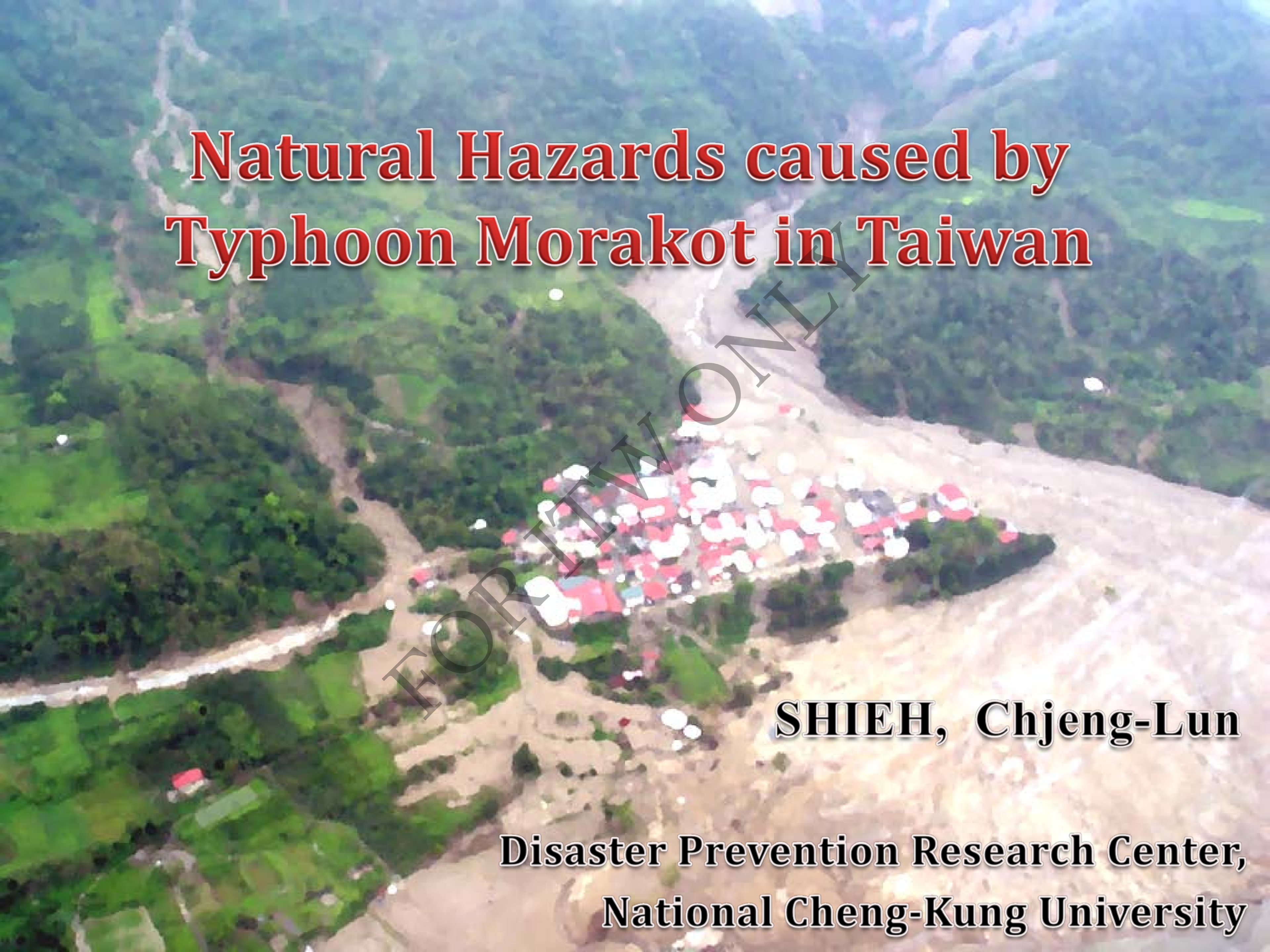


Natural Hazards caused by Typhoon Morakot in Taiwan

SHIEH, Chjeng-Lun

Disaster Prevention Research Center,
National Cheng-Kung University

Presentation Frame

1. Natural Hazards in Asia
2. Typhoon Morakot
3. Disasters of Typhoon Morakot
4. Disasters Characteristics
5. Compound Disasters
6. Face the Challenge
7. Renovation strategy
8. Time scale consideration
9. Importance Evaluation of Villages
10. Simulation Model
11. Conclusions

