

Capacity Building Programme on
Flood Risk Assessment and Management
30 October - 8 November 2017

Session 1: Flood and drought hazards, their formation and predictability with examples

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Water-related Natural Disasters

1. Floods: Flash Floods, Gradually Rising Floods and Stagnant Ponding Floods

2. Droughts: Meteorological Droughts, Hydrological Droughts and Agricultural Droughts

3. Water Pollution: Waste Water, Salinity Intrusion, etc.

Floods

Simple Definition

Floods is the inundation of land by large amounts of water. Floods nearly always involve significant property loss, such as, loss of life.

Causes of flooding

- Excessive rainfall
- Rivers and waterways to overrun their normal channels and spread out across the adjacent countryside
- Ocean being driven inland across low-lying areas (High tide)
- Usually by storm-force winds, such as those that occur in hurricanes

Floods (1)

- **Flood impact is one of the most significant disasters in the world**
- **More than half of global flood damages occur in Asia**
- **Flood disaster management involves both structural and non-structural measures**
- **Flood disaster management should not be limited to reactive response but also proactive response to flood situation**
- **Preparedness to future or-in coming flood disaster is required to reduce flood impacts**

Floods (2)

- **Floods cause losses of life and damage properties**
- **Population increase results in more urbanization, more impervious area and less infiltration and greater flood peak and runoff**
- **Problems become more critical due to more severe and frequent flooding, socio-economic damage, population affected & public outcry, limited allocation of funds.**

Floods (3)

TYPES OF FLOODING

1. Flash floods such as in steep slope areas
2. Gradually rising floods such as in mild slope areas
3. Stagnant pondage floods in low lying or depression areas or coastal areas, etc.

CAUSES OF FLOODING

1. Natural Factors

Heavy Rainfall, High Flood, High Tides, Sediment Deposit, etc.

2. Human factors:

road construction and blocking of drainage ways, over pumping of ground water causing land depression, improper land use, deforestation in headwater regions, garbage dumping, etc.

Droughts

- When an area receives too little rain over a protracted period, a **drought** can result
- **Drought** is by far the most serious hazard to world agriculture, and has a massive effect on national and world economies, as well as on the ability of particular society to feed and clothe it self.
- **Drought** has such a severe impact on the landscape that plant and animal ecosystems can be changed irrevocably

Different types of drought

1. **Seasonal drought**; This occurs in those areas of the world that experience a pronounced wet season/dry season climate such as Australia, central Africa and the India-Pakistan region.
2. **Contingent drought**; (meaning uncertain, or happening by chance, without obvious cause), which is possibly the most **damaging** form because agricultural producers are frequently unprepared, and the consequences are therefore usually considerable.

Specific Types and Causes of Droughts

Drought types can be classified into 5 types. They can occur separately or simultaneously

- 1. Meteorological Drought** – defined by degree of dryness compared to average amount usually over the last 30 years as well as the duration of the dry periods
- 2. Hydrological Drought** – inadequacy of rainfall which leads to depletion of water resources (reservoirs, lakes, rivers, and ground water).
- 3. Agricultural Drought** – deficiency in soil moisture, especially in agricultural lands, which results to low levels of water available for plant.

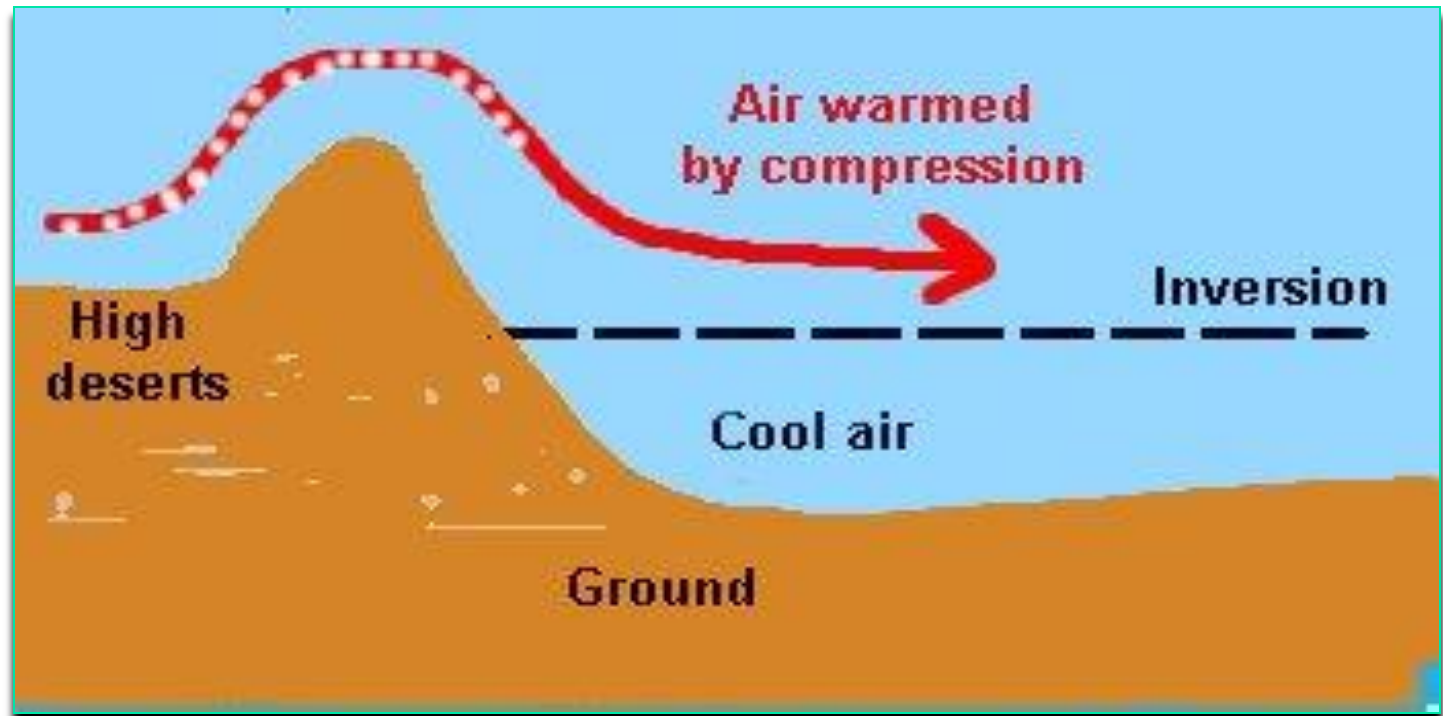
Specific Types and Causes of Droughts (Cont.)

- 4. Socio-economic Drought** – demand for an economic good exceeds supply because of weather-related shortfall in water supply.
- 5. El Nino Phenomenon** - is a combination of meteorological and hydrological droughts which occurs every 2-7 yrs.

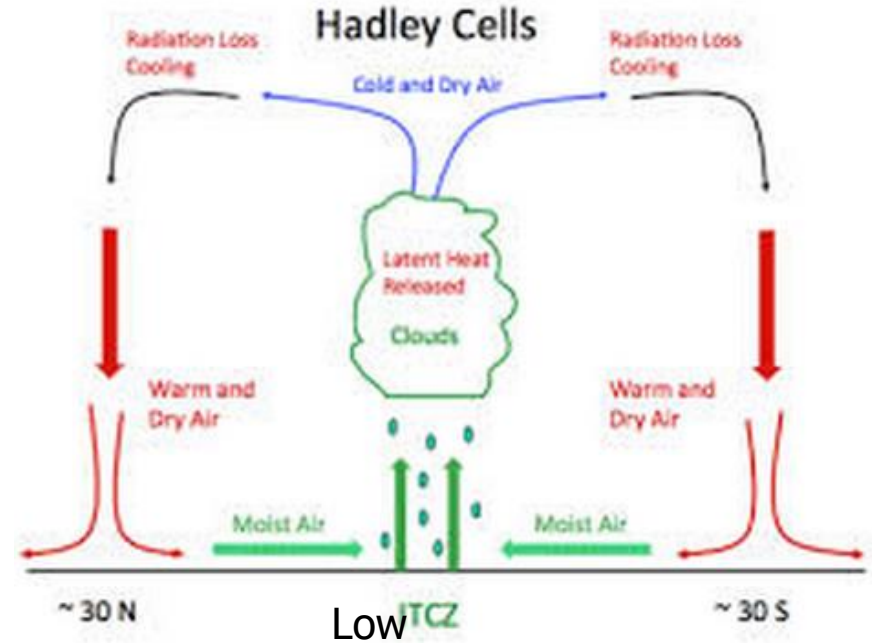
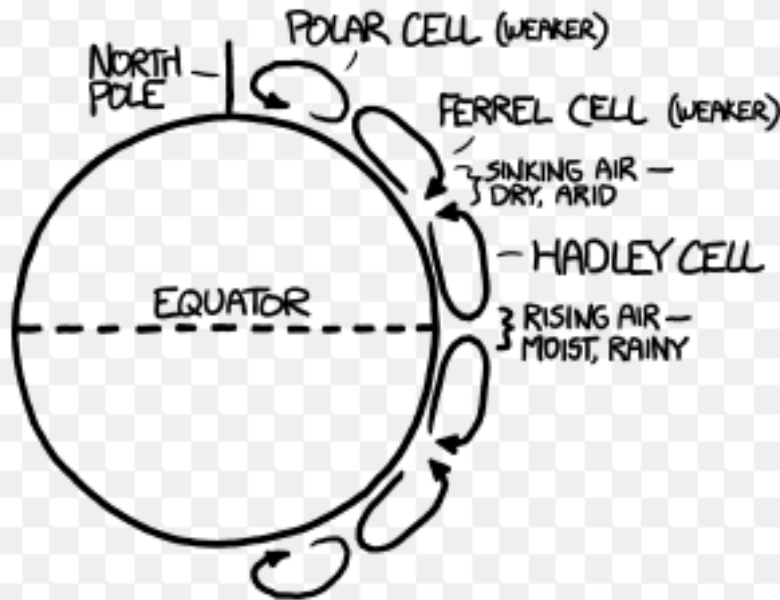
Causes of Droughts (1)

1. Subsidence – presence of warm, dry air in the middle troposphere

The **troposphere** is the lowest portion of Earth's atmosphere. It contains approximately 80% of the atmosphere's mass and 99% of its water vapor and aerosols.



Causes of Droughts (2)



2. High Pressure Cells

A circulatory movement of air that initially rises close to the Equator along the **Inter-Tropical Convergence Zone (ITCZ)**. Shedding or releasing its moisture there as convective rain, the air moves pole-wards at high altitude before being forced to descend at the tropics as a result of **jet stream** activity. Now hot and dry, this descending air is responsible for **high pressure** and **arid desert conditions** throughout much of the tropics. The entire circulatory system, comprising of low-pressure along the ITCZ and high pressure at the tropics, is known as the **Hadley Cell**.

Droughts Around the World



Causes of Droughts (3)

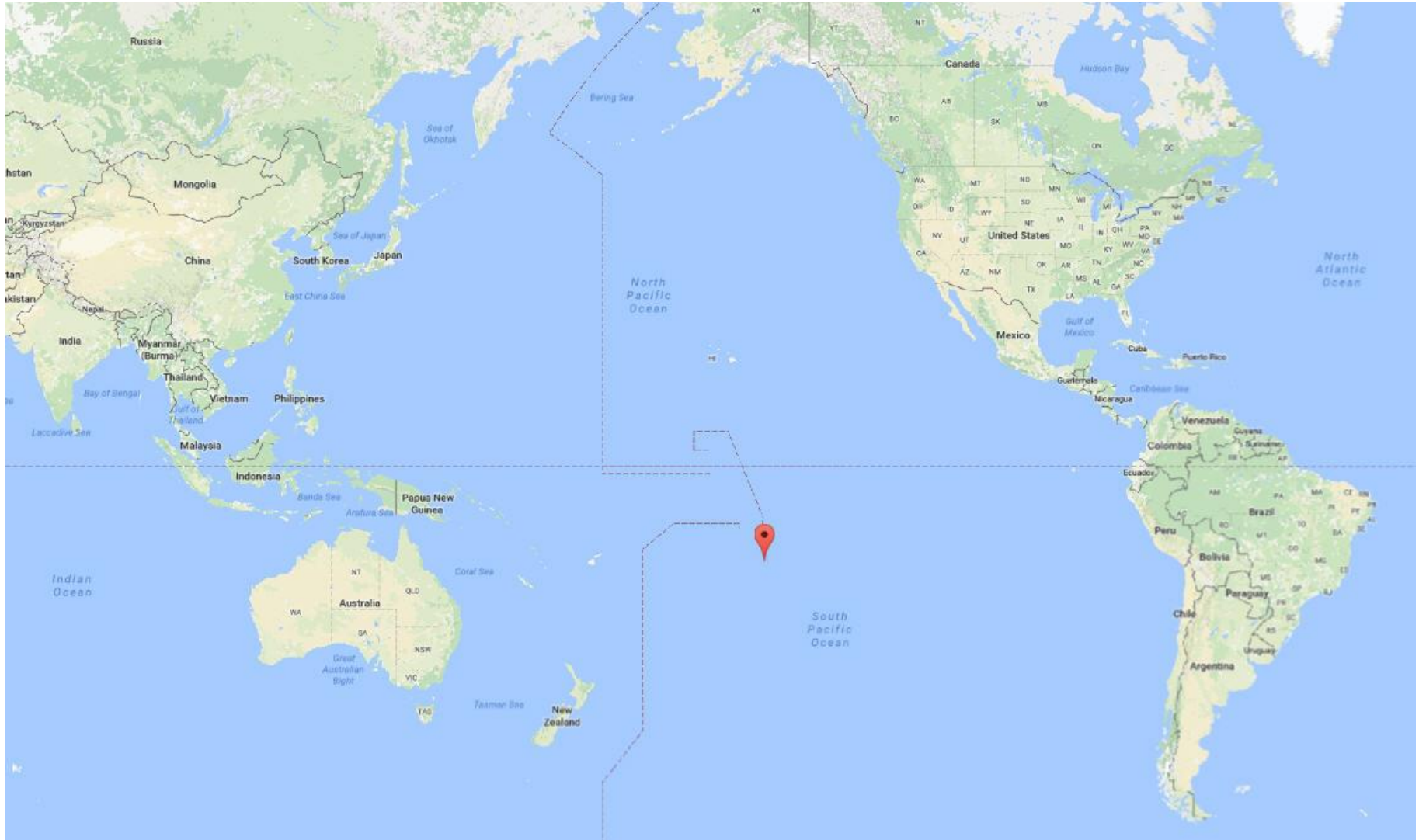
3. El Nino Effect (Walker, 1923)

Normally, lower air pressure over Darwin and higher pressure over Tahiti encourages a circulation of air from east to west, drawing warm sea surface water westward and bringing precipitation to Australia and the western Pacific.

- When the pressure difference weakens, the westward sea surface current becomes weaker (El Niño conditions), parts of the western Pacific, such as Australia experience severe drought.
- While across the Pacific ocean to South America, due to El Nino, heavy precipitation can bring flooding to the west coast of equatorial South America (Peru and Equador, etc).
- El Niño* reaches full strength toward the end of the year and occurred at irregular intervals of 2-7 years and usually lasted for 5 months or more

***The opposite to El Nino is called La Nina which brings heavy rainfall more than normal to Australia and West pacific**

Darwin Australia and Tahiti



Causes of Droughts (4)

4. Self-Generating Mechanisms

Local Effects : such as high evaporation, strong wind, soil moisture holding condition

5. External Factors

- Solar energy
- Anthropogenic Influences



Climate Change on Floods and Droughts

(International Water Agency)

- Billions of people will be at greater risk from storms, floods and droughts in the years ahead, partly as a result of global warming
- Most countries are not ready to deal adequately with the severe natural disasters
- Expected climatic change during the 21st century will further intensify the hydrological cycle:
 - Rainy seasons becoming shorter and more intense in some regions
 - Droughts in other areas will grow longer in duration, which could endanger species and crops and lead to drops in food production globally
- -Cost of extreme weather and flood catastrophes is severe and set to rise, hitting poorest nations the hardest
- -Number of major flood disasters has risen relentlessly. There were 6 in the 1950s; 7 in the 1960s; 8 in 1970s; 18 in the 1980s; and 26 in the 1990s
- -Droughts are becoming more severe and widespread. Up to 45% of reported deaths from natural disasters between 1992 and 2001 resulted from droughts and famines.

Example of a Case Study

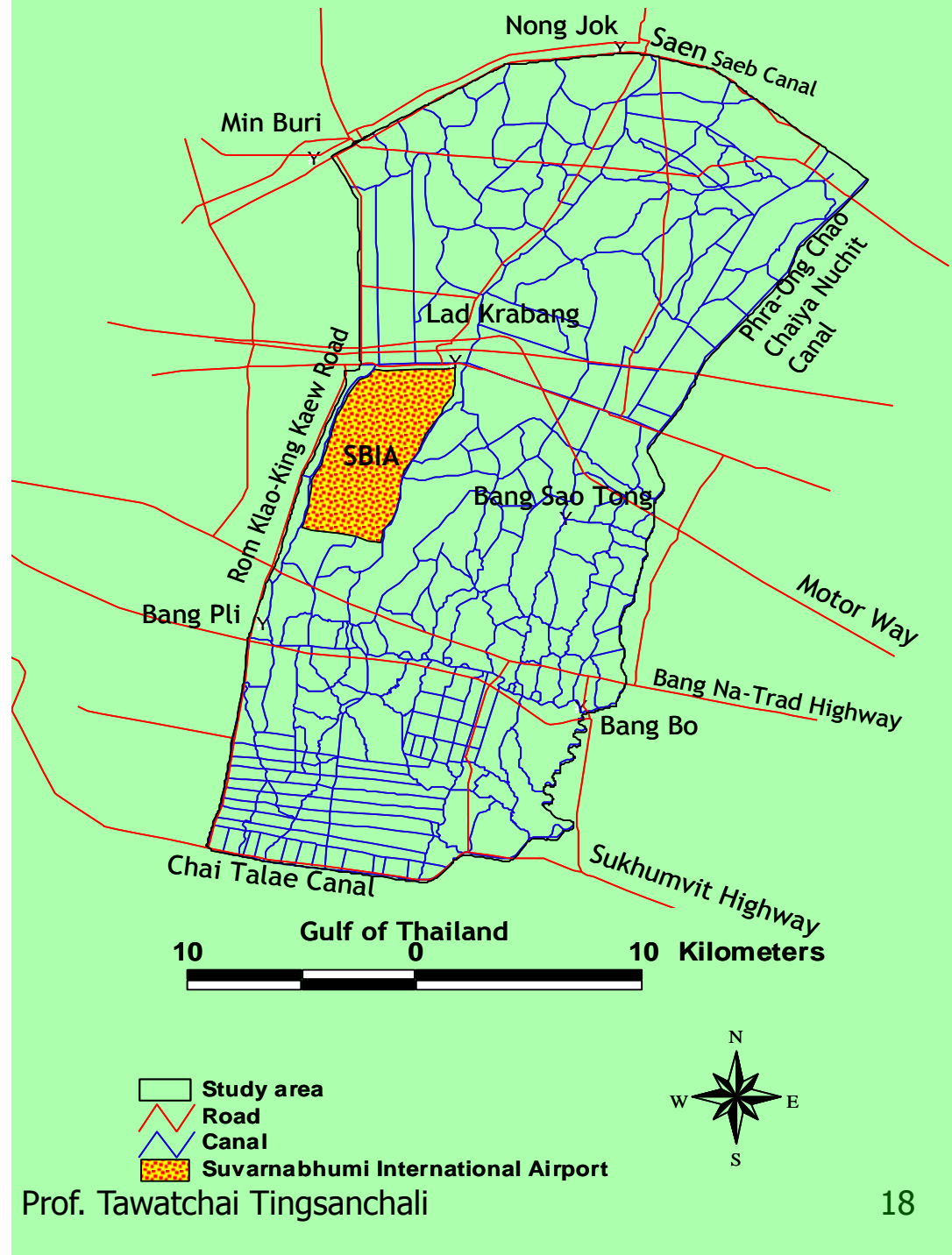
- Flood Hazard and Estimation
- A Case Study of Surrounding Area of Suvarnabhumi Bangkok International Airport (SBIA)

Study Area

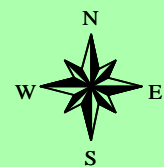
Location Map of the Second Bangkok International Airport



— HIGHWAY
+++++ RAILWAY
~ RIVER



Study area
— Road
~ Canal
 Suvarnabhumi International Airport



Problem statements

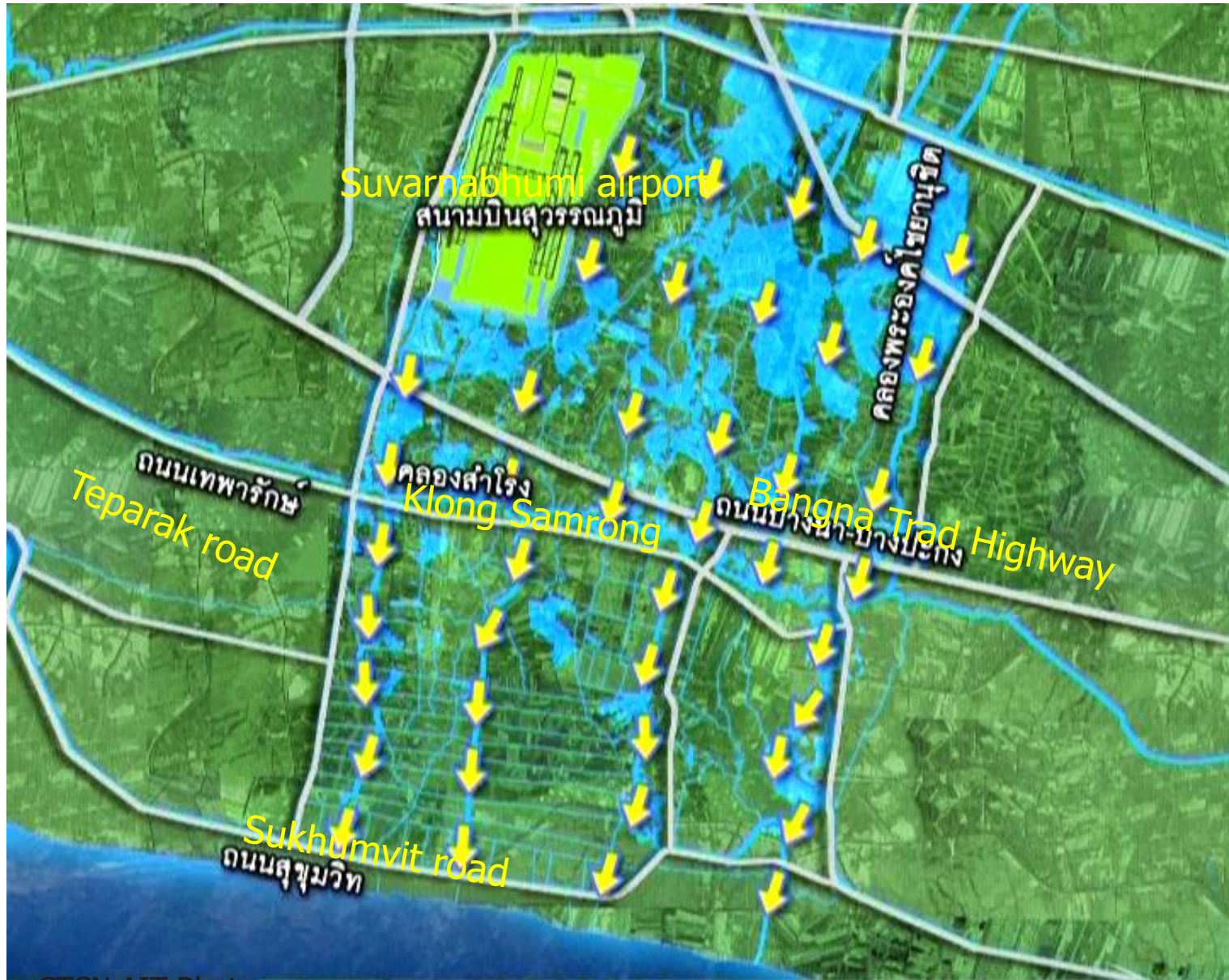
Causes of flooding in eastern part of the Lower Chao Phraya River Delta in the vicinity of (SBIA)

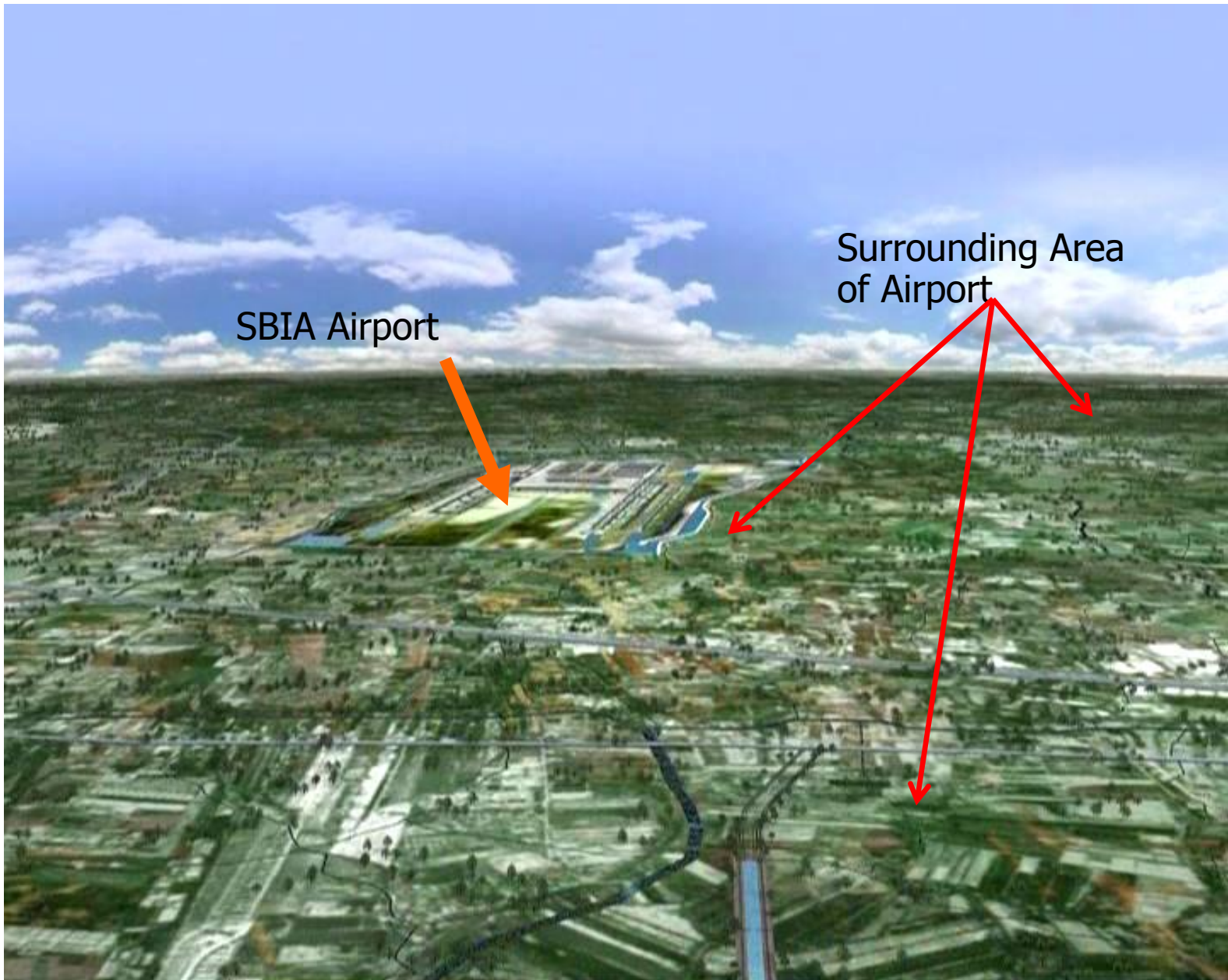
- ❑ Heavy local rainfall in the area
- ❑ Storm runoff from surrounding areas
- ❑ Limited flood drainage capacity

Problem statements

The limitation of flood drainage capacity is due to:

- ❑ General reduction of canal capacities due to deposition of sediment, vegetation and encroachment by human activities
- ❑ Insufficient drainage openings of the east-west highway
- ❑ Insufficient drainage canals in north-south
- ❑ Local land depression due to over abstraction of groundwater





SBIA Airport

Surrounding Area
of Airport

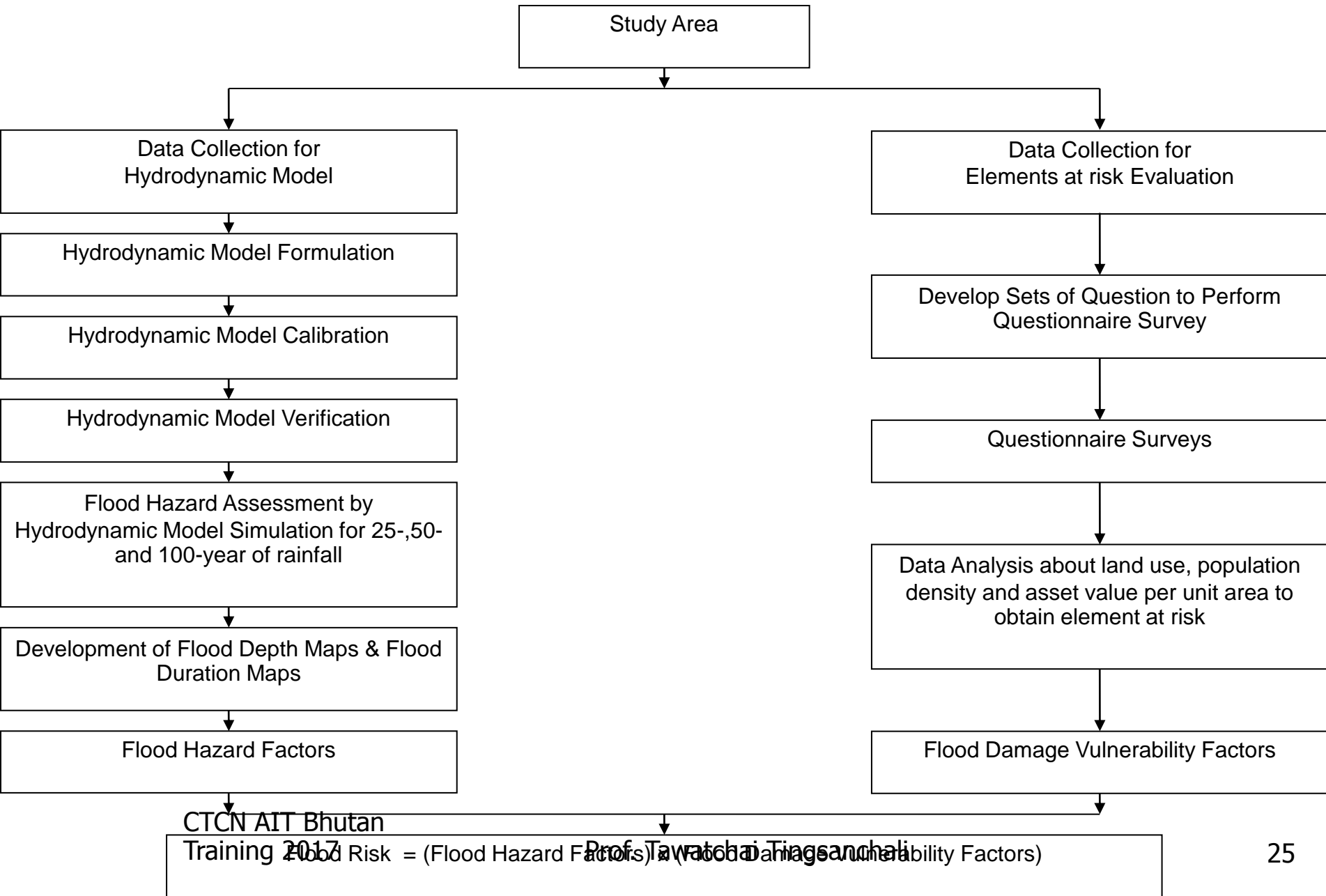
Scope of work

- **Development of flood hazard map for 25-year, 50-year and 100-year return period of rainfall**

Flood Hazard Assessment

- Because of large floodplain & flat topography, both flood depth & flood duration were considered in calculating the hazard

Flowchart of research Framework



Research methodology

- This study identifies flood hazard & risk areas for priority-based flood mitigation planning by using a hydrodynamic model in conjunction with a GIS
- A hydrodynamic model namely **MIKE FLOOD (DHI 2003)** was used to simulate the flood flow through the canal network and floodplain.

MIKE FLOOD Model

- **MIKE FLOOD**
 - **Hydrodynamic Integrated model with 1D and 2D flow**
- **1D Model**
 - **MIKE 11 : For Computing and Analyzing Canal/Channel Flow**
- **2D Model**
 - **MIKE 21 : For Computing and Analyzing Flood Inundation in Flood Plain Area**

Simulation of Flood Flow

Condition of Boundary Conditions :

- ➔ Direct rainfall in 1995 (about 50 years return period)
- ➔ The pumped discharge from the SBIA of $12 \text{ m}^3/\text{s}$.

Schematic diagram of canal network

Klong Prawate canal

Klong Bang Phli canal

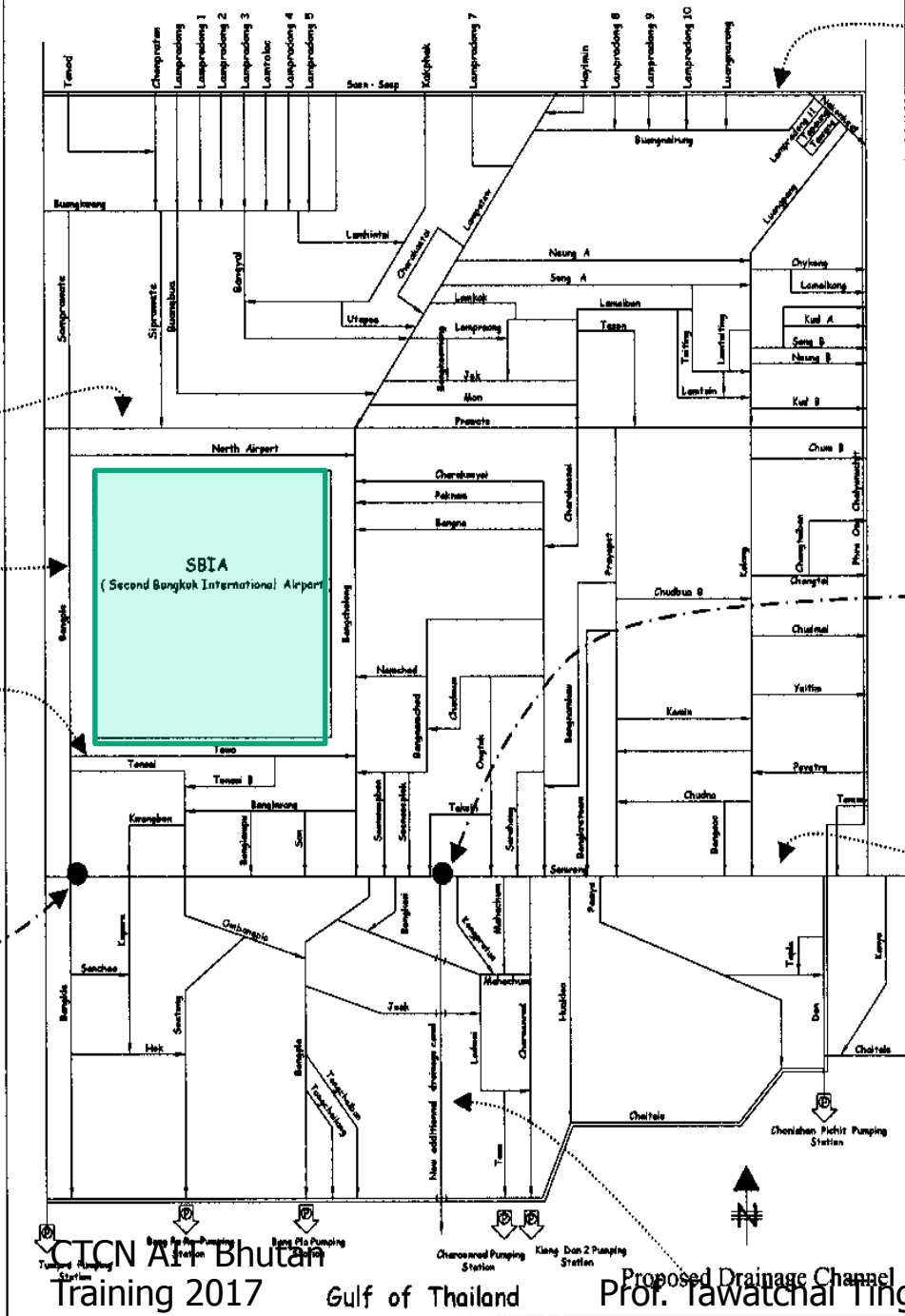
Klong Tawa canal

Klong Samrong canal Chainage 16200 (Bang Phli water gate)

Klong Saen Saeb canal

Klong Samrong canal Chainage 23000

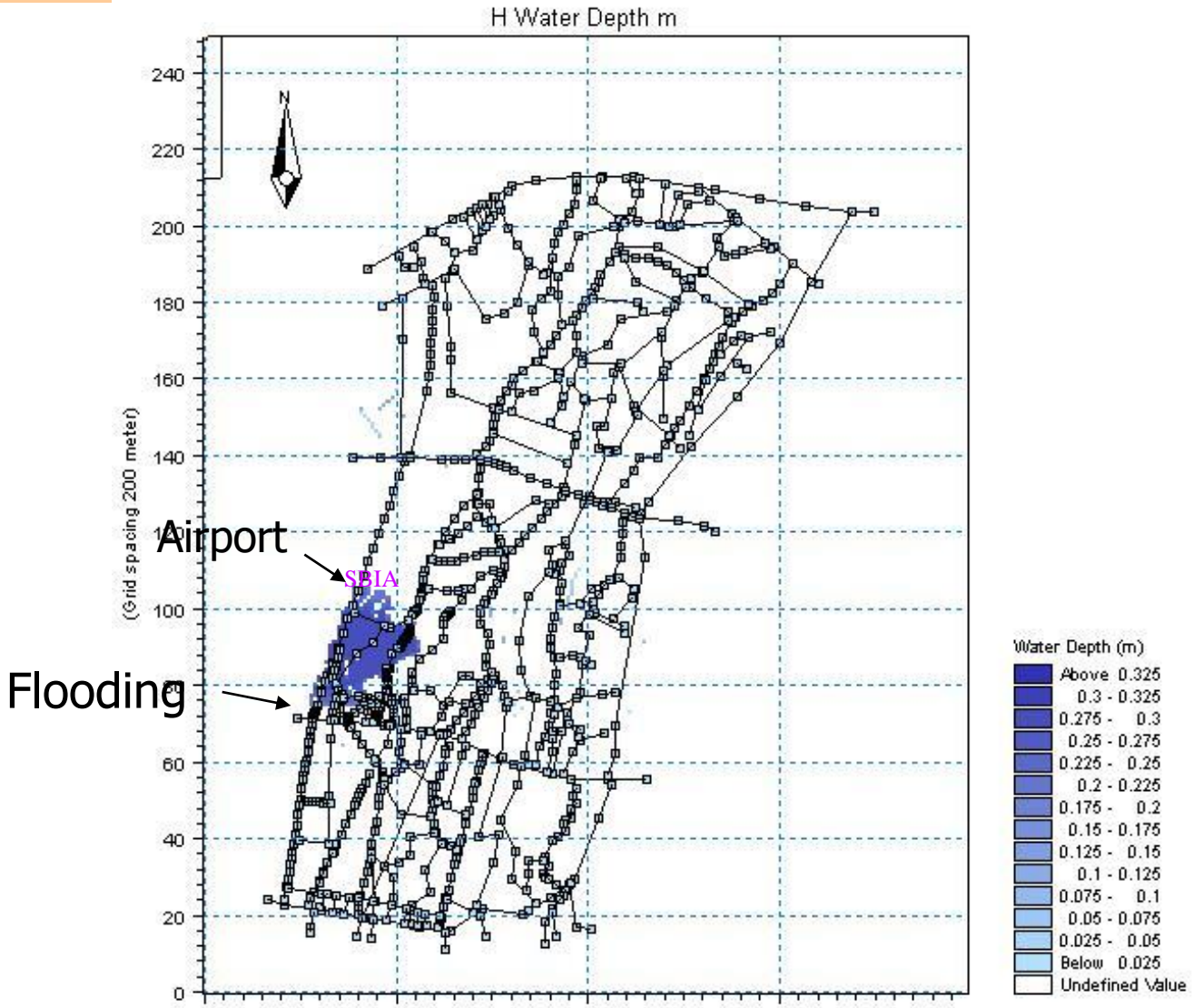
Klong Samrong canal



Research methodology (continued)

- **After model calibration and verification, it was used to simulate the flood flow in terms of flood depth for different return periods of rainfall**

Results of MIKE 21 model simulation in flood plain after 30 days



Selection of Return Period of Floods

- Extreme hazard events generally ranging from 20- to 400-year return periods are considered for planning and designing of water resource systems based on the purpose and type of structure
- flood-disaster mitigation projects are often designed for a 100-year return period (UNDRO, 1991).
- This study placed emphasis on a 100-year return period of rainfall, while we investigated 25- and 50-year return periods of rainfall for comparison in relation to the 100-year return period of rainfall.

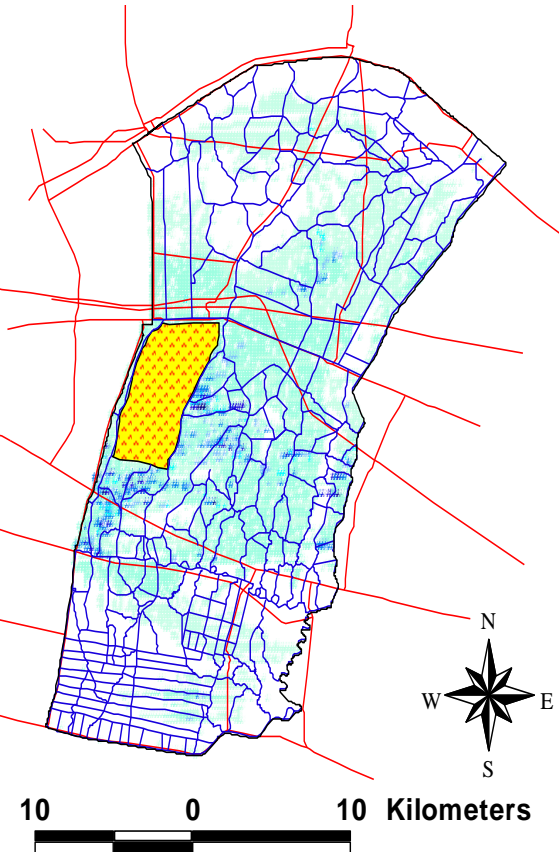
Hydrodynamic model

- MIKE Flood hydrodynamic model
- Input → design daily rainfall of 25, 50 and 100 years return period
- 1 September to 31 October
- Output → Hourly flood depth in each grid within study area
- Square grid size 200 m x 200 m

Flood Depth

- Maximum flood depths were considered as depth hazard
- Four depth hazard categories are based on marginal depths (0.45 m, 0.90 m and 1.20 m)

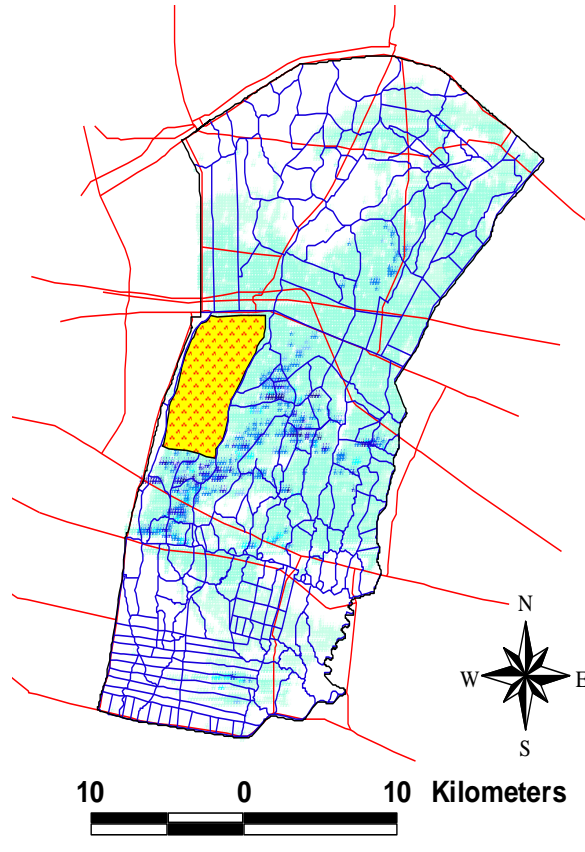
Peak flood depth



- Study area
- Canal
- Road
- Suvarnabhumi International Airport

25-year Peak flood depth (m)

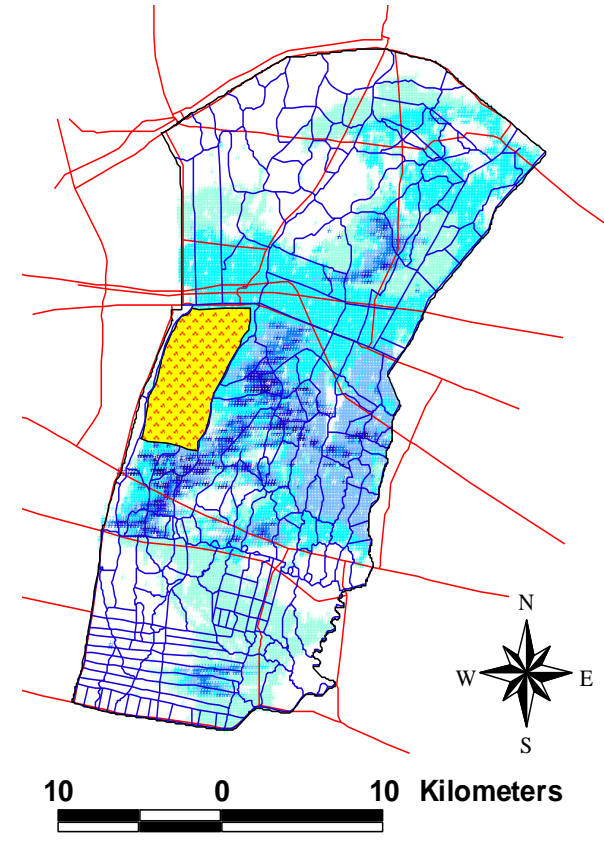
- 0.00 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60



- Study area
- Canal
- Road
- Suvarnabhumi International Airport

50-year Peak flood depth (m)

- 0.00 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60

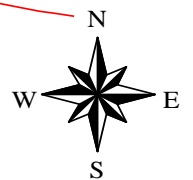
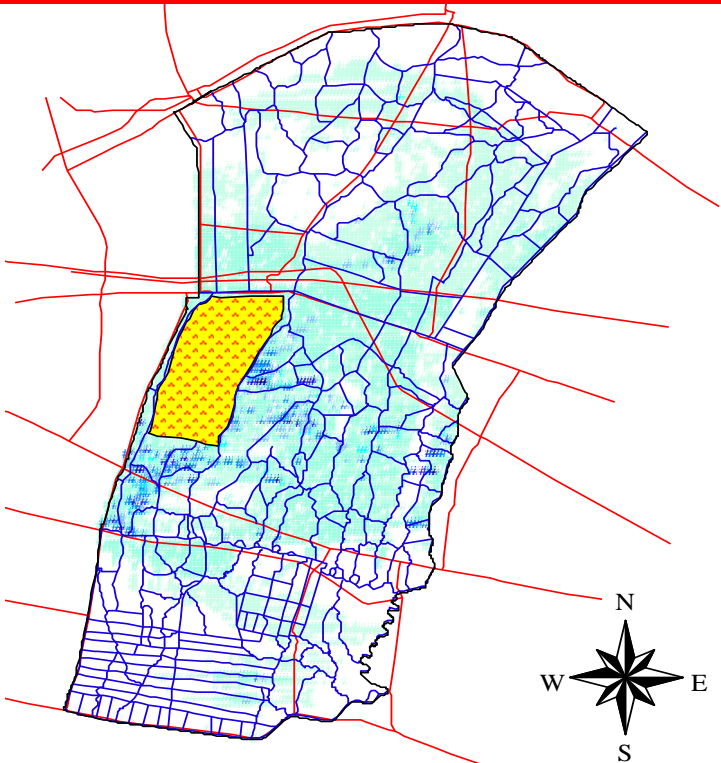


- Study area
- Canal
- Road
- Suvarnabhumi International Airport

100-year Peak flood depth (m)

- 0.00 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60

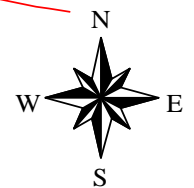
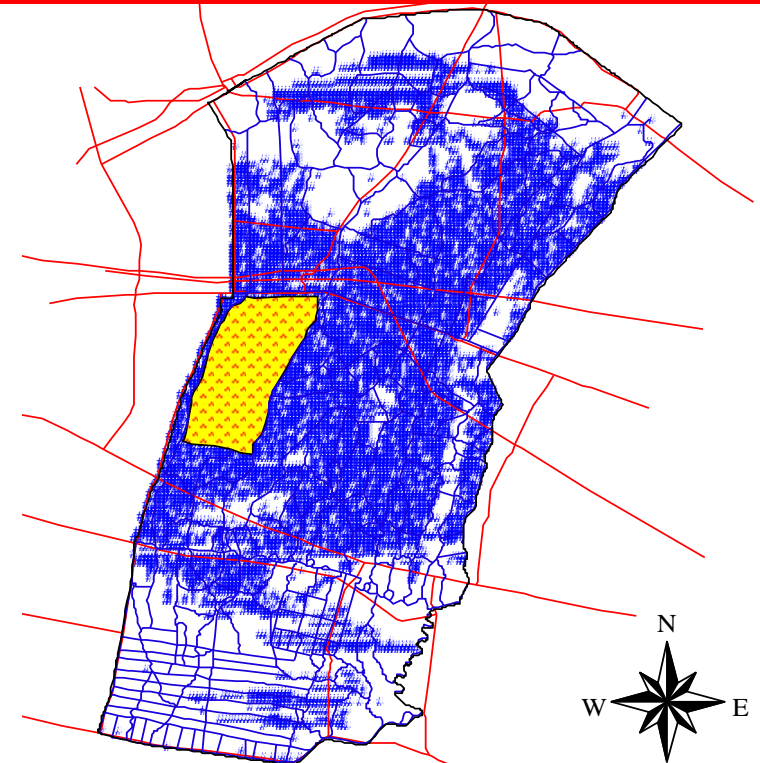
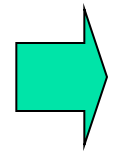
Peak flood depth for $T_r = 25$ years



- Study area
- Canal
- Road
- Suvarnabhumi International Airport

25-year Peak flood depth (m)

- 0.00 - 0.20
- # 0.20 - 0.40
- # 0.40 - 0.60
- # 0.60 - 0.80
- # 0.80 - 1.00
- # 1.00 - 1.20
- # 1.20 - 1.40
- # 1.40 - 1.60



- Study area
- Canal
- Road
- Suvarnabhumi International Airport

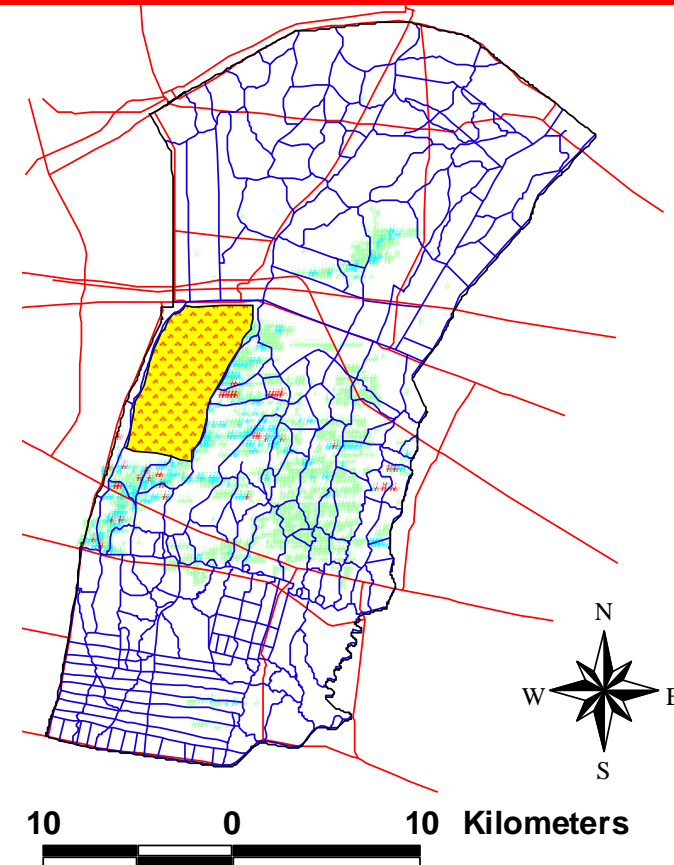
25-year Peak flood affected area

- Insignificant area
- # Flood affected area





Maximum flood depth classification for 25-year flood

Depth categories	Depth range (m)	Flooding area (% of total)
Low	0-0.45	85.96
Medium	0.45-0.90	10.35
High	0.90-1.20	2.90
Very high	> 1.20	0.79

These included 14.48 % of non-flooding areas (flood depth = 0 m)



-  Study area
-  Canal
-  Road
-  Suvarnabhumi International Airport

- 25-year Peak flood depth classification
-  Low
 -  Medium
 -  High
 -  Very high

Flood Duration

- Rising flood, peak flood and recession flood were considered (September 22, 24, 28 and October 8)
- Insignificant flood area and flood affected area are divided with depth of 0.22 m
- Flood affected areas were considered in assessing flood duration

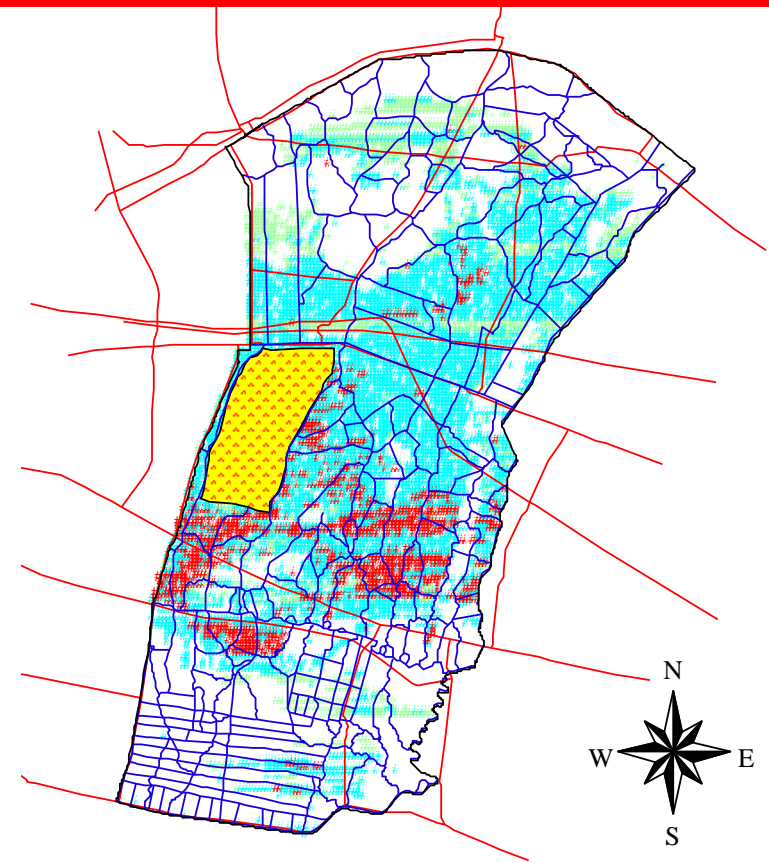
Classification of Flood Duration

Duration	Criteria
Short	Area of flood standing flooded from 22 Sep to 24 September
Medium	Area of flood standing between 22-28 September
Long	Area of flood standing between 22 Sep and 8 Oct
Very Long	Area of flood standing from 22 Sep to longer than 8 Oct

Flood duration of $T_r = 25$ years

Duration categories	Flooding area (% of total)
Short	33.71
Medium	8.75
Long	35.96
Very long	7.10

These excluded 14.48 % of non-flooding areas (flood depth = 0 m)



- Study area
- Canal
- Road
- Suvarnabhumi International Airport

25-year Flood duration

- Short
- Medium
- Long
- Very long

Flood Hazard Factor (FHF)

- FHF = Flood Hazard Factor FHF
= $\beta(\text{FHI}_y) + (1-\beta)(\text{FHI}_t)$

Where $0 \leq \beta \leq 1$

FHI_y = Flood Depth Indicator

FHI_t = Flood Duration Indicator

Flood Hazard Assessment

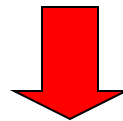
Simulation of flood flow

by Hydrodynamic Model (MIKE FLOOD)

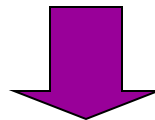
for different return periods of rainfall



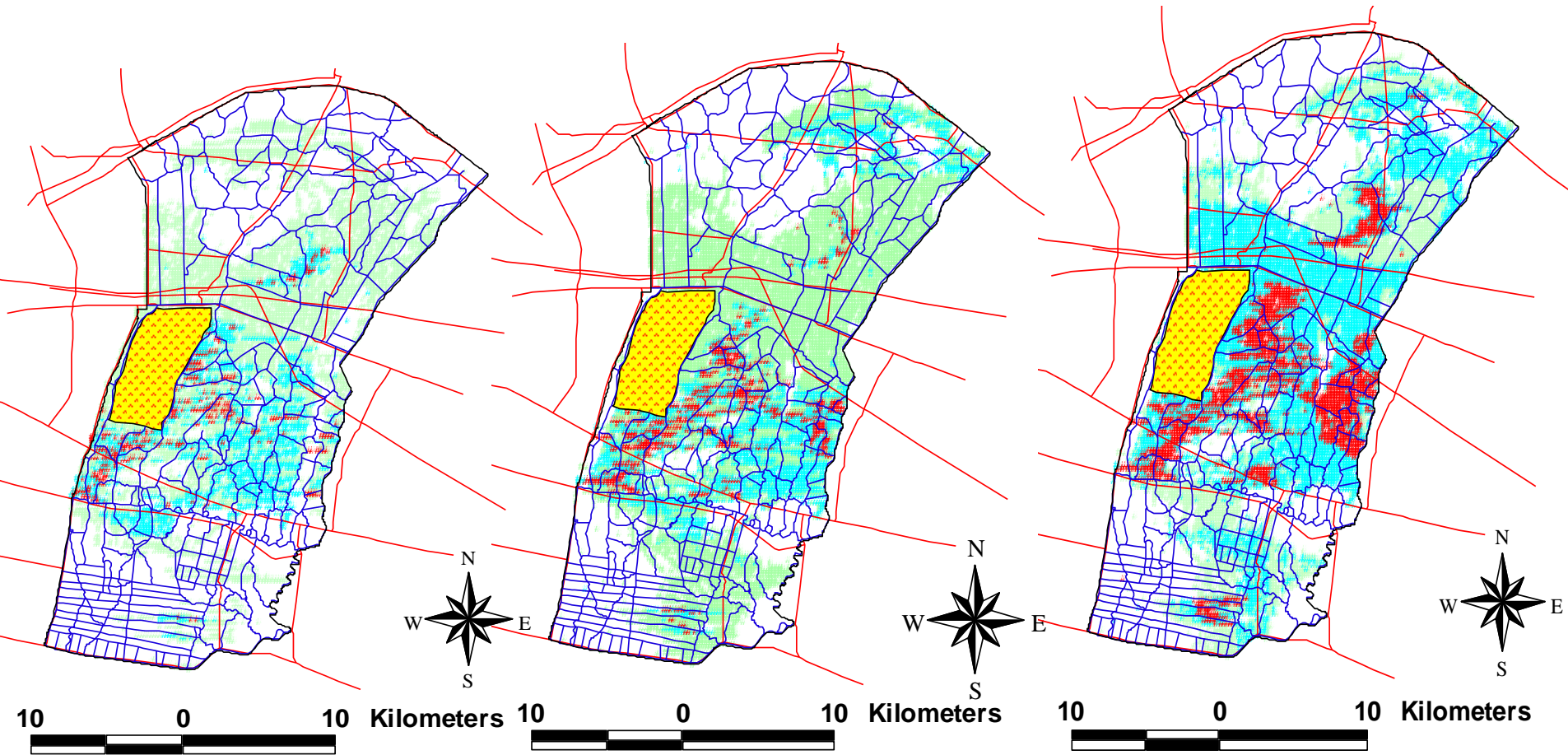
Flood depth/duration $\rightarrow (FHH)_y$ & $(FHH)_t$



$$FHF = \beta (FHH)_y + (1 - \beta) (FHH)_t$$



Flood Hazard Maps



- Study area
- Canal
- Road
- Suvarnabhumi International Airport

25-year Flood hazard

- Low (56.94 %)
- Medium (32.56 %)
- High (7.38 %)
- Very high (3.12 %)

- Study area
- Canal
- Road
- Suvarnabhumi International Airport

50-year Flood hazard

- Low (36.40 %)
- Medium (44.36 %)
- High (13.52 %)
- Very high (5.72 %)

- Study area
- Canal
- Road
- Suvarnabhumi International Airport

100-year Flood hazard

- Low (37.92 %)
- Medium (18.94 %)
- High (32.91 %)
- Very high (10.23 %)

Flood Hazard Indicators (FHI) for Flood Depth & Flood Duration

- FHI : 4 flood hazard categories which represent severity of flood hazard are taken: low, medium, high and very high
- Small integer numbers such as 0, 1, 2, 3 etc., were used for the 4 categories of FHI
- 3 options of FHI_y for flood depth and 3 options of FHI_t for flood duration are considered
- In total, 9 combinations of hazard indicators FHI_y and FHI_t are considered

Flood hazard indicators for flood depth (FHI_y)

Flood depth, y (m)	Hazard Category	Flood hazard indicator, FHI _y		
		Option 1a	Option 2a	Option 3a
$0.00 < y \leq 0.45$	Low	0	1	2
$0.45 < y \leq 0.90$	Medium	1	2	3
$0.90 < y \leq 1.20$	High	2	3	4
$y > 1.20$	Very high	3	4	5

Flood hazard indicator for flood duration (FHI_t)

Flood duration	Hazard Category	Flood hazard indicator, FHI _t		
		Option 1b	Option 2b	Option 3b
Short	Low	0	1	2
Medium	Medium	1	2	3
Long	High	2	3	4
Very long	Very high	3	4	5

Patterns of flood hazard factor calculation for nine case studies

Case studies for flood hazard assessment	Flood hazard indicator options	
	Flood depth	Flood duration
A	1a	1b
B	1a	2b
C	1a	3b
D	2a	1b
E	2a	2b
F	2a	3b
G	3a	1b
H	3a	2b
I	3a	3b

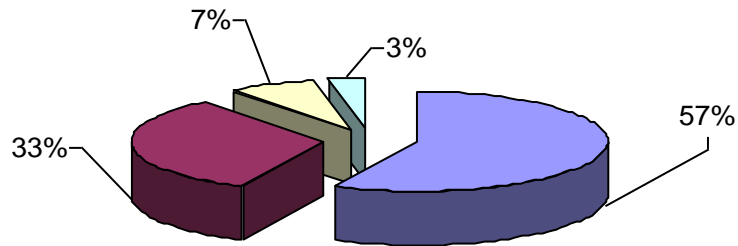
Land areas within each flood hazard zone

Case studies for flood hazard assessment	Land area (% of total study area)			
	Low hazard	Medium hazard	High hazard	Very high hazard
A	94.09	3.72	1.90	0.29
B	94.09	3.72	1.90	0.29
C	87.96	9.85	1.90	0.29
D	87.96	6.13	3.72	2.19
E	87.96	6.13	3.72	2.19
F	87.96	6.13	3.72	2.19
G*	56.94	32.56	7.38	3.12
H	51.26	37.12	7.86	3.76
I	56.94	37.15	3.72	2.19

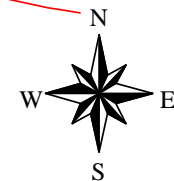
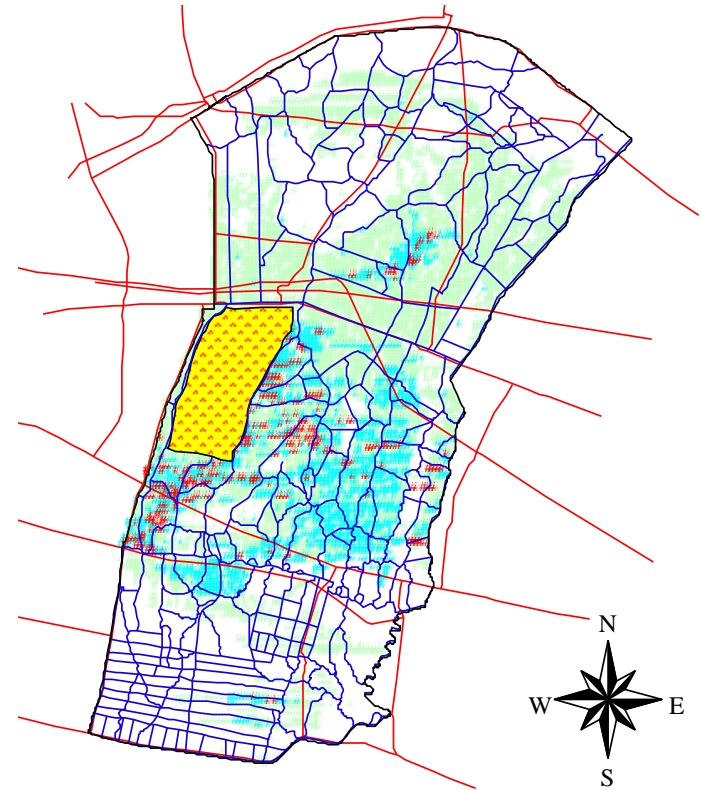
* CTCN ATF Bhutan Training 2017
 Case G is the most similar to the actual flood situation T=50 yrs
 Prof. Tawatchai Tingsanchai

Flood hazard map for $T_r = 25$ years

Percentage area for different degree of flood hazard



■ Low Hazard
 ■ Medium Hazard
 ■ High Hazard
 ■ Very High Hazard

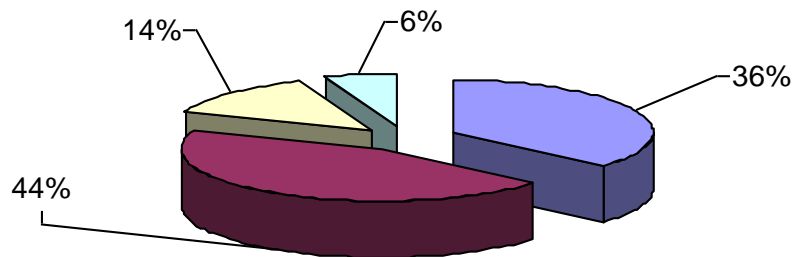


- Study area
- Canal
- Road
- Suvarnabhumi International Airport

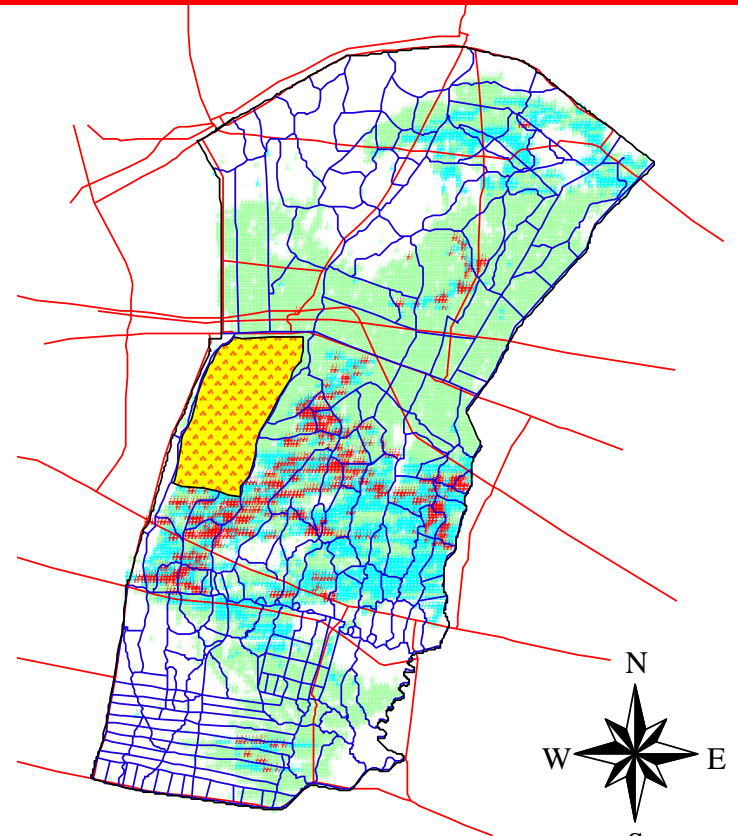
25-year Flood hazard
■ Low (56.94 %)
■ Medium (32.56 %)
■ High (7.38 %)
■ Very High (3.12 %)

Flood hazard map for $T_r = 50$ years

Percentage area for different degree of flood hazard



■ Low Hazard
 ■ Medium Hazard
 ■ High Hazard
 ■ Very High Hazard



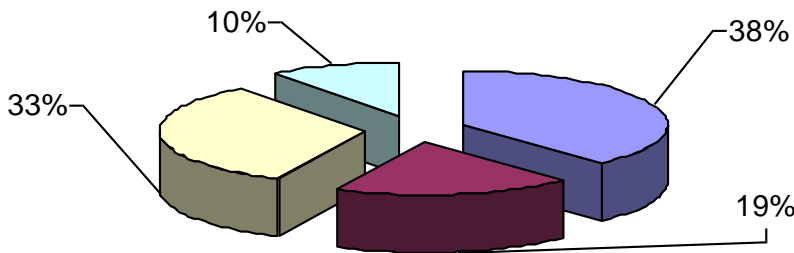
10 0 10 Kilometers

- Study area
- Canal
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- Suvarnabhumi International Airport

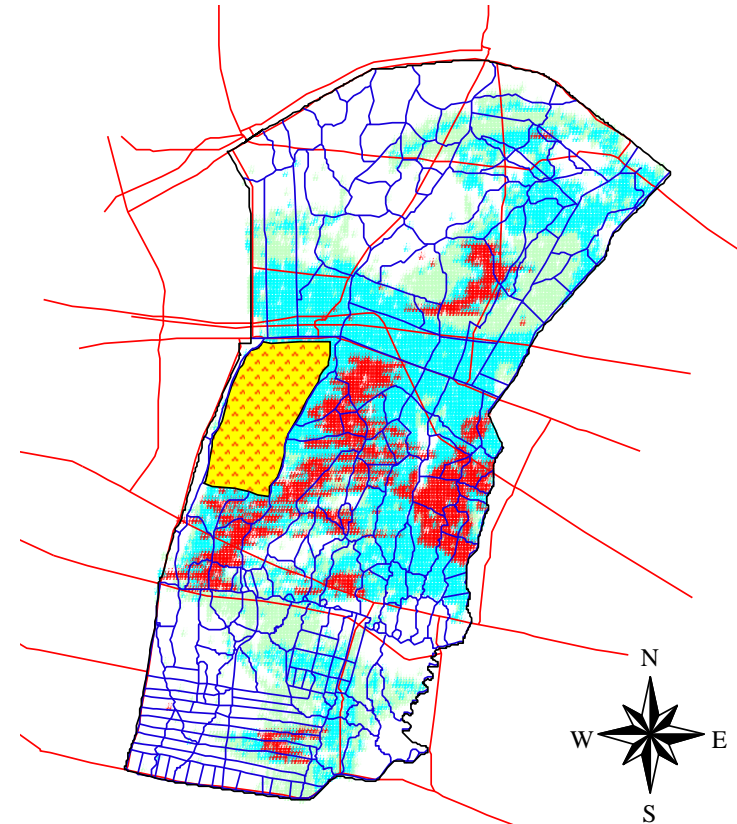
50-year Flood hazard
 Low (36.40 %)
■ Medium (44.36 %)
■ High (14.52 %)
■ Very high (5.78 %)

Flood hazard map for $T_r = 100$ years

Percentage area for different degree of flood hazard



■ Low Hazard
 ■ Medium Hazard
 ■ High Hazard
 ■ Very High Hazard



- Study area
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100-year Flood hazard
 Low (37.92 %)
 Medium (18.94 %)
 High (33.11 %)
 Very high (10.23 %)

Conclusions

- Flood hazard is the extent of flood magnitudes such as depth, duration and velocity which can cause potential damages in a study area.
- The magnitude of flood hazard can be calculated by mathematical models.
- Flood hazard increases with flood return period and improper land use change
- Where there is no people or no asset, flood hazard still exists although there is nothing to damage except environmental degradation.

