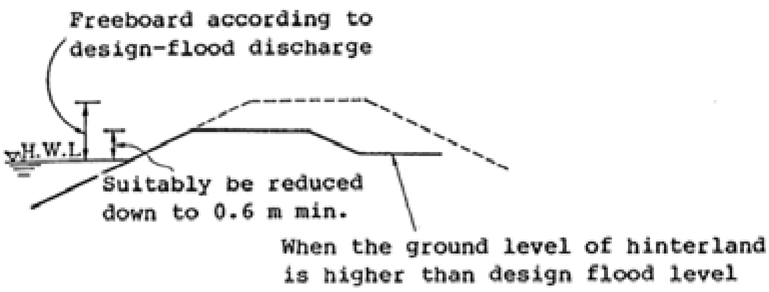


Figure 6.3 Freeboard

6.5 Levee Crest Width

1. The crest width of a levee shall be decided in accordance with the design flood discharge, and shall not be less than the value given in the following table: Provided that, when the

inland ground height is higher than the design flood level and when it is expected in view of topographic features that no trouble with flood control will occur, the crest width can be made 3 m or more irrespective of the design flood discharge.

Design Flood Discharge and Crest Width

Design flood discharge (m^3/s)	Crest width (m)
Less than 500	3
500 and up to 2,000	4
2,000 and up to 5,000	5
5,000 and up to 10,000	6
10,000 and over	7

2. In the backwater section of a tributary, the crest width of the levee shall be so decided that it is not narrower than the levee crest width of the main river: Provided that, the same shall not apply when reverse flow check facilities are provided, when the levee height from the ground of hinterland is less than 0.6, when it is inevitable because of topographic reason, etc.

As in the case of freeboard, the crest width must be decided originally according to the characteristics of each river and each section, such as importance, levee material, duration of a flood, etc. However, the difference of crest width according to place means difference in sectional size of levee, and gives a large psychological influence to the regional inhabitants. Therefore, the width of the pathway for regular patrolling or including the width necessary for river control such as flood prevention activity on the occasion of a flood is decided in steps according to the design flood discharge, as in the case of freeboard. Since it is problematic to change the crest width at the change point of the design flood discharge, it is generally changed at a point of interruption such as mountain-connected levee, as in the case of the freeboard.

The proviso of text 1 specifies that when the levee height is less than 0.6 m and when topographic features allow, the crest width provided is not necessary to correspond to the design flood discharge. However, even if it is still desirable to provide a series of widths throughout the upper and lower reaches as a control pathway to have continued crest width from upper to lower reaches.

Of the proviso of test 2, when the reverse-flow check facilities such as gate are provided (in the case of so called semi-backwater levee), the river water is insulated from the main river by gate, etc. and therefore it is not necessary to provide the same crest width as that of the main river. In general, it is decided according to the design flood discharge of the tributary.

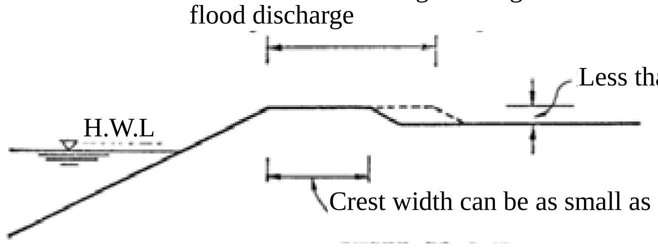


Figure 6.4 Explanatory Drawing of Proviso of Text 1

6.7 Banquettes of Levee

1. The banquettes of a levee shall be provided at the middle of the levee, when it is recognized to be inevitable due to topographic conditions, and other special reasons.
2. The banquette shall be provided every 3 m to 5 m from the crest on the waterside if the levee height is 6 m or more, and every 2 m to 3 m from the crest on the landside if the levee height is 4 m or more.
3. The width shall be 3 m or more.

The banquette arrangement is decided as required to secure the stability of the levee, in view of the levee body material, duration of a flood, stability to the seepage of flood, and foundation ground of the levee etc. The above shows the standard arrangement of banquettes, considering the soil used and non-uniformity in execution of work. A width of 3 m or more is specified for traffic reason, etc. at least one lane should be secured.

Also as regards the arrangement of banquettes for the tributary levee in the backwater section of the main river, the same arrangement as with the main river levee shall be taken in principle as in the case of crest width and freeboard, but since the width of a waterside banquette of the width and freeboard, but since the width of a waterside banquette of the width and freeboard, but since the width of a waterside banquette of the levee is decided with the safety against the scour on the occasion of a flood taken into consideration, in addition to the banquette width for the stability of the levee, the same waterside banquette as with the main river may not be required to be provided for the backwater section.

A banquette provided on the waterside is called a waterside banquette and a banquette provided on the landside is called a landside banquette. The banquettes are called 1st banquette, 2nd banquette, in the descending order from the crest.

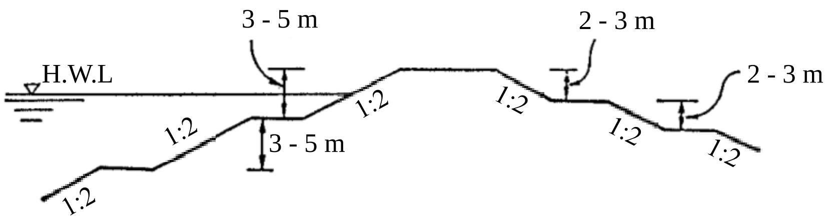


Figure 6.5 Arrangement of Levee Banquettes

6.8 Slope Gradient

The slope gradient of a levee shall be a gentle gradient of 20 % or less: Provided that the same shall not apply, when the face of slope is covered with concrete or similar material.

The slope gradient is decided from the soil of levee body, etc. but a gradient steeper than 20 % is generally not preferable in view of the stability conditions of the slope face of river levee. In the past, some levees of small scale, etc. had the slope gradient of 15 %, but there were many cases of sliding and sloughing, etc. caused not only by seepage of high water but also by rainfall. Therefore, 20 % should be regarded as the upper limit.

In the case of a large levee, 30 % or more is often employed for the slope below the 2nd banquette inclusive.

6.9 Levees of the Section Affected by High Tide

Design Bed Slope

7. Revetment

7.1 Basic Concept

In general for planning a revetment, the place of construction, extension, method of construction, etc. shall be decided in consideration of river regime, longitudinal and cross-sectional forms, slope gradient of levee, soil, etc.

Because a levee is generally made of earth and sand, a revetment is applied to protect the levee against erosion and seepage by river flow.

The construction cost of revetments occupies a large portion in the river improvement work, and therefore it is important to exercise ingenuity for execution of work according to the river characteristics and to find economical construction method.

Generally, the revetments of a steep river extend over the entire stretch. In the case of a mild river, the necessary places of construction are shorter than those in a steep river since the places to be protected are limited to water colliding front. With a small river, revetments are planned for the entire stretch since the water colliding fronts are not clear in most cases.

Regarding urban rivers in the district with few green zones, it is desirable to select not only the revetment of steel sheet pile or concrete but also nature-oriented revetment.

Since the revetment is mostly broken by the scour of foundation, planning must be made with utmost attention to the change of river regime in future. At the place at which the foundation of revetment is supposed to be scoured by water hammer or strong flowing force, foot protection shall be employed together.

7.2 Revetment Surrounding the Structures

1. The place and length of a revetment shall be decided in consideration of the change of hydraulic phenomena in the waterway.

2. The revetments of banks or levees in contact with the ground sill or weir shall be provided in the section from the longer of 10 m from the upstream end of the ground sill or weir of 5 m from the upstream end of the mattress in the upper reach, to the longer of 15 m from the downstream end of the apron of 5 m from the downstream end of the mattress in the lower reach.

3. The revetments of banks or levees in contact with the gate shall be provided in the section from the longer of 10 m from the upstream end of the gate of 5 m from the upstream end of the mattress in the upper reach of the channel with gate crossing, to the longer of 15 m from the downstream end of the apron of 5 m from the downstream end of the mattress in the lower reach of the channel with gate crossing.

4. The revetment of a bank or levee with gate or sluiceway crossing shall be provided in the section covering respectively 10 m in the upper reach and lower reach from the gate: Provided that the same shall not apply to a small sluiceway of not more than 0.5 m^2 in the sectional area, when the unnecessity is recognized due to topographic conditions.

5. The revetments to be involved in the construction of a bridge shall be provided in the sections toward the upper reach and the lower reach from the upstream and downstream ends of the bridge respectively with the extension correspoindeing to more than a half the span length of the bridge (30 m if the span length is more than 30 m) as specified: Provided that the extension shall not less than 10 m.

Natural banks and soil levees are eroded and scoured when the river flow is fast, but upto what velocity the revetments are not required depends upon the soil of the levees, the extent of compaction, etc., and is a very difficult question. Considering the past examples and experiences, the place of construction and extension are decided.

When land acquisition is difficult I urban districts for medium to small rivers, or when the velocity is too large to allow protection against erosion by slope sodding only, the slope gradient is often taken at 20 % or less (generally less than design flood level), on condition that revetments are to be executed. Therefore, in these cases, revetments are planned in full scale.

Since the river flow is disordered in the upper and lower reaches of any structures such as bridge, sluiceway, conduit, gate, weir, ground sill, etc., revetments must be constructed for considerably long length covering the upper and lower reaches.

The extension of a revetment shall be decided, considering that the provision of the revetment often moves the water hammer toward the lower reach.

7.4 Alignment of Revetments

The revetment alignment shall be as smooth as possible, with flow direction taken into consideration.

The high water revetments are provided along levee alignment, and therefore depend on the alignment form of levees. However, they are desirable to be as smooth as possible.

As for the low flow revetment alignment, the alignment suitable for the flow direction of low flow is taken, but the flow on the occasion of high water also must be taken into account for decision.

7.5 Height

In general, the height of levee revetments shall be as high as the design flood level in principle: Provided that it shall be as high as the levee crest if necessary in a retarding basin, a place with wide river width, a place to have wind and waves in the vicinity of a river mouth or a torrential river. The low flow revetments shall be as high as necessary according to the conditions of the waterway.

In small and mild size rivers, revetments may be constructed as high as the middle water level, but in a river or place requiring revetments, they shall be constructed as high as the design flood level in principle. The crest of low flow revetments is as high as the height of the high water channel.

7.6 Embedment

The embedment must be deep enough to be safe against the scour of riverbed at time of high water.

Since a revetment is broken mostly be scour of the foundation, embedment is desirable to be planned with sufficient margin.

The tractive force on the occasion of freshet increases at the time of upturn and decreases at the time of downturn. Namely, it is considered that the tractive force reaches its maximum around the time with highest water level, and then gradually declines to cause sediment. Therefore, the embedment to endure the scour at time of upturn is required.

In general, as regards the depth of embedment, it is about 50 cm to 1.0 m in a medium to small river, and more 1 m in a large river, based on the lower of design riverbed or existing riverbed.

However, when the low water level is high, it may be technically impossible to make embedment below the design riverbed or existing riverbed. In such a case, with the embedment is made shallow, it is necessary to take measures such as the protection of the foundation by foot protection, or the provision of ground sill to prevent drop of the depth of embedment include (1) the portion in water hammer zone where deep scouring is expected, (2) the lower reach of weir of ground sill, (3) the short-cut, flood way, etc. with bed drop expected, and the embedment will be required to be deeper than in ordinary places.

The embedment is planned based on the design riverbed or existing riverbed. However, when there is a local deep scouring in the waterway or on the other side of the river, etc. apart from the place of revetment works, it may not affect the surroundings of the revetment work. In this case, it may not always be necessary to consider the existing riverbed uniformly as the foundation of embedment depth.

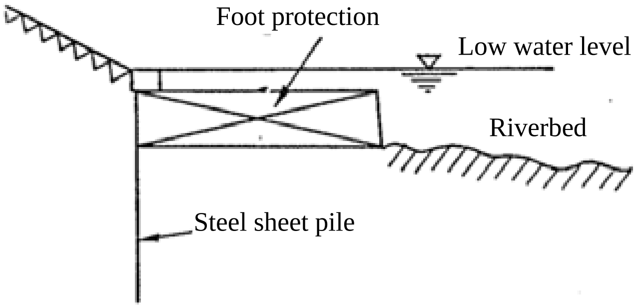
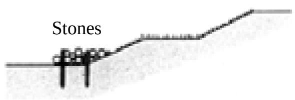
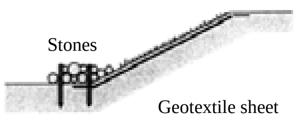


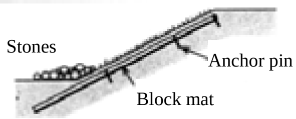
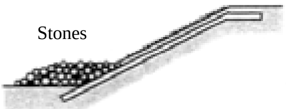
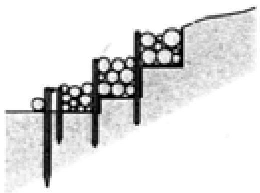
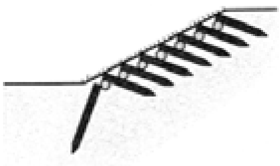
Figure 7.1 A Case of Deep Water

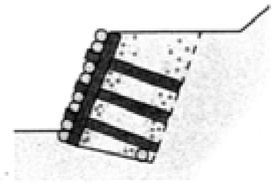
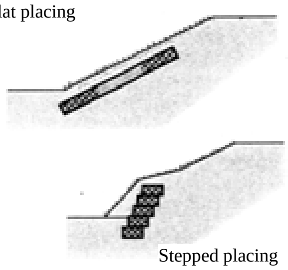
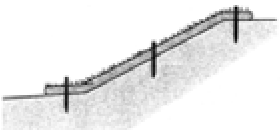
7.7 Revetment Work

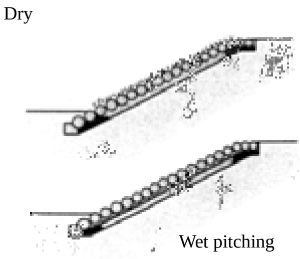
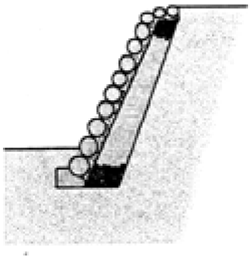
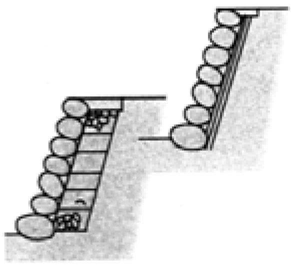
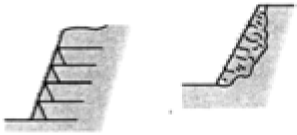
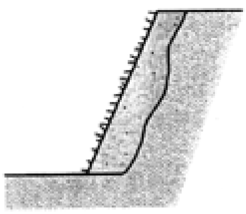
It is important to select the revetment type appropriate for the river characteristics, hinterland conditions, etc. The features and design principles by type of revetment are shown in Table 7.1. And the applicable velocity range for each type is shown in Table 7.2.

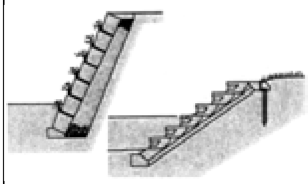
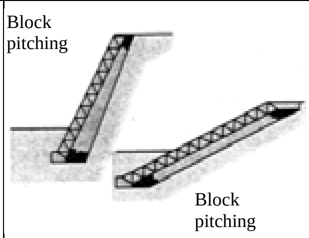
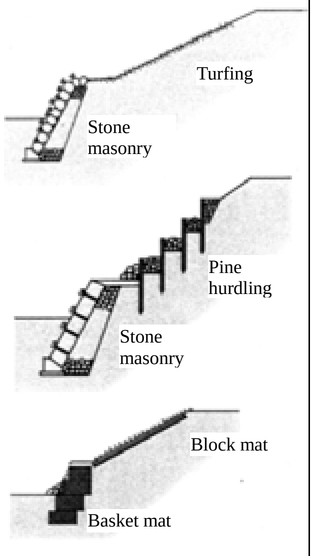
Table 7.1 Illustration of and Design Principles for Revetment (1)~(5)

Type		Image	Design principles
Vegetative type	Turfing		- Soil of at least 30 cm in thickness is secured as the critical life for the turf. - Applicable to a site where the critical velocity is 2 m/s or less for the survival of the turf (root layer thickness: 5 cm). - The gradient should generally be gentler than 1: 2.0 to stabilize the slope. - Sufficient maintenance to keep the turf as the survival rate is affected by the level of maintenance. - The turf must be not inundated by the ordinary water level and not exposed to flowing water until the turf is firmly rooted. - At the low water channel, consolidating stonework is conducted as part of the work to gather surplus soil and piling work is also conducted to prevent the rolling of the stones.
Sheet type	Geotextile work		- The surface is covered by geotextile sheet or block mat to allow the plants spreading the roots to reinforce the revetment. - The critical flow velocity for the use of geotextile sheet or block mat is 3.0 m/s and 4.0 m/s respectively. - The gradient for a geotextile sheeting-covered slope should generally be gentler than 1: 2.0 to stabilize. - As geotextile sheet is vulnerable to sunlight, the covering soil should be adequately maintained.

	Block mat work		- In principle, block matting is used for a slope of which the gradient is gentler than 1: 1.5. For a slope between 1: 1.5 and 1:2.0, piles should be used to anchor the mat. - The sheet/mat should be covered by soil with a thickness of some 10 cm to allow the spreading of plant roots. - Vegetation cover, for example, turf, is required for the surface. - At the low water channel, consolidating stonework is conducted as part of the work to gather surplus soil and piling work is also conducted to prevent the rolling of the stones.
Connection type	Connected blocks		- This method is used to secure a safe reserve length against over-turning or sliding by the flow near the revetment. - Applicable to a river of the velocity being 5.0 m/s or slower. - In principle, block matting is used for a slope gentler than 1: 1.5. When used for a slope between 1: 1.5 and 1: 2.0, piles should be used to anchor the mat. - The surface should be covered by soil to restore vegetation. - As the bottom is vulnerable to over-turning, ripraps are used to stabilize the foot of the revetment.
Wood type	Pile hurdle		- This method protects a bank through a combination of wooden piles and filled stones. - Applicable to a river of the velocity being up to 4.0 m/s. - Applicable to a slope of 1: 0.5 or gentler. - Applicable to a river with few boulders. - The stones for filling should be large enough to remain stable, sufficiently resisting the flow near the revetment. - As wooden piles tend to quickly rot in a part above the ordinary water level and a part with a fluctuating water level, they are often combined with such vegetation as willow.
	Fascine slope cover		- A fascine is used to construct crib work over a slope for bank protection. - Applicable to a river of the velocity being up to 4.0 m/s. - Applicable to a slope of 1: 0.5 or gentler. - Applicable to rivers with few boulders. - The stones for filling should be large enough to remain stable, sufficiently resisting the flow near the revetment.
	Log grating		- Thinned wood should be actively used. - The vegetation can be quickly restored with planting work. - Applicable to a river of the velocity being up to 4.0 m/s. - High quality soil should be used to fill the grating

			and should be well compacted. - As wooden piles tend to quickly rot in a part above the ordinary water level and a part with a fluctuating water level, they are often combined with such vegetation as willow.
	Wooden blocks		- Thinned wood should be actively used. - Applicable to a river of the velocity being up to 3.0 m/s. - Applicable only to places which are not subject to wheel load. - Applicable to an excavated channel. - Measures to prevent or slow down the decay of the wooden blocks are necessary.
Basket type	Basket matting		- Not applicable to a river with high acidity or a high salt content (except when anti-corrosion treatment is conducted for the wires) or many boulders. - Flat placing is used for a river of the velocity being up to 5.0 m/s while stepped placing is used for a river of the velocity being up to 6.5 m/s. - Stones which do not move due to the non-dimensional design tractive force are used. - Basket mat must be designed in accordance with the Technical Guidelines. - Flat placing is used for a slope of 1: 1.5 or gentler while stepped placing is used for a slope of 1: 1.0 or steeper. - As it is liable to drying due to many cavities, the soil cover of the baskets or a similar measure is required to restore the vegetation. - Attention must be paid to preventing sliding or hitching at the waterfront. - At a small river, proper attention must be paid to lowering of the water level due to sub-flow.
	Vegetative gabion		- A gabion is characterized by its unique flexibility and greening function. - The surplus soil as a filling material can be used to restore local vegetation. - The use of a vegetative gabion is desirable for a slope of up to 1: 1.5 but measures to prevent sliding are required. - Applicable to the velocity being up to 5.0 m/s. - The laying direction should be determined taking the various site conditions into consideration. - Measures to prevent over-turning are particularly important at the upstream and downstream ends, the crown and the foot. - Because of its weak light resistance, the soil cover must be properly maintained.