1. Natural Hazards in Asia

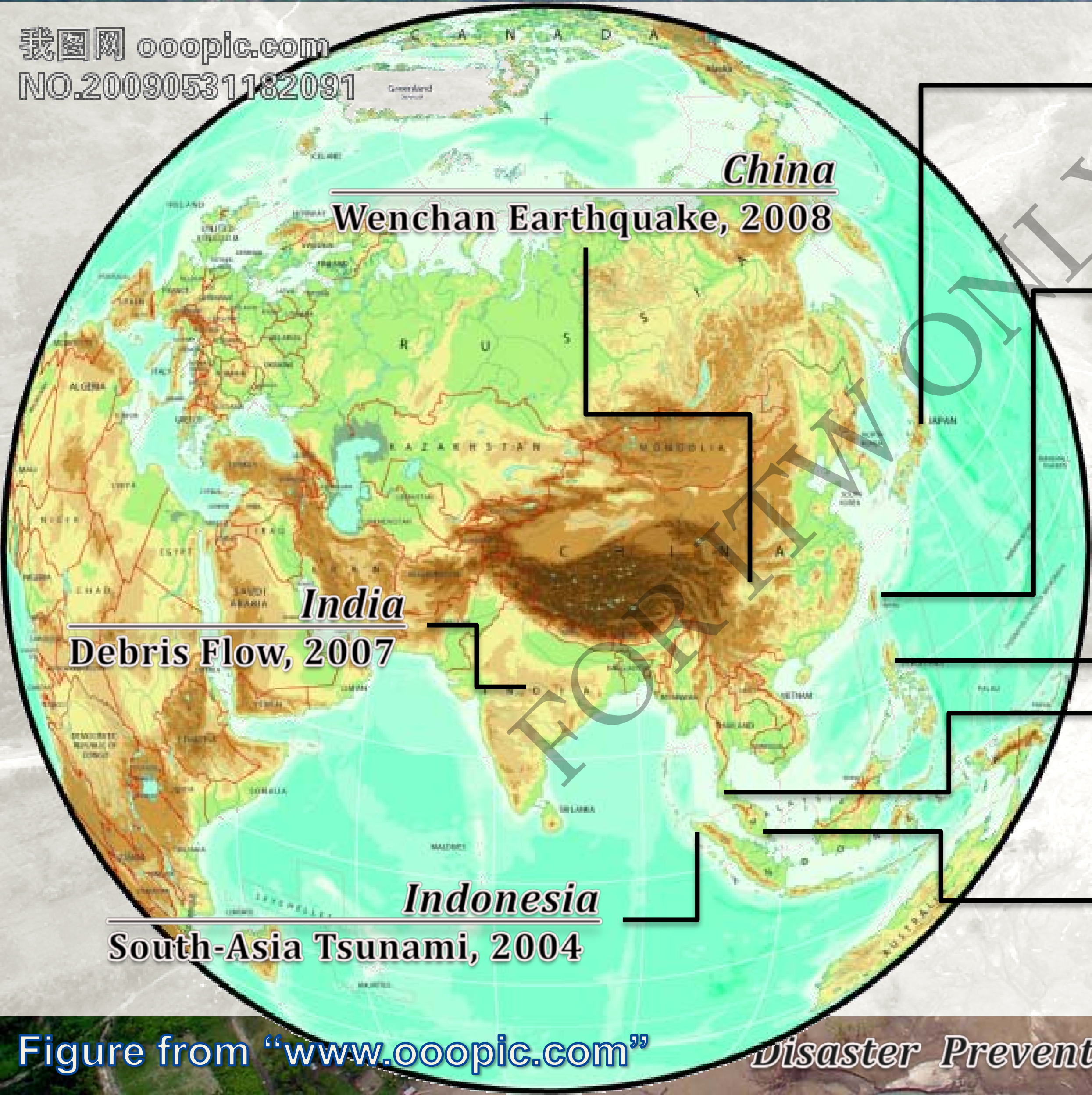


Figure from "www.ooopic.com"