Thank you

Capacity Building Programme on
Flood Risk Assessment and Management
30 October - 8 November 2017

Sessions 2&3: Flood hazard and vulnerability assessment: Thailand Example for Samdrupjhonkar municipality

Prof. Tawatchai Tingsanchali

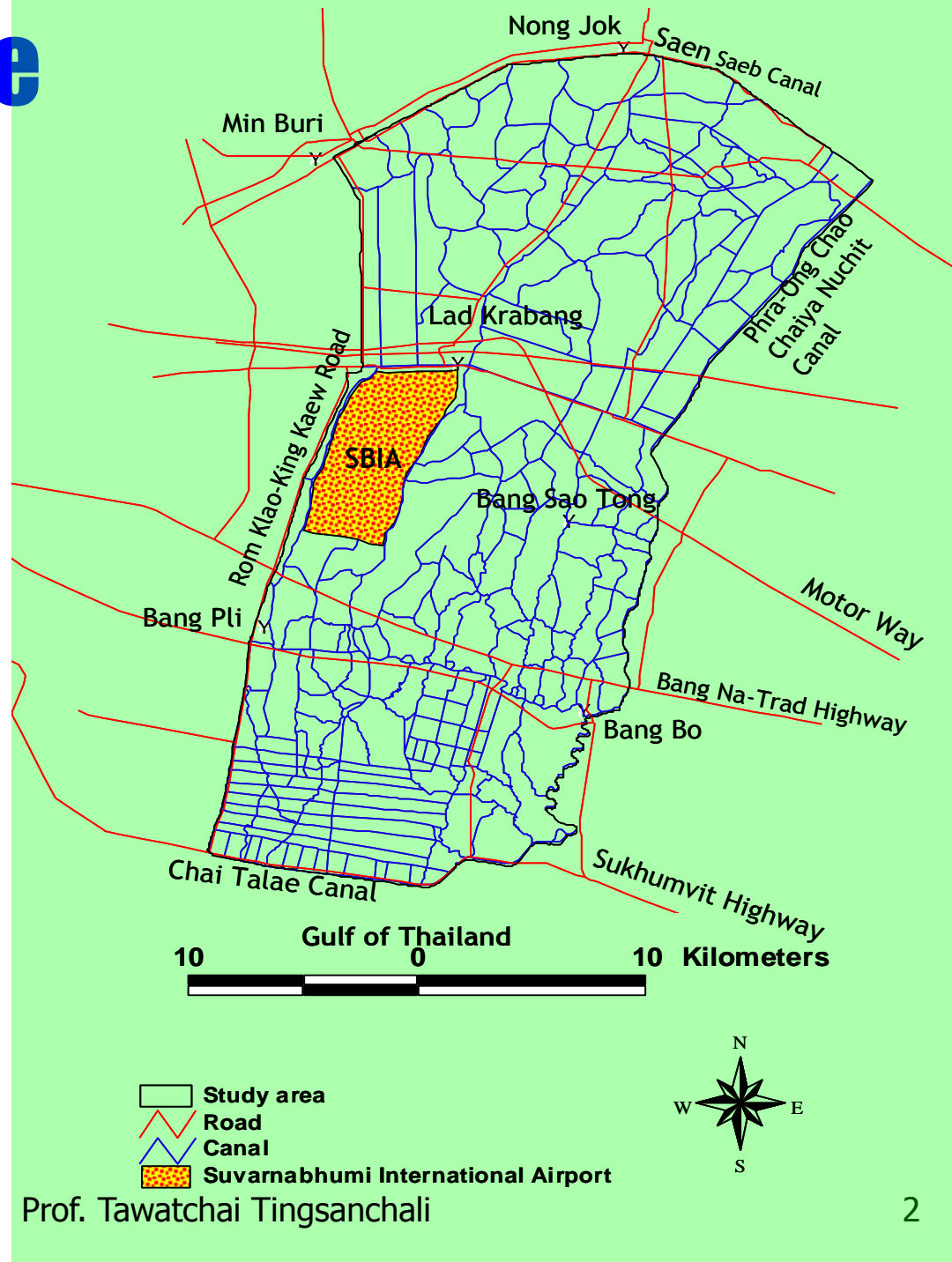
Water Engineering and Management
Asian Institute of Technology, Thailand

Thailand Example Study Area

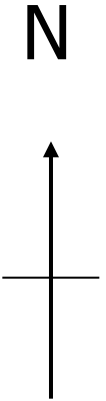
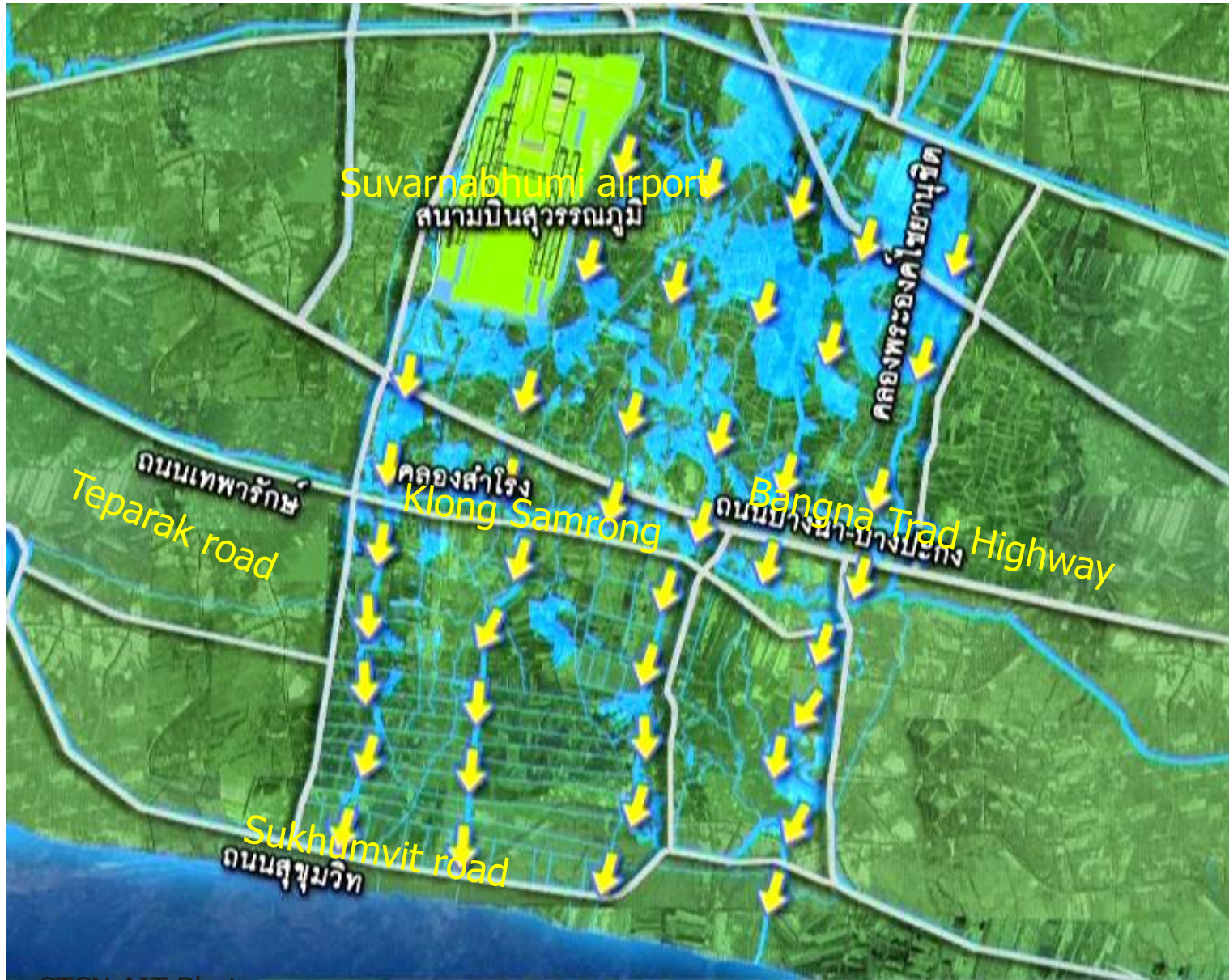
Location Map of the Second Bangkok International Airport

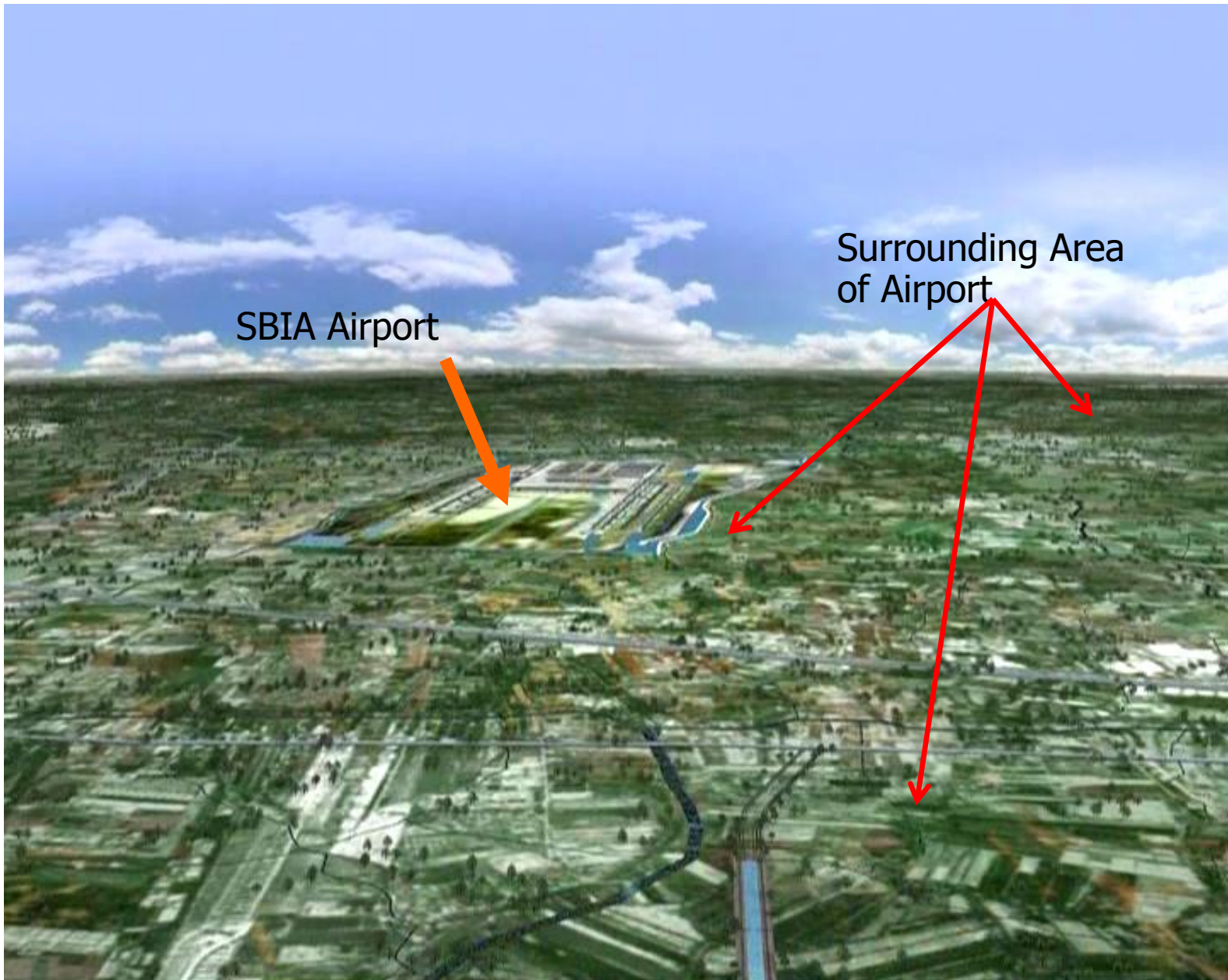


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SBIA Airport

Surrounding Area
of Airport

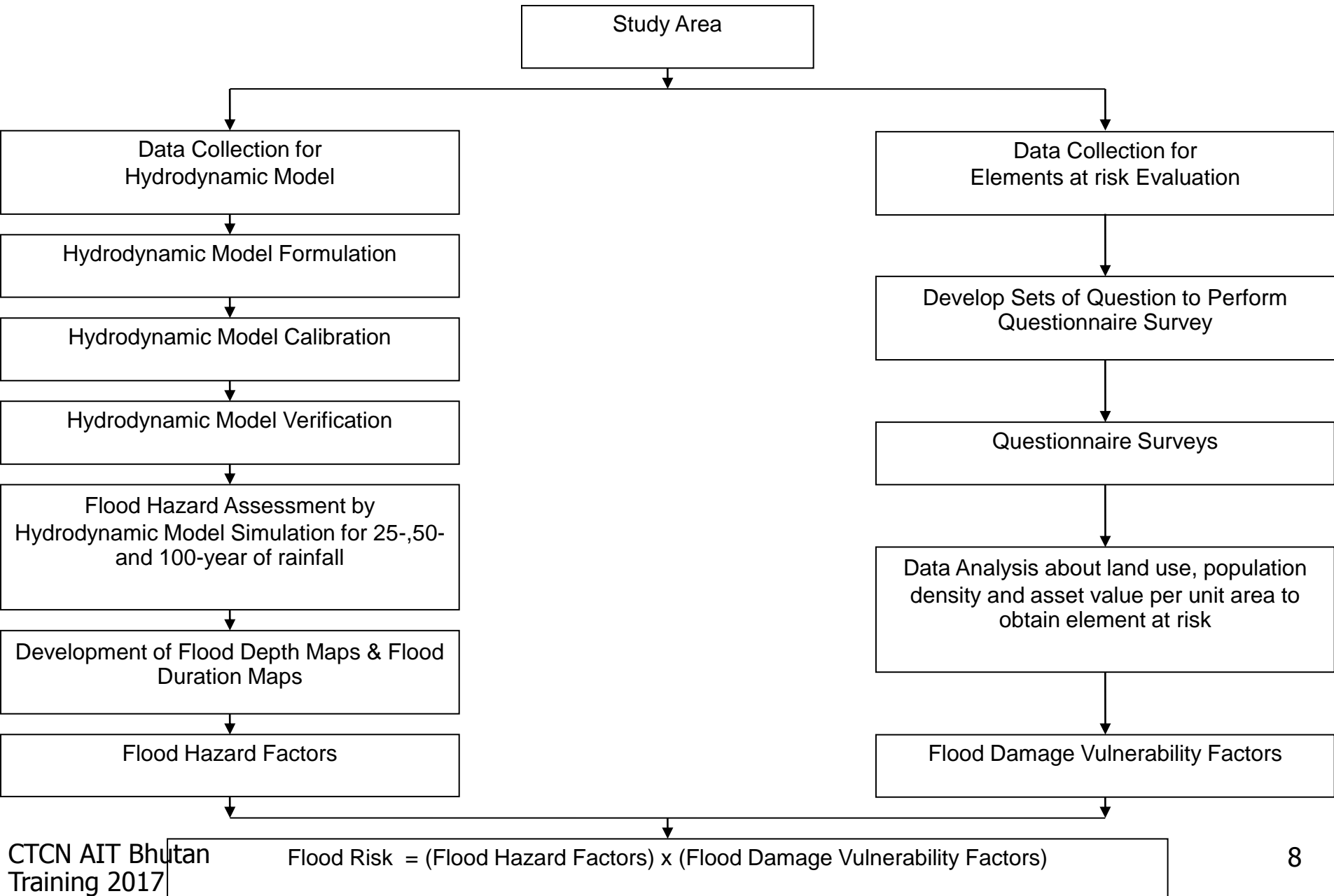
Scope of work

- To assess flood damage vulnerability of the study area and develop the vulnerability map

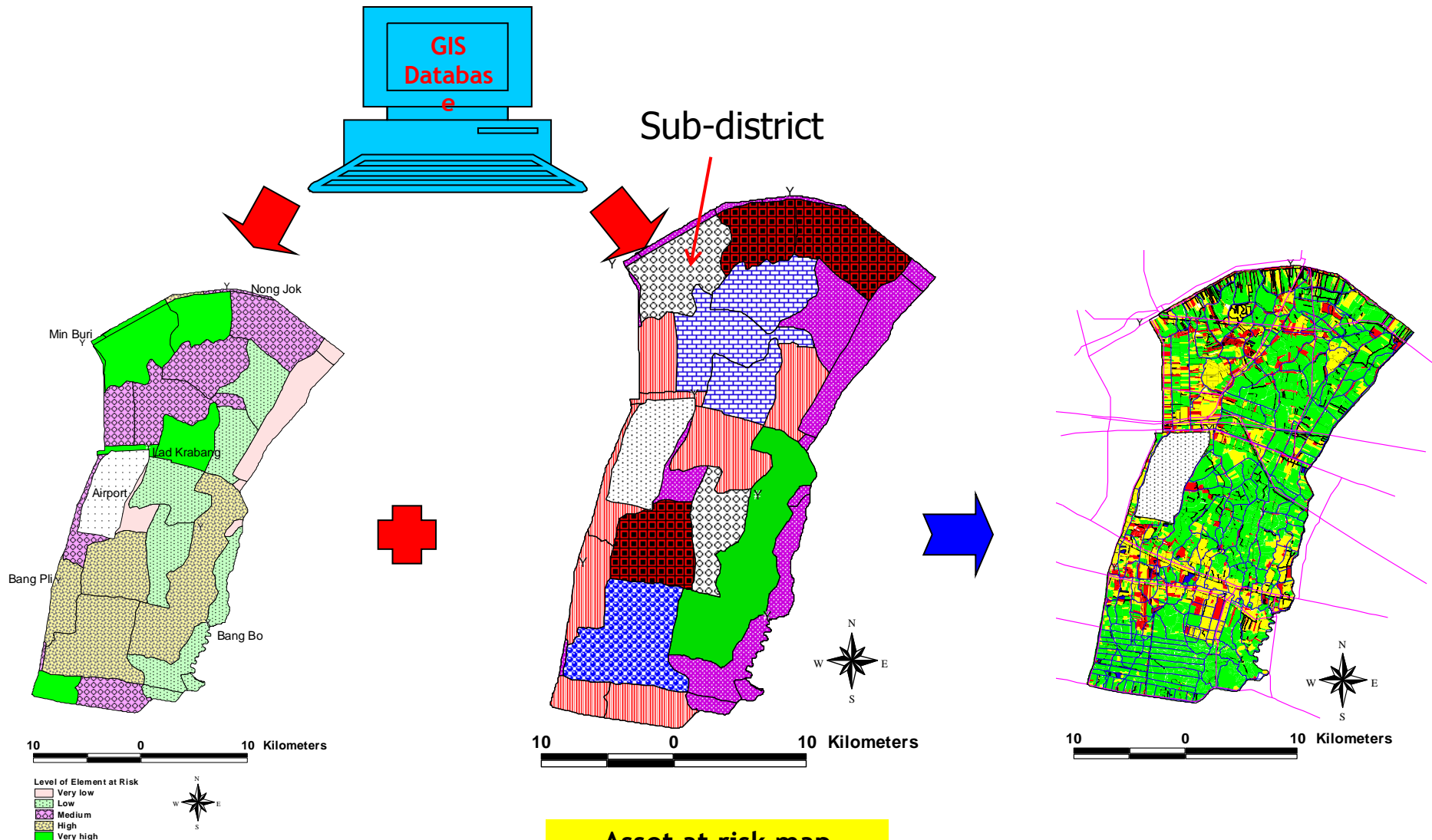
Flood Hazard Assessment

- Large floodplain & flat topography
- Flood depth & flood duration were considered

Flowchart of research Framework



Determination of Flood vulnerability Map



Population at risk map

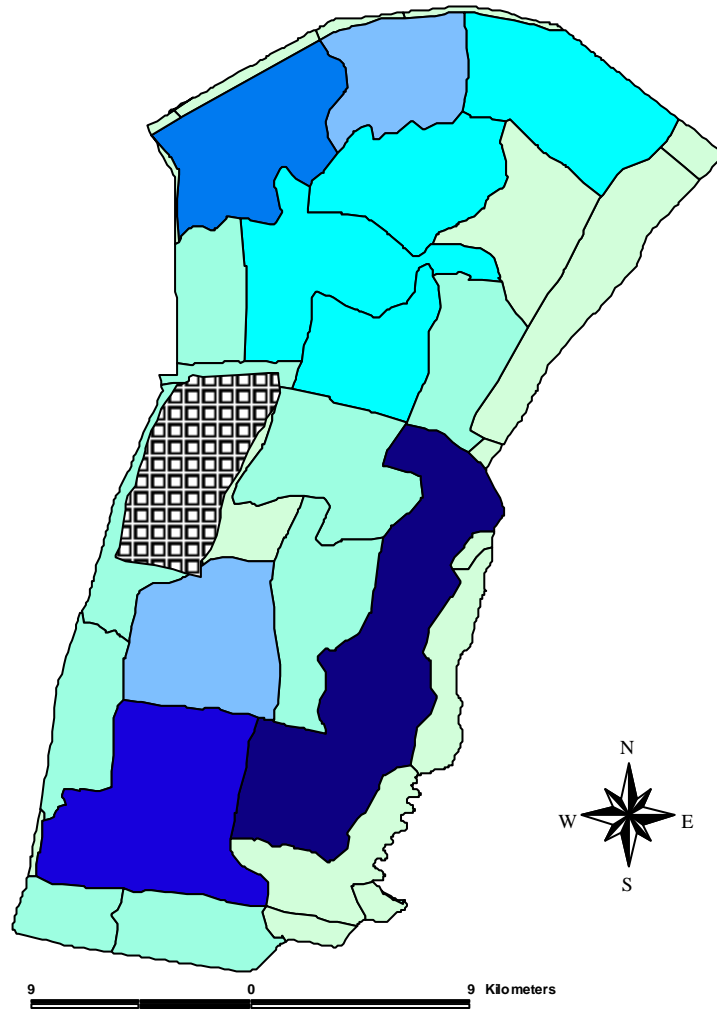
Asset at risk map


Flood vulnerability map

Element at Risk







- **Population at risk**
- **Asset at risk**

Number of Population in 2004

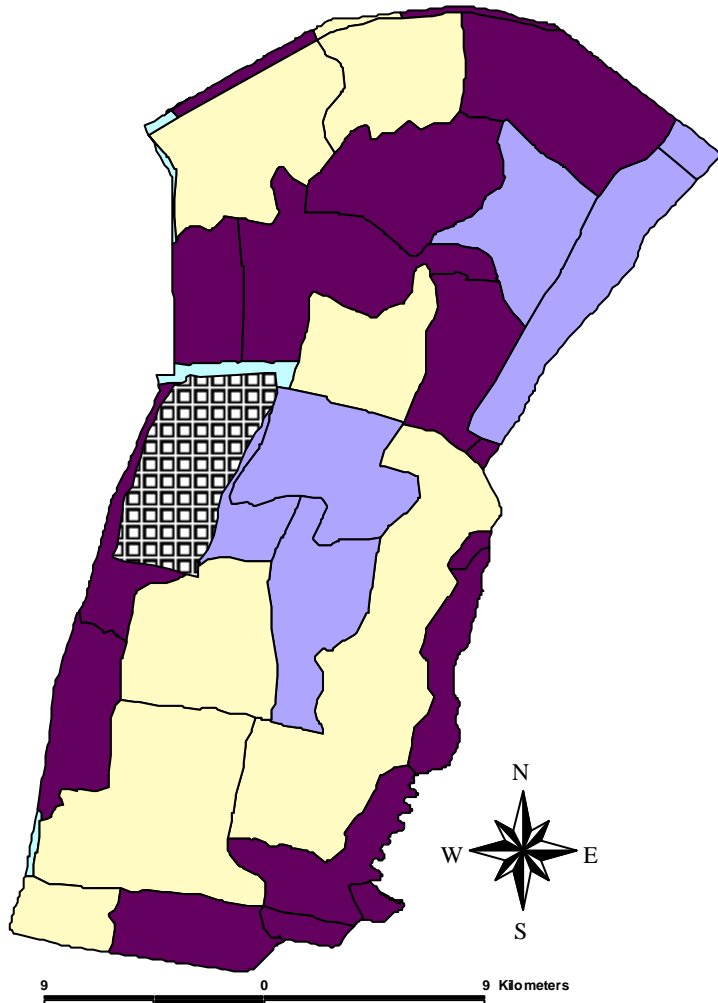


 Suvarnabhumi International Airport

Number of population in each sub-district (person)





-  0 - 5,000
-  5,000 - 10,000
-  10,000 - 15,000
-  15,000 - 20,000
-  20,000 - 25,000
-  25,000 - 30,000
-  > 30,000

Population density

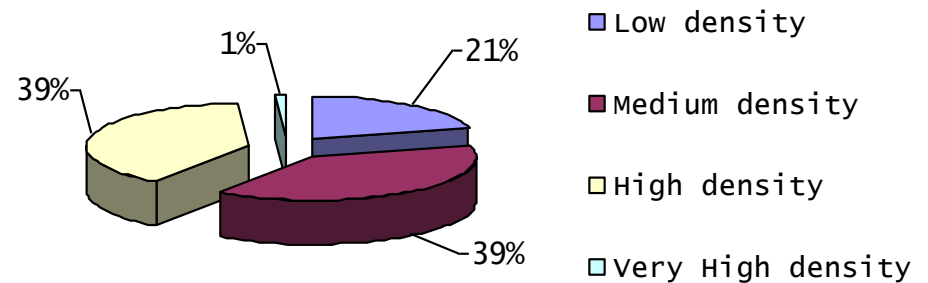


 Suvarnabhumi International Airport

Population density

-  Low (0 - 250 person/sq.km.)
-  Medium (251 - 500 person/sq.km.)
-  High (501 - 750 person/sq.km.)
-  Very high (over 750 person/q.km.)

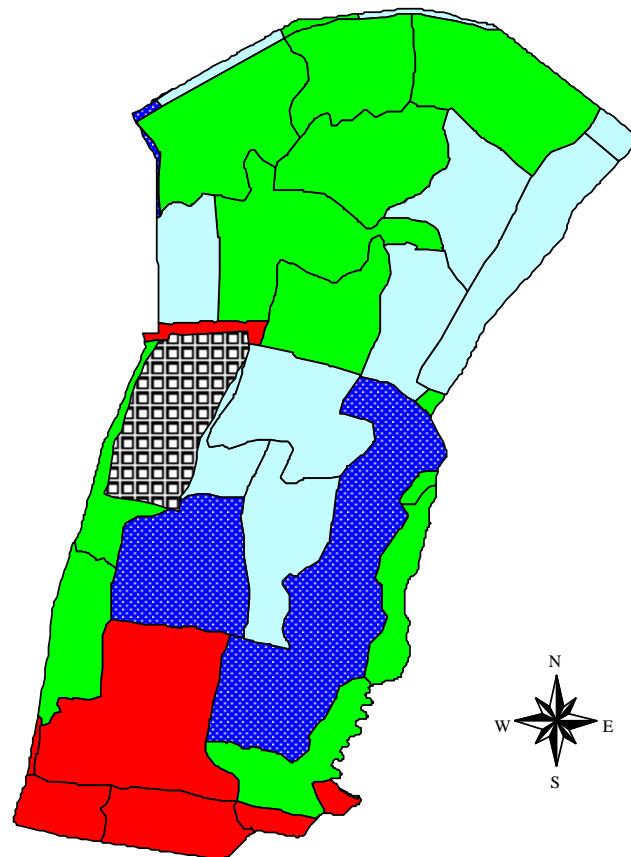
Percentage area of different categories of population density



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Flood vulnerability indicators of population at risk (FVip)



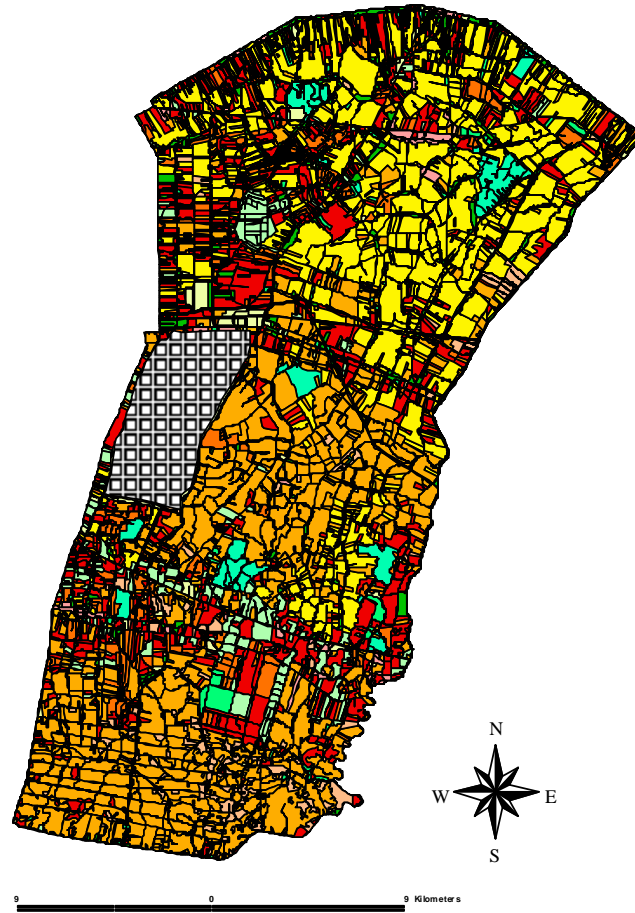
9 0 9 Kilometers

 Suvarnabhumi International Airport

Flood vulnerability indicator of population at risk (FVip)

-  Low
-  Medium
-  High
-  Very high

Asset value per unit area

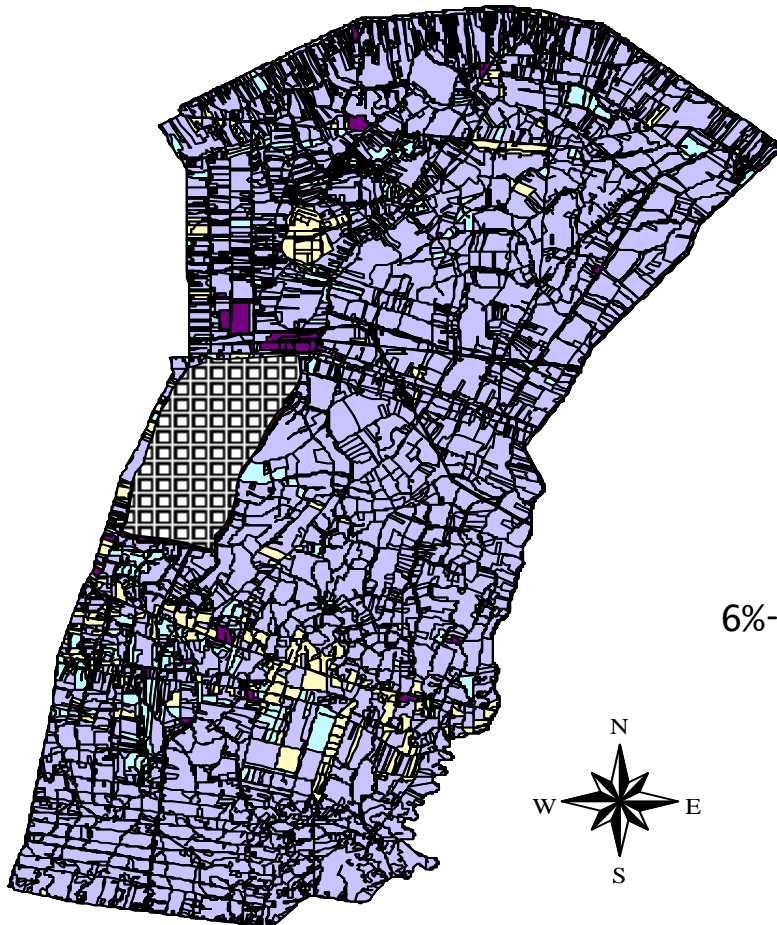


 Suvarnabhumi International Airport

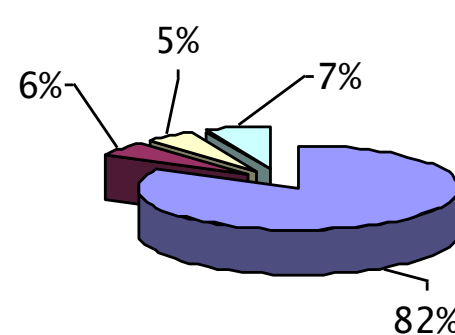
Asset value per unit area

- Non considered area
- Paddy field (20.4 Baht/sq.m.)
- Fish farms (42.34 Baht/sq.m.)
- Orchard area (71.97 Baht/sq.m.)
- Shrimp farms (113.87 Baht/sq.m.)
- Road (580.28 Baht/sq.m.)
- Rural community (762.42 Baht/sq.m.)
- Golf course/Public park (1681.08 Baht/sq.m.)
- Institutional area (9510.72 Baht/sq.m.)
- Industrial land (11360.52 Baht/sq.m.)
- Urban community (14,995 baht/sq.m)
- Housing estate (17895.34 Baht/sq.m.)
- Commercial/Business area (18320.86 Baht/sq.m.)

Classification of asset value per unit area



Percentage area of different categories of asset value per unit area



- Low asset value
- Medium asset value
- High asset value
- Very high asset value

9 0 9 Kilometers

▣ Suvarnabhumi International Airport

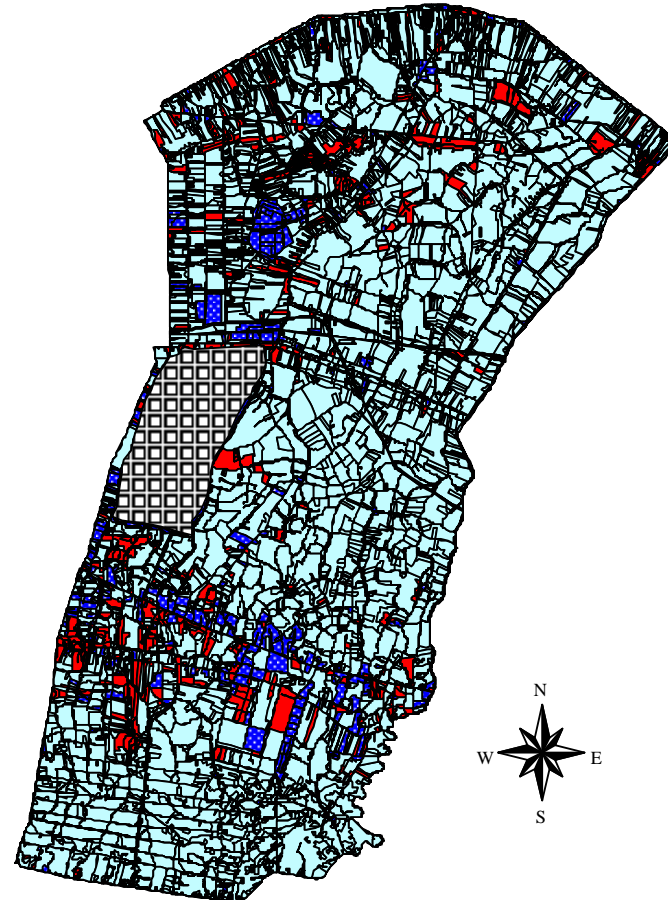
Average asset value per unit area

- Low (0 - 5,000 Baht/sq.m.)
- Medium (5,001 - 10,000 Baht/sq.m.)
- High (10,001 - 15,000 Baht/sq.m.)
- Very high (over 15,000 Baht/sq.m.)

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Flood vulnerability indicators of asset at risk (FVIA)



9 0 9 Kilometers

 Suvarnabhumi International Airport

Flood vulnerability factor of asset at risk (FVFa)

-  Low
-  Medium
-  High
-  Very high

Flood damage vulnerability factor for Regional Level (FVF)

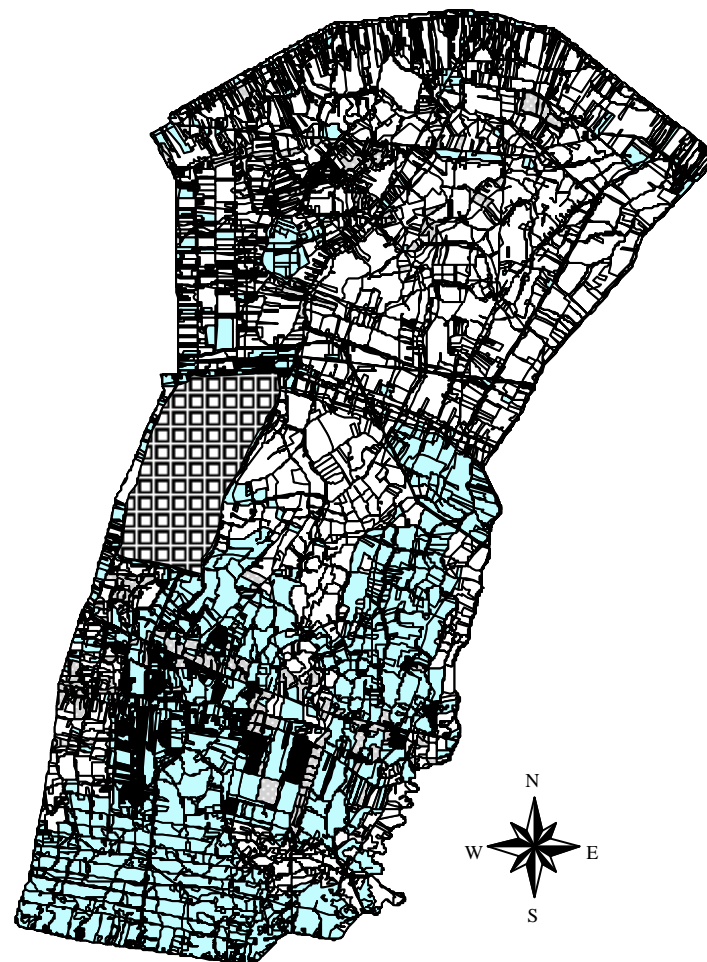
- FVF : the resultant susceptibility of overall element at risk exposed to flood
- $FVF = \theta (FVI_p) + (1-\theta)(FVI_a)$

Where $0 \leq \theta \leq 1$

FVI_p = Flood Vulnerability Indicator for Population

FVI_a = Flood Duration Indicator for Asset


Flood damage vulnerability factor (FVF)



9 0 9 Kilometers

 Suvarnabhumi International Airport

Flood damage vulnerability

-  Low
-  Medium
-  High
-  Very high

EXAMPLE

Calculation of Socio Economic Vulnerability (SeVI) at Household Level

SOCIO-ECONOMIC VULNURABILITY ANALYSIS

Location ID	Location Name	Population density (Pop/ km ²)	Area (km ²)	Total Population	Household
1	A	918	7.57	6,949	1,737
2	B	1,959	4.28	8,386	2,096
3	C	1,285	23.43	30,107	7,526
4	D	1,952	19.69	38,434	9,608
Grand total				83,876	20,967

No. of samples at each location

Location ID	Location Name	No. of household
1	A	50
2	B	45
3	C	75
4	D	57

No.	Variables	Used	
1	Household size	Used variables	
2	Gender of household head		
3	Education level of household head		
4	Health status of the household head		
5	Dependency ratio		
6	Number of the disable family member		
7	Length of residence with this community		
8	Occupation of the household head		
9	Total income of the household		
10	Multiple earning source		
11	Savings		
12	ATM Card		
13	Households take loan on a regular basis		
14	Interest rate of loan		
15	Social capital		
16	Location of the house		
17	Distance of the river from house		
18	Distance of the evacuation shelter from house		
19	Additional land outside the riverbank failure prone area		
20	Households understand warning		
21	Households having mobile phone		
22	Households experienced riverbank failure in past		CTCN AIT Bhutan Training 2017
23	Households possess indigenous knowledge		
24	Household share warning with others		Prof. Tawatchai Tingsanchali 22

Scoring

Components	Variables	Classes	Score	Remark	Source
Social	Family size	<= 5	33	Large family needs more resource and facility	Saqib et al.,(2016) Rana and Routray, (2016)
		6 – 10	67		
		> 10	100		
	Gender of household head	Male	40	Women may face more difficulties during the emergency	Cutter et al.,(2003) ; Malakar and Mishra,(2016)
		Female	60		
	Education level of the household head	College or University	20	High illiteracy decrease the capacity of understanding preparedness measures	Qasim et al., (2016) ; Rana and Routray, (2016)
		Higher secondary	40		
		Secondary	60		
		Primary	80		
		Illiterate	100		
	Health status of the household head	Excellent	25	Working capacity depends on the health condition	Saqib et al., (2016)
		Good	50		
		Fair	75		
		Poor	100		
	Dependency ratio	<= 0.25	20	High proportion of dependents is the driving force behind the increase of vulnerability	Morin et al., (2016) ; Cutter et al.,(2003); Rana and Routray, (2016)
		0.26 – 0.50	40		
		0.51- 0.75	60		
0.76 – 1.00		80			
>1.00		100			

Scoring

Components	Variables	Classes	Score	Remark	Source
------------	-----------	---------	-------	--------	--------

Economic	Disable member	0	0	Special needs for disable people during emergency causes mobility problem	Ahsan and Warner, (2014)
		1	50		
		>1	100		
	Length of residence with this community (year)	>15	25	Long term living in a community helps to make good network within the community, which acts to decrease vulnerability	Morin et al., (2016)
		11 - 15	50		
		6 - 10	75		
		<=5	100		
	Occupation of the household head	Service	20	Unstable income source increases the vulnerability	Morin et al., (2016) ; Rana and Routray, (2016)
		Business	40		
		Agriculture	60		
		Daily wage	80		
		Unemployment/ Old allowance	100		
	Total income of the household	>35000	20	Less income means less financial capacity to absorb shocks	Bormudoi and Nagai, (2017); Cutter et al., (2003) ; Qasim et al., (2016); Morin et al., (2016)
		25001-35000	40		
15001-25000		60			
5001- 15000		80			
<5000		100			
Multiple earning source	Yes	0	Diversified income sources provide more financial security	Alam et al.,(2017); Qasim et al., (2016)	
	No	100			
Savings	Yes	0	To relocate the house during riverbank failure, savings can be utilized	Braun and Abheuer, (2011) ; Qasim et al., (2016)	
	No	100			
ATM card	Yes	0	Provides access of money beyond banking hours		
	No	100			
Households take loan on a regular basis	Yes	100	Households have liability of paying money back are economically stressed	Morin et al., (2016), Rana and Routray, (2016)	
	No	0			

Scoring

Components	Variables	Classes	Score	Remark	Source
	Interest rate of loan	0 %	0	More interest rate means more liability	
		1- 20 %	50		
		>20 %	100		
	Social capital	Yes	0	Social capital provides both financial and social support during emergency	
No		100			
Physical	Location of house	Inside protected polder	0	Houses located outside the protected polders are more at risk	
		Outside polder	100		
	Distance of river from house	>750	25	Houses close to riverbank are likely to be eroded	
		500-750	50		
		250-500	75		
		<250	100		
	Distance of evacuation shelter from house	<=500	20	Evacuation centers located at a longer distance are not easily accessible	
		501-1000	40		
		1001-1500	60		
		1501-2000	80		
		>2000	100		
	Additional land outside the riverbank failure prone area	Yes	0	Households having no land outside the riverbank failure prone areas face difficulties to resettle	
		No	100		
Exposure to hazard	Households understand warning	Yes	0	Face problem in taking decision during emergency	Yadav and Barve, (2017)
		No	100		
	Households having mobile phone	Yes	0	Mobile phones are useful for households to receive hazard information	
		No	100		

Scoring

Components	Variables	Classes	Score	Remark	Source
	Households experienced bank failure	> 6	20	Less experience of facing hazard increases vulnerability	
		5-6	40		
		3-4	60		
		1-2	80		
		0	100		
	Households possess indigenous knowledge	Yes	0	No indigenous knowledge means more dependent on other	Hiwasaki et al., (2014)
		No	100		
	Households share warning with others	Yes	0	Vulnerability increases for the whole community	
		No	100		

Calculate Socio- economic Vulnerability (Example for Social Part)

Components	Indicator	Vulnerability Score			
		A(50)	B (45)	C (75)	D (57)
Social	Household size	37.74*	35.27	38.44	36.58
	Gender of household head	41.60	46.67	40.53	42.46
	Education level of household head	87.60	93.78	82.40	91.58
	Health status of the household head	54.00	48.89	51.33	47.81
	Dependency ratio	62.00	52.89	62.93	60.00
	Number of the disable family member	4.00	2.22	5.33	5.26
	Length of residence with this community	54.00	73.33	67.67	55.70
	Social vulnerability index (SVI)	48.71	50.43	49.81	48.48

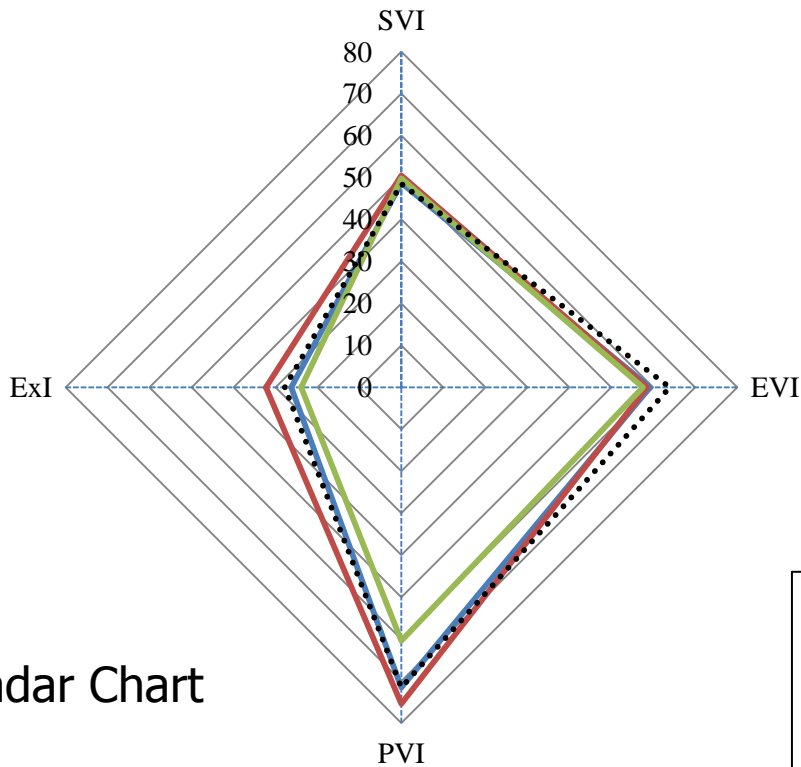
Variables	Classes	Location A		Score	Weighted Score
		N	%		
Household size	<= 5	44	88.0	33	2904
	6 – 10	5	10.0	67	670
	> 10	1	2.0	100	200
			Sum 100		Weight Sum/100 =37.74

*Note

Indicies of the vulnerability components

Legend for Location

- A —
- B —
- C —
- D



Radar Chart

SVI = Social Vulnerability Index
 EVI = Economic Vulnerability Index
 PVI = Physical Vulnerability Index
 ExI = Exposure Index

$$\text{SeVI} = \frac{\text{SVI} + \text{EVI} + \text{PVI} + \text{ExI}}{4}$$

Where,

SeVI – Socio-economic vulnerability Index

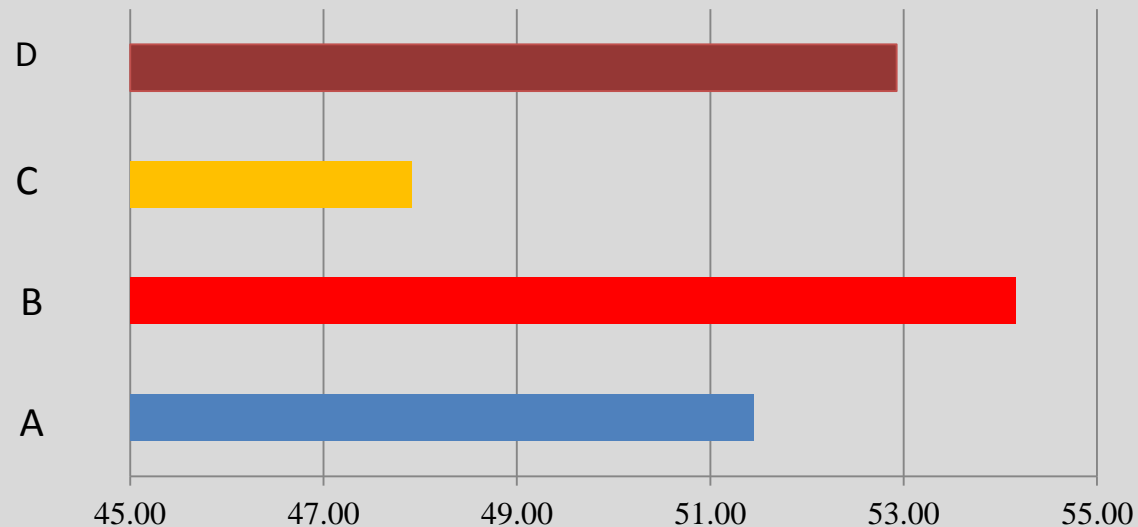
SVI- Social Vulnerability Index

EVI – Environmental Vulnerability Index

PVI – Physical Vulnerability Index

ExI – Exposure Index

Composite socio-economic vulnerability index



Risk calculation

Location ID	Location Name	Normalized Hazard Index (HI)*	Vulnerability Index (VI)			Risk	
			Population density and asset value (Regional scale)*	Socio-economy (SeVI) Household scale)	Avg. VI	HI x Avg. VI	Normalize Risk Index
1	A	100	38.46	51.44	44.95	4,495	58.32
2	B	100	100	54.15	77.07	7,707	100
3	C	66.67	15.38	47.91	31.64	2,109.4	27.37
4	D	100	53.85	52.93	53.39	5,339	69.27

RISK

* Taken from another study at regional scale

Conclusions

- The presence of the airport and rapid urbanization adversely affect flood risk in the area
- Because of high cost of investment we cannot afford to prevent all level of flooding or protect all risk areas simultaneously.
- The changing of land use without planning causes adverse effect to flood risk situation

Conclusions (Continued)

- Regional Flood damage vulnerability = $f(\text{population, asset})$
- Household flood damage vulnerability = $f(\text{social, economic, physical and exposure})$
- Overall vulnerability = weighted sum of regional and household vulnerability

Thank you



GIS for Flood Management

Dr. Chitrini Mozumder [chitrini@ait.ac.th]
Dr. Rajesh Chowdhary [vrajeshc@ait.ac.th]
RS&GIS, Asian Institute of Technology
Thailand [31st Oct 2017]

Presentation Nuts and Bolts



- Geographic Information Systems definitions
- GI Technologies: RS, GNSS, GIS
- GIS components, architecture and Data Models
- GIS essential vocabulary
- GI Technologies for Flood Management

GIS--What is it?

No easy answer anymore!

- Geographic/Geospatial Information
 - information about places on the earth's surface
 - knowledge about “what is where & when”(Don't forget time!)
 - Geographic/geospatial: synonymous
- GIS--what's in the S?
 - **S**ystems: the technology
 - **S**cience: the concepts and theory
 - **S**tudies: the societal context

Geographic Information *Technologies*

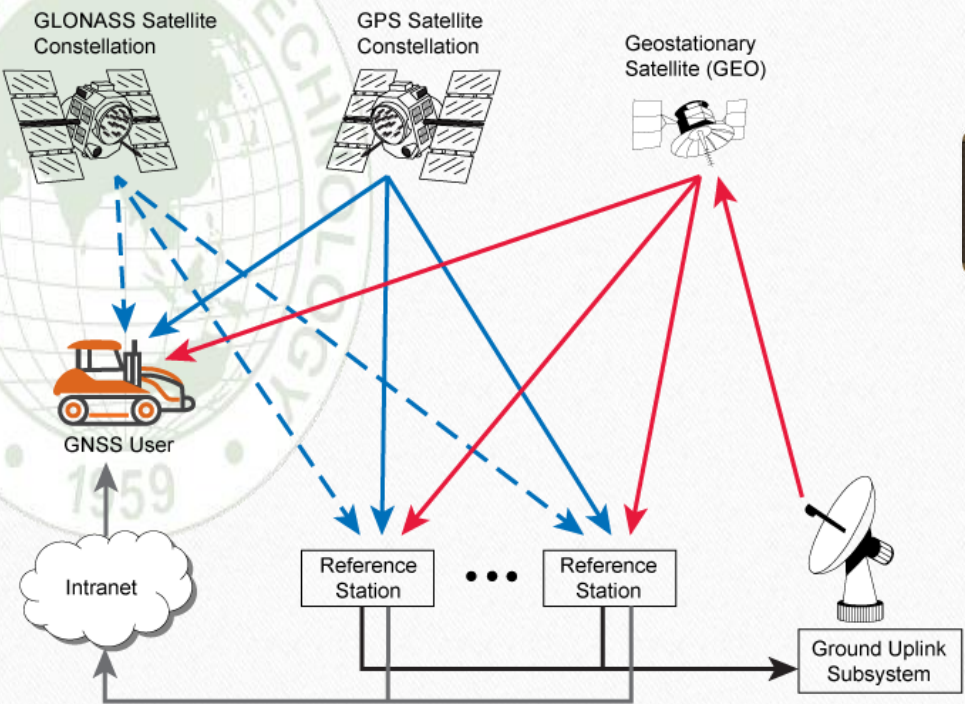
- Global Navigation Satellite Systems (GNSS)
 - a system of earth-orbiting satellites which can provide precise (100 meter to sub-cm.) location on the earth's surface (in lat/long coordinates or equiv.)
- Remote Sensing (RS)
 - use of satellites or aircraft to capture information about the earth's surface
 - Digital ortho images a key product (map accurate digital photos)
- Geographic Information **S**ystems (GISy)
 - Software systems with capability for input, storage, manipulation/analysis and output/display of geographic (spatial) information

GPS and RS are sources of input data for a GISy.

A GISy provides for storing and manipulating GPS and RS data.

GNSS: as a data source to GIS

- GNSS (Global Navigation Satellite Systems) started with the launch of the U.S Department of Defense Global Positioning System (GPS) in the late 1970's
- GNSS systems currently include
 - GPS (United States)
 - GLONASS (Russia)
 - Galileo (European Union)
 - BeiDou (China)



Remote Sensing: as a data source to GIS

Broad definition: “acquiring of data about an object without touching it”

Includes cameras, telescopes, optical-mechanical scanners, linear and area arrays, lasers, radio-frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, X-ray, and other medical applications

Types:

- Active Remote Sensing: Microwave remote sensing, Radar
- Passive Remote Sensing: Optical Remote Sensing, LiDAR

Platforms

- Spaceborne - Satellite
- Airborne – Aeroplane, Unmanned Aerial Vehicle (UAV)



Downwelling radiation from the Sun

Instrumentation

Sensor

Passive Remote Sensing System

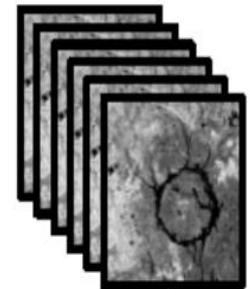
Upwelling radiation (radiance) from the landscape

Signal transmission to the ground

Data in multispectral image form ready for use (registered radiance at sensor)



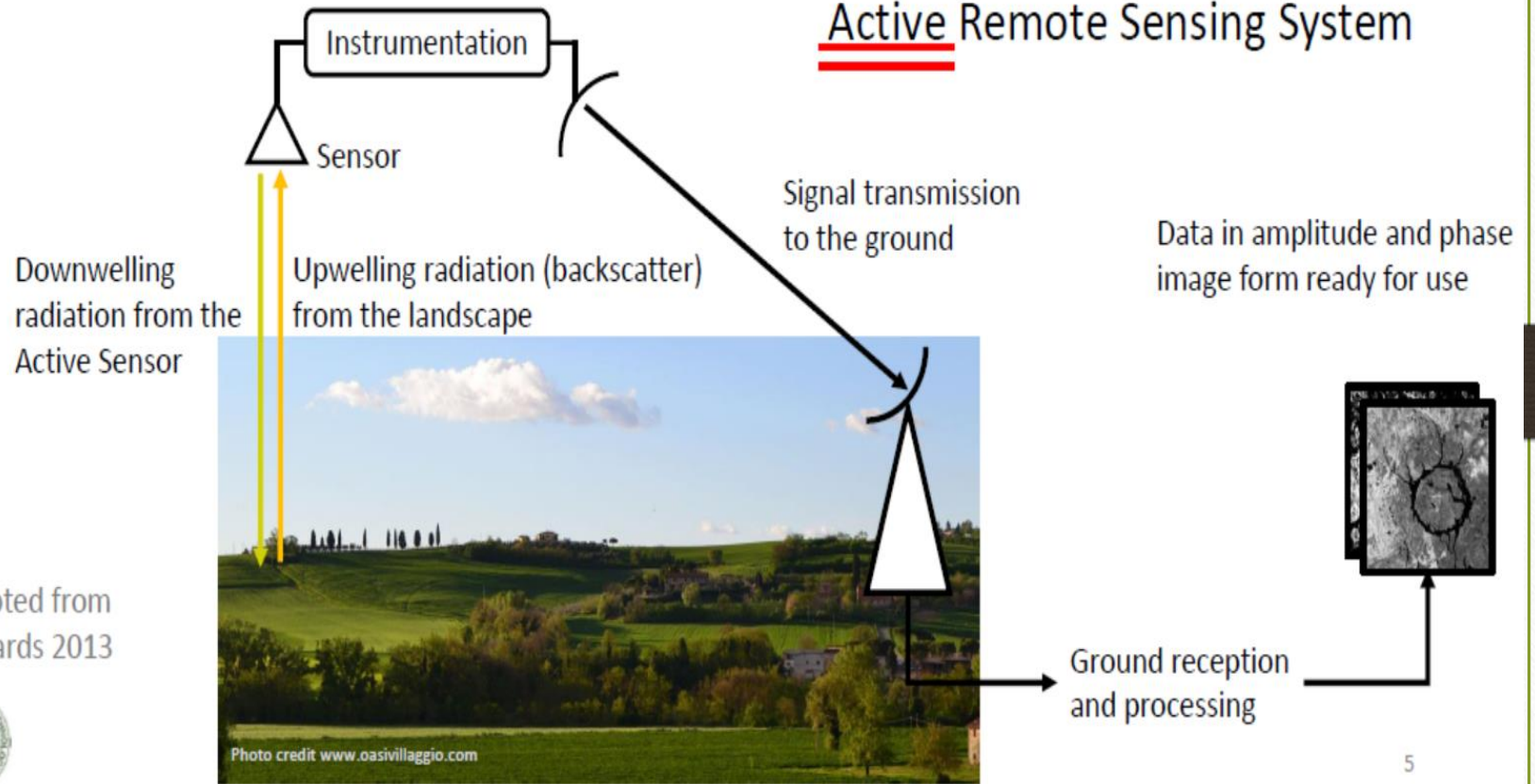
Ground reception and processing



Adapted from Richards 2013



Active Remote Sensing System



Downwelling radiation from the Active Sensor

Upwelling radiation (backscatter) from the landscape

Signal transmission to the ground

Data in amplitude and phase image form ready for use

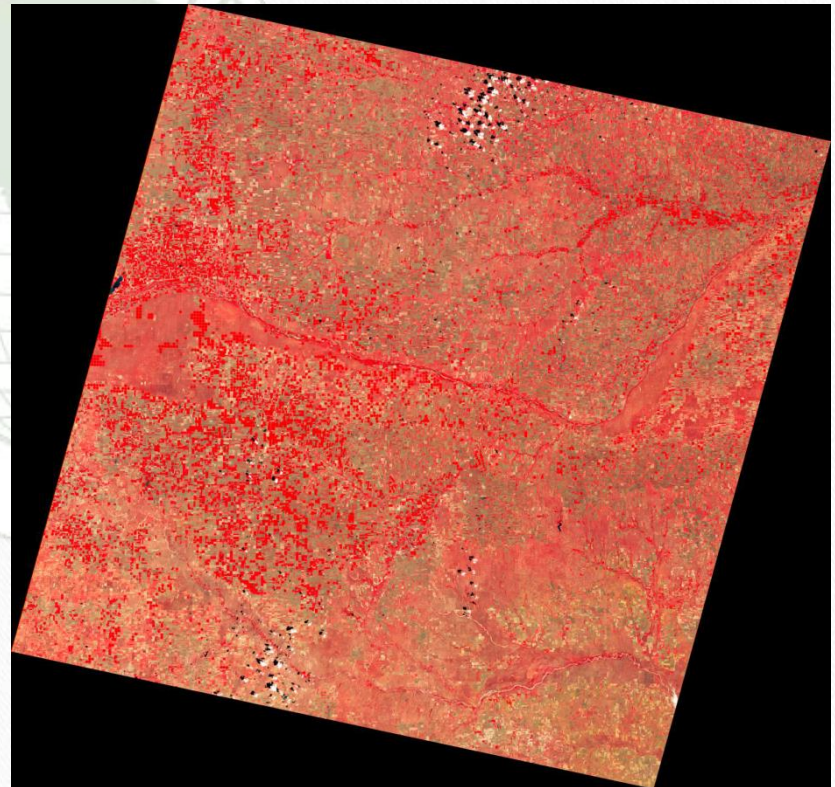
Adapted from Richards 2013



Photo credit www.oasivillaggio.com

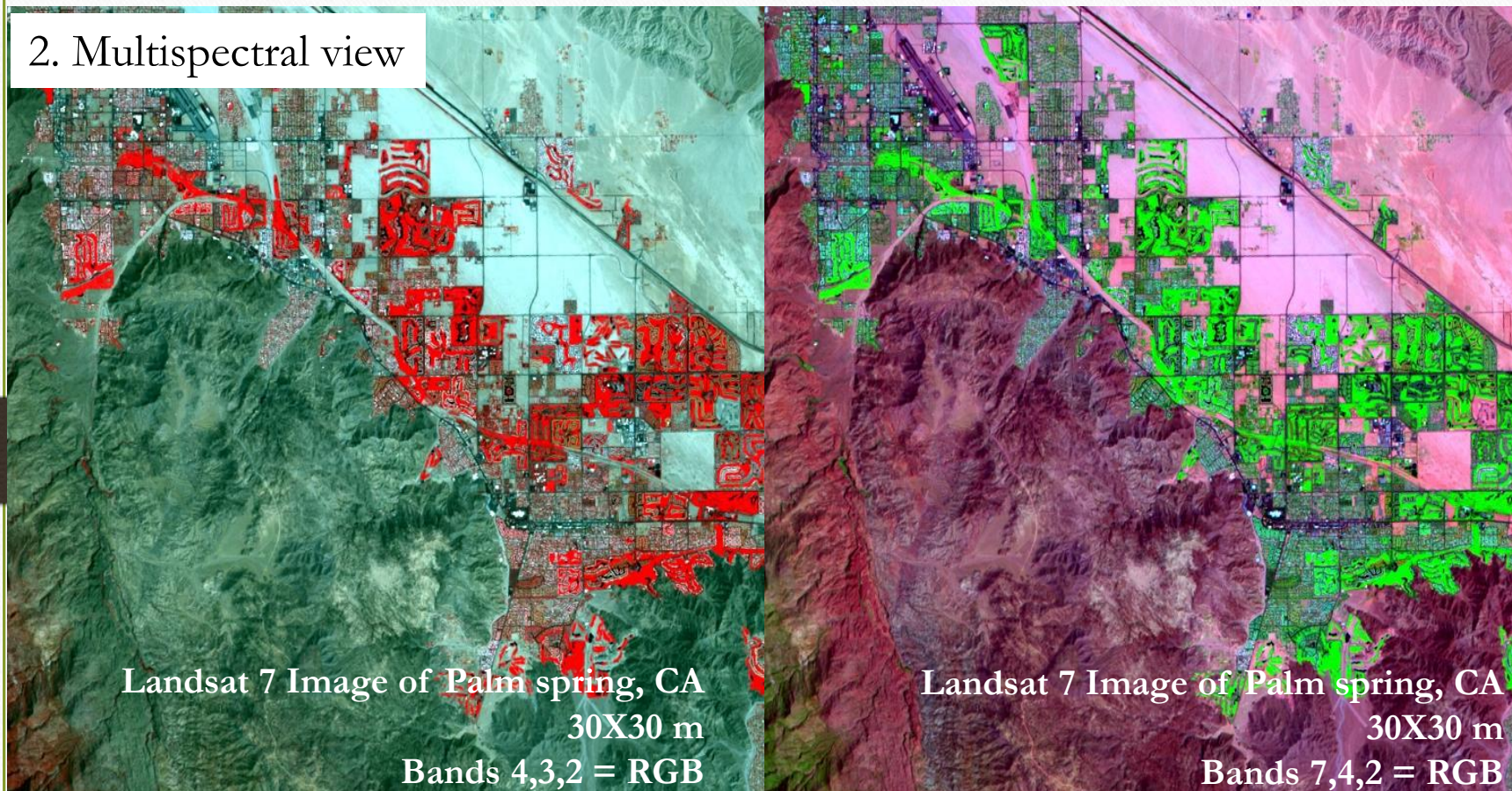
Remote Sensing: Advantages

1. **Synoptic view:**
opportunity to capture
large geographic areas
with a single
observation, or scene

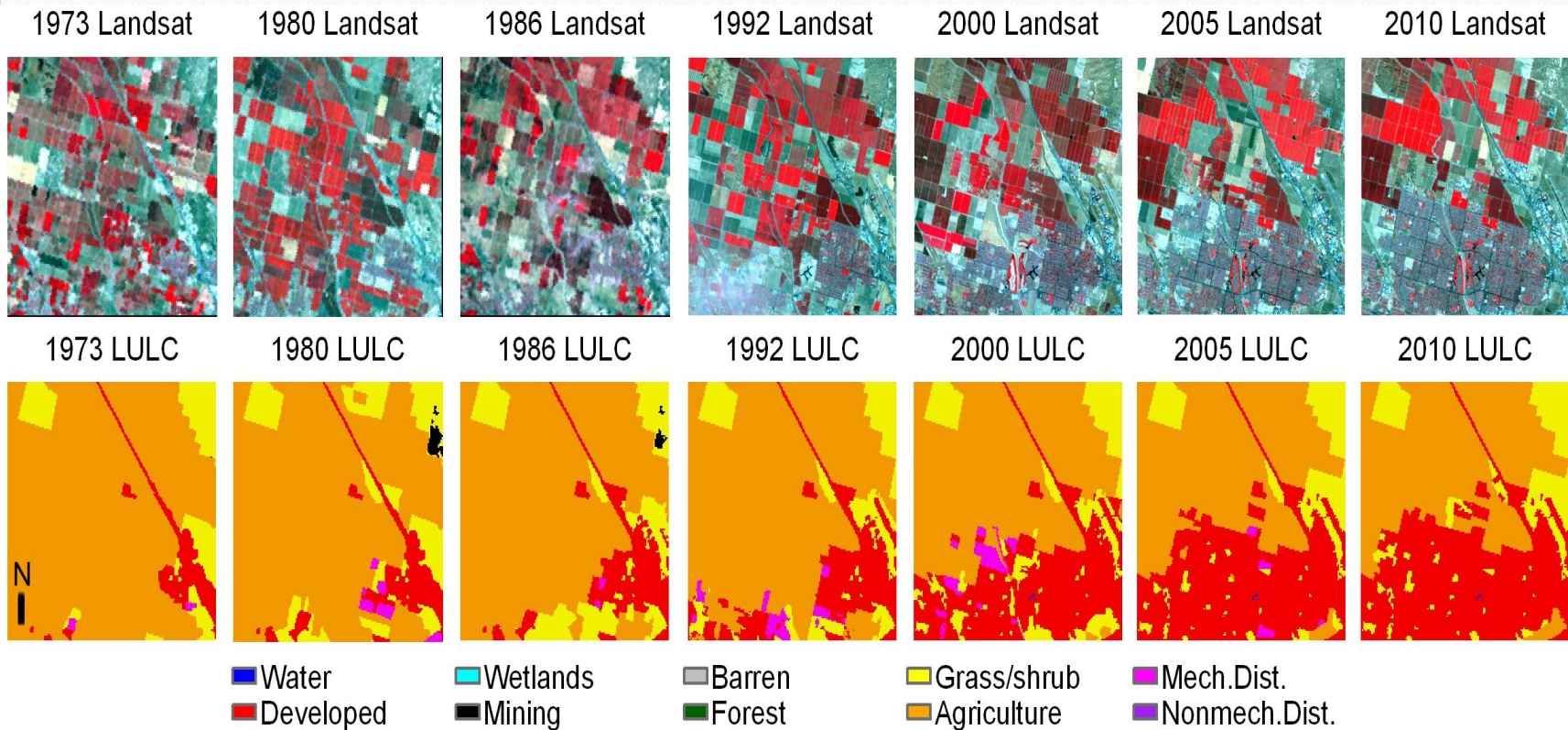


<http://visibleearth.nasa.gov/view.php?id=78644>

2. Multispectral view



Jensen, 2000



<https://eros.usgs.gov/doi-remote-sensing-activities/2013/usgs>

3. Revisiting Cycle on a regular period

4. Geographic and thematic

Remotely Sensed Data

- Resolution

- How much detail we can detect:

Spatial Resolution

- How much to distinguish between surface types:

Spectral Resolution

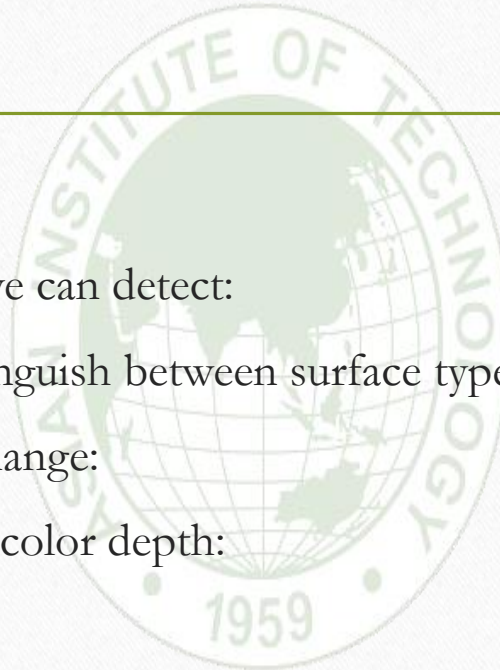
- How fast does it change:

Temporal Resolution

- How intense is the color depth:

Radiometric resolution

- Scale



Spatial Resolution & Scale

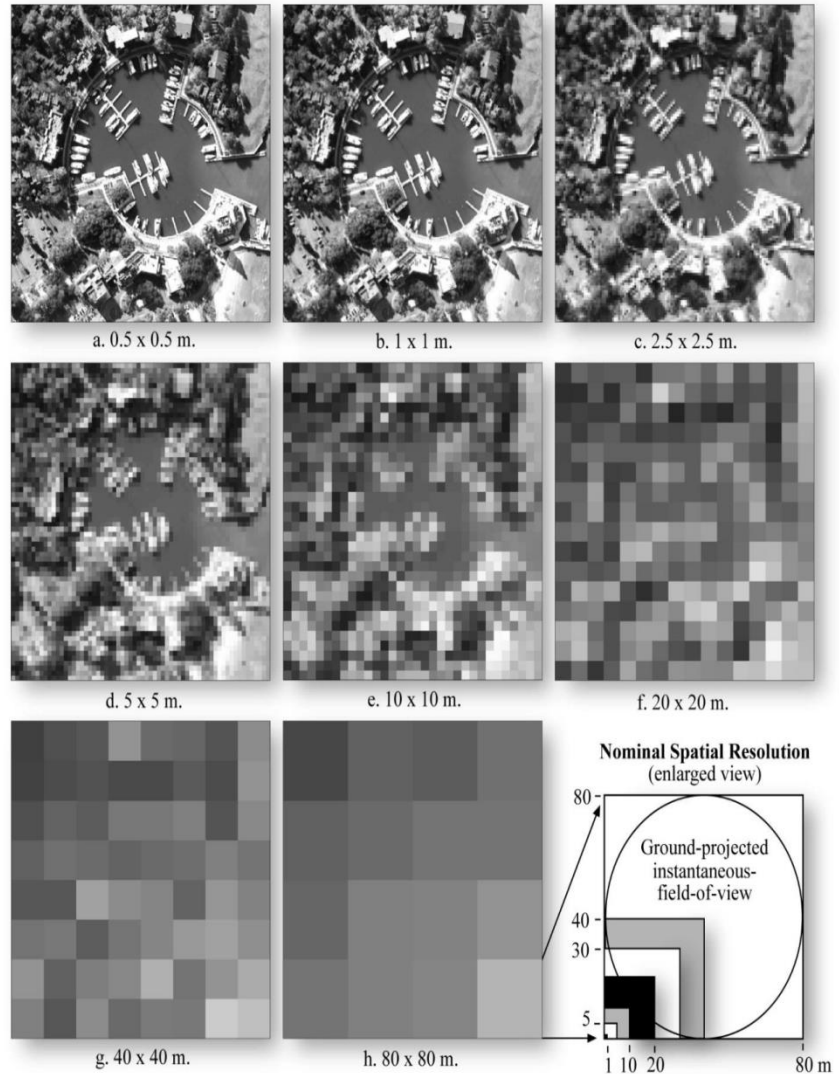
Spatial Resolution: Ability of RS objects to discriminate spatial objects

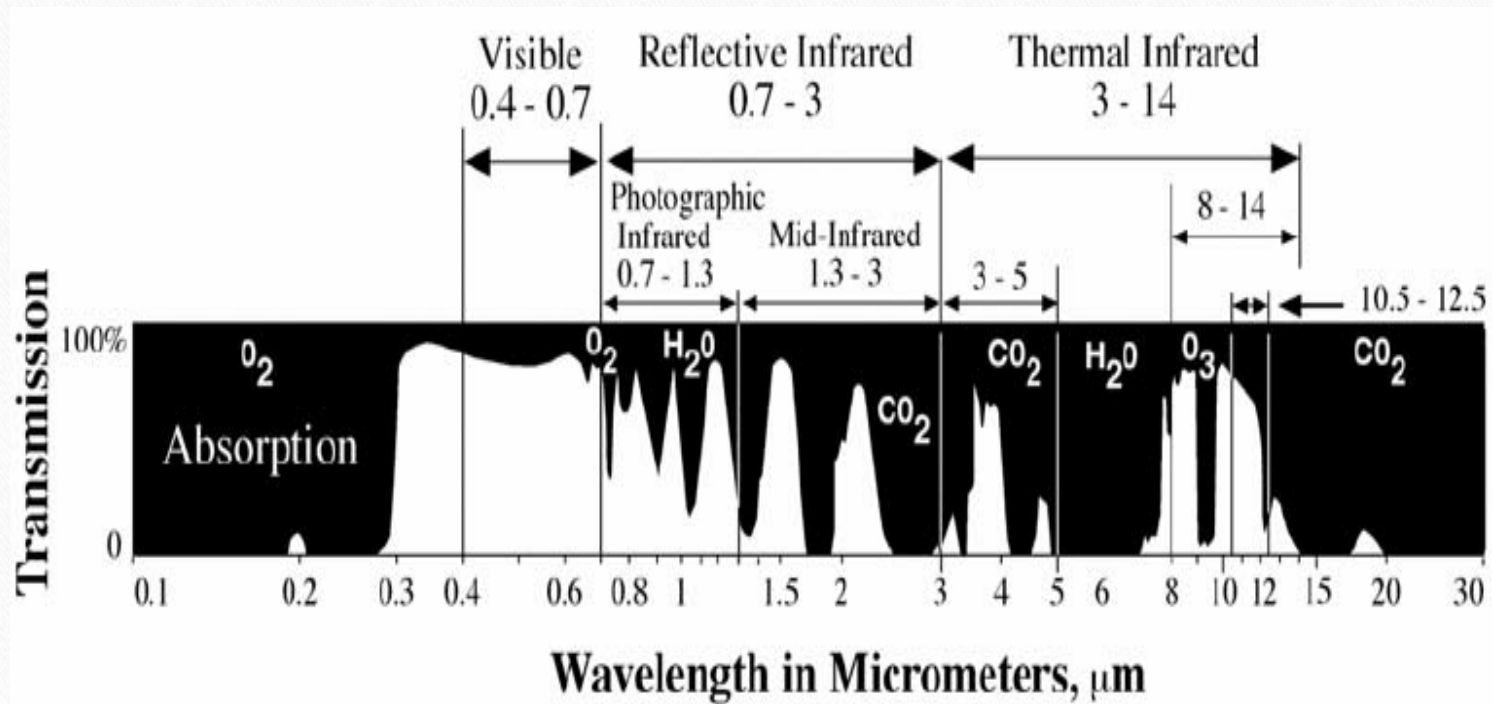
Pixel size in m	Definition	Platform/sensor ^a	Application scale
0.1–0.5	Extremely high res.	Airborne scanner, aerial photos, geoeye-1 (pan), worldview-1 (pan), worldview-2 (ms)	1:500–1:5,000
>0.5–1	Very high res.	IKONOS (pan), quickBird (pan), orbview (pan)	1:5,000–1:10,000
>1–4	High res.	IKONOS (ms), quickBird (ms), orbview (ms), geoeye-1 (ms), IRS (pan)	1:10,000–1:15,000
>4–12	Medium res.	IRS (pan), IRS (LISS-IV ms), SPOT (pan)	1:15,000–1:25,000
>12–50	Low res.	ASTER, IRS (ms), Landsat-TM/ETM+ (pan, ms), SPOT (ms)	1:25,000–1:100,000
>50–250	Very low res.	Landsat MSS	1:100,000–1:500,000
>250	Extremely low res.	NOAA	>1: 500,000

^a pan: panchromatic; ms: multispectral

Bhatta, 2011

Imagery of Harbor Town in Hilton Head, SC, at Various Nominal Spatial Resolutions





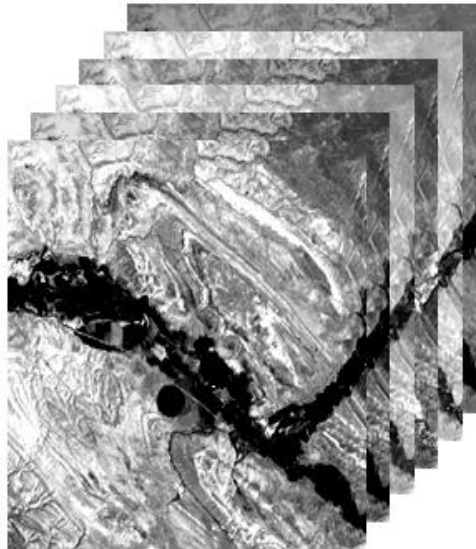
Spectral Resolution: Number and location of spectral bands

Panchromatic



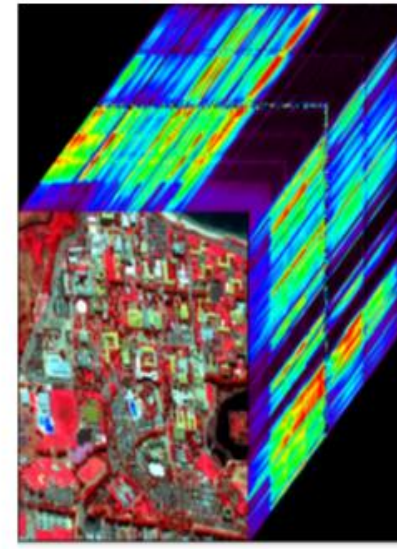
1 Band

Multispectral



Several Bands

Hyperspectral

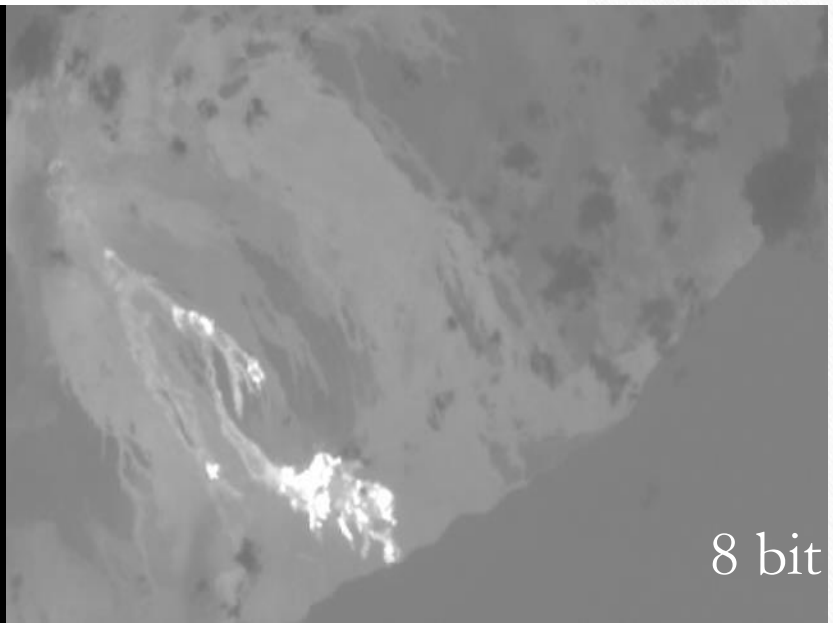
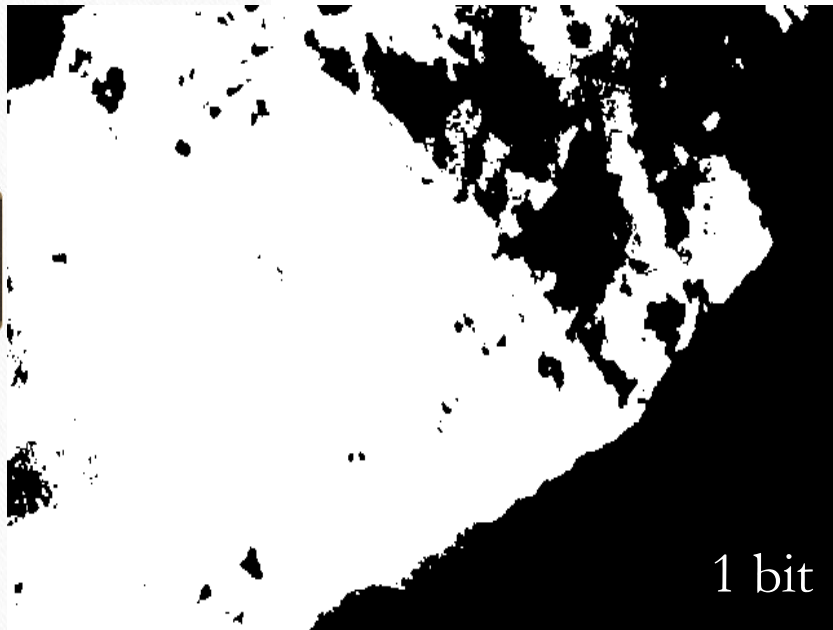


Hundreds of Bands

1959

Spectral Resolution: Number and location of spectral bands

							8 bits		11 bits		
							↓		↓		
1	2	3	4	5	6	7	8	9	10	11	Number of bits
2	4	8	16	32	64	128	256	512	1024	2048	Maximum Values



Radiometric Resolution: Sensitivity of the RS system

Temporal Resolution

- Time required to revisit the exact location
- The time factor in imaging is important when
 - Persistent clouds offer limited clear views of the earth's surface (often in the tropics).
 - Short-lived phenomena (floods, oil slicks, etc.) need to be imaged.
 - Multi-temporal comparisons are required (e.g., the spread of a forest disease from one year to the next).