	Natural stone pitching		< Dry Pitching > - The stones should have a safe diameter calculated by the model using the flow near the revetment. - Applicable to the velocity of up to 5.0 m/s. - Applicable to the slope of 1: 1.5 or gentler. - The restoration of vegetation is stimulated. - Clenching between the stones should be considered. < Wet Pitching > - Applicable to a velocity of faster than 5.0 m/s. - Applicable to the slope of 1: 1.5 or gentler. - The filling concrete should have deep joints so that they do not appear on the pitching surface.
	Natural stone masonry		< Wet Masonry > - Applicable to the velocity being 5.0 m/s or faster. - Applicable to the slope being 1: 1.0 or steeper. - If the buttress thickness is equivalent to the concrete block masonry, the structure is considered to have the same strength as the block masonry. - The filling concrete should have deep joints so that they do not appear on the pitching surface.
	Connected natural stones		- With a buttress and over-turning prevention measures, the structure can be made safe vis-à-vis the flow and soil pressure. - With the skilled placement of natural stones of a carefully selected size, porous space can be created. - Applicable regardless of the velocity if the buttress is thick enough. - Foot protection using gathered stones and measures to prevent over-turning at the crown and at the upstream and downstream ends should be implemented. - In addition to natural stones, simulated stones made of concrete can also be used.
Reinforced soil type	Reinforced soil		- The use of reinforcing materials improves the resistance of the soil itself to create an integrated revetment. - This method aims at creating harmonious vegetation with the natural environment. - This method may be successfully used at the upper section of a compound revetment. - Measures to prevent suction are required if this method is used below the ordinary water level. - Applicable to the velocity of up to 6.0 m/s.
Vegetative retaining wall	Vegetative retaining wall		- The use of porous concrete enables natural regreening. - As the use of cast-in-place concrete is possible, work corresponding to the site conditions can be conducted. - Applicable regardless of the velocity if the buttress is thick enough. - The strength to resist impact and weight to resist the soil pressure should be taken into careful

			consideration.
Block type	Environmental conservation type blocks		- This method offers the same level of erosion resistance to the conventional concrete block masonry. - If the buttress thickness and weight are the same as those of concrete block masonry, it is unnecessary to examine the stability vis-à-vis the fluid force. - The use of local soil as regreening is preferable. - The flood control performance and environmental conservation performance vary depending on the type of blocks used. - Particular attention is required in regard to those blocks which only have a landscaping function or hardly any environmental conservation function.
	Block masonry/pitching		- The standard design should be used. - The standard buttress thickness is 35 cm. - While this method can be used in almost any area of a river, its rigid structure may be vulnerable to lowering of the bed, possibly resulting in the loss of river characteristics. - In principle, this method should not be used except when other nature-friendly revetments cannot be applied. - As this method has no river environment conservation function, special consideration is required in regard to the water edge and the foot as well as top of the slope.
Compound type			- A compound type revetment is applied when there are restrictions posed by boulders on the bed and the slope, etc. Various types of revetments are combined to suit the river characteristics. - In the case of a river with many boulders, it is possible to introduce a combination where the lower section of the revetment is made up of natural stone or concrete block in view of its durability while the upper section is made up of a method which is suitable vis-à-vis the flow velocity and environmental conservation. - If the foot of the existing slope is steep, the application of a compound revetment to introduce a gradient which reflects the topography should be considered. Even if the available land is limited, the selection of a method offering better potential for vegetation restoration by the introduction of a gentle gradient for the upper section should be considered. - In the case where a slope of 1: 2.0 selected for a narrow river threatens progressive scouring, narrowing of the bed or environmental deterioration due to the narrow width, the lower section should be given a steeper gradient (approximately 1:0.5) to create a rich water edge. For a compound revetment, safety calculation should be conducted if it is necessary. - A suitable combination of different types of

			revetments for the upper and lower sections and the location should be determined through comprehensive analysis of the river conditions as well as site conditions. - The structure of a compound revetment should not be determined exclusively on the basis of the design velocity but should actively try to use a less rigid method, taking the past performance of each method into consideration.

Table 7.2 Design Velocity for Revetment Work

Type		Design velocity (m/s) 2	3	4	5	6	7	8	Application conditions
Vegetative type	Turfing	■							- Applicable to an area which is not inundated at the ordinary water level and which is not exposed to flowing water until the turf is established. - Applicable to an area below the ordinary water level with a combination of gathered stones, wood hurdling or basket-type foot protection works - Applicable where there is no housing or important facilities in the hinterland.
Sheeting type	Geotextile	■	■						- Applicable to a river with few boulders or an area other than a flow impact section. - Applicable where there is no housing or important facilities in the hinterland.
	Block matting	■	■	■					- Applicable to a river with few boulders or an area other than a flow impact section. - Applicable where there is no housing or important facilities in the hinterland.
Wood type	Log grating	■	■	■					- Applicable to an excavated channel. - Applicable to a low water bank with a wide flood channel. - Applicable where there is no housing or important facilities in the hinterland.
	Fascine slope cover	■	■	■					- Applicable to an excavated channel. - Applicable to a river with few boulders. - Applicable to a low water bank with a wide flood channel. - Applicable where there is no housing or important facilities in the hinterland.
	Pile hurdles	■	■	■					- Applicable to an excavated channel. - Applicable to a river with few boulders. - Applicable to a low water bank with a wide flood channel. - Applicable where there is no housing or important facilities in the hinterland.
Stone type	Natural stone (dry pitching)	■	■	■	■				- Applicable when the stones to be used are readily available nearby (common condition for all stone-based revetments).
	Natural stone (wet pitching)	▒	▒	▒	▒	■	■	■	- Deep joints are adopted so that the filled concrete cannot be seen on the revetment surface.
Basket	Vegetative gabion	■	■	■	■				- Applicable to an excavated channel - Applicable where there is no housing or important

type									facilities in the hinterland.
	Basket matting (flat placing)	■	■	■	■				- Applicable to an excavated channel. - Should not be applied in a manner which invades the standard cross-section of an embankment.
Block type	Connected blocks	■	■	■	■				- When steel wire is used to bind the blocks, this method should not be used in an area with high acidity or a high salt content.
	Environmental conservation type blocks	■	■	■	■	■	■	■	- As there are many different types, a type which is appropriate for the local environment should be selected.
	Concrete block pitching	‖	‖	‖	‖	‖	‖	‖	- In principle, this method should not be used except when other revetment construction methods cannot be used.

- Applicable to a Revetment Slope of 1: 1.5 or Gentler (to be reviewed based on the performance of different types of work)
- The application ranges shown in the table are rough guidelines determined based on the past performance of each method. Accordingly, a method already used can be re-applied outside the above application range provided that any cause of damage to the existing work is properly dealt with depending on the state of damage.
- A rational method which is suitable for the design flow velocity can be actively used even if it is not listed in the table.
- Efforts must be made to expand the table based on the "Basic Guidelines for Disaster Rehabilitation Work to Protect Beautiful Mountains and Rivers" prepared by each prefectural government.

7.8 Foundation Works

The foundation works for a revetment must have a structure which is able to support the slope protection works in consideration of scour in front of revetment. The most general case of damage to a revetment is that the foundation works or the slope protection works are collapsed because the foundation is exposed by local scour during flood.

In general, the foundation of revetment is installed 0.5–1.5 m deep from the deepest riverbed level. However, it should be determined considering the river scale, scour situation, estimated maximum scour depth, past damage, depth of footing surrounding structures, etc.

When the estimated maximum scour depth is deeper than the level of the foundation crown or when stabilization of the foundation works is required according to the past damage, installation of foot protection works is effective.

In refilling at the foundation, it is required sensitivity to the environment. For example, diversity at waterside is secured by utilizing surplus soil in riverbed.

For pile foundations, some measures, including gathered stones, are necessary to prevent scouring at the front and to ensure diversity at the water edge.

Underpinning works are introduced to protect the foundation when the foundations of an existing revetment are either exposed or damaged due to scouring or lowering of the bed and should not have a structure, which disturb the flood flow. Conservation of the water edge diversity should also be taken into consideration.

7.9 Soil Cover

In principle, the revetment should be covered with surplus soil. The covering of a revetment with soil secures the presence of soil for plant growth. As the major factors determining plant growth are light, water and soil, a porous soil cover to a revetment provides favorable conditions for plant growth as in the case of a natural bank. The cover thickness should be sufficient to hide the revetment and to facilitate thick vegetation.

Soil cover has such positive effects as an increase of the revetment strength, creation of favorable conditions for plant growth, restoration of the river's character, improvement of the landscape and improved accessibility to the water edge. In view of conservation of the ecosystem and the effective utilization of resources, soil at the site is used for soil cover. The soil should be spread, not be compacted.

7.10 Selection of Construction Method

The construction method shall be selected according to the roughness of riverbed materials, the strength of flowing force and the slope gradient of revetment at the planned place of river.

The revetment is required to have the strength corresponding to the roughness of the riverbed of each planned place, and at the same time, the construction method must be decided in consideration of construction cost, future maintenance, etc. The availability of the materials used must be also considered.

For revetments, there are proper construction methods according to height and slope gradient, and the following table shows the outline of the relationship among height, slope gradient and construction method.

Table 7.3 Relationship among Height, Slope Gradient and Construction Method

Structure of slope protection		Height of slope protection (m)	Slope gradient
Stone masonry, concrete block masonry	Wet	3 or more Less than 5	1:0.5
		Less than 3	1:0.3
	Dry	Less than 3	1:1.0
Stone pitching, concrete block pitching	Wet		1:1.5
	Dry	Less than 3	1:2.0

Concrete slope frame			1:1.5
Wire cylinder (gabion), connection concrete block work		3 or more	1:2.0
		Less than 3	1:1.5

7.11 Foot Protection

1. The construction method, the width, thickness, etc. of the foot protection shall be decided according to the roughness of bed, the strength of flowing force, water depth, and bed variation.
2. The top of the foot protection shall not be higher than the design riverbed level (existing riverbed level if the existing riverbed level is lower than the design riverbed level)

Since the revetment is broken from the lower part in most cases, the foot protection provided to prevent it by decreasing the flowing force at the point and preventing scour is very important. The requisites of foot protection include resistance to tractive force, large durability, flexibility to meet riverbed variation, etc. Therefore, it must have proper flexibility and roughness, and also proper weight.

The construction method of foot protection shall be selected according to the respective characteristics of rivers.

The width, thickness, etc. of foot protection depend on the conditions off riverbed variation, state of bed and scale of the river and are difficult to be decided generally, and it is important to refer to the experiences in the river and examples of similar rivers.

Foot protection works are introduced to stabilize the foundation works for a revetment, taking the design velocity and bed fluctuations, including localized scouring, into consideration. Illustrations of and the design principles for different types of foot protection works are given in Table 7.4. The applicable velocity range for each type of works is shown in Table 7.5.

The structure of foot protection works must be decided in consideration of the velocity and bed materials in view of resisting rolling, scattering or abrasion. Meanwhile, the width must be refer to the width of similar structures in the upstream and downstream and should be wide enough to resist the maximum scouring.

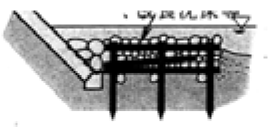
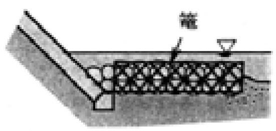
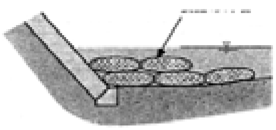
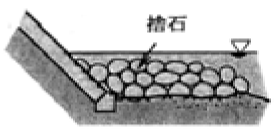
For the introduction of foot protection works, proper consideration should be given to the conservation of a diverse water edge environment, including the preservation of pools.

In a small river, special care is required as foot protection works can have significant impacts on the river environment. Careful attention is also required for the use of basket type foot protection at a river with a small discharge as these can make the flow into a sub-flow.

Foot protection must be flexible enough to follow the bed change while withstanding the velocity so that rapid scouring does not occur. Foot protection must also be wide enough to prevent lowering of the bed in front of the revetment foundations.

As foot protection works can provide shelter as well as feeding grounds for fish, etc., there should be a sufficient water depth above these works. In addition, a porous material and a method which provides many cavities should be selected. Even though the preferred type of foot protection works depends on the site conditions, wooden, submerged bed or riprap type foot protection works are desirable because of their porous nature and flexibility.

Table 7.4 Illustration of and Design Principles for Foot Protection Works

Type	Image	Design Principles
Mattress		- A fascine mattress and wooden mattress tend to be used for sluggish streams and rapid streams respectively. - The size of the filling material should be designed based on the non-dimensional tractive force. - There is an improved mattress where the wood is replaced by concrete. - Thinned wood should be used as much as possible if it is available. - The wood should always be submerged to avoid decay.
Basket		- The basket material must have sufficient strength and durability. - The size of the filling material should be designed based on the non-dimensional tractive force. - Special attention should be paid to the use of this type if a river is used for some purposes near the site. - Not applicable to a river with many boulders.
Sack		- When the velocity is high, the use of wire to connect the sacks or piles should be used to make the sacks less movable. - Not applicable to a river with many boulders. - The filling material should be a local material if possible.
Stone		- The width in front of the foundations of the revetment must be stable even if the works are deformed due to lowering of the bed. - The riprap size should be designed based on the non-dimensional tractive force. - Local stones should be used as much as possible. If stones from another area are used, special attention should be paid to achieving harmony between these stones and the surrounding environment.

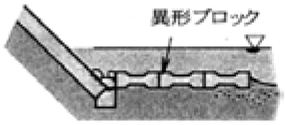
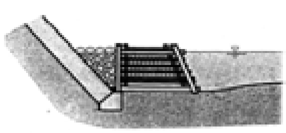
Block		- When neighboring blocks are integrated by means of binding or interlocking, the structure is further stabilized. - The design must evaluate the prospect of sliding or moving caused by fluid force. - A diverse water edge can be achieved through combination with porous blocks and stones, etc.
Single-sloping continuous cribwork		- The size of the filling material should be designed based on the non-dimensional tractive force. - When wooden single-sloping cribwork is used above the ordinary water level, it may quickly decay. - Many environmental conservation ideas can be applied using the space between the revetment and the cribwork. - Applicable to a river with a surplus discharge capacity.

Table 7.5 Design Velocity for Foot Protection Works

External force / Type	Design velocity (m/s) 1	2	3	4	5	6
Mattress, Basket, Sack, Riprap and Single-Sloping Continuous Cribwork	▬	▬	▬	▬	▬	
Foot Protection Block	▬	▬	▬	▬	▬	▬

The applicable range for each type of foot protection works in the table is based on the maximum velocity among past work to allow comparison of the different types. For further details of the selection and specifications of individual foot protection works, refer to the “Draft Technical Standards for Rivers and Sediment Control of the Ministry of Construction Explained” and the “Dynamic Design Method of Revetment”.

8. Leak Prevention

The levee must have the structure to intercept seepage water and not to cause the phenomena of quicksand and piping by seepage water, in consideration of levee body material, foundation subsoil material, water level, duration of high water, etc.

The leakage includes the leakage from levee body and the leakage from foundation subsoil, and the runoff of levee body earth and the phenomena foundation subsoil, and the runoff of levee body earth and the phenomena of quicksand and piping by seepage water cause the breakdown of a levee. Therefore, the following countermeasures must be considered against the leakage of levee body.

1. As for the levee body, less permeable material must be selected. When sandy soil is used as the material, the surface must be covered sufficiently with the soil of fine quality with sufficient tamping applied.

2. The sectional form of the levee shall be sufficiently large. Considering the quality of banking material, the duration of high water, etc., the levee and the banquette width must be enlarged.
3. For executing the embankment, compaction shall be made surely and uniformly.
4. The face of slope shall be protected with revetment.
5. Permeable material shall be used for the toe of the back slope, with dry pitching, etc. applied, for smooth draining, and reinforcement of the toe of back slope.

Against the leakage of foundation ground, the following countermeasures must be considered.

1. Sheet wall, steel sheet pile, etc. shall be provided in the neighborhood of the toe of waterside slope, with replacement by clay made for intercepting seepage water.
2. The waterside permeable ground shall be covered with less permeable material.
3. On the landside, a well for drainage shall be provided to lower the seepage line.

9. Groynes

9.1 Basic Concept

Groynes are provided to prevent scours caused by the suppression of the velocity at the revetment or the front face of bank, to cast river flow for making midstream leave from the revetment or bank, to fix normal channel, and to guide river flow, etc., and shall be planned according to river regime, with emphasis on the correlationship with the channel plan and the revetment plan with which it has colose relation, in consideration of the influence to the upper and lower reaches and to the other side of the river.

The functions of the groynes are

1. To increase resistance to river flow, for decreasing the velocity.
2. To be a direct obstacle to river flow, causing the flow to turn the direction for preventing the collision of the flow with the place to be protected.

These correspond to the following meanings in terms of hydraulics.

1. To perform the function of roughness.
2. To form a groyne zone (zone which is protected from the action of river water, and generally corresponds to the dead water zone).

The purpose of the groynes shown in the text is achieved by applying these functions of groynes.

As is known from the purpose shown in the text, since the plan of groynes has a close relation with the channel plan and the revetment plan, it must be executed according to river regime, with emphasis placed on the correlationship, in consideration of the influence to the upper and lower reaches and to the other side of the river.

The advantages and disadvantages of revetment and the groyne are as follows:

1. Since the revetment directly covers the riverbank to prevent erosion, and the purpose can be easily and definitely achieved.
2. The revetment little decreases the velocity in the vicinity of the bank, but may increase it in some cases, often causing riverbank erosion in the upper and lower reaches of the district with revetment work made, and scouring the foot of the revetment. However, the groynes are less liable to cause such phenomena.
3. The groynes are indirect as a means of riverbank protection, but being properly provided, can well achieve the purpose.
4. The groynes often cause silting up in the vicinity demonstrating the effect of decreasing the velocity more positively.
5. The groynes may change the water hammer zone in the lower reach.
6. Scour occurs around the groynes.

9.2 Selection on the Type of Construction

The type of construction of groynes shall be selected according to each purpose, examining the river regime such as the plane, longitudinal and cross sectional forms of the river, discharge, water level, bed material, bed variation, etc.

In accordance with the functions of groynes shown in the commentary of 9.1 in this chapter, the groynes with the following structure are to be selected.

For the purpose of decreasing velocity:

(1) Low in height
(2) Permeable
(3) Light structure mainly comprising piles, etc.
(4) Several or several decades of groynes are arranged side by side, to provide the intended action as a whole

For the purpose of casting water:

(1) High in height
(2) Semi-permeable or impermeable
(3) Voluminous and heavy structure mainly comprising debris, concrete, etc.
(4) Single groyne or several groynes arranged side by side

The types of construction of groynes include Block, Hijiriushi, Yonkikoh, Sankikoh, Triangle frame, Post, Earth squrdyke, Wooden mattress (including improved wooden mattress), Pile dyke, Covered fascine mattress, etc.

Generally, they are used for steep rivers to mild rivers in this order. These types of construction are roughly classified into those with the resistance as piles applied and those with the gravity of groyne used for resistance to river flow. In mild rivers, pile dykes are mostly used, and in steep rivers, block or Hijiriushi work placed on the riverbed to resist river flow by gravity are often used, since pile driving is impossible in view of the strength of the groyne or too large grading of bed material.

9.3 Direction

The groynes shall be generally arranged upward or at right angles to the direction of river flow.

The groynes can be arranged upward, at right angles or downward in the direction form river to the axis of channel, but are mostly arranged upward or at right angles. But they are seldom arranged upward by 20 degrees or more. Furthermore, they are seldom arranged downward, and this direction is little employed for purposes other than water casting and low slow channel maintenance.

This is because the downward groyne tends to make the bed sand in the vicinity of the groynes flow toward midstream along the groynes, enlarging the bed drop in the vicinity of groyne roots.

9.4 Length, Height and Intervals

The length, height and intervals of groynes shall be decided, considering the river regime, purpose of groynes, influence to the upper and lower reaches and the other side of the river, and to the safety of the structure itself.

In general, providing one strong groyne to resist the river flow causes large turbulent flow, often making large scour in the vicinity of the groyne, and the maintenance of the groyne itself is not easy. Therefore, it is necessary to decide the structure and arrangement so that the velocity is decreased by the comprehensive force of a grounp of groynes in a certain section and that the respective groynes can demonstrate equal resistance force. In view of the above, there are cases in which short groynes are arranged on the upper side, to lighten the burden against water force of the groynes on the upper side.