Storm Flooding in Philippines, 2009

Tsunami in Malaysia, 2004

Pictures from Associated Press

Tsunami in Thailand, 2004

Pictures from Associated Press

Earthquake in China, 2008

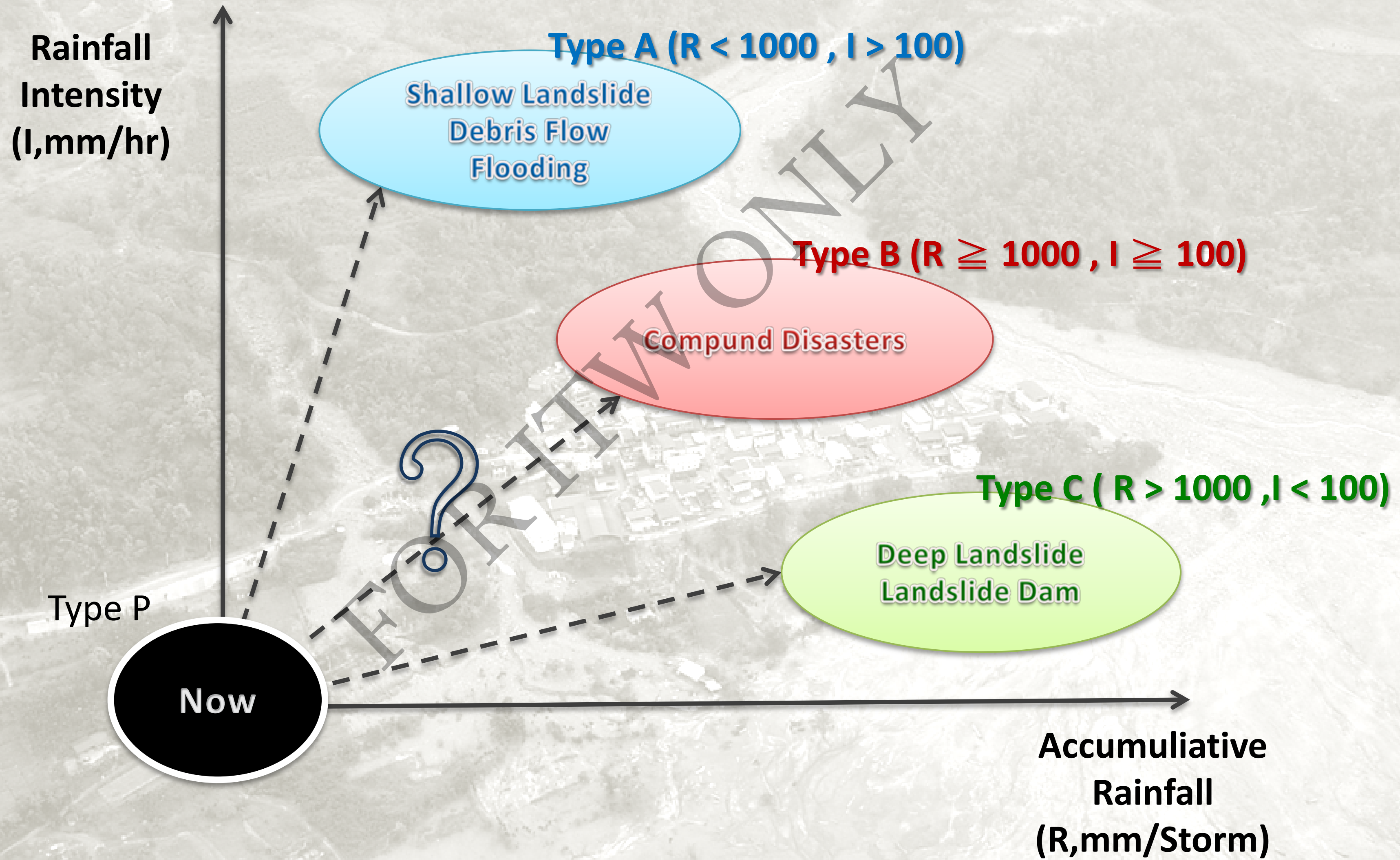
Pictures from 新華社、中科院山地災害與環境研究所

In the Future?