Example:

NOAA AVHRR: <1 day

MODIS: 1-2 days

QuickBird: 1-3.5 days

IKONOS: 16 days

Landsat: 16 days

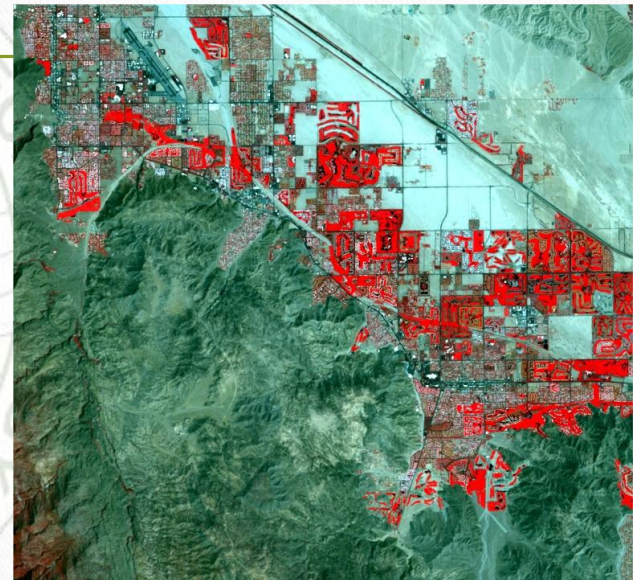
RADARSAT: 24 days

SPOT5: 26 days

Remotely Sensed Data Types

Region of EMR

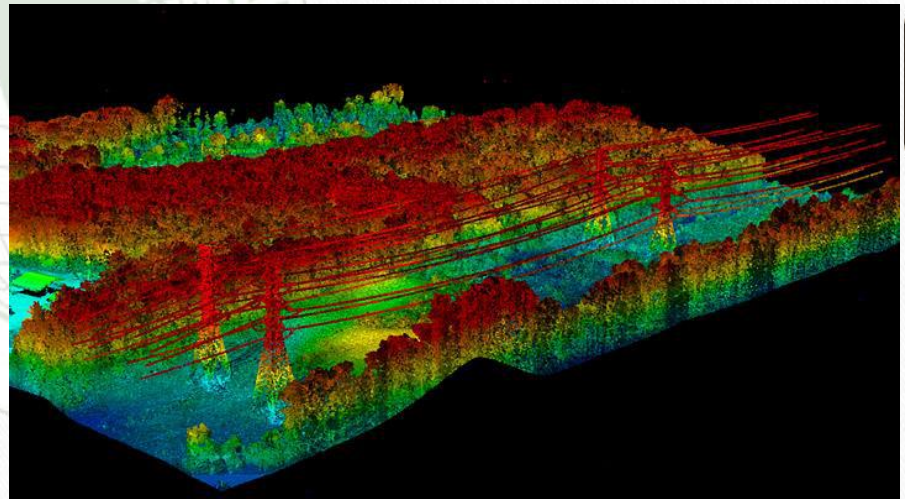
- Optical Remote Sensing (Passive)
 - Visible, NIR and SWIR
 - Reflected energy
 - High spatial and temporal resolution
 - Common applications
 - Land use cover classification
 - Crop inventories
 - Mineral exploration
 - Monitoring and modeling: vegetation, urban, hydrology, geology
 - Common Sensors
 - Landsat, Theos, Aster, Quickbird, Ikonos, Worldview, IRS



Remotely Sensed Data Types

Region of EMR

- Optical Remote Sensing (Active)
 - LiDAR
 - Green and NIR
 - One light pulse=several returns
 - Common Applications
 - Digital Elevation Models
 - Agriculture and forestry
 - Shoreline mapping
 - Urban utilities

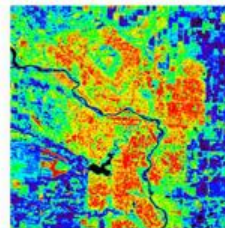


Remotely Sensed Data Types

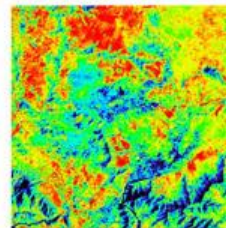
Region of EMR

- Thermal Remote Sensing

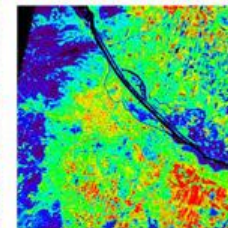
- Emitted energy
- Common Applications
 - Forest fire
 - Urban Heat Island
 - Active volcanos
 - Military purposes
- Common Sensors
 - Landsat
 - Aster



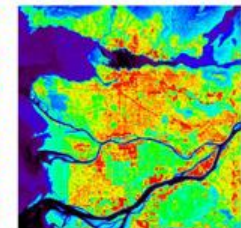
Calgary



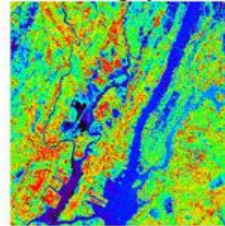
Kabul



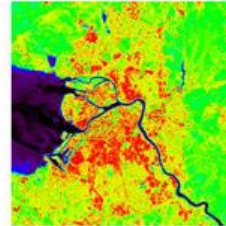
Vienna



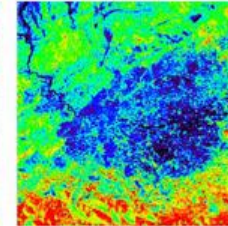
Vancouver



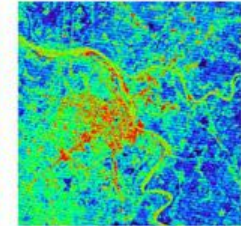
New York



St. Petersburg



Damascus

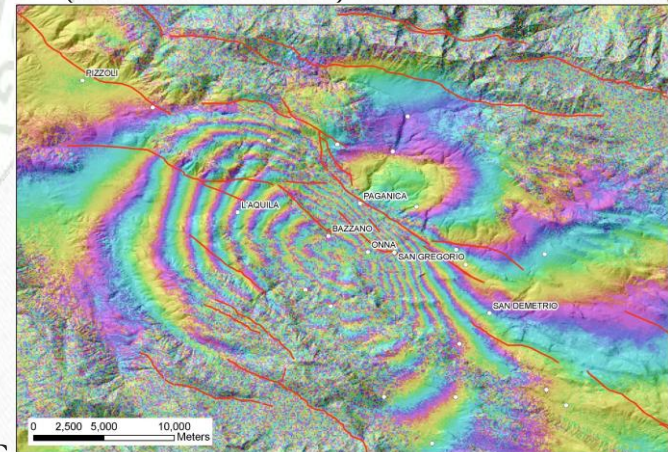


Hanoi

Remotely Sensed Data Types

Region of EMR

- Microwave Remote Sensing
 - Active (backscattering) & Passive (Emission)
 - Generally low spatial resolution
 - Can penetrate clouds, vegetation canopy, soil (few cm to m)
 - Common applications
 - Sea and glacial ice monitoring
 - Ocean winds
 - Soil Moisture
 - Vegetation
 - Precipitation
 - Common sensors: Radars and Radiometers



Defining Geographic Information Systems (GIS)

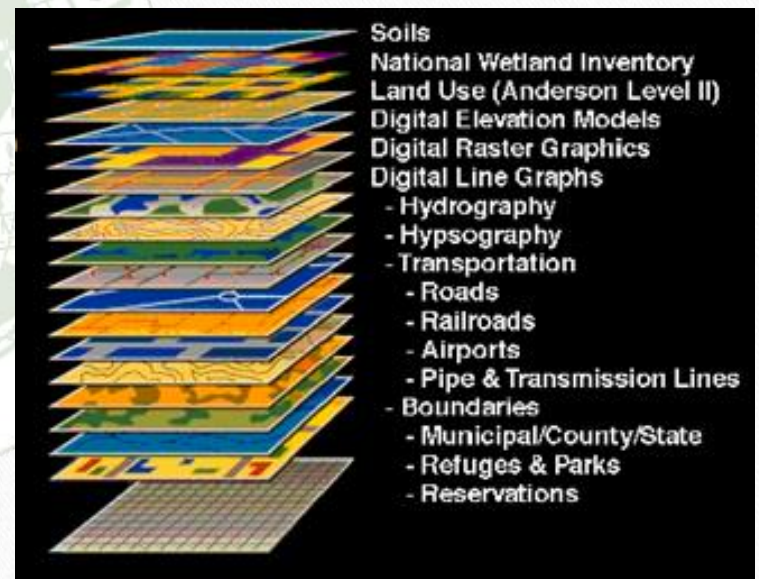
- The *common ground* between information processing and the many fields using spatial analysis techniques. (Tomlinson, 1972)
- A powerful *set of tools* for collecting, storing, retrieving, transforming, and displaying spatial data from the real world. (Burroughs, 1986)
- A computerised *database management system* for the capture, storage, retrieval, analysis and display of spatial (locationally defined) data. (NCGIA, 1987)
- A *decision support system* involving the *integration* of spatially referenced data in a problem solving environment. (Cowen, 1988)

Geographic Information System: *intuitive description*

- A map with a database behind it.
- A virtual representation of the real world and its infrastructure.
- A consistent “as-built” of the real world, natural and manmade

Which is

- *queried* to support *on-going operations*
- *summarized* to support *strategic decision making and policy formulation*
- *analyzed* to support *scientific inquiry*



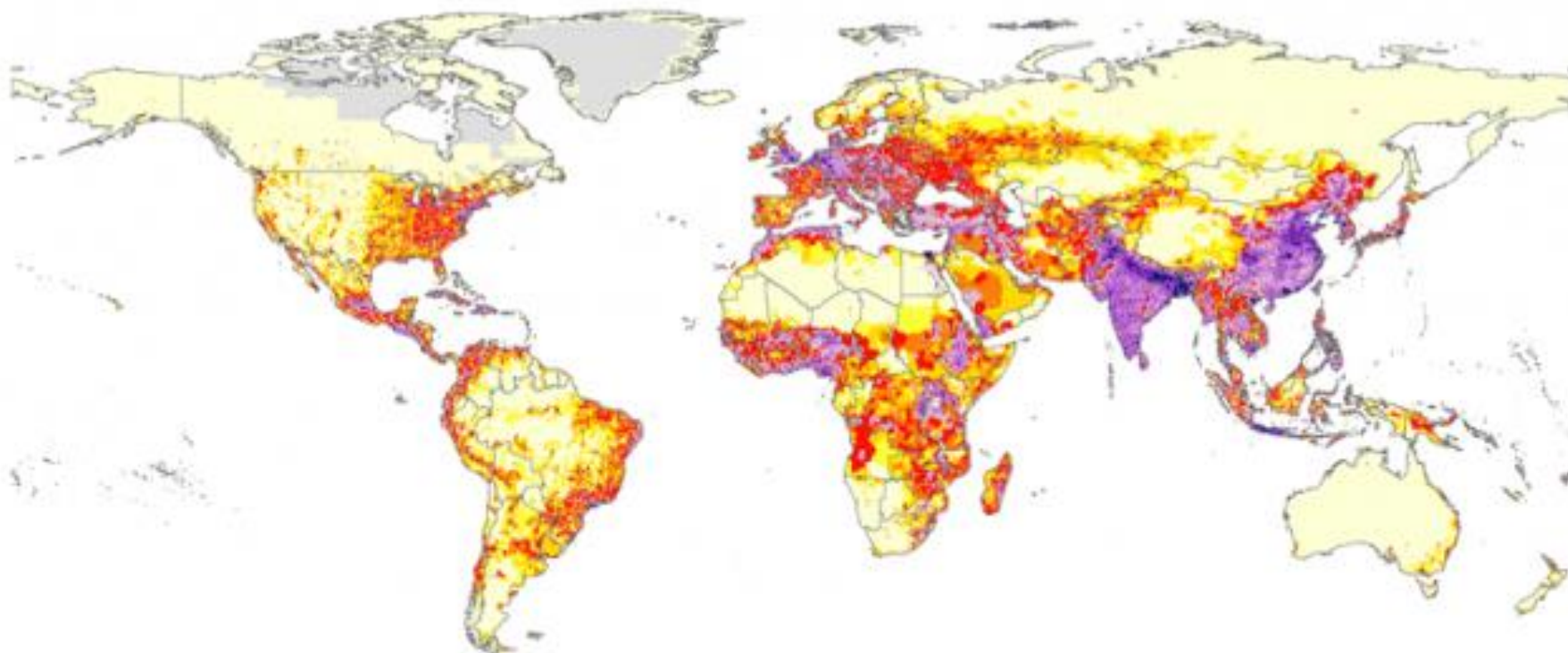
Map: Basic Elements

A map portrays 3 kinds of information about geographic features:

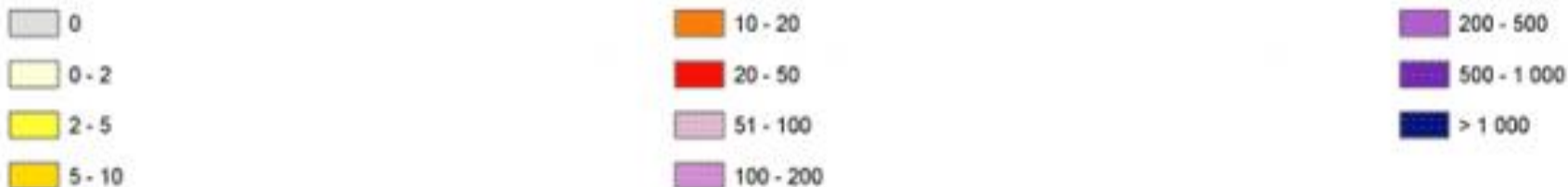
- ✓ Location and extent of the feature
- ✓ Attributes (characteristics) of the feature
- ✓ Relationship of the feature to other features

Elements:

- ✓ Title
- ✓ Legend
- ✓ Names of Feature
- ✓ Directional Indicator
- ✓ Scale
- ✓ Map Grid



Persons per square kilometre

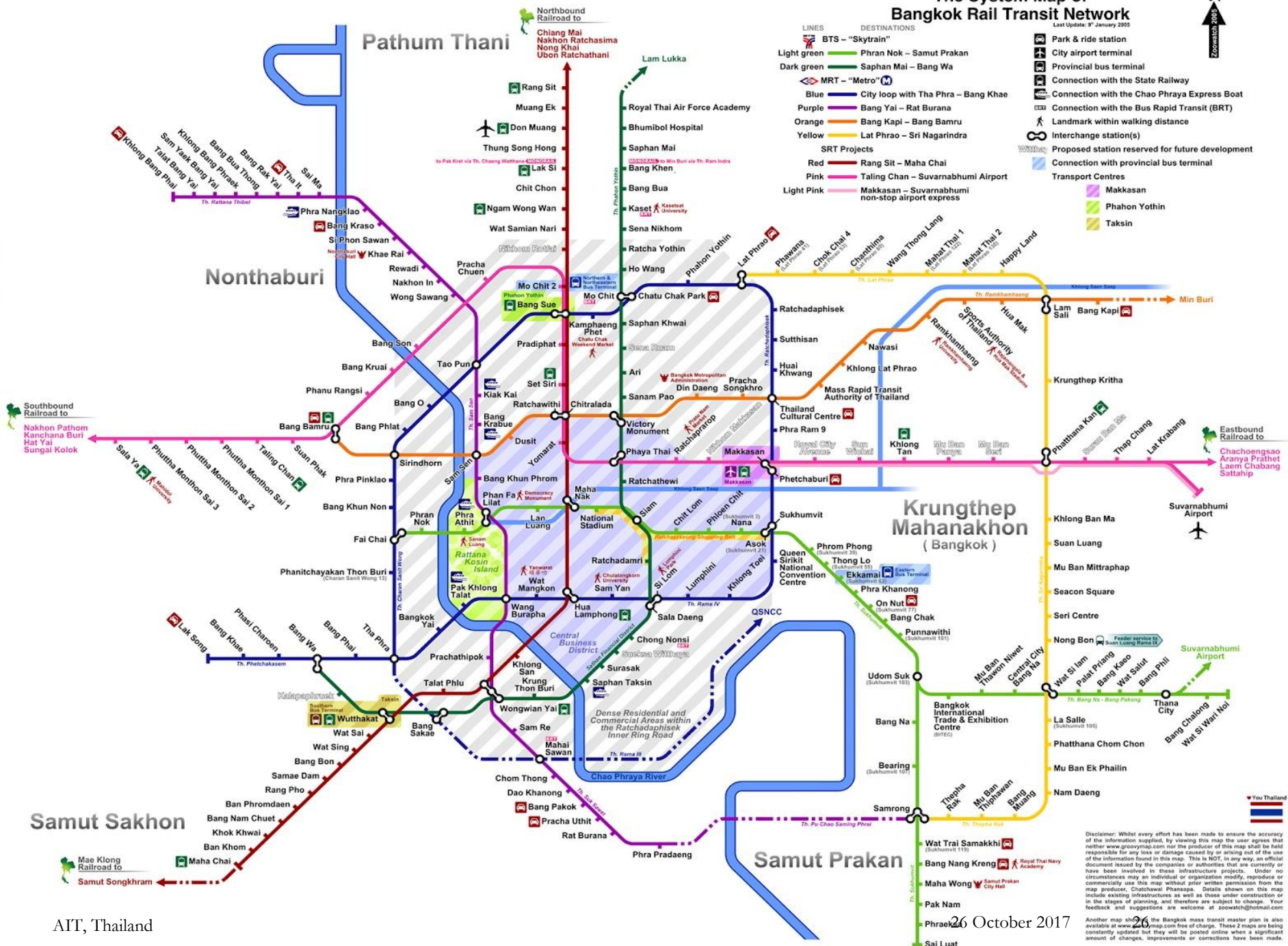


Reference: FAO, 2005. "Mapping global urban and rural population distributions", by M. Salvatori, F. Pozzi, E. Ataman, B. Haddleton & M. Birsa. Environmental and Natural Resources Working Paper No. 24. Rome.

This map was printed from the DVD included in "Food Insecurity, Poverty and Environment Global GIS Database: DVD and Atlas for the Year 2000", Environmental and Natural Resources Working Paper No. 26. FAO, Rome 2006. The geographic representations employed on this map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any country, territory, or of its authorities, or concerning the delimitation of its boundaries. Please, see the full FAO disclaimer in the above documents. © FAO & CIESIN

The System Map of Bangkok Rail Transit Network

Last Update: 9th January 2015



Disclaimer: Whilst every effort has been made to ensure the accuracy of the information supplied, by viewing this map the user agrees that neither www.goovias.com nor the producer of this map shall be held responsible for any loss or damage caused by or arising out of the use of the information found in this map. This is NOT, in any way, an official document issued by the companies or authorities that are currently or have been involved in these infrastructure projects. Under no circumstances may an individual or organization modify, reproduce or commercially use this map without prior written permission from the map producer, Chatchawal Phansopa. Details shown on this map include existing infrastructures as well as those under construction or in the stages of planning, and therefore are subject to change. Your feedback and suggestions are welcome at zowatch@hotmail.com.

Another map of the Bangkok mass transit master plan is also available at www.goovias.com free of charge. These 2 maps are being constantly updated but they will be posted online when a significant amount of changes, improvements or corrections have been made.

GIS Components

A Geographic Information System (GIS) links locational (spatial) and database (tabular) information and enables a person to visualize patterns, relationships, and trends. This process gives an entirely new perspective to data analysis that cannot be seen in a table or list format. The five components of a GIS are listed below.

HARDWARE

The hardware is the computer and peripherals on which the GIS operates. Today, this could be a centralized computer server running the UNIX or Windows NT operating systems, a desktop PC, or an Apple Macintosh. The computer may operate in isolation or in a networked configuration.

- Computers
- Networks
- Peripheral Devices
 - Printers
 - Plotters
 - Digitizers



SOFTWARE

GIS software provides the functions and tools users need to store, analyze, and display geographical information. The key software components are:

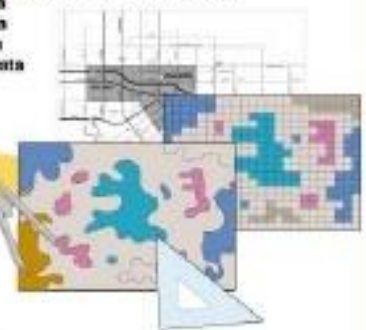
- GIS Software
- Database Software
- OS Software
- Network Software



DATA

One of the most important component of GIS is the data. It is absolutely essential that data be accurate. The following are different data types:

- Vector Data
- Raster Data
- Image Data
- Attribute Data



GIS

PEOPLE

GIS technology is clearly of limited value without people to manage the system and to develop plans for applying it. Users of GIS range from highly qualified technical specialists to planners, foresters, and market analysts who use GIS to help with their everyday work.

- Administrators
- Managers
- GIS Technicians
- Application Experts
- End Users
- Consumers



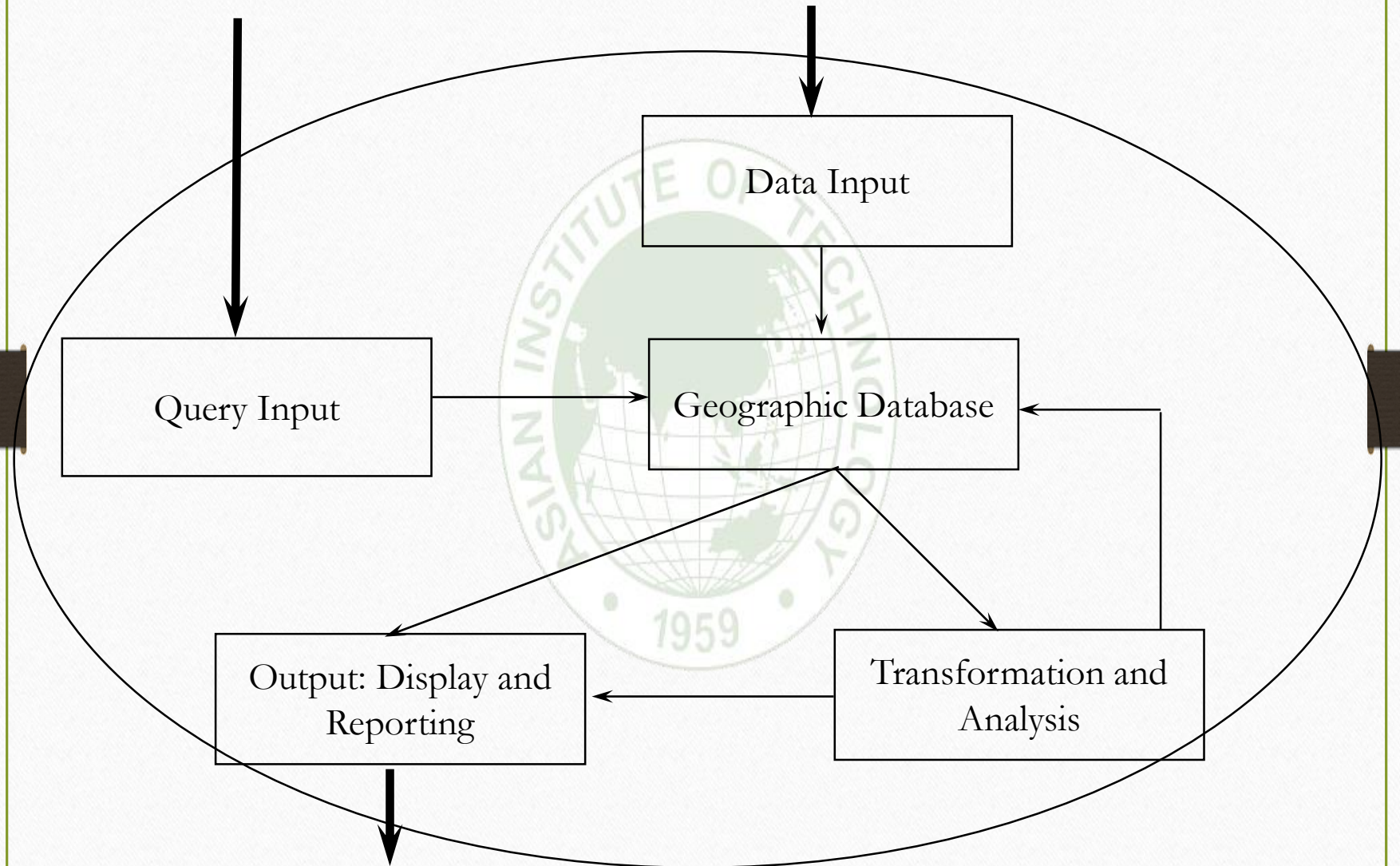
METHODS

Methods are well designed plans and application-specific business rules describing how technology is applied. This includes the following:

- Guidelines
- Specifications
- Standards
- Procedures



GIS System Architecture



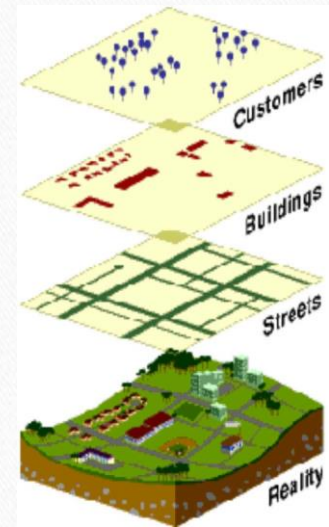
GIS – Data Analysis

Basically, GIS software can answer 2 types of questions about our world :

1. Spatial Query: What countries border with Bhutan?
2. Attribute Query: What are the countries having population more than 50 millions?

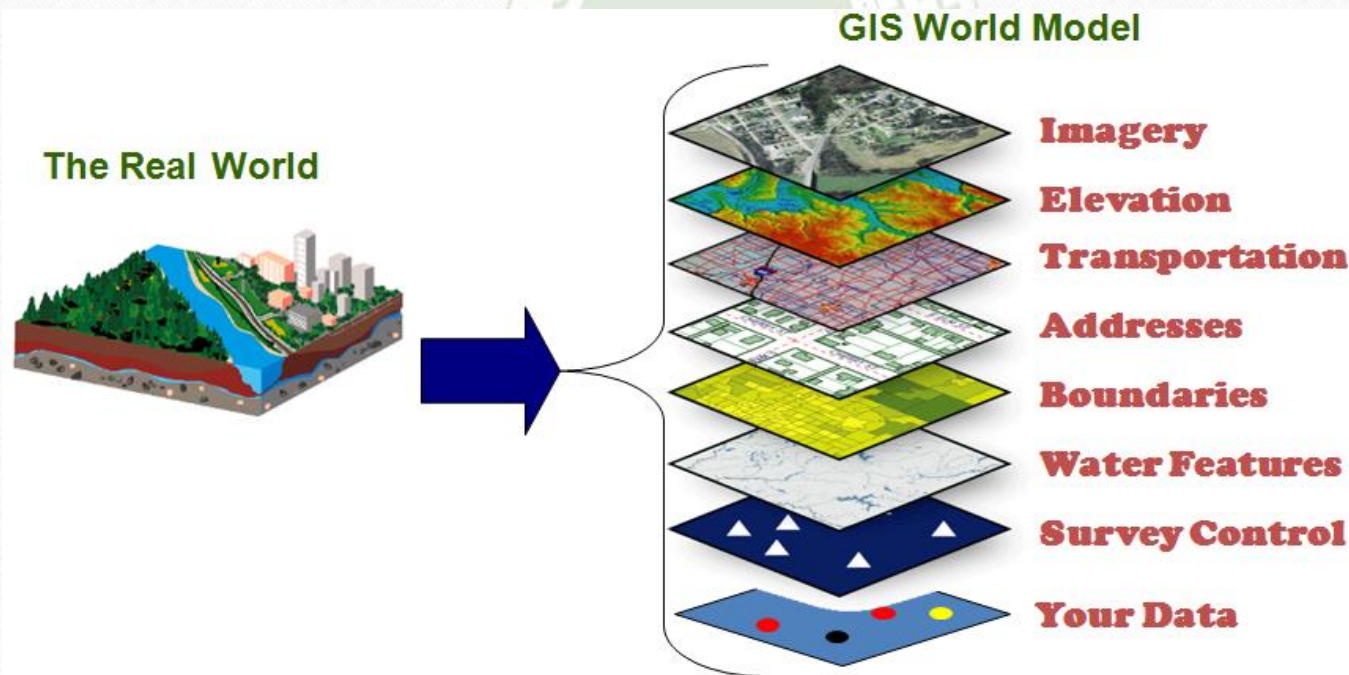
How GIS Works:

- Different type of information represented as separate map layers/themes
- Each layer/theme is linked to descriptive information
- Layer/themes are combined to make a map

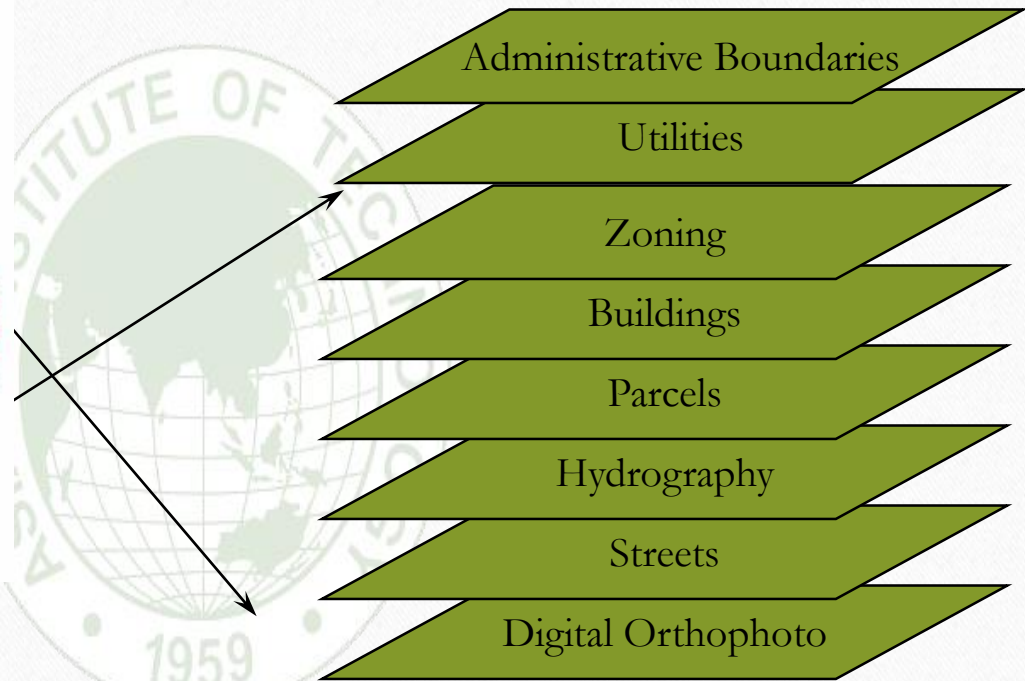


GIS Data Model

Allows the **geographic features** in **real world locations** to be digitally represented and stored in a database so that they can be abstractly presented in **map** (analog) form, and can also be worked with and **manipulated** to address some **problem**

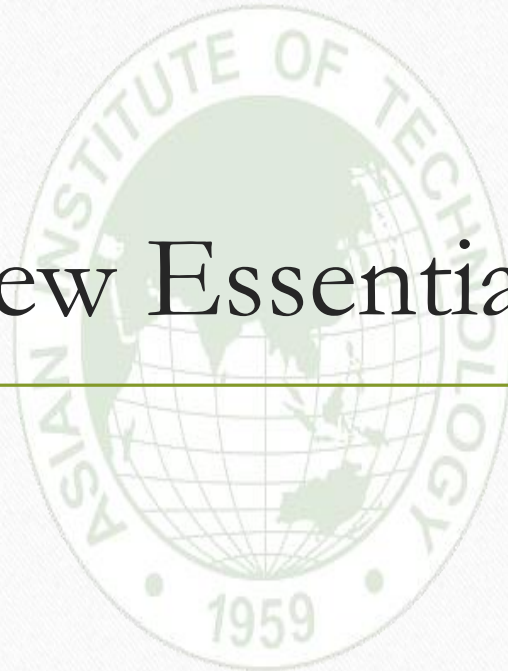


The GIS Data Model: Implementation



- Data is organized by layers, coverages or themes (synonymous concepts), *with each layer representing a common feature.*
- Layers are integrated using explicit location on the earth's surface, *thus geographic location is the organizing principal.*

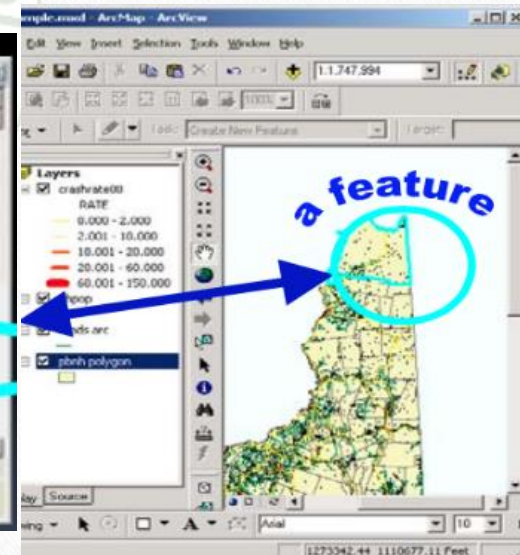
Few Essentials



Spatial and Attribute Data

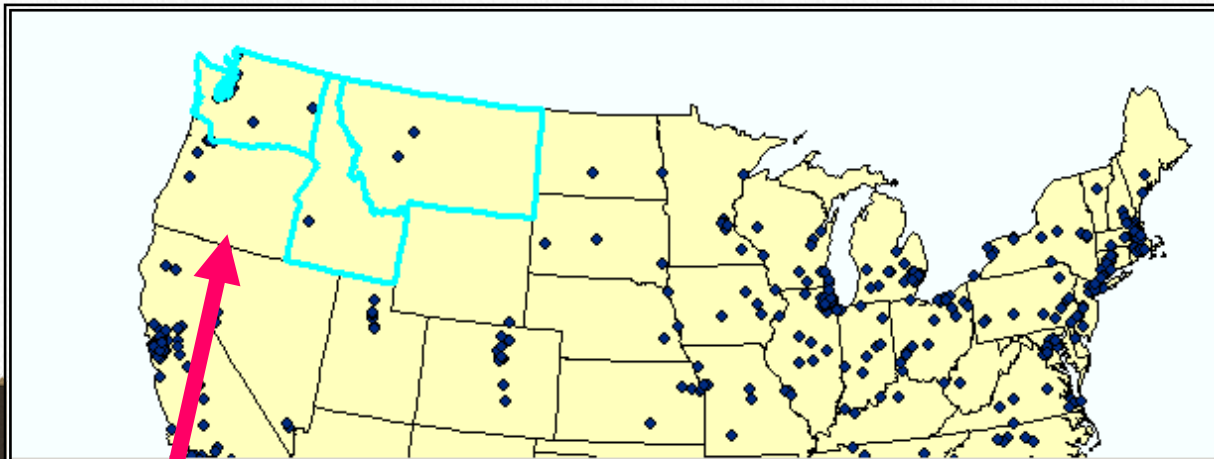
- Spatial data (*where*)
 - specifies location
 - stored in a *shape file*, *geodatabase* or similar geographic file
- Attribute (descriptive) data (*what, how much, when*)
 - specifies characteristics at that location, natural or human-created
 - stored in a data base table
- GIS systems traditionally maintain spatial and attribute data separately, then “join” them for display or analysis

FID	Shape*	AREA	PERIMETER	PENNR	PENH ID	FIPS	NAME	RPA_COUNTY
1	Polygon	81,0291,2364	564363,9625	2	1	7160	Pittsburg	7
3	Polygon	1738721440	219488,453125	3	2	7040	Clarksville	7
4	Polygon	539022912	104318,296875	4	3	7005	Abbeville & Gilberton	7
5	Polygon	1307633536	176385,65625	5	4	7190	Stewartstown	7
6	Polygon	1166270840	139129,9375	6	5	7175	Second College	7
7	Polygon	1270191872	166006,9375	7	6	7075	Deville	7
8	Polygon	959462864	105578,84375	8	7	7070	Don Grant	7
9	Polygon	1137201480	165905,671875	9	8	7045	Colebrook	7
10	Polygon	1708427000	189406,625	10	9	7000	Columbia	7
11	Polygon	1935937536	176429,46875	12	11	7085	Emul	7
13	Polygon	1260529664	144672,0625	13	12	7140	Millsfield	7
14	Polygon	104816344	42764,125	14	13	7090	Erving's Location	7
15	Polygon	1264136360	149679,709375	15	14	7190	Dodd	7
16	Polygon	2231643136	268728,19625	16	15	7135	Statham	7
17	Polygon	1441701120	151562,629375	17	16	7025	Cambridge	7



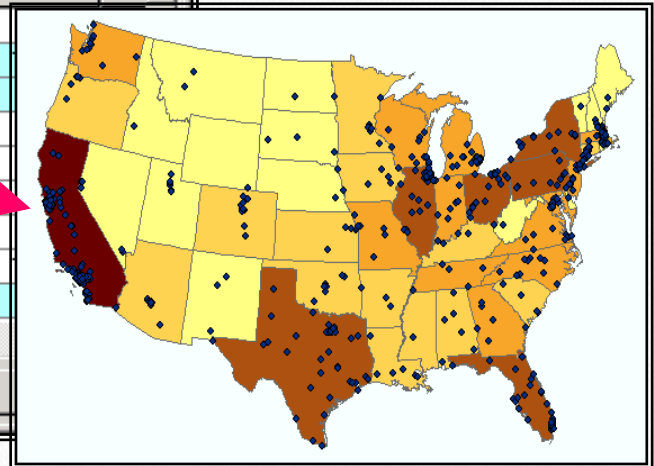
Features linked to data

Each feature is linked to an entry in a data table containing information about the feature.

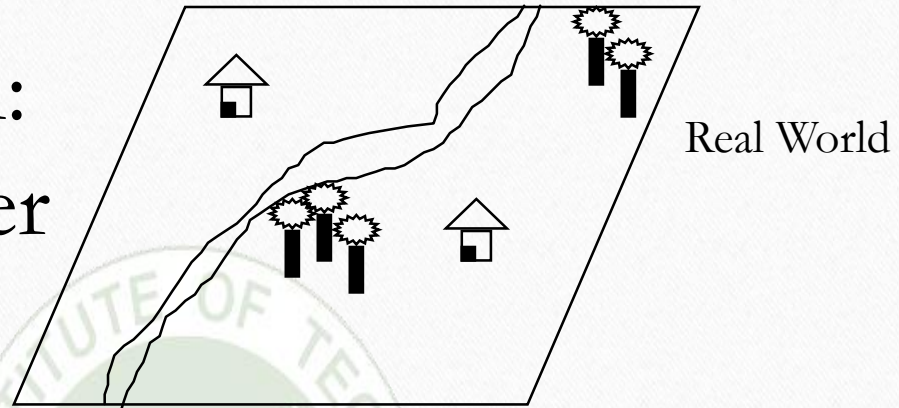


FID	Shape*	STATE_NAM	ABBR	POP1990	POP2000	POP90_SQMI	HOUSEHOLD	M
0	Polygon	Hawaii	HI	1108229	1184688	174		
1	Polygon	Washington	WA	4866692	5835089	72		
2	Polygon	Montana	MT	799065	885795	5		
3	Polygon	Maine	ME	1227928	1257819	38		
4	Polygon	North Dakota	ND	638800	631032	9		
5	Polygon	South Dakota	SD	696004	734993	9		
6	Polygon	Wyoming	WY	453588	479673	5		
7	Polygon	Wisconsin	WI	4891769	5277833	87		
8	Polygon	Idaho	ID	1006749	1273309	12		

Record: 1 Show: All Selected Records: (3 out of 51 Selected.)



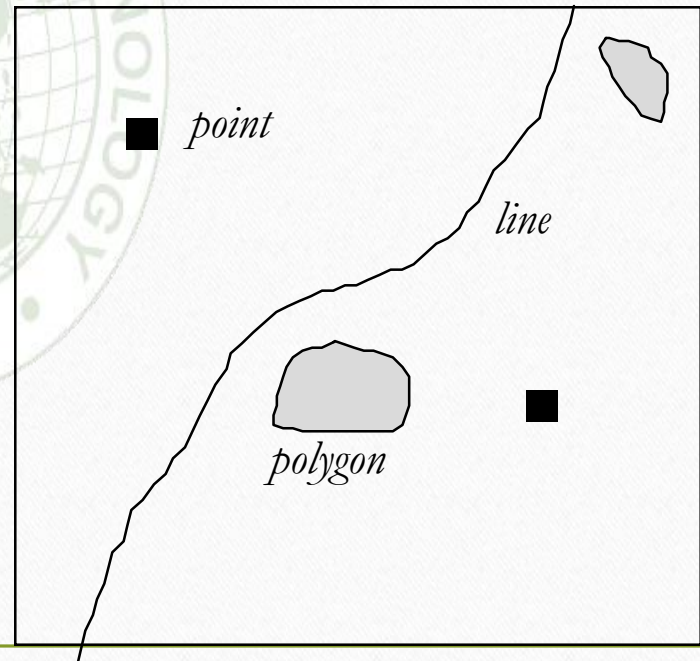
GIS Data Model: Vector and Raster



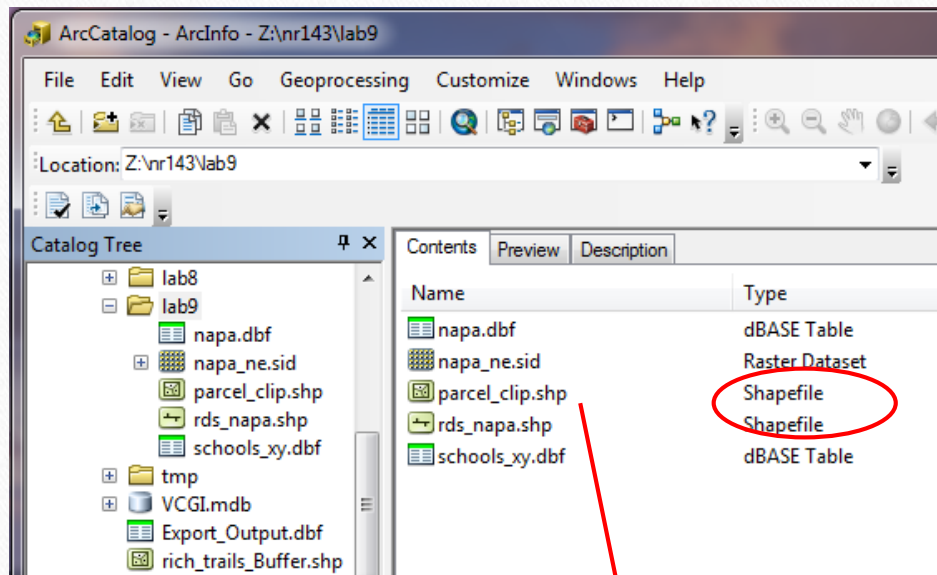
Raster Representation

	0	1	2	3	4	5	6	7	8	9
0								R	T	
1							R			T
2		H					R			
3							R			
4					R	R				
5				R						
6			R		T	T		H		
7			R		T	T				
8		R								
9		R								

Vector Representation



Vector File Formats: Shapefiles



.shp - The main file that stores the feature geometry.

.shx - The index file that stores the index of the feature geometry.

.dbf - The dBASE table that stores the attribute information of features.

There is a one-to-one relationship between geometry and attributes, which is based on record number. Attribute records in the dBASE file must be in the same order as records in the main file.

.sbn and **.sbx** - The files that store the spatial index of the features.

parcel_clip.dbf	11/9/2009 12:54 PM	DBF File	160 KB
parcel_clip.sbn	11/9/2009 12:54 PM	SBN File	96 KB
parcel_clip.sbx	11/9/2009 12:54 PM	SBX File	5 KB
parcel_clip.shp	11/9/2009 12:54 PM	SHP File	4,257 KB
parcel_clip.shp.xml	11/9/2009 12:54 PM	XML file	8 KB
parcel_clip.shx	11/9/2009 12:54 PM	SHX File	76 KB

Raster File Formats

- **Esri grid** – proprietary **binary** and metadataless **ASCII** raster formats used by **Esri**
- **GeoTIFF** – **TIFF** variant enriched with GIS relevant metadata
- **JPEG2000** – Open-source raster format. A compressed format, allows both lossy and lossless compression..
- **netCDF**-CF – netCDF file format with **CF metadata conventions** for earth science data. Binary storage in open format with optional compression. Allows for direct web-access of subsets/aggregations of maps through **OPeNDAP** protocol.

Other Data formats

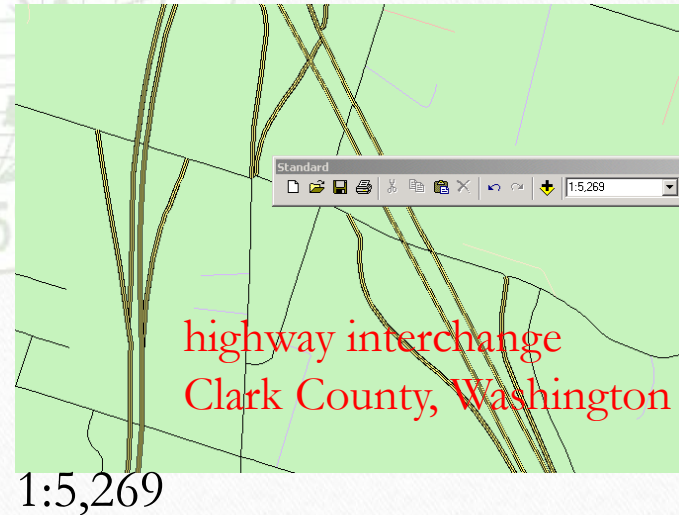
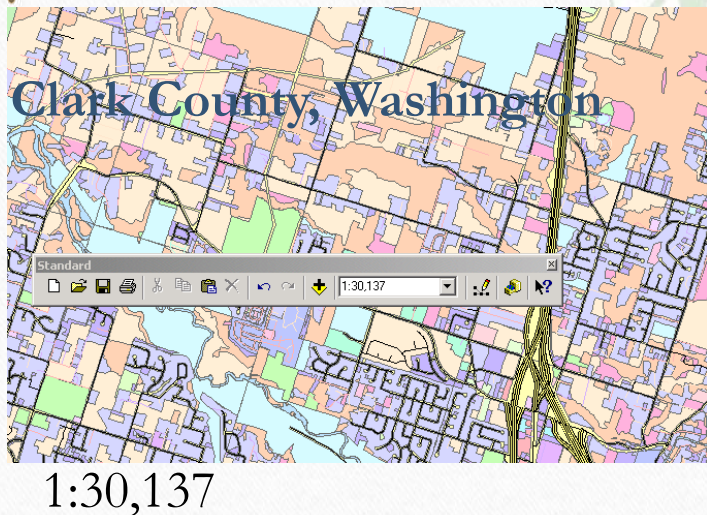
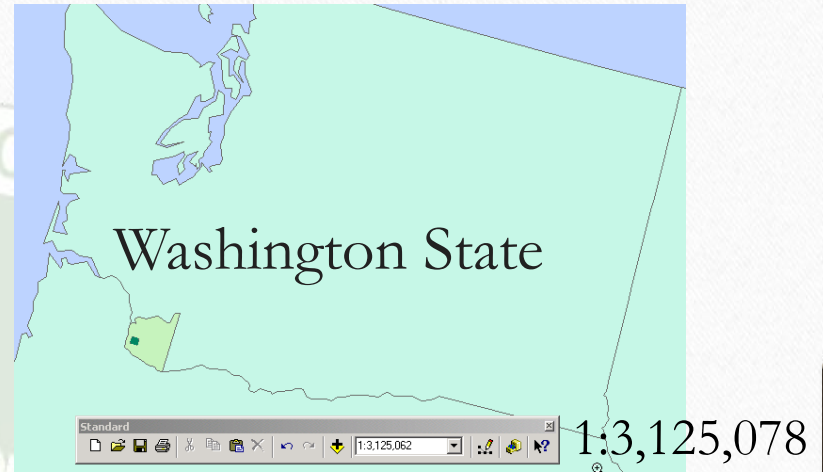
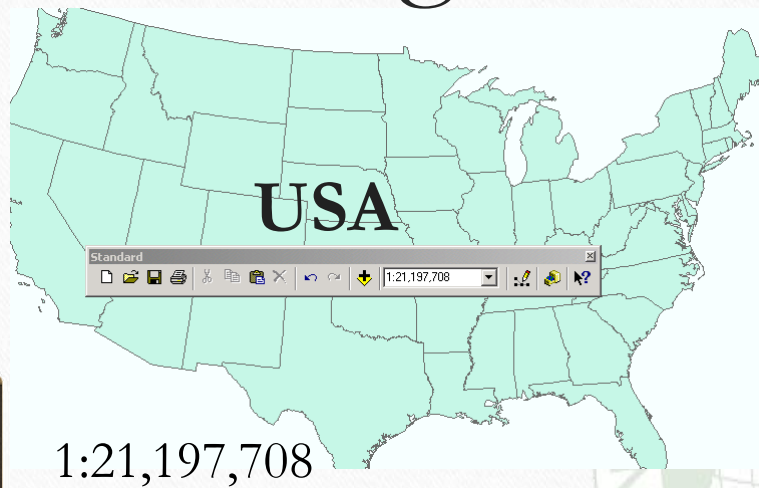
- **Tabular data:** data table (often non-spatial) that can be used in a GIS
 - Spreadsheet
 - Dbase database file -- .dbf
- **Map document:** a project file—it stores your map layout and preferences in ArcGIS....but not the data!

Scale

- Translation factor between one unit on the map and same unit in the real world
 - map units: ground units (ratio)
 - 1:10,000 means that 1 inch equals 10,000 inches in real world
- Scale is a dimensionless number

1 foot is 1.98 million feet in real world

Large vs. Small Scale



Coordinate Systems

- All spatial data is in a **coordinate system**
- Often loosely, but incorrectly, called a **map projection**
- Coordinate System consists of **two** main things:
 - **Datum**: normally WGS84 or NAD 27 or NAD 83
 - The same location may have different coordinates just because of datum
 - **Projection**
 - The transformation by which 3D lat/long is converted to 2D X/Y Cartesian values
 - *parameters* normally required to describe the exact nature of the projection
 - Projected Coordinates must be in some *measurement unit*: usually feet or meters
 - A “geographic projection” uses lat/long values as X/Y Cartesian coordinates (not recommended)
- Thus, for any a spatial data set, knowing simply the name of the projection is **not sufficient**. Must also know:
 - Datum
 - Parameter(s)
 - Measurement units

We often say map projection, when we really mean coordinate system!

What Can GI Technologies Do for Flood Management

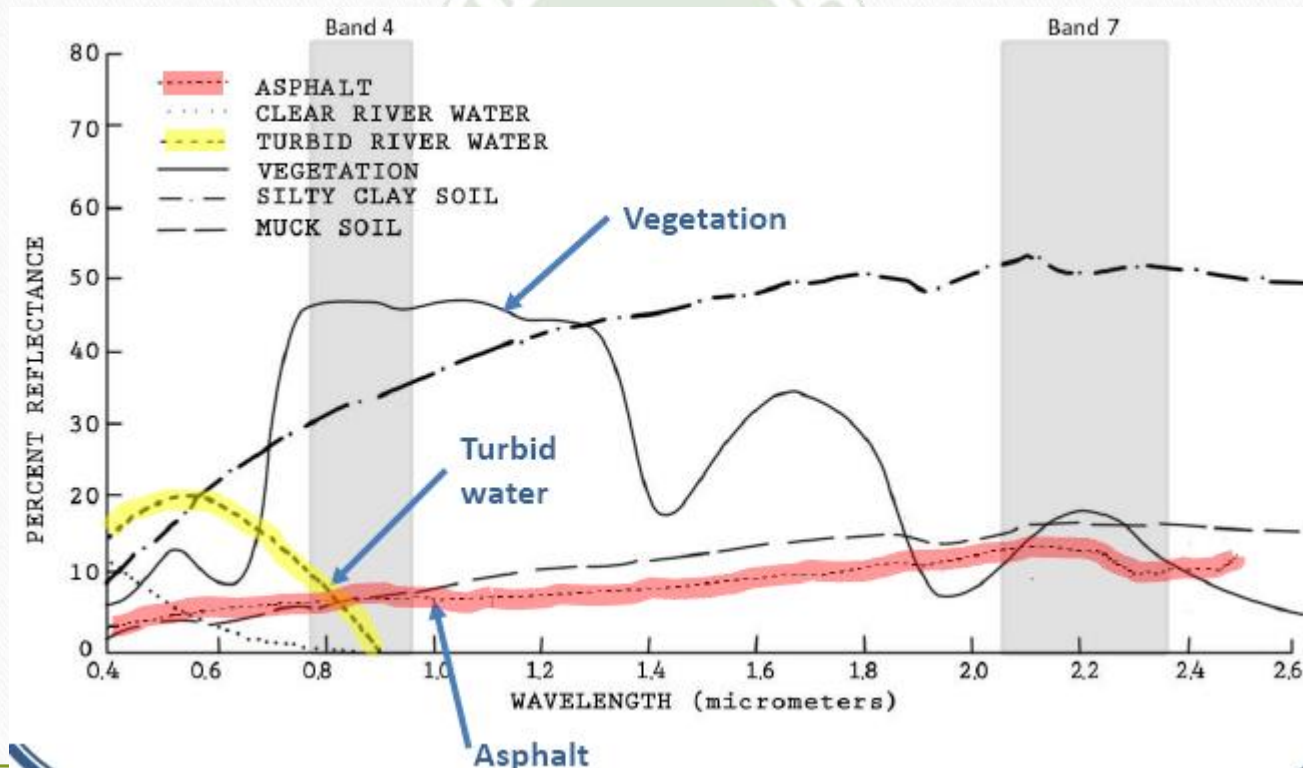


GI technologies in Flood Management

- A. Derivation of flood extent and depth! (Flood mapping and monitoring)
- B. Subsequent products:
 - A. Evacuation route
 - B. Identifying flood shelter (refuge locations)
 - C. Vulnerability/ Damage Assessment
 - D. Risk Mapping**

A. Flood Mapping

- Optical Remote Sensing
 - Using spectral signatures: dry and wet areas have different spectral signatures: water absorbed at higher wavelengths
 - Using indices: Normalized Difference Water Index





Landsat 5 TM Image Subset
Path 23, Row 34
Acquired: 14 October 2010



Landsat 5 TM Image Subset
Path 23, Row 34
Acquired: 10 May 2011

A. Flood Mapping

- Optical Remote Sensing

Advantages	Limitations
Spectral Resolution-allows the use of bands and spectral signatures to classify flooded pixels	Satellite revisit time
Free or low cost imagery	Cannot detect under cloud and canopy condition

A. Flood Mapping

- Microwave Remote Sensing

- Using surface roughness:

- Water: smooth surface --> specular reflection --> low reflection to radar sensor
 - Land: rough surface --> diffuse indirect reflection --> sharp edge reflection --> double bounce effect

- Using backscatter values: Flooded areas have low backscatter values

Change Detection - - > Thresholding on intensity difference

31st October 2008

6th November 2010

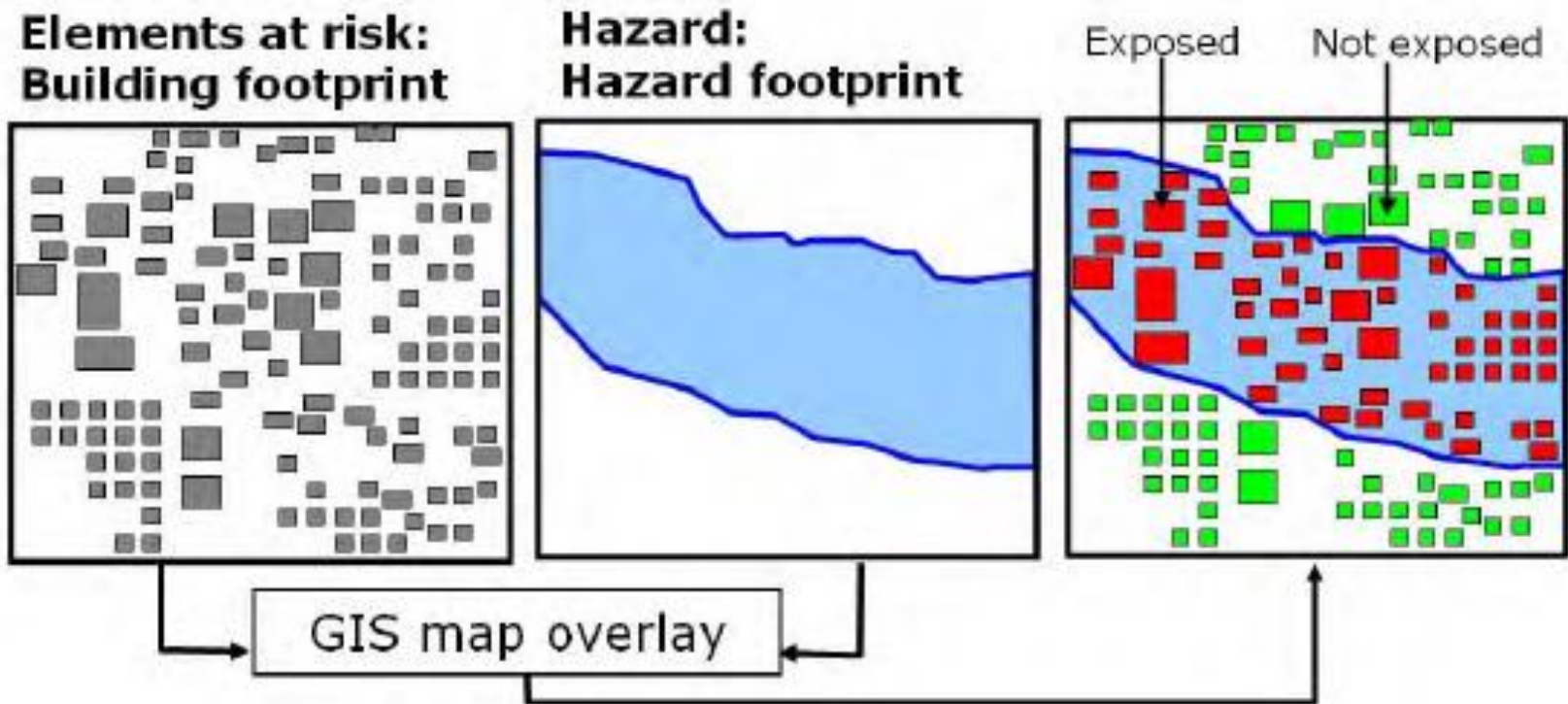


A. Flood Mapping

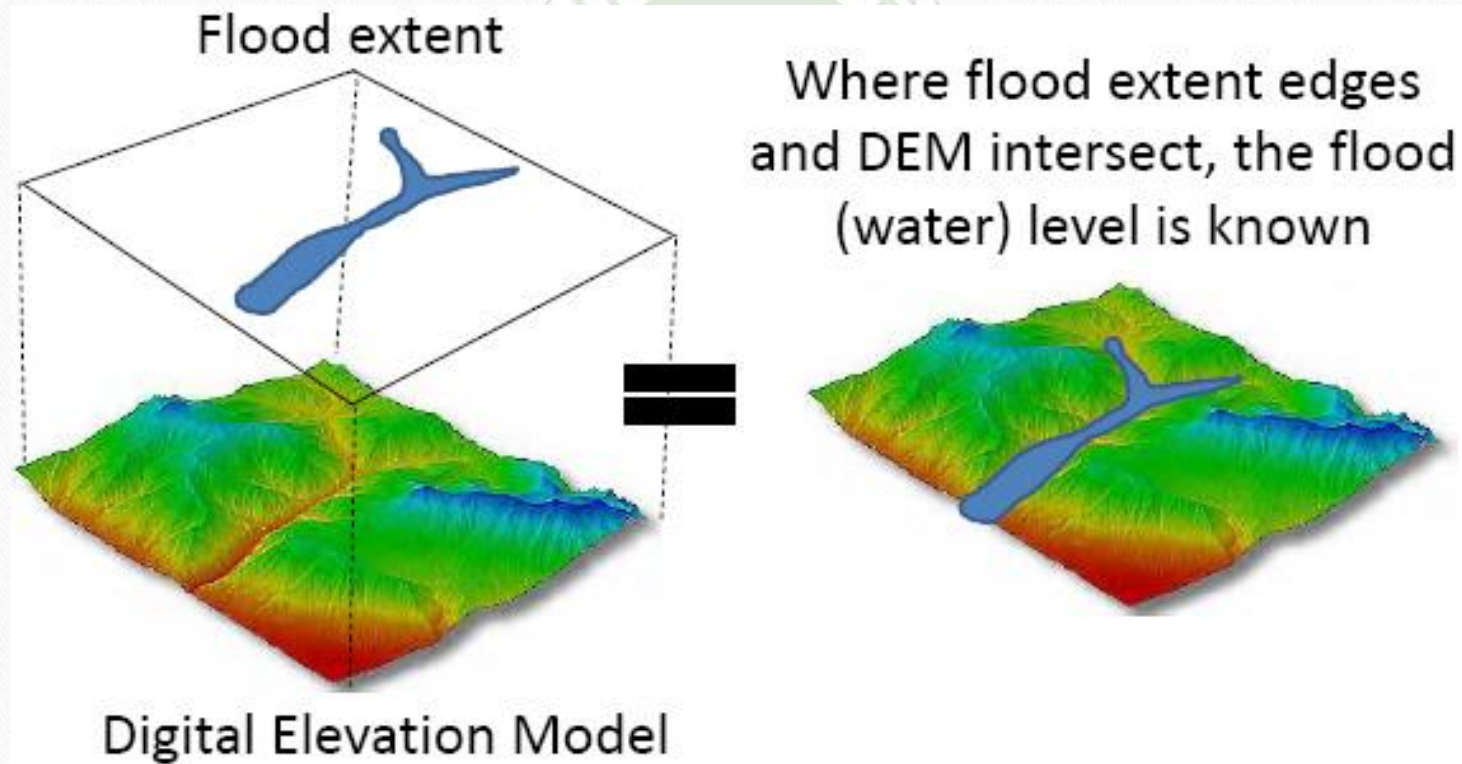
- Microwave Remote Sensing

Advantages	Limitations
Can Penetrate cloud and canopy cover	Expensive and high end processing
Day and night measurements (own energy source)	Long revisit time

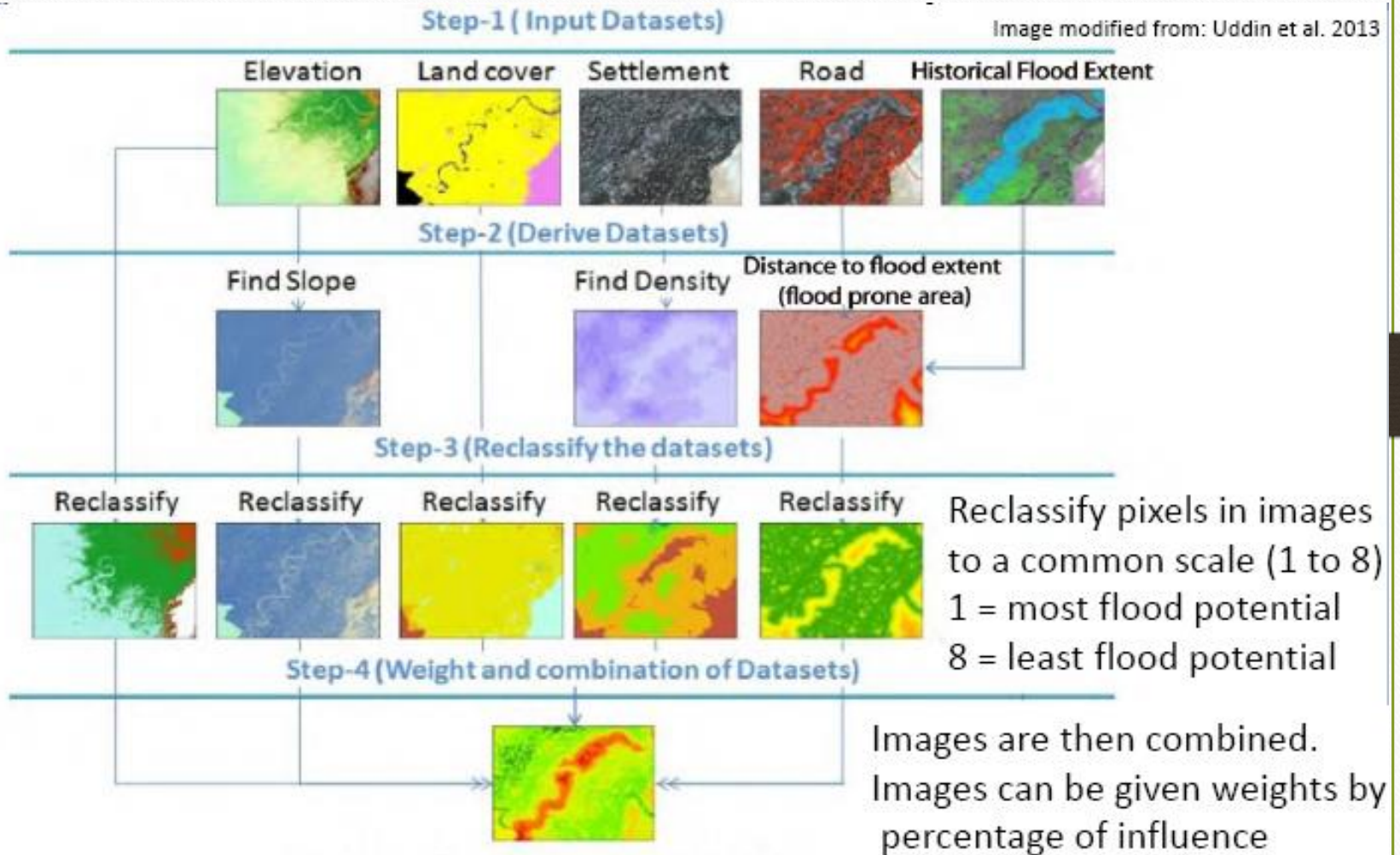
B. Subsequent products: Vulnerability assessment: Extent



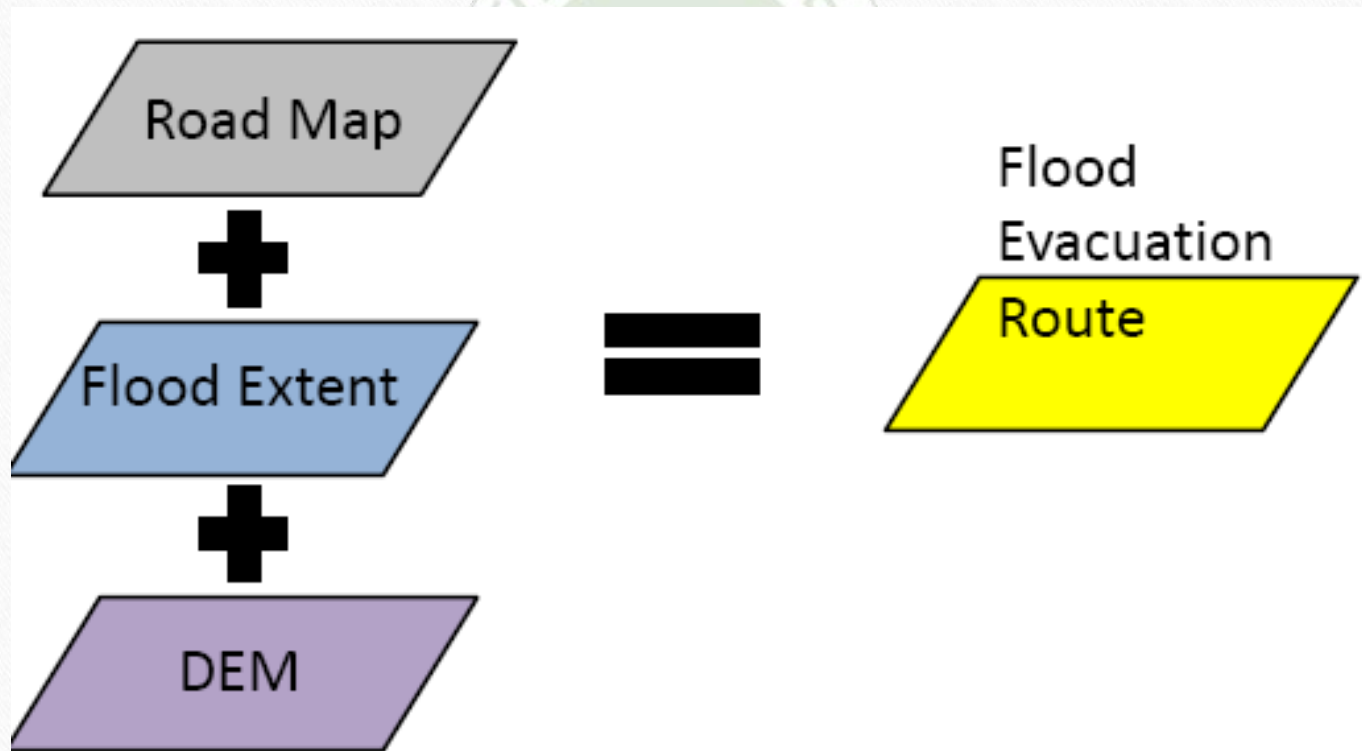
B. Subsequent products: Flood level calculation



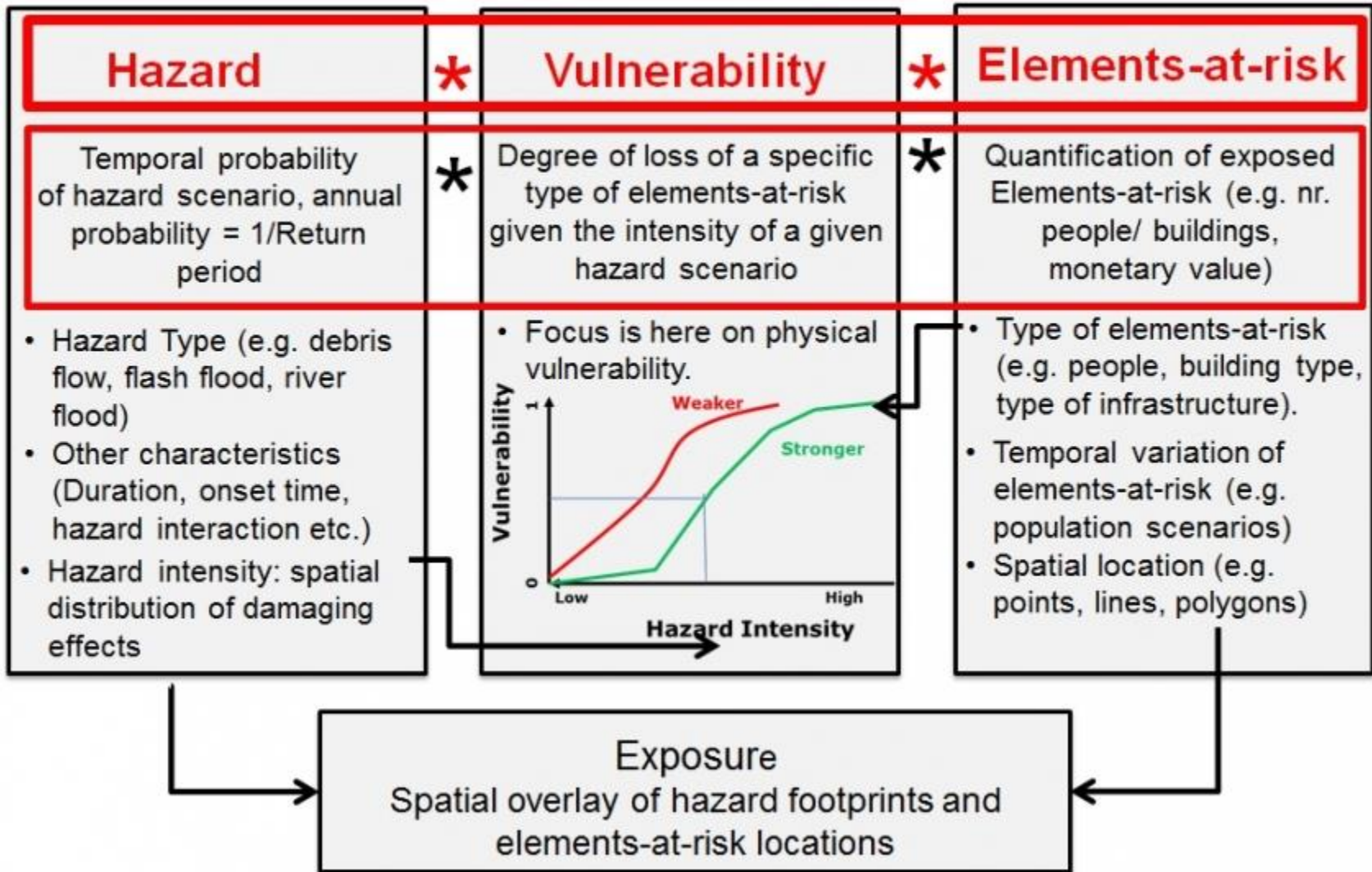
B. Subsequent products: Flood Shelter Analysis



B. Subsequent products: Flood evacuation route



Risk = probability of losses =



Issues of GI technologies in Flood Management?