There are cases in which lengths of groynes are decided according to the low flow alignment (adjusting of the alignment of low flow channel toward the axis of channel), and in this case, particular care should be taken so as not to affect the opposite side of the river and the lower reach.

In general, it is often economical in terms of maintenance and work cost, to provide the groynes together with a revetment without making the groynes too long, and the length is mostly decided to be 10 % or less of the river width.

However, for mild rivers, in some cases, very long groynes are used to prevent the river water from approaching the riverbanks on condition that revetments are not constructed.

Anyway, too long groynes give bad influence to others, and too short groynes do not allow to demonstrate their functions well, requiring the decision to be made on careful examination.

The height of permeable groynes is desirable to be low for lessening the scour in the perimeter, and generally, the height of most groynes is about 0.5 to 1.0 m above the average low water level in the vicinity of fot.

The intervals must be decided in consideration of the relation with the height and length, in addition to the matters specified in the text. It is known that intervals, of about 10 times the groyne height provide the most effective function of roughness, but economic conditions must be also considered.

In order to leave the midstream from the riverbank by making the resistance of riverbank large, and in order to facilitate the maintenance of groynes themselves, it is ordinary to let groynes themselves have a downslope of 1/10 to 1/100, toward the axis of channel.

9.5 Types of Groynes

(1) Groynes

For the selection of a suitable type of groyne, the characteristics of the target river must be clarified and so-called traditional methods should be actively used. As shown in Table 9.1, there are three categories of groynes, i.e. permeable groynes, semi-permeable groynes and solid groynes. Solid groynes are further classified into the overflow type and the non-overflow type.

A groyne performs multiple functions which contribute to the conservation and development of the natural environment, including change of the flow direction, creation of complicated bank micro-topography to create a diverse water edge and the provision of shelter for fish at the time of flooding. These functions must be utilized as much as possible. Meanwhile, a groyne may alter a flow impact part in the downstream. As a groyne has the shortcoming of causing scouring around it, careful attention must be paid to its design and construction.

When wood is used as the groyne material, it must be noted that wood near the water surface is vulnerable to decay. The use of porous materials (stones and baskets, etc.) may be advantageous.

Table 9.1 Types of Groynes

River character	Permeable groyne	Solid groyne
Sluggish stream		Skeleton spur dyke; pile dyke with top cover (*1)
	A-frame cribwork; pile dike	
Rapid stream	Triangular cribwork; post; skeleton spur dyke; various triangular skeleton works; raft skeleton works; quadrangular skeleton works; semi-crib spur	Basket dyke; earth spur dyke; stone spur dyke
	Reinforced quadrangular skeleton works; reinforced triangular skeleton works; large crib spur	Concrete blocks (*2); stone spur dyke

(*1) It must be noted that an originally permeable groyne can change to a solid groyne because of sedimentation over time.
(*2) Special care should be paid to the environment when the use of concrete blocks is planned. The use of concrete blocks in combination with a riprap or improvement of the structure of the blocks themselves is preferable.

(2) Vane Works

Vane works are used to prevent local scour at a bend. The scope of the work covers the entire bend in the longitudinal direction. In regard to the cross-sectional direction, the vane is located at one-quarter of the channel width from the outer bank of the bend towards the inner bank. The length along the flow direction is 0.5 – 2.0 times the water depth while the height from the average bed height is 1/3 – 1/4 of the water depth. The interval between neighboring vane works should be 3 – 5 times the length of a single vane. What is crucial is the orientation of the vane to constitute an angle of 20º to the flow direction towards the outer bank.

10. GroundSill

10.1 Basic Concept

The groundsill plan decide the necessary location, the structure as to height and form, etc. to stabilize the riverbed.

The groundsill is classified into two types with head and without head. It is constructed for the following purposes to stabilize the riverbed.

1. To moderate the bed slope, decreasing the scouring force of the river water, for stabilization of the riverbed in the upper reach (generally, with head).
2. To prevent turbulent flow, fixing the flow direction (mostly, with head)
3. To prevent the scour and drop of the riverbed (generally, without head)

If the riverbed is scoured by the action of river water, the foundation of revetment, etc. rises, being dangerous for flood control, and the riverbed drops, making the intake of various irrigation water difficult, together with other problems involved. In such cases, to maintain and stabilize the riverbed at the height necessary for the channel plan, the ground sill is constructed across the waterway.

In view of increasing the flow capacity of the waterway by making the sectional form of flow of the waterway as large a possible, the measures to be first discussed against the bed drop are to deepen the embedment of revetment, etc., and to protect the function of revetment, etc. by the foot protection, groynes, etc. Moreover, the groundsill plan becomes necessary when the bed height must be maintained at a predetermined height various irrigation water, or from the relationship between the longitudinal slope of river and bed material, etc.

10.2 Form and Direction

The plane form of a groundsill shall be linear as a general rule. The direction shall be at right angles to the direction of river flow in the lower reach in principle, considering the direction of river flow on the occasion of high water.

The relationship between the plane form of groundsill and flow direction is as shown in the following figure.

1. Linear form at right angles to the flow direction of: This is the form most commonly used, and is less problematic for flood control and cheaper in work cost than other forms.
2. Linear form at an angle to the flow direction: This should not be used in principle except in the case of meeting the flow direction in the lower reach of the groundsill, in consideration of levee alignment in the lower reach, etc. This is often seen with old agricultural intake weirs, etc. but often badly affects the rivers.

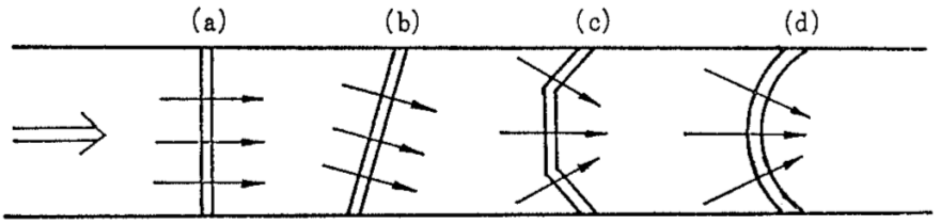


Figure 10.1 Plane Forms of Groundsills and Flow Direction

3. Polygonal form with a vertex at the center of river: The midstream in the lower reach of the groundsill can be collected centrally, But it involves high work cost, being liable to cause deep scouring, etc. in the lower reach, and the maintenance of the groundsill and the

riverbed in the lower reach becomes difficult.

4. Curved form with a vertex at the center of river: A circular arc of parabola is used mostly, but it has the same difficulty as the polygonal form.

10.3 Height, etc.

1. The crest height of a groundsill shall coincide with the design bed height in general, and the standard height (referring to the bead of riverbed by the groundsill work) shall be within 2 m.
2. The both ends of a groundsill body shall be inserted sufficiently in the levees, high water channel, etc.
3. In the lower reach of a groundsill, an apron shall be provided according to necessity.

The groundsill is provided to stabilize the riverbed, but it involves the largest problem as to the stability of the riverbed in the immediate lower reach. Therefore, the groundsill is normally as high as about 1 to 2 m.

The crest height is generally the same as the design bed height, but in a river with considerable bed variation, the crest height must be decided in reference to the existing bed and future trend.

Lest the ends of the groundsill should be scoured, both ends of the groundsill must be sufficiently inserted.

10.4 Apron and Mattress

The apron and mattress shall have the necessary lengths and structures required for keeping the safety of ground sill body.

Conceivable causes for breaking the groundsill include the runoff of sediment by the seepage water below the body, apron, etc. and the scouring the lower reach by river water, etc. Therefore, as a countermeasure, the apron must be sufficiently long. Furthermore, impervious walls must be provided in the upper and lower reaches of the apron, with sheet piles, etc. driven, or any other method must be taken, to cope with the scour of the riverbed in the lower reach of apron, or to prevent the runoff of sediment below the bottom.

For the structure of the mattress, generally there are fascine mattress, wooden mattress, improved wooden mattress, concrete mattress, concrete block, etc. a construction methods to reduce the flowing force as practically as possible. It must have flexibility. Gradual arrangement from hard structure to soft structure should be employed for making it familiar with the riverbed.

11. Sluiceway and Conduit

11.1 Selection of Location

The location of a sluiceway, etc. shall be selected according to the purpose of construction, but the place with unstable river regime shall be avoided as practically as possible. Furthermore, the number of construction places shall be made as small as possible so as to promote integration.

Sluiceways, etc. are constructed for the purposes of irrigation, drainage and dual purpose. A sluiceway, etc. to replace part of a levee may become a weak point of the levee.

Considering the operation and maintenance, the number is desirable to be as small as possible, and integration must be executed as far as possible.

11.2 Direction

The direction of a sluiceway, etc. shall be at right angles to the levee alignment in principle.

Since the construction of a sluicegate, etc. may pose a weak point to the levee, the above is specified to avoid the complication of structure and to secure the reliability of work. However, if an oblique arrangement is inevitable due to the form of confluence with tributary distance to the other side of the main river, etc., sufficient measures should be taken for securing the safety in structure and execution of work.

11.3 Foundation Height

The foundation height of sluiceways, etc. for the purpose of irrigation shall be decided according to the purpose of respective intake, but bed variations in the future shall also be taken into account.
For the purpose of drainage, the height shall be decided, considering the height of the riverbed or the foundation height of the channel to be connected.

There are many cases where intake becomes difficult in irrigation sluiceway, etc. due to bed drop. For the construction of a sluiceway, etc., it is necessary to examine the trend of bed variation in the past, and to sufficiently discuss the possibility of bed drops in the future. However, too low a foundation height may give the volume of intake of more than the water right, and therefore the volume of intake must be adjusted.

As for the drainage sluiceway, etc., too low a foundation height causes sedimentation, decreasing the effective sectional area, and too high a foundation height decreases the drainage capacity, requiring much cost for the maintenance of the outfall. The relationship with the bed height of the river or the foundation height of the channel to be connected with a conduit, etc. must be sufficiently discussed to decide the foundation height of the sluiceway.

11.4 Decision of Sectional Profile

The sectional form of a sluiceway for irrigation shall be large enough to secure the design intake volume even in the intended dry season, within the safe range of the intake plan.

For drainage, the drainage discharge shall be decided by making inner water analysis based on the rainfall depth in the drainage basin to be covered by the sluiceway, the freshets of main river and inner water. It shall be arranged that the velocity in the drainage sluiceway does not considerably change in comparison with the velocity of a tributary to be connected.

The minimum diameter of the section of a sluiceway shall be 60 cm.

As for the irrigation sluiceway, etc., particular interpretation seems to be unnecessary. However, if the possible intake volume becomes excessive due to too low, foundation height or employment of minimum section of 60 cm, measures shall be taken in the channel to be connected to the sluiceway, etc., so as not to allow intake exceeding the design intake volume.

As regards the velocity in the discharge sluiceway, normally 1 to 2 m/s is taken as the design velocity of a river in the level terrain. However, when the sectional form is decided in reference to the maximum discharge by the rational formula without making the inner water analysis even for a small scale sluiceway, a rather large velocity of about 3.5 m/s shall be employed, since the momentary peak value is in question. If atrial ponding is allowed, the velocity of about 2.5 m/s shall be standard to avoid sedimentation.

11.5 Span Length of Sluiceway Consisting of Plural Blocks

The span length of a sluiceway consisting of plural blocks shall be as follows:

The interior width of the sluiceway shall be 5 m or more: Provided that the same shall not apply when the interior width is double the interior height or more.

If the span length of the sluiceway provided across the river to be drained is insufficient, flowing matters may be caught to prevent the drainage, and therefore it is desirable to be as long as possible. However, in the case of a small scale sluiceway, the span length of 5 m or more gives structurally uneconomical form, and thus the proviso is provided.

[Early Warning System]

Technical Manual
For
Improvement of Community Early Warning
(Draft)

TF-FRM (Flood Risk Management)

Project on Capacity Development in Disaster Management
in Thailand – Phase 2 –

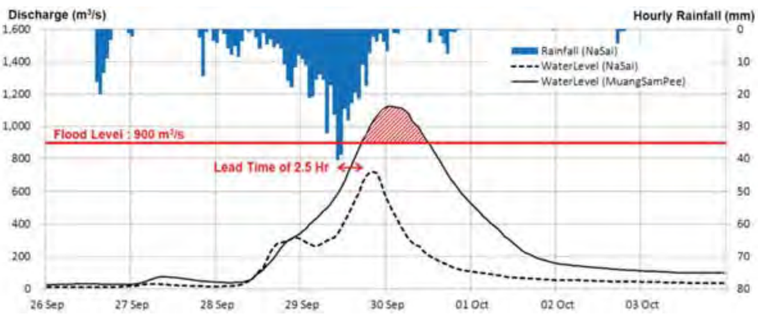
Introduction

Background

A number of manual-type rain gauges have been installed into to the risk communities by DDPM and the other relevant agencies. These gauges are practically effective to raise awareness of disaster risk of community residents as well as to strengthen sustainable community disaster management.

In general, however, the rainfall criteria of manual-type gauges are uniformly defined without any scientific evidences (e.g.100 mm rainfall in most case). Thus, people doesn't know how much rainfall in the upstream area will generate how severe flood in the downstream, and how long lead time for evacuation and preparation after heavy rainfall.

If the criteria are defined based on actual observation, the manual-type rain gauges will be utilized practically and effectively, without high-tech early warning system.



Introduction

Model Site and Instruments

Basing of this concept, TF-FRM has installed several auto-rain gauges and water level gauges into the project model site of Muang Sam Pee village, Li district, Lamphun province, where severe flood strikes the community almost every years.

The costs of instruments are reasonable and it is easy to install and remove. After observation of 1 to 2 years, the instruments can be relocated to the other risk community to define rainfall criteria.

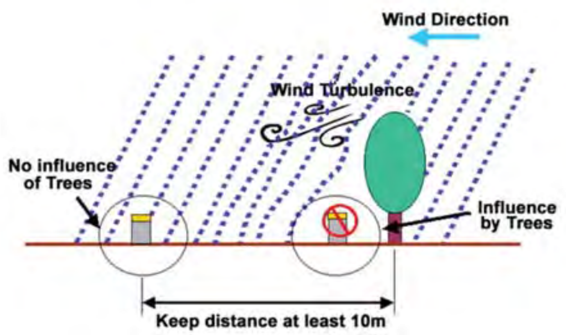
The data was collected and analyzed by TF-FRM and DPM regional office 10, Lampang province.

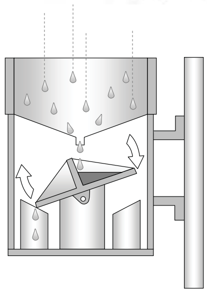
Installation

Installation of Rain Gauge

Appropriate installation is required for accurate observation. The rainfall is often affected by wind turbulence caused by high trees and/or buildings. Insects and leaves into the bucket are also impediment factors for accurate observation.

The installed rain gauge is tipping bucket type, which is most popular rain gauge. Two small vessels are joined together on a tumble axis such as a seesaw. When a side of vessel is filled by a certain amount of raindrops, the vessel tumbles down due to the weight of the poured water. Then raindrops start to fill the other side of vessel. The sensor counts the number of tumbling and records it to the logger inside of the bucket.





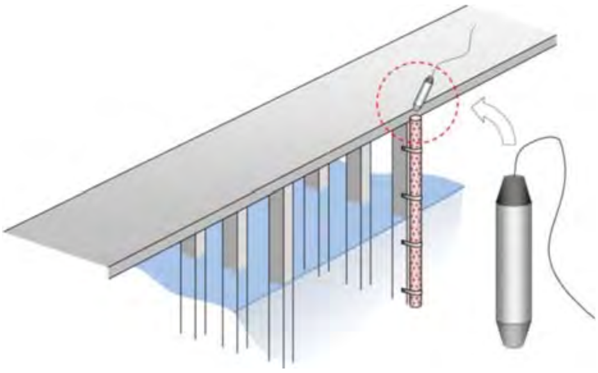
Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Installation

Installation of Water Level Gauge

Pressure-type water level gauge is a popular gauge system with easy install and reasonable. Two sets of sensors inside/outside of water, measure water pressure and barometric pressure respectively. The water depth is calculated from water and barometric pressures.

It is recommended to put the sensor behind of bridge pier, where the sensor is protected from debris and draft woods during flood. Make holes on PVC pipe and fix it along bridge pier. Sensor should be placed at some height from the bottom to avoid buried by silting.



Instruments

Rain Gauge

The rain gauge contains a pair of tipping buckets and a data logger chip inside. During rainfall, the absolute time (date, hour, minute, second) of 1 tipping is recorded. 1 tipping indicates 0.2 mm rainfall amount.

The logger can record approximately 16,000 tips and temperature. Normally, it can record events more than 1 year. But the recordable duration will be limited by the battery life that may be 1year. You are required to collect data (replace battery) at least **one in 6 months**.

Model	Data Logging Rain Gauge RG3-M
Maximum Rainfall Rate	127 mm per hour
Resolution	0.2 mm
Housing	152.4 mm (6 inch)
Logger Time Stamp Resolution	1.0 second
Logger Battery	CR-2032 3V lithium battery
Logger Battery Life	1year typical use
Logger Memory	64 KB In most case, battery life (not memory capacity) will be the factor that limits deployment duration.
Logger Temperature Range	-20° to 70°

Instruments

Water Level Gauge

The installed water level gauge is a pressure type, which can record absolute pressure in the water. To convert the data from pressure into water level, therefore, you need to settle another sensor to record air pressure outside of river. In Muang Sam Pee, the air pressure gauge was installed at village headman's house.

The battery life of water level gauge is more than 5 years in case of 1 minute logging interval. However, you may need to collect data at least **one in 3 months**, due to the limitation of logger memory (21,700 samples).

Model	**U20-001-02 (Water Level)** **U20-001-01 (Air Pressure)**
Operation Range	0 to 400 kPa (0 to 30.6 m)
Burst Pressure	500 kPa (40.8 m)
Resolution	4.1 mm
Water Level Accuracy	Typical Error: 15 mm, Maximum Error: 30 mm
Logger Battery	2/3 AA, 3.6 V Lithium, Factory-replaceable
Logger Life	5 years with 1 minutes or greater logging interval
Logger Memory	64 KB 21,700 pressure and temperature samples. **In case of 10 minutes interval of pressure and temperature, it can record 150 days data.**
Logger Temperature Range	-20° to 50°

Instruments

Waterproof Shuttle

In the portable case of water level gauge, "Waterproof Shuttle (U-DTW-1)" and several "Couplers" are also contained.

Waterproof Shuttle allows you to collect data from the sensors either rain gauge and water level gauge in the field without computer. You can just bring Waterproof Shuttle and collect data, and then transfer the collected data to your computer in the office.

The Couplers are used to connect Sensor and Waterproof Shuttle.

Connect Sensor and Shuttle

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Setting

Initial Setting of Waterproof Shuttle

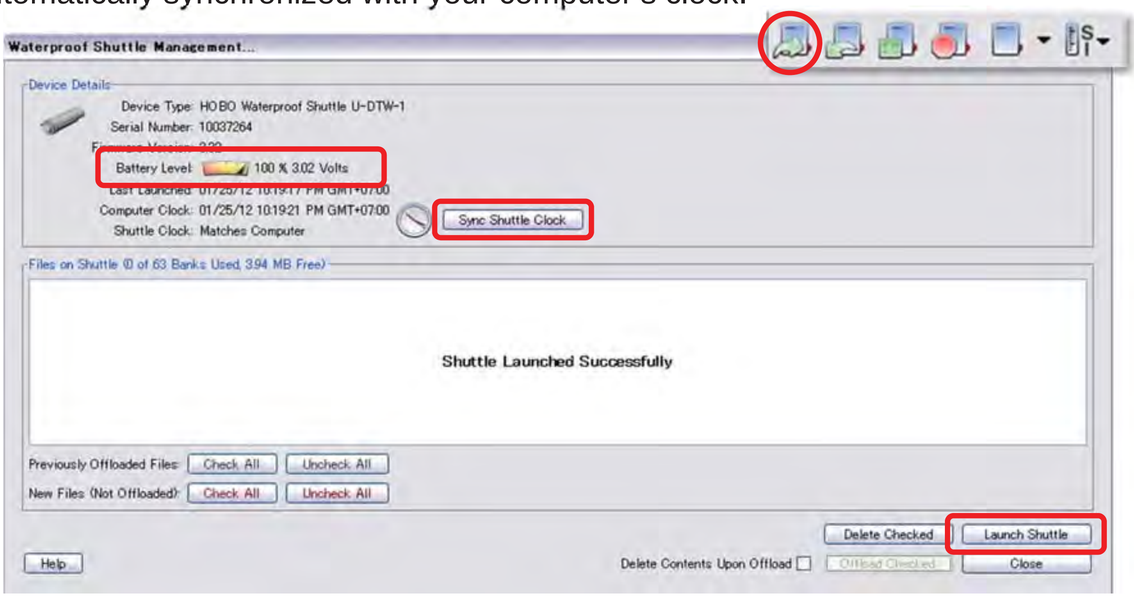
Before using the shuttle first time, you must launch and set it with HOBOware Pro.