- **Global climate prediction by IPCC (2007)**
  - **Catastrophic heavy rainfall > 90%**
  - **Extreme Drought > 66%**
  - **Extreme weather events will appear frequently and broadly in future years**
    - **Heat wave**
    - **Drought**
    - **Heavy storm**
    - **Typhoon**

Hurricane Katrina *(data from wiki)*

Rainfall Change & Related Disasters

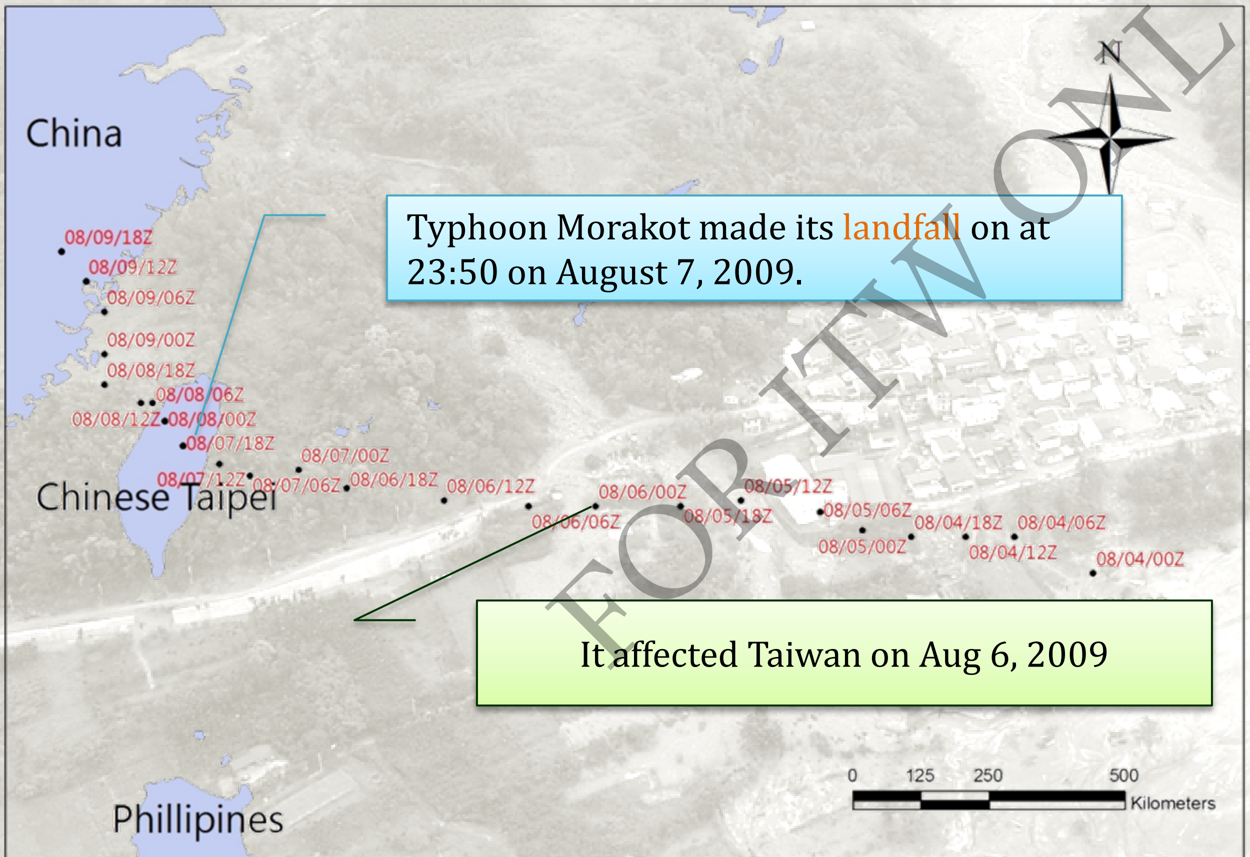


Catastrophic Strom in Taiwan

- During 1991 ~ 2000
  - Averagely **3.3** typhoons stroke Taiwan in one year (Tsuang et al.,1996)
- After 2000
  - It increased from **3.3** to **5.7** typhoons in one year (Tu et al.,2009)