- Not accurate as gauges
- Measurements do not occur as often (limited by satellite revisit time)
- Dependency on DEM

Thank You

**Questions
&
Comments**

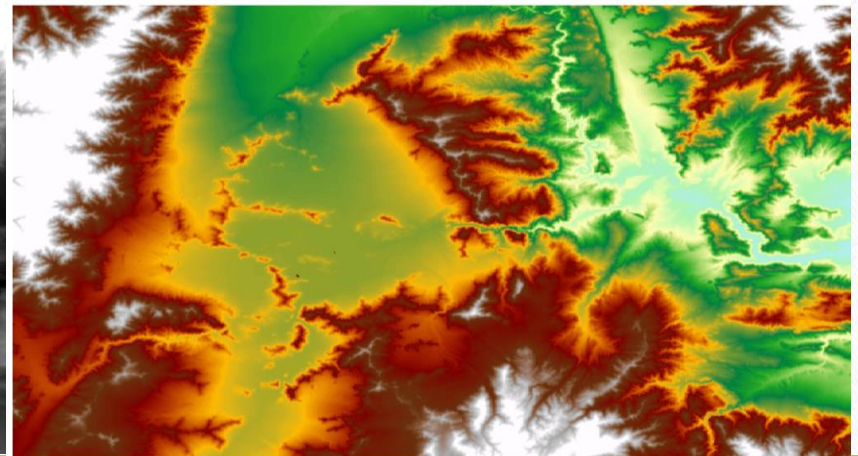
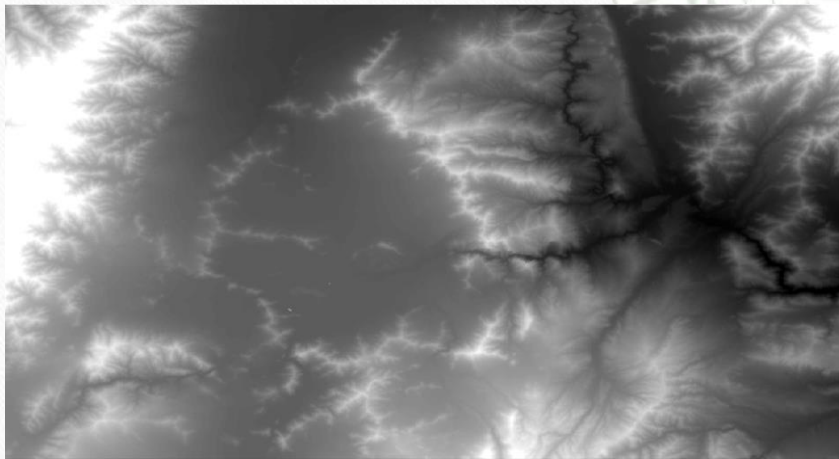


Digital Elevation Model



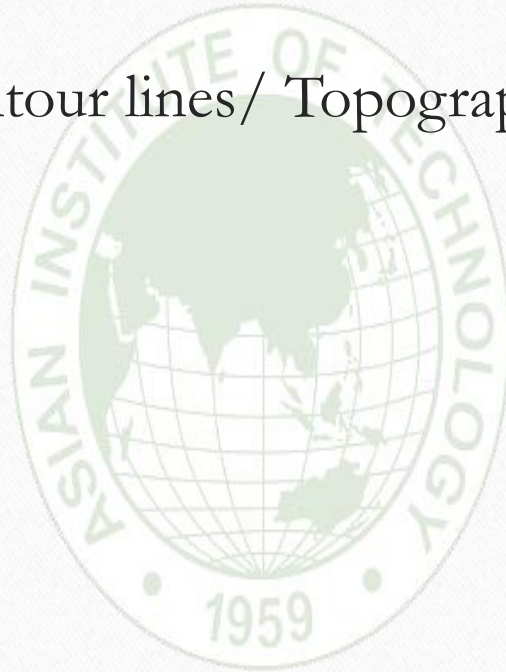
Digital Elevation Model

- the term digital elevation model or DEM is frequently used to refer to any digital representation of a topographic surface
 - however, most often it is used to refer specifically to a raster or regular grid of spot heights
- the resolution, or the distance between adjacent grid points, is a critical parameter
 - the best resolution commonly available is 30 m, with a vertical resolution of 1 m
 - coverages of the entire globe, including the ocean floor, can be obtained at various resolutions

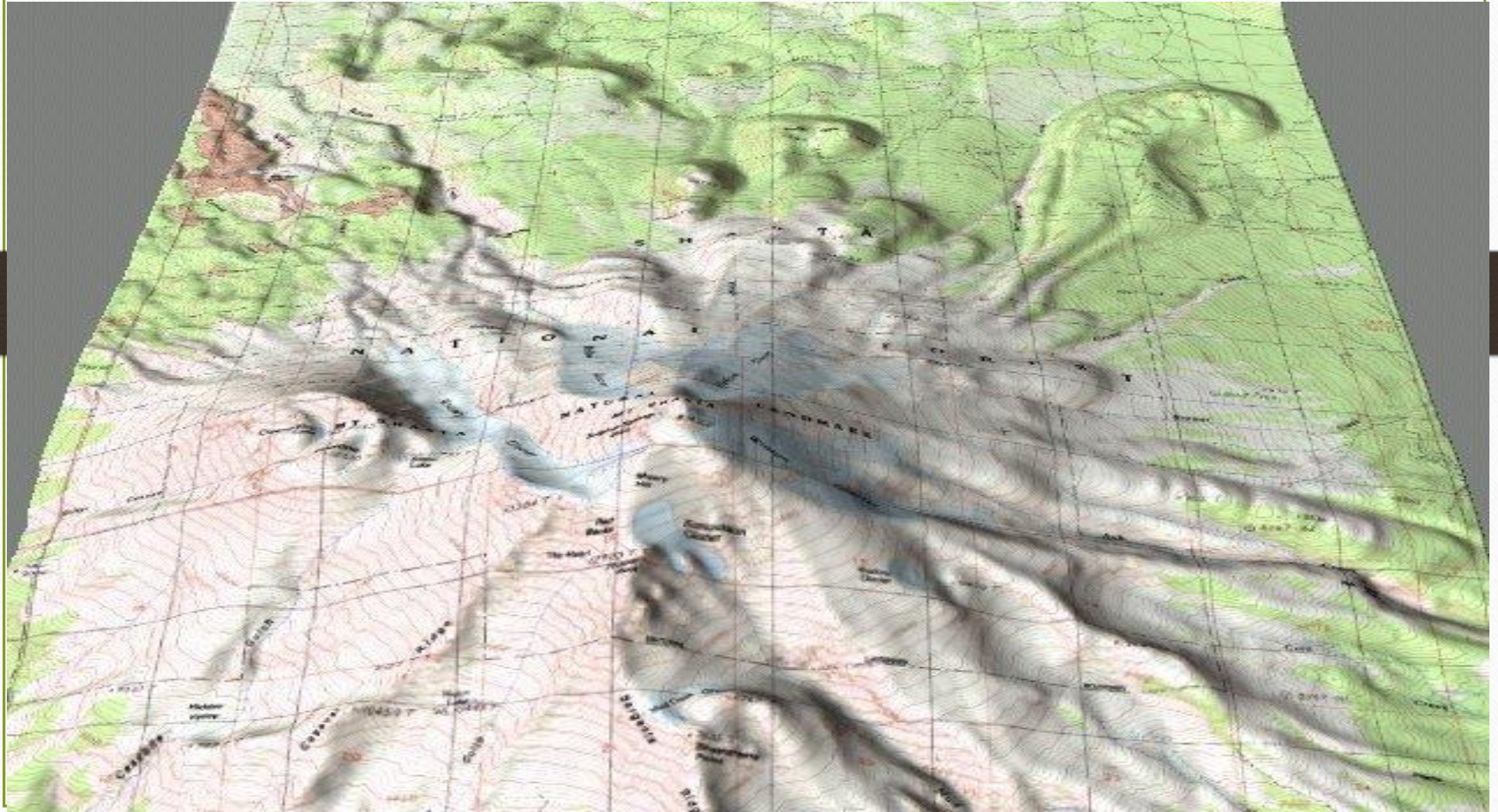


Creation of DEMs

- Conversion of contour lines/ Topographic Maps
- Photogrammetry
- Satellite Stereo
- Radar Stereo
- Radar Interferometry
- Laser Altimetry



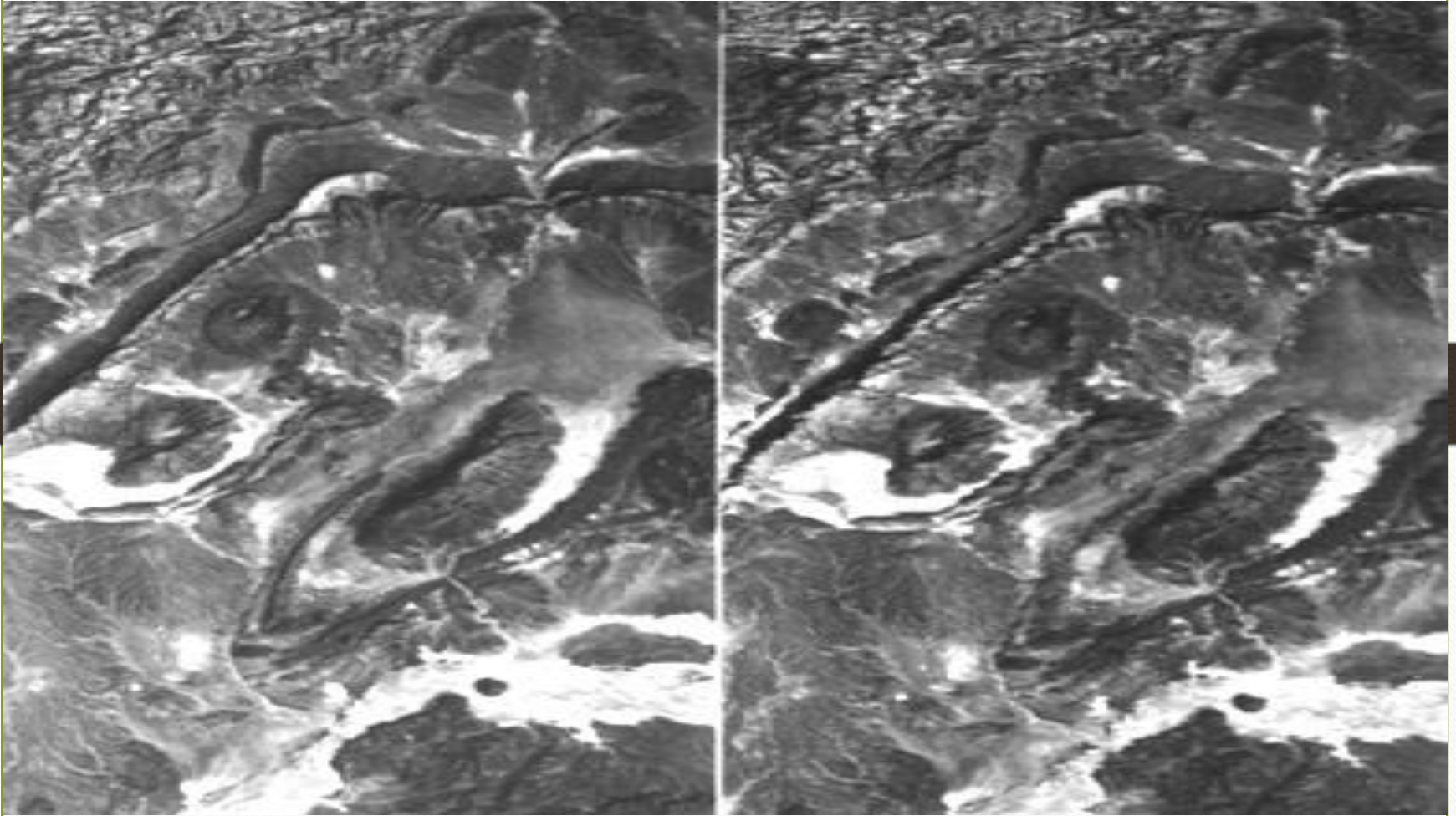
Conversion of Topographic Maps



Photogrammetry

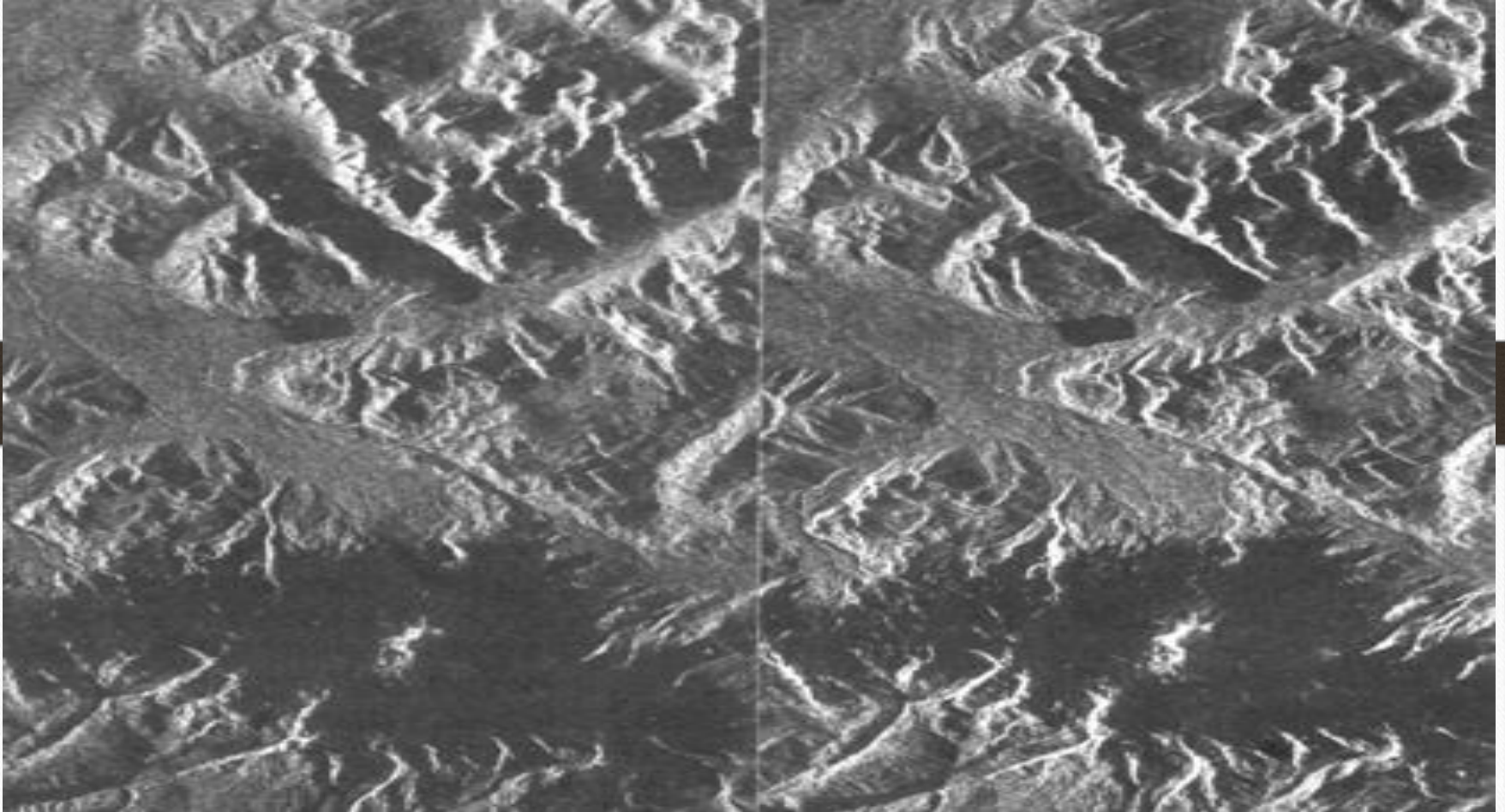


Stereo Satellite



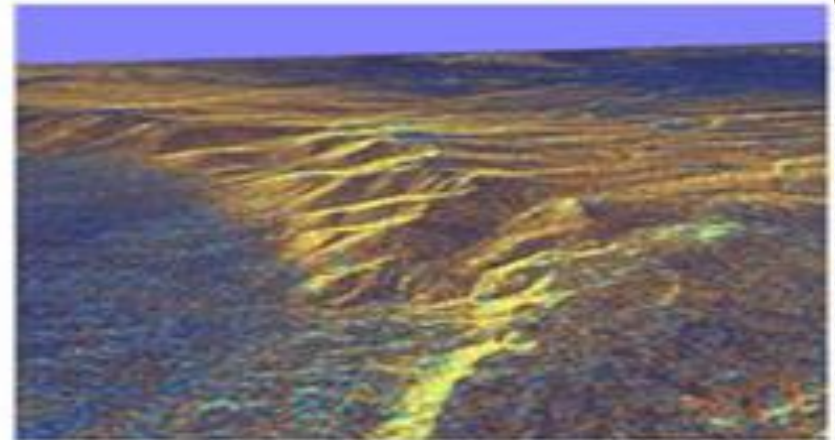
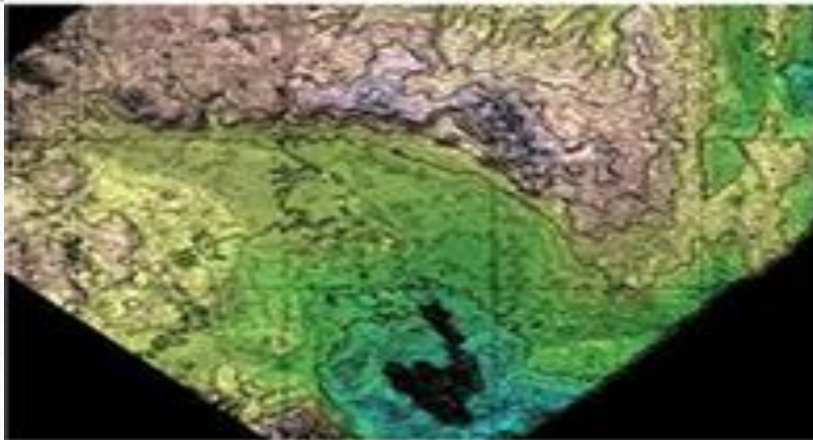
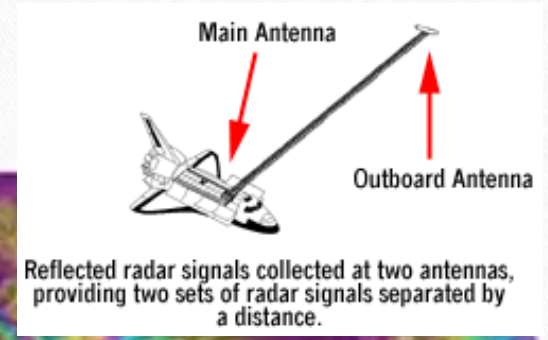
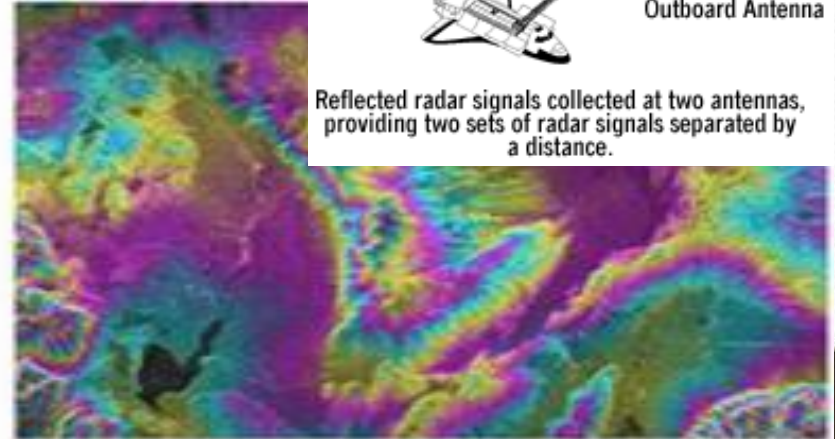
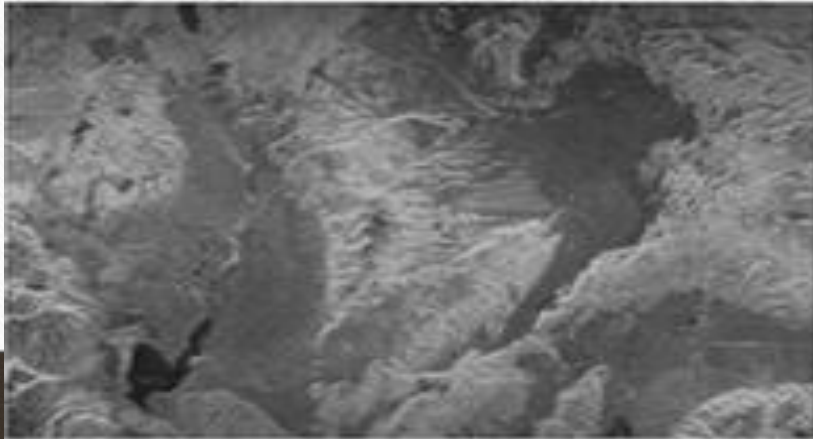
Two satellite passes are combined to get effective “stereo” view

Stereo Radar



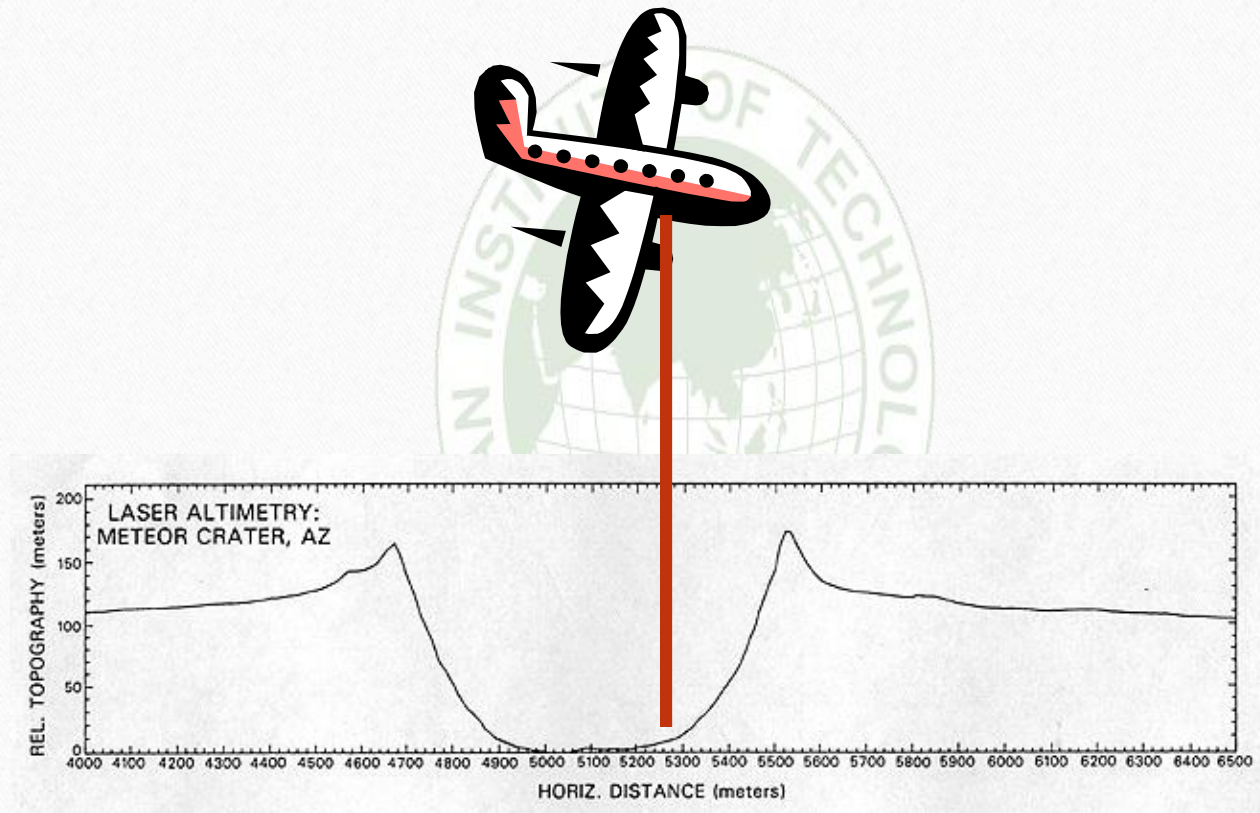
Can be done from space or airborne with side-looking-airborne-radar (SLAR)

Radar Interferometry



Uses phase difference in two radar signals to measure elevation differences

Laser Altimetry



Fly laser over area, and time reflection of laser.

Global DEMs

- GTOPO30
- Aster
- Shuttle Mapping Program
- IKONOS



Available Resolutions of DEM

Map Scale	Geographic Coordinates	Projected Coordinated
1:24,000	1'' (arc-second)	30 m
1:100,000	2''	60 m
1:250,000	3''	100 m
1:1,000,000	30''	1 km

DEM Data Sources

- Shuttle Radar Topography Mission (**SRTM**)
 - **30m** DEMs from 1:24,000 scale map
 - **1"** National Elevation Dataset
 - **3"** (100m) DEMs from 1:250,000 scale maps
 - **30"** DEM of the earth (**GTOPO30**)



Applying GeoSpatial Science
for a Sustainable Future...

SRTM Data Selection Options

Chinese users : [中国用户可通过中国科学院镜像站点下载](#)

1. Select Server: CGIAR-CSI (USA) HarvestChoice (USA) JRC (IT) King's College (UK) TelaScience (USA)

2. Data selection method: Multiple Selection Enable Mouse Drag Input Coordinates

Many tiles can be selected at random locations. These selected tiles are listed in the results page for download.

Decimal Degrees (ie 34.5, -100.5)

Degrees: Minutes: Seconds (ie 34 30 00 N, 100 30 00 W)

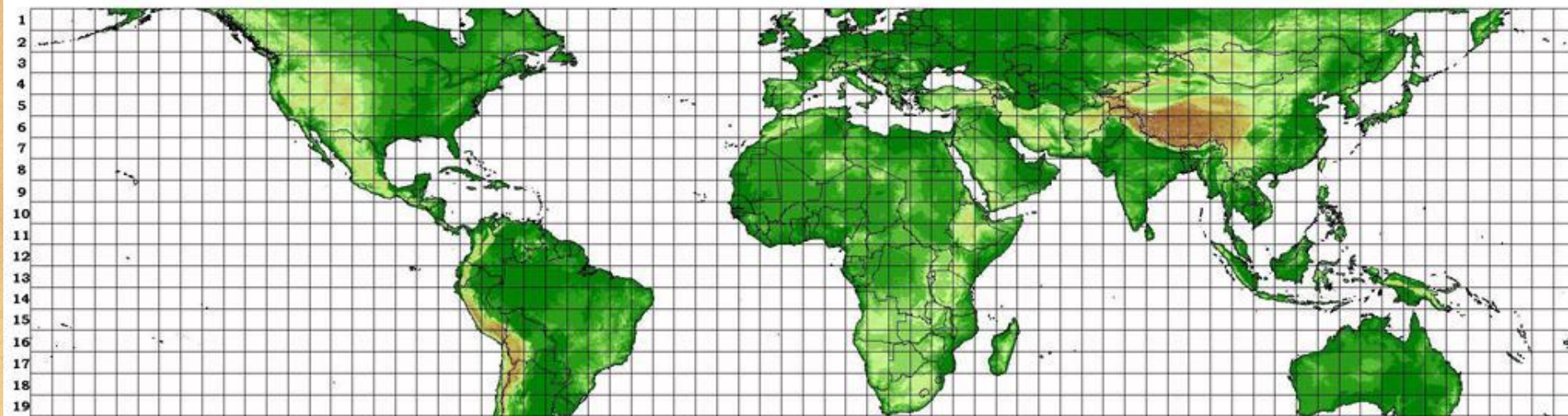
Longitude - min: max: Longitude - min: East ▼ max: East ▼

Latitude - min: max: Latitude - min: North ▼ max: North ▼

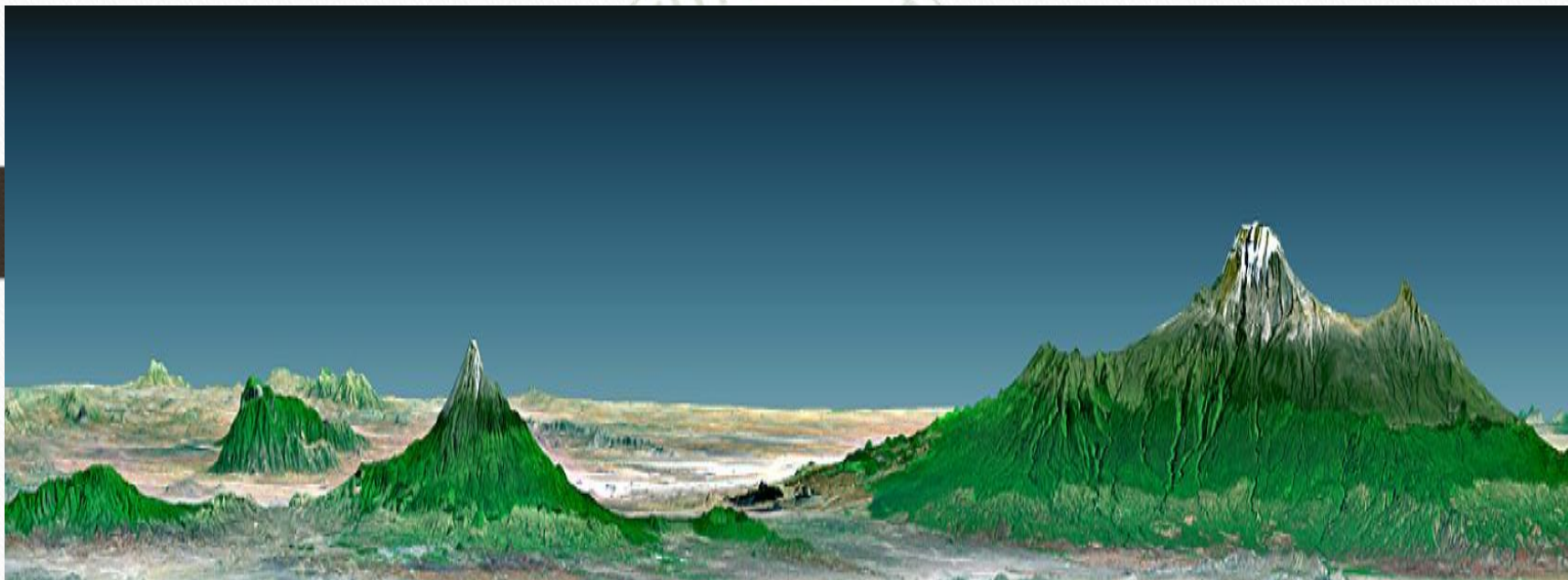
Longitude: 177.48 Latitude: 15.54 Tile X: 72 Tile Y: 9

3. Select File Format: GeoTiff ArcInfo ASCII

[Click here to Begin Search >>](#)

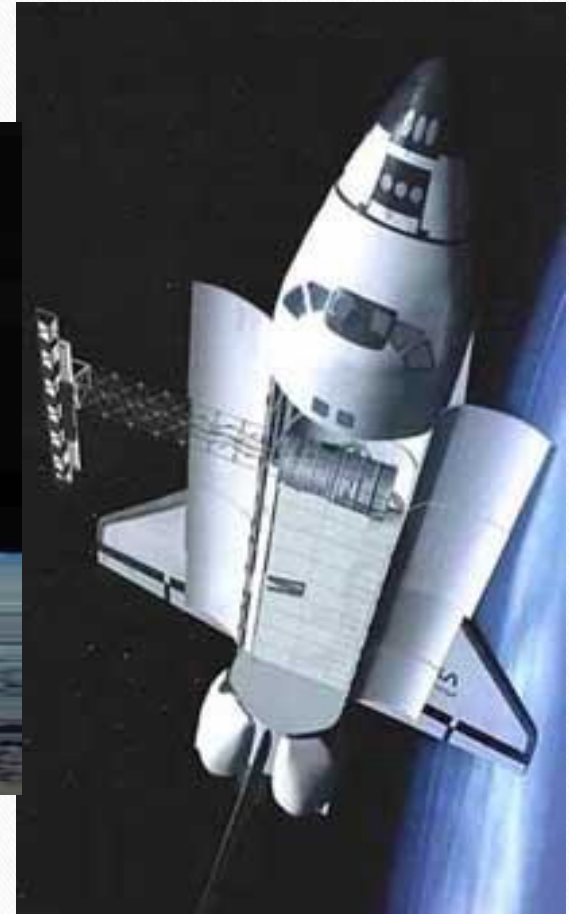


Mt Kilimanjaro, Tanzania



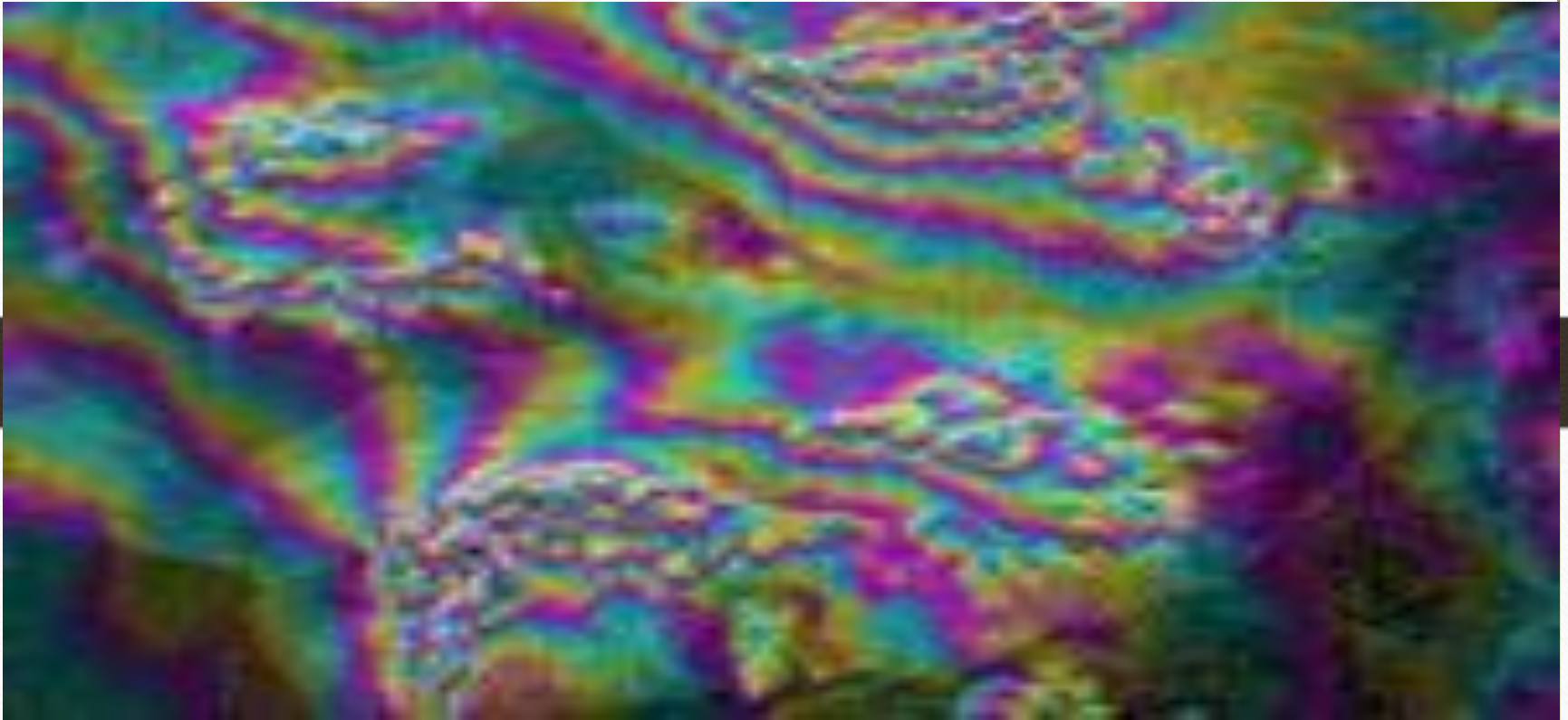
<http://srtm.usgs.gov/srtmimagegallery/index.html>

Shuttle Radar Topography Mission (SRTM)



- 1 arc-second elevation data and
- 3 arc-second data for the globe
- Produced by radar measurements from a Shuttle mission, Feb 11-22, 2000

Interferometry used by SRTM



In interferometry, two images are taken from different vantage points of the same area. The slight difference in the two images allows scientists to determine the height of the surface.

SRTM DEM

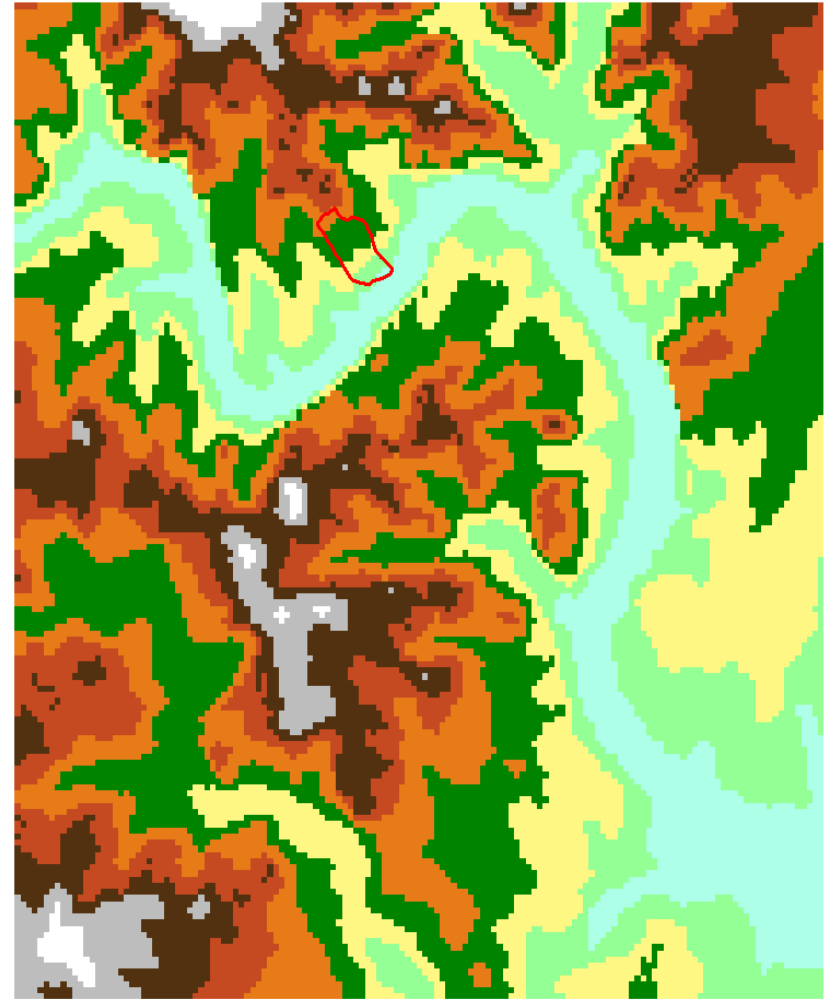
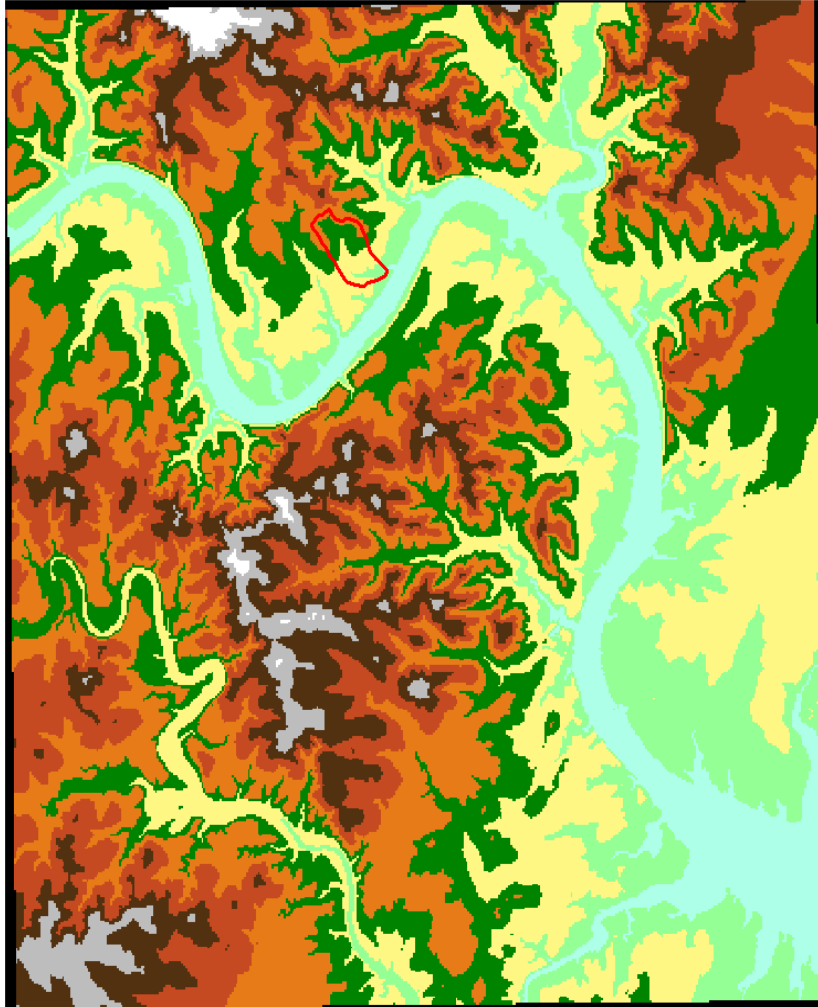
Product Specifications

Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Meters
Spatial Resolution	1 arc-second for global coverage (~30 meters) 3 arc-seconds for global coverage (~90 meters)
Raster Size	1 degree tiles
C-band Wavelength	5.6 cm

30m

Cell Size

90m

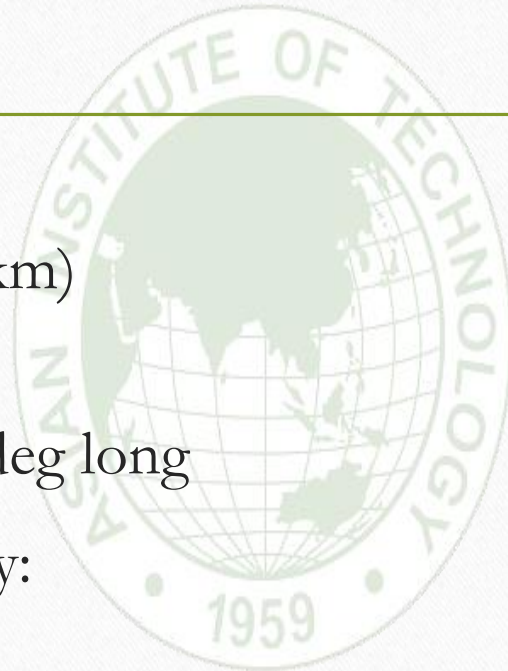


30" DEM GTOPO30

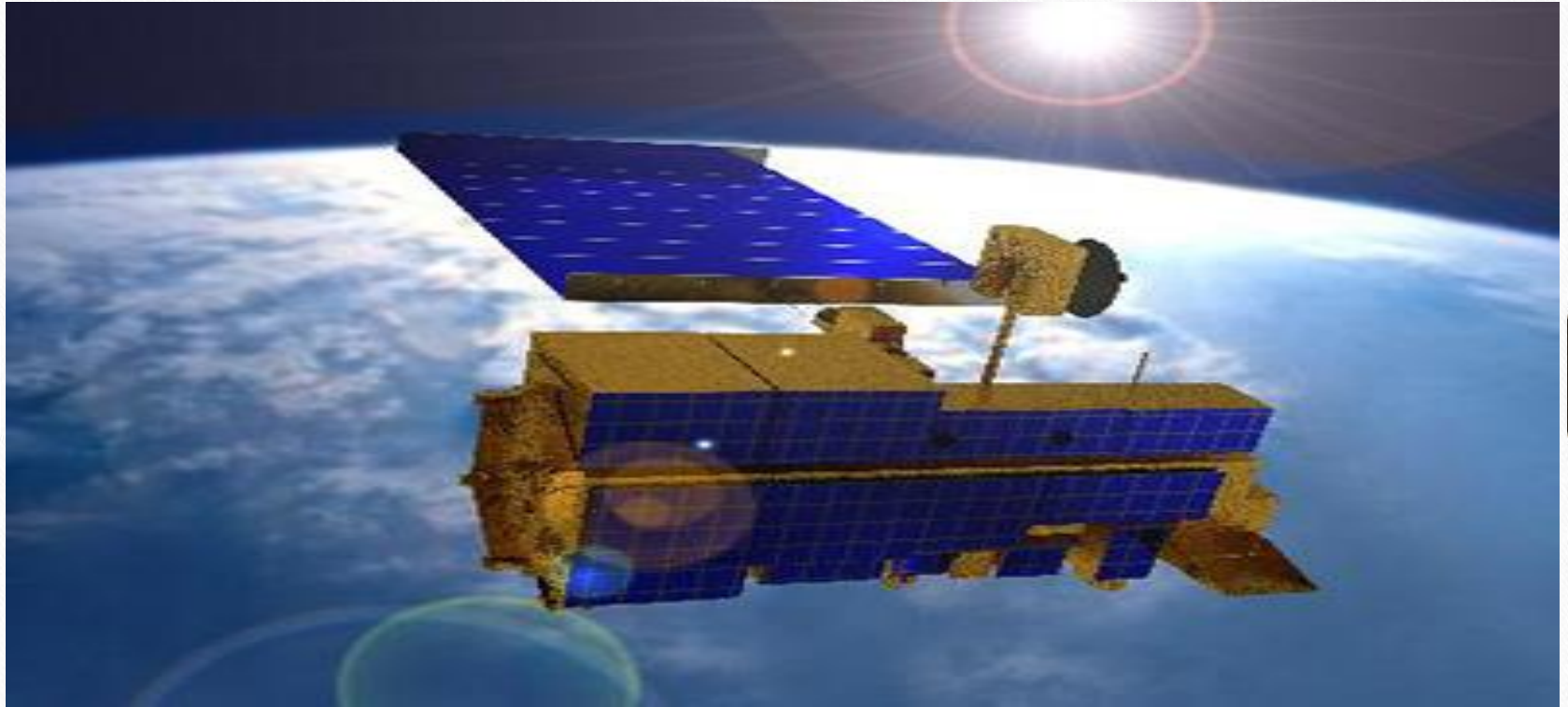
- Produced by **USGS** from 3" grids and Digital Chart of the World topography
- Coverage complete for the **earth**
- Projected cell size is **1km**
- Data must be **projected** before use
- [Link](http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html) <http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html>

GTOPO30

-
- Resolution:
30-second (~ 1 km)
 - Coverage:
50 deg lat x 40 deg long
 - Vertical Accuracy:
30 m



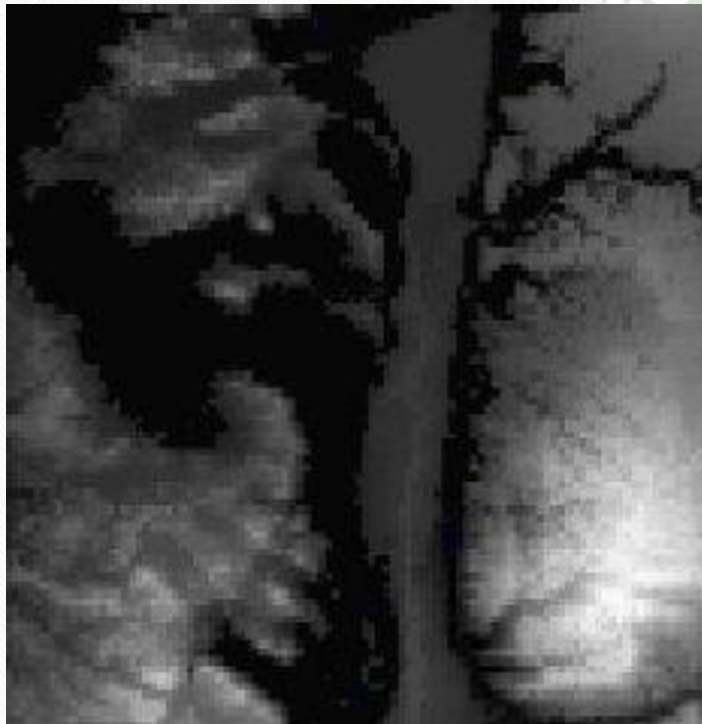
ASTER DEM



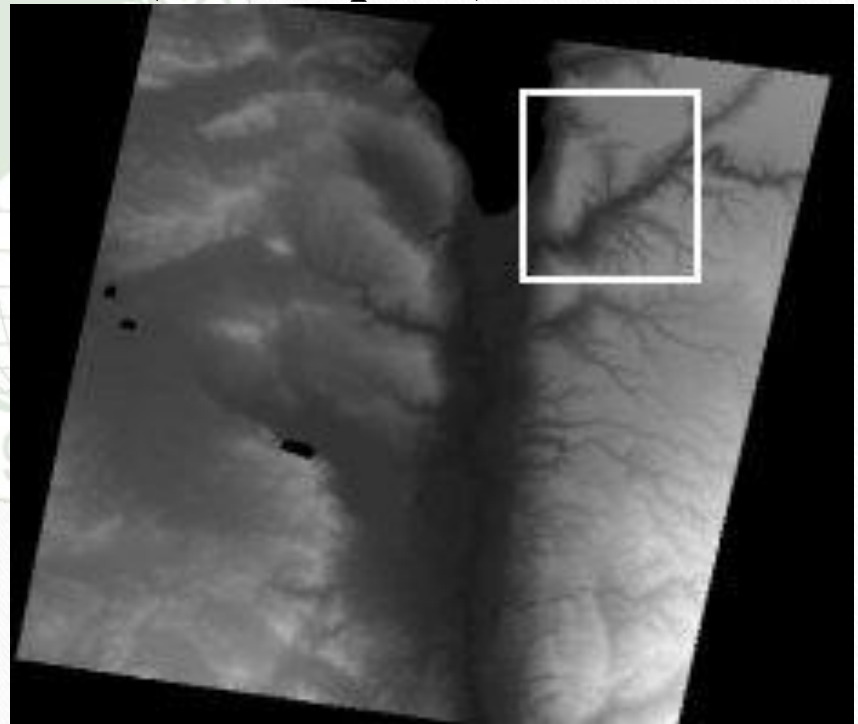
Advanced Spaceborne Thermal Emission and Reflection Radiometer, Off-Nadir pointing allows DEM, First international DEM of decent quality available, Must request generation of DEM (slow turnaround) but FREE!

Aster DEM

- GTOPO30
(1 km²/pixel)

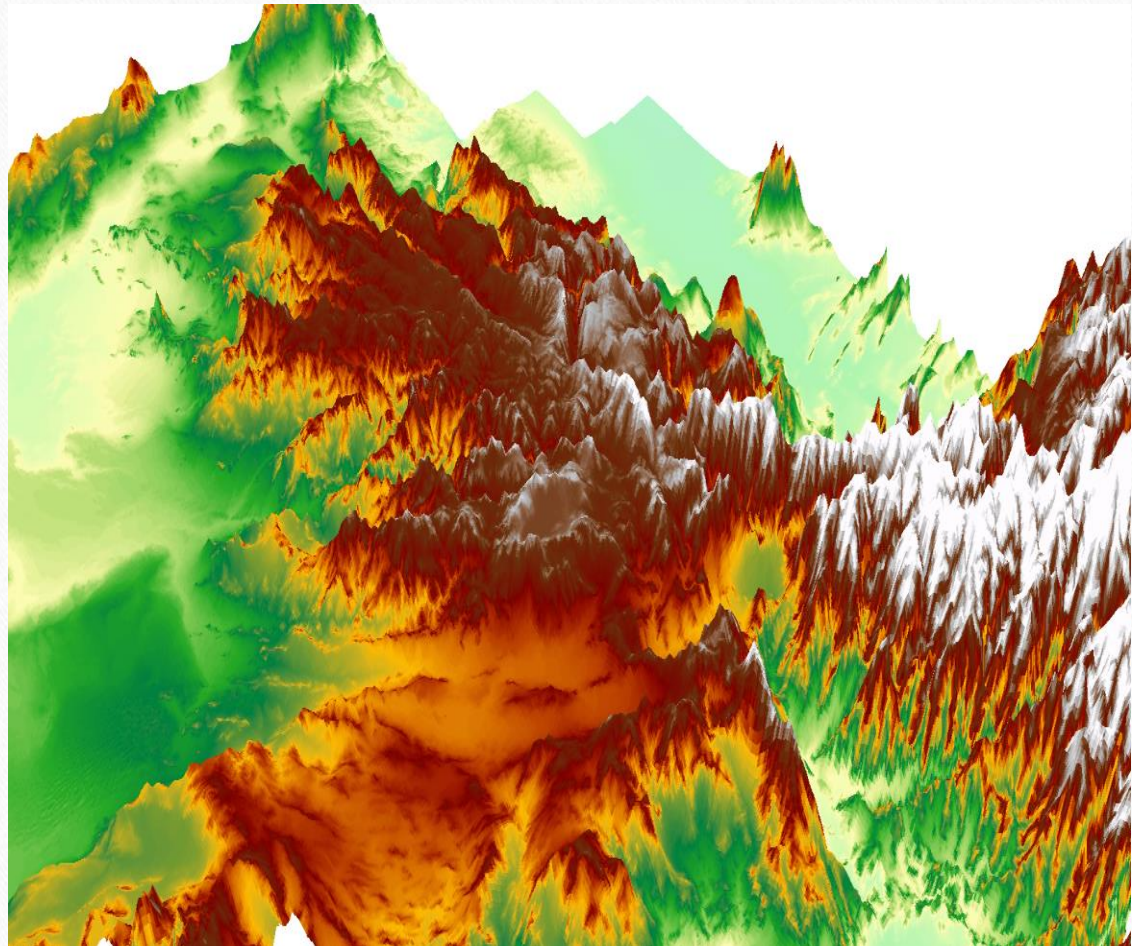


- ASTER
(30 m²/pixel)



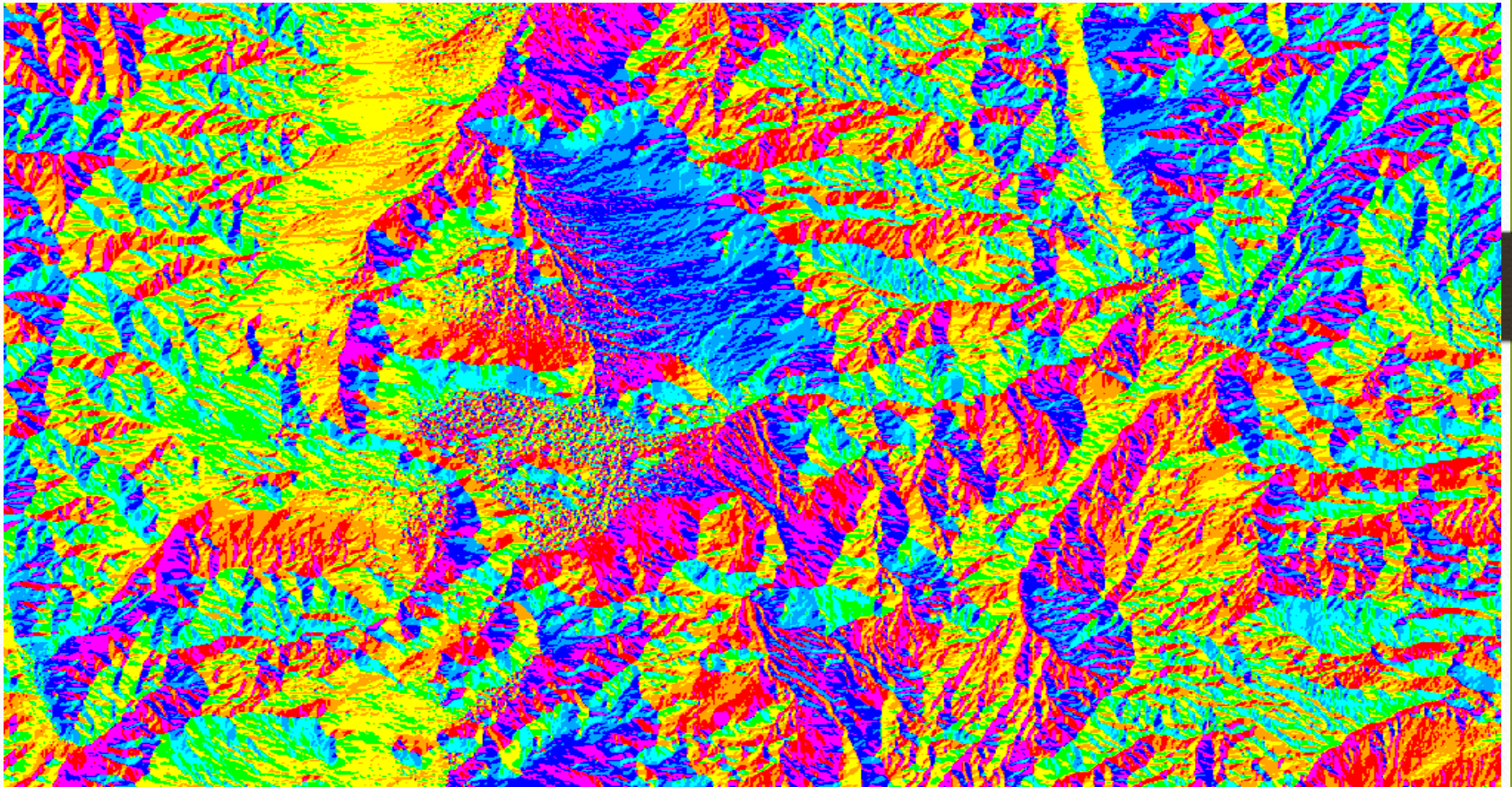
Products of DEMs

- Aspect
- Contour
- Hillshade
- Slope
- Viewshed



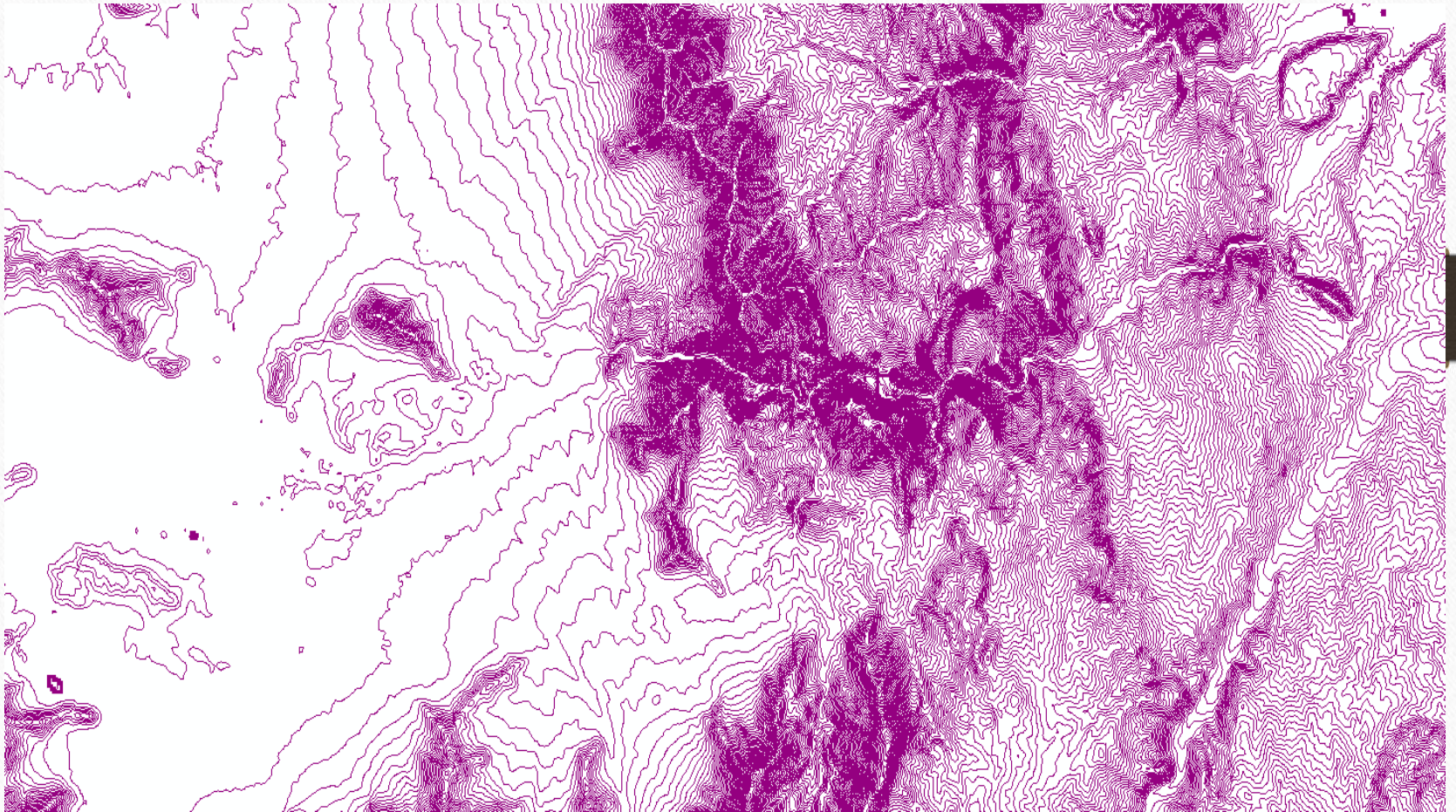
Aspect

Downslope direction of the maximum rate of change in value
from each cell to its neighbors.



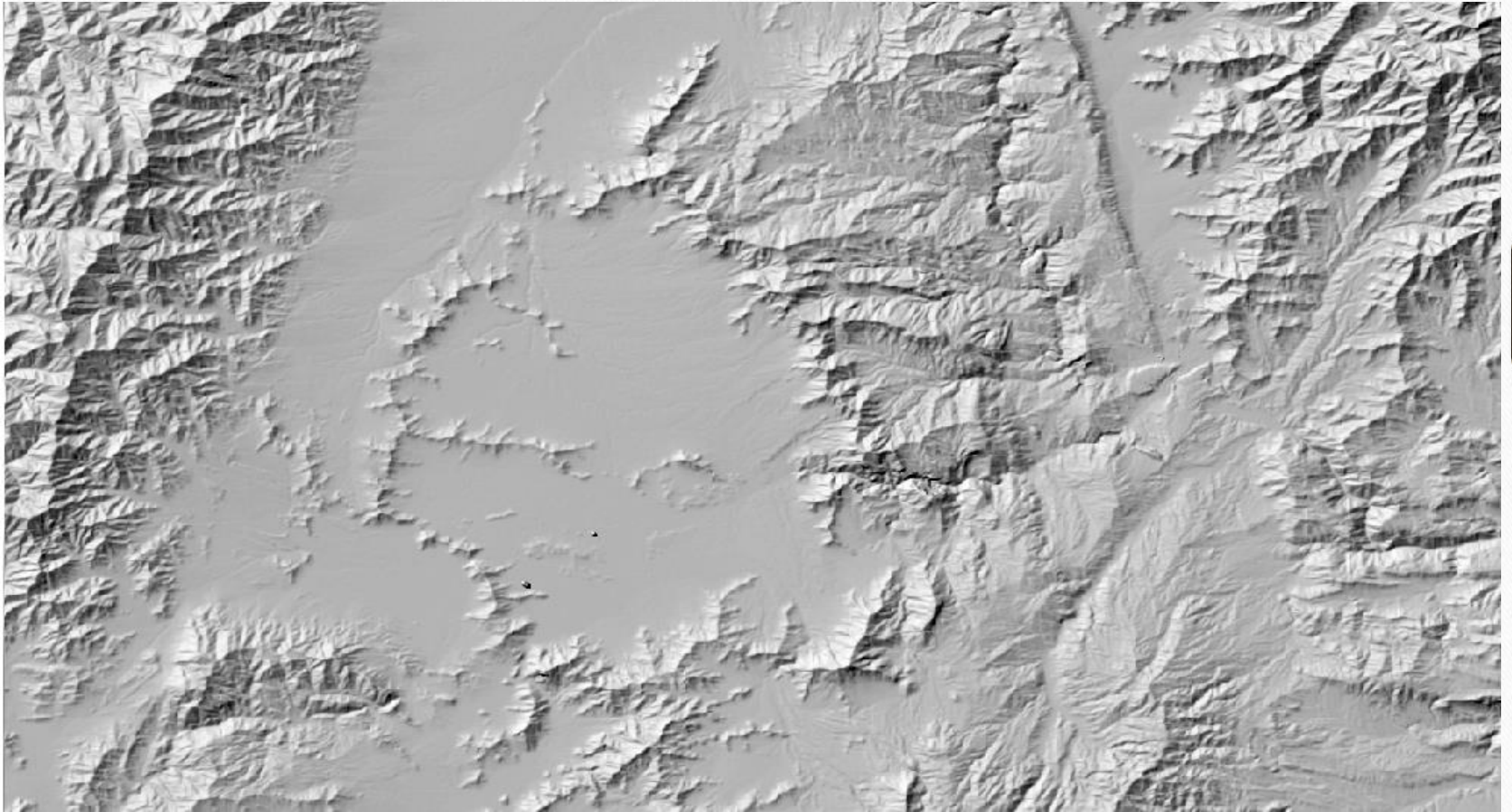
Contours

A contour line joins points of equal elevation above a given level (usually mean sea level)



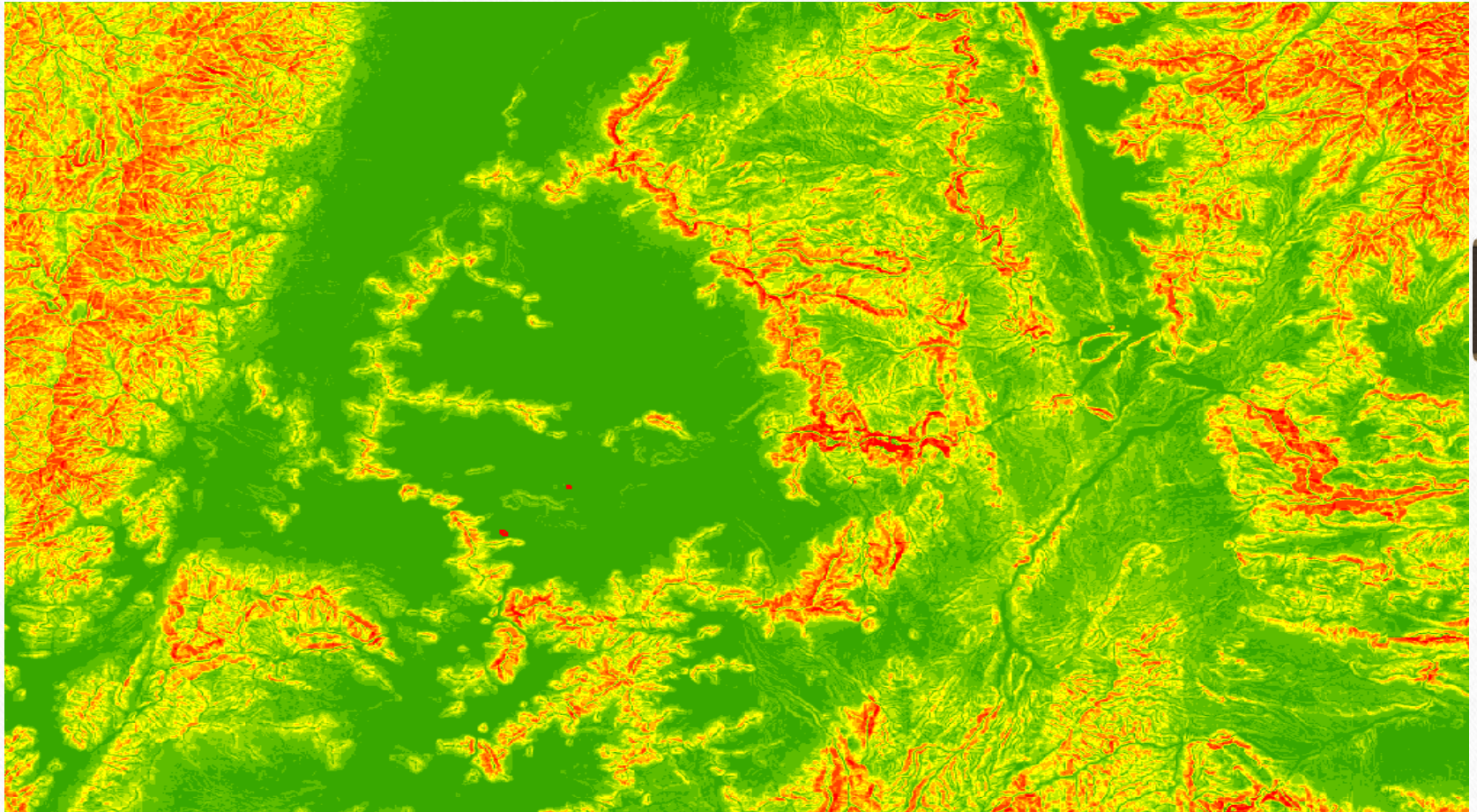
Hillshade

3D representation of the surface, with the sun's relative position taken into account for shading the image.



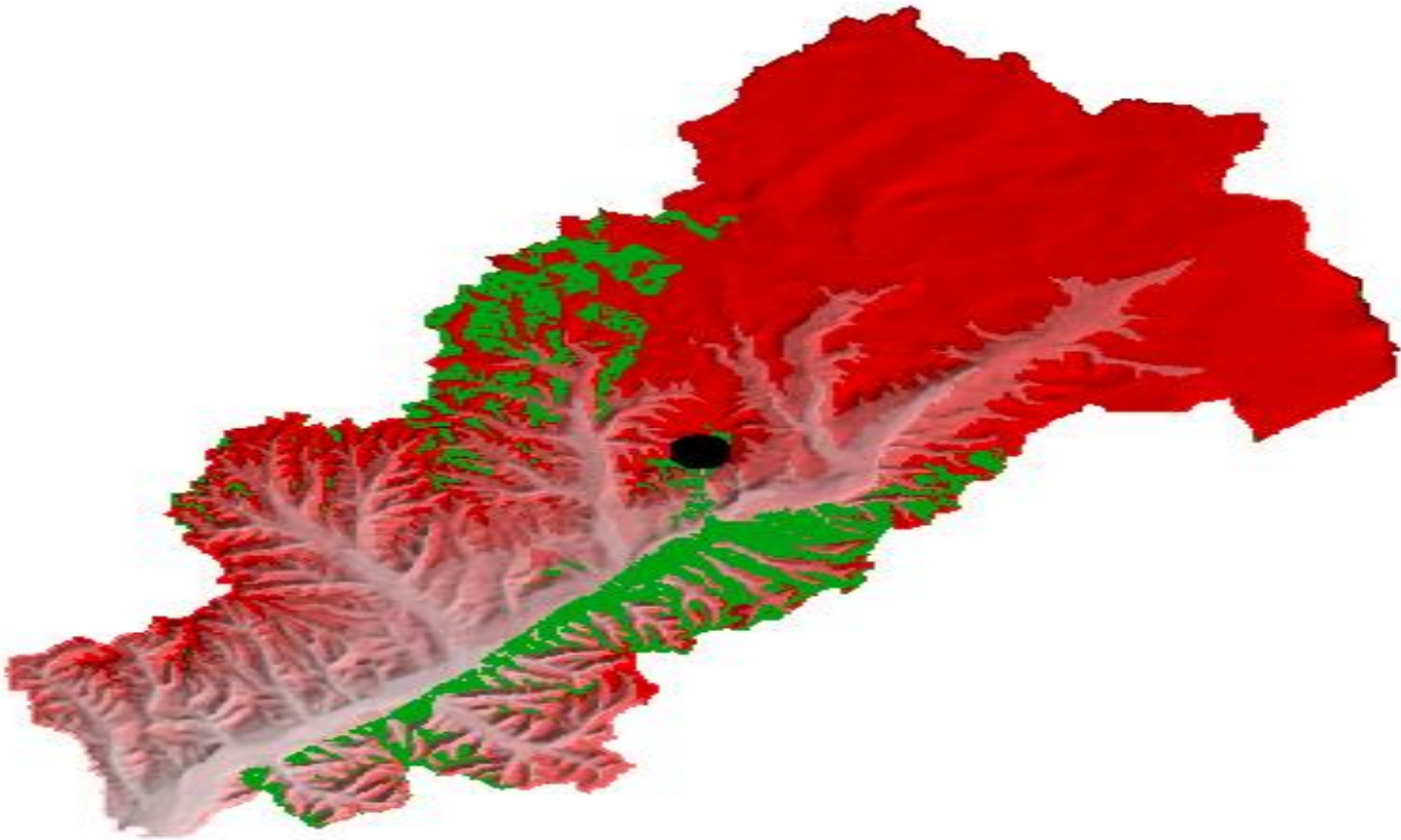
Slope

Slope is defined by a plane tangent to a topographic surface, as modelled by the DEM at a point

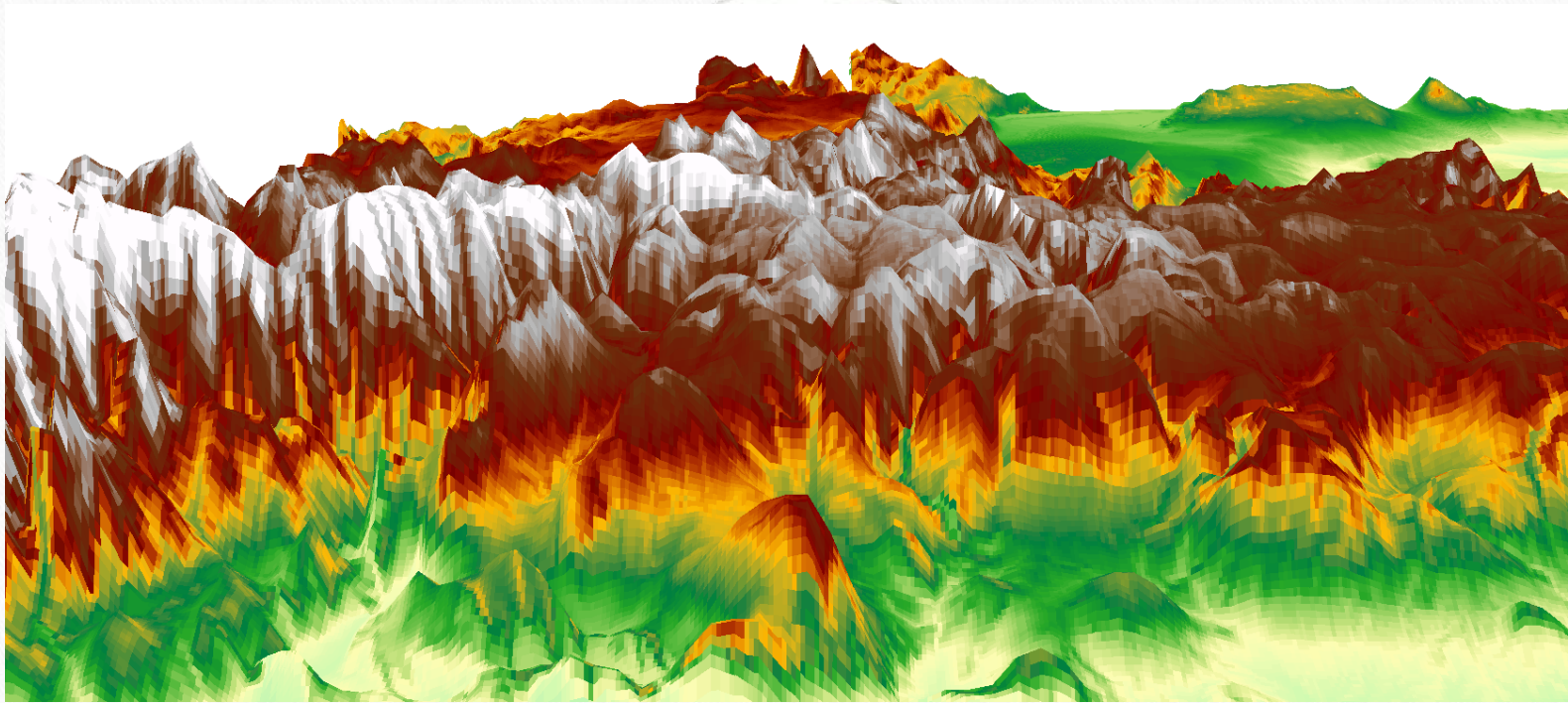


Viewshed

What land is visible from the selected location?



Viewing DEM in 3D



Thank You

Questions & Comments



Session 14: Challenges and Opportunities in Planning for Flood Management under Climate Change

Capacity Development Workshop:

“Flood Risk Assessment for Dungsumchu Basin in Samdrupjhomkar District, Bhutan “

30 October – 08 November 2017

Mukand S. Babel (msbabel@ait.ac.th)

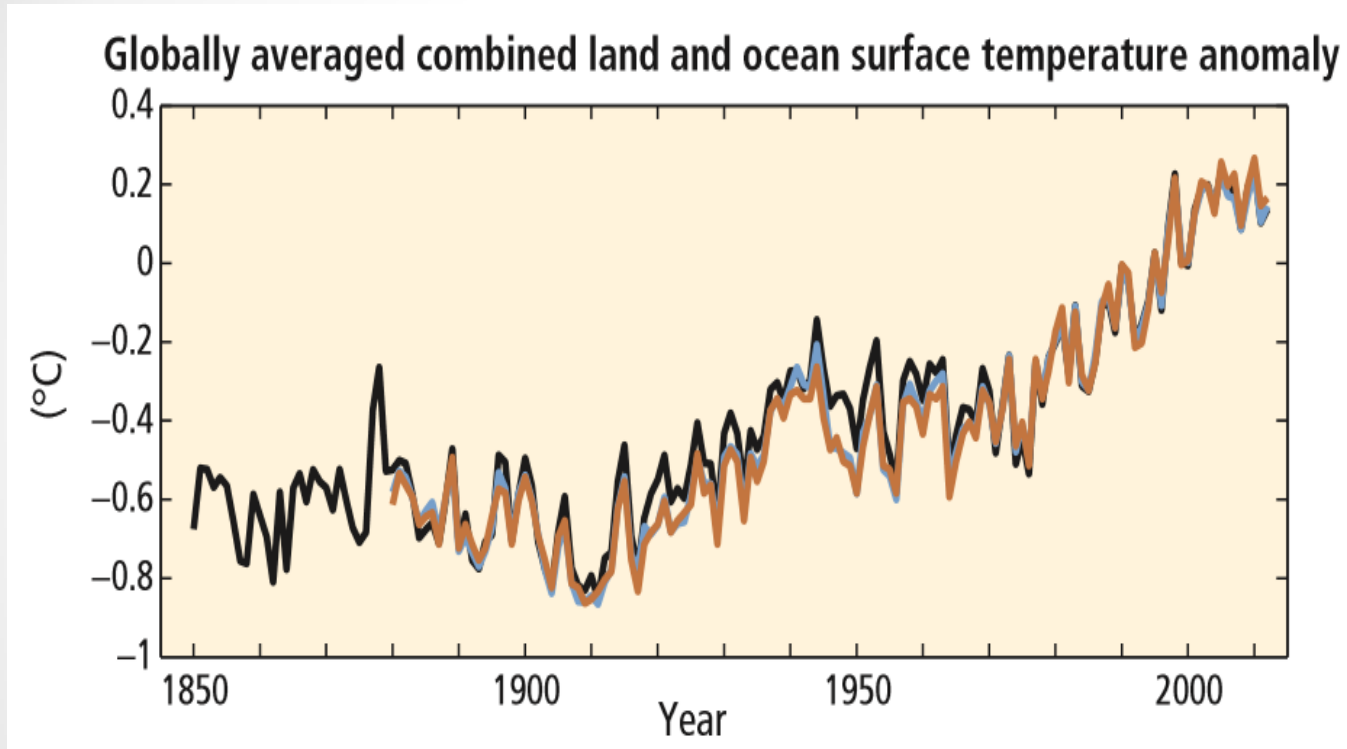
Professor, Water Engineering and Management (WEM)

Asian Institute of Technology (AIT), Thailand

- Facing the Facts
- Climate Projections
- Key Challenges
 - Uncertainties in Climate Change Studies
 - Climate Change impact on Design discharge
- Risks and Opportunities

Facing the Facts

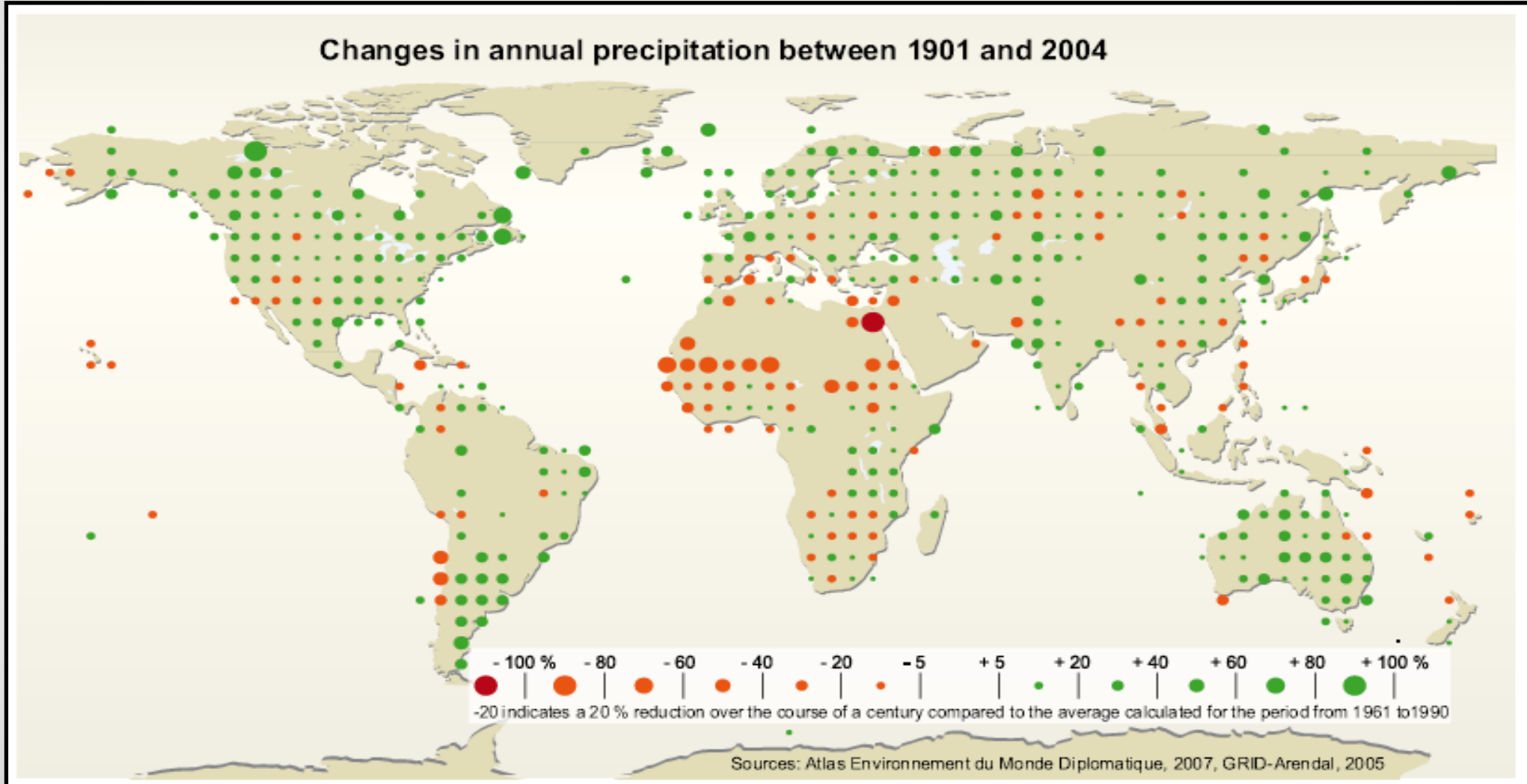
Changes in temperatures (1980-2012)



Relative to the average over the period 1986 - 2005

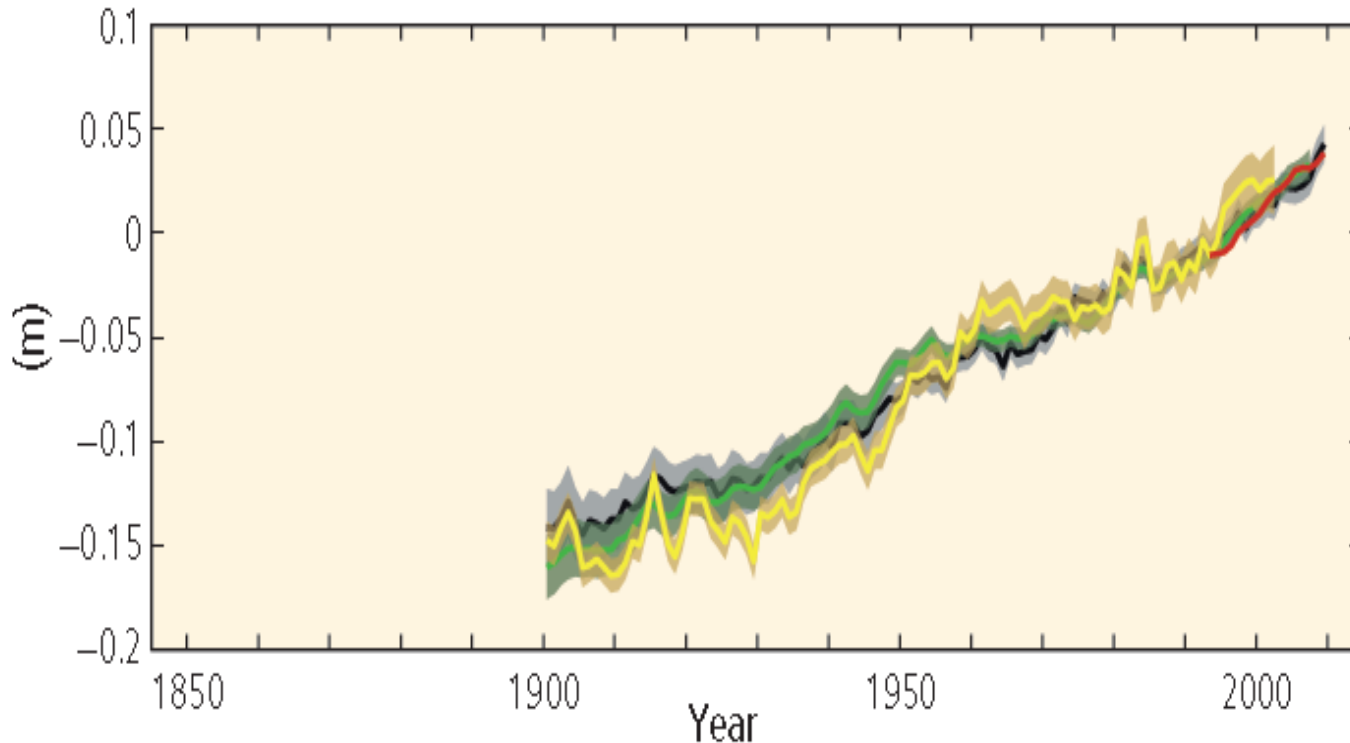
- According to WMO, 14 of the 15 hottest years on record have occurred since 2000
- 2015 hottest since 1850, exceeding previous record by 0.1°C

Precipitation



Mean Sea Level

Globally averaged sea level change



Relative to the average over the period 1986 - 2005

Sea levels across the globe have risen in a way consistent with the warming – since 1961 at an average of 1.8 mm per year, and since 1993 at 3.1 mm per year.