- Plug the large end of a USB interface cable into a USB port on computer.
- Unscrew the center cap on the shuttle. Plug the small end of the USB interface cable into the USB port in the shuttle (It may take a few seconds for you computer to recognize the new device).

Setting

Initial Setting of Waterproof Shuttle

- Launch HOBOware Pro. Then click launch icon.
- Make sure the battery level is good. If it is week, you need to change the battery.
- Click [Sync Shuttle Clock] or [Launch Shuttle] to initialize the clock of shuttle. It is automatically synchronized with your computer’s clock.



Setting

Initial Setting of Sensors

It is required to setup sensors when you need to change buttery or reset the recording intervals and the other setting. Make sure the battery level is good. If it is week, you need to change the battery.

- Plug the large end of a USB interface cable into a USB port on computer, and the small end of the USB into USB port in the shuttle.
- Make sure the communication end of the shuttle is clean. Attach the correct coupler for the logger (ensure that it is seated properly).
- Insert the logger of rain gauge or water level gauge into the coupler. Momentarily press the coupler's lever (press hard enough so the lever bends).

Setting

Initial Setting of Sensors

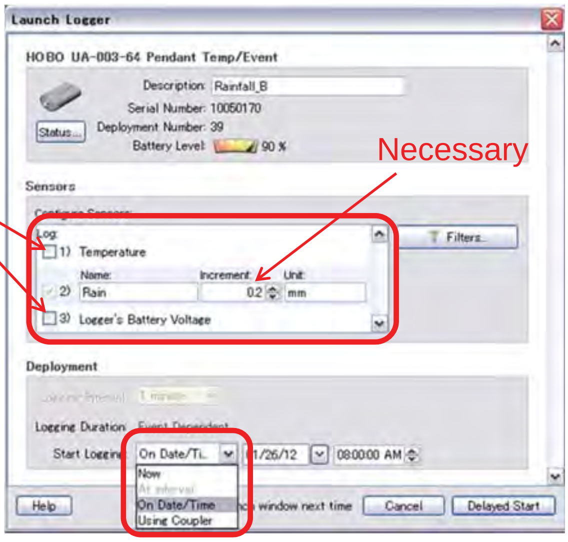
- The amber LED blinks momentarily, then the green LED should glow steadily to indicate that the logger is ready to communicate with HOBOware. (If the red LED blinks instead, the logger was not found. Make sure the logger and coupler are aligned and seated properly.
- Launch HOBOware Pro. Then click launch icon.

- You may aware the following warning appeared. Click [OK].

Setting

Initial Setting of Sensors

- In the following dialog of rain gauge, set the sensors which you want to record. You can select the [Logging Duration] in the [Deployment].
- When you don't set any other sensors such as Temperature and Voltage, recording of rainfall will be immediately started. However, when you select Logging Interval for Temperature and Voltage, the first record of rainfall (first tipping) will be started after first logging of Temperature and Voltage.



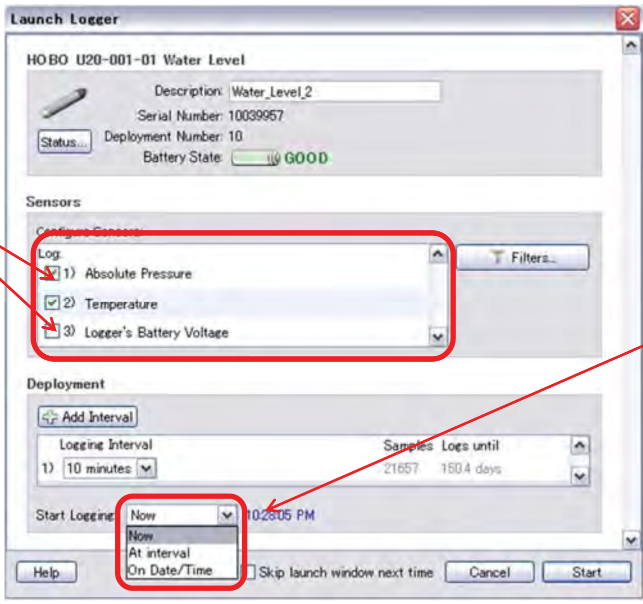
Not necessary

Necessary

Setting

Initial Setting of Sensors

- In the following dialog of water level gauge, you need to select sensors of both of **Absolute Pressure** and **Temperature**, Because Temperature is necessary to convert and calibrate from air pressure into water depth.
- The interval must be **10 minutes** to know the flood arrival time of the target river.



Necessary

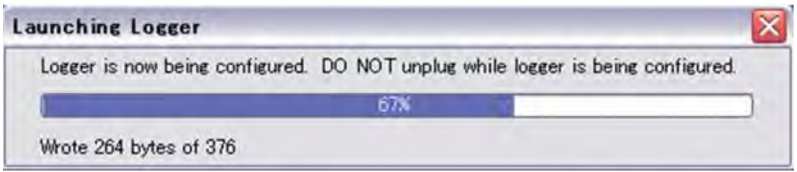
Better to set a certain 10 minutes to adjust with rainfall data

(On Date / Time)

Setting

Initial Setting of Sensors

- Make sure the launching logger.
- When the launching is finished, remove the logger from the coupler. The green LED stops glowing when you disconnect the logger or the USB cable.



Reading Out and Re-launching

If not necessary reset logging schemes of loggers, you can just follow the next steps in the field.

- Plug the large end of a USB interface cable into a USB port on computer, and the small end of the USB into USB port in the shuttle.
- Make sure the communication end of the shuttle is clean. Attach the correct coupler for the logger, and ensure that it is seated properly.
- Insert the logger of rain gauge or water level gauge into the coupler. Momentarily press the coupler's lever (press hard enough so the lever bends). Readout should begin immediately. The amber LED blinks continuously while readout and re-launch are in progress. Do not remove the logger when the amber LED is blinking.

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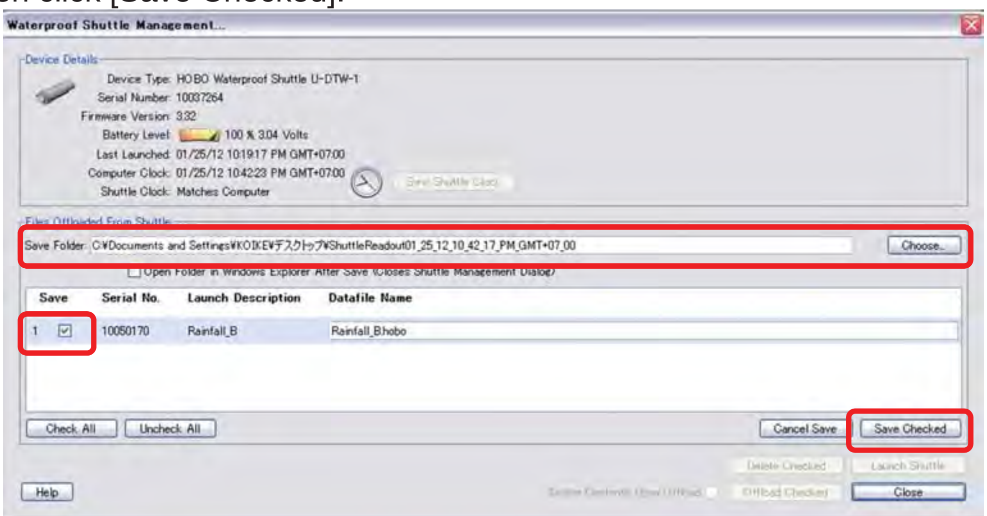
Reading Out and Re-launching

- After reading out the logger, the shuttle synchronizes the logger's clock to the shuttle's internal clock and re-launches the logger, using the description, channels to log, logging interval, and other settings that are already in the logger.
- When the re-launch has completed, the green LED blinks for 15 minutes or until you momentarily press the coupler levers to stop it.
- Make sure that the LED of the logger blinks **one every one to four seconds** (the shorter the logging interval, the faster the light blinks). If the logger is awaiting a start because it was launched in [Start At Interval] or [Delay Start] mode, then blinks o**nce every eight seconds** until logging begins.

Data Offloading from Shuttle

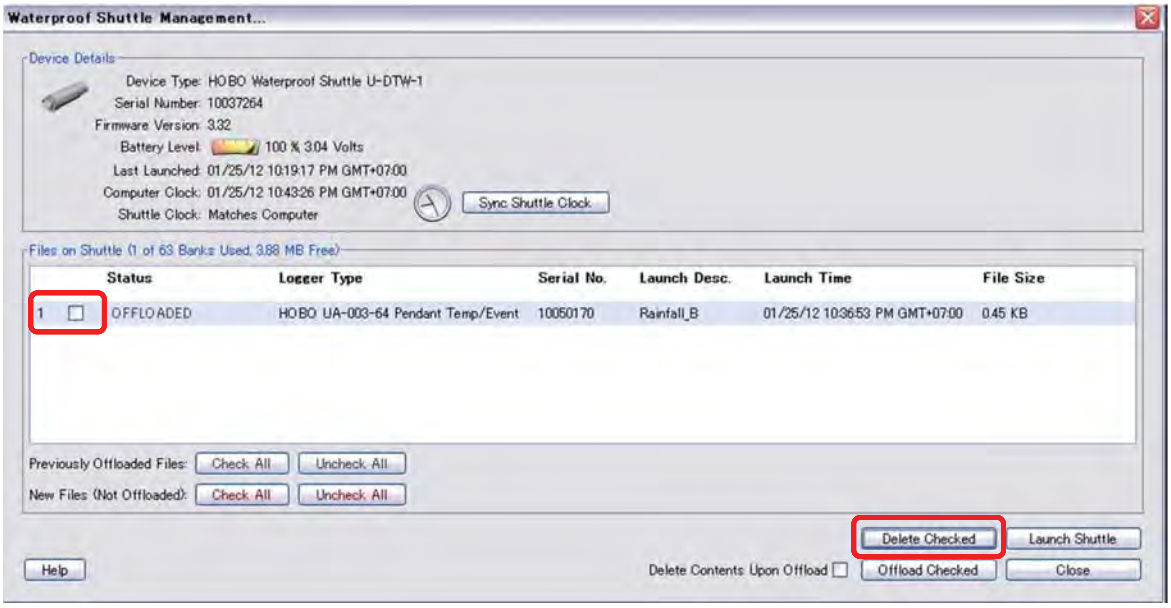
You can offload the data stored in the shuttle even when the batteries are depleted. Take following steps:

- Connect the shuttle to a host computer running HOBOware Pro.
- Click [Readout Device]. 
- The data in the shuttle will be read in the [Waterproof Shuttle Management] dialog as follow. Select folder where you want to save the data and check the file you want save, and then click [Save Checked].



Data Offloading from Shuttle

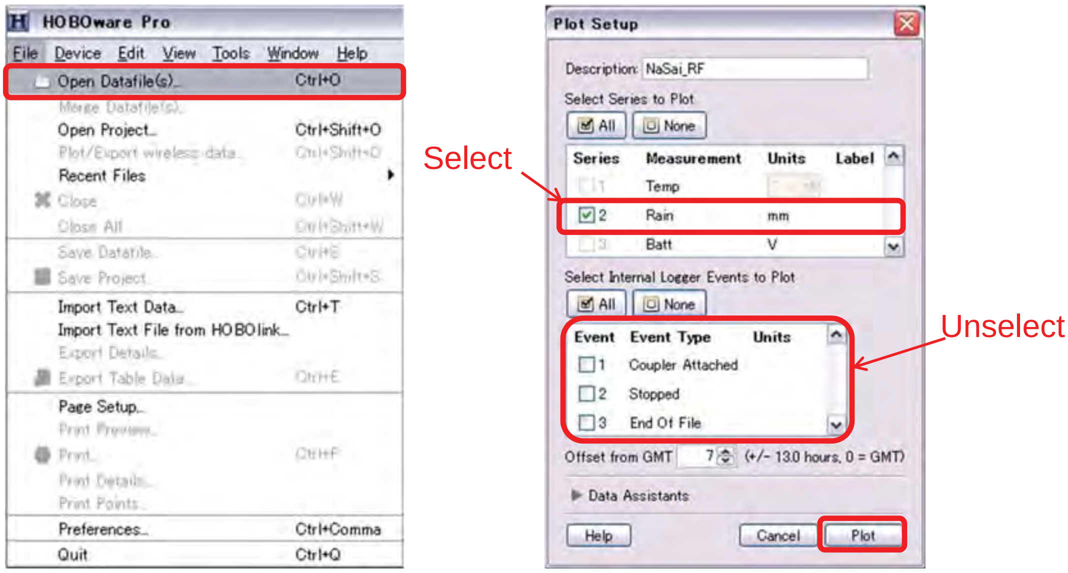
- Review the list of banks. You can delete any data that are no longer needed.
- Make sure the battery level is good, and change the batteries now if they are weak.



Data Checking

Rain Gauge

- Open HOBOware Pro, and select [File] – [Open Datafile(s)].
- In the following [Plot Setup] dialog, select item you want to show in HOBOware Pro. In this case, you can select [Rain] and unselect all of logger events. Then click [Plot].



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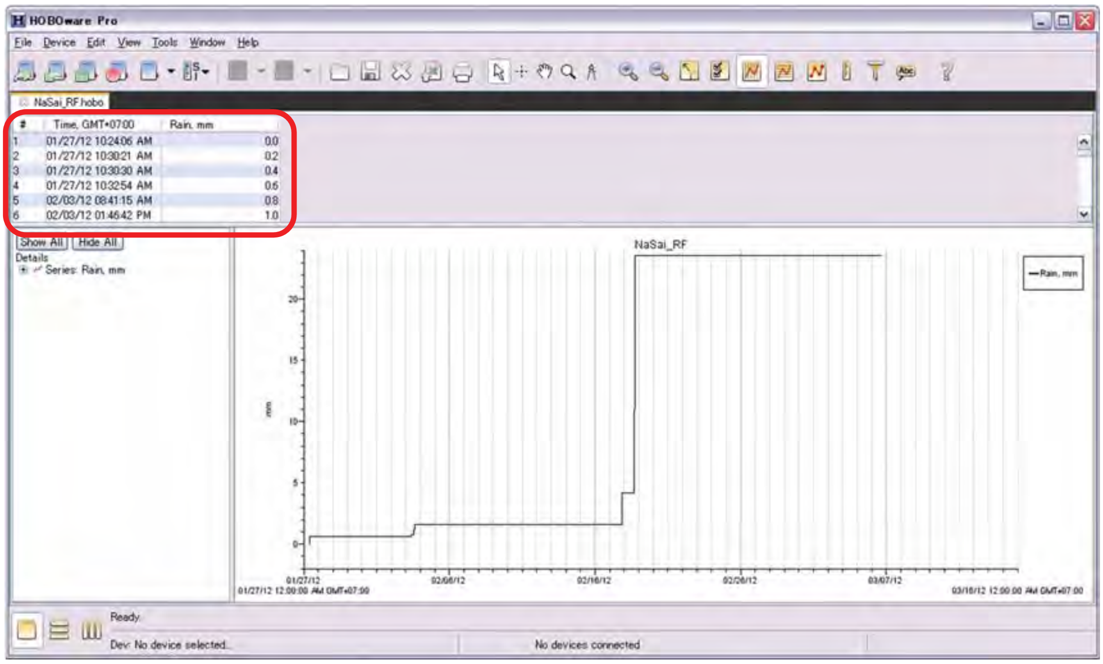
Data Checking

Rain Gauge

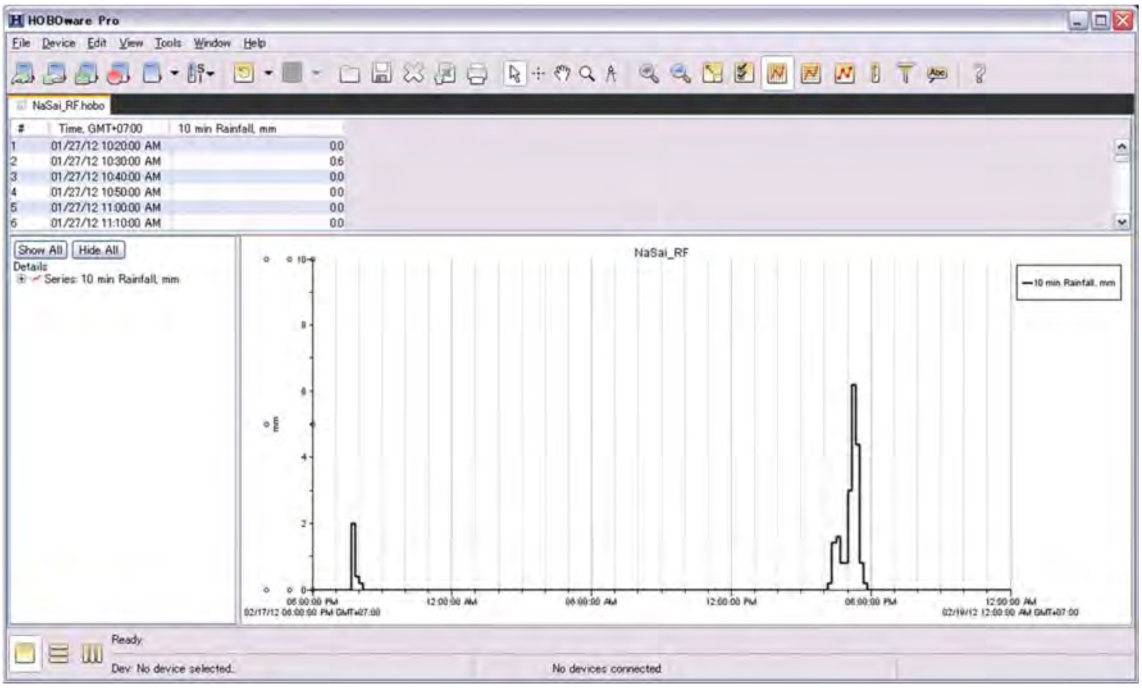
- The accumulated rainfall graph will be shown as bellow. Absolute time of bucket tipping the rain bucked tipped are shown in the time series table. The resolution of this rain gauge is 0.2 mm.



Data Checking

Rain Gauge

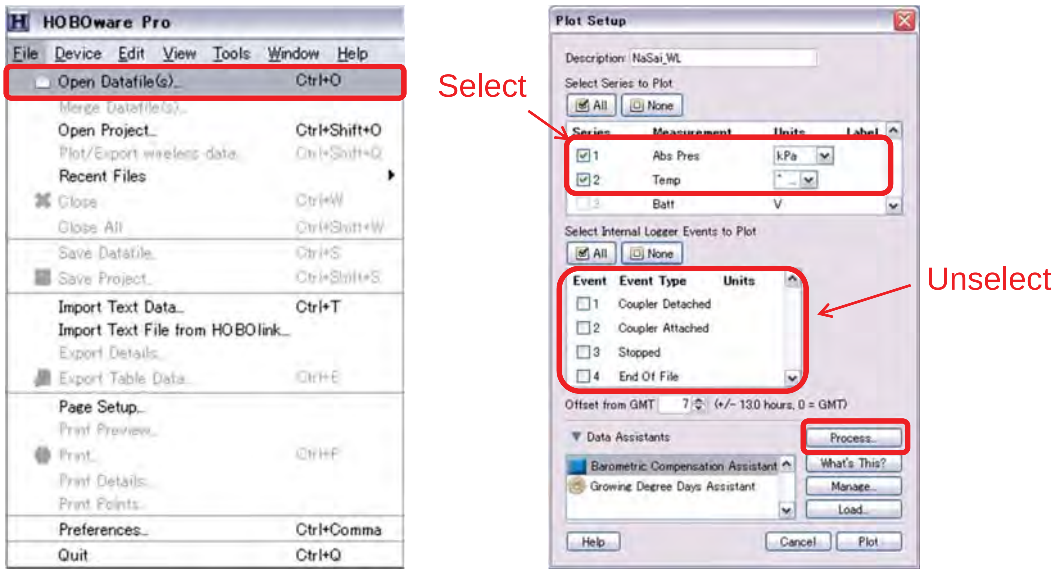
- When you adjust the graph scale, you can see 10 minutes rainfall amount as following picture.