2. Typhoon Morakot

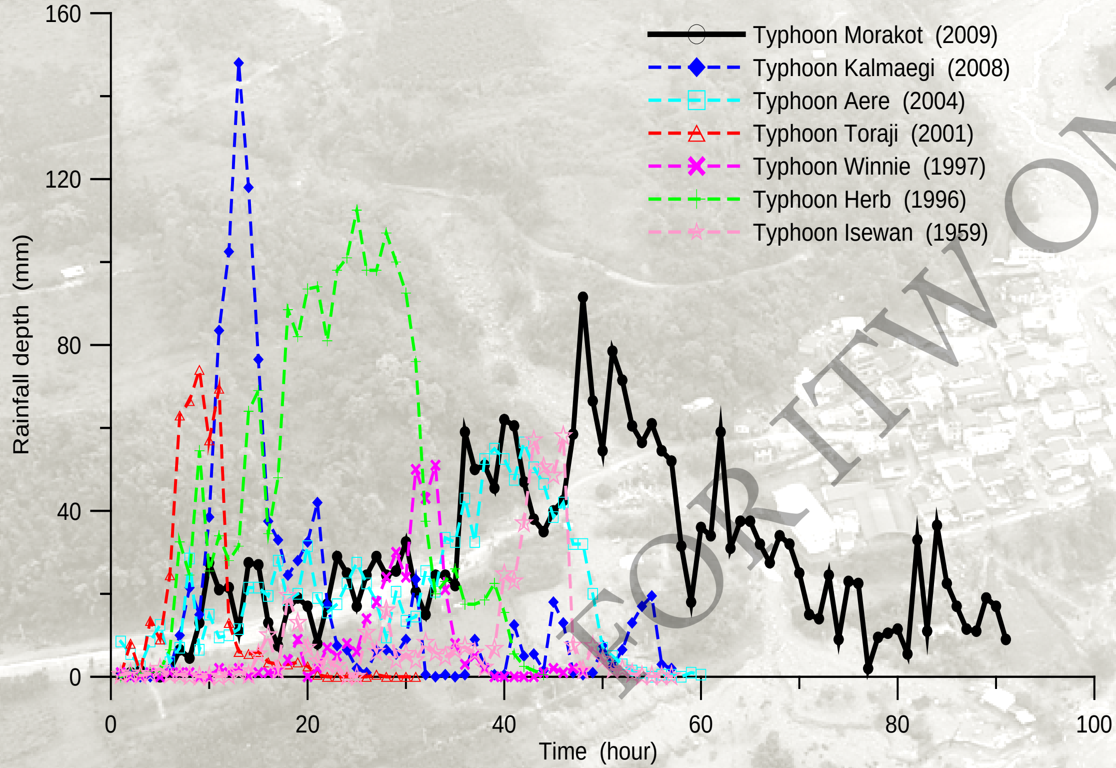
Path of the center of Typhoon Morakot



- On August 2, 2009 a tropical depression formed on the sea, northwest to Philippines.
- It strengthened gradually into a tropic storm and was gave a name, Morakot.
- The storm turned into a typhoon on August 5.
- It started raining on Aug 6, 2009 in Taiwan.
- The eye of the typhoon left Taiwan from Taoyuan at 14:00 on August 8, 2009.