Merrifield et al., 2009:

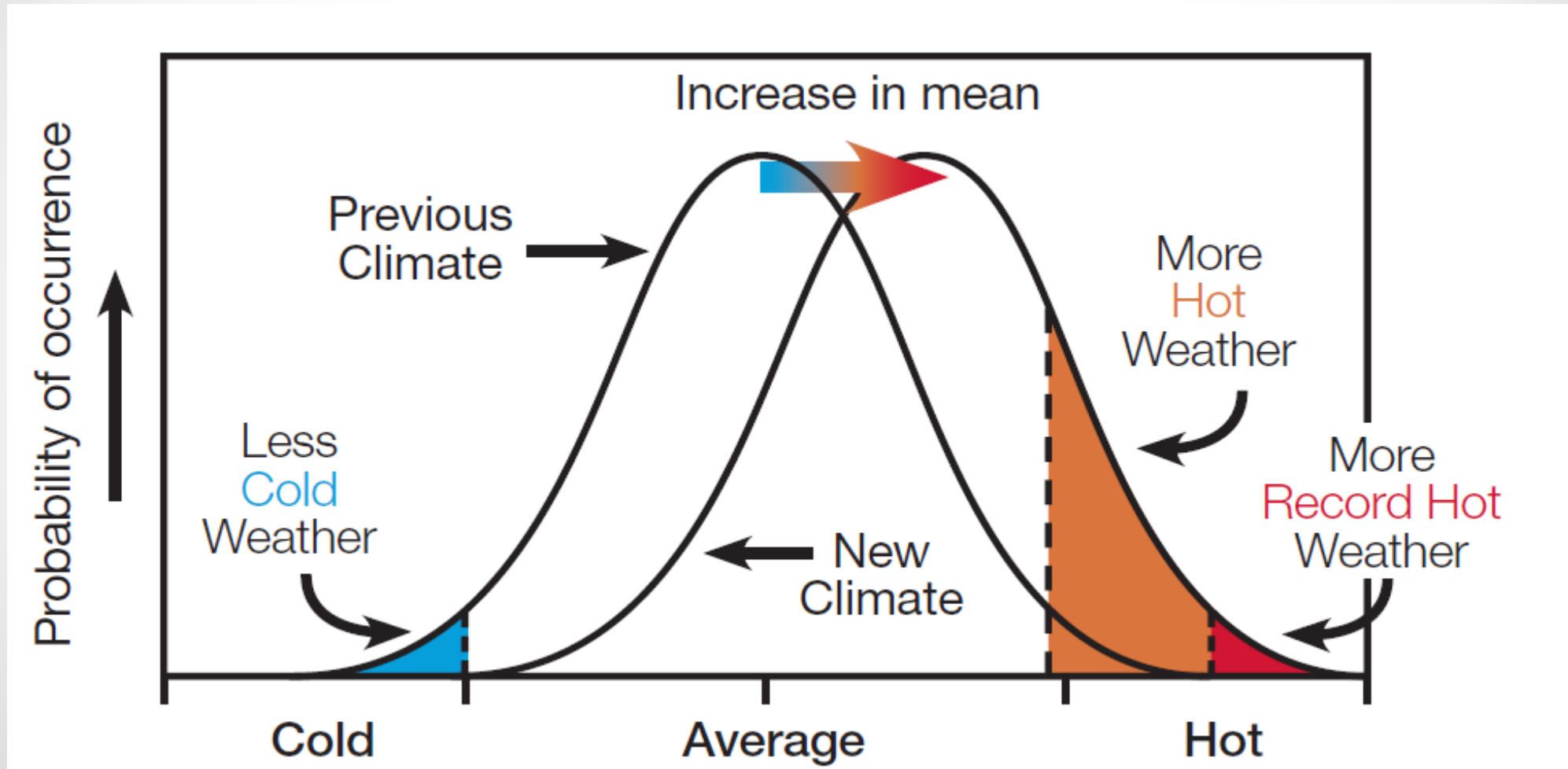
[1993–2008] (3.5 ± 0.4) mm/yr

IPCC 2007:

[1993–2003] (3.1 ± 0.7) mm/yr

Facing the facts

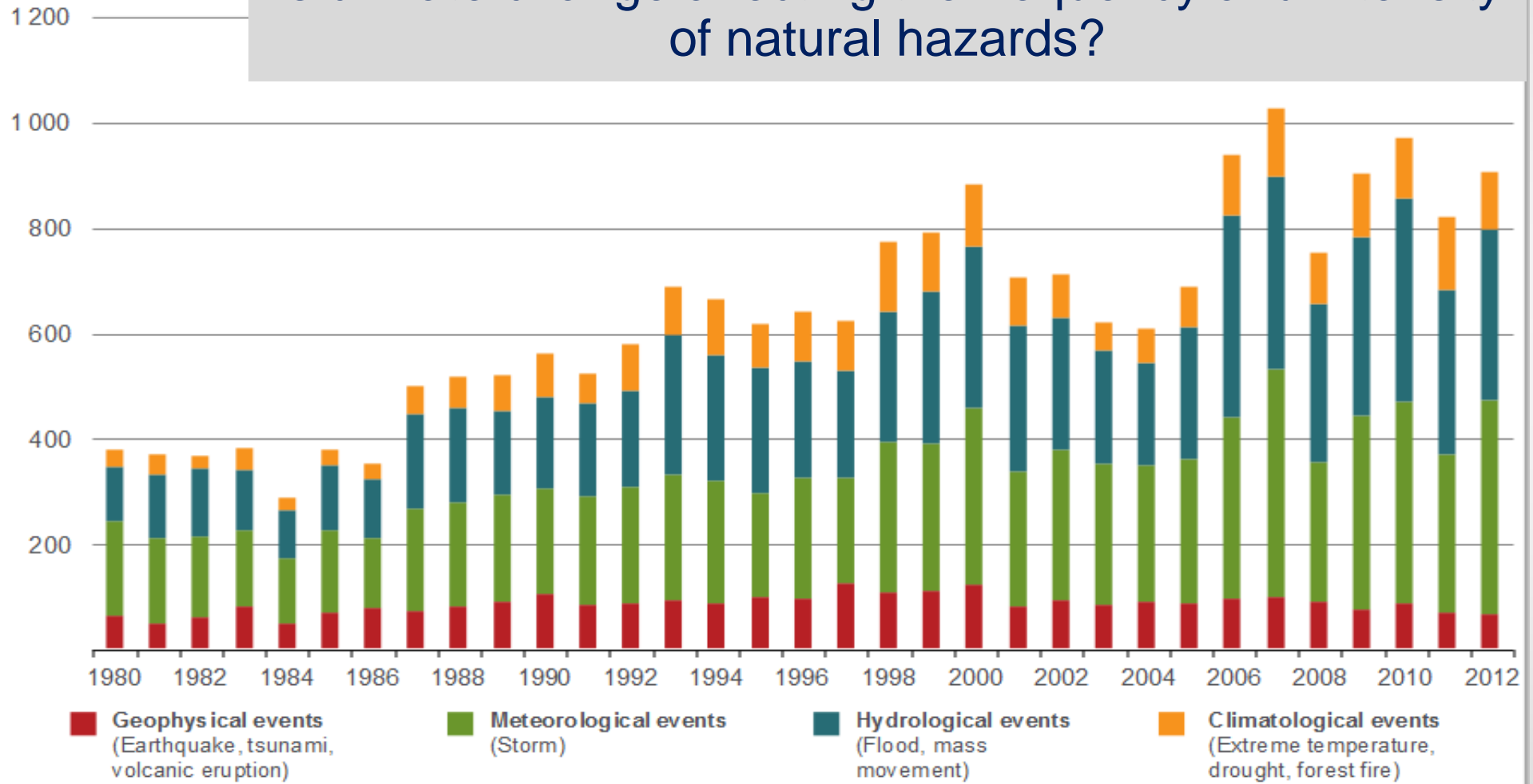
Effect of increase in average temperature on extreme temperature



Facing the facts

Catastrophes and extreme events

Is climate change affecting the frequency and intensity of natural hazards?



Record breaking meteorological events in the last decade

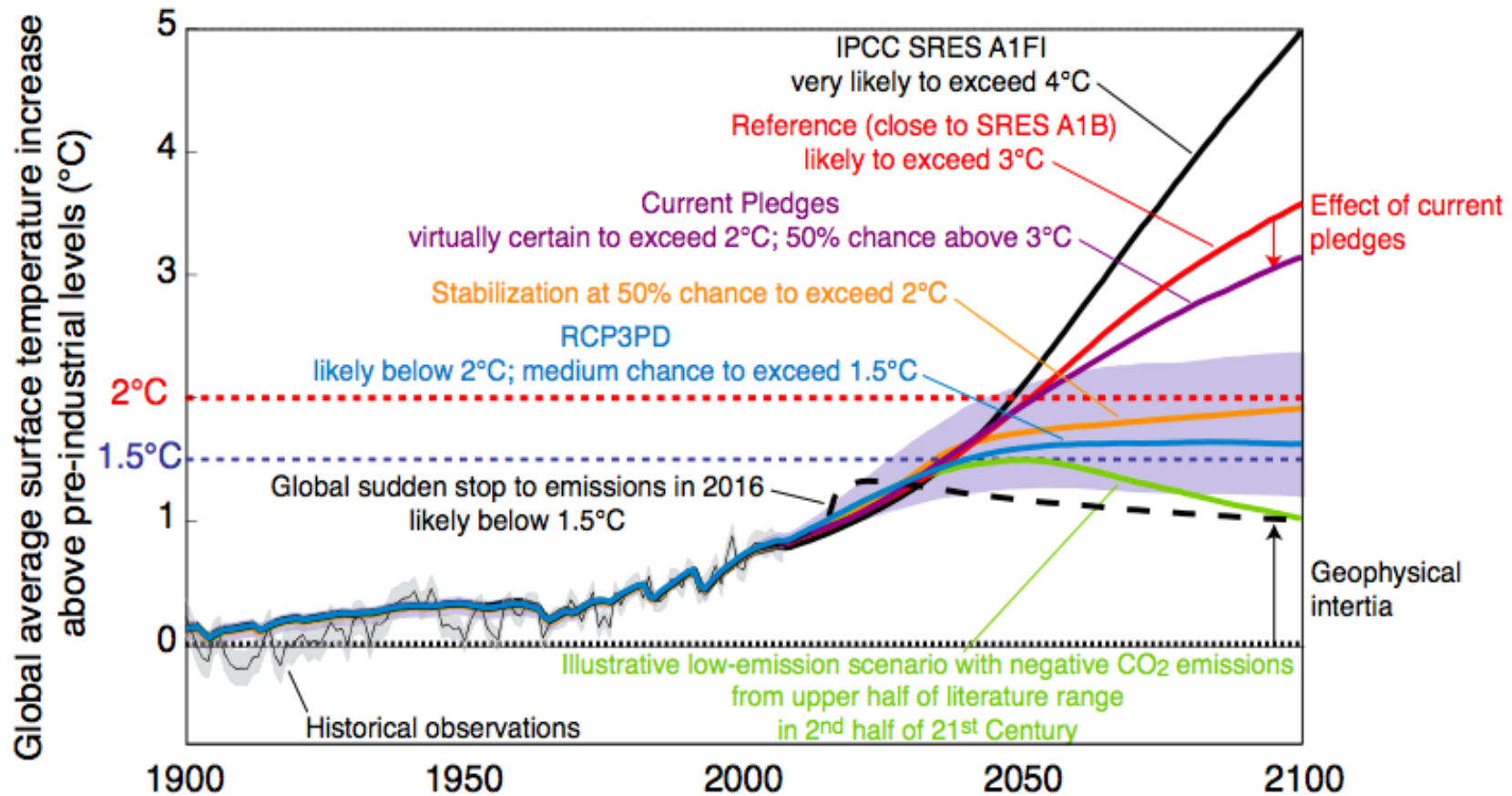
Region	Meteorological record breaking event	Confidence in attribution to climate change	Impact costs
England and Wales (2000)	Wettest autumn since 1766 ¹	Medium ^{2,3}	£ 1.3 Billion ²
Europe (2003)	Hottest summer in 500 years ⁴	High ^{5,6}	Death toll >70,000 ⁷
Pakistan (2010)	Rainfall records ⁸	Low to medium ^{9,10}	Worst flooding in its history; 3000 deaths; 20M people affected ¹¹
Eastern Mediterranean and Middle East (2008)	Driest winter since 1902	High ¹²	Substantial damage to cereal production ¹³
4 US states (TX, OK, NM, LA) (2011)	Summer heat and drought since 1880 ¹⁴	High ¹⁴	Wildfires burning 3 M acres (preliminary impact of \$6 to \$8 B) ¹⁵

Source: World Bank (2012)

¹ Alexander and Jones (2001) ² Min et al. (2011) ³ Kay et al. (2011) ⁴ Luterbacher (2004) ⁵ Della-Marta et al. (2007); Stott et al. (2004) ⁶ Coumou et al. (in review); Hansen et al. (2012) ⁷ Robine et al. (2008) ⁸ Webster et al. (2011) ⁹ Trenberth et al. (2012); ¹⁰ Lau and Kim (2012); ¹¹ Hong et al. (2011); ¹² Hoerling et al. (2012); ¹³ Ricardo et al. (2010); ¹⁴ Rupp et al. (2012); ¹⁵ NOAA (2011)

Climate Projections

Global projections: Temperature



Even with the current mitigation commitments and pledges fully implemented, there is a 20% likelihood of exceeding 4°C by 2100. 50% chance of temperature rise above 3°C by 2100.

Local projections: Temperature

Impact on Maximum Temperature (Change in °C)

Basin/Area, Country	A2			B2		
	Early	Mid	Late	Early	Mid	Late
Wangchu, Bhutan	0.5	1.0	1.9	0.6	0.9	1.4
Sikkim, India	0.4	0.8	1.4	0.4	0.7	1.0
Citarum, Indonesia	0.1	0.7	1.5	0.2	0.5	1.0
Nam Ou, Laos	0.5	1.6	3.5	0.5	1.4	1.9
Koshi, Nepal	0.8	2.2	4.2	0.9	1.8	2.6
Jhelum, Pakistan	0.2	0.6	1.0	0.3	0.5	0.8
Mun, Thailand	1.5	1.7	3.5	-	-	-
Bangkok, Thailand	0.3	0.7	1.2	0.3	0.5	0.9
Pak Phanang, Thailand	0.7	1.7	3.0	0.8	1.6	2.2

Maximum temperature is projected to increase in all the basins during three future periods. The range of increase varies from **1.0 to 4.2°C** under A2 scenario and from **0.8 to 2.6°C** under B2 scenario in late century period.

Local projections: Temperature

Impact on Minimum Temperature (Change in °C)

Basin/Area, Country	A2			B2		
	Early	Mid	Late	Early	Mid	Late
Wangchu, Bhutan	0.4	1.1	1.2	0.5	0.9	1.4
Sikkim, India	0.4	0.9	1.6	0.4	0.7	1.1
Nam Ou, Laos	0.5	1.6	3.5	0.5	1.3	1.9
Bagmati, Nepal	0.6	2.1	3.0	0.6	2.0	2.3
Koshi, Nepal	0.8	2.2	4.2	0.9	1.9	2.6
Jhelum, Pakistan	0.1	0.4	0.7	0.1	0.3	0.4
Mun, Thailand	0.9	2.1	3.1	-	-	-
Bangkok, Thailand	0.3	0.8	1.6	0.4	0.6	1.1
Pak Phanang, Thailand	1.3	2.5	4.2	1.3	2.3	3.2

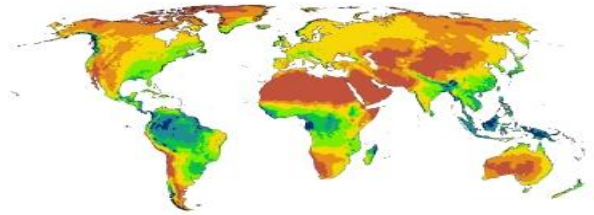
The range of increase in T_{min} varies from 0.7 to 4.2°C under A2 scenario and from 0.4 to 2.6 °C under B2 scenario in late century period.

Global projections: Precipitation

For RCP8.5, global precipitation over land increase in most of the regions during 2070-2099 from period 1971-2000. The relative increase of 99–111%, is also projected in some regions of Africa.

Differences exist in GCM projections in direction as well as magnitude of change.

(a) GCM mean 1971-2000



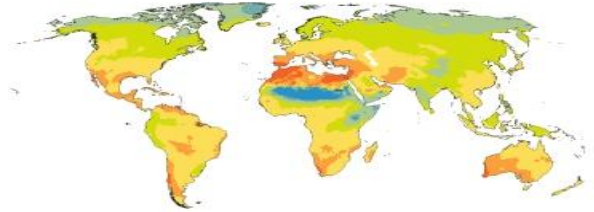
(a) Precipitation in mm/yr



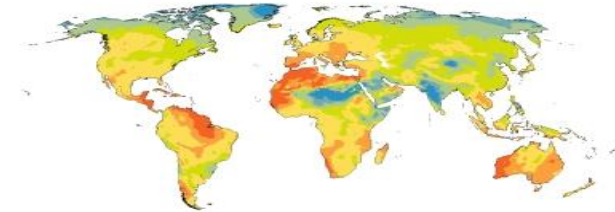
(b) Precipitation change in %



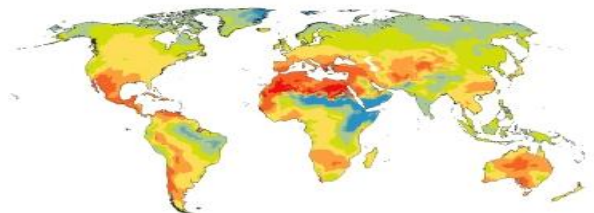
(b) GCM mean 2070-2099



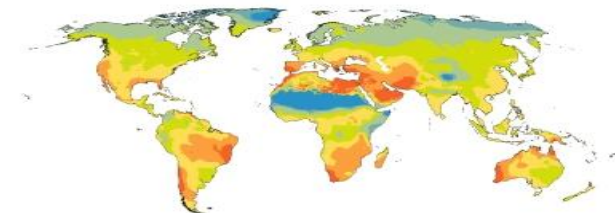
HadGEM2-ES



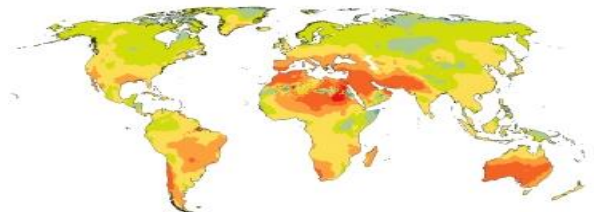
IPSL-CM5A-LR



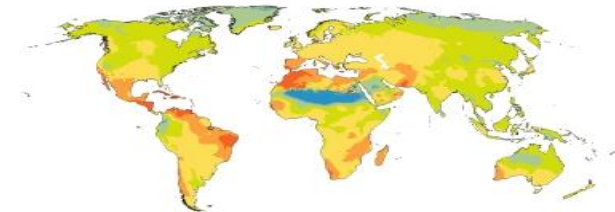
MIROC-ESM-CHEM



GFDL-ESM2M



NorESM1-M



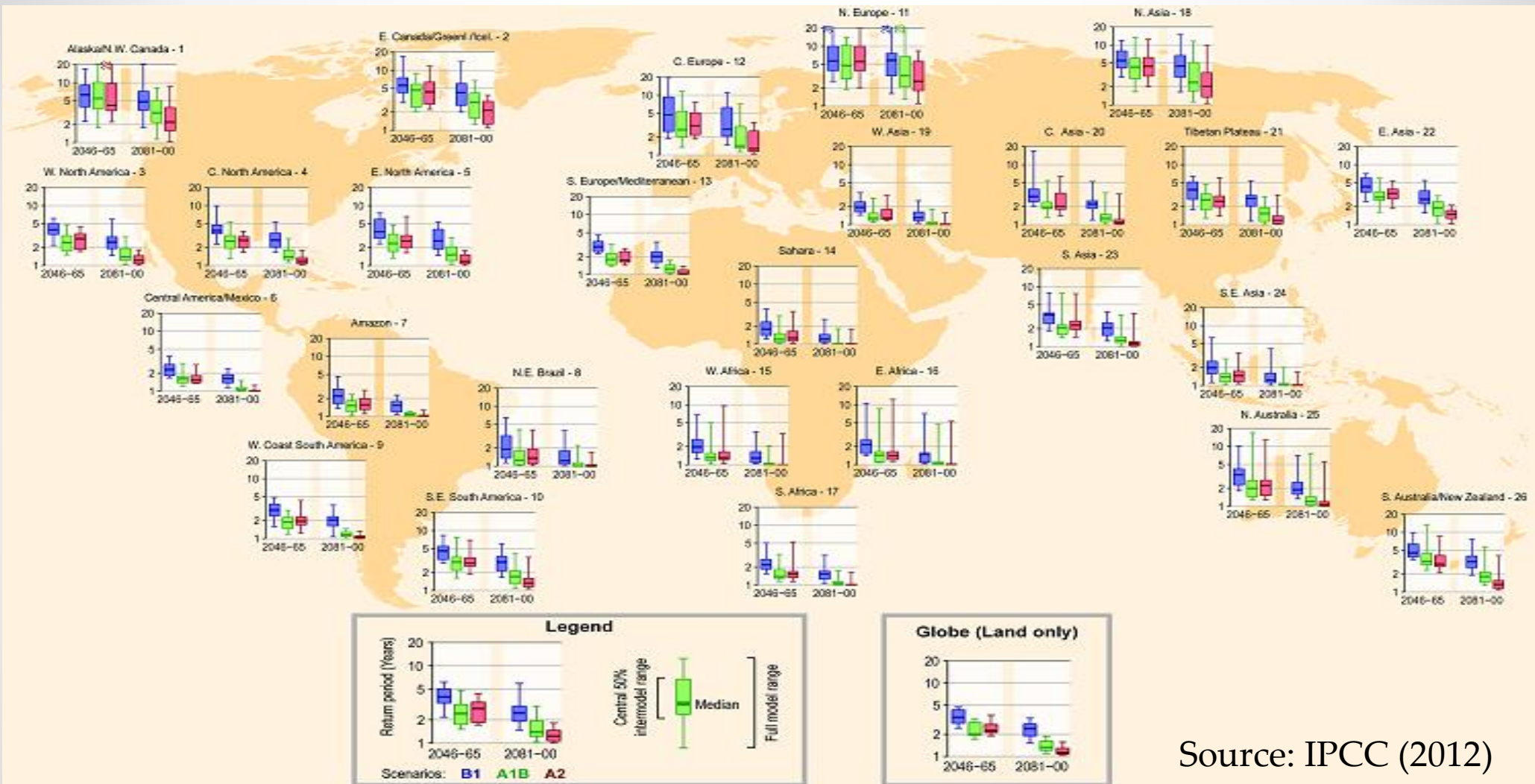
Local projections: Precipitation

Impact on Precipitation (% change)

Basin/Area, Country	A2			B2		
	Early	Mid	Late	Early	Mid	Late
Wangchu, Bhutan	3.5	9.8	18.7	1.0	1.0	6.0
Sikkim, India	-5.9	-7.4	-14.6	-9.2	-9.1	-11.4
Citarum, Indonesia	23.0	55.0	88.0	27.0	36.0	46.0
Tamakoshi, Nepal	6.0	15.0	25.0	6.0	13.0	19.0
Koshi, Nepal	0.9	1.3	14.2	-0.1	3.3	4.0
Indus, Pakistan	-	14.0	3.0	-	37.0	8.0
Mun, Thailand	10.0	45.0	3.0	-	-	-
Bangkok, Thailand	-2.0	-0.4	3.4	-0.3	-1.1	-1.8
Southern Vietnam	0.4	1.0	1.6	0.4	1.0	1.4

Precipitation shows different directions of change in various basins. The range varies from -14.6 to 88% change under A2 scenario and from -11.4 to 46% change under B2 scenario for late 21C.

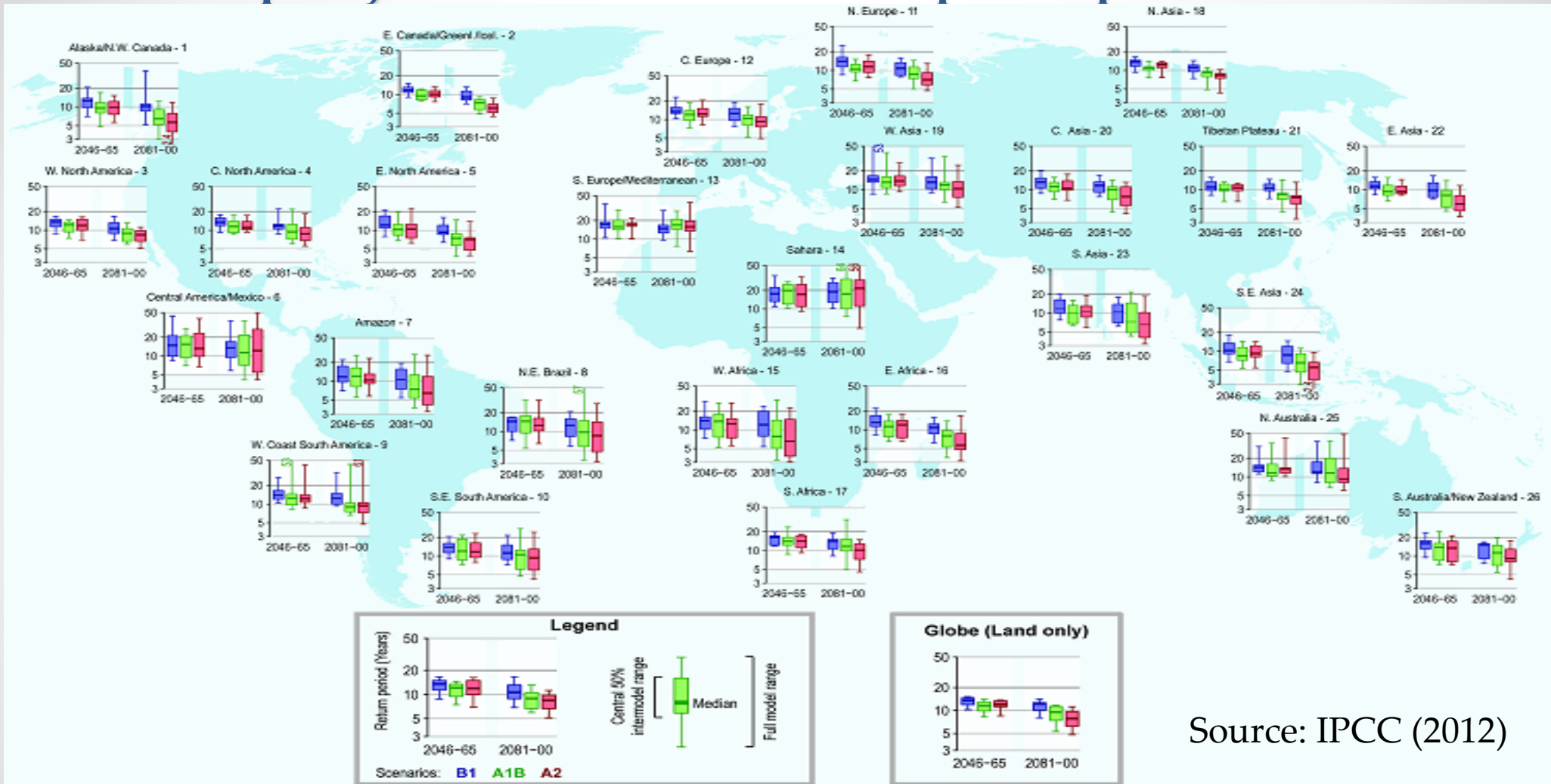
Global projections: Daily maximum temperature



Source: IPCC (2012)

The frequency of 20-year return period temperature is expected to increase to once in every 1 to 6 years for SE Asia and 2 to 5 years at Global level during 2046-65.

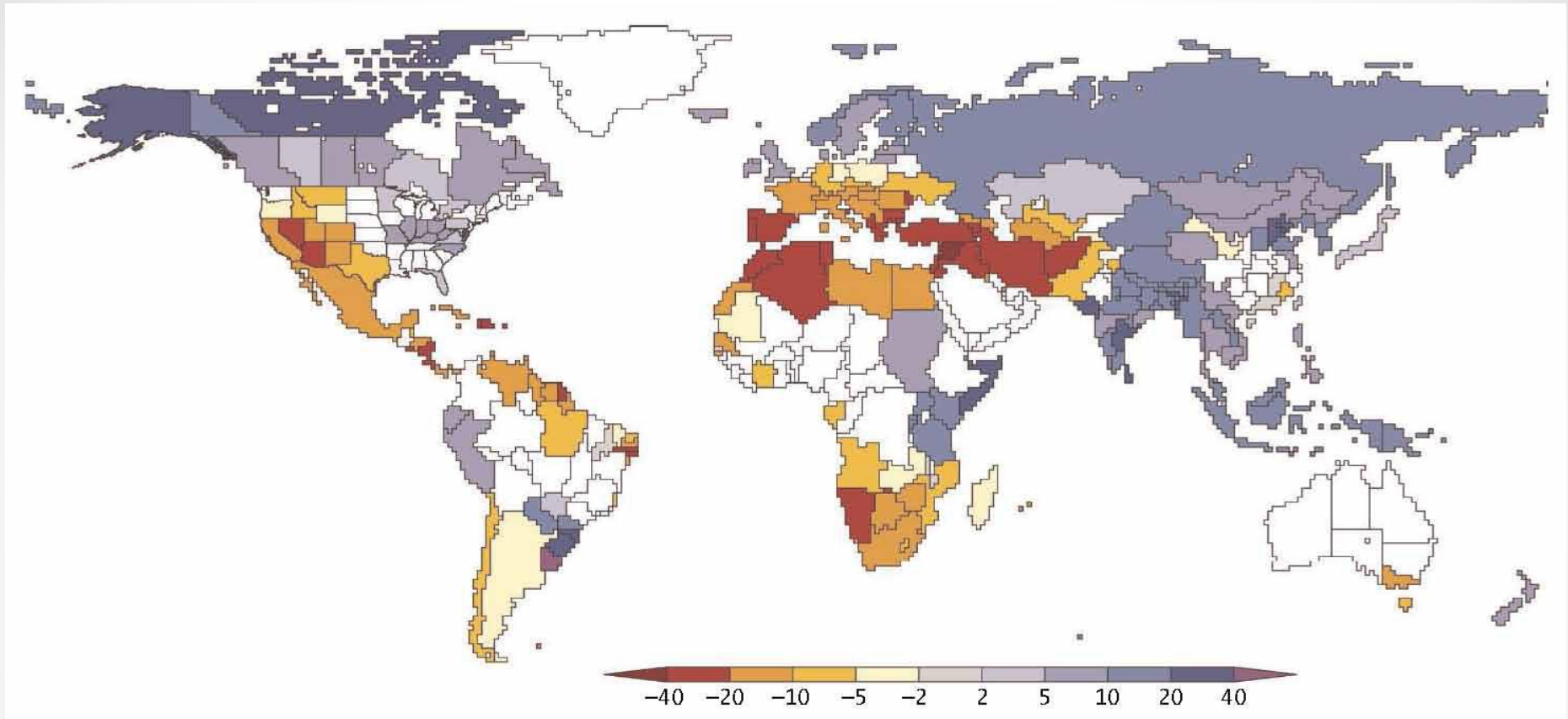
Global projections: Extreme precipitation event



Source: IPCC (2012)

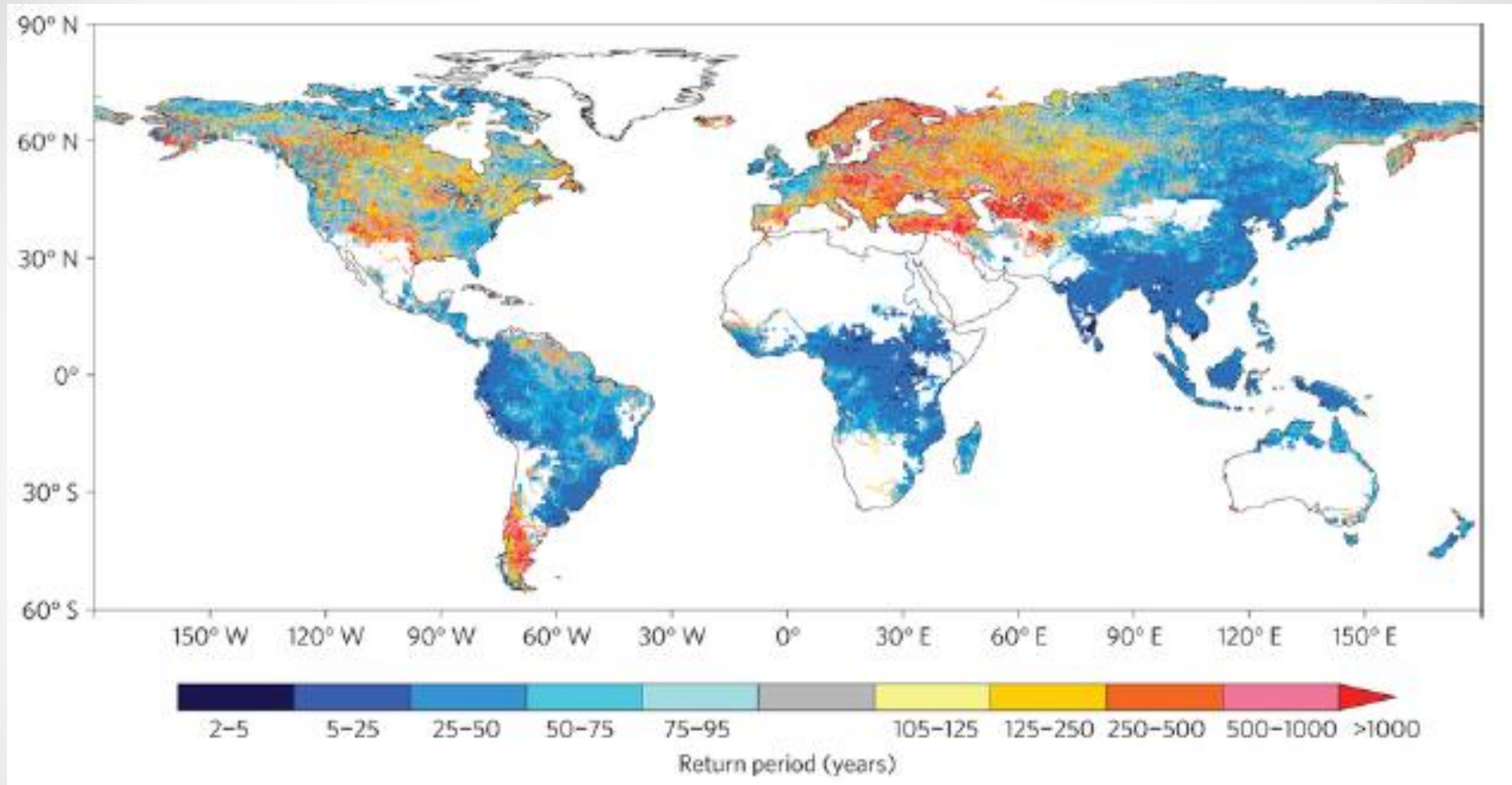
The frequency of 20-year return period precipitation event is expected to increase to once in every 5 to 20 years for SE Asia and 9 to 15 years at Global level during 2046-65

Global projections: Change in runoff



Projected change in annual runoff volume by the middle of the 21st century, relative to the historical period 1900-1970. Color denotes percentage change (median value from 12 models). Presence of color indicates that at least 8 of 12 models agreed on the direction (increase or decrease) of runoff change under the IPCC "SRES A1B" emissions scenario

Global projections: Flood frequency



The 100-year return period flood is expected to occur with 5- to 25-year return period in 21st Century in S and SE Asia for RCP8.5

Key Challenges

- Interpreting and using climate data at different scales in order to plan the development of water resources more effectively
- **Uncertainties in future climate projections**
- Forecasting extreme events
 - **Past is not a good indicator of future**
 - Frequency, location, magnitude, duration of extremes may change
 - Chance of extreme event is not the same from one year to next and is strongly related to large-scale climate drivers like ENSO
- Develop more accurate and reliable early warning systems
- Future local climate information (e.g. atlas)
- Translating the impacts to societal implications (vulnerability and risks)
- Impacts are visible, suitable adaptation and mitigation measures are required
- Science-policy dialogue

Key Challenges

- Preparing and implementing the adaptation strategies for long term and short term regional and local level impacts:
 - more intensive precipitation events
 - increased drought risk
 - reduced access to water and food
 - ecosystems shift in space and in species composition
 - change in growing season for traditional crops
- Shifting balance because of changed water demand while changed water supplies to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, energy producers, and manufacturers
- Lack of knowledge and capacity at different levels
- Lack of technology and infrastructure in developing countries
- Technology transfer
- How global and local communities can more meaningfully be brought together?

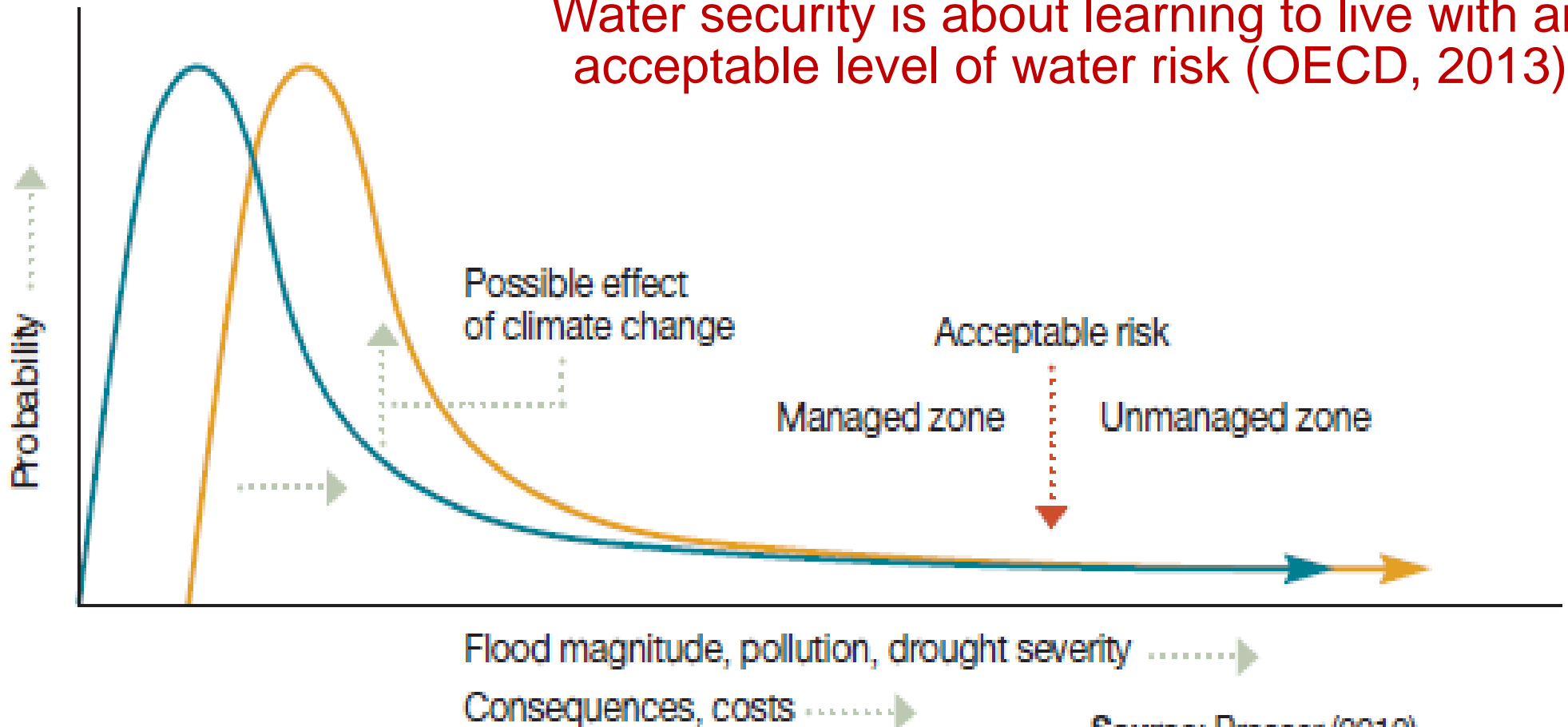
Uncertainties in Climate Change Studies in Water Resources

Climate Change Impact on Design Flood Discharge

Risks and Opportunities

Risks and Opportunities

Water security is about learning to live with an acceptable level of water risk (OECD, 2013)



Source: Prosser (2012).

Risks and Opportunities

- Abnormal weather becomes normal as a result of adaptation
- Probability as a measure of the costs of adaptation:
 - How high should be the protective dams be?
 - Flexible flood protection
- Three crucial factors of risks and opportunities posed by climate changes
 - Climate variability,
 - forecasting skills and
 - responsiveness
- Climate protection

Thank you...

Session 15:

Management of Flash Floods

Capacity Development Workshop:

“Flood Risk Assessment for Dungsumchu Basin in Samdrupjhomkar District,
Bhutan “

30 October – 08 November 2017

Mukand S. Babel

Professor, Water Engineering and Management (WEM)

Asian Institute of Technology (AIT), Thailand

- Flash Flood Characteristics
- Flash Flood Risk Assessment
- Strategies for Flash Flood Management
 - Structural measures to mitigate flash flood hazards
 - Strategies for exposure
 - Strategies to reduce vulnerability
 - Requirements for a flash flood management in a legal and institutional framework
- Local Level Activities
- Summary

Flash Flood Characteristics

Definitions

‘A flood of short duration with a relatively high peak discharge’
(WMO)

‘A flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area’ (Am. Met. Soc.)

In nutshell: A flash flood is, in short a sudden local flood of great volume and short duration which follows within a few hours (usually 6h) of heavy or excessive rainfall

Also, flash flood can occurs due to dam or levee failure, or sudden release of water impounded by a landslide dam, ice jam in a river or as a result of a glacier lake outburst (GLOF)



How Flash Floods Generate?

- Flash floods caused by rainfall events due to hydro-meteorological phenomenon and
 - the amount and location of rainfall is an important factors
 - hydrologic characteristics of ground surface also important
- Heavy rain events of short period but
 - with very high intensity
- Flash floods are common in mountainous areas and desert regions
- Flash floods are a potential threat in any area where the
 - terrain is steep,
 - surface runoff rates are high,
 - streams flow occurs in constrained channels and severe convective rainfall prevail
- Topography characteristics can be an indicator for areas susceptible to flash floods

Dangers of Flash Floods

- Flash floods occur in very short time from the triggering events
- Sudden rise in water levels and high flow velocities
- Carries large amount of debris

So that,

- Flash flood forecasting and early warning is important in terms of flood management
- Current forecasting techniques may not able to forecast all types of flash floods
- Forecasting capabilities and public awareness can help to improve the flash flood warnings and reducing the risk

Flash Floods vs. Riverine Floods

	Riverine floods	Flash floods
Features	<ul style="list-style-type: none"> • Slow water level rise • Reaches peak flow within hours to days • Slow recession • Mostly coinciding with high base flow levels • Medium to long lag times 	<ul style="list-style-type: none"> • Rapid water level rise • Reaches peak flow within minutes up to a few hours • Rapid recession • Often dissipating quickly • Not necessarily related to base flow levels • Short lag times
Causes	<ul style="list-style-type: none"> • Prolonged seasonal precipitation of low to high intensity • Seasonal snow and glacial melt 	<ul style="list-style-type: none"> • Very high intensity • Rapid snow/glacial melt • Dam breaks
Associated Problems	<ul style="list-style-type: none"> • Inundation 	<ul style="list-style-type: none"> • Often carry high sediment and debris loads • Very high hydraulic force and together with erosive power

Flash Floods vs. Riverine Floods

	Riverine floods	Flash floods
Frequency	<ul style="list-style-type: none"> Annually during rainy season 	<ul style="list-style-type: none"> Occasional, any time during year
Affected areas	<ul style="list-style-type: none"> River plains and valleys Local to regional extent Large areas can be affected 	<ul style="list-style-type: none"> River plains and valleys Alluvial fans Mostly local extent Generally small to medium areas
Forecasting	<ul style="list-style-type: none"> With appropriate technology and measures in place forecasting is easily possible Local information is less valuable Hydrologic forecasting is necessary 	<ul style="list-style-type: none"> Very difficult to forecast Local information is very valuable Hydro-meteorological forecasting is necessary

Flash Flood Risk Assessment

Hazard

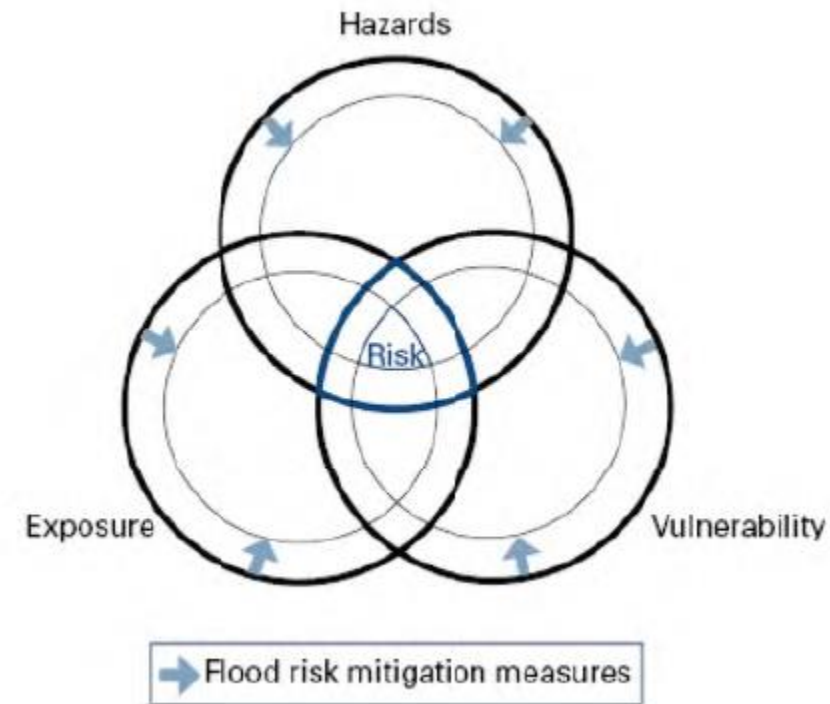
- Flash flood magnitude which define by the probability of occurrence
- The information can be translate to inundation maps showing depth of inundation and related velocities

Exposure

- Human activity and environment in the hazard zone

Vulnerability

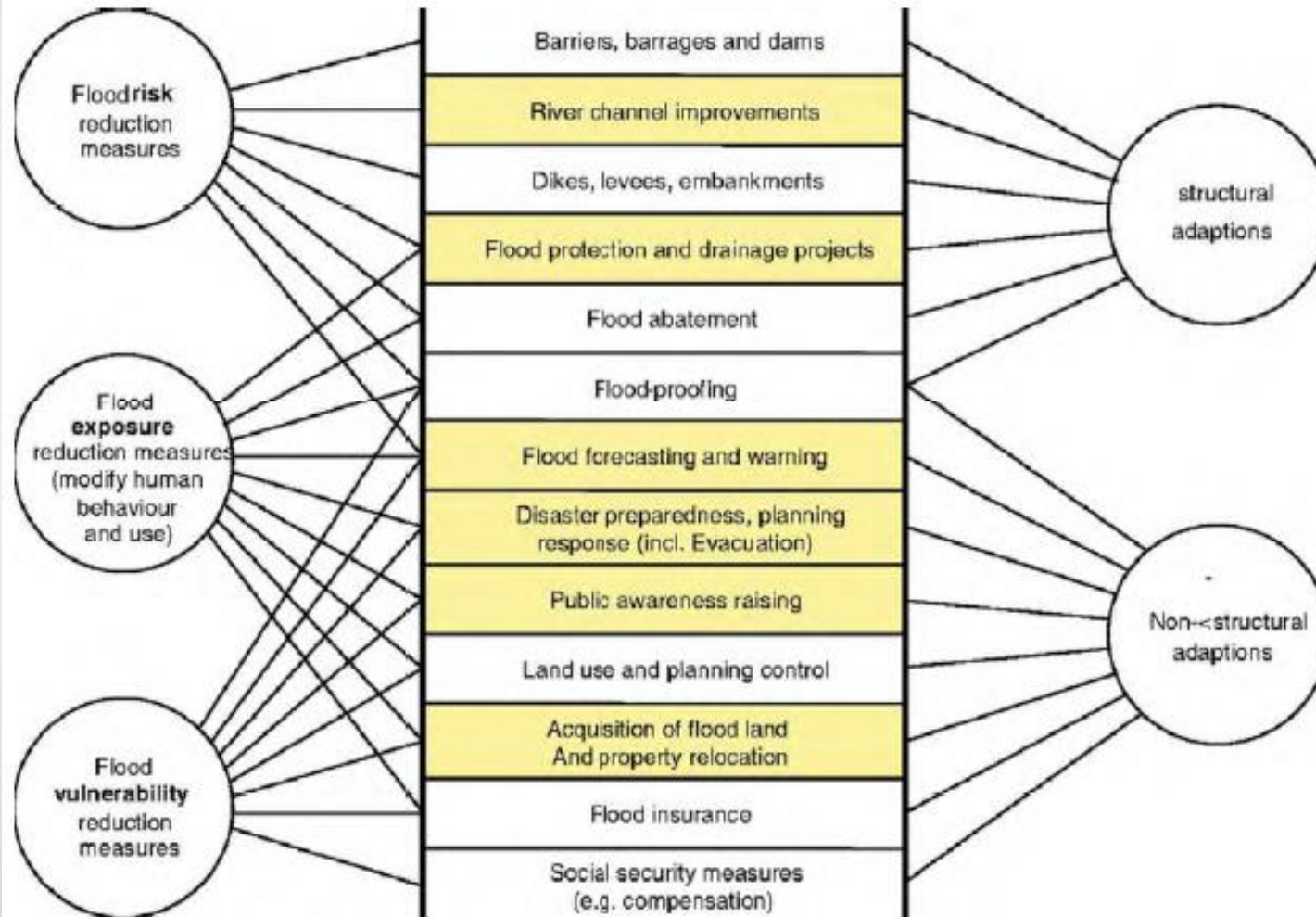
- The susceptibility of a region to flood losses, defined via the geophysical, economic and social attributes of a region



Flood risk characterization (WMO, 2006)

Strategies for Flash Flood Management

- Two types of measures : structural and non-structural
- Both complement each other



Flash flood management measures (Parker, 2000)

Mitigate hazard

- Directly reduce the magnitude of flash flood hazard
- Not always efficient or cost effective
- Can enhance the flood problem by shifting or increasing the hazard in other locations
- Structural measure that can be crucial in areas where flash floods occur can be divided into four groups:
 - Measures in the whole of the catchment: To delay the speed of surface run off and limit the erosion
 - Terraced farm crops
 - Construction of stone walls on the baulk
 - Promotion of correct farming strategies and practices
 - Stabilization of the beds of small streams via wooden or stone thresholds
 - Reinforcing steep slopes
 - Stabilizing the bottom and sides of drainage ditches

Mitigate Hazard (cont..)

- Regulating rivers and streams: To control the water regime through limiting the slope of river and streambeds
 - Barriers made of wood
 - Stone or gabions
 - Wooden or stone thresholds
 - Various types of anti debris dams
 - Dikes and embankments to protect buildings
- Shaping retention: To shaping retention to reduce immediate flooding
 - Retention reservoirs
 - Dry reservoirs and polders
 - Small dikes and dames raised from local materials
- River conservation: To prepare river valley for direct flood water

Strategies for Exposure

- Flood forecasting considerations and Uncertainties
 - To provide timely and accurate information and data for the development of warnings to save lives and property
 - Quantitative precipitation forecast (QPF) could be a possibility for flash flood watch
 - Numerical Weather Prediction Models (NWPM) → QPF
 - Radar-based now-casting system
 - Prediction by individuals by observing clouds in upper catchments
- End-to-end forecasting and warning systems
 - Forecast should provide sufficient lead time
 - Forecast should be sufficiently accurate to promote confidence
 - End-to-end forecast and response/ decision support system consists of :
 - 1) Data collection and communication,
 - 2) Meteorological and hydrologic forecasting and forecast product generation
 - 3) Disseminating forecasts to users
 - 4) Decision making and support
 - 5) Action taken by users

Strategies for Exposure (cont..)

- Flash flood warnings
 - Informed through disaster management agencies
 - Warning systems should be supported by response plan
 - Should identify what assistance is required from emergency services
- Organizational requirements
 - Cooperation involving stakeholders are necessary
 - Emergency services at the local level should cooperate with NHMS
 - Use of mass media for warnings dissemination
- Spatial Planning
 - Limiting the increase of flash flood exposures by limiting the flood damage potentials
 - Mechanisms to ensure cohesion between spatial management plans based on administrative boundaries and FFMP based on catchments
 - Land-use regulation controls new constructions in high flood risk regions
 - Flood proofing at household level to reduce exposure

Strategies for Vulnerability

- Participatory Planning
 - Limiting danger to people’s lives and protect properties
 - Requires planning of simple advisory and educational activities, carried out systematically and over the course of years
 - Plans at the local level should be initiated by self government, but the planning should be conducted with the participation of all stakeholders

- Planning Preparation

Activity	Action
Initial identification of the sites at risk	Residents at risk, people running business, owners of building, public agencies, communal sites
Establishment of local and greater institutions	Crisis response services, police, firefighters and greater institutions responsible for maintaining the river, forecasting, warnings, etc.
Establishing the structure and principles	Deciding leader and group structure and the work principles
Establishing methods of supplying information	Deciding how the local community will be informed on the result of work

Planning Processes

Activity	Action
Identification of danger	Establishing which areas are at risk, what kind of risk are taking place there and what is at risk.
Establishment of what has already been done	Collecting information on past and present activities of various institutions in limiting flood damage in the area.
Establishing the goals	Describing what the plan hopes to achieve. This task leads to the establishment of main goals in limiting flood and what dangers floods introduce for various spheres.
Defining the possible situations	Establishing what paths could be taken to reach the set goal, what work should be carried out. Non-structural and structural measures should be taken into consideration.
Developing an implementation plan	Planning the proposed order of activities, institutions responsible, possible sources of financing or sources to aid the realization of the plan.

Strategies for Vulnerability (cont.)

- Challenges in community participation
 - Passivity of local communities in addressing and solving their own problems
 - Areas whose development has been blocked or in poor regions

- Raising Awareness and Preparedness
 - Planning of awareness raising activities
 - Activity target groups
 - Topics
 - Methods
 - Local flooding signs which are showing the depth and extent of historical event

- Flood insurance

Legal and Institutional Framework

- Flash flood management needs to address several sectoral specific areas of public law
- Laws and regulations:
 - Define institutional roles and responsibilities
 - Determine and protect rights and obligations
 - Provide mechanisms for dispute management
- If implemented, framework must clarify:
 - Responsibility of each level of administration
 - The rights and obligations of individuals
 - Required authority for various parts of the administration
 - Liability issues if forecasts provided are inaccurate or warnings are inappropriate
 - Legal responsibility of government organizations when flash flood events and warnings are missed and/or false alarms
 - Judgement about the efficiency of putting into practice legal responsibility for NMHS and local government considering existing uncertainties.

Local Level Activities

Step 1: Evaluation of Community Readiness

- It is essential to confirm the condition of awareness and preparedness of local community,
 - prior to plan development activities
- Meetings devoted to flash flood matters, distribution of surveys amongst the at risk residents
- Plan preparation should start with a flash flood education program
- Convince the community by showing positive examples
 - the result of similar activities that have been achieved in other locations make for good education material

Step 2: Creating a Planning Team

- Decision making competencies and approaches change
 - according to local conditions and capabilities
- Team should consists of
 - local leaders,
 - residents,
 - representatives of various at risk populations,
 - representatives of social organizations and
 - specialists
- Avoid issues and conflicts which rise due to the
 - different levels of education and knowledge,
 - capacities,
 - life experiences and
 - personalities

Step 3: Public Consultation

- It is important to give the local community access to information on problems which directly involve them
- Community consultation include:
 - Analysis of the local flood risk
 - Proposed aims of the activities included in the plan and priorities
 - Analysis of the proposed solutions
- To ensure the participants influence on the decisions made in the planning process,
 - disseminating information about the planned activities beforehand is a necessity
- Documents and materials which share with public should be understandable to all and easily accessible •

Summary

- Flash floods are, by their characteristics, difficult to manage
 - by traditional flood management approaches
- Reducing the hazard requires the best mix of structural measures and non-structural measures
- Forecasting and warning play an important role
 - still a challenge at times to give accurate and timely forecast and warning information
- Appropriate spatial planning can help to reduce exposures
 - and lessen the magnitude of flash flood hazards
- Participatory approaches enable local communities to be aware of flash flood risks
 - and this increases the efficiency of flash flood management
- An appropriate legal and institutional framework is necessary to develop a successful flood management plan.
 - the role of local disaster management organizations important and should be given appropriate powers and responsibilities both legally and institutionally

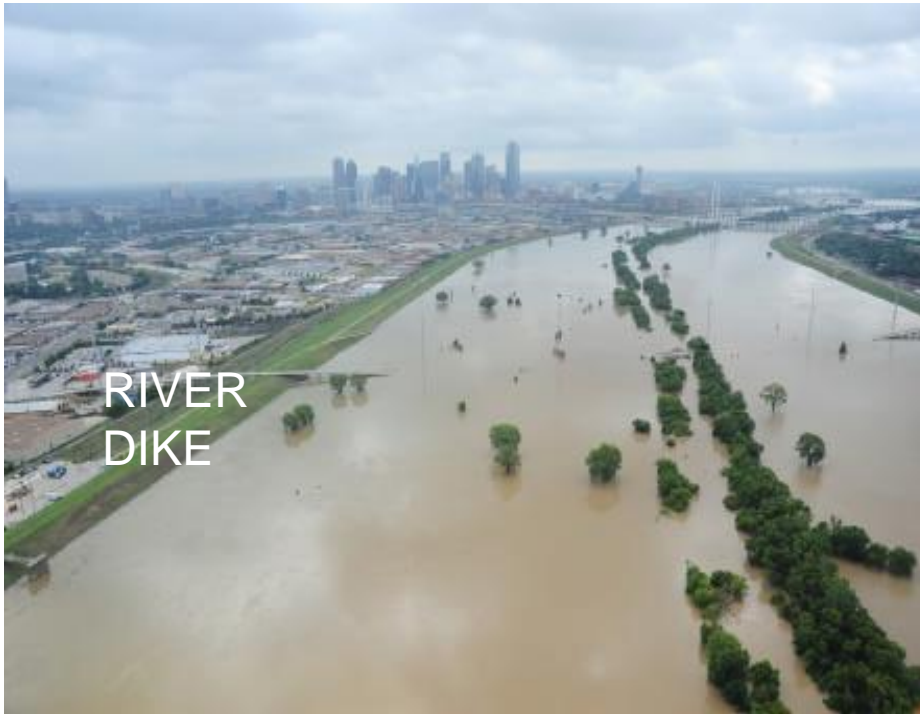
Thank you ...

Capacity Building Programme on
Flood Risk Assessment and Management
30 October - 8 November 2017

Sessions 17a: Design of River Dikes

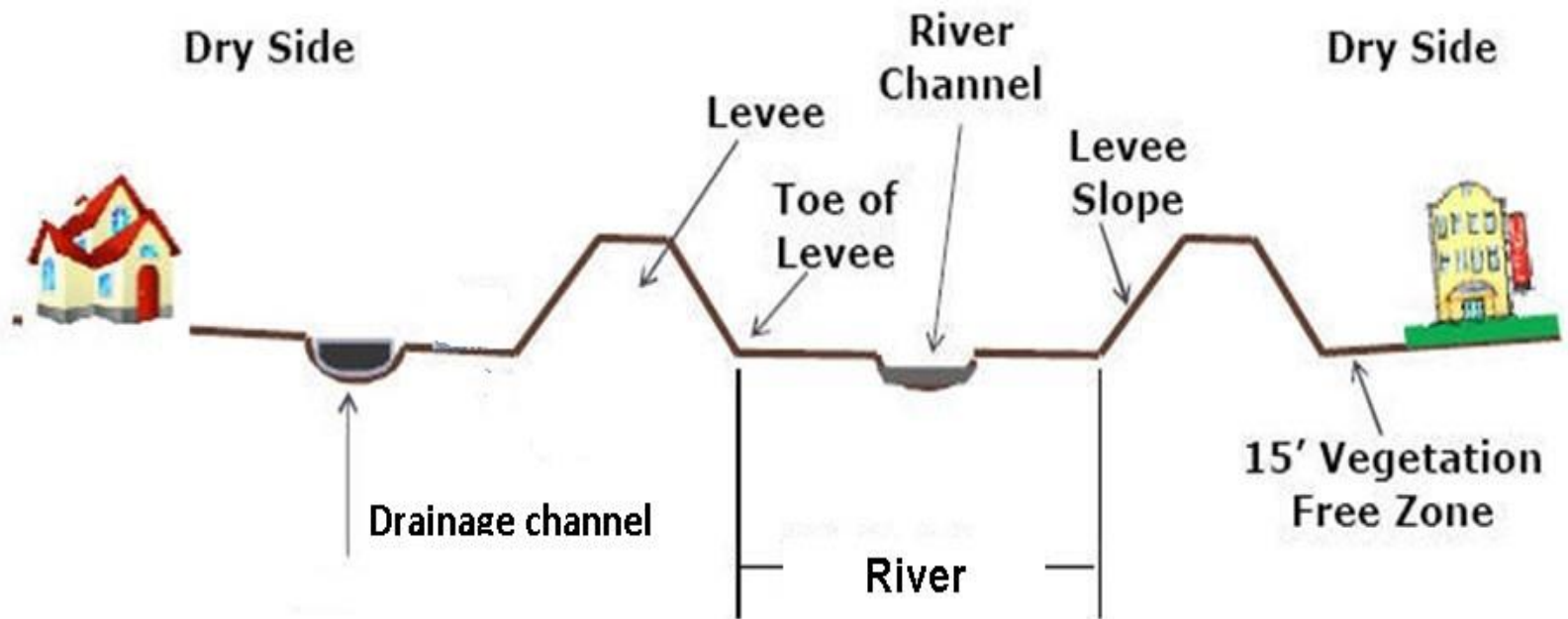
Prof. Tawatchai Tingsanchali

Water Engineering and Management
Asian Institute of Technology, Thailand



- A river dike or levee is an earth embankment constructed along river or coastline to protect adjacent land from flooding.
- Flood walls are concrete structures designed for urban areas that have insufficient room for levees.
- Levees and flood walls are important components of flood risk reduction for many flood prone areas

Design Criteria on Management and Maintenance of River Dike or Levee



- **Dike must be easily accessible under all circumstances and road on dike crest must be usable**
- **Angles of slopes should allow good grass cover**
- **Surrounding elements such as buildings, tree , cable and pipes etc on or in the dike be allowed only if they pose no problems**
- **Water adjacent to dike toe require provision to prevent musk-rats to damage the dike**

Design Criteria for River Dike or Levee

- Hydraulic boundary condition
- Soil investigation, pore pressure, peizometric head
- Crest level/Free board
- Water tightness
- Resistance to erosion
- Slope stability with respect to internal erosion and sliding

Hydraulic Boundary Condition

- Design water level
- Wave attack
- Wind set-up
- Rapid drop in water level after a flood

Design Criteria for Crest level/Free Board

Height of Dike = Design
water level (DHW)
+ required free board (w)
+ Surplus height (z) design
for expected settlement of
dike in next 50 years

Design water level (DHW) =
max. high water level

Freeboard = at least 0.5 m

$$a = \text{DHW} + w + z$$

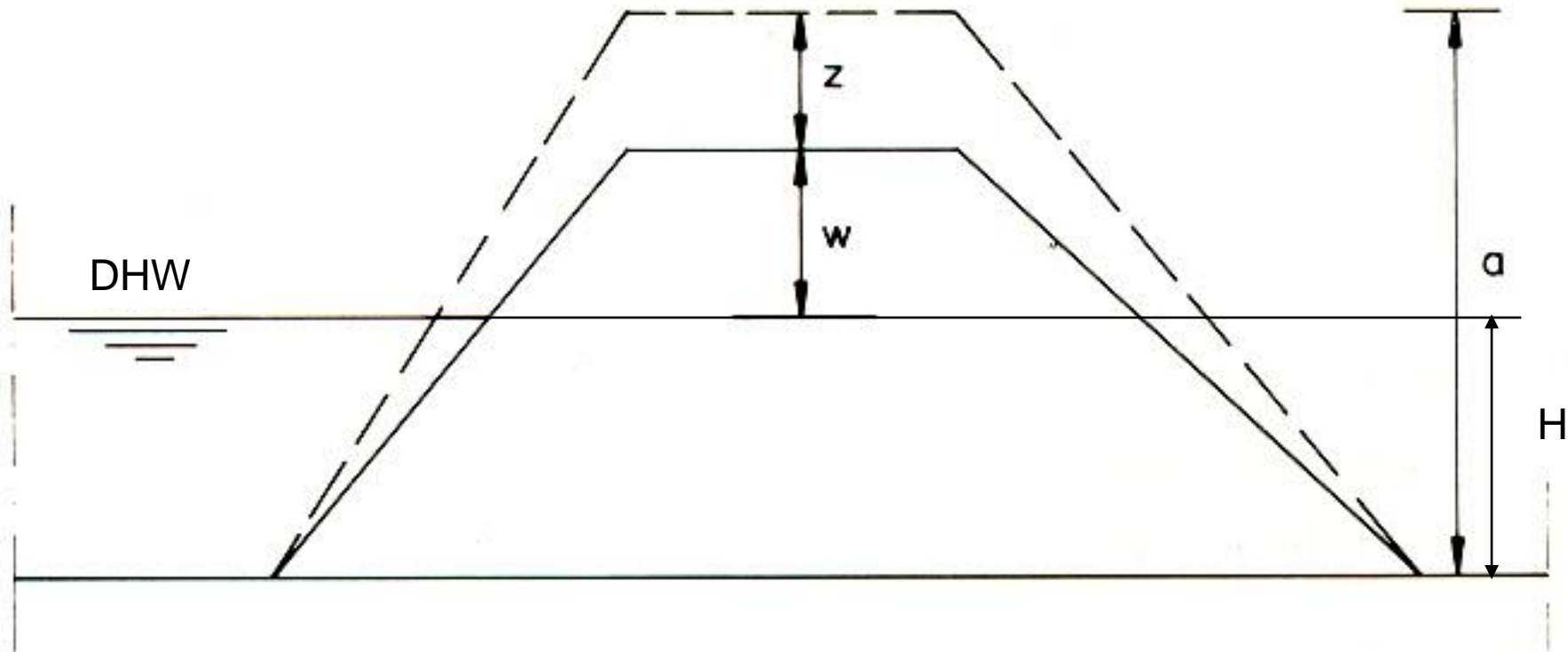


Fig. Determination of the construction height of a dike.

Determinant High Water Level DHW

- It is design water level based on a design return period such as 100 or 1000 years depending on budget and potential risk of protected area.
- In general, a design return period of 100 years has been adopted.

Detailed Design of River Dike

- Dike alignment
- Dike profile
- Clay covering on slopes and crest
- Resistance to erosion of inner slope and crest
- Protection on outer slope
- Drainage and filter construction
- Sheet pile walls, retaining wall cofferdams and low dike walls
- Watertight screen (flow cut-offs)

Dike Alignment

- Existing dike alignment should not be changed for dike improvement
- For new dikes, structure of subsoil must be considered
- Areas with thick soft clay or peat strata highly compressible and prone to settlement are not suitable for dike construction due to stability and settlement

Dike Profile

- Outer slope of 1:2 or smaller is recommended with hard protection
- Inner slope of 1:3 or smaller is recommended for wider space to prevent sand boil
- If there is no access road for dike inspection, a minimum crest width of 4 m is needed
- To prevent rats nesting in dike, open water along dike toe should be avoided. Use of stone pitching or gabions can be used for rat protection.

Soil investigation, pore pressure and peizometric head

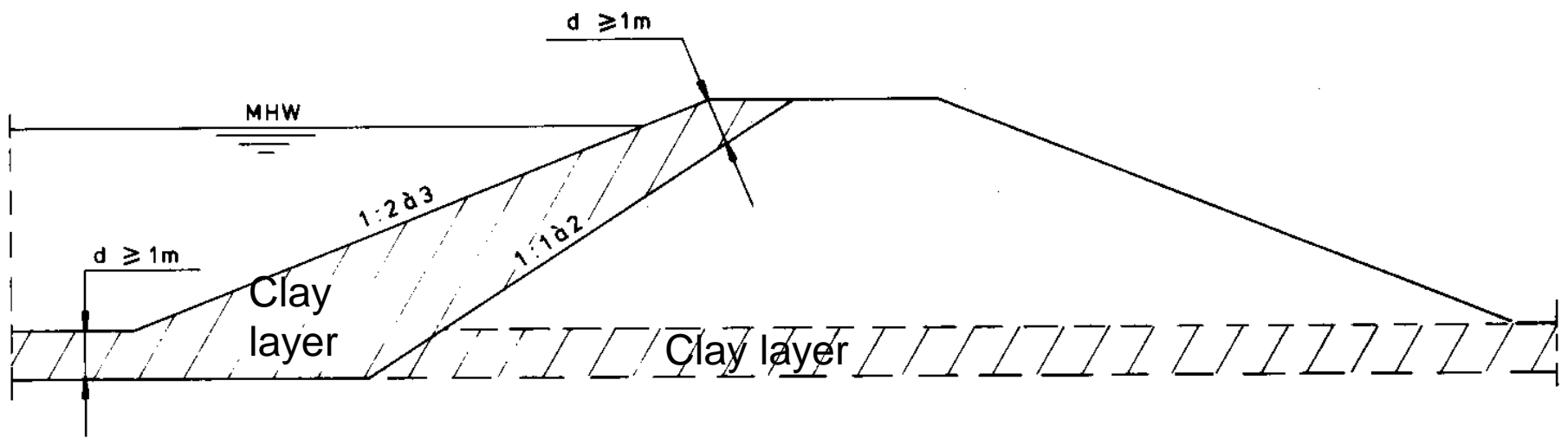
- **Investigation of longitudinal profile of soil along outer toe and along inner toe**
- **Cone penetration test and hand boring for reconnaissance survey**
- **Well and pumping test and infiltration test**
- **Borings of undisturbed samples for lab test**
- **Determination of soil parameters**
- **Computing pore pressure, peizometric head by ground water model using design values of geometrical, soil and hydrological parameters**

Water Tightness Criteria

- To prevent high pore water pressure in dike and seepage of water
- Placing of clay layer on outer slope and over foreland and under dike
- Clay layer of at least 1 m thick with clay percentage of 20%-35%
- Clay should be put in wedge shape for impermeability and stability
- Upper clay layer should be erosion resistant

Criteria for Resistance to Erosion of Inner Slope

- Erosion due to flow overtopping or rain over crest and inner slope
- Critical discharge:
 - 0.1 litre/s/m length for dike with sandy soil with poor grass cover
 - 1 litre/s/m length for dike with clayey soil and good grass cover
 - 10 litre/s/m length for dike for clay revetment and grass cover



Representative Cross-section of a Dike

Criteria for Resistance to Erosion of Outer Slope due to Wave and Current Attack

- Generally clay with good grass cover is sufficient
- For heavy attack, hard revetment such as stones or asphalt is required for safety assurance up to dike crest level

Design Criteria for Internal Erosion and Stability

- No heave of sealing layer may occur within a zone of $5H$ measured from intersecting line of DHW with inner slope
- Mean vertical pore pressure gradient may not exceed 0.5 at intersection of inner slope with mean ground level
- Mean vertical pore pressure gradient may not exceed 0.7 at a distance of $5H$ from this intersection

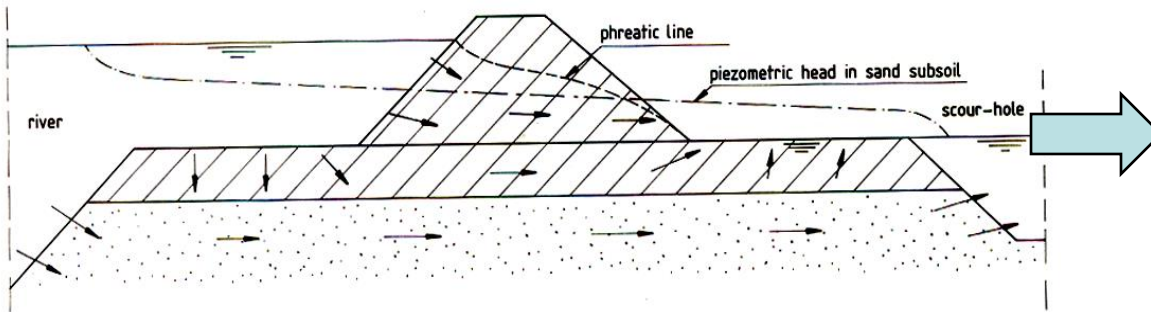
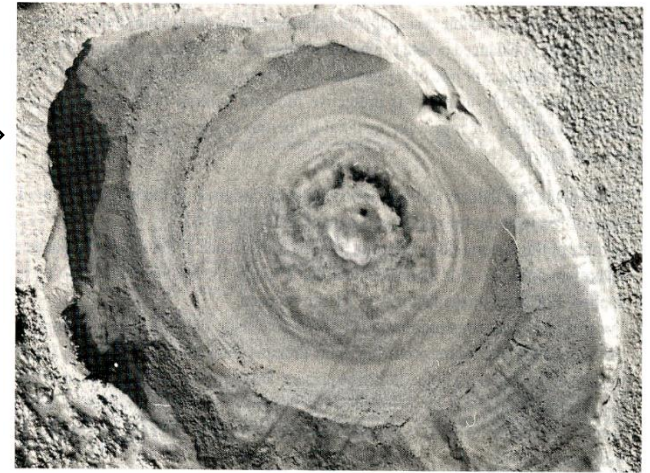


Fig. 28. Groundwater flow near a river dike.



Sand-carrying boil with crater formation.

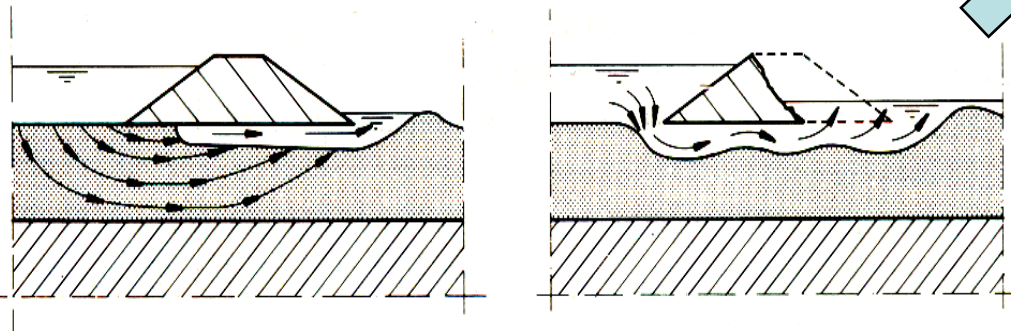


Fig. 52. Piping due to groundwater flows under a dike.

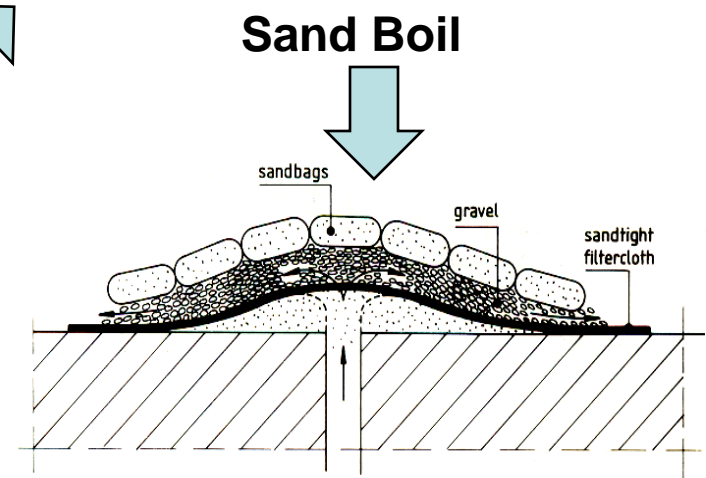


Fig. Covering of a boil with a filter cloth with ballast.

Piping due to Groundwater Flow Under Dike

Cover Sand Boil with Filter Cloth and Ballast

Clay Covering Slope and Crest

- Covering clay should have high cohesion and high density.
- For outer slope, typical low permeability mixture is 20-40% clay, 25-40% sand and organic material < 3%
- Min clay thickness for outer slope should be 1 m for water tightness and cracking
- For inner slope, permeability of cover should be higher, clay content should not exceed 25%
- Clay should be fertile for grass growing

Resistance to Erosion of Inner Slope and Crest

- Grass cover in clay subsoil can resist flow velocity up to 6 m/s for a long time period. If subsoil is sandy clay, soil serious erosion can occur within a short period at velocity of 3 m/s
- Apart from rainwater, wave overtopping can erode crest and inner slope.
- Overtopping is not allowed if inner slope and crest covered by very sandy, inhomogeneous soil with poor grass cover.
- Usual brick or asphalt road pavements on river dikes is sufficient to protect erosion of underlying earth body.

Protection on Outer Slope

- **Hard construction is applied at locations to places where grass cover is not sufficient for protection such as river current that directly hits the dike.**
- **Due to high cost, revetment is done only below maximum water level of 100 year return period.**
- **Various materials such as stone, concrete, bituminous mixture and geotextiles are used in slope revetment.**
- **It is necessary for the slope revetment to follow the settlement without damages**

Drainages and Filter

- To prevent drainage blocking caused by high groundwater levels and seepage water.**
- To achieve controlled outflow of seepage so that soil particles cannot be washed out.**
- Drainage is provided on the inner berm of the dike or on the ground surface behind the dike where water outflow occurs.**
- Drainage reduces pore water pressure in the dike body and the ground hence increases dike stability.**

Drainages and filter constructions (Toe or Slope Drainage)

- Properties of filter materials follow Terzaghi equation

The classical Terzaghi's criteria for granular filters are expressed by the following two equations:

$$d_{15F} \geq 4 \text{ or } 5 d_{15S} \quad (1)$$

$$d_{15F} \leq 4 \text{ or } 5 d_{85S} \quad (2)$$

where: $d_{15F} = d_{15}$ of the filter; $d_{15S} = d_{15}$ of the soil; and $d_{85S} = d_{85}$ of the soil. (d_x is defined as the particle size such that the soil contains x% by mass of particles smaller than d_x .)

Drainages and filter constructions (Toe or Slope Drainage)

- Coarse sand, crushed stone sand, gravel and crushed rubble are generally used for drainage construction in river dikes.
- Geotextile sheet can be used to replace lowest layer of a more layer filter.