Data Checking

Rain Gauge

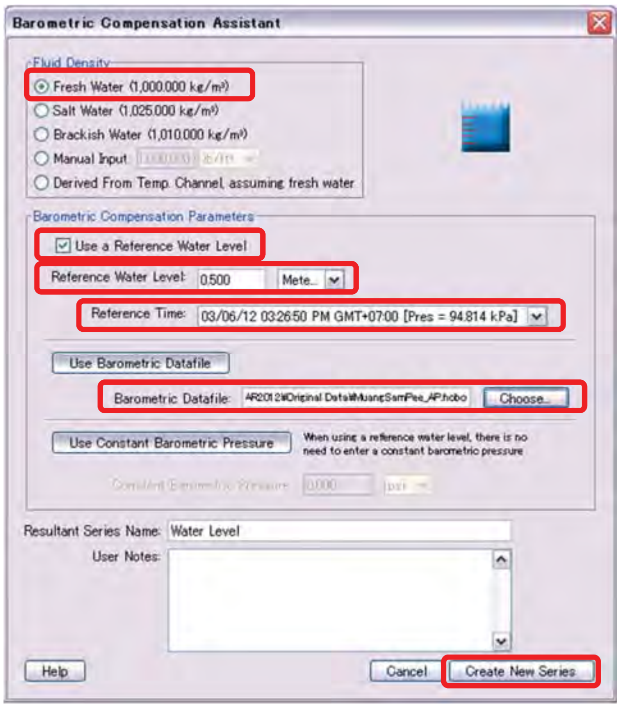
- Open HOBOware Pro, and select [File] – [Open Datafile(s)].
- In the following [Plot Setup] dialog, select item you want to show in HOBOware Pro. As mentioned before, the water level gage records only absolute pressure in the water, so you need to convert it into the water level by use of air pressure measured outside of river. Click [Process] at the bottom



Data Checking

Water Level Gauge

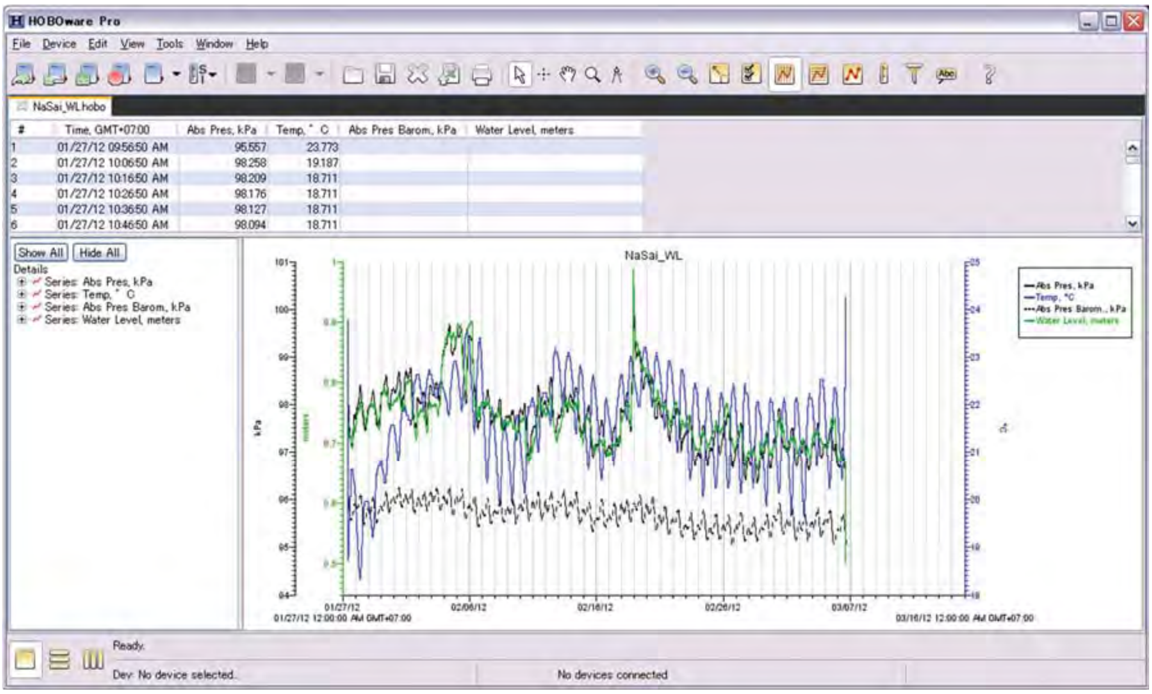
- In the following dialog of [Barometric Compensation Assistant], select [Fresh Water].
- Check [Use a Reference Water Level] that is measured water level when you collected the sensor data.
- Enter the [Reference Water Level] in meter, and select [Reference Time]. You may measure the actural water level when you collect the data. Thus the reference time must be the final time in the logger.
- Click [Use Barometric Datafile], and choose Air Pressure data. In this case “MuangSamPee_AP”.
- Then click [Create New Series].



Data Checking

Water Level Gauge

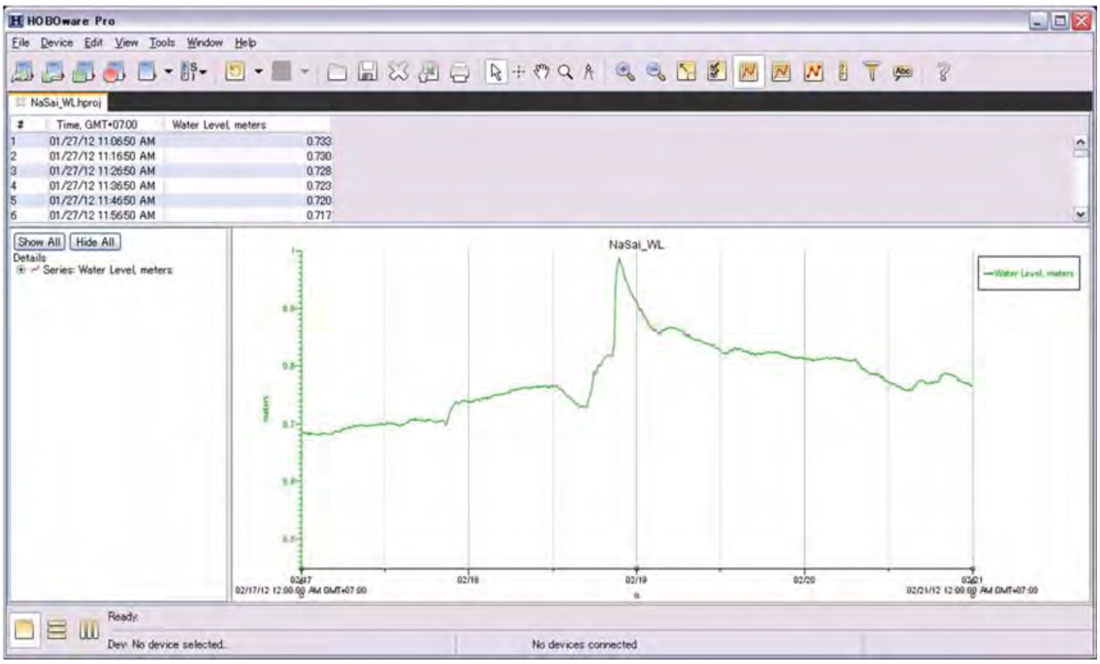
■ The following graph can be obtained.



Data Checking

Water Level Gauge

■ When you adjust the graph scale, you can see the changing of water level in each 10 minutes.



Observation Result
&
Warning Criteria at Muang Sam Pee
(Draft)

TF-FRM (Flood Risk Management)

Project on Capacity Development in Disaster Management
in Thailand – Phase 2 –

Location

2 sets of Rain Gauge, 3 sets of Water Level Gauge

Location

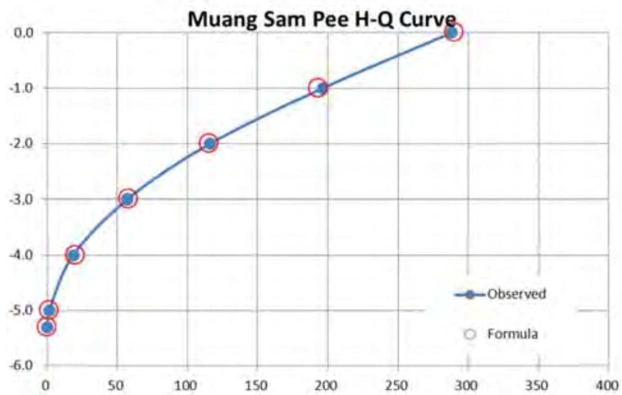
Rain Gauge

Pha Lad Tai

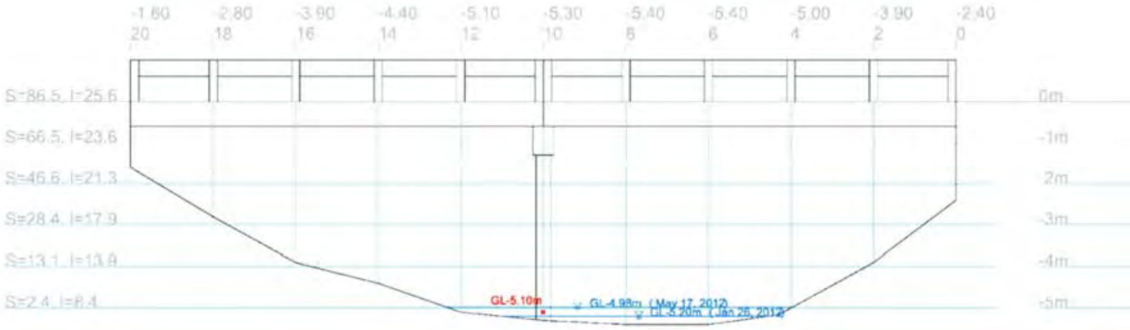
Na Sai

Location

Water Level Gauge (Muang Sam Pee)



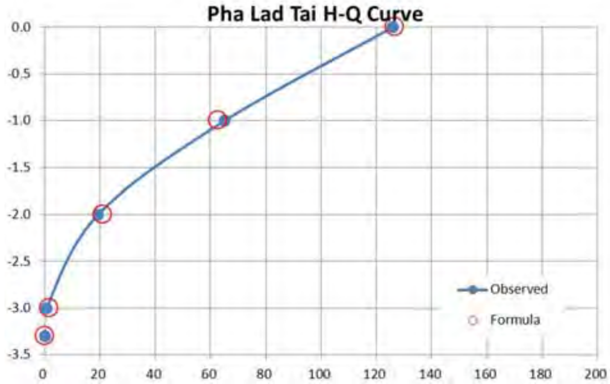
* H-Q curve to be modified



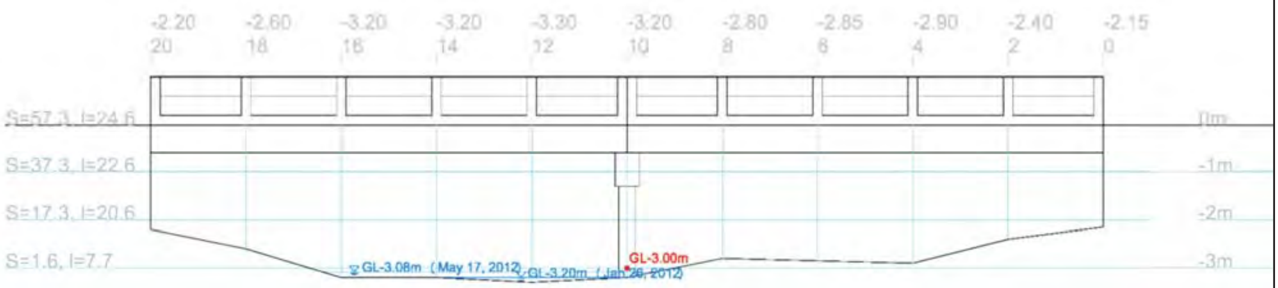
* The sensor was replaced after flood on May 6, 2012

Location

Water Level Gauge (Pha Lad Tai)

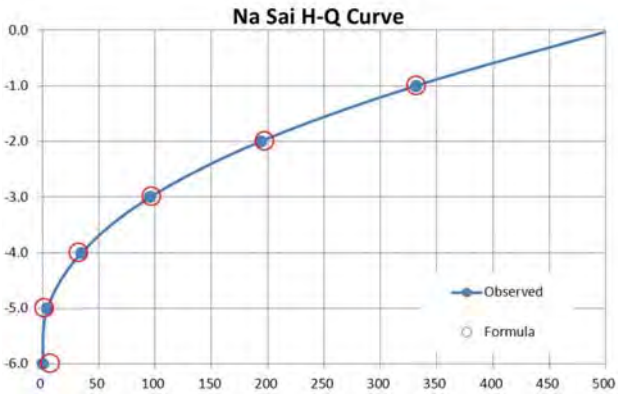


* H-Q curve to be modified

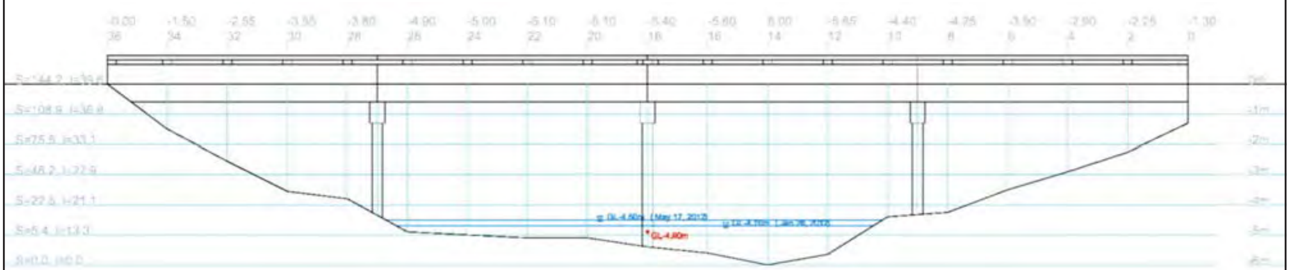


Location

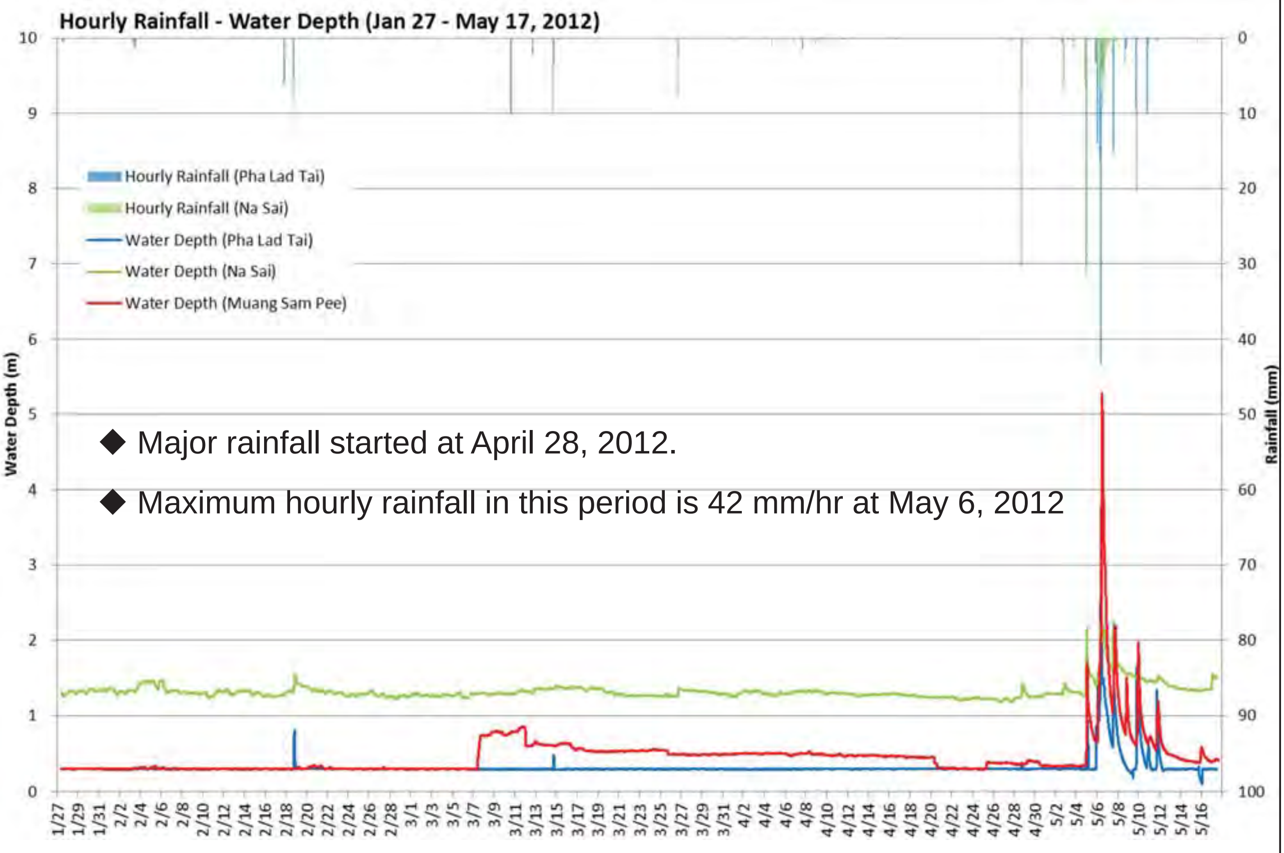
Water Level Gauge (Na Sai)



* H-Q curve to be modified



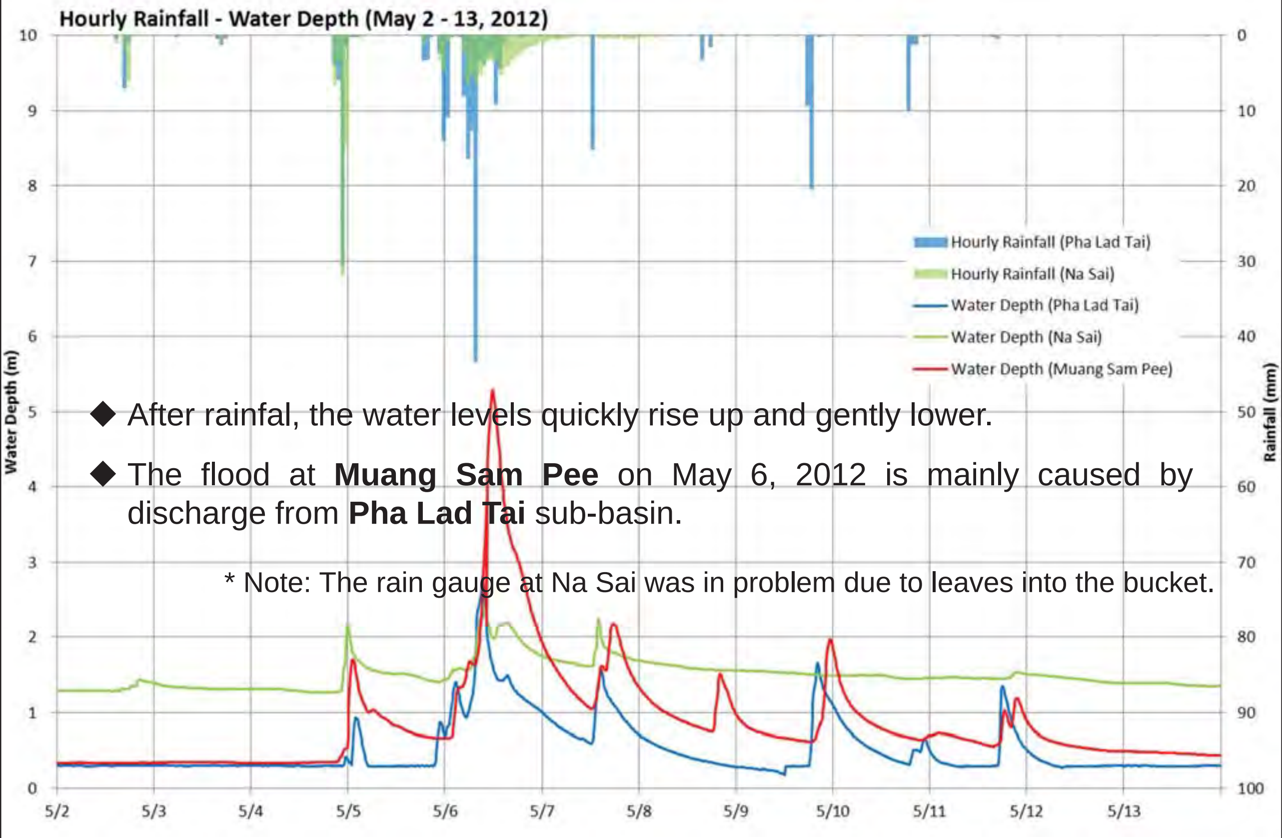
Observation Result



- ◆ Major rainfall started at April 28, 2012.
- ◆ Maximum hourly rainfall in this period is 42 mm/hr at May 6, 2012