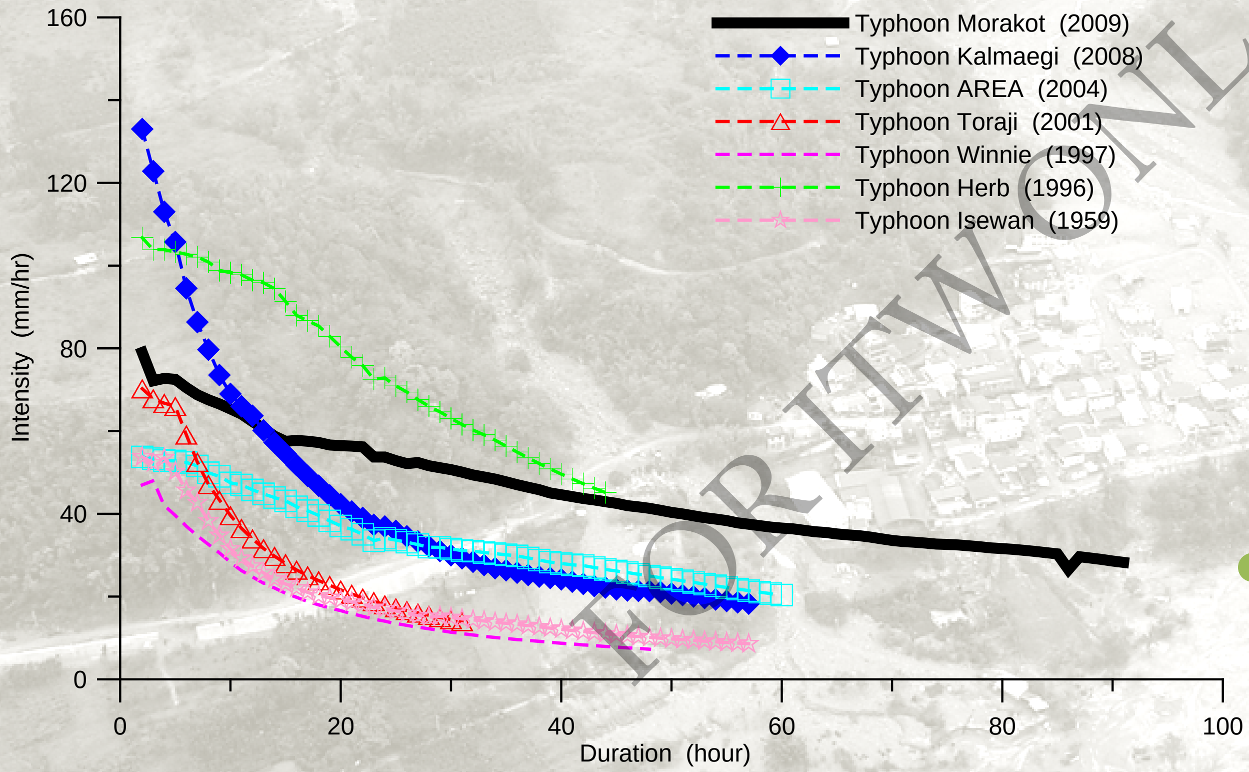
The track data is from the UniSys Weather (2009).
http://weather.unisys.com/hurricane/w_pacific/2009/MORAKOT/track.dat

Rainfall Characteristics ~ Long duration



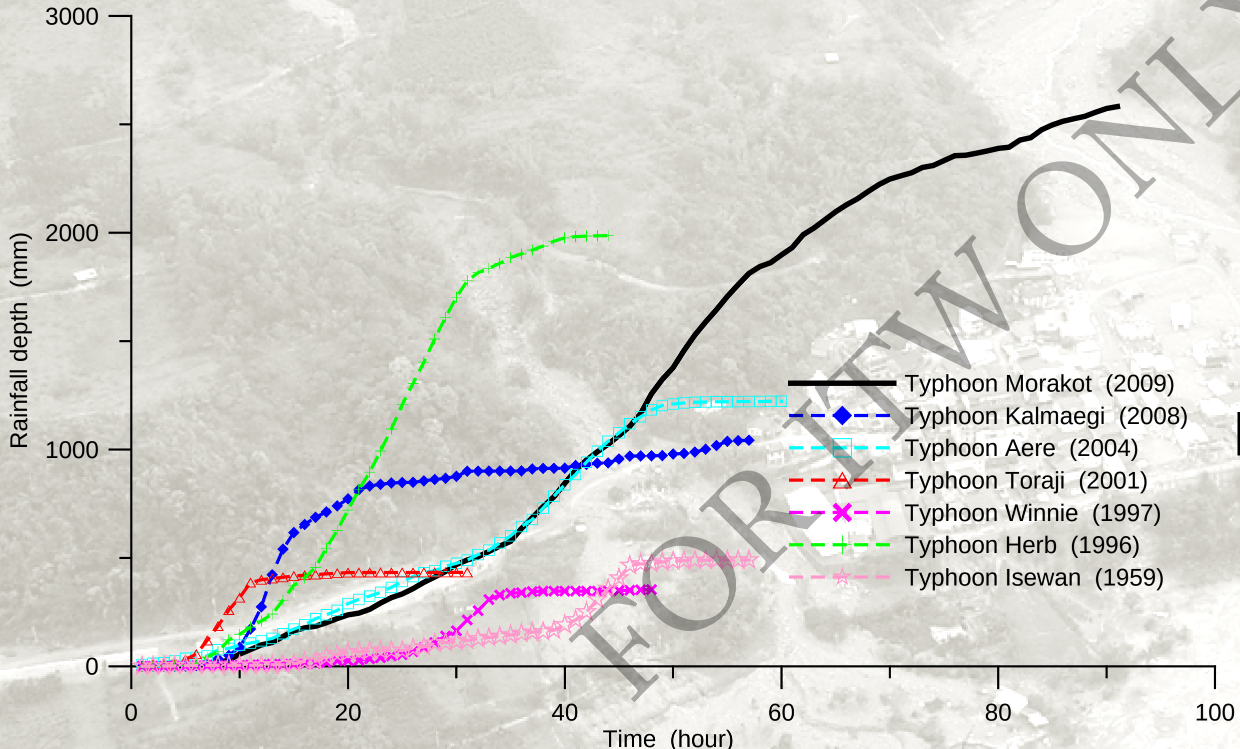
- At the rain gauge Yuyushan, the record shows that it rained continuously from August 6, 2009 to August 10, 2009.
- The duration is 91 hours.