Sheet Pile Walls and Retaining Walls

- Sheet piles or retaining walls can be used to reduce space required for construction of river dike that satisfy safety criteria such as based on water seepage.
- They are normally used at water retaining side of dike to increase strength and safety of river dike when river level is highest or when river level drops quickly.

Seepage Flow Cutoff (Water Tight Screen)

- To interrupt totally or partially seepage flow so as to prevent sand boils or piping
- To decrease pore-water pressure in the soil at the inner side, which has favorable effect on stability of inner slope
- Watertight screen is effective to cut-off seepage flow in highly permeable sand layer

Sheet Pile Walls and Retaining Walls

Fig.1 Stabilization of an existing dyke with steel sheet piles

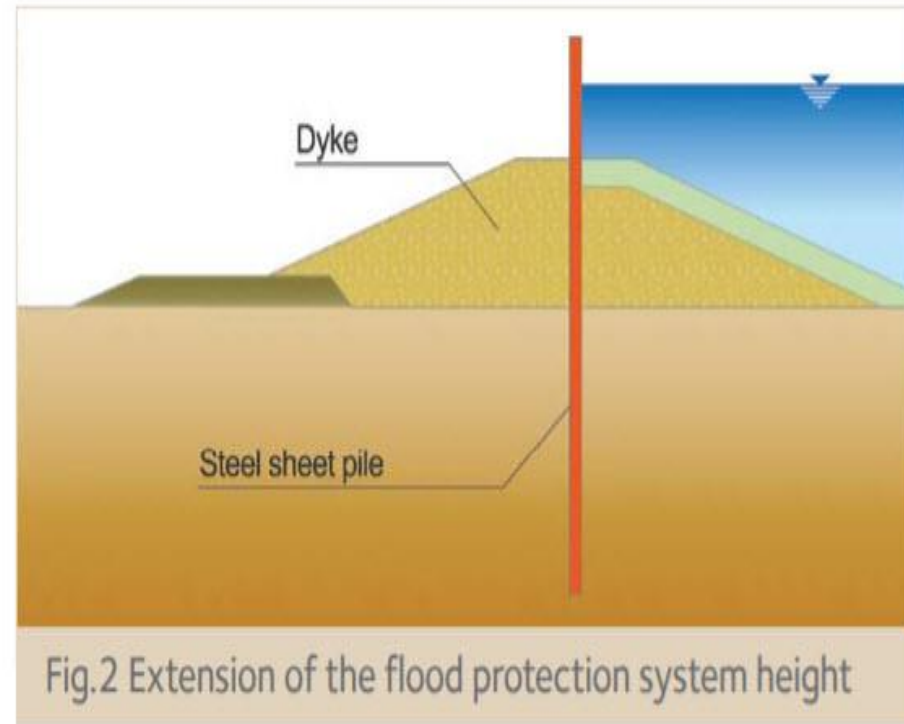
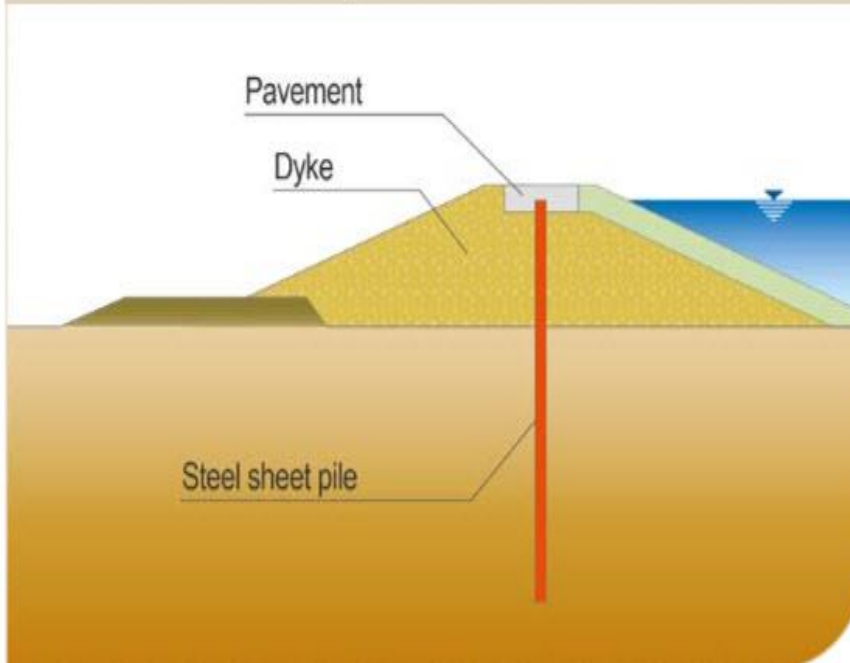
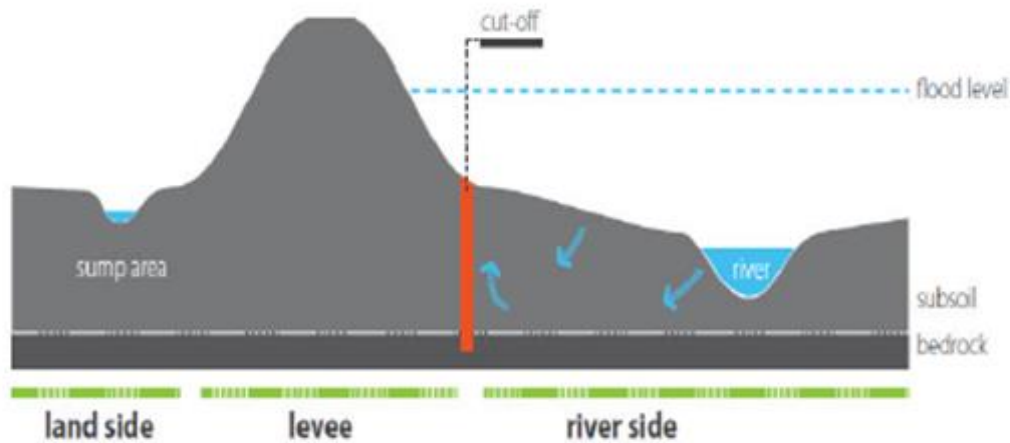
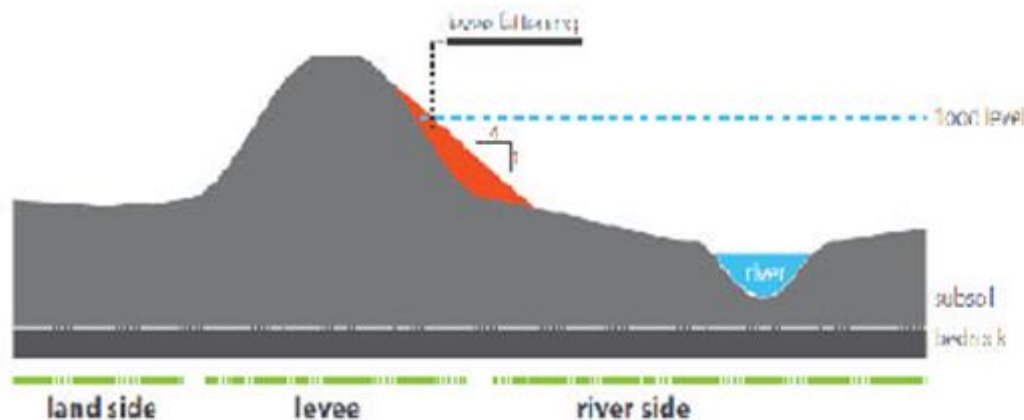


Fig.2 Extension of the flood protection system height

LEVEE IMPROVEMENTS



Cut-Off walls are proposed to address seepage concerns, where water could move through sand layers from river side to dry side of land



Levee fattening to address slope stability – shallow slides have been experienced along the River

Watertight Screen (Flow Cutoff)

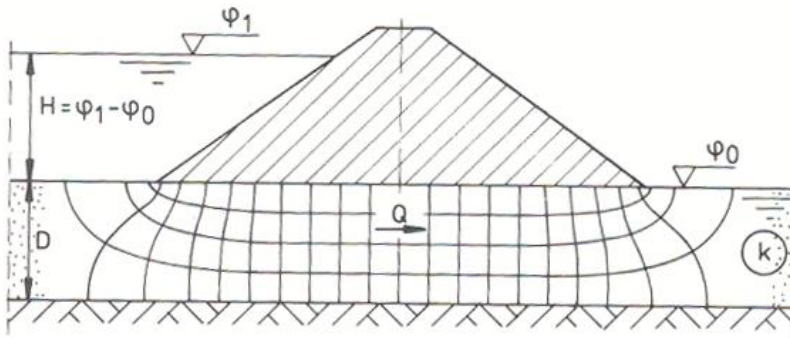


Fig. Flow net for sand layer under a clay dike.

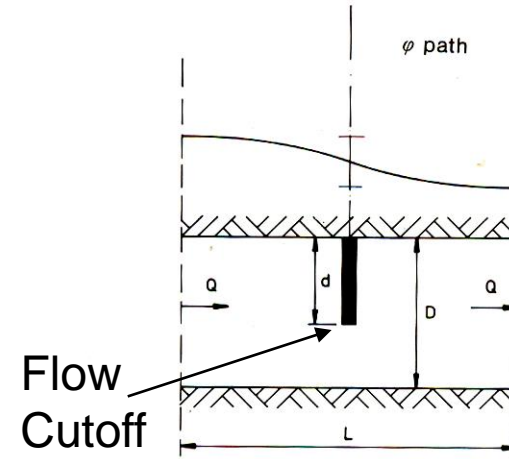


Fig. 66. Situation of watertight screen.

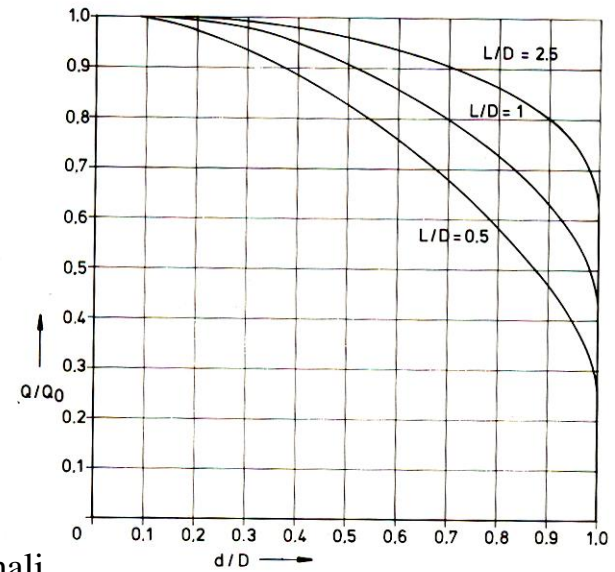


Fig. Relation between size of a screen and groundwater flow.

CONCLUSION

- General design criteria of river dikes are given.
- Considerations on hydraulic boundary conditions required for design of river dikes are described including soil investigation, pore water pressure and peizometric head.
- Detailed design of river dike, its cutoff core, slopes, crest level, free board, outlets and filters are provided.
- Water tightness, resistance to erosion and stability of earth dikes are given.

Thank You

Capacity Building Programme on
Flood Risk Assessment and Management
30 October - 8 November 2017

Sessions 17b: Design of Embankment Dams

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Asian Institute of Technology, Thailand

EARTH EMBANKMENT DAM

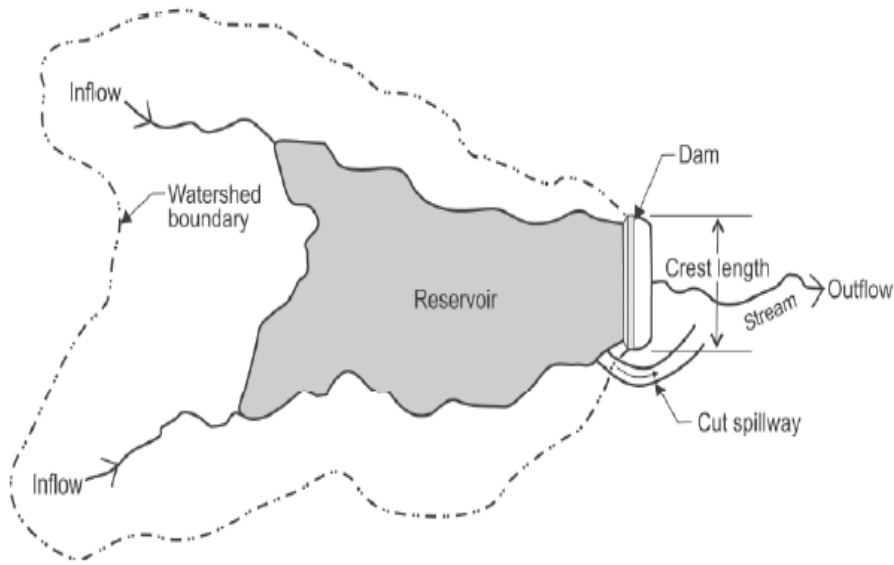


Figure Plan view of dam and reservoir

● An earth embankment is a dam made from compacted soil to impound rain water runoff. Embankment dams are made of earth or rock.

Height of earth embankment is vertical distance from natural stream bed measured at downstream toe of embankment to its top.

TYPES OF EMBANKMENT DAMS

Basically, there are two types :

1. **Homogeneous embankment**

is composed of one kind of material (excluding slope protection) sufficiently impervious to provide adequate water barrier and slopes must be moderately flat for stability and ease of maintenance

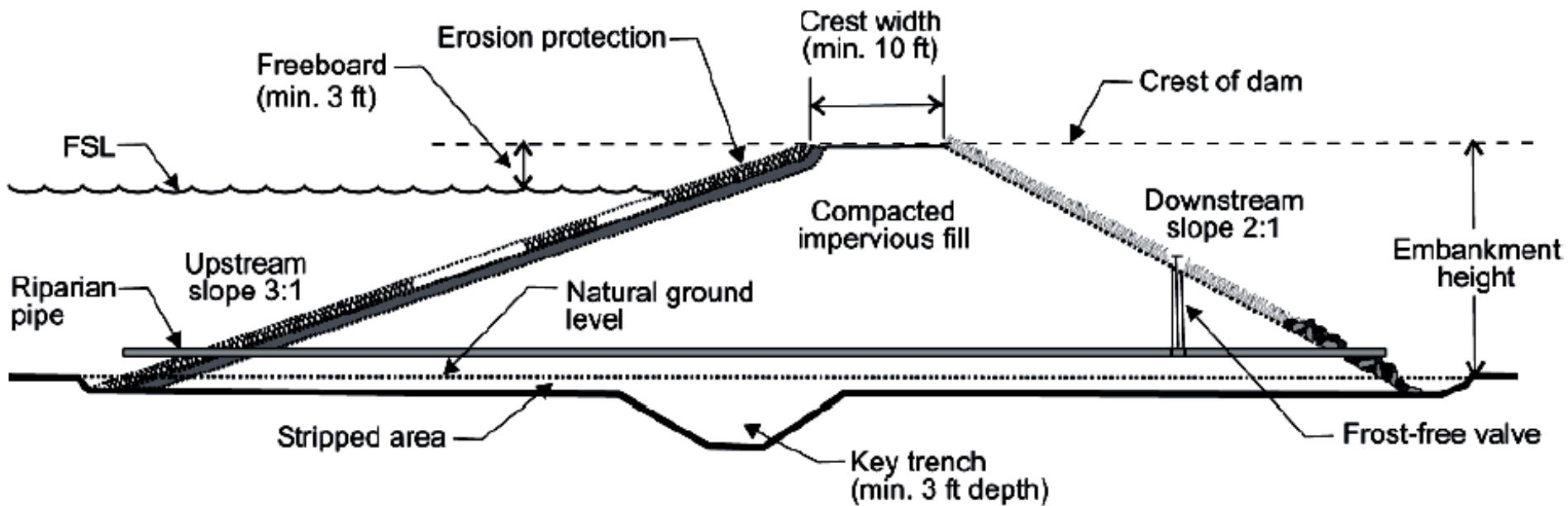
2. **Zoned embankment**

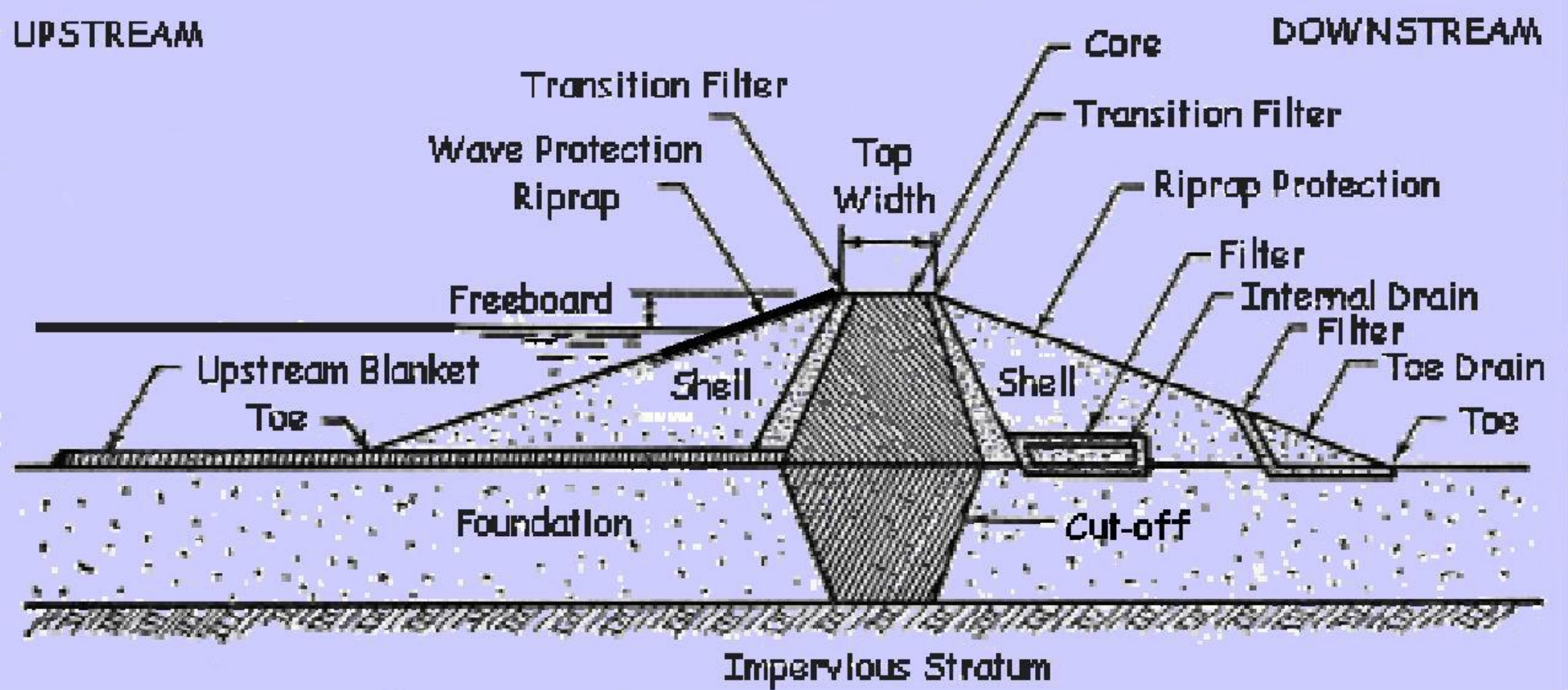
contains central impervious core, flanked by zones of more pervious material, called shells. Zoned embankment requires internal drain (filter) between impervious zone and downstream shell and between shell and foundation

HOMOGENEOUS EMBANKMENT

- In high embankment having rapidly fluctuating reservoir water levels for long periods, excessive pore pressures and seepage can be a problem.
- If seepage is excessive, this can lead to instability and eventual failure of all or part of downstream face.

HOMOGENEOUS EMBANKMENT DAM





Zoned Embankment Dam

SELECTION OF DAM TYPES

Depends on availability of materials in nearby areas due to high transportation cost

-Select homogeneous embankment dam if there is a lot of impervious material nearby

-Select zoned embankment dam if there is limited impervious core material and rock is available

BASIC DESIGN CRITERIA

U.S. Corps of Engineers (1968)

1. Embankment slopes must be stable under all construction and operating conditions, including reservoir drawdown.
2. The embankment must not impose excessive stresses on the foundation or abutments.
3. Seepage flow through the embankment, foundation and abutments must be controlled so that piping, sloughing, or removal of material by solution does not occur. Seepage flow quantities may also be limited by storage considerations.
4. Spillways, outlet capacities and freeboard must be sufficient to prevent overtopping. Freeboard must include allowances for post construction embankment and foundation settlements.

DESIGN OF EMBANKMENT DAMS

- Homogeneous dams should have flat slopes (1:3 upstream and 1:2 downstream) to protect possible instability. A flatter upstream slope, required by all earth dams, prevents slumping of saturated upstream section below water level.
- Water levels should not be allowed to fall or rise too fast, especially if the embankment material is impermeable. This is because a rapid lowering of the reservoir could lead to slumping of the upstream face

SOIL TYPES FOR EMBANKMENTS

- Sands and clays, and their combinations are most suitable for earth dam. Silty soils are unsuitable due their inherent instability when wet and should not be used.
- upstream shoulder does not require highly impermeable clays as these could lead to undesirable uplift pressures developing beneath this section of embankment.
- Sandy clay soils are most suited for upstream section as they compact well, reduced much seepage but do not allow build up of high soil–water pressures.
- Clays are not required in downstream shoulder as it is essential to have free draining.
- Avoid including silts in any section of embankment
- Soil with a predominance of sand should not be used in dam construction. Sandy soil can be used in downstream shoulder but should not be used elsewhere

CUTOFF TRENCH, CORE DEPTH AND THICKNESS

- Soils containing a significant percentage of clay are ideal for core.
- Cutoff in dam foundation will reduce seepage and improve stability.
- Cutoff material should be placed in layers of
 - max. 50 to 75 mm thick and 1-2 m wide for small dams
 - 75 to 150 mm thick and 2-4 m wide for larger dams.
- Cores and cutoffs are expensive in construction and should be designed to minimum required according to full supply level FSL.
- Depths of cutoff should be to good foundation (solid rock or impermeable subsoil layer) or to at least 0.75 times height of embankment.

FREEBOARD

- Freeboard (**dry freeboard**) for small dams should never be less than 0.5 m with 0.75 - 1.0 m preferred.
If wave action is significant, **wet freeboard** may be required.

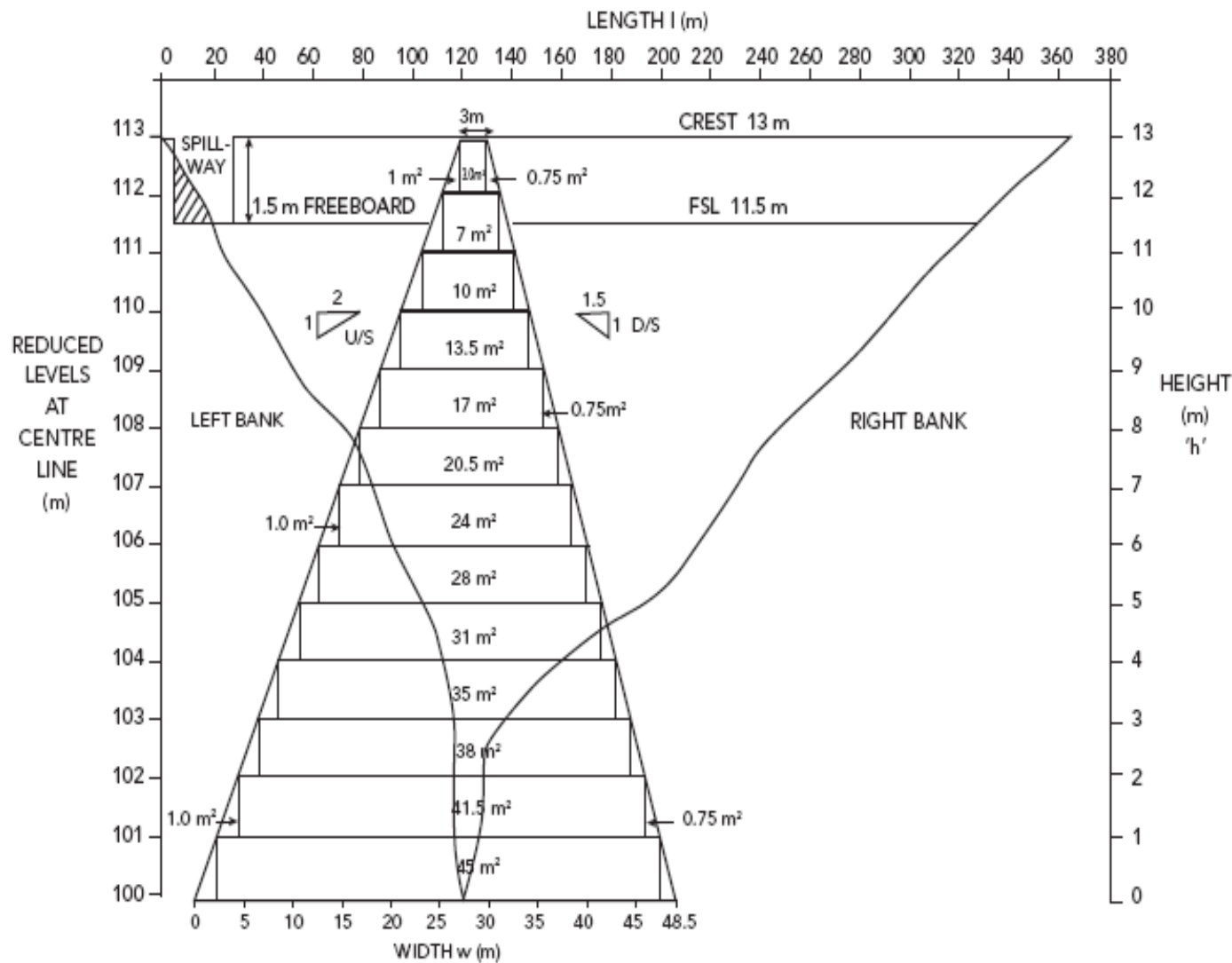
$$\text{Wet Freeboard } H'' = 0.014 (F)^{0.5}$$

H'' is in m, F = fetch length or longest distance in km, across storage area (Throwback),

- Overall freeboard height = **wet freeboard**, H'' + **dry freeboard**

Crest Width of Embankment

- In all cases, the embankment crest width should be designed to allow the safe passage of plant and equipment used in the dam construction and should be no less than 2 m wide.
- Alternatively for small dams > 5 m in height, a standard crest width of 3 m can be adopted or by using the formula:
- $Cw \text{ (in m)} = 0.4H + 1$
- where Cw is the crest width and H is the maximum height of the dam in meters.

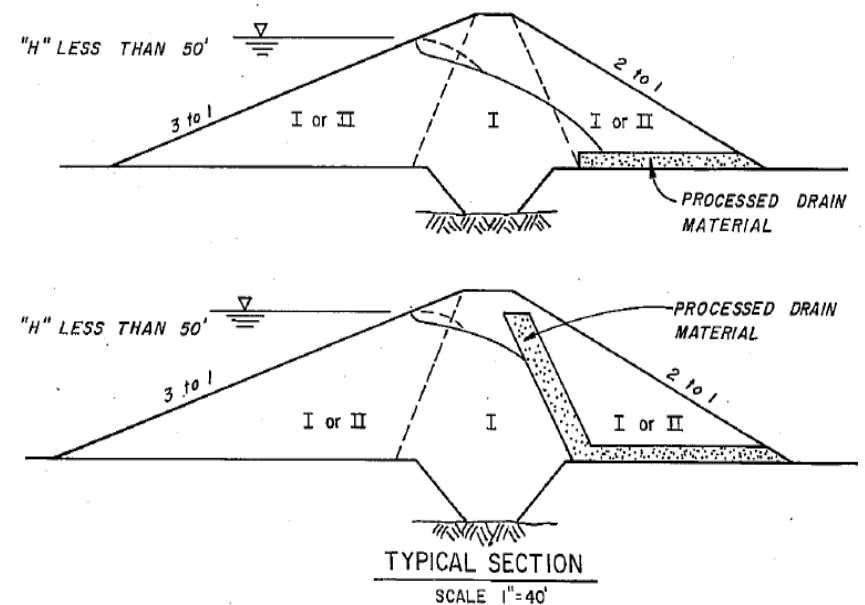
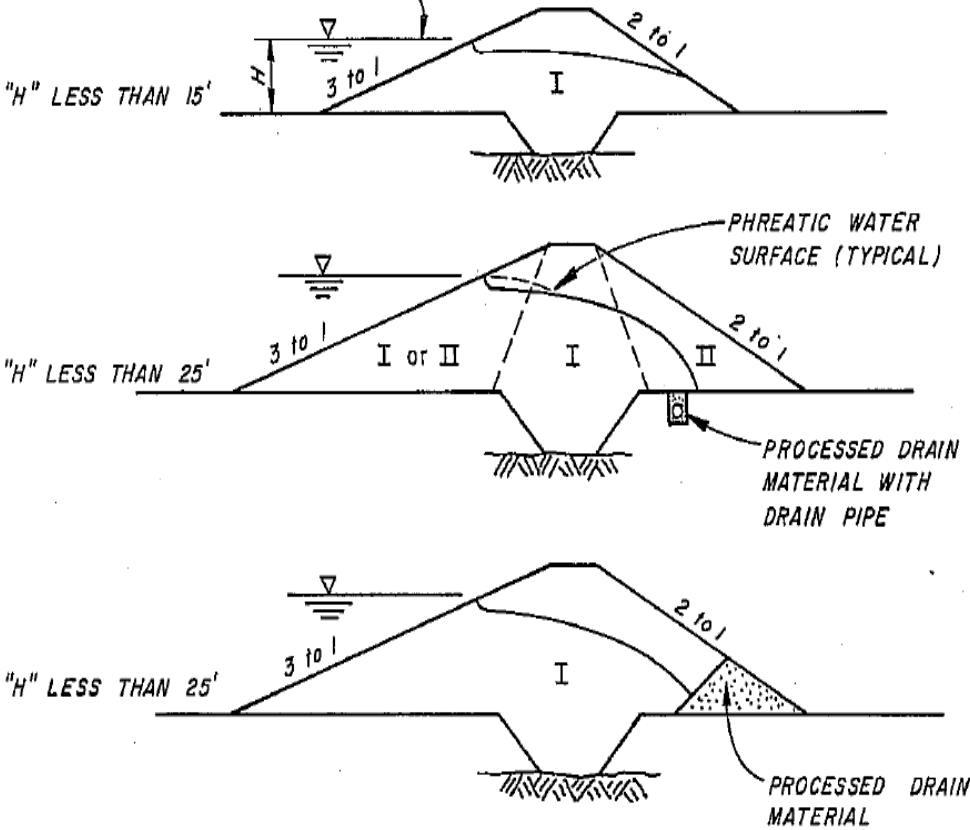


AREA OF CROSS SECTION w x h (m ²)	LENGTH OF LONG SECTION l (m)	VOLUME w x h x l (m ³)
4.75	317	1 506
8.75	286	2 502
11.75	271	3 184
15.25	232	3 538
18.75	194	3 637
22.75	160	3 640
25.75	133	3 425
29.75	106	3 153
32.75	63	2 063
36.75	31	1 139
39.75	11	437
43.25	9	389
46.75	25	117
EMBANKMENT VOLUME		28 730 m³
TR. BANK VOLUME		294 m³
TOTAL VOLUME		29 024 m³
SETTLEMENT 10%		2 902 m³
FINAL VOLUME		31 926 m³

ESTIMATION OF EARTH WORK VOLUME

SEEPAGE FLOW LINE AND INTERNAL DRAINAGE METHODS

RESERVOIR WATER SURFACE
AT SPILLWAY CREST (TYPICAL)



LEGEND

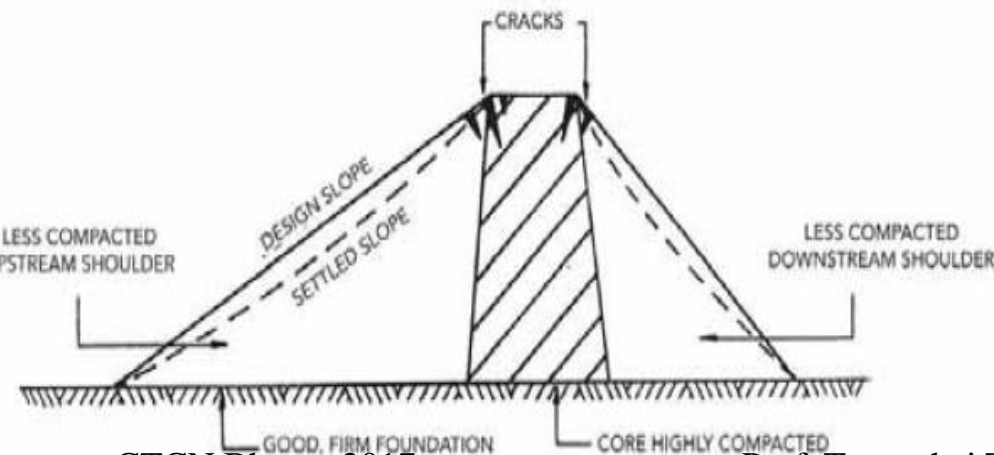
I - IMPERVIOUS

II - SEMI-IMPERVIOUS TO PERVIOUS

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
DIVISION OF SAFETY OF DAMS
**SEEPAGE FLOW LINES
INTERNAL DRAINAGE METHODS**

SETTLEMENT ALLOWANCE

Embankment will always settle a little after construction. Finished crest should be given a settlement allowance that raises it above its design height at mid-point by between 5 - 10 % and tapering off to spillway and valley sides.



SEEPAGE FILTERS

- seepage 'filter' drains water to lower phreatic surface (seepage line) within embankment to prevent water from emerging from downstream slope which can cause slumping of material and endanger whole structure.
- Trenches dug into subsoil beneath downstream face and toe (3-5 m below), at time of construction, and filled with rock and gravel continued can safely bring seepage lines down to allow flow out from beneath embankment.

ESTIMATION OF STORAGE REQUIREMENT AND CATCHMENT AREA

- From contour map preferably scale 1:50,000, surface area and volume of reservoir can be estimated at full supply and other levels.
- Max. design reservoir capacity is directly related to catchment yield multiplied by a design factor derived from history of other local dams. A max. of 5 % of total water storage can be added as dead storage.
- This storage will supply water for irrigation, livestock, domestic water, losses to seepage, evaporation and dead storage.
- Catchment area can be estimated from aerial photograph or large-scale topo map. This is essential in calculation of catchment yield and peak flood.
- For both, hydrological data (mainly rainfall and runoff), topographical factors and shape of catchment will be the main influences.

CATCHMENT RUNOFF AND RESERVOIR CAPACITY

- Catchment annual runoff Y
 $Y \text{ (m}^3\text{)} = R_r \times A \times 1,000$
where R_r = runoff coeff. (assumed 10-20%),
 A = catchment area in km^2
- Approximate reservoir capacity
 $V \text{ (m}^3\text{)} = LTH'/6$
- L = length of dam wall at full supply level, T = longest distance straight upstream from dam wall in m (Throwback), H' = max dam height at FSL in m, 6 = factor (conservative), a value between 6-4 can be used.

RATIONAL METHOD FOR FLOOD PEAKS

- Estimate peak floods on small catchments based on catchment area and assumed uniform rainfall intensity and runoff .
- Most appropriate for catchments under 15 km^2 . and requires knowledge on catchment area & max daily rainfall.
- Other factors such as topography (slope, etc), shape of catchment and vegetation cover may also be considered.

ESTIMATION OF PROBABLE MAX. FLOOD (PMF) BY RATIONAL METHOD

1. Locate the dam or new site on appropriate topographic map (e.g. 1:50,000 scale) and draw catchment boundary upstream of the embankment centre-line.
2. Use planimeter to measure catchment area, 'A', in km².
3. Measure 'actual length, L', of main river/stream, upstream of the site and to the main river source, in km.
4. Estimate bed elev. difference, 'h', in m, between dam site and main stream at its source.
5. Determine time of concentration, 'Tc', in hours

$$T_c = (0.87 L^3/h)0.385$$

6. From rainfall data estimate mean annual rainfall for catchment. Using **Fig. 6a**, estimate 1-day storm rainfall P, for return periods 1:20 to 1:25 year for smaller catchments and 1:50 year for larger ones.
7. Derive storm depth ratio, 'R', from **Fig. 6b** and using the Tc determined earlier.
8. Calculate extreme height channel slope in percent of [100 h/(1 000 m)] and estimate a runoff coefficient, Cr for assumed return period using **Fig. 6c**.
9. If runoff is known to be excessive, such as on bare, eroded slopes, Cr can be increased by 20%
10. Determine PMF ,Qp, in m³/s,
$$Q_p = 0.278 A P R C_r/T_c$$

Figure 6a - One day storm rainfall

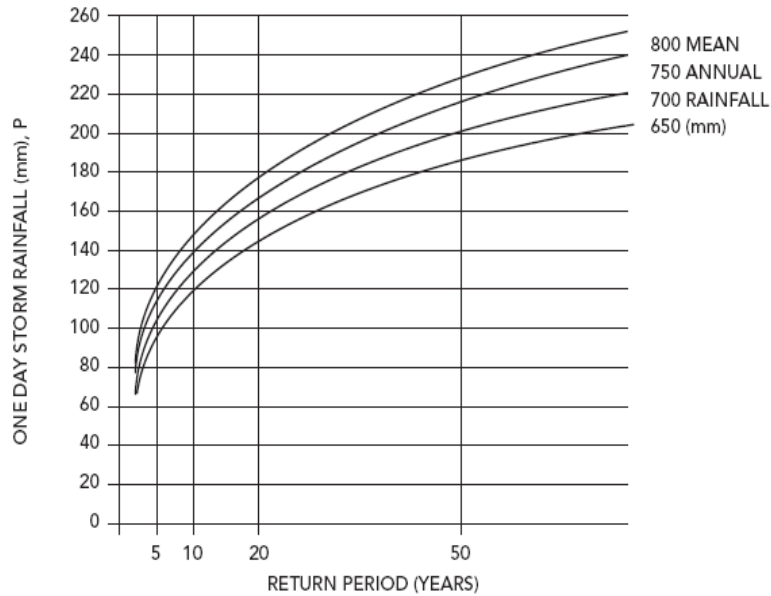


Figure 6b - Storm depth ratio

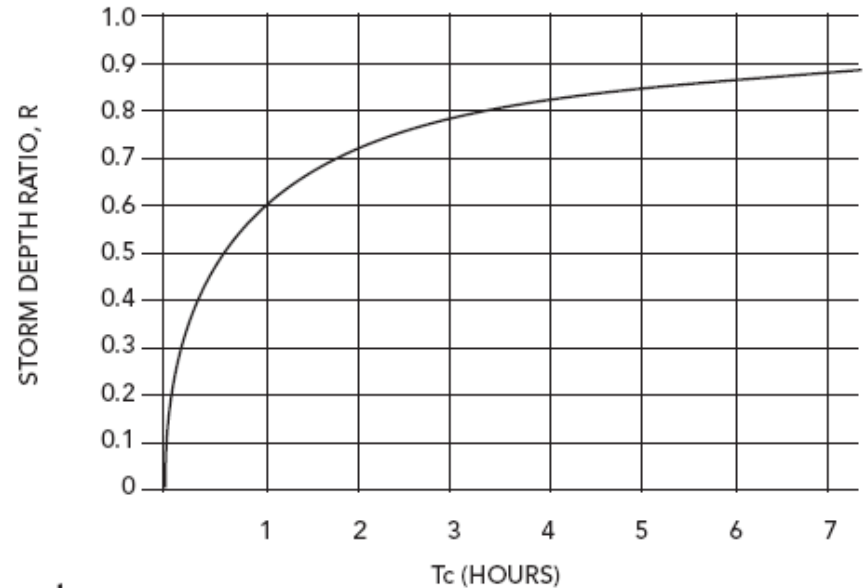
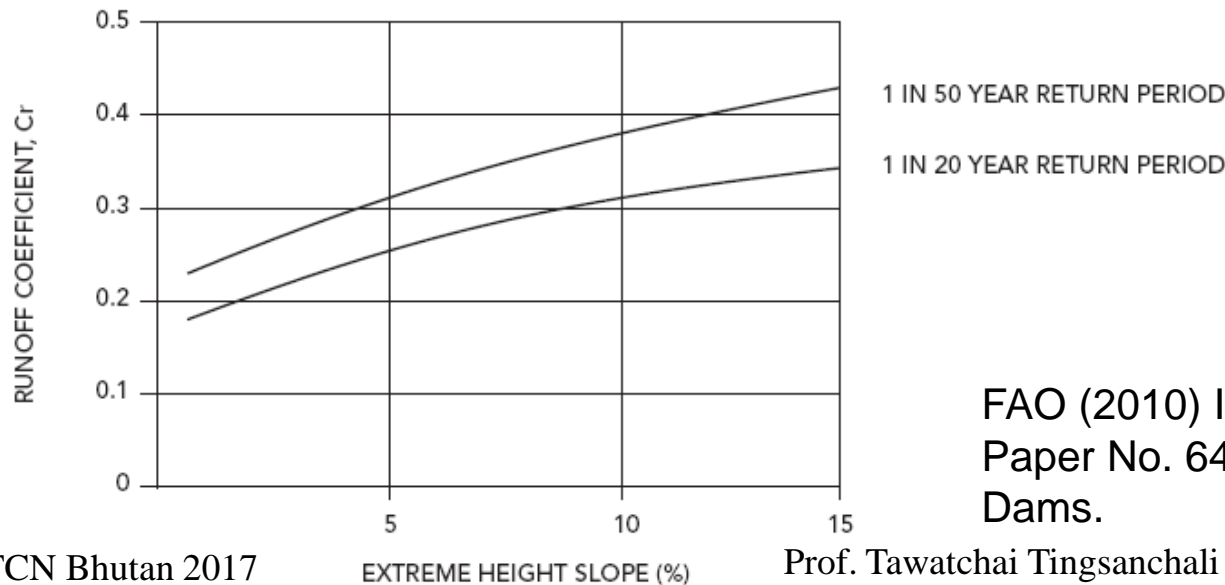


Figure 6c - Runoff coefficient



FAO (2010) Irrigation and Drainage Paper No. 64 , Manual on Small Earth Dams.

SPILLWAY DESIGN

- Knowing PMF, Q_p ; spillway width **b** can be calc. by

$$b = Q_p / (1.7 D^{1.5})$$

where b = min. width of spillway
 D = depth of spillway at crest, s normally 0.75-1.5 m for small dams and comprises the total freeboard.

- On catchments greater than 5-8 km² and rivers of a flashy nature, rock spillways are virtually essential. A minimum spillway width of 15 m at 1.5 m freeboard for a dam on a catchment of around 5 km² may prove suitable

Table Guideline discharges and velocities for earth dam spillways

Type of surface	Sand to sandy loam	Sandy loam to sandy clay loam	Sandy clay loam	Light clay	Heavy clay gravel friable rock	Hard rock
Max velocity (m/s)	0.30	0.60	0.75	1.00	1.25	1.50
Flow depth (m) at spillway entrance	0.15	0.30	0.50	0.60	0.75	1.50
Discharge (m ³ /s per m width)	0.05	0.20	0.35	0.60	1.00	2.50

OUTLET WORKS

- Spillway is the most important outlet. It is a concrete permanent structure located at a level that allows overflow to occur when necessary .
- Other outlet structures can be pipes or boxes leading through the embankment high up on one end at full supply level may prove cheaper than a box inlet type overflow.
- The pipe exit end leads flow to streambed downstream usually stone pitched or lined with brick or concrete.

QUANTITIES AND COST ESTIMATE

Table Quantities and costs of dam construction

Item	Description	Unit	Quantity	Rate	Amount
1	Site investigation	Sum			
2	Engineer fees	Sum			
3	Movement charge	Sum			
4	Clearing site	Hours			
5	Excavating cutoff/core	m ³			
6	Backfilling	m ³			
7	Embankment work	m ³			
8	Training bank(s)	m ³			
9	Spillway	m ³			
10	Topsoil return	m ³			
11	Trimming/tidying	Hours			
12	Other			
				Subtotal	_____
				Contingencies @ x%	_____
				Total	20

CONCLUSION

- Embankment dams and their types are explained. Design criteria and specific detailed design of embankment and its components are provided including estimation of earth work volume.
- Seepage and internal drainage methods in embankment as well as settlement allowance and seepage filter at downstream toe are described.
- Methods of estimating area and slope of catchment, rainfall runoff and maximum probable flood (PMF) are described. These computed data are used to estimate dam height freeboard and reservoir capacity required to accommodate the flood volume.
- Design of other outlet components such as spillway or outlet pipe are also given.



Thank you for your attention
tawatch_t@hotmail.com



Capacity Building Programme on
Flood Risk Assessment and Management
30 October - 8 November 2017

Sessions 17c: Dams on Pervious Foundation

Prof. Tawatchai Tingsanchali
Water Engineering and Management
Asian Institute of Technology, Thailand

Dams on pervious soil foundation

Uplift forces

-Uplift pressures under a concrete dam on a pervious foundation are related to seepage through permeable materials.

-Water percolating through pore spaces in the materials is retarded by frictional resistance (same as water flowing through a pipe)

-Uplift pressure on the dam can be decreased by increasing the length of the path of percolation,
 $\Delta P \propto L$

-For small dams ($h < 10$ m) Lane's weighted creep theory can be used to determine uplift pressure:

Uplift is assumed to decrease linearly with the weighted length: $\Delta P \propto Lw$

Therefore the pressure drop/ weighted length can be computed as follows:

$$\frac{\text{Pressure drop}}{\text{Weighted length}} = \frac{\text{Total pressure drop}}{\text{Total weighted length}}$$

Where weighted length = coeff x creep distance

Creep distance = actual distance x coefficient

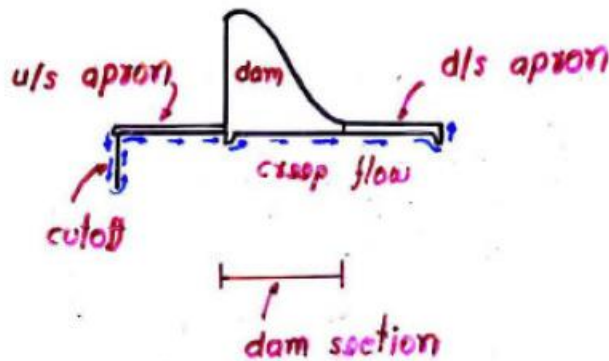
Coeff =1 for vertical creep (slope > 45degree)

=1/3 for horizontal creep (slope < 45 degree)

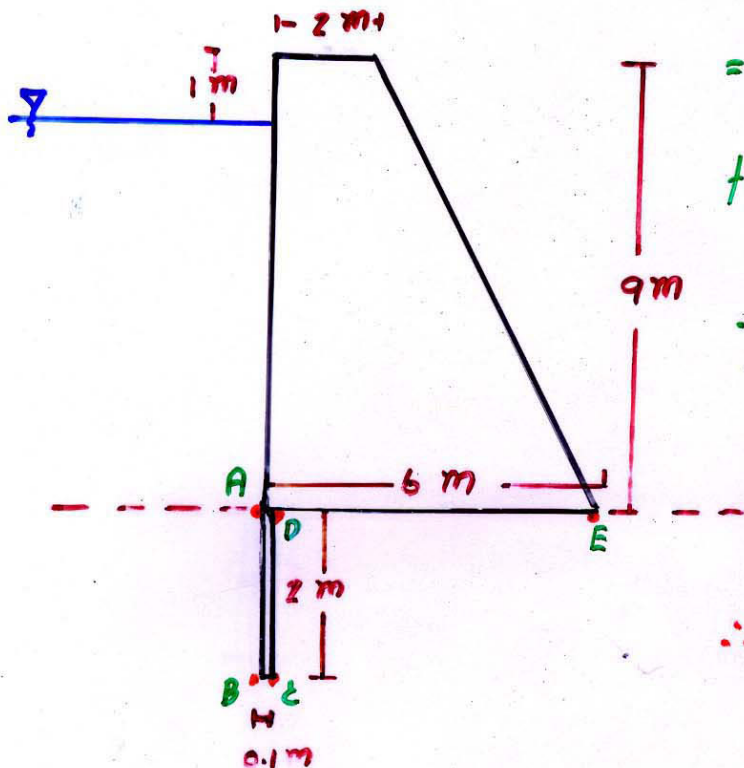
Uplift under dam can be reduced by increasing creep distance using

a) apron at upstream or downstream end of dam

b) cutoff at upstream or downstream end of dam



Determine uplift force acting on the dam shown below



weighted length of path

$$= 2 + 2 + \frac{1}{3}(6) = 6 \text{ m.}$$

total pressure drop = $\gamma_w 8$

\therefore pressure will drop from $\gamma_w 8 \rightarrow 0$ within length of 6 m.

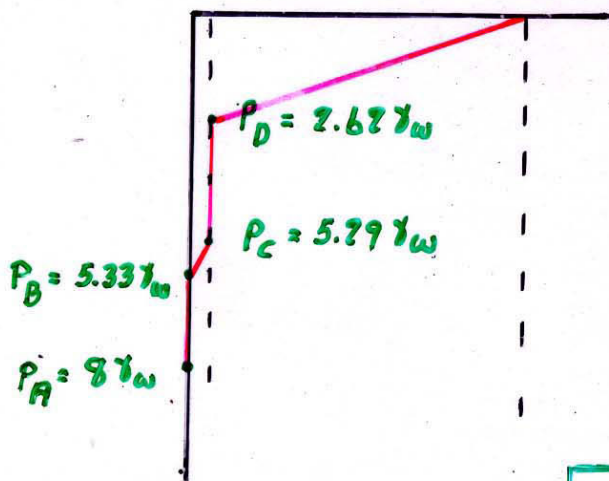
\therefore pressure at A = $\gamma_w 8$

$$P_B = \gamma_w 8 - \left(\frac{2}{6}\right) \gamma_w 8 = 5.33 \gamma_w$$

$$P_C = \gamma_w 8 - \left(\frac{2 + \frac{0.1}{3}}{6}\right) \gamma_w 8 = 5.29 \gamma_w$$

$$P_D = \gamma_w 8 - \left[\frac{2 + \frac{0.1}{3} + 2}{6}\right] \gamma_w 8 = 2.62 \gamma_w$$

$$P_E = \gamma_w 8 - \left[\frac{2 + \frac{0.1}{3} + 2 + \frac{5.9}{3}}{6}\right] \gamma_w 8 = 0$$

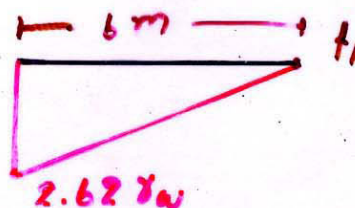


uplift pressure

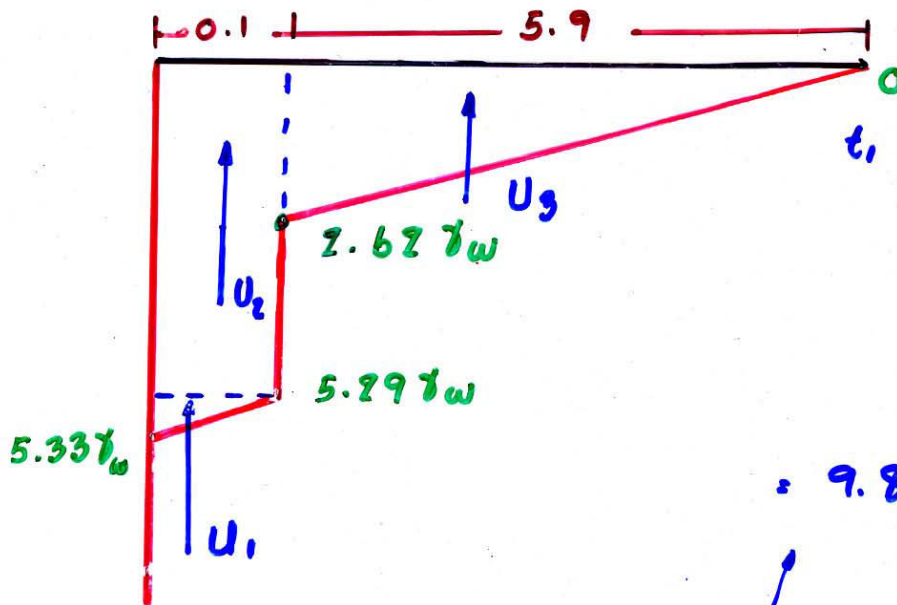
b) neglect width of cutoff

$$U = \frac{1}{2} 6 (2.62 \gamma_w) = 7.86 (9.8) = 77.03 \text{ kN}$$

$$\bar{x} = \frac{2}{3} (6) = 4 \text{ m. from } t_1$$



a)



$$U_1 = \frac{1}{2} \cdot 0.1 \cdot (5.33 - 5.29) \delta_w = 0.02 \text{ kN/m}^2$$

$$\text{line of action} = 5.9 + \frac{0.1(2)}{3} = 5.97 \text{ m. from } t_1$$

$$U_2 = 0.1 \cdot (5.29 \delta_w) = 5.18 \text{ kN/m}^2$$

$$\text{line of action} = 5.9 + \frac{0.1}{2} = 5.95 \text{ m. from } t_1$$

$$U_3 = \frac{1}{2} \cdot 5.9 \cdot (2.62 \delta_w) = 75.74 \text{ kN/m}$$

$$\text{line of action} = \frac{2}{3} \cdot 5.9 = 3.93 \text{ m. from } t_1$$

$$\text{total uplift force} = 0.02 + 5.18 + 75.74 = 80.94 \frac{\text{kN}}{\text{m}}$$

$$\bar{x} = \frac{\bar{x}_1 U_1 + \bar{x}_2 U_2 + \bar{x}_3 U_3}{U_1 + U_2 + U_3} \quad \text{about } t_1$$

$$= \frac{0.02(5.97) + 5.95(5.18) + 3.93(75.74)}{80.94}$$

$$\bar{x} = 4.06 \text{ m}$$

Piping Analysis

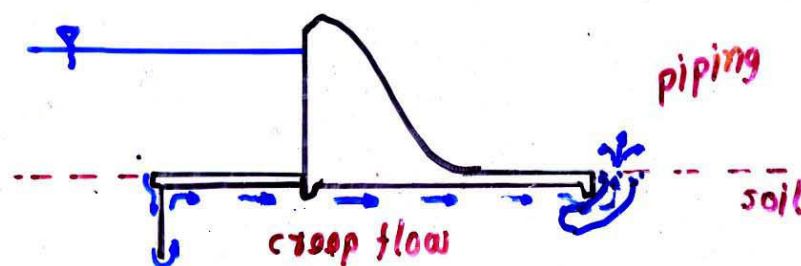
For small dams on pervious foundation, there is seepage flow through the foundation.

The pressure will drop from headwater to tailwater along the contact line of the dam and foundation.

The rate of seepage increases with the increase of the rate of pressure drop or hydraulic gradient dh/dl .

And such an increase would cause “boiling” of soil surface. This phenomenon is called “piping”.

$$Q = KA (dh/dl) \text{ or } Q \text{ varies with } dh/dl$$



Based on analysis of more than 200 dams on pervious foundations, Lane (1935) suggested that:

If $(Lwt / \Delta Ht) > WCR_{min}$ → dam is safe from piping (this is design of small dams).

Where Lwt = total weighted length

ΔH = total head drop

$(Lwt / \Delta Ht)$ = weighted creep ratio (WCR)

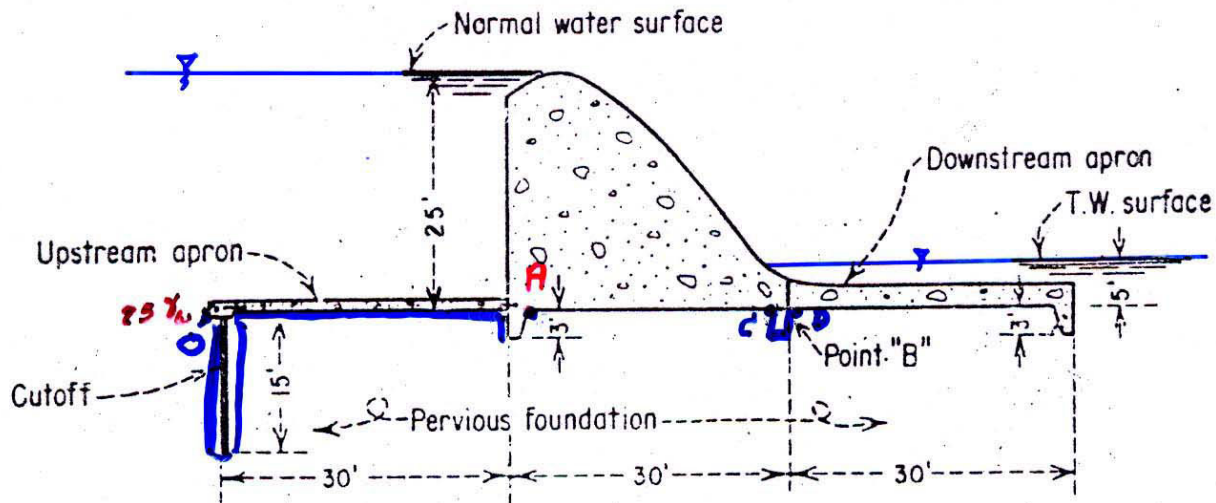
WCR_{min} depends on material

(see next table)

Minimum Weighted Creep Ratio for Various Foundation Materials

Material:	<i>min. WCR.</i> Ratio
Very fine sand or silt	8.5
Fine sand	7.0
Medium sand	6.0
Coarse sand	5.0
Fine gravel	4.0
Medium gravel	3.5
Coarse gravel including cobbles	3.0
Boulders with some cobbles and gravel	2.5
Soft clay	3.0
Medium clay	2.0
Hard clay	1.8
Very hard clay or hardpan	1.6

Determine on what type of foundations, this dam would be judged safe from piping. Also determine the uplift force U acting on the dam.



$$\text{weighted length of path} = 15 + 15 + \frac{30}{3} + 3 + 3 + \frac{60}{3} + 3 + 3$$

$$= 72'$$

$$\text{head drop} = 25 - 5 = 20'$$

$$\therefore \text{weight/cramp ratio} = \frac{72}{20} = 3.6$$

\therefore the dam would be safe from piping on medium gravel - hardpan foundation.

assume ^{width of} cutoff at A = very small

$$P_A = \frac{25 \gamma_w - (15 + 15 + \frac{30}{3} + 3 + 3) 20 \gamma_w}{72} = 12.22 \gamma_w$$

$$P_B = \frac{25 \gamma_w - (15 + 15 + \frac{30}{3} + 3 + 3 + \frac{30}{3}) 20 \gamma_w}{72} = 9.44 \gamma_w$$

$$\therefore \text{total uplift} = \frac{1}{2} (12.22 + 9.44) (62.5) 30 = 20,306 \frac{\text{lb}}{\text{ft}}$$

Thank You



**US Army Corps
of Engineers**

Hydrologic Engineering Center

HEC-RAS (4.1)

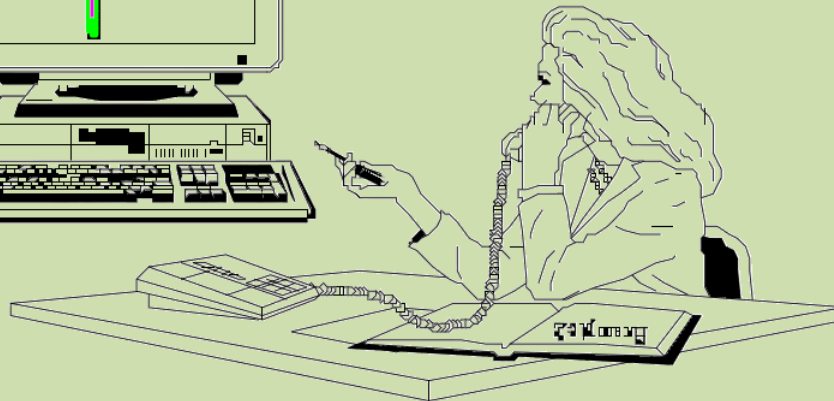
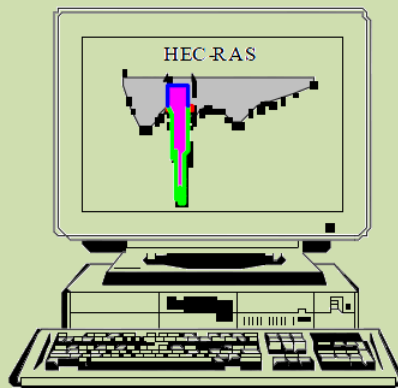
Hydrologic Engineering Center – River Analysis System

by

Nat Marjang, Ph.D.

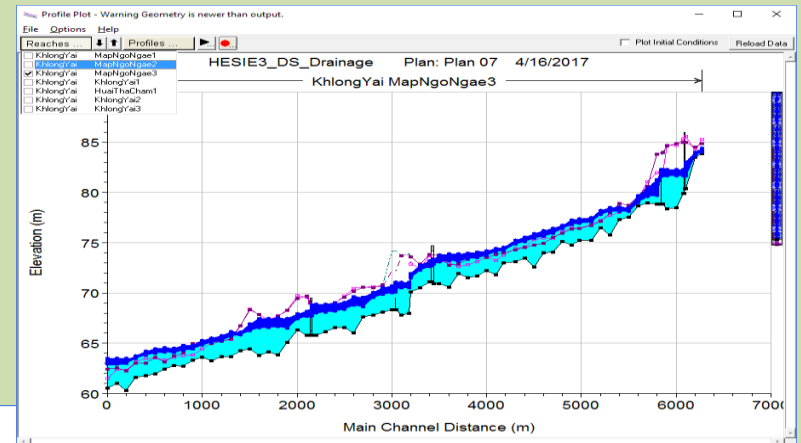
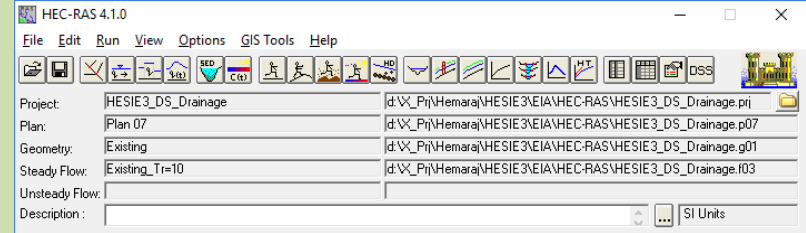
Introduction

- 💧 Hydrologic Engineering Center – River Analysis System
- 💧 Developed by US Army Corps of Engineers (USACE)
- 💧 The previous version : HEC-2
- 💧 Freeware: Download at <http://www.hec.usace.army.mil/software/hecras/downloads.aspx>



Software Package:

- 💧 Graphical User Interface (GUI)
- 💧 Analysis Components
- 💧 Data Storage & Management
- 💧 Graphics
- 💧 Report Generation



Cross Section Output

File Type Options Help

River: KhlongYai Profile: PF 1

Reach: MapNgoNgae1 RS: 7808.62 Plan: Plan 06

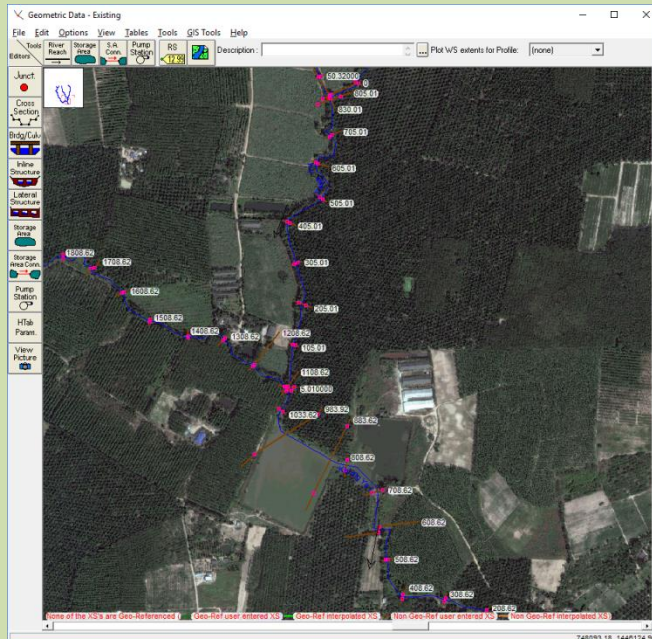
Plan: Plan 06 KhlongYai MapNgoNgae1 RS: 7808.62 Profile: PF 1				
	Element	Left OB	Channel	Right OB
E.G. Elev (m)	88.39			
Vel Head (m)	0.06	0.045	0.033	0.045
W.S. Elev (m)	88.33	100.00	100.00	100.00
Cut W.S. (m)	88.30	2.85	1.79	6.59
E.G. Slope (m/m)	0.009100	2.85	1.79	6.59
Q Total (m3/s)	10.25	1.74	2.97	5.54
Top Width (m)	48.40	18.96	3.48	26.37
Vel Total (m/s)	0.91	0.61	1.66	0.84
Max Chl Dpth (m)	0.97	0.15	0.51	0.25
Conv. Total (m3/s)	107.4	18.2	31.2	58.1
Length W/d. (m)	100.00	18.56	4.10	26.38
Min Ch El (m)	87.36	13.72	38.90	22.29
Alpha	1.50	3016.31	112.95	279.56
Frcn Loss (m)	1.31	0.14	4.06	0.33
C & E Loss (m)	0.00	0.93	15.74	1.32
		Cum Volume (1000 m3)		
		Cum SA (1000 m2)		

Errors, Warnings and Notes

Warning: The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than 0.7 or greater than 1.4. This may indicate the need for additional cross sections.

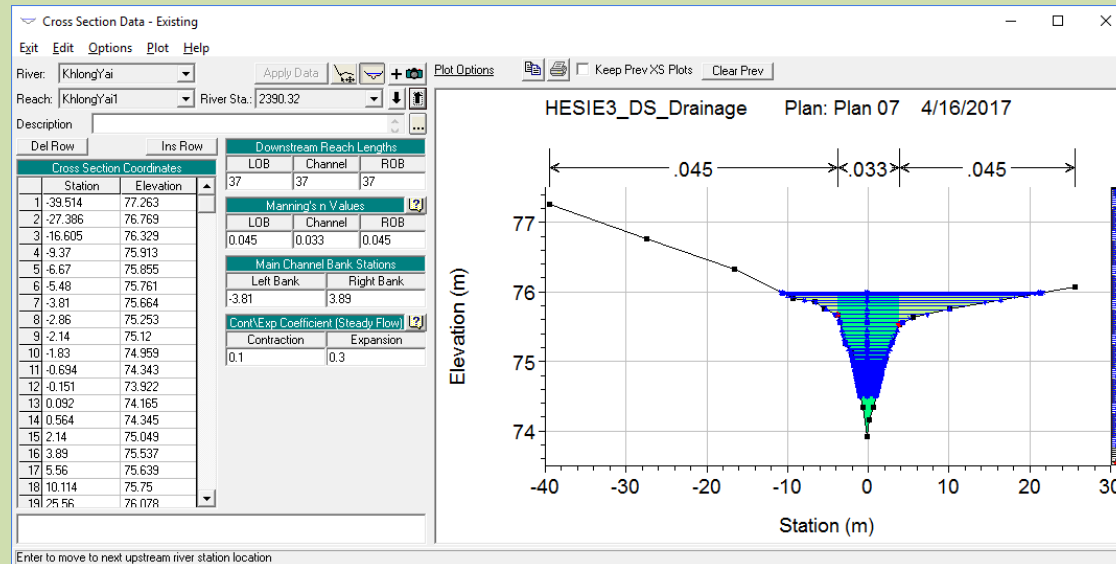
Warning: The energy loss was greater than 1.0 ft (0.3 m), between the current and previous cross section. This may indicate the need for additional cross sections.

Select Profile



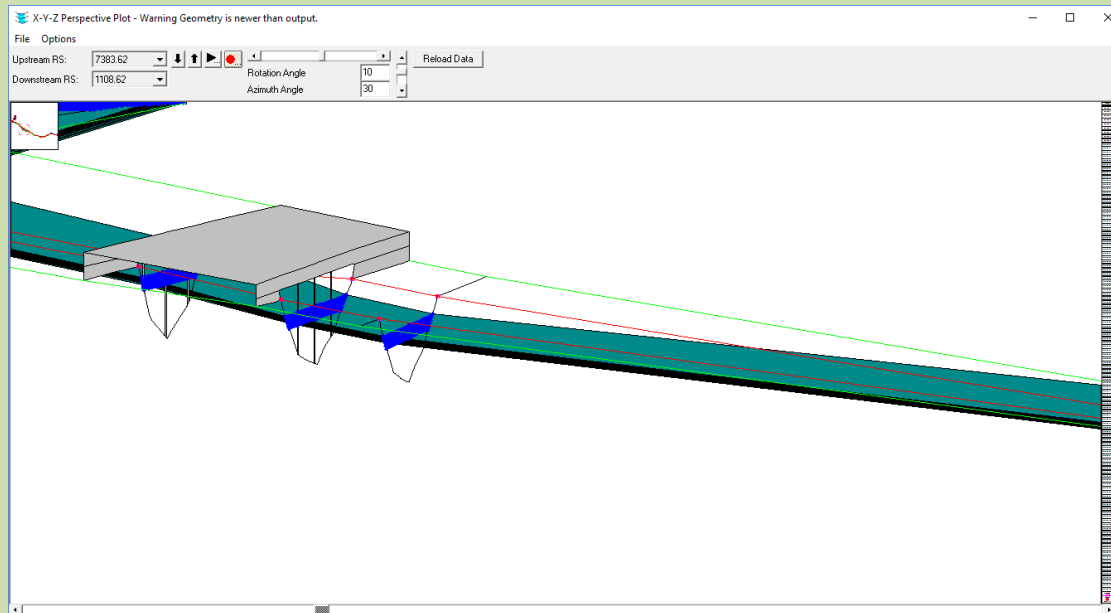
Model Capability

- 💧 One - Dimensional (1D) River Analysis
- 💧 Steady Flow Water Surface Profile Computations
- 💧 Unsteady Flow Routing
- 💧 Hydraulic Design Features
- 💧 Sediment Transport Computations
- 💧 Water Quality Analysis



Applications:

- 💧 Various Flow Analysis
- 💧 Bridge, Culvert Modeling
- 💧 Inline Structures :Dams, Weirs and Gates
- 💧 Lateral Structures: Weirs, Spillways
- 💧 Flood Management



Steady Flow Water Surface Profile Computations

Energy Equation

$$Z_2 + Y_2 + \alpha_2 \frac{V_2^2}{2g} = Z_1 + Y_1 + \alpha_1 \frac{V_1^2}{2g} + h_e$$

Where:

Z_1, Z_2 = elevation of the main channel inverts, m.

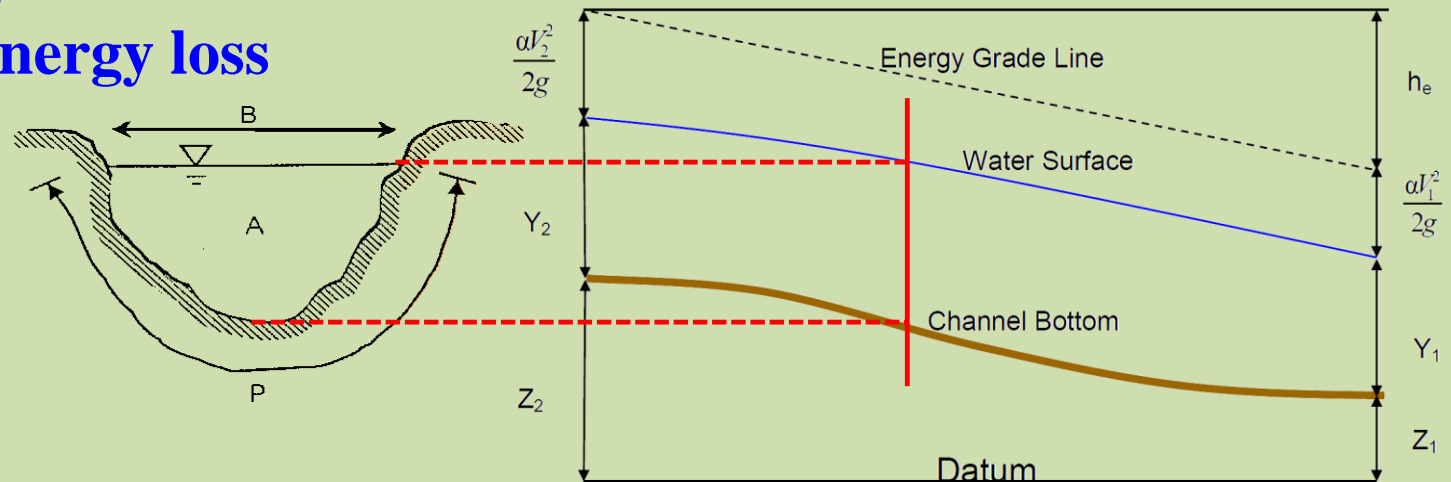
Y_1, Y_2 = depth of water at cross sections, m.

V_1, V_2 = average velocities (total discharge / total flow area)

α_1, α_2 = velocity weighting coefficients

g = gravitational acceleration

h_e = energy loss



Steady Flow Water Surface Profile Computations

Conveyance Calculation using Manning Equation

$$Q = \frac{1}{n} AR^{2/3} S_f^{1/2}$$

$$K = \frac{1}{n} AR^{2/3}$$

$$Q = KS_f^{1/2} \quad (\text{SI Unit})$$

Where:

Q = discharge (m³/s)

n = manning's coefficient

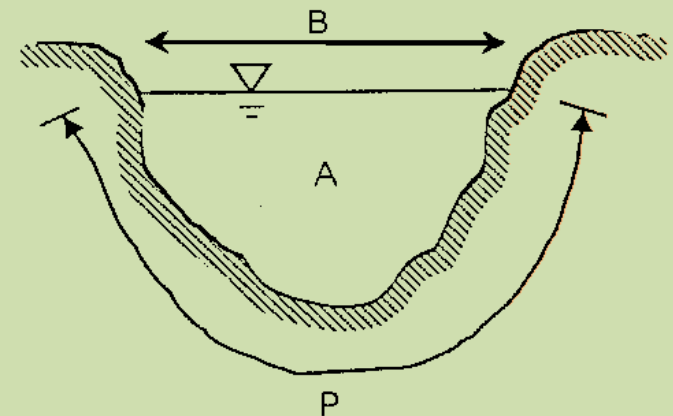
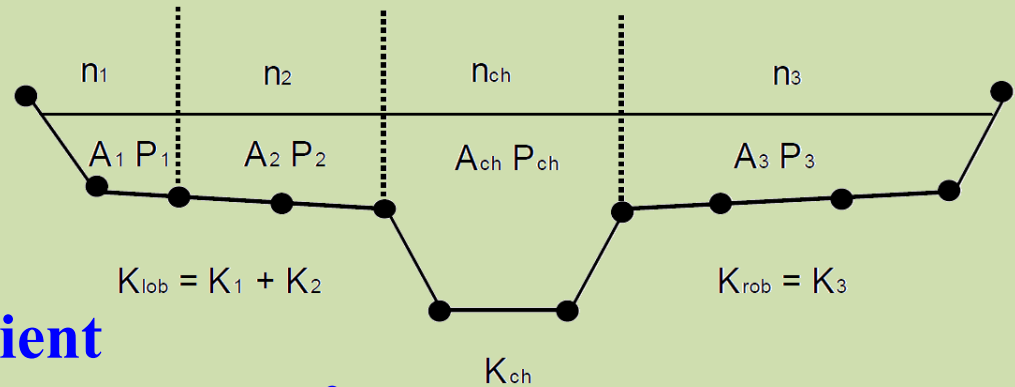
A = cross sectional / Flow area (m²)

R = hydraulic radius (m.) = A/P

S_f = fiction slope (m./m.)

K = conveyance

P = wetted perimeter (m.)