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Observation Result

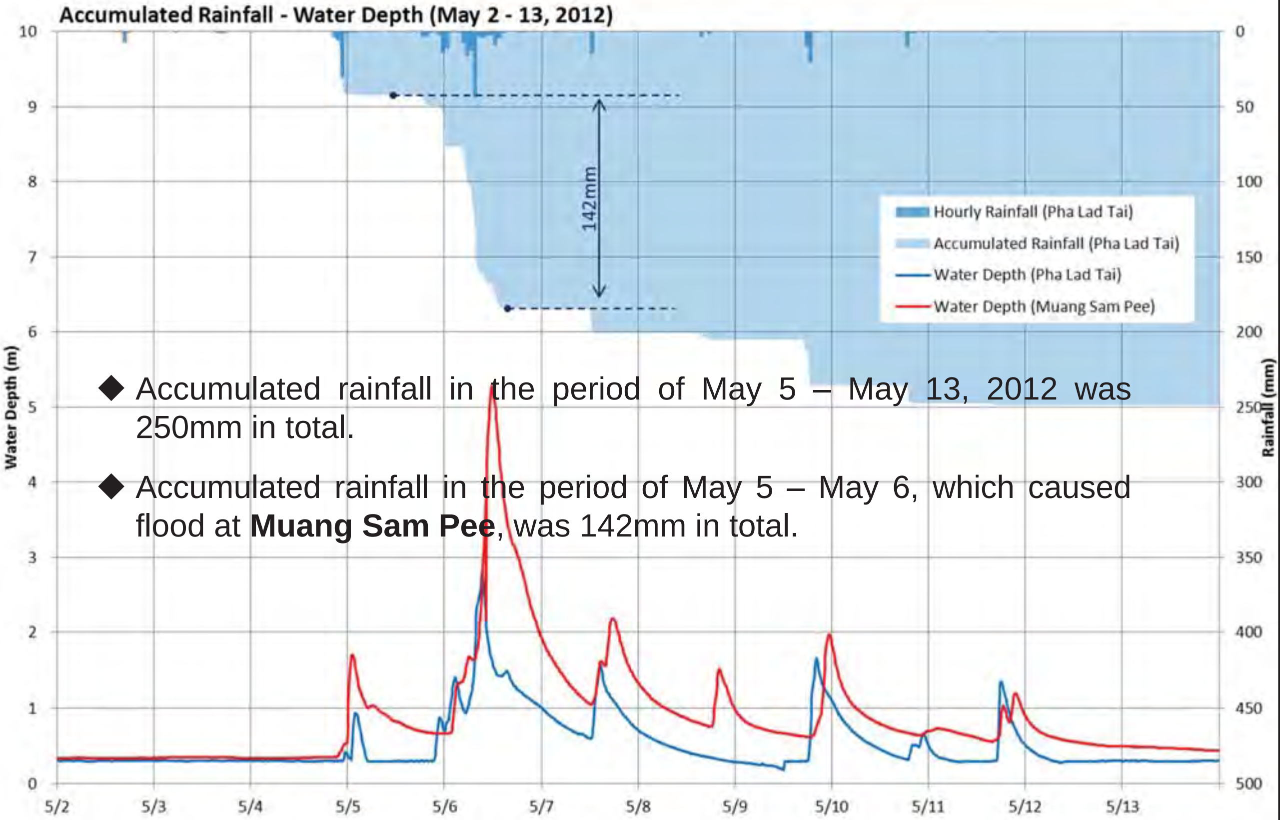


- ◆ After rainfal, the water levels quickly rise up and gently lower.
- ◆ The flood at **Muang Sam Pee** on May 6, 2012 is mainly caused by discharge from **Pha Lad Tai** sub-basin.

* Note: The rain gauge at Na Sai was in problem due to leaves into the bucket.

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Observation Result



- Accumulated rainfall in the period of May 5 – May 13, 2012 was 250mm in total.
- Accumulated rainfall in the period of May 5 – May 6, which caused flood at **Muang Sam Pee**, was 142mm in total.

Flood on May 6, 2012

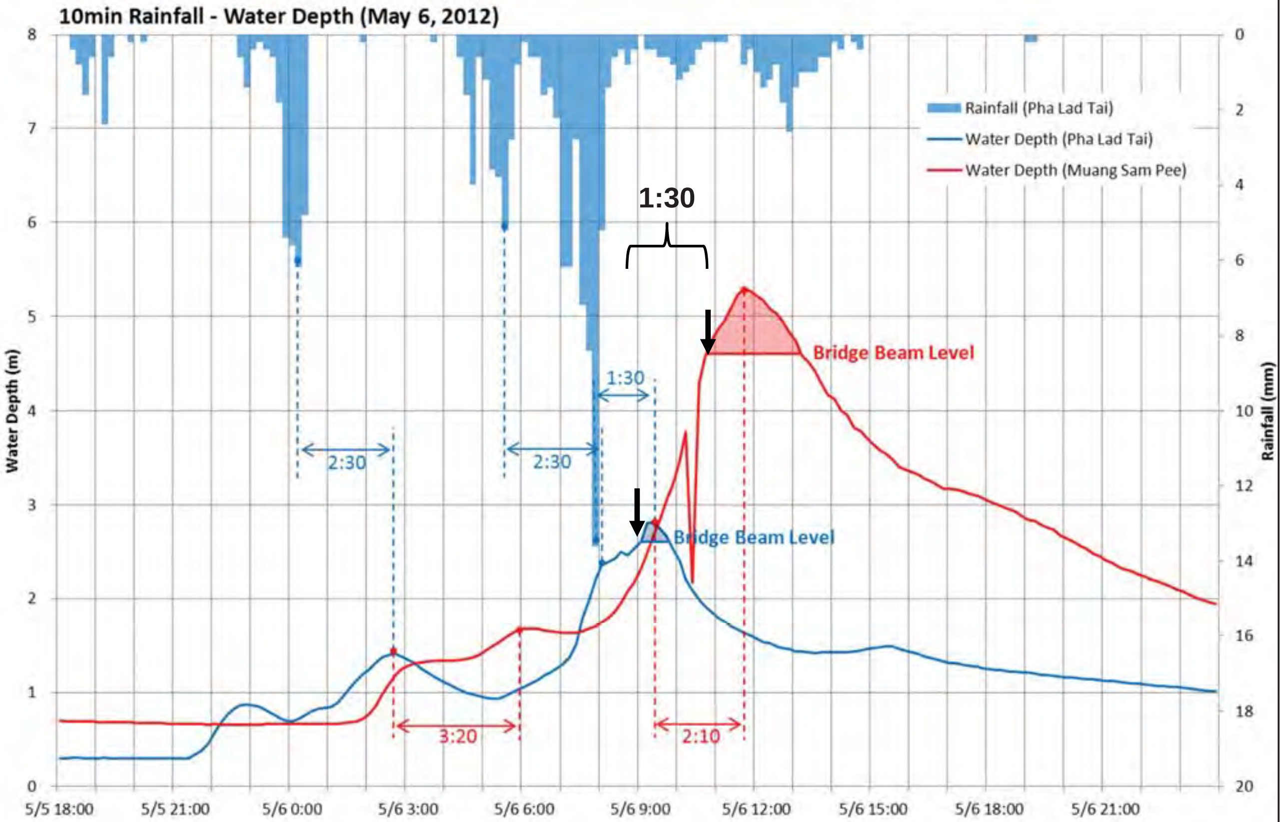
Flood at Muang Sam Pee Village

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Flood on May 6, 2012

Flood at Muang Sam Pee Village

Warning Criteria by Water Level Upstream



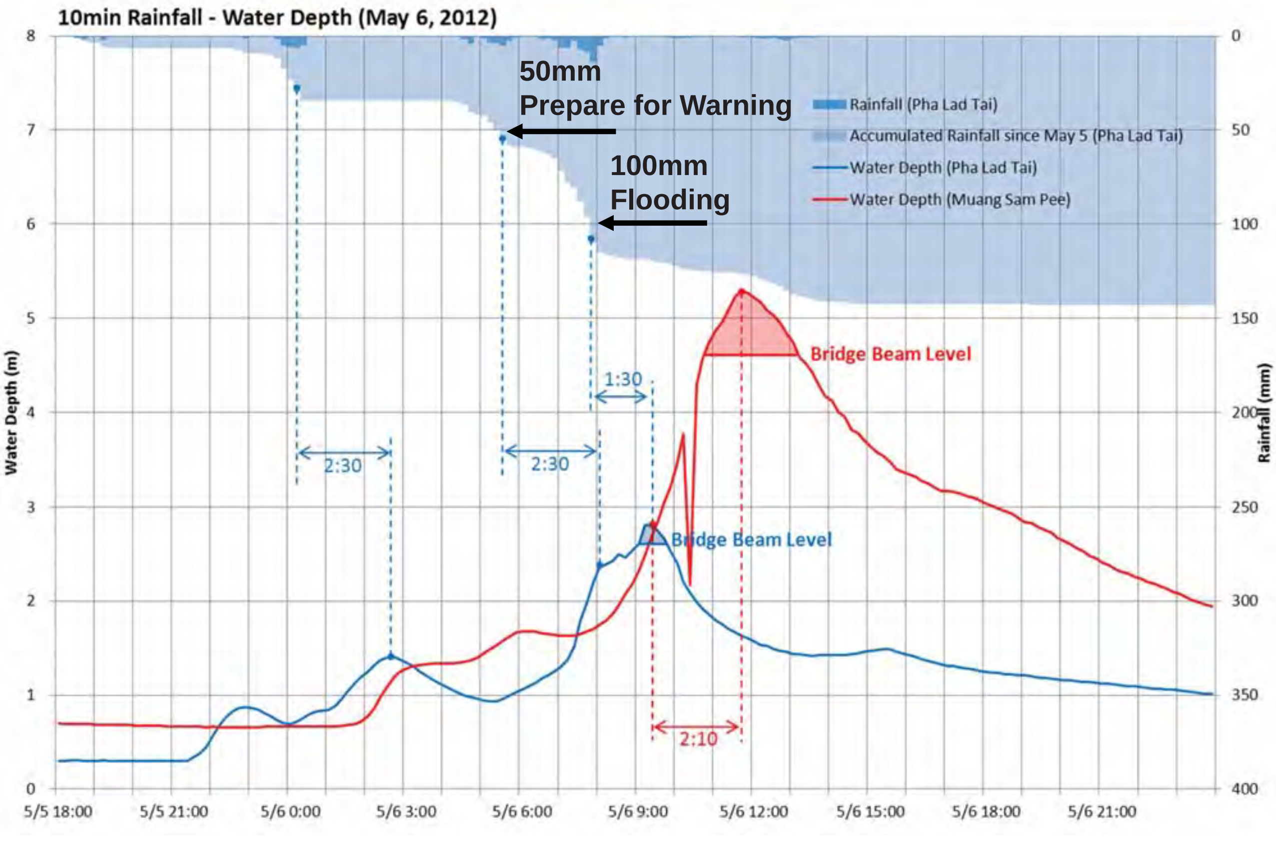
Warning Criteria by Water Level Upstream

- Lag time between rainfall peak and water level peak at **Pha Lad Tai** is about **1:30 ~ 2:30** hours.
- Flood arrival time from **Pha Lad Tai** to **Muang Sam Pee** is about **3:20** hours in normal condition, whereas **2:10** hours in flooding time, because of the high flow velocity in the flooding time.
- About **1:30** hours after the water level reached to the **Pha Lad Tai** bridge beam, the water level reached to the **Muang Sam Pee** bridge beam.

- Therefore, residents at **Muang Sam Pee** can be warned for evacuation at least **1:30** before flooding by checking the water level at **Pha Lad Tai**.

Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Warning Criteria by Accumulated Rainfall



Project on Capacity Development in Disaster Management in Thailand – Phase 2 –

Warning Criteria by Accumulated Rainfall

- Accumulated rainfall less than **30mm** may not cause any flood at the downstream .
- Decision maker/Mr. Warning are required to prepare for warning in case the accumulated rainfall reaches to **50mm** from beginning of rainfall. If rainfall continues, the water level at **Pha Lad Tai** may reach to the critical level.
- Accumulated rainfall more than **100mm** probably generate overflow at **Pha Lad Tai** bridge, which leads flooding at **Muan Sam Pee** as well. So the decision maker must warn to residents before **100mm** (**80mm** or so)
- In case of continuous heavy rainfall after **100mm**, the decision maker must to consider evacuation directive to the residents.

Note: The criteria is a tentative assumed from relation between rainfall and water level focused on Pha Lad Tai sub-basin. Further observation and analysis is required.

END

Project on Capacity Development
in Disaster Management in Thailand – Phase 2 –

ANNEX 9

Manuals for Development and Operation of GIS Database for Monitoring DPM Action Plan, CBDRM and Disaster Education

The Project on Capacity Development
in Disaster Management in Thailand
(Phase-2)

Manuals for Development and Operation of GIS Database for Monitoring DPM Action Plan, CBDRM and Disaster Education

November 2013

0. Installation of Quantum GIS
- 0.1 Data Copy
- 0.2 Installation (QGIS)
- 0.3 Installation (plugins and settings)

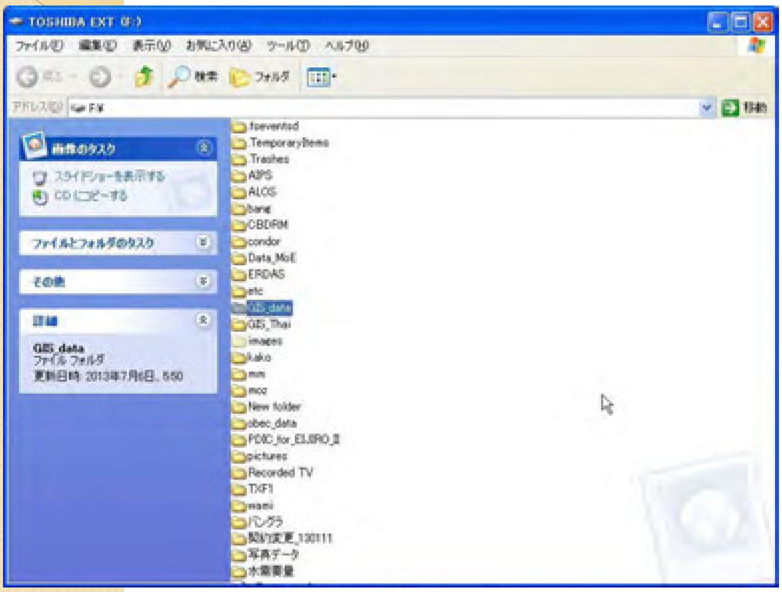
1. Constitution of GIS Data and How to Use GIS Software
- 1.1 GIS data and Outline of the Inventory Map
- 1.2 Examples of GIS Software
- 1.3 How to Use GIS Software
  - 1.3.1 Quantum GIS
    - Kinds of GIS data
    - Explanation of sub windows and fields
    - Locale setting
    - Add layers
    - Remove layers
    - Add web map layer
    - CRS (Coordinate Reference System)
    - Open Street Map
    - Attribute table
    - Editing
    - Properties of layers
      - "General" setting tab
      - "Labels" tab
      - "Join" tab
      - "Style" tab
      - "Diagram" tab
      - "Overlay" tab
    - Print composer
      - Legend
      - Map
      - Text box

2. Making Inventory Maps (Risk Community)
- 2.1 Making Risk Community Map
  - 2.1.1 Making Risk Community Shape File
  - 2.1.2 Import Administrative Data
  - 2.1.3 Import Elevation Data
  - 2.1.4 Making Hill Shade Data
  - 2.1.5 Import Online Maps
  - 2.1.6 Import Open Street Map
  - 2.1.7 Import Other Data

3. Making Inventory Maps (Disaster Education)
- 3.1 Making Model/Pilot Schools and ESAO Map
  - 3.1.1 Import PESAO and SESAO File
  - 3.1.2 Import PESAO and SESAO Data from Excel File
  - 3.1.3 Join Attribute Table
- 3.2 Making PESAO Map
  - 3.2.1 Import Data

0. Installation of Quantum GIS

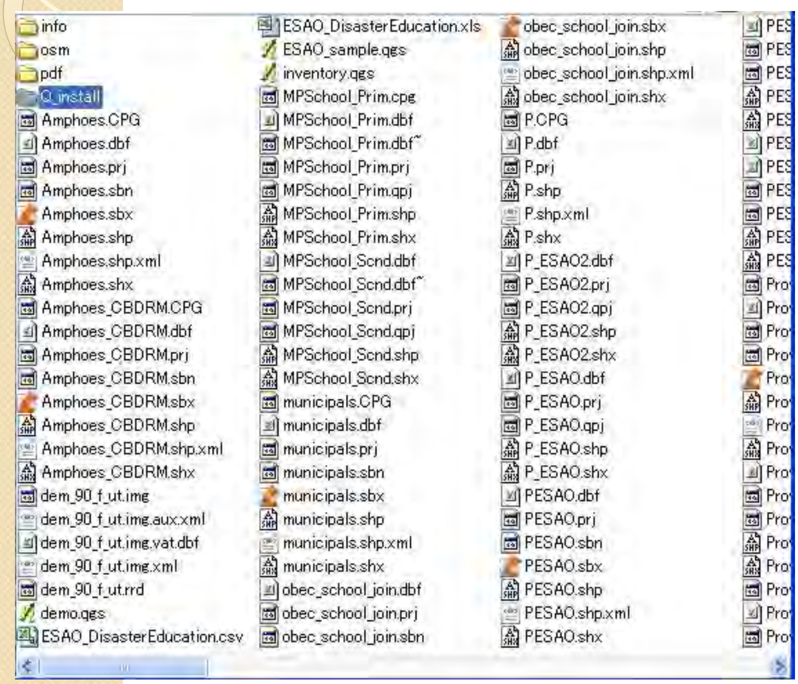
0.1 Data copy



Copy "GIS_data" folder to your PC.

0. Installation of Quantum GIS

0.1 Data copy

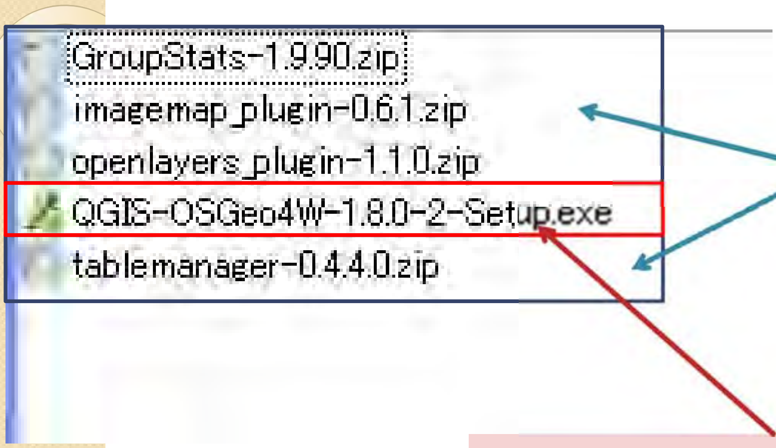


"GIS_data" folder contains GIS data (shape files and so on) and QGIS installer.

Open "Q_install" folder.