Rainfall Characteristics ~ High intensity



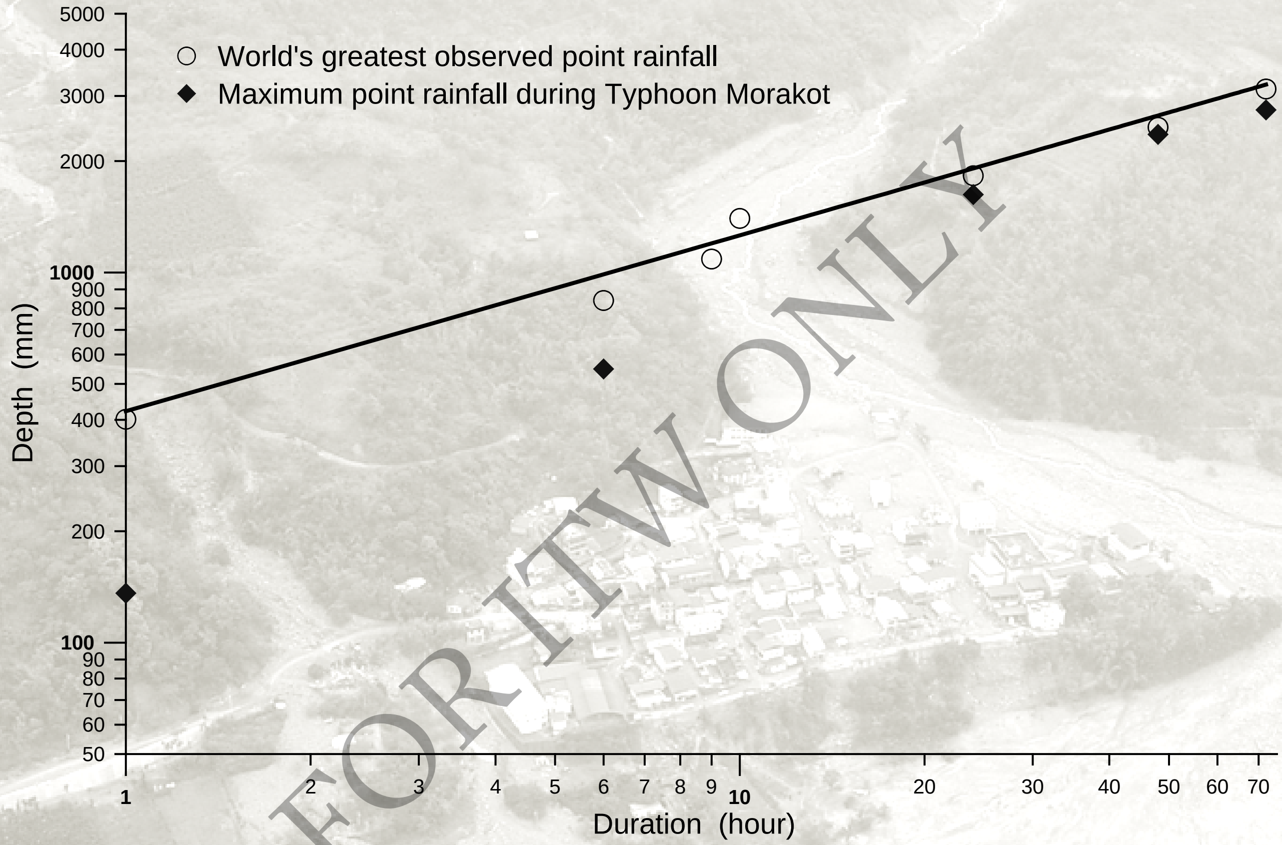
- The comparison reveals that the rainfall intensity of Typhoon Morakot remained high for **91** hours.
- The maximum intensity was 123 mm/hour at Alishan.