Steady Flow Water Surface Profile Computations

Manning's n Values

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Canals and ditches:				
Earth, straight and uniform	0.017	0.020	0.225*	0.025
Dredged earth channels	0.025	0.028	0.030	0.033
Earth bottom, rubble sides	0.028	0.030	0.033*	0.035
Natural Stream Channels:				
1. Clean, straight bank, full stage, no rifts or deep pools	0.025	0.028	0.030	0.033
2. Same as #1, but some weeds and stones	0.030	0.033	0.035	0.040
3. Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
4. Same as #3, lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
5. Same as #3, some weeds and stones	0.035	0.040	0.045	0.050
6. Same as #4, stony sections	0.045	0.050	0.055	0.060
7. Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
8. Very weedy reaches	0.075	0.100	0.125	0.150

Steady Flow Water Surface Profile Computations

Energy head loss

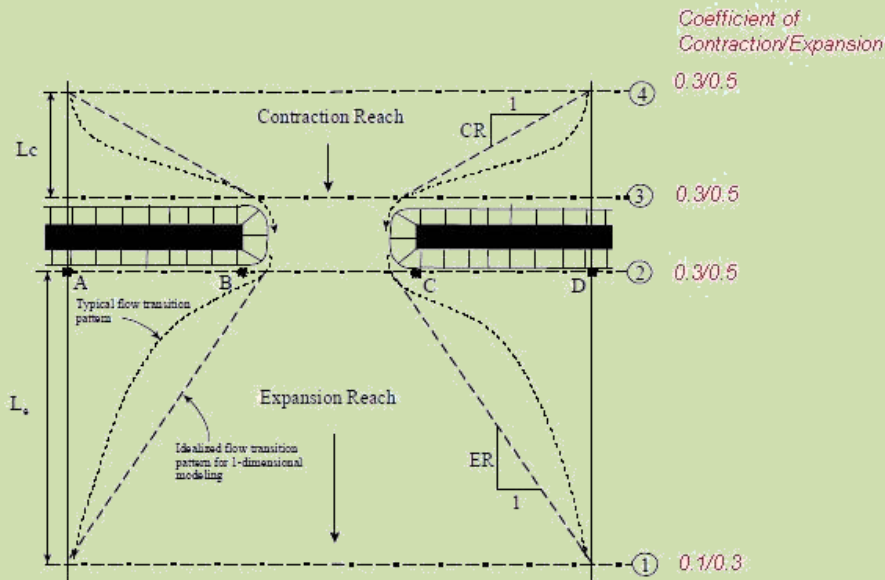
$$h_e = L\bar{S}_f + C \left| \alpha_2 \frac{V_2^2}{2g} - \alpha_1 \frac{V_1^2}{2g} \right|$$

Where:

L = discharge weighted reach length

\bar{S}_f = representative friction slope between two sections

C = expansion or contraction loss coefficient



Cross Section Data - Existing

Exit Edit Options Plot Help

River: KhlongYai Apply Data

Reach: KhlongYai1 River Sta.: 2390.32

Description

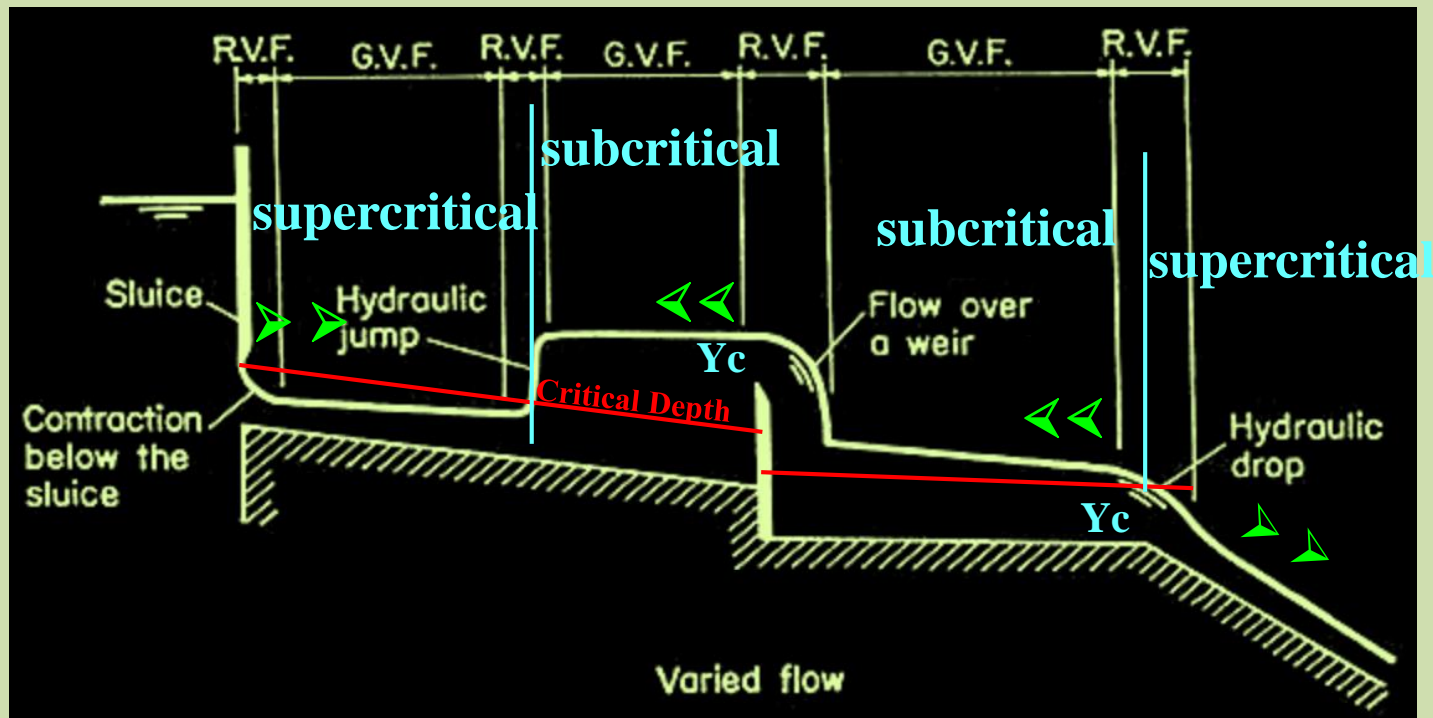
Del Row	Ins Row	Downstream Reach Lengths		
Cross Section Coordinates		LOB	Channel	ROB
		37	37	37
Manning's n Values		LOB	Channel	ROB
		0.045	0.033	0.045
Main Channel Bank Stations		Left Bank	Right Bank	
		-3.81	3.89	
Cont\Exp Coefficient (Steady Flow)		Contraction	Expansion	
		0.1	0.3	

Station	Elevation
1	-39.514
2	-27.386
3	-16.605
4	-9.37
5	-6.67
6	-5.48
7	-3.81
8	-2.86
9	-2.14
10	-1.83

Computational Procedures

Control Section:

- subcritical flow ($Fr < 1$) : evaluate from downstream to upstream
- supercritical flow ($Fr > 1$) : evaluate from upstream to downstream

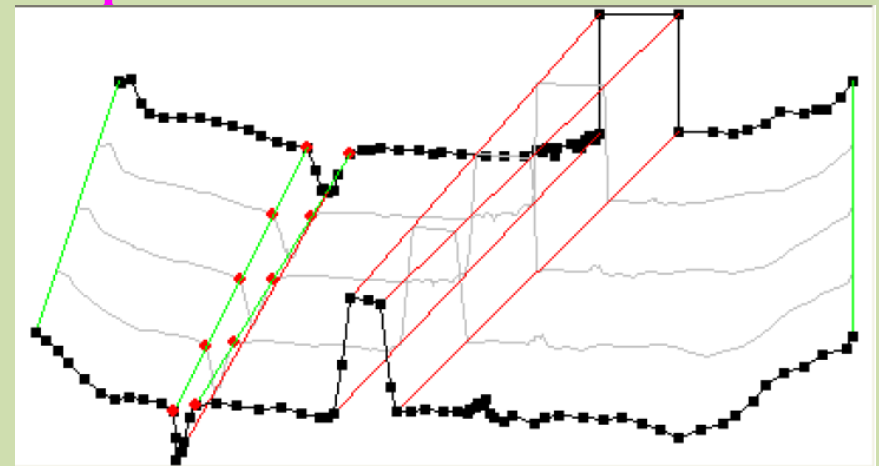
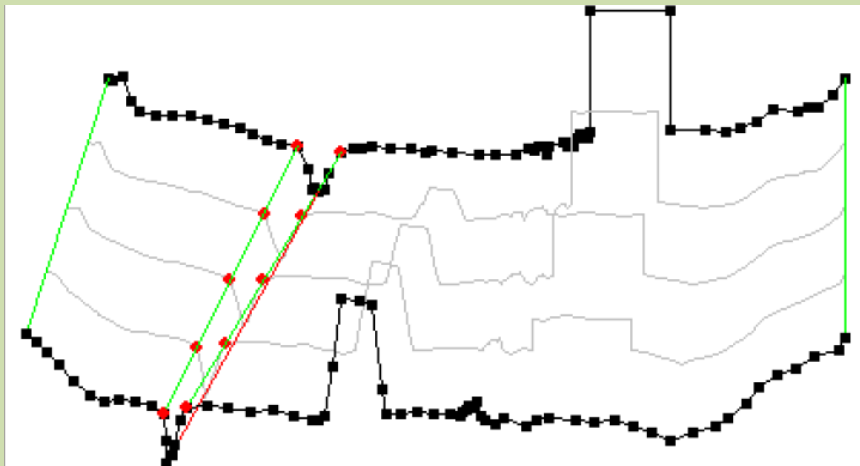


Computational Procedures

Common sources of error:

- ➔ Inadequate number of cross sections (reach length too long)
- ➔ Bad cross section data
- ➔ Wrong boundary condition specified (subcritical/supercritical/critical)

Cross section interpolation



HEC-RAS

Main window

Unsteady Flow Data: Edit and/or enter unsteady flow data

Unsteady Flow Analysis: Perform an unsteady flow simulation

XYZ Perspective Plot: View 3D multiple cross section plot

Open Project: Open an existing project

Water Quality Data: Enter and edit water quality data

Cross Sections: View cross section plots

Hydraulic Properties: Plots and tables of hydraulic properties

Geometric Data: Edit and/or enter geometric Data

Water Quality Analysis:

General Profile Plot: View computed variables along the channel

Profile Summary Table: View summary output at multiple locations by profile

View DSS: View Data stored in DSS

HEC-RAS 4.0.0

File Edit Run View Options Help

Project: Single Bridge - Example 2
Plan: Press/Weir Method
Geometry: Beaver Cr. + Bridge - PAW
Steady Flow: Beaver Cr. - 3 Flows
Unsteady Flow:
Description:

US Customary Units

Save Project: Save an existing project

Sediment Data: Enter/edit sediment data

Sediment Analysis: Perform Sediment Transport Analysis

Rating Curve: View computed rating curves

Profile Plot: View water surface profile plots

Sum Errs, Warn, Notes: Summary of Errors, Warnings, and Notes

Steady Flow Data: Edit and/or enter steady flow data

Hydraulic Design Functions: Perform hydraulic design computations

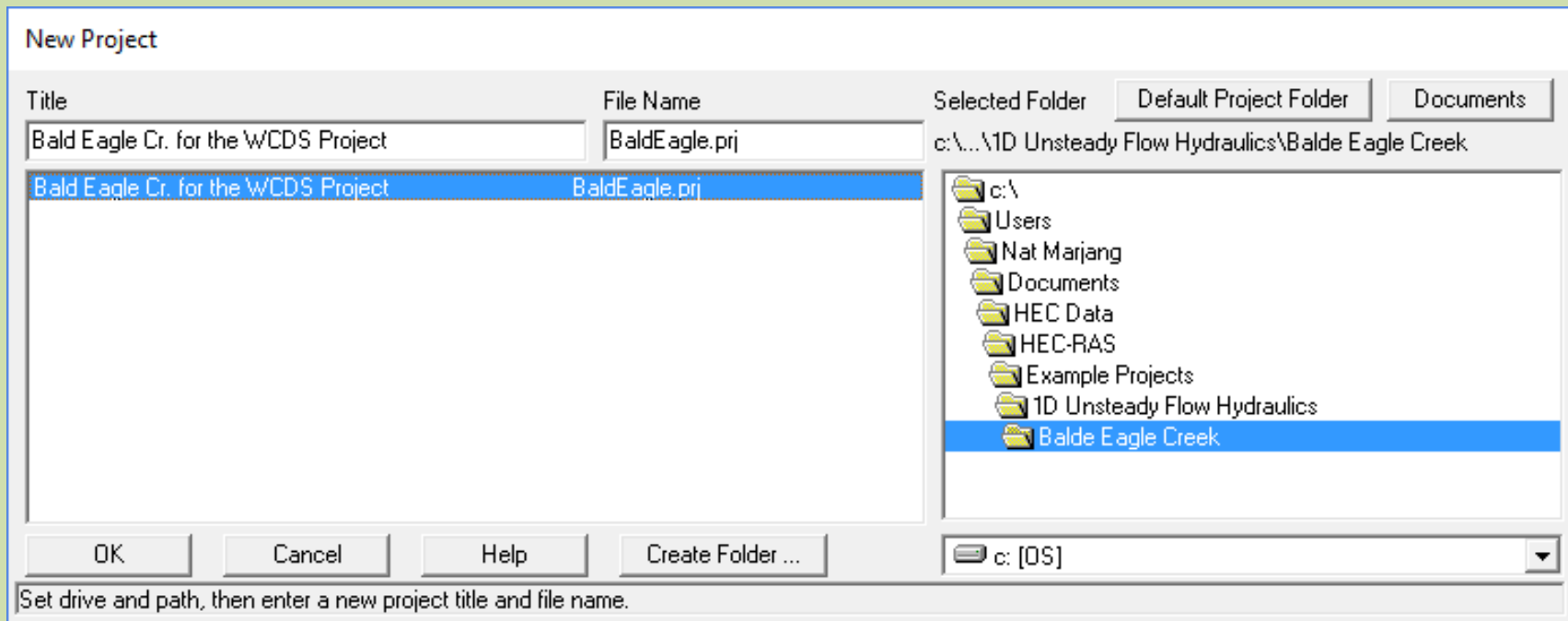
Steady Flow Analysis: Perform a steady flow simulation

Detailed Output Table: View detailed output at cross-sections, bridges, culverts, etc...

Stage and Flow Hydrographs: Plot stage and flow hydrographs

Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
- ➔ Entering geometric data
- ➔ Entering flow data and boundary conditions
- ➔ Performing the hydraulic calculations
- ➔ Viewing and printing results

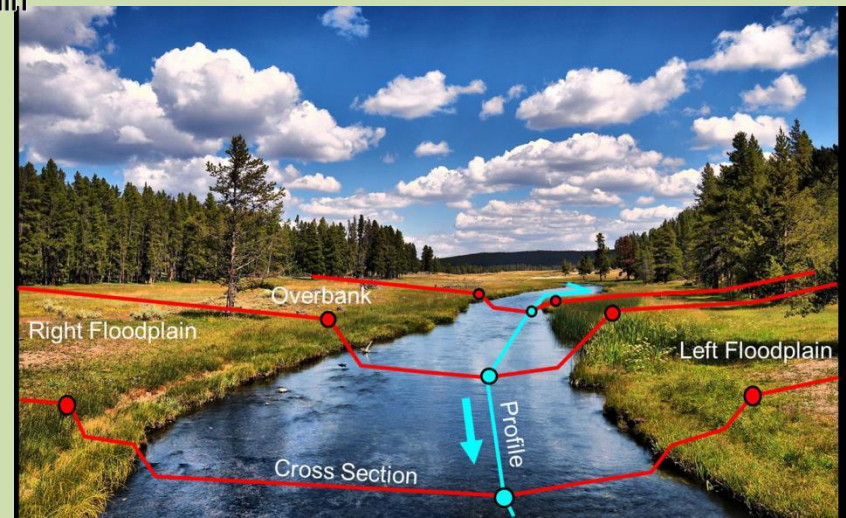
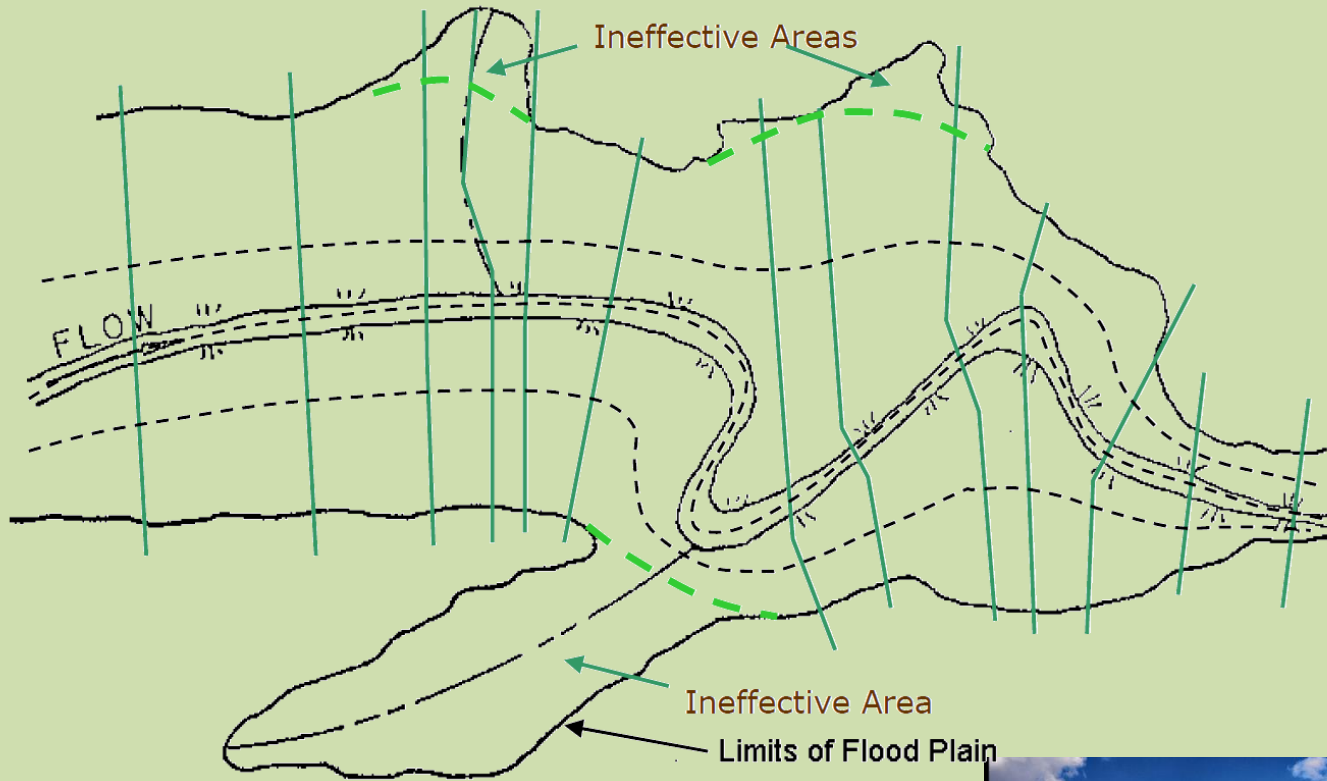


Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
- ➔ **Entering geometric data**
- ➔ Entering flow data and boundary conditions
- ➔ Performing the hydraulic calculations
- ➔ Viewing and printing results

The screenshot shows the HEC-RAS 4.1.0 interface. The main window is titled "Geometric Data - Base Geometry Data". The top toolbar includes menus for File, Edit, Options, View, GIS Tools, and Help. Below the menus are various tool icons, including a red arrow pointing to the "Description" field. The main workspace displays a river network diagram with several reaches and structures. The reaches are labeled "Upper Reach", "Lower Reach", and "Tributary". The structures are labeled "Sutter" and "But to Cr.". The diagram shows a river network with various reaches and structures, including a junction, cross-sections, bridges/culverts, inline structures, lateral structures, storage areas, and pump stations. The diagram is overlaid on a map background. The status bar at the bottom right shows the coordinates "0.6211, 0.9771".

Cross section layout

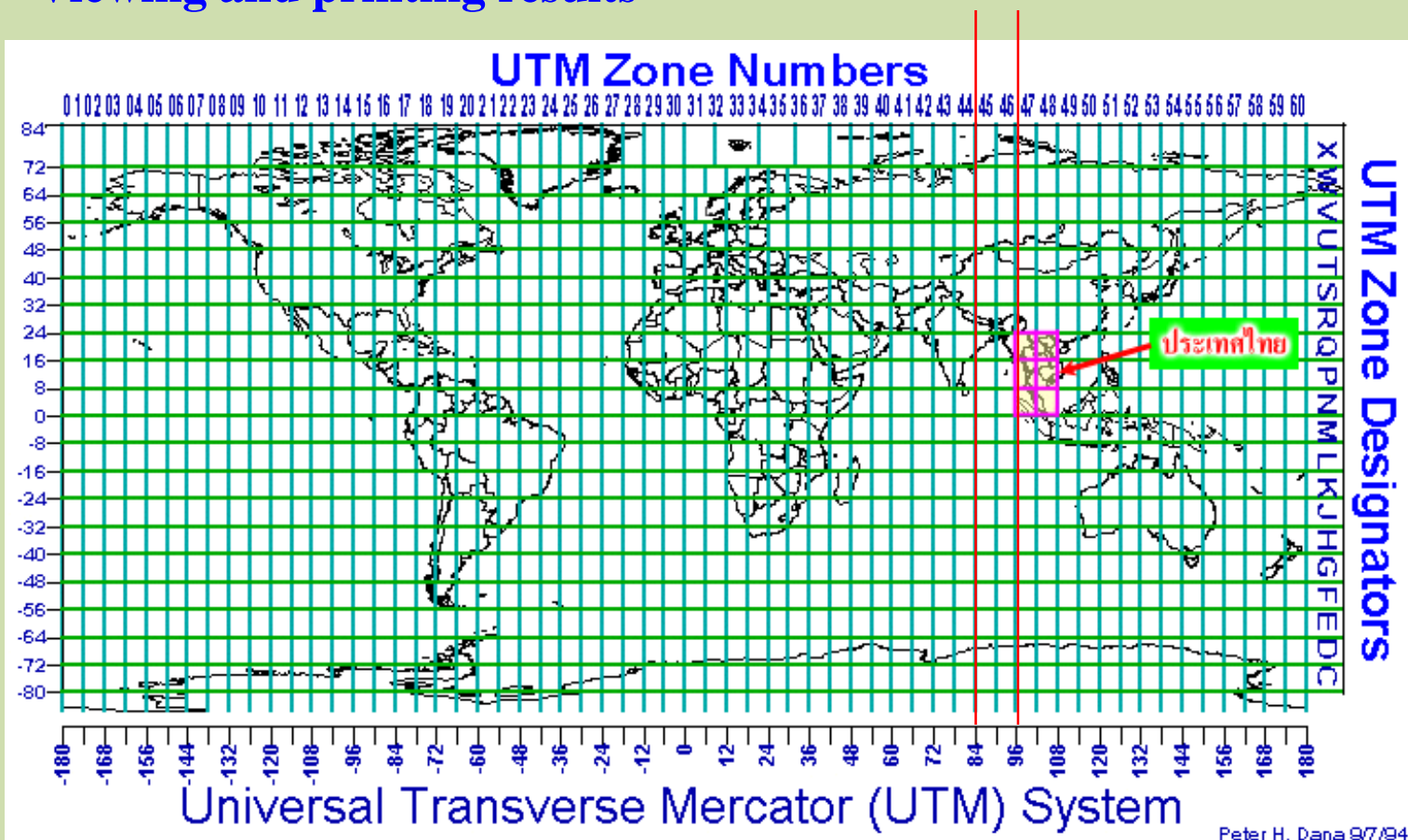


Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
- ➔ **Entering geometric data**
- ➔ Entering flow data and boundary conditions
- ➔ Performing the hydraulic calculations
- ➔ Viewing and printing results

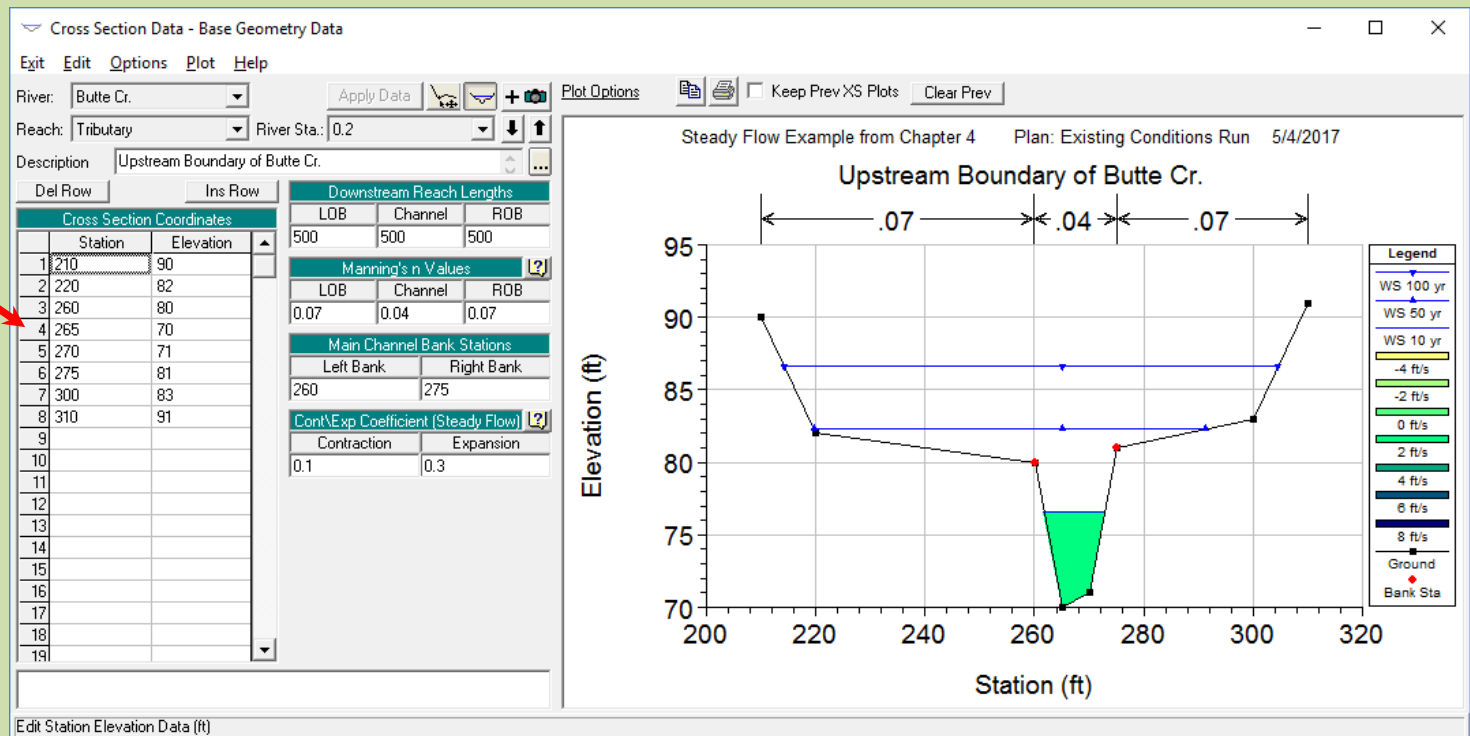
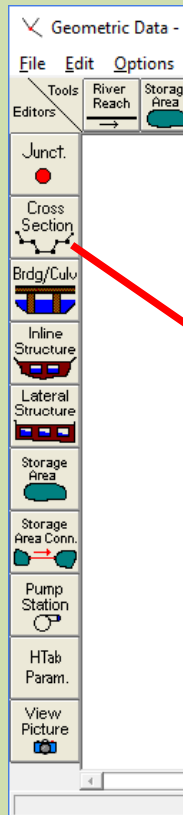
Bhutan

Long 88.75°-92.11°



Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
- ➔ **Entering geometric data**
- ➔ Entering flow data and boundary conditions
- ➔ Performing the hydraulic calculations
- ➔ Viewing and printing results



Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
- ➔ **Entering geometric data**
- ➔ Entering flow data and boundary conditions
- ➔ Performing the hydraulic calculations
- ➔ Viewing and printing results

Deck/Roadway Data Editor

Distance	Width	Weir Coef
110	40	2.6

Clear Del Row Ins Row Copy US to DS

Upstream			Downstream		
Station	high chord	low chord	Station	high chord	low chord
1 856.	36.1		856.	36.1	
2 917.	34.8		917.	34.8	
3 972.	33.9		972.	33.9	
4 993.	33.8		993.	33.8	
5 1007.	33.8		1007.	33.8	
6 1027.	33.7		1027.	33.7	
7 1095.	35.7		1095.	35.7	
8 1150.	37.2		1150.	37.2	

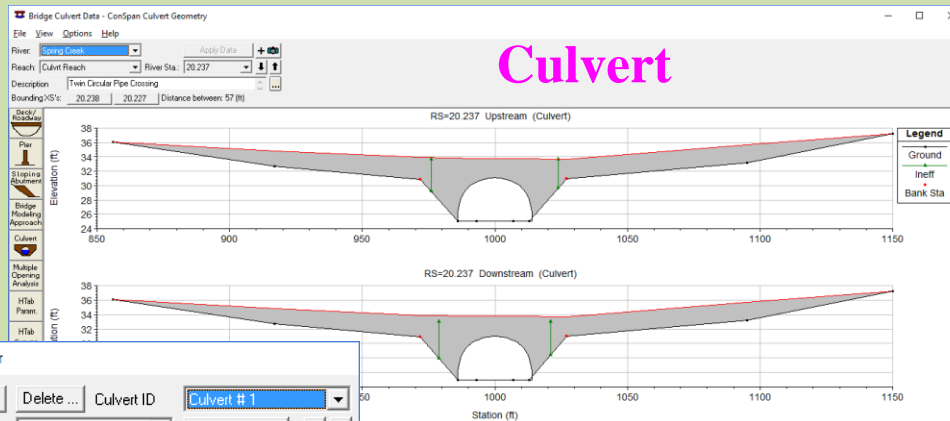
U.S Embankment SS: 2 D.S Embankment SS: 2

Weir Data
 Max Submergence: 0.95 Min Weir Flow El: 33.7

Weir Crest Shape
 Broad Crested
 Ogee

OK Cancel

Enter distance between upstream cross section and deck/roadway. (ft)



Culvert Data Editor

Add ... Copy Delete ... Culvert ID: Culvert #1

Solution Criteria: Highest U.S. EG Rename ...

Shape: Conspan Arch Span: 28 Rise: 6
 Conspan Culvert shape is a predefined 28 ft. span arch

Chart #: 61- Span/Rise ratio approximate 4:1
 Scale #: 3 - 90 degree wing wall angle

Distance to Upstrm XS: 5 Upstream Invert Elev: 25.1
 Culvert Length: 50 Downstream Invert Elev: 25

Entrance Loss Coeff: 0.5 # identical barrels: 1
 Exit Loss Coeff: 1

Manning's n for Top: 0.013
 Manning's n for Bottom: 0.03

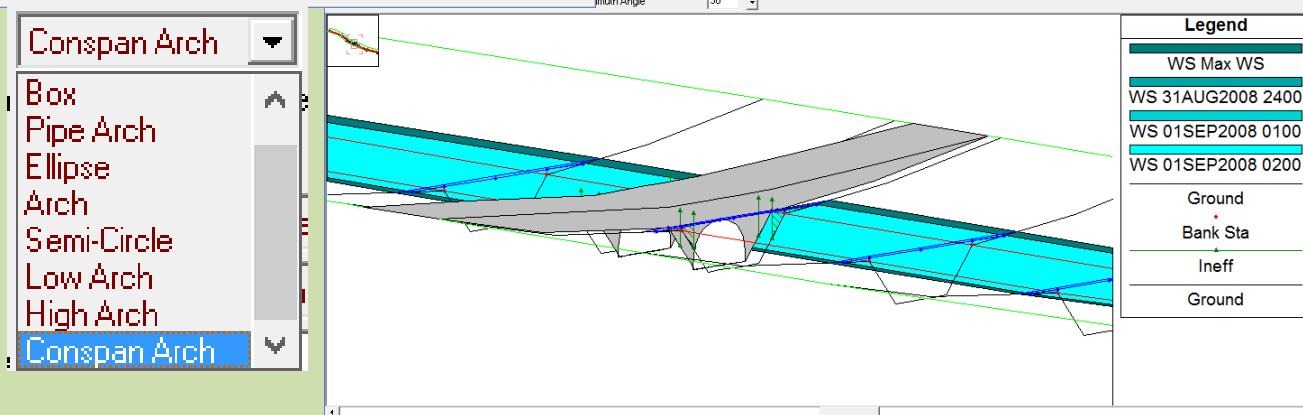
Depth to use Bottom n: 0.5
 Depth Blocked: 0

Centerline Stations

	Upstream	Downstream
1	1000.	1000.
2		
3		
4		

OK Cancel Help

Select culvert to edit



Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
- ➔ Entering geometric data
- ➔ **Entering flow data and boundary conditions**
- ➔ Performing the hydraulic calculations
- ➔ Viewing and printing results

The screenshot displays the HEC-RAS 4.1.0 interface. A red arrow points from the 'Steady Flow Data' dialog box to the 'Steady Flow Boundary Conditions' dialog box, indicating the flow of information from data entry to boundary condition setup.

Steady Flow Data - 10, 2 and 1% chance events

File Options Help

Enter/Edit Number of Profiles (25000 max): Reach Boundary Conditions ... Apply Data

Locations of Flow Data Changes

River: Add Multiple...

Reach: River Sta.: Add A Flow Change Location

Flow Change Location			Profile Names and Flow Rates			
River	Reach	RS	10 yr	50 yr	100 yr	
1	Butte Cr.	Tributary	0.2	100	500	1500
2	Fall River	Upper Reach	10	500	2000	5000
3	Fall River	Lower Reach	9.79	600	2500	6500
4	Fall River	Lower Reach	9.6	650	2700	7000

Steady Flow Boundary Conditions

Set boundary for all profiles

Available External Boundary Condition Types

Selected Boundary Condition Locations and Types				
River	Reach	Profile	Upstream	Downstream
Butte Cr.	Tributary	all		Junction=Sutter
Fall River	Upper Reach	all		Junction=Sutter
Fall River	Lower Reach	all	Junction=Sutter	Normal Depth S = 0.0004

Steady Flow Reach-Storage Area Optimization ...

Enter to accept data changes.

Project Information:

HEC-RAS 4.1.0

File Edit Run View Options GIS To

Project: Steady Flow Example from Chapt

Plan: Existing Conditions Run

Geometry: Base Geometry Data

Steady Flow: 10, 2 and 1% chance events

Unsteady Flow:

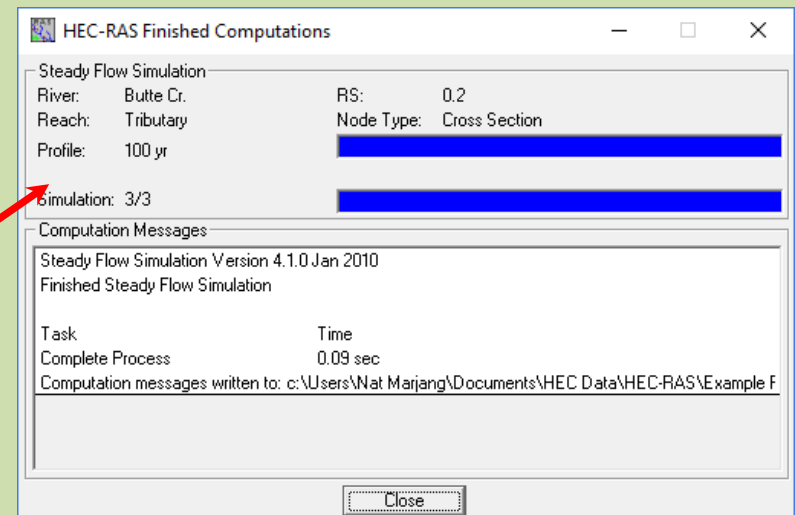
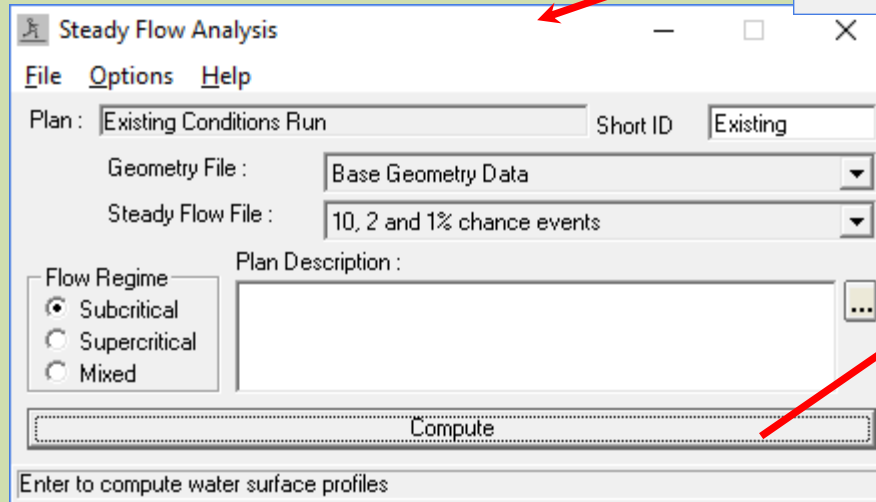
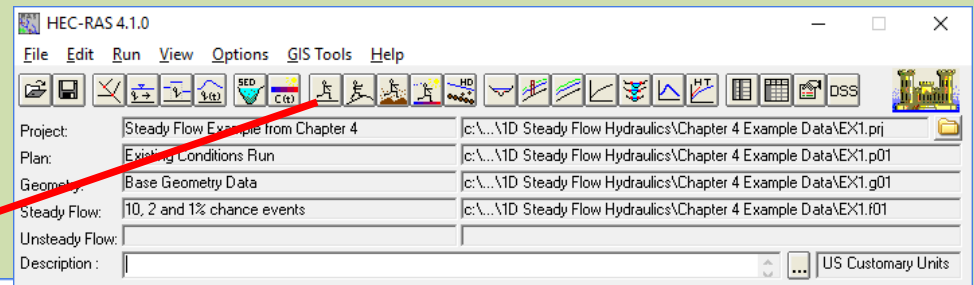
Description:

River Reach Diagram:

The diagram shows a river network with three reaches: Upper Reach (Fall River), Tributary (Butte Cr.), and Lower Reach (Fall River). The Sutter junction is marked. Stationing is provided for each reach: Upper Reach (10, 9.9), Tributary (0.2, 0.1), and Lower Reach (9.8, 9.79, 9.7, 9.6, 9.5).

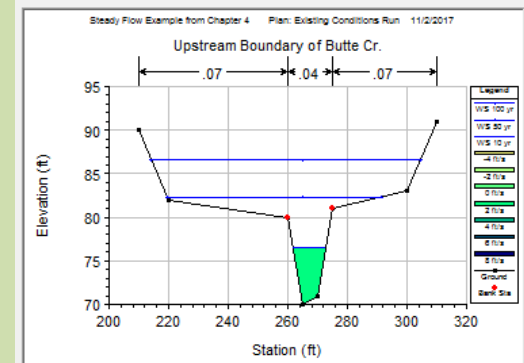
Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
- ➔ Entering geometric data
- ➔ Entering flow data and boundary conditions
- ➔ **Performing the hydraulic calculations**
- ➔ Viewing and printing results



Steps in Developing a Hydraulic Model with HEC-RAS

- ➔ Starting a new project
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Profile Plot

File Options Help

Reaches ... Profiles ...

Butte Cr. Tributary
Fall River Upper Reach
Fall River Lower Reach

Steady Flow Example from Chapter 4 Plan: Existing Conditions

Elevation (ft)

2500 3000

X-Y-Z Perspective Plot

File Options

Upstream RS: Downstream RS: Rotation Angle 10 Azimuth Angle 30

Legend

- WS 10 yr
- WS 50 yr
- WS 100 yr
- Ground
- Bank Sta

HEC-RAS 4.1.0

File Edit Run View Options GIS Tools Help

Project: Steady Flow Example from Chapter 4
Plan: Existing Conditions Run
Geometry: Base Geometry Data
Steady Flow: 10, 2 and 1% chance event
Unsteady Flow:
Description:

Profile Output Table - Standard Table 1

HEC-RAS Plan: Existing

River	Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude #	Chl #
Fall River	Upper Reach	10	10 yr	500.00	70.00	76.44		76.59	0.000772	3.06	163.31	34.86	0.25	
Fall River	Upper Reach	10	50 yr	2000.00	70.00	81.61		81.84	0.000646	4.31	751.24	232.22	0.25	
Fall River	Upper Reach	10	100 yr	5000.00	70.00	86.15		86.35	0.000435	4.63	1826.65	241.30	0.22	
Fall River	Upper Reach	9.9	10 yr	500.00	69.50	76.08		76.22	0.000712	2.98	168.05	35.19	0.24	
Fall River	Upper Reach	9.9	50 yr	2000.00	69.50	81.31		81.53	0.000599	4.21	754.62	213.35	0.24	
Fall River	Upper Reach	9.9	100 yr	5000.00	69.50	85.92		86.13	0.000438	4.71	1757.63	221.65	0.22	
Fall River	Upper Reach	9.8	10 yr	500.00	69.10	75.73		75.86	0.000691	2.94	169.86	35.32	0.24	
Fall River	Upper Reach	9.8	50 yr	2000.00	69.10	80.97		81.22	0.000630	4.34	690.50	178.78	0.25	
Fall River	Upper Reach	9.8	100 yr	5000.00	69.10	85.61		85.88	0.000522	5.16	1534.73	185.45	0.24	

Total flow in cross section.

Advantages vs Disadvantages

Advantages:

- 💧 Simple to Use
- 💧 Accepted by most government and private agencies
- 💧 Extensive Support by USACE
- 💧 Add-on packages available

Disadvantages:

- 💧 Numerical instability during unsteady analyses
- 💧 Problems modeling highly dynamic rivers and streams
- 💧 1D modeling is less detailed

Session 12: Climate Outlook Scenarios

Capacity Development Workshop:
“Flood Risk Assessment for Dungsumchu Basin in Samdrupjhomkar
District, Bhutan “
30th Oct – 8th Nov, 2017

Victor R. Shinde

Water Engineering and Management (WEM)
Asian Institute of Technology (AIT), Thailand

Background Information and Structure of CTCN

- Operative arm of the UNFCCC Technology Mechanism
- Working for National Designated Entities
- In partnership with:
 - UNEP, UNIDO
 - 12 independent, regional and global consortium partner organizations with expertise in climate change technologies
 - International network of 300+ academic, multilateral, NGO and private sector institutions
 - Strategic Partner DNV GL



Linkages between the UNFCCC Technology and Financial Mechanisms

- Mechanisms created at COP16 at Cancun in 2010
- COP21 and 22 decisions have built on shared activities (SB44 workshop, Technology Mechanism Chairs at GCF B.14) and lessons learned
- Linkages guidance relates not only to institutional collaboration, but to the importance of in-country collaboration among stakeholders
 - In particular among NDE/NDA/GEF focal points
- Clearest guidance from Parties on TM/FM linkages at COP22

Ongoing collaboration between the GCF and the CTCN

Following guidance on the need to increase linkages between the Finance and Technology mechanism of the UNFCCC:

1. Opportunity for countries to submit, with support from the CTCN, **Readiness proposals** to the GCF Secretariat for technical assistance
2. CTCN developed a **Capacity Building module** to develop GCF concept notes
3. CTCN and GCF started organizing **regional meetings/ structured dialogues** with NDEs and NDAs back to back with each other

Support to Readiness proposals

Three CTCN requests endorsed by NDE and NDA submitted to GCF Readiness Support Programme

- Early Warning and Forecasting System: Improving resiliency of crops to drought through strengthened early warning within **Ghana** – under review by GCF Secretariat
- Development of an Energy Efficiency Master Plan for **Tonga** – approved by GCF Secretariat
- Design for flood and drought management decision making in **Myanmar**

Assistance in Tonga:

- Tonga depends entirely on imported fossil fuel for its energy
- The government developed a national target in 2012, to achieve 50% of its electricity generation from renewable energy by 2020
- The technical assistance support the development of a Tonga Energy Efficiency Master Plan (TEEMP)
- Plan will include achievable energy efficiency (EE) and greenhouse (GHG) targets to ensure the transition

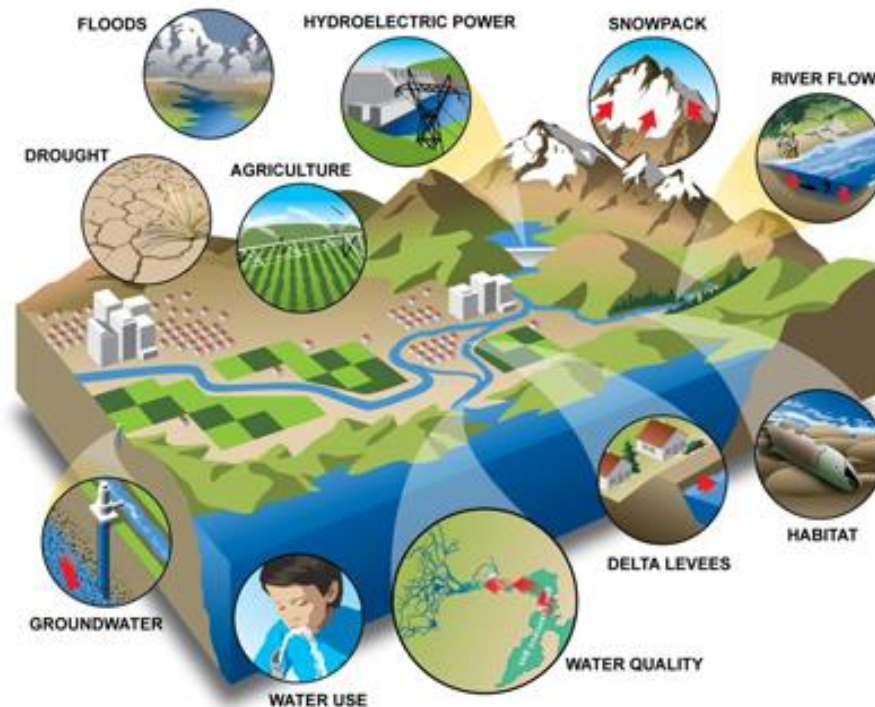
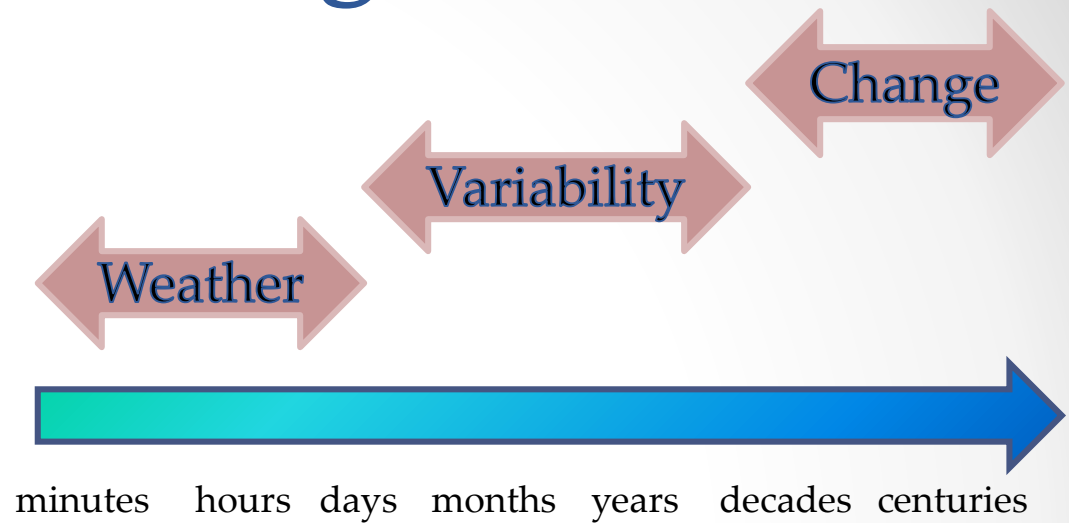
The specific objectives of this technical assistance are:

- The development of a survey, data collection, and a baseline/benchmarking study;
- The development of EE and GHG targets (including energy intensity targets);
- A needs assessment of potential EE activities for the energy sector; and Initial capacity development and training for Energy Department staff and identification of a longer-term capacity building plan.

Climate change

Definition:

A long-term change in the earth's climate, especially a change due to an increase in the average atmospheric temperature



Definitions of terms

Projection:

Any description of the future and the pathway leading to it

Forecast/Prediction:

When a projection is designated 'most likely' it becomes a forecast or prediction.

Scenario:

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world

Baseline/Reference:

The baseline is any datum against which change is measured

Why Use Climate Change Scenarios?

- We are unsure exactly how regional climate will change
- Scenarios are plausible combinations of variables consistent with what we know about human-induced climate change
- One can think of them as the prediction of a model, contingent upon the GHG emissions scenario
- Since estimates of regional change by models differ substantially, an individual model estimate
 - should be treated more as a scenario

What are Reasonable Scenarios?

- Scenarios should be:
 - Consistent with our understanding of the **anthropogenic effects** on climate
 - Internally consistent
 - e.g., clouds, temperature, precipitation
- Scenarios are a communication tool about what is known and not known about climate change
 - Should reflect plausible range for key variables

Scenarios for Impacts Analysis

- Need to be at a scale necessary for analysis
- Spatial
 - e.g., to watershed or farm level
- Temporal
 - Monthly
 - Daily
 - Sub-daily

Options for Creating Scenarios

- Past climates: analogues
- Spatial analogues
- Arbitrary changes; incremental
- Climate models

Past Climates

■ Options

- Instrumental record
- Paleoclimate reconstructions

■ Instrumental record

○ Pros

- Can provide daily data
- Includes past extreme events

○ Cons

- Range of change in past climate is limited
- Data can be limited

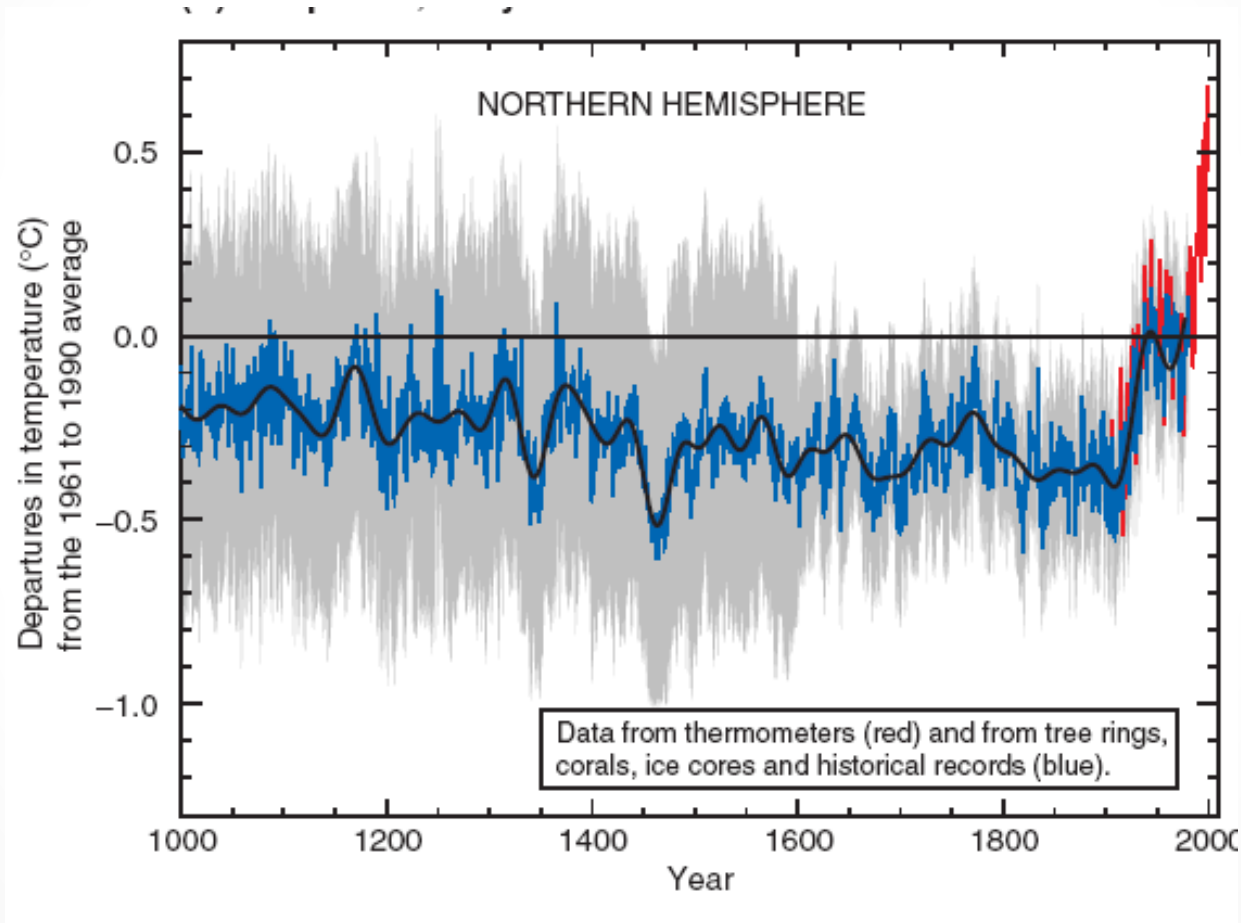
Past Climates (continued)

- Paleoclimate reconstructions (e.g. from tree rings)
 - The light-colored rings represent wood that grew in the spring and early summer, while the dark rings represent wood that grew in the late summer and fall.
 - One light ring plus one dark ring equals one year of the tree's life.
 - Tree rings usually grow wider in warm, wet years and they are thinner in years when it is cold and dry
 - If the tree has experienced stressful conditions, such as a drought, the tree might hardly grow at all in those years.

Past Climates (continued)

- Paleoclimate reconstructions
 - From tree rings, boreholes, ice cores, etc.
 - Can give annual, sometimes seasonal, climate
 - Can go back hundreds of years
- Pro
 - Wider range of climates
- Cons
 - Incomplete data
 - Uncertainties about values

Reconstruction of Northern Hemisphere Temperatures



Spatial Analogues

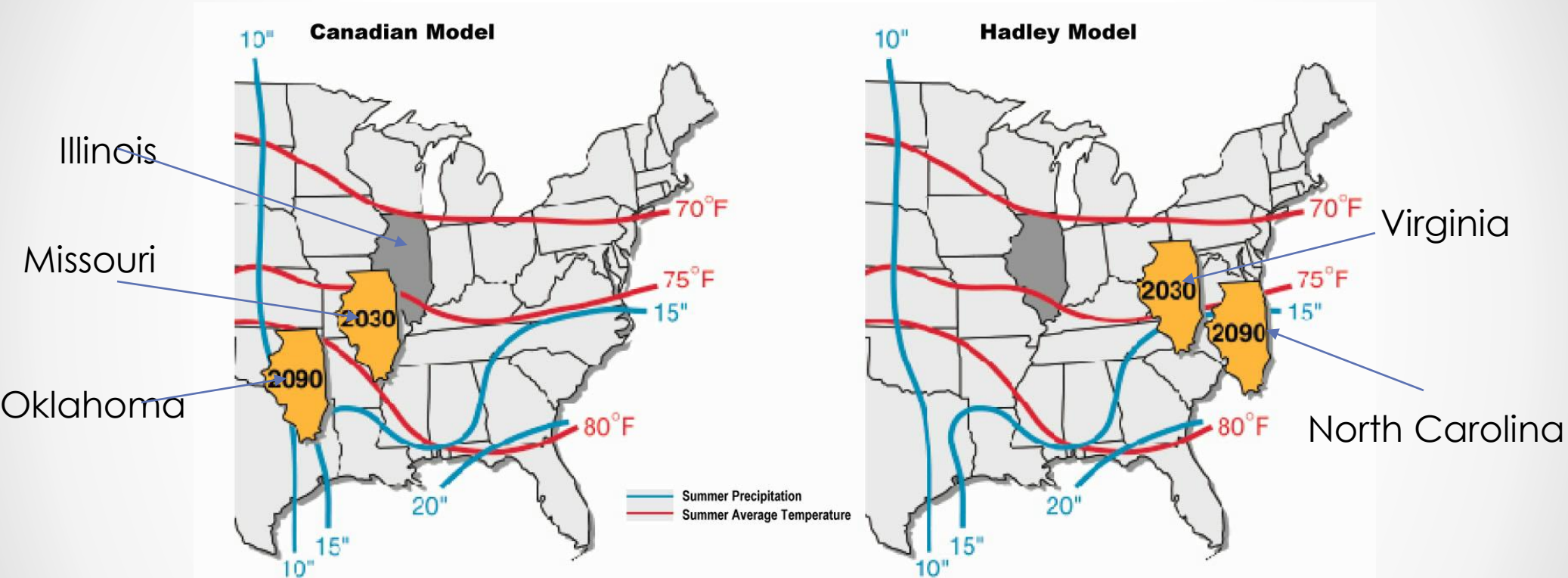


Illustration of how the summer climate of Illinois would shift under the Canadian and Hadley model scenarios. Under the Canadian scenario, the summer climate of Illinois would become more like the current climate of southern Missouri in 2030 and more like Oklahoma's current climate in 2090. The primary difference in the resulting climates of the two models relates to the amount of summer rainfall.

Spatial Analogues (continued)

■ Advantage

- Communication tool: perhaps easier to understand

■ Disadvantages

- Require using a model result to choose the spatial analogue region
- Do not capture changes in variability

Arbitrary/Incremental Scenarios

- Assume uniform annual or seasonal changes across a region
- e.g., +2°C or +4°C for temperature
- +/-10% or 20% change in precipitation
- Can also make assumptions about changes in variability and extremes

Arbitrary/Incremental Scenarios

■ Pros

- Easy to use
- Can simulate a wide range of conditions

■ Cons

- Assuming a uniform change over the year or across a region may fail to capture important seasonal or spatial details
- Combinations of changes in climate for different variables can be physically implausible

Climate Models

- Models are mathematical representations of the climate system
- They can be run with different forcings, e.g., higher GHG concentrations
- Models are the only way to capture the complexities of increased GHG concentrations

General Circulation Models

■ Pros

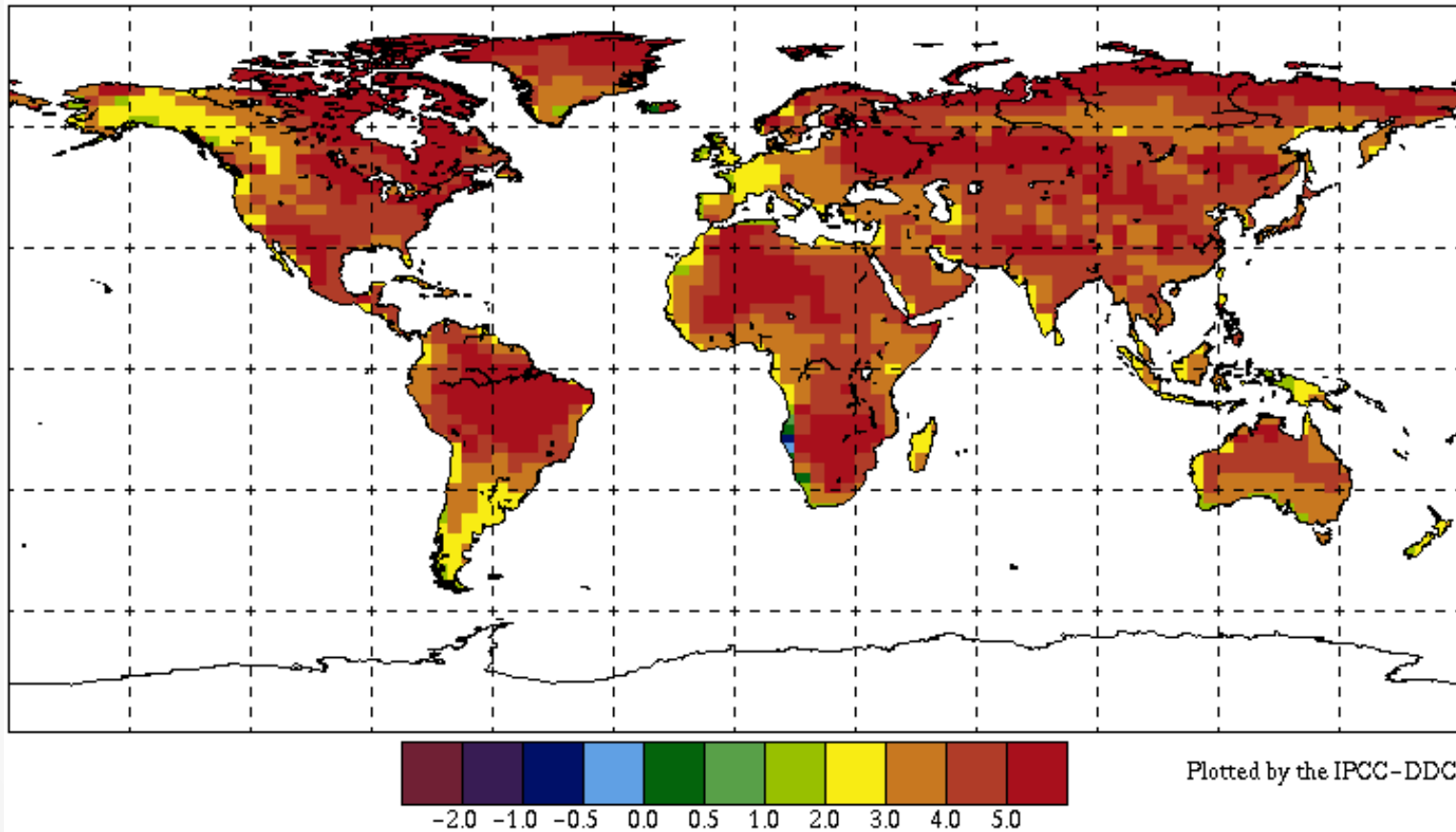
- Can represent the spatial details of future climate conditions for all variables
- Can maintain internal consistency

■ Cons

- Relatively low spatial resolution
- May not accurately represent climate parameters

Example of GCM Output

HadCM3/A2b April to April Mean Temperature (degrees C) 2080s relative to 1961-90



Downscaling from GCMs

- Downscaling is a way to obtain higher spatial resolution output based on GCMs
- Options include:
 - Combine low-resolution monthly GCM output with high-resolution observations
 - Use statistical downscaling
 - Easier to apply
 - Assumes fixed relationships across spatial scales
 - Use regional climate models (RCMs)
 - High resolution
 - Capture more complexity
 - Limited applications
 - Computationally very demanding

Combine Monthly GCM Output with Observations

- An approach that has been used in many studies
- Typically, one adds the (low resolution) average monthly change from a GCM to an observed (high resolution) present-day “baseline” climate
 - 30 year averages should be used, if possible
 - e.g., 1961-1990 or 1971-2000
 - Make sure the baseline from the GCM (i.e., the period from which changes are measured) is consistent with the choice of observational baseline

Combine Monthly GCM Output with Observations

- This method can provide daily data at the resolution of weather observation stations
- Assumes uniform changes within a GCM grid box and over a month
- No spatial or daily/weekly variability

Statistical Downscaling

- Statistical downscaling is a mathematical procedure that relates changes at the large spatial scale that GCMs simulate to a much finer scale
 - For example, a statistical relationship can be created between variables simulated by GCMs such as air, sea surface temperature, and precipitation at the GCM scale (predictors) with temperature and precipitation at a particular location (predictands)

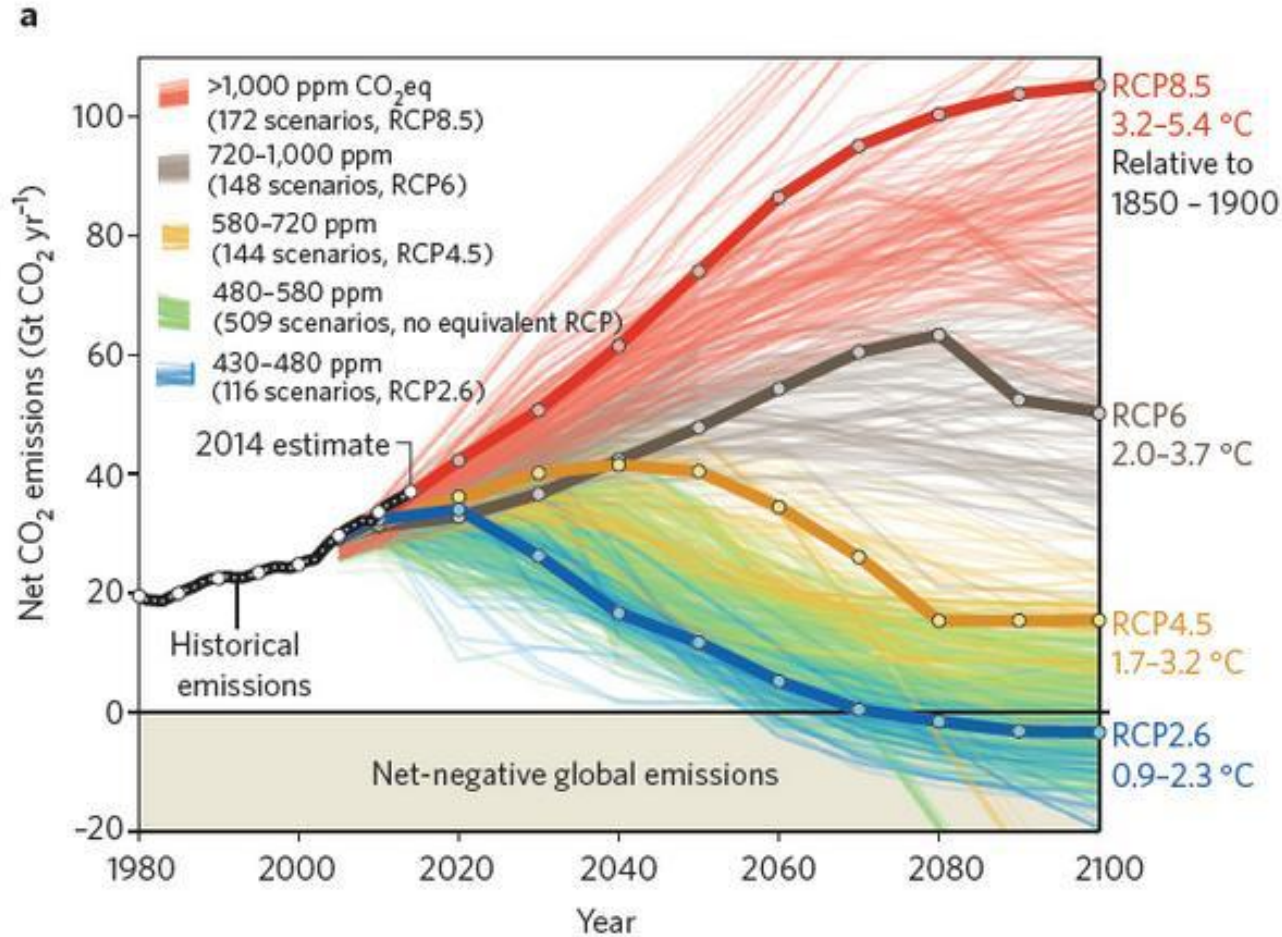
Statistical Downscaling (continued)

- Is most appropriate for
 - Subgrid scales (small islands, point processes, etc.)
 - Complex/heterogeneous environments
 - Extreme events
 - Exotic predictands
 - Transient change/ensembles
- Is not appropriate for
 - Data-poor regions
 - Where relationships between predictors and predictands may change
- Statistical downscaling is much easier to apply than regional climate modeling

Statistical Downscaling (continued)

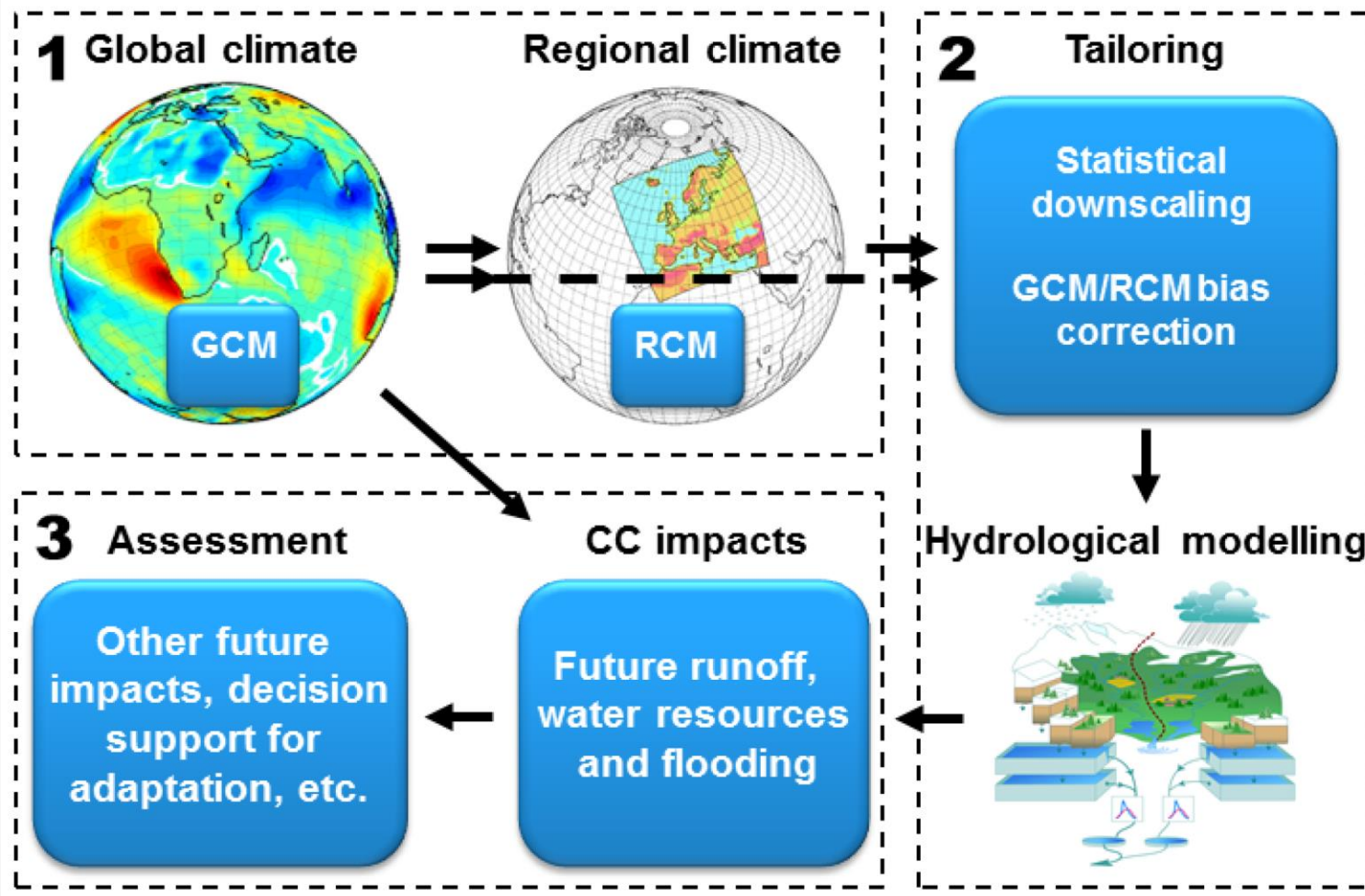
- Statistical downscaling assumes that the relationship between the predictors and the predictands remains the same
- Those relationships could change
- In such cases, using regional climate models may be more appropriate

RCP scenarios



- Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000.

CC Impact Assessment



Source: Olsson et al., (2016)

Non structural flood management – Introduction

Non structural flood management – Introduction and Definition

Non structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and education.

Source: <https://www.unisdr.org/we/inform/terminology>

Non structural flood management – Introduction and Definition

Physical non structural measures are applied on a structure by structure basis.

- Acquisition/Buyout (land is purchased)
- Relocation (outside floodplain)
- Elevation (lifted up above the base flood)
- Basement removal with utility addition (filling with sand and gravel)
- Wet Flood Proofing (water resistant materials)
- Dry Flood Proofing (floodwaters are prevented from entering structure)

Non structural flood management – Definition and Introduction

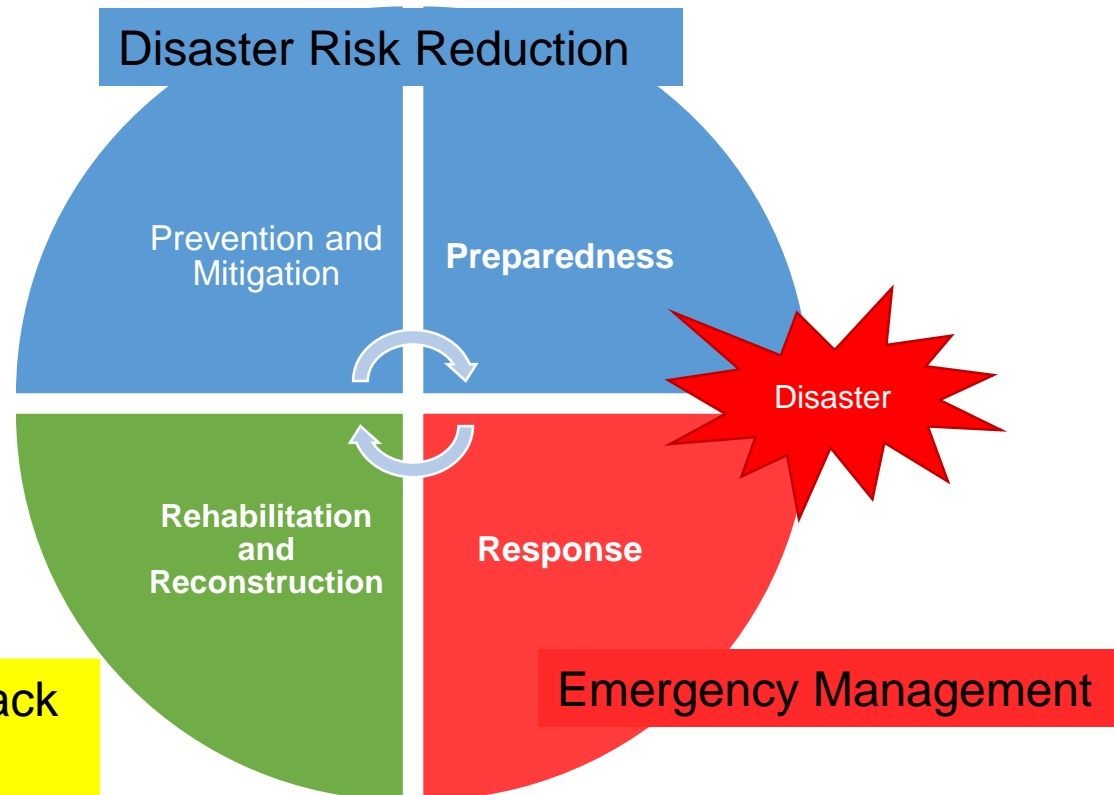
Non physical non structural measures are floodplain management activities which address flood risk through regulation, programs, and best management practices.

- Floodplain mapping
- Flood Emergency (Preparedness) Plans
- Flood warning system
- Evacuation Plans
- Land Use Regulations/Zoning/Building Codes
- Risk Communication

Non structural flood management – Flood Emergency Plan

Non structural flood management – Flood Emergency Plan

Disaster Risk Management Cycle



Non structural flood management – Flood Emergency Plan

Flood emergency management plays a vital role in overall flood management. It can be divided into three stages:

- *Preparedness*: pre-flood measures to ensure effective response
- *Response*: measures to reduce adverse impacts during flooding
- *Recovery*: measures to assist the affected community to rebuild itself

Non structural flood management – Flood Warning System

Non structural flood management – Flood Warning Systems

Definition:

An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events. (UNISDR 2017)

Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources

(source: <http://www.iwhr.com/zgskyww/rootfiles/2010/06/23/1276836877842853-1276836877844996.pdf>)

Combination of two systems:

- Flood: runoff over-flow channel
- Landslide: Water over-holding capacity

Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources

Instruments in use:



GPRS (General Packet Radio Service)
Communication

Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources

Instruments in use:



GPRS (General Packet Radio Service)
Communication

Warning signal

Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources

Instruments in use:



IP-STAR Communication (Satellite)

Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources

Instruments in use:



Manual and Automatic rain gauge (Tipping bucket)

Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources

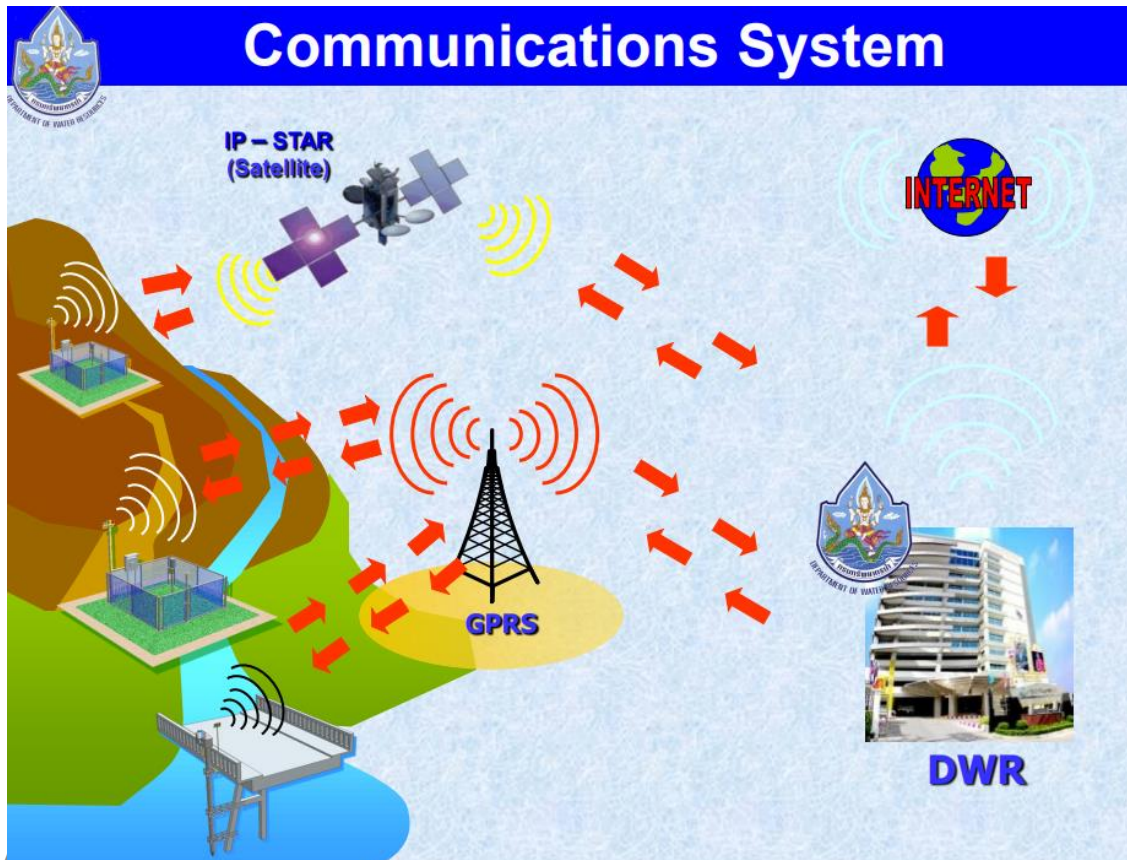
Instruments in use:



Automatic water level, Automatic rain gauge and Staff gauge

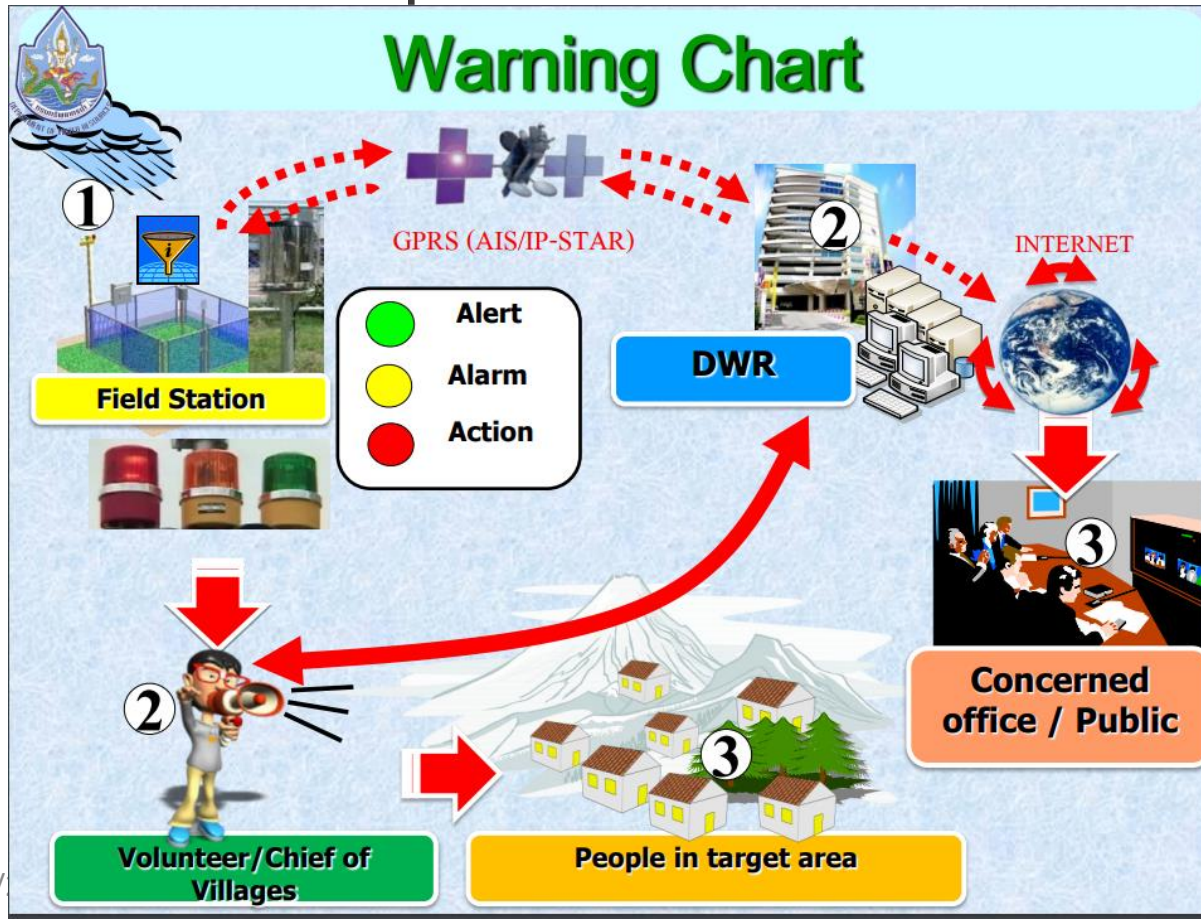
Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources




Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Department for Water Resources





Non structural flood management – Flood Warning Systems – Example Thailand DWR


Thailand Department for Water Resources

 **Three levels Traffic light concept**

- 1. Green = observe and monitor (Alert) Level 1**
- 2. Yellow = prepare for evacuation (Alarm) Level 2**
- 3. Red = decision for evacuation (Action) Level 3**

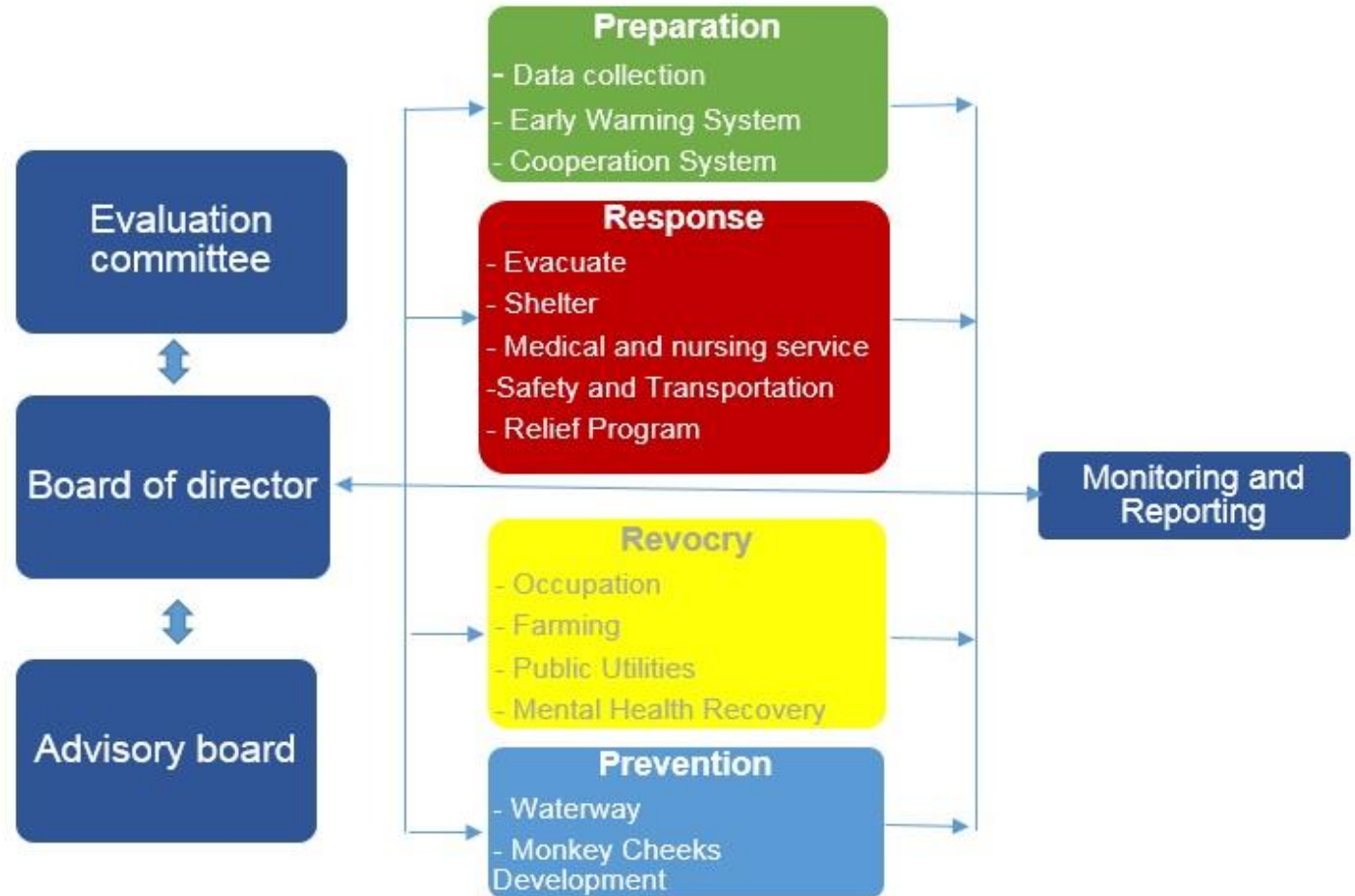
 **EWSR**

 **Local participation**

 **Field Station**

Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand Phitsanulok



Non structural flood management – Flood Warning Systems – Example Thailand DWR

Thailand One Tambon One Search and rescue (OTOS)



Mr Warning trained by DDPM to monitors the water level and warn people about flash flood

One Tambon One Search and rescue (OTOS) DDPM initiated programmes with fully equipped search and rescue facilities called OTOS in some of the selected high-risk villages.