0. Installation of Quantum GIS

0.2 Installation (QGIS)



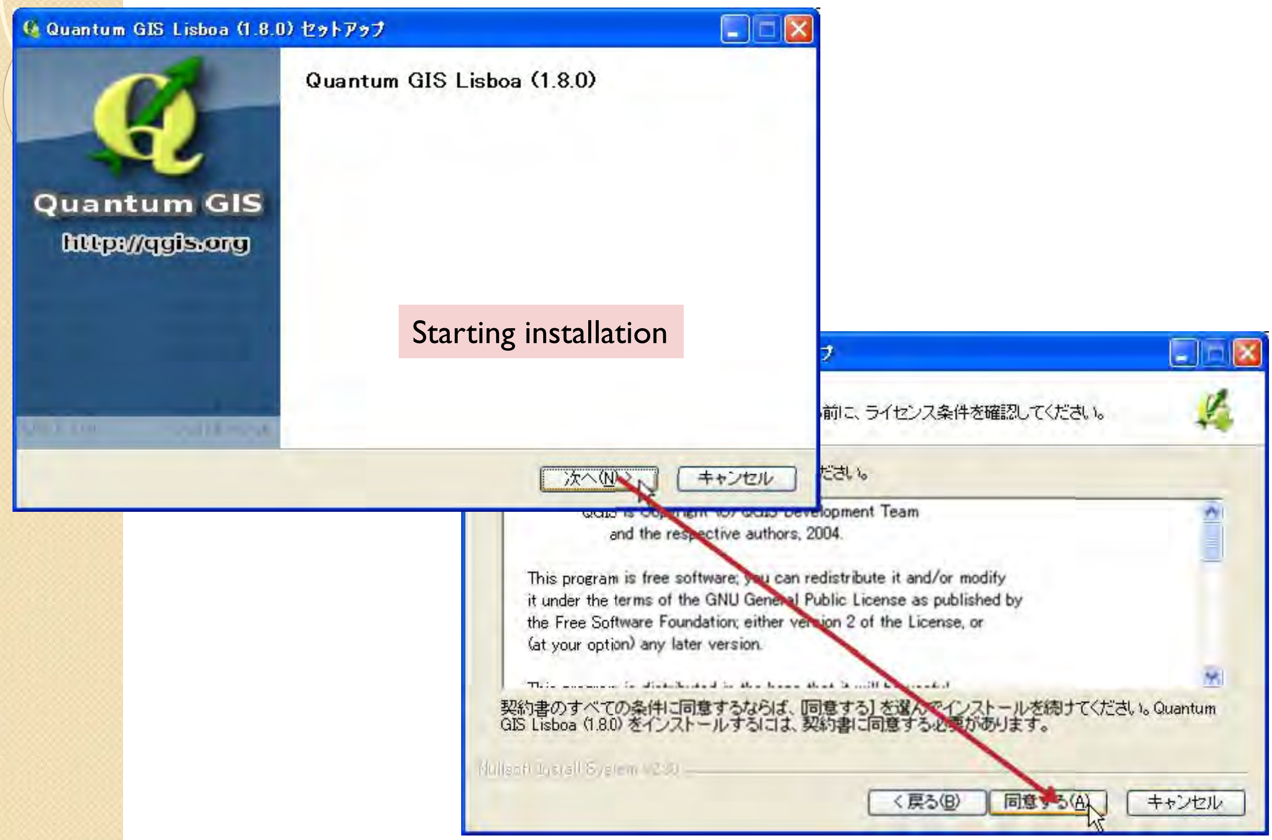
Plugin files

This file is QGIS installer.
Double click QGIS installer to start set up.

If you use windows 7 or later. In some case, it is necessary to install by administrator. Right click the QGIS installer and select "run as administrator".

0. Installation of Quantum GIS

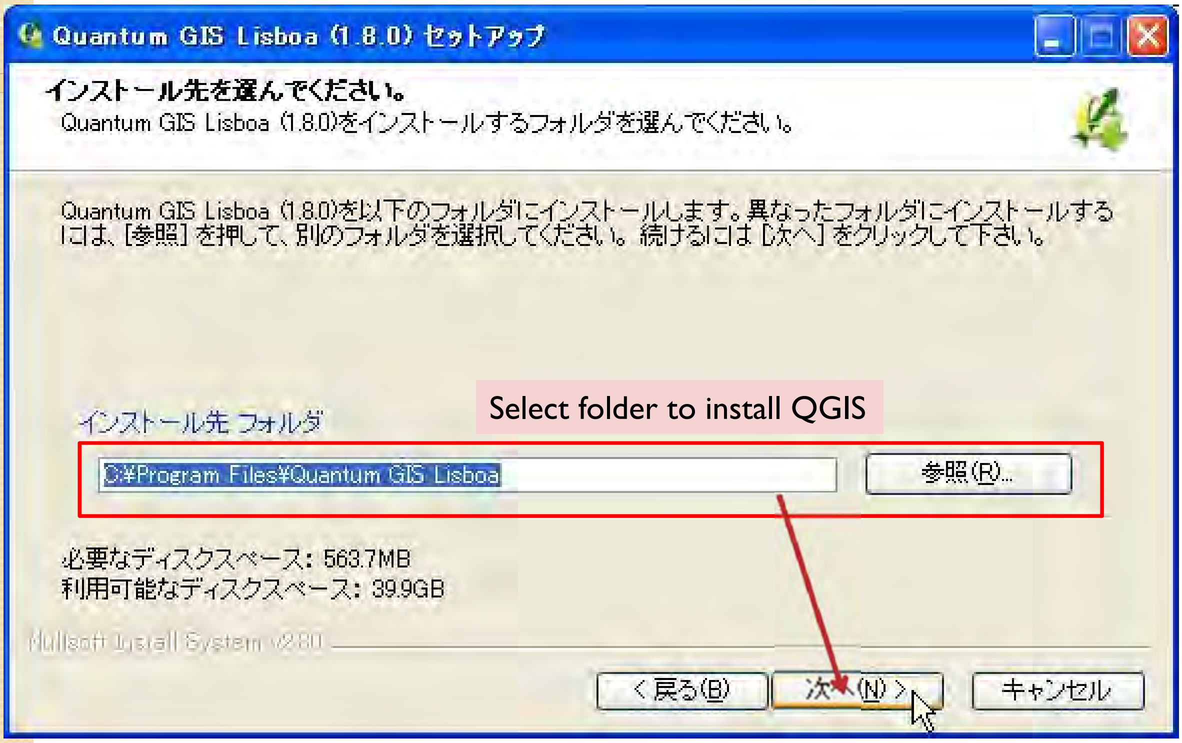
0.2 Installation (QGIS)



Starting installation

0. Installation of Quantum GIS

0.2 Installation (QGIS)



0. Installation of Quantum GIS

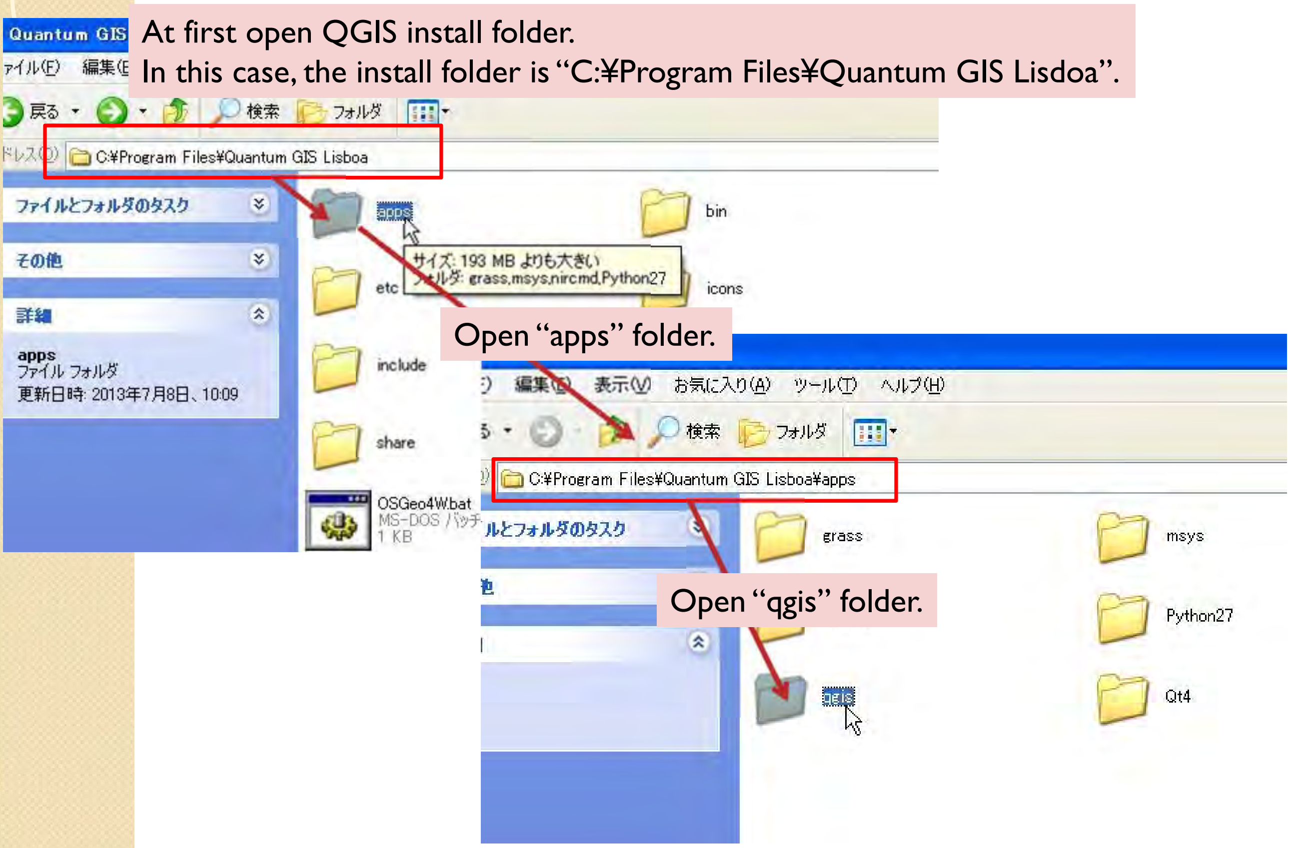
0.2 Installation (QGIS)