Non structural flood management – Flood Warning Systems – Example Austria

Warning for mobile local destinations e.g. hikers in the mountains

Cooperation between the public and private sector

Central Agency for Meteorology and Geodynamik (Zentralanstalt für
Meteorologie und Geodynamik - ZAMG)

University of Linz

Hutchison 3 G Austria

Allianz Insurance

Non structural flood management – Flood Warning Systems – Example Austria

Warning for mobile local destinations e.g. hikers in the mountains

The screenshot displays the ZAMG (Zentralanstalt für Meteorologie und Geodynamik) website interface. The header features the ZAMG logo and a navigation menu with categories: News, Weather (highlighted), Climate, Environment, Geophysics, Research, and Products. A Facebook link is also present. The main content area is titled 'Wetter / Wetterwarnungen / Link für Ihre Homepage' and 'Wetterwarnungen für Ihre Homepage'. It explains that the 5-day weather warning includes a warning map and a warning trend bar. A map of Austria shows current warning levels, with some areas in yellow and orange. Below the map, a trend bar shows the highest warning level for each day of the week (Mo, Di, Mi, Do, Fr). The right sidebar contains sections for 'today Wednesday' with a map of Austria, 'Additional Warnings' with icons for various hazards, and 'MeteoAlarm' with a map of Europe. The footer includes the ZAMG logo and the logo of the Federal Ministry of Science, Research and Economy (BmWF).

ZAMG
Zentralanstalt für
Meteorologie und Geodynamik

News Weather Climate Environment Geophysics Research Products Facebook

Wetter / Wetterwarnungen / Link für Ihre Homepage

Wetterwarnungen für Ihre Homepage

Die 5-Tage-Wetterwarnung umfasst die Warnkarte und die Warrtrendleiste:

Die Karte zeigt die aktuelle Warnsituation für den heutigen Tag. Die Gemeinden sind entsprechend der jeweils höchsten Warnstufe eingefärbt.

© ZAMG

Additional Warnings

MeteoAlarm

search for ZIP/placename:
(min. 4 Chars)

ZAMG a Research Institute of the
bmwfw
Bundesministerium für
Wissenschaft, Forschung und Wirtschaft

In der Trendleiste ist jedem Tag die österreichweit höchste Warnfarbe zugeordnet.

Um die 5-Tage-Wetterwarnung mit Link zu den ZAMG-Wetterwarnungen in Ihre Homepage einzubinden, kopieren Sie den HTML-Code zwischen den Zeilen

Non structural flood management – Self Protection

Non structural flood management – Self Protection

When staying in buildings, the following should be avoided shortly before or during floods:

Senior or handicapped citizens should not stay in parts of the building lying below the maximum flood depth (southern France 1999, 10 casualties)

The use of rooms without any possibility of escaping to higher floors (Brig CH 1993, 2 casualties)

Use of basements and underground garages (Boll, CH 1987, 1 casualty)

Use of elevators (Augsburg D 1999, divers rescued 1 person)

Non structural flood management – Self Protection

When staying in open air, the following should be avoided shortly before or during floods:

To stay on bridges and embankments during a flood

To camp in the course of flood water discharge (Savoie 1987, 23 casualties)

To drive on flooded roads (Switzerland, 1987, 3 casualties, southern France, 1999, 10 out of 24 casualties)

Flood tourism

Non structural flood management – Self Protection

In Switzerland, misconduct played an important role in 40 % of the 67 casualties due to floods registered between 1972 and 2001.

Non structural flood management – Economic aspects

Non structural flood management – Economic aspects



Upstream investments:

Who?

- Public sector
- (Internat.) donor organization
- Private sector
- Civil society
- Etc.

Why?

- RB Master Plan
- Flood protection
- Land management
- Economic purpose
- Etc.

What?

- Forest
- Reservoir
- Floodplain
- Etc.

Non structural flood management – Economic aspects



Upstream investments:
i.e. rehabilitation of forest

Downstream beneficiaries:
Lower peak flow
Less areas flooded

Non structural flood management – Economic aspects



Upstream investments:
i.e. rehabilitation of forest

Downstream beneficiaries:
Lower peak flow
Less areas flooded

Compensation
payments

Non structural flood management – Economic aspects



Upstream investments:
i.e. rehabilitation of forest

Downstream beneficiaries:
Lower peak flow
Less areas flooded

Loss & Damages

Non structural flood management – Economic aspects

Loss & Damages



12/7/2017



giz Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

Source: <http://www.bbc.com/news/world-us-canada-39841255>;
<http://www.walesonline.co.uk/news/wales-news/schools-homes-been-hit-flooding-13357359>

Non structural flood management – Economic aspects



Decision making process:

- Cost Benefit Analysis
- Cost Effectiveness Analysis

Non structural flood management – Economic aspects



Decision making process:

- Cost Benefit Analysis
- Cost Effectiveness Analysis

Non structural flood management – Economic aspects

Ecosystem-based Adaptation (EbA)

A new approach to advance natural solutions for climate change adaptation



Conservation

To promote the sustainable management and conservation of biodiversity to save benefits provided by ecosystems.



Integration

To build the capacity of civil society and government institutions to support integrated approaches to adaptation.



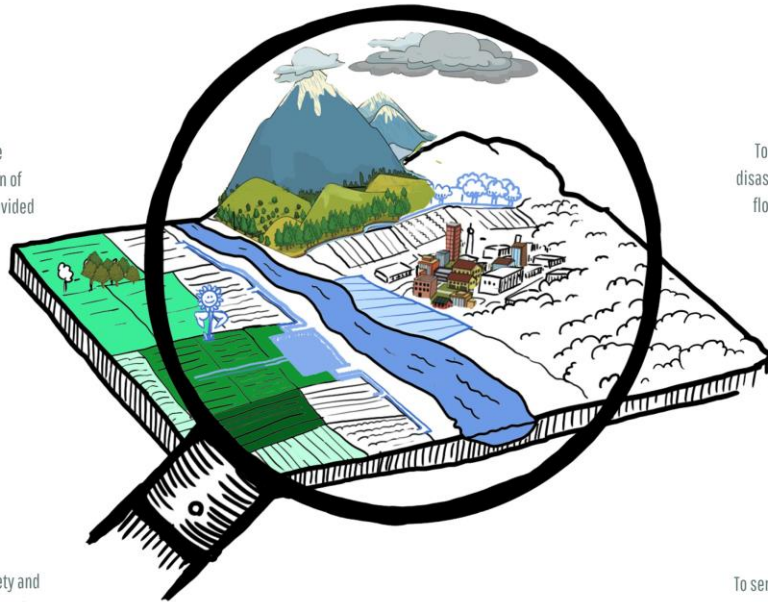
Mitigation

To reduce the impacts of natural disasters such as storms, drought and floods, on vulnerable people and ecosystems.



Maintenance

To serve as coping mechanisms during periods of scarcity contributing to livelihoods security.



Non structural flood management – Economic aspects

Question 1) Name two economic aspects

Answer 1) Compensation payments, investments - decision making, loss & damage

Question 2) Is the loss and damage higher in rural or in urban areas?

Answer 2) Urban areas

Question 3) Can the private sector invest in flood protection measures?

Answer 3) yes

Non structural flood management – Land management

Non structural flood management – Land management



Source: https://en.wikipedia.org/wiki/File:St.Goarshausen_Loreley_Burg_Katz_2016-03-27-17-13-57.jpg

Effects:
Land availability
High velocity
Deep & tight water

12/7/2017

No space for water



Source: https://en.wikipedia.org/wiki/Rhine#/media/File:Vue_a%C3%A9rienne_du_Rhin_%C3%A0_Dusseldorf.jpg

Non structural flood management – Land management



Source: https://en.wikipedia.org/wiki/Rhine#/media/File:Vue_a%C3%A9rienne_du_Rhin_%C3%A0_Dusseldorf.jpg

Effects:

Land availability

Consequences:

- Economic development
- Increasing flood risks – directly (along the river) and indirectly (downstream)

Non structural flood management – Land management



Source: https://en.wikipedia.org/wiki/Rhine#/media/File:Vue_a%C3%A9rienne_du_Rhin_%C3%A0_Dusseldorf.jpg

Effects:

High velocity

Consequences:

- Fast run-off (increasing flood risk downstream)
- Low groundwater recharge

Non structural flood management – Land management



Source: https://en.wikipedia.org/wiki/Rhine#/media/File:Vue_a%C3%A9rienne_du_Rhin_%C3%A0_Dusseldorf.jpg

Effects:

Deep & tight water

Consequences:

- Economic use
- Fast run-off (increasing flood risk downstream)
- Against nature

Non structural flood management – Land management



Effects:
Deep & tight water

- Against nature

Water is naturally flat and wide



Non structural flood management – Land management



- Effects:
Deep & tight water
- Against nature

New style: give space back to the water
Example: Munich, Germany



Non structural flood management – Land management

Retention ponds
Example: Munich, Germany



ES4 - Biodiversity preservation	High
ES7 - Flood risk reduction	High
ES11 - Aesthetic/cultural value	High
PO9 - Take adequate and co-ordinated measures to reduce flood risks	High
PO11 - Better protection for ecosystems and more use of Green Infrastructure	High
PO14 - Prevention of biodiversity loss	High
BP1 - Store runoff	High
BP2 - Slow runoff	High
BP9 - Intercept pollution pathways	High
BP10 - Reduce erosion and/or sediment delivery	High
BP12 - Create aquatic habitat	High
ES9 - Filtration of pollutants	High

12/7/2017

Source: <http://nwrn.eu/measure/retention-ponds>

18

Non structural flood management – Land management



Land use conversion in a catchment: Afforestation

Effects:

Natural land

Biodiversity

Natural water balance

Consequences:

- Improved water quality
- Improved soil quality
- Control of soil erosion

Source: http://nwrn.eu/sites/default/files/nwrn_ressources/f3_-_afforestation_of_reservoir_catchments_0.pdf

Non structural flood management – Land management

It is our choice



Source: http://nwrn.eu/sites/default/files/nwrn_ressources/f3_-_afforestation_of_reservoir_catchments_0.pdf

Non structural flood management – Land management

It is our choice



Source: http://nwrn.eu/sites/default/files/nwrn_ressources/f3_-_afforestation_of_reservoir_catchments_0.pdf

Non structural flood management – Land management

Question 1) What are possible negative of too less space for the water?

Answer 1) Increases velocity, fast run-off increases flood risk downstream, reduces groundwater recharge etc.

Question 2) what is the natural water flow? Deep and tight or flat and wide?

Answer 2) Flat and wide

Question 3) Can the water quality be improved by land conversion of agricultural land through forest?

Answer 3) yes

Non structural flood management – Ecosystem-based adaptation measures

Non structural flood management – Ecosystem-based adaptation measures

EU Site with possible EbA Measures

Hydro Morphology		Slowing and Storing Runoff				Reducing Runoff			Reducing Pollution	Soil Conservation			Creating Habitat	Climate Alteration				
		BP1	BP2	BP3	BP4	BP5	BP6	BP7	BP8	BP9	BP10	BP11	BP12	BP13	BP14	BP15	BP16	BP17
		Store runoff	Slow Runoff	Store river water	Slow River Water	Increase evapotranspiration	Increase infiltration and/or groundwater recharge	Increase soil water retention	Reduce Pollutant Source	Increase Pollution Pathways	Reduce Erosion and/or Sediment Delivery	Improve Soils	Create Aquatic Habitat	Create Riparian Habitat	Create Terrestrial Habitat	Enhance Precipitation	Reduce Peak Temperature	Absorb and/or retain CO2
N1	Basins and Ponds	1	1			1	3		2	3		3						
N2	Wetland restoration and management	1	1	2	2	2	2		2	3	3	1	1	3			1	
N3	Floodplain restoration and management	1	1	1	1	2	1	2	2	2	1	2	1	1		2	2	
N4	Re-Meandering	2	2	2	1	3	2	2	3	1	1	2	1	1	2	2	3	
N5	Stream bed renaturalization			2	1	3	1		2	1	2	1	1	3		2	3	
N6	Restoration of reconnection of seasonal streams	1	1	1	1	3	1	2	3	2	1	3	1	1	3	3	3	
N7	Reconnection of oxbow lakes and similar features	1	1	1	1	3	1	2	3	2	1	3	1	1	3	3	3	
N8	Riverbed material renaturalization	2	2	2	2				2	3		1	1					
N9	Removal of dams and other longitudinal barriers							3		2		1						
N10	Natural bank stabilization	3	3	3	2	2	3	2	3	2	1	1	1	1	3	3	3	
N11	Elimination of riverbank protection	3	3	1	1	3	3	3		2	2	2	2				3	
N12	Lake restoration	1	2	1	2	3	3	3	3	1	3	1	1					
N13	Restoration of natural infiltration to groundwater		2				1	3		3	3							
N14	Re-naturalization of polder areas	1	2	1	2	3	2	3		3	3	3	1	2	3			

Non structural flood management – Ecosystem-based adaptation measures

EU Site with possible EbA Measures

Hydro Morphology

		ES1	ES2	ES3	ES4	ES5	ES6	ES7	ES8	ES9	ES10	ES11	ES12	ES13	ES14
		Provisioning			Regulatory and Maintenance						Cultural		Abiotic		
		Water Storage	Fish Stock and Recruiting	Natural Biomass Production	Biodiversity Preservation	Climate Change Adaptation and Preservation	Groundwater/Aquifer Recharge	Flood Risk Reduction	Erosion/Sediment Control	Filtration of Pollution	Recreational Opportunities	Aesthetic/Cultural Value	Navigation	Geological Resource	Energy Production
N1	Basins and Ponds	1	3	3	3		1	1		2	2	2			
N2	Wetland restoration and management	2	1	2	1	2	2	2		2	2	2			
N3	Floodplain restoration and management	1	1	1	1	2	1	1	1	2	1	1			
N4	Re-Meandering	2	2	1	1	2	1	1	1	2	1	1			
N5	Stream bed renaturalization			2	1			2	1	2	2	2			
N6	Restoration of reconnection of seasonal streams	2	2	3	1	2	2	2	1	2		2			
N7	Reconnection of oxbow lakes and similar features	2	2	3	1	2	2	2	1	2	3	2			
N8	Riverbed material renaturalization	2	2	2	1			2	1	2		3			
N9	Removal of dams and other longitudinal barriers		1		1				2				2		2
N10	Natural bank stabilization	3	1	1	1	3	3	2	1	1	1	1			
N11	Elimination of riverbank protection	2	2	2	2		3	1	2	2	2	2			
N12	Lake restoration	1	1	1	1		2	2	1		1	1			
N13	Restoration of natural infiltration to groundwater	2				3	2		3					1	
N14	Re-naturalization of polder areas	1	2	2	1		2	2	3	3	3	2	3		

Non structural flood management – Ecosystem-based adaptation measures

Measures	Flood	Drought	Sedimentation	Erosion	Water Quality
Maintenance of forest cover in headwater areas	79%	29%	30%	33%	33%
Land use conversion	75%	30%	30%	32%	34%
Afforestation of reservoir catchment	66%	28%	29%	32%	30%
Detention basins	61%	28%	30%	33%	34%
Trees in urban areas	59%	13%	21%	22%	30%
Early sowing	57%	15%	21%	23%	26%
Meadows and pastures	55%	9%	16%	18%	18%
Green cover	55%	15%			22%
Swales	54%	20%			29%
Soakways	54%	30%	30%	32%	30%
Targeted planting for "catching" precipitation	48%	29%	25%	27%	25%
Rain gardens	46%	25%	22%	26%	29%
Infiltration basins	46%	29%	30%	33%	36%
Urban forest parks	43%	19%	20%	21%	24%
Overland flow areas in peatland forests	39%	19%	18%	21%	24%
Buffer strips and hedges	38%	11%	10%	12%	13%
Infiltration trenches	38%	25%	25%	26%	26%

Co-Benefits

Non structural flood management – Ecosystem-based adaptation measures

EU Site with possible EbA Measures

Measures	Side Effects									
	Relevance	Drought	Sedimentation	Erosion	Water Quality	Water born diseases	Management	Climate Change	Ecosystems	Economics
Basins and Ponds	52%	40%	28%	35%	48%	32%	32%	26%	42%	30%
Wetland restoration and management	56%	44%	34%	41%	62%	40%	40%	43%	64%	37%
Floodplain restoration and management	100%	58%	49%	58%	83%	50%	50%	51%	87%	44%
Re-Meandering	81%	50%	44%	47%	76%	50%	50%	46%	80%	40%
Stream bed renaturalization	52%	39%	41%	42%	60%	41%	41%	42%	66%	37%
Restoration of reconnection of seasonal streams	82%	52%	44%	53%	72%	46%	46%	41%	74%	34%
Reconnection of oxbow lakes and similar features	82%	53%	44%	53%	72%	47%	47%	40%	74%	35%
Natural bank stabilization	52%	45%	46%	49%	70%	47%	47%	50%	80%	44%
Elimination of riverbank protection	52%	42%	42%	43%	60%	45%	45%	39%	59%	38%
Lake restoration	60%	47%	45%	51%	69%	46%	46%	45%	70%	41%
Re-naturalization of polder areas	63%	49%	41%	47%	60%	43%	43%	39%	59%	37%

The tool provides basic ideas of measures, which still needs to be planned and designed very carefully to be effective. Location, size, detailed planning etc. are still very important for successful implementation.

Non structural flood management – Ecosystem-based adaptation measures



Removal of infrastructure



Non structural flood management – Ecosystem-based adaptation measures



Protection walls



are not always protecting



but can harm. This happened opposite
of the protection wall!

Non structural flood management – Ecosystem-based adaptation measures

Natural Water Flow in the
mountains – Video waterfall

Thank you for your attention!

Roland Treitler

Email: roland.treitler@exaqua.at

Skype: roland_treitler

Capacity Building Programme on
Flood Risk Assessment and Management
30 October - 8 November 2017

Sessions 10 &11: Flood risk assessment: Example for Samdrupjhonkar municipality

Prof. Tawatchai Tingsanchali

Water Engineering and Management
Asian Institute of Technology, Thailand

Introduction

1. Flood risk can be defined as “The combination of the probability of a flood and its negative consequences” (UN/ISDR, 2009).
2. **Flood Risk = Flood Hazard x Flood Damage Vulnerability**
3. Flood hazard is a function of flood characteristics such as depth, duration and velocity, etc. that can potentially cause loss and damages to people and their assets
4. **Flood damage vulnerability is a function of number of death /injury of people and damage cost of their assets that are exposed to flood risk**
5. The elements that are exposed to flood risk are called exposure. These elements can be people and their assets such houses, furnitures, farmland, cattle, etc.

Notes

- There are varieties of definition of flood risk, for example
- Flood Risk = Flood Hazard X Exposure x Vulnerability

Or

- Flood Risk= Flood Hazard x Consequences

Where

- Consequences=Exposure x Vulnerability

Calculation of Total Risk (Regional + Household)

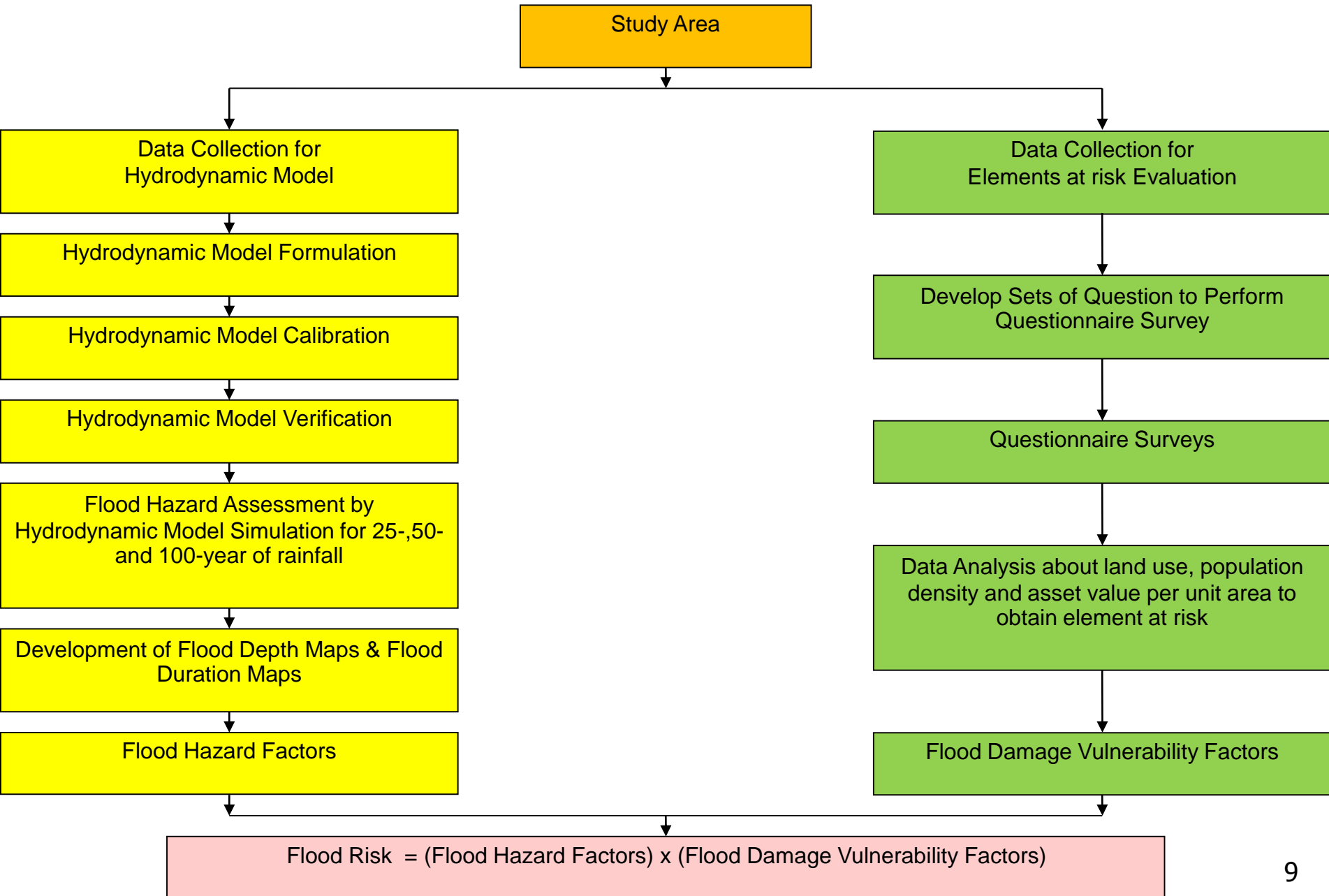
- The same flood hazard exists both at regional scale and household scale
- Vulnerability (VR) at Regional Scale and vulnerability (VH) at Household Scale has to be determined separately
- Total vulnerability = $\theta VR + (1-\theta)VH$,
where θ = weighting factor between 0 and 1
- Total flood risk = flood hazard x total vulnerability

EXAMPLE

Flood Risk Map at Regional Scale

- Development of flood risk maps for 25-year, 50-year and 100-year return period of the area surrounding SBIA

Flowchart of research work



Research methodology

- This study identifies flood hazard & flood risk areas for priority-based flood mitigation planning by using a hydrodynamic model in conjunction with a GIS
- A hydrodynamic model namely **MIKE FLOOD (DHI 2003)** was used to simulate the flood flow through the canal network and floodplain.

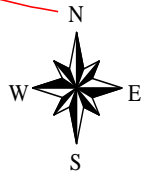
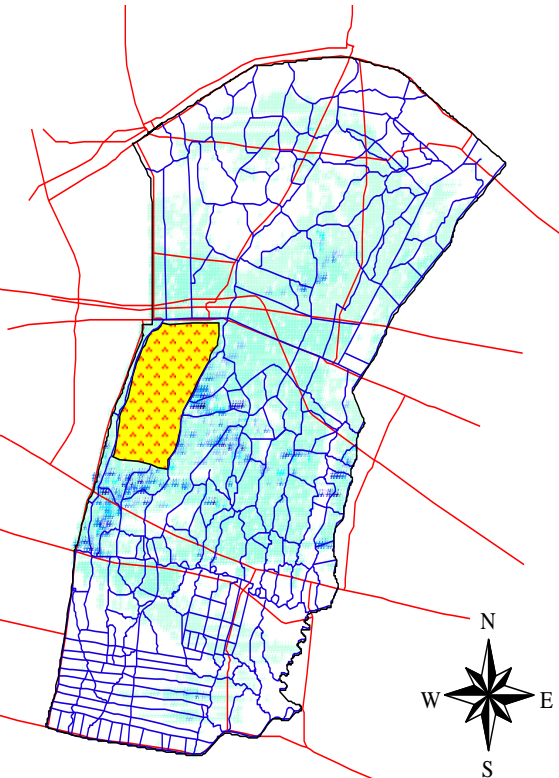
Research methodology (continued)

- After model calibration and verification, it was used to simulate the flood flow in terms of flood depth for different return periods of rainfall
- Flood risk assessments were performed by incorporating flood hazard and flood damage vulnerability

Flood Depth

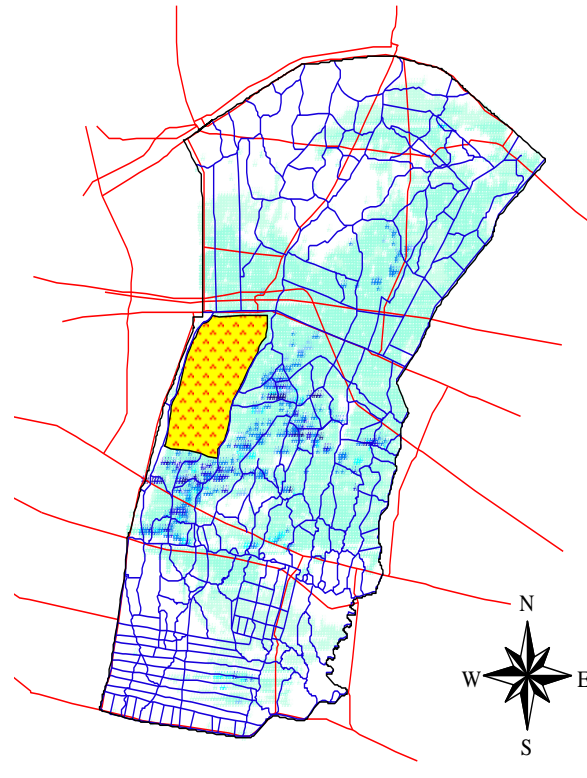
- Flood hazard is considered as a function of maximum flood depths and duration
- Four depth hazard categories are based on marginal depths (0.45 m, 0.90 m and 1.20 m)

Peak flood depth



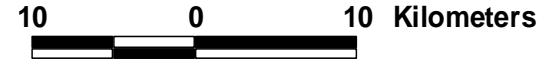
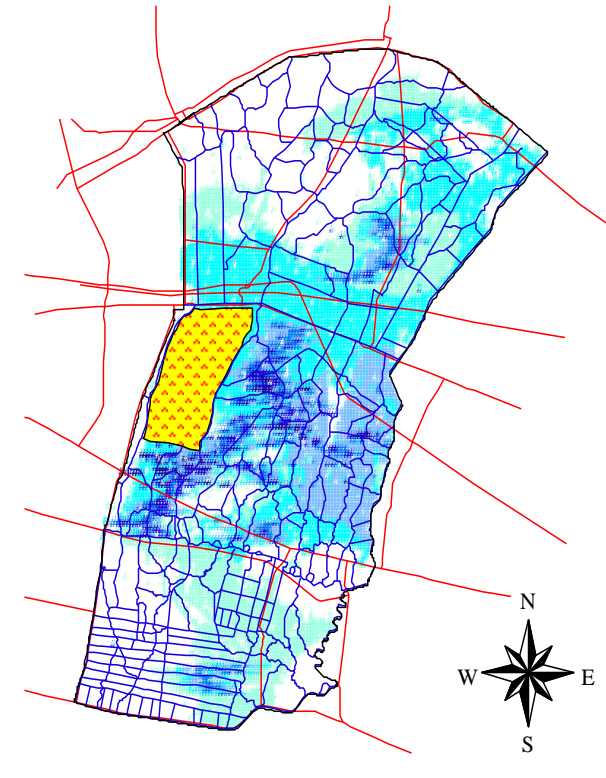
- Study area
- Canal
- Road
- Suvarnabhumi International Airport

- 25-year Peak flood depth (m)
- 0.00 - 0.20
 - 0.20 - 0.40
 - 0.40 - 0.60
 - 0.60 - 0.80
 - 0.80 - 1.00
 - 1.00 - 1.20
 - 1.20 - 1.40
 - 1.40 - 1.60



- Study area
- Canal
- Road
- Suvarnabhumi International Airport

- 50-year Peak flood depth (m)
- 0.00 - 0.20
 - 0.20 - 0.40
 - 0.40 - 0.60
 - 0.60 - 0.80
 - 0.80 - 1.00
 - 1.00 - 1.20
 - 1.20 - 1.40
 - 1.40 - 1.60



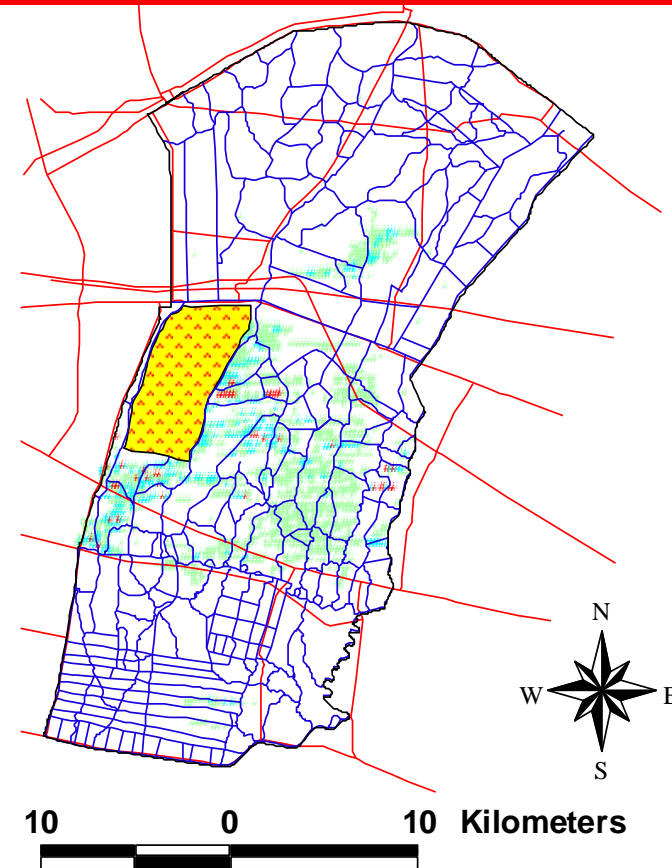
- Study area
- Canal
- Road
- Suvarnabhumi International Airport

- 100-year Peak flood depth (m)
- 0.00 - 0.20
 - 0.20 - 0.40
 - 0.40 - 0.60
 - 0.60 - 0.80
 - 0.80 - 1.00
 - 1.00 - 1.20
 - 1.20 - 1.40
 - 1.40 - 1.60





Maximum flood depth classification for 25-year flood

Depth categories	Depth range (m)	Flooding area (% of total)
Low	0-0.45	85.96
Medium	0.45-0.90	10.35
High	0.90-1.20	2.90
Very high	> 1.20	0.79

These included 14.48 % of non-flooding areas (flood depth = 0 m)



-  Study area
-  Canal
-  Road
-  Suvarnabhumi International Airport

- 25-year Peak flood depth classification**
-  Low
 -  Medium
 -  High
 -  Very high

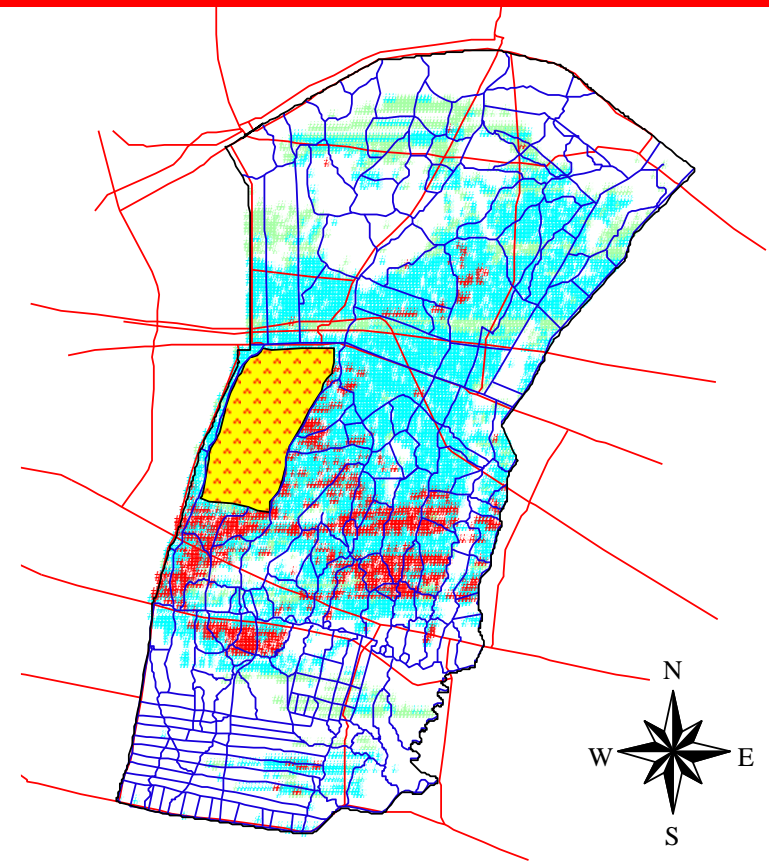
Flood Duration

- Rising flood, peak flood and recession flood were considered (September 22, 28 and October 8)
- Insignificant flood area and flood affected area are divided with depth of 0.22 m
- Flood affected areas were used to assess flood duration

Flood duration of $T_r = 25$ years

Duration categories	Flooding area (% of total)
Short	33.71
Medium	8.75
Long	35.96
Very long	7.10

These excluded 14.48 % of non-flooding areas (flood depth = 0 m)



- Study area
- ∧ Canal
- ∧ Road
- Suvarnabhumi International Airport

- 25-year Flood duration**
- Short
 - # Medium
 - # Long
 - # Very long

Indicators (FHI) for Flood Depth & Flood Duration

- 4 flood hazard categories are used to represent severity of flood hazard namely: low, medium, high and very high
- Small integer numbers such as 0, 1, 2, 3 etc., were used for the 4 categories of FHI
- 3 options of FHI_y for flood depth and 3 options of FHI_t for flood duration are considered
- In total, 9 combinations of hazard indicators FHI_y and FHI_t are considered

Flood hazard indicators for flood depth (FHI_y)

Flood depth, y (m)	Hazard Category	Flood hazard indicator, FHI _y		
		Option 1a	Option 2a	Option 3a
$0.00 < y \leq 0.45$	Low	0	1	2
$0.45 < y \leq 0.90$	Medium	1	2	3
$0.90 < y \leq 1.20$	High	2	3	4
$y > 1.20$	Very high	3	4	5

Flood hazard indicator for flood duration (FHI_t)

Flood duration	Hazard Category	Flood hazard indicator, FHI _t		
		Option 1b	Option 2b	Option 3b
Short	Low	0	1	2
Medium	Medium	1	2	3
Long	High	2	3	4
Very long	Very high	3	4	5

Patterns of flood hazard factor calculation for nine case studies

Case studies for flood hazard assessment	Flood hazard indicator options	
	Flood depth	Flood duration
A	1a	1b
B	1a	2b
C	1a	3b
D	2a	1b
E	2a	2b
F	2a	3b
G	3a	1b
H	3a	2b
I	3a	3b

Flood Hazard Factor (FHF)

- FHF = Flood Hazard Factor FHF
= $\beta(FHI_y) + (1-\beta)(FHI_t)$

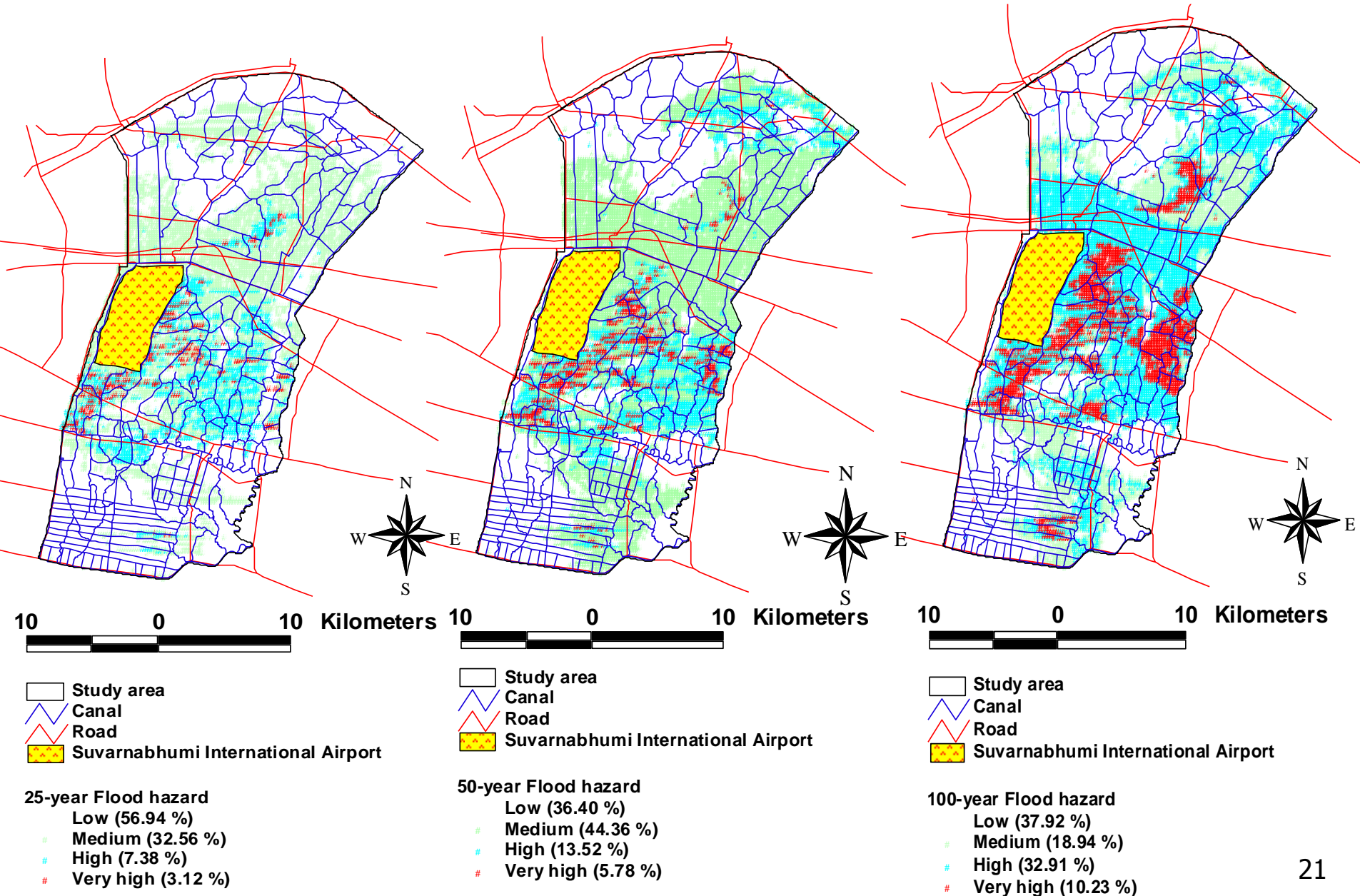
Where $0 \leq \beta \leq 1$

FHI_y = Flood Depth Indicator

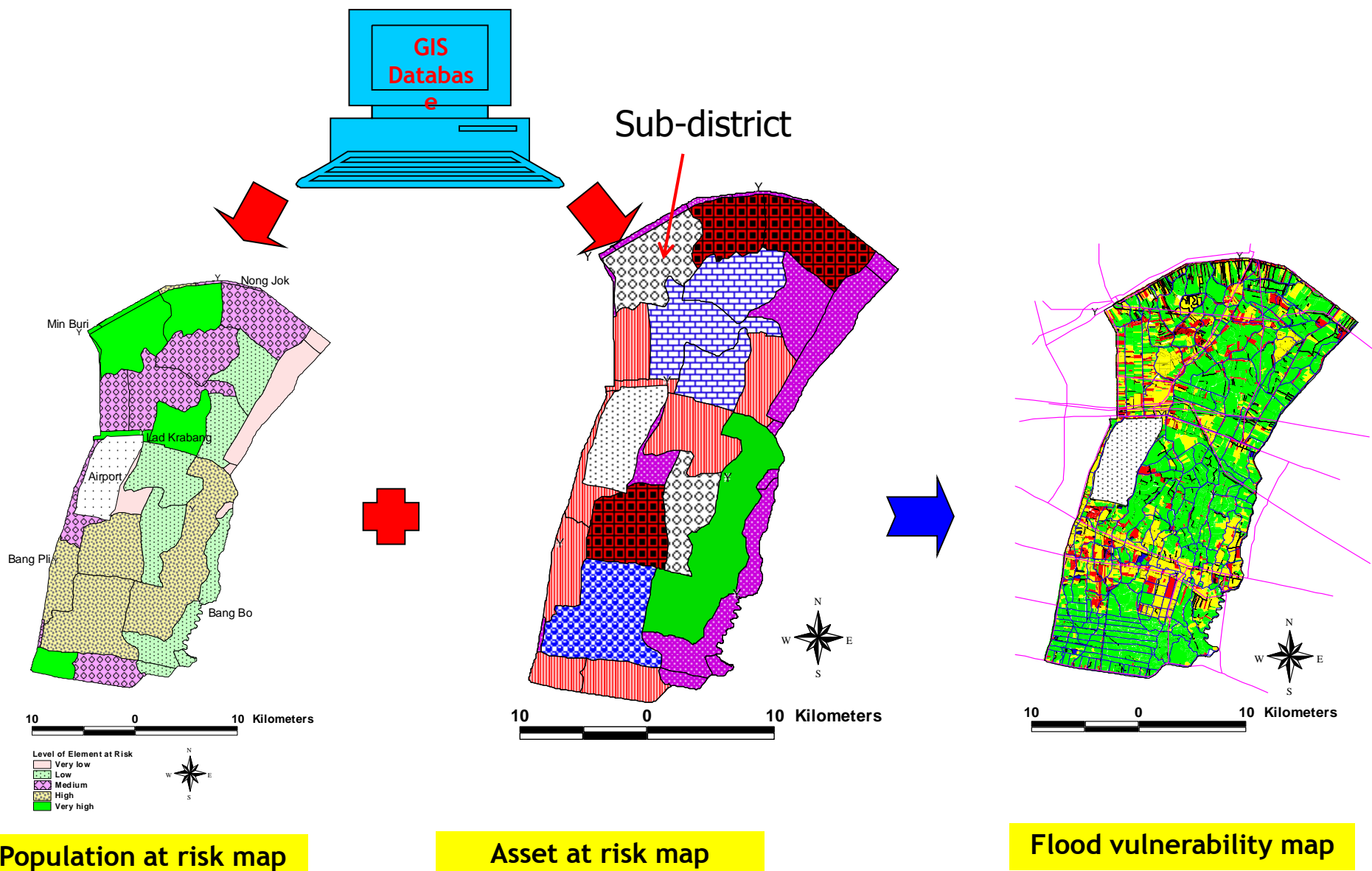
FHI_t = Flood Duration Indicator

- Plot of flood hazard factor FHF over the DEM of study area is called flood hazard map

Flood Hazard Maps



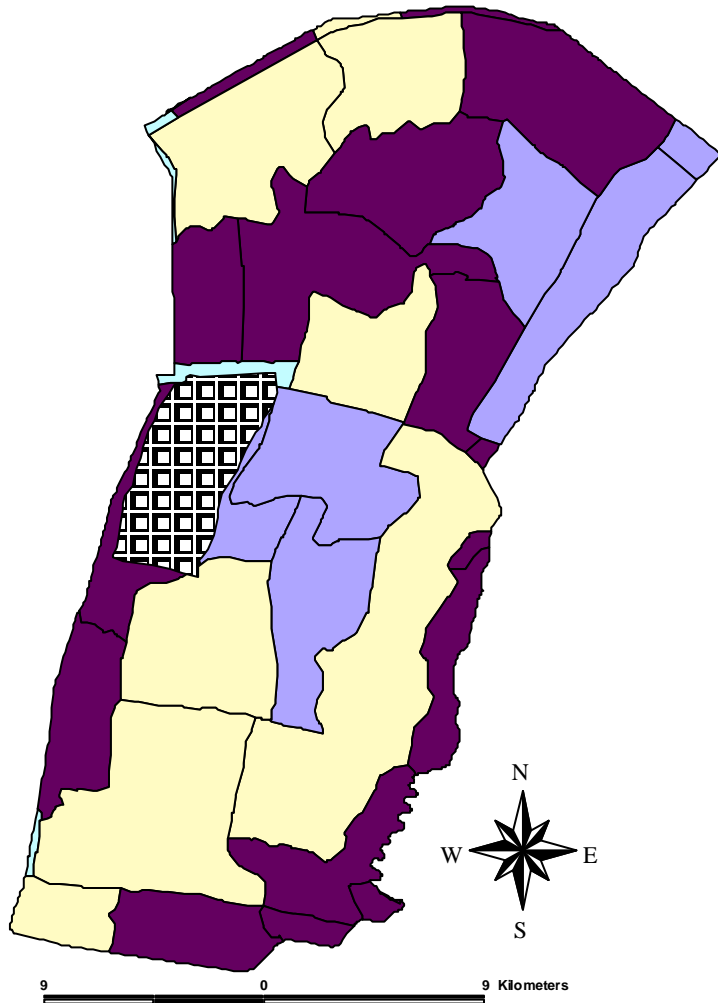
Determination of Flood vulnerability Map



Elements at Risk (EXPOSURE)





- **Population exposed to flood risk**
- **Assets exposed to flood risk**

Population density

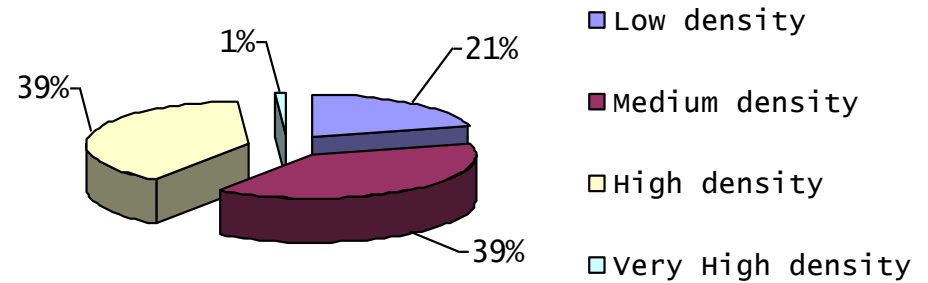


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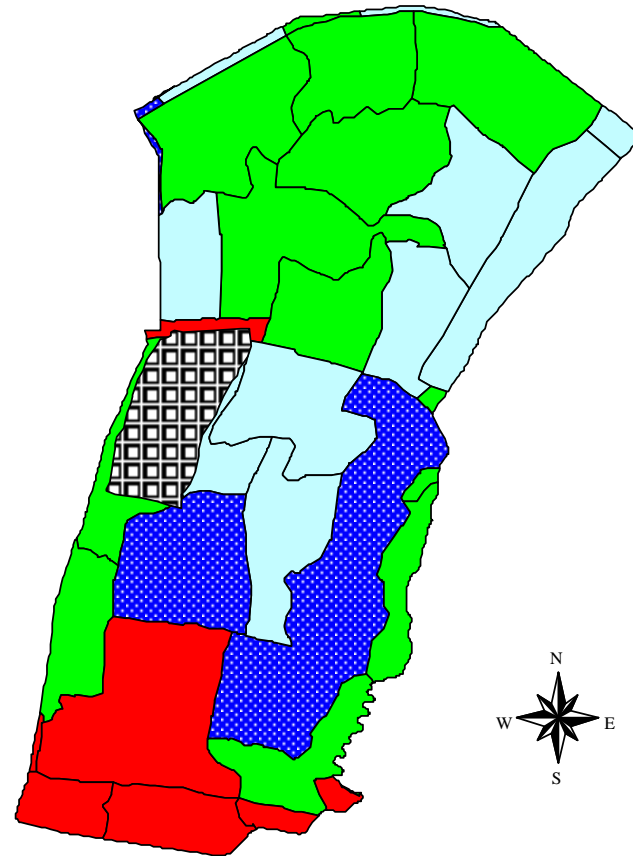
Population density

-  Low (0 - 250 person/sq.km.)
-  Medium (251 - 500 person/sq.km.)
-  High (501 - 750 person/sq.km.)
-  Very high (over 750 person/q.km.)


Percentage area of different categories of population density







Flood vulnerability indicators of population at risk (FVip)



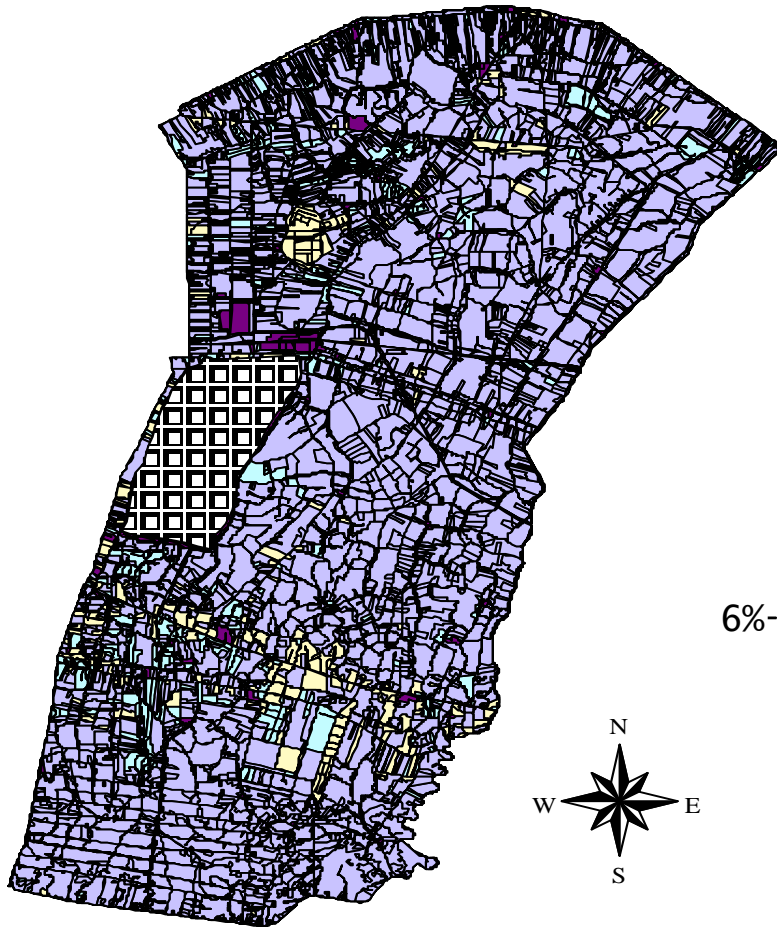
9 0 9 Kilometers

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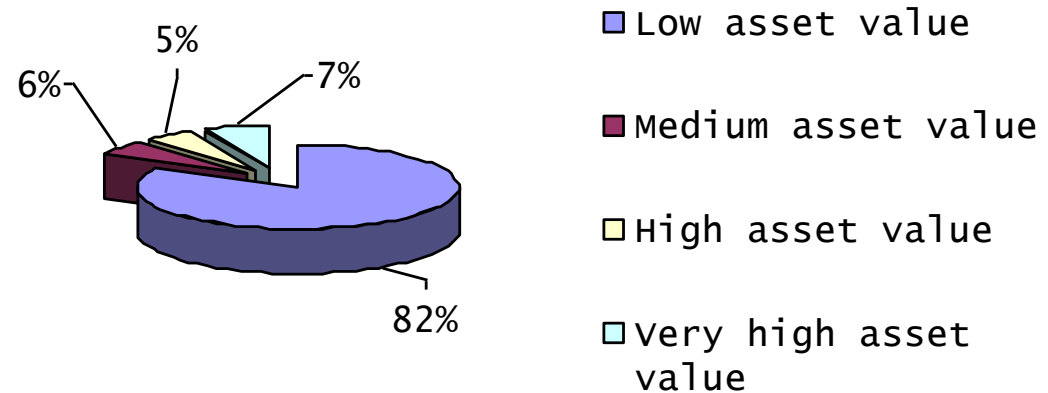
Flood vulnerability indicator of population at risk (FVip)

-  Low
-  Medium
-  High
-  Very high

Classification of asset value per unit area



Percentage area of different categories of asset value per unit area



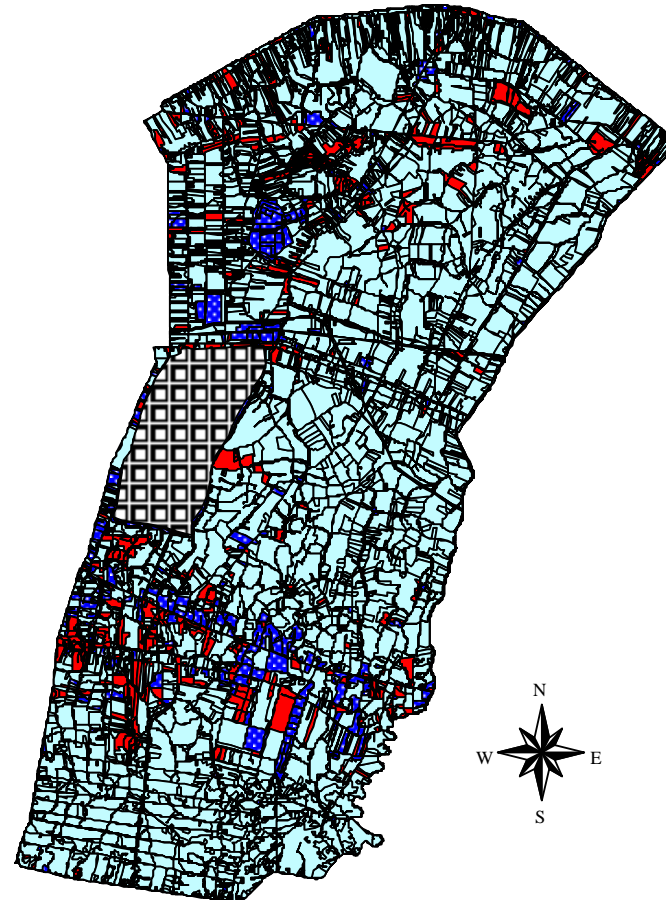
9 0 9 Kilometers

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Average asset value per unit area

- Low (0 - 5,000 Baht/sq.m.)
- Medium (5,001 - 10,000 Baht/sq.m.)
- High (10,001 -15,000 Baht/sq.m.)
- Very high (over 15,000 Baht/sq.m.)

Flood vulnerability indicators of asset at risk (FVIa)



9 0 9 Kilometers

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Flood vulnerability factor of asset at risk (FVFa)

-  Low
-  Medium
-  High
-  Very high

Flood damage vulnerability factor (FVF)

- FVF : the resultant susceptibility of overall elements exposed to flood risk
- $FVF = \theta (FVI_p) + (1-\theta)(FVI_a)$

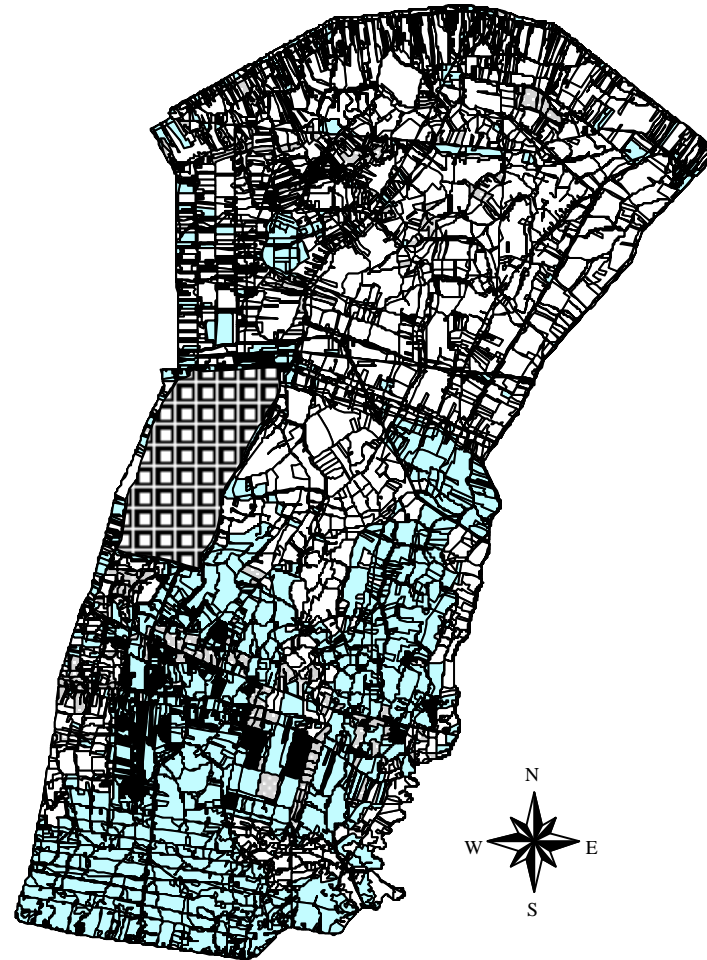
Where $0 \leq \theta \leq 1$

FVI_p = Flood Vulnerability Indicator for Population

FVI_a = Flood Duration Indicator for Asset

- Plot of FVF over the DEM of study area is called flood vulnerability map





Flood damage vulnerability factor (FVF)



9 0 9 Kilometers

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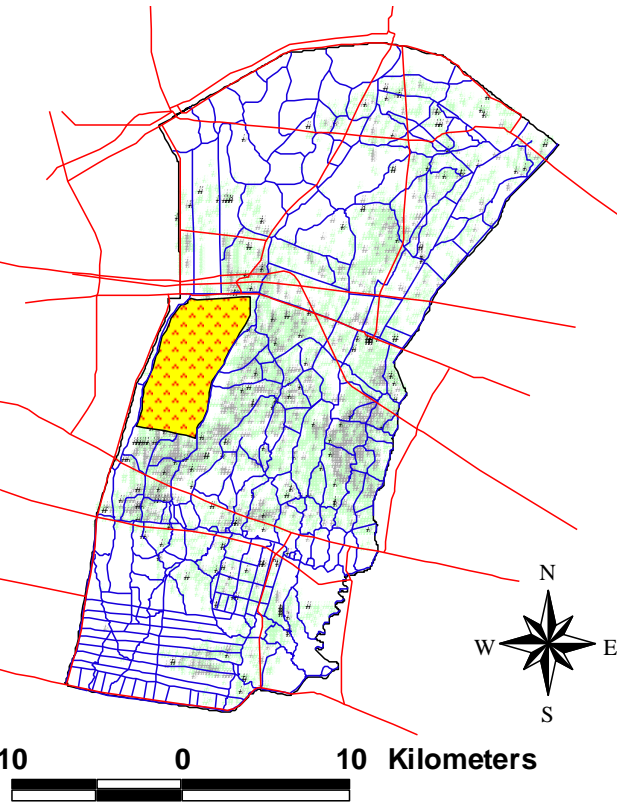
Flood damage vulnerability

-  Low
-  Medium
-  High
-  Very high

Flood risk assessment

- Flood risk : the expected degree of damage that caused by flood to element at risk
- Flood risk = $f(\text{hazard, vulnerability})$
- $\text{FRF} = (\text{FHF}) \times (\text{FVF})$

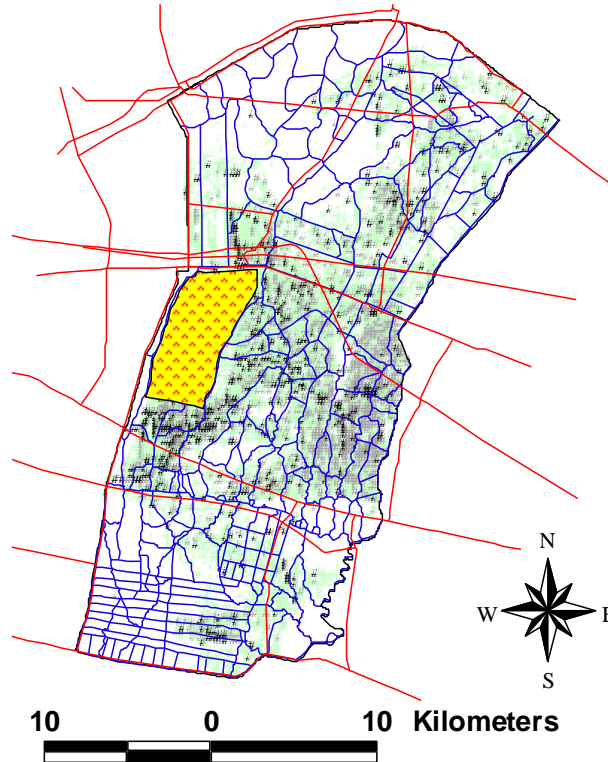
Flood Risk Maps



- Road
- Canal
- Study area
- Suvarnabhumi International Airport

Flood risk (25-year return period)

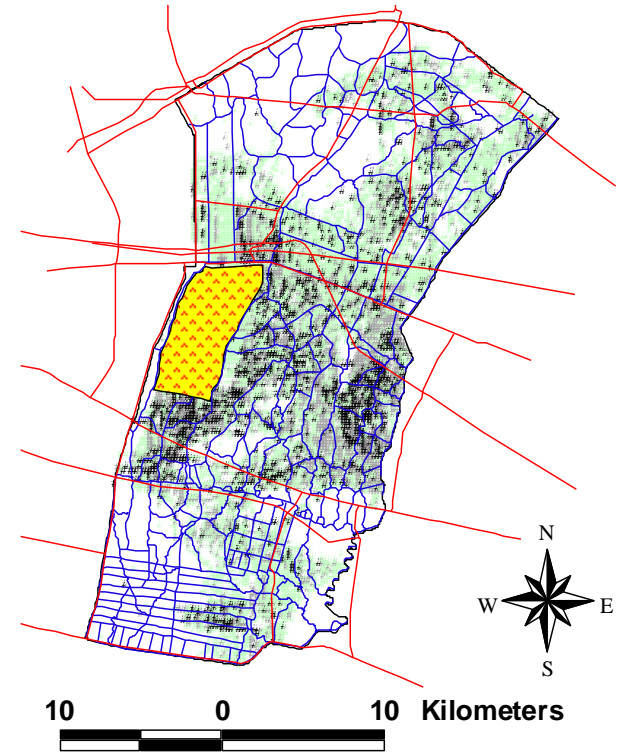
- Low
- Medium
- High
- Very high



- Road
- Canal
- Study area
- Suvarnabhumi International Airport

Flood risk (50-year return period)

- Low
- Medium
- High
- Very high

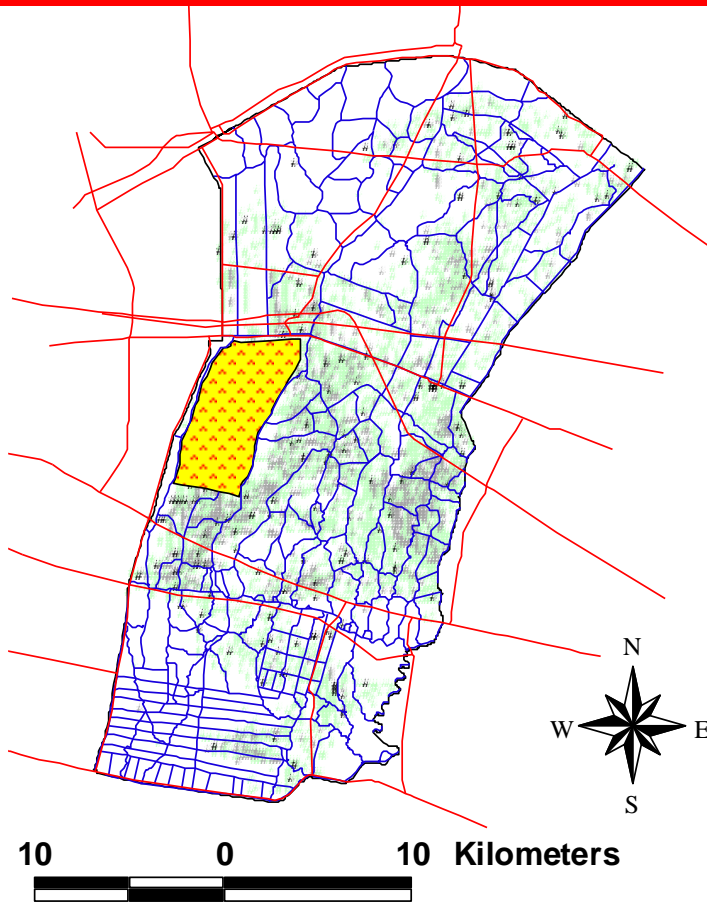


- Road
- Canal
- Study area
- Suvarnabhumi International Airport




Flood risk (100-year return period)

- Low
- Medium
- High
- Very high

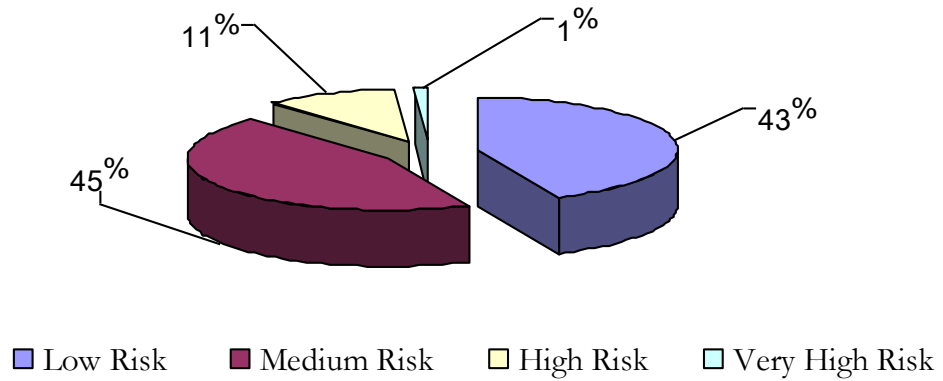
Flood risk map for $T_r = 25$ year



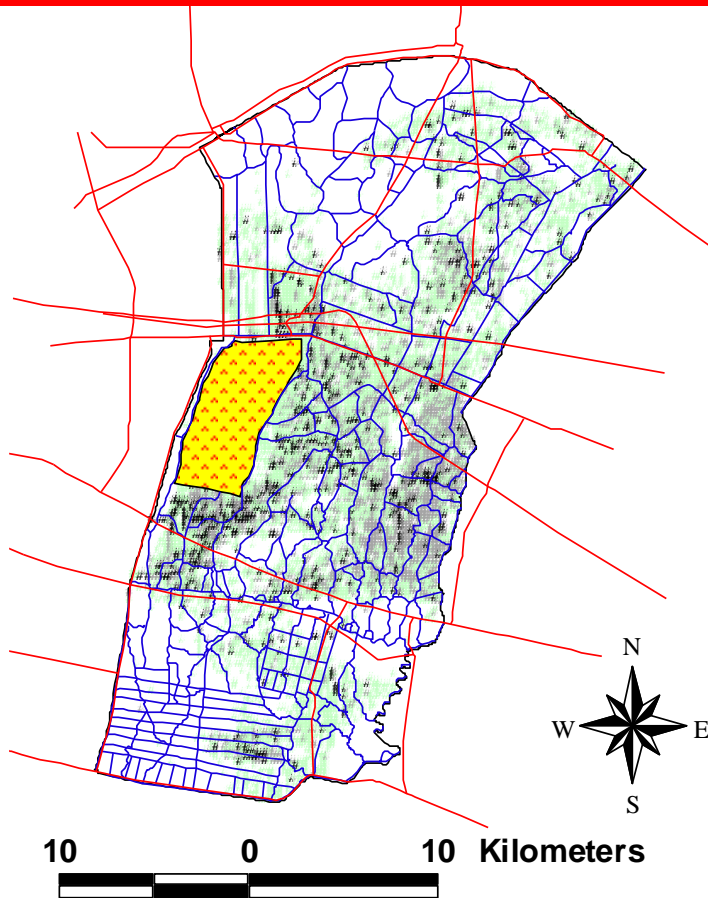
-  Road
-  Canal
-  Study area
-  Suvarnabhumi International Airport

- Flood risk (25-year return period)
- Low
 -  Medium
 -  High
 -  Very high




Percentage area for different degree of flood risk



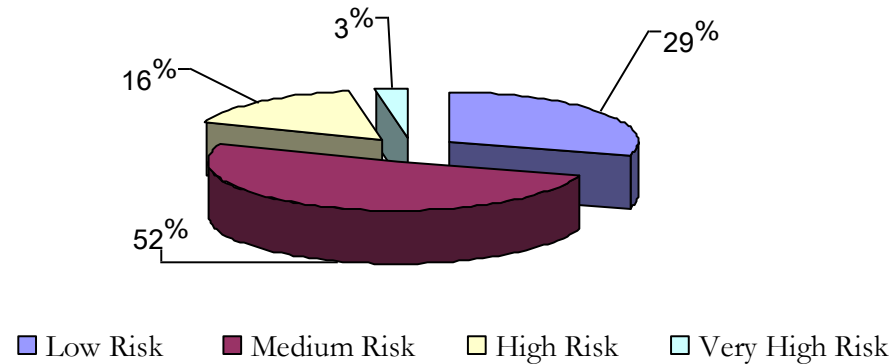
Flood risk map for $T_r = 50$ year



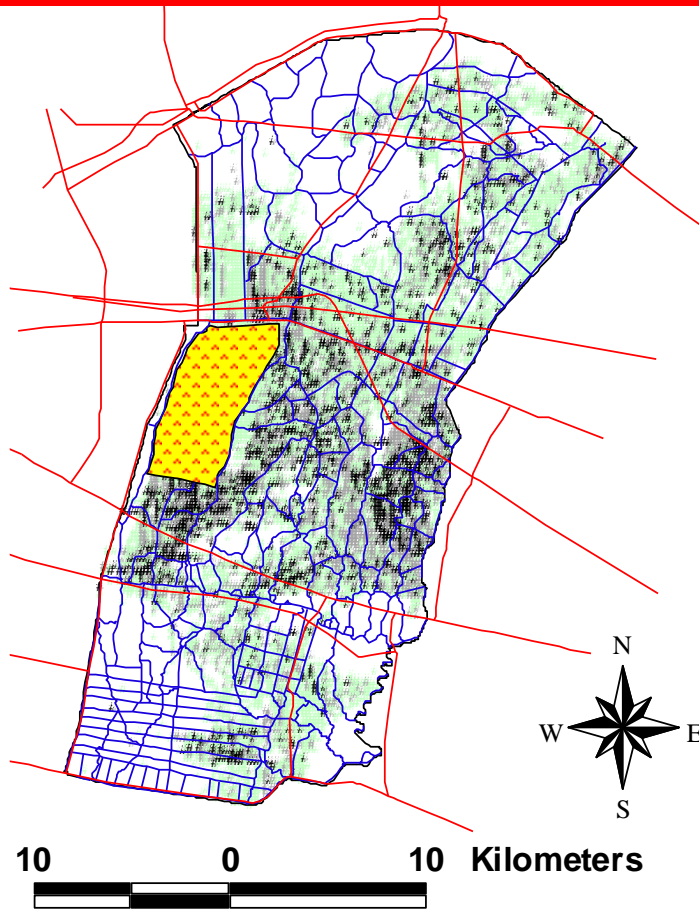
-  Road
-  Canal
-  Study area
-  Suvarnabhumi International Airport

- Flood risk (50-year return period)**
- Low
 -  Medium
 -  High
 -  Very high

Percentage area for different degree of flood risk






Flood risk map for $T_r = 100$ year



-  Road
-  Canal
-  Study area
-  Suvarnabhumi International Airport

Flood risk (100-year return period)

- Low
-  Medium
-  High
-  Very high

Total Risk Calculation

Location ID	Location Name	Normalized Hazard Index (HI)	Vulnerability Index (VI)			Total Risk	
			Population density and asset value (Regional scale)	Socio-economy (SeVI) Household scale)	Avg. VI	HI x Avg. VI	Normalized Risk Index
1	A	100	38.46	51.44	44.95	4,495	58.32
2	B	100	100	54.15	77.07	7,707	100
3	C	66.67	15.38	47.91	31.64	2,109.4	27.37
4	D	100	53.85	52.93	53.39	5,339	74.86

RISK

CONCLUSIONS

- ❑ Due to the presence of the airport and rapid urbanization, flood risk in the area surrounding the SBIA increases.
- ❑ This study presents flood risk-based zoning maps for 25-, 50- and 100-year return periods in the area surrounding SBIA
- ❑ Because of high cost of investment, one cannot afford to prevent all levels of flooding or protecting all risk areas simultaneously.
- ❑ Planning for flood risk mitigation plan will make use of the flood risk maps for scheduling the implementation in accordance to available budget and needs of the considered area.

CONCLUSIONS (CONTINUED)

- ❑ **The finding provided useful information about the flood risk zones which can be very useful to concerned authorities in prioritizing projects for flood mitigation**
- ❑ **The residents in the floodplain can use the information for self-preparedness to minimize flood damage.**
- ❑ **The changing of land use without planning causes adverse effect to flood risk situation**

CONCLUSIONS (CONTINUED)

- ❑ It can be concluded that the flood risk depends on the degree of flood hazard and flood damage vulnerability.
- ❑ **Flood hazard = f(depth, duration, etc)**
- ❑ **Flood damage vulnerability = f(population, asset exposed to flood risk)**
- ❑ **Flood Risk= flood hazard x flood damage vulnerability**
- ❑ **Flood risk changes with the return period and condition of land use**
- ❑ **Flood risk should be re-estimated if effect of climate change and land use are significant.**

It is necessary to note that :

- ❑ Water needs space, once the areas have been protected from flooding, it will automatically exacerbate the flood problem in another area
- ❑ To overcome this hindrance, systematically basin-wide planning based on flood risk map is necessary to develop an effective flood risk management strategy.

Thank you