0. Installation of Quantum GIS

0.2 Installation (QGIS)

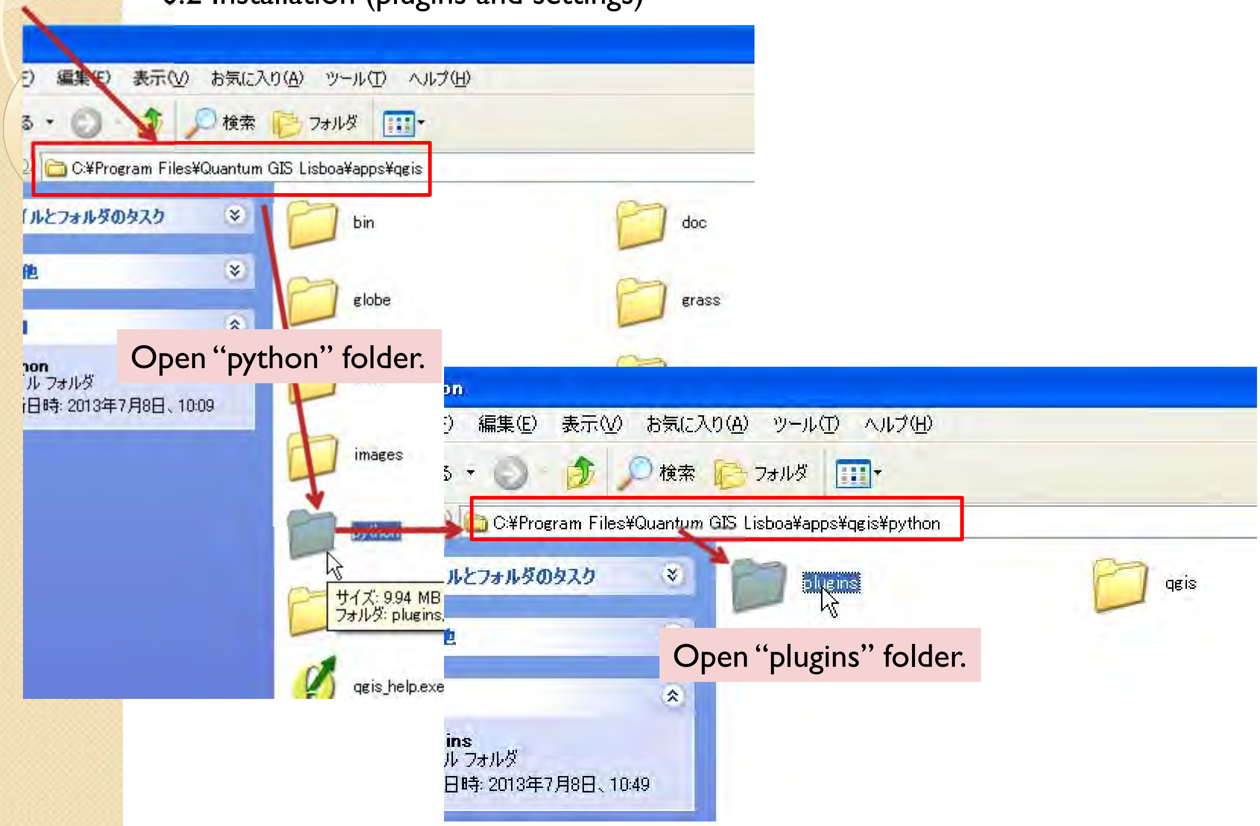
0. Installation of Quantum GIS

0.2 Installation (plugins and settings)



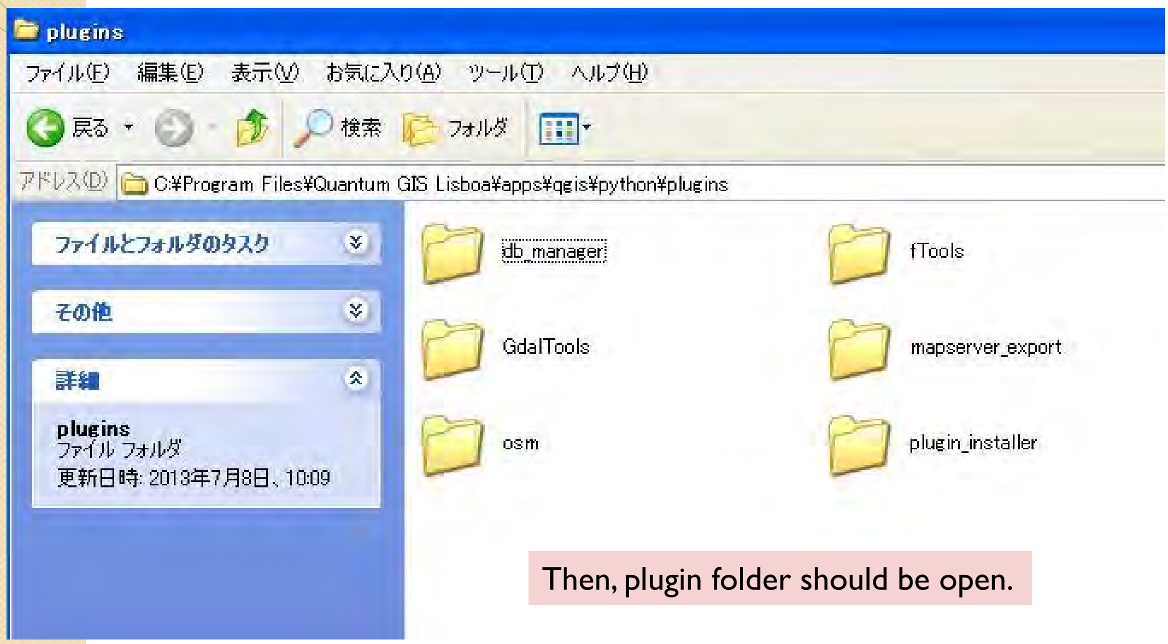
0. Installation of Quantum GIS

0.2 Installation (plugins and settings)



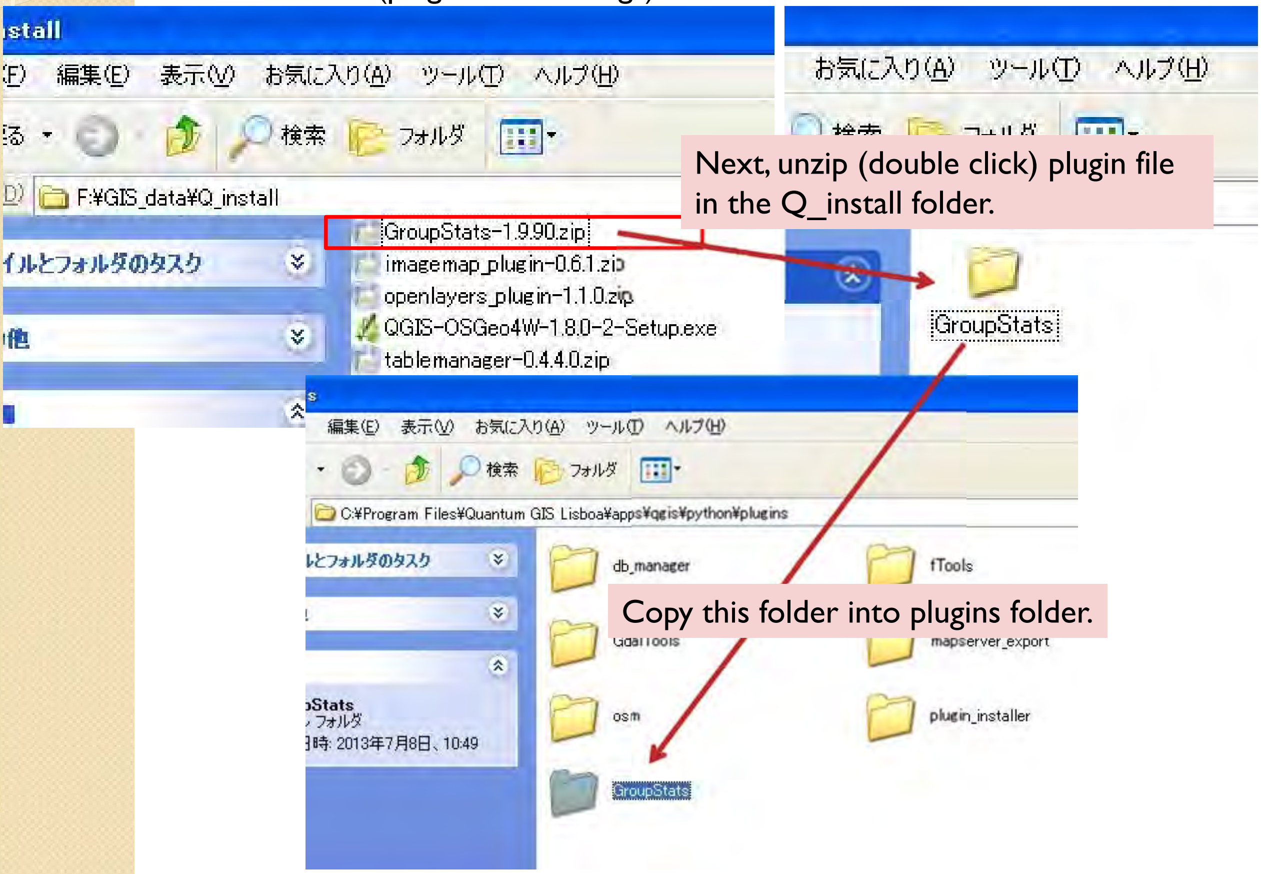
0. Installation of Quantum GIS

0.2 Installation (plugins and settings)



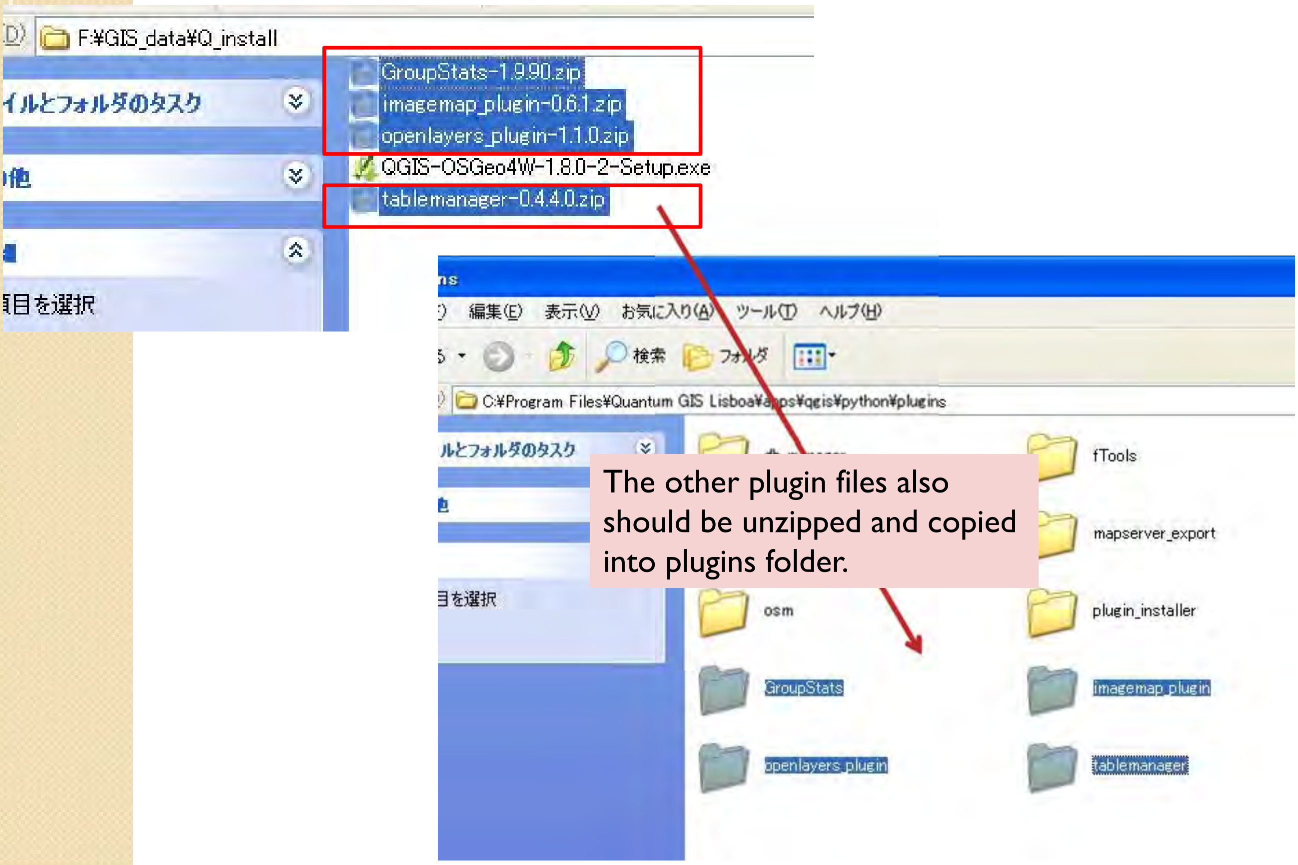
0. Installation of Quantum GIS

0.3 Installation (plugins and settings)



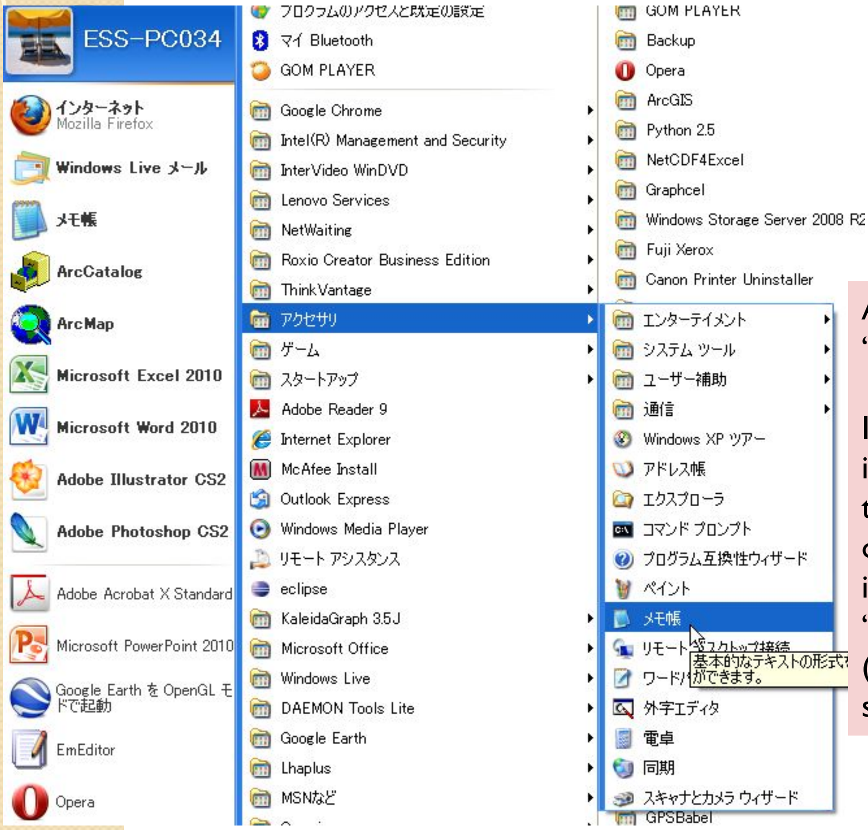
0. Installation of Quantum GIS

0.3 Installation (plugins and settings)



0. Installation of Quantum GIS

0.3 Installation (plugins and settings)

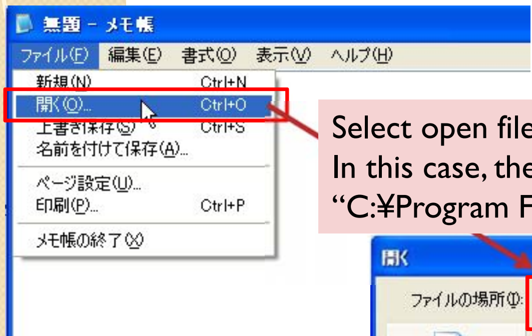


At the last of the setting, open "notepad".

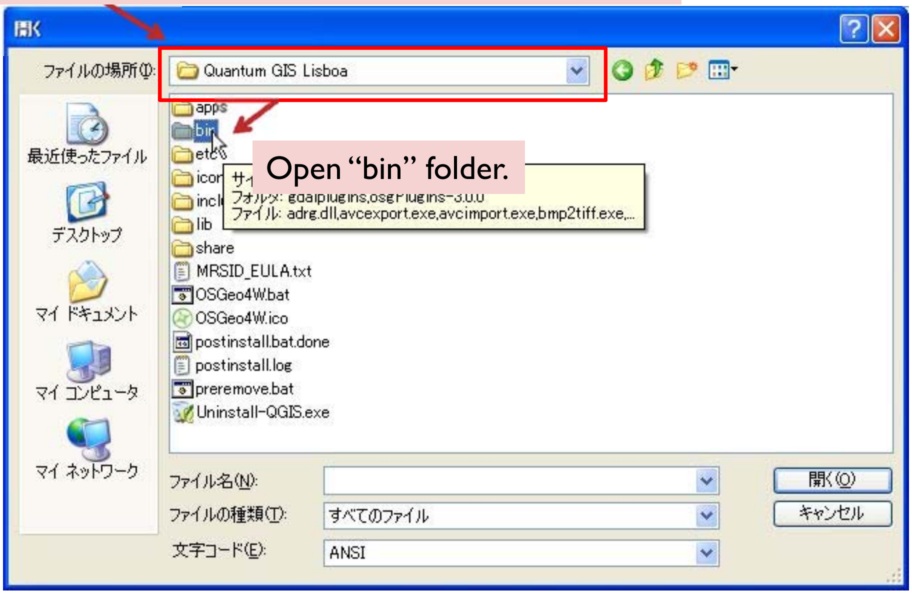
If you use windows 7 or later, in some case (ex. you install the program by "administrator" or into "program files" folder), it is necessary to open the "notepad" as administrator (right click "notepad" and select "run as administrator").

0. Installation of Quantum GIS

0.3 Installation (plugins and settings)

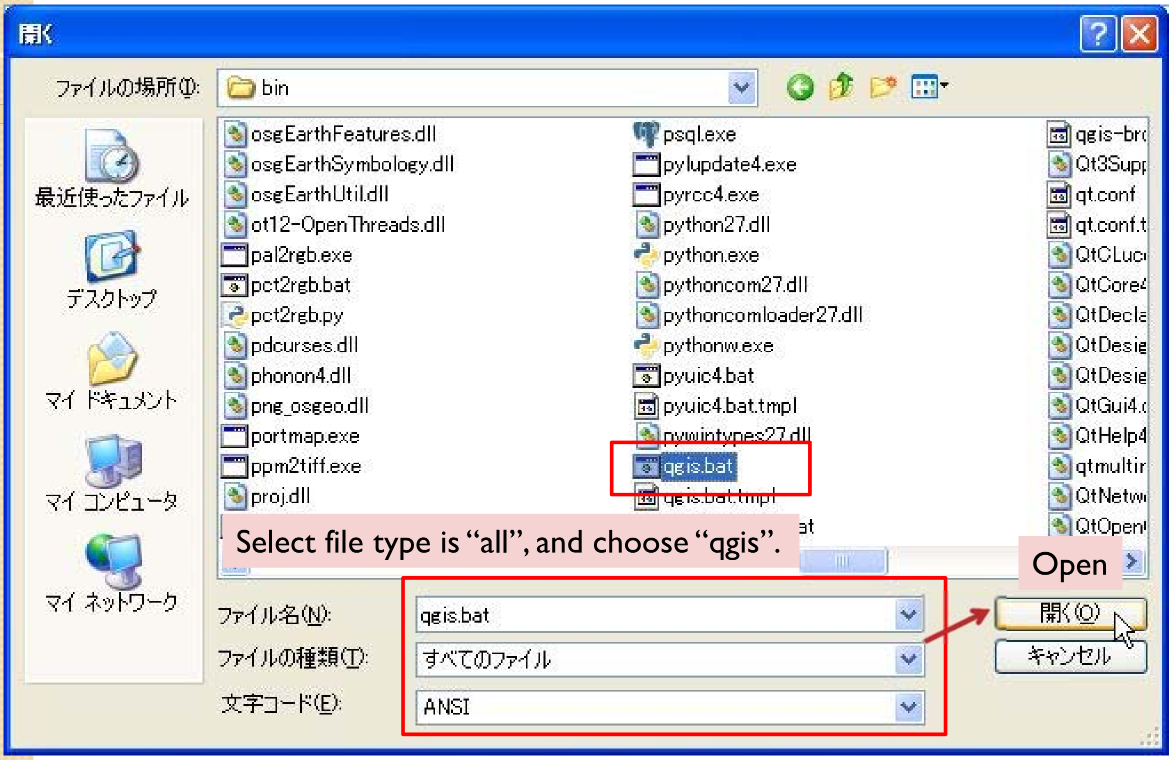


Select open file. Open QGIS install folder.
In this case, the install folder is
"C:¥Program Files¥Quantum GIS Lisdoa".



Open "bin" folder.

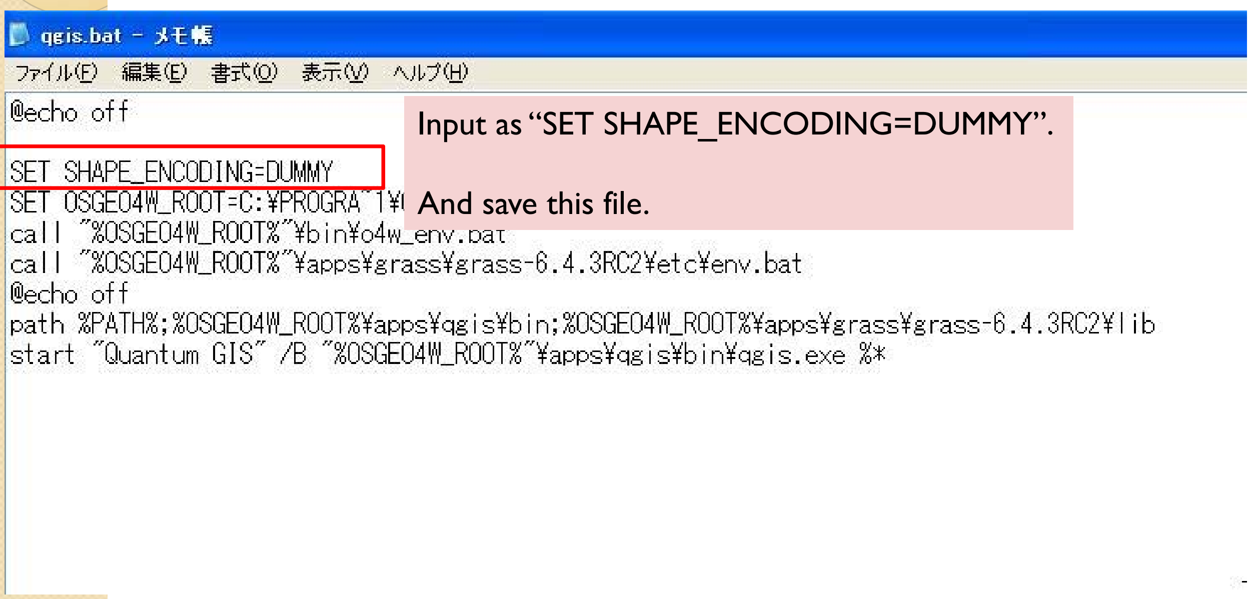
0.3 Installation (plugins and settings)



0. Installation of Quantum GIS

0.3 Installation (plugins and settings)

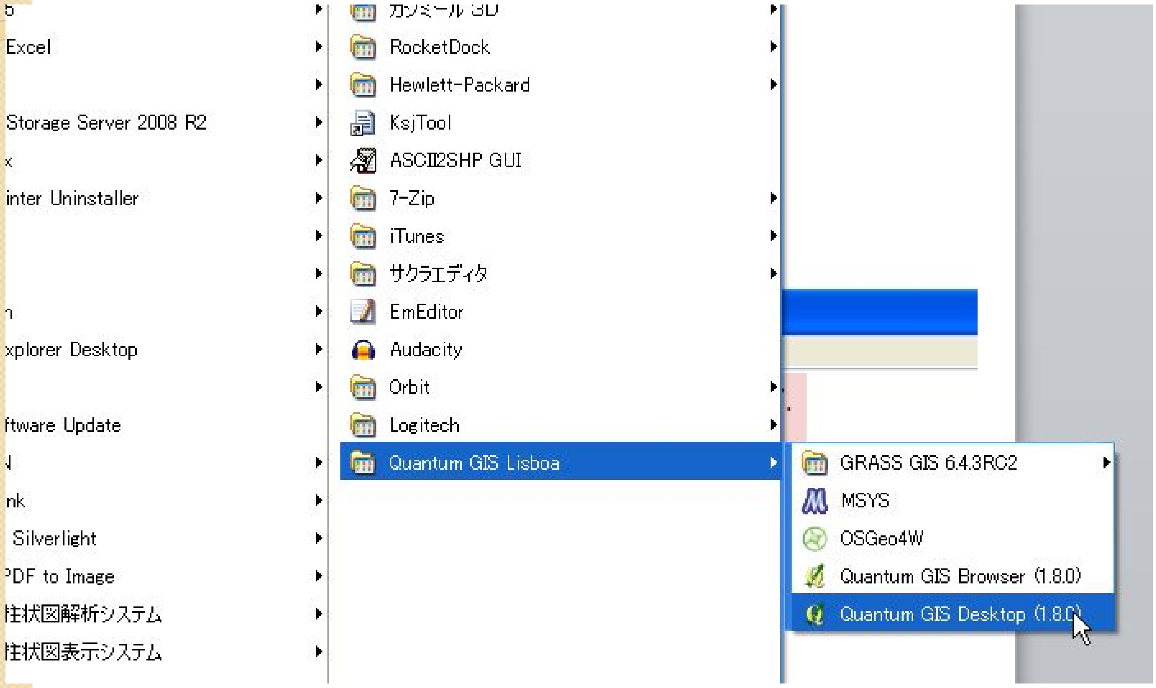
Then, the file is open.



0. Installation of Quantum GIS

0.3 Installation (plugins and settings)

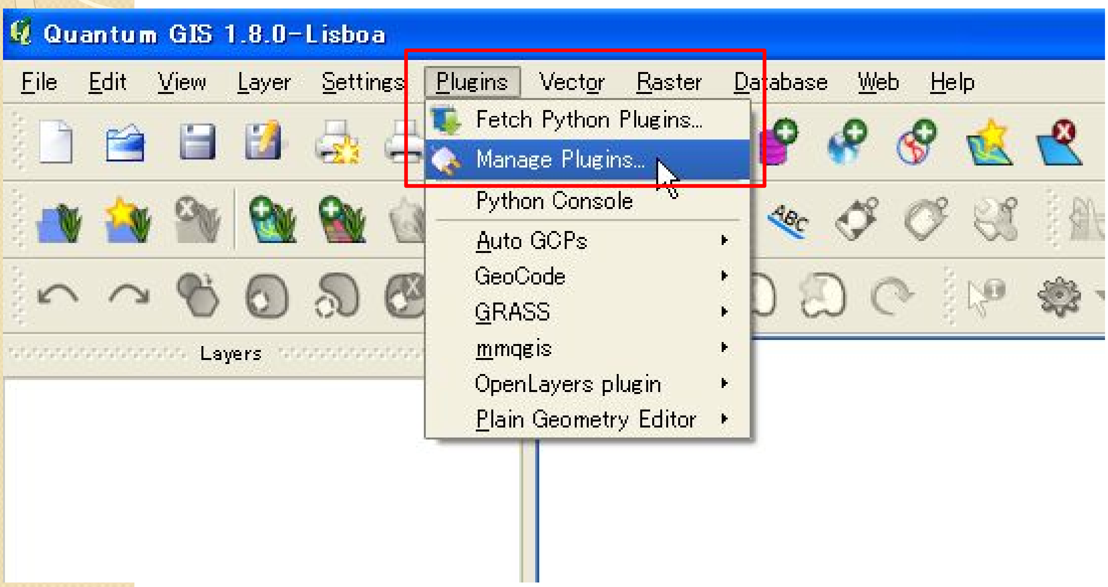
Now, you can start "Quantum GIS Desktop".



0. Installation of Quantum GIS

0.3 Installation (plugins and settings)

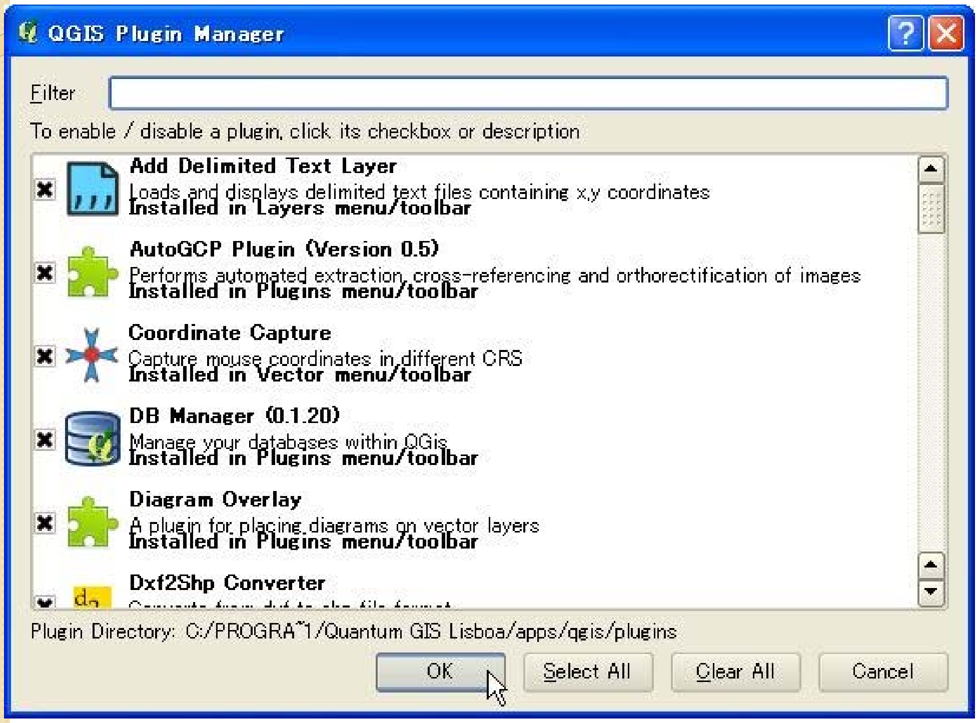
Click "Plugins" – "Manage Plugins".



0. Installation of Quantum GIS

0.3 Installation (plugins and settings)

Select all and click OK to enable plugins.



0. Installation of Quantum GIS

0.3 Installation (plugins and settings)

Right click and check "Browser" to show file browser.

Then, it is ready to use QGIS.

Official QGIS HP is below. You may find more information and plugins.

http://www.qgis.org/