Rainfall Characteristics ~ Large Accumulated Depth



- The accumulated rainfall depth of Typhoon Morakot is far larger than that of others.
- The largest accumulated rainfall depth was observed 3,079 mm at Alishan.

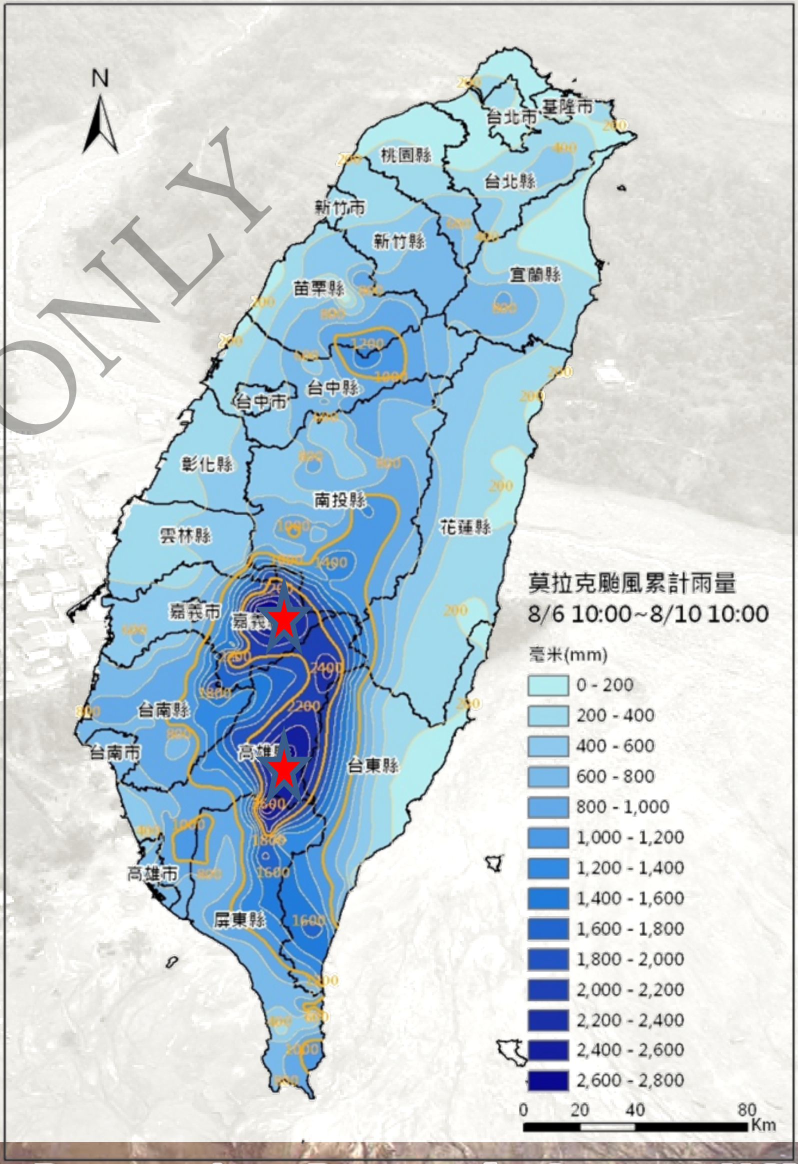
Accumulated rainfall depth



- Rainfall data is compared with the world's greatest observed point rainfalls (WMO, 1994).
- Cumulative rainfall depths for 24-hour, 48-hour and 72-hour are close the world's greatest observed point rainfalls.

Rainfall Characteristics ~ Broad extent

- Most of Taiwan was covered under the heavy rainfall.
- Two storm centers can be found in the Isohyet.
- The values of accumulated rainfall depth at these two points reached 3,000 mm.
- One-fifth of Taiwan was covered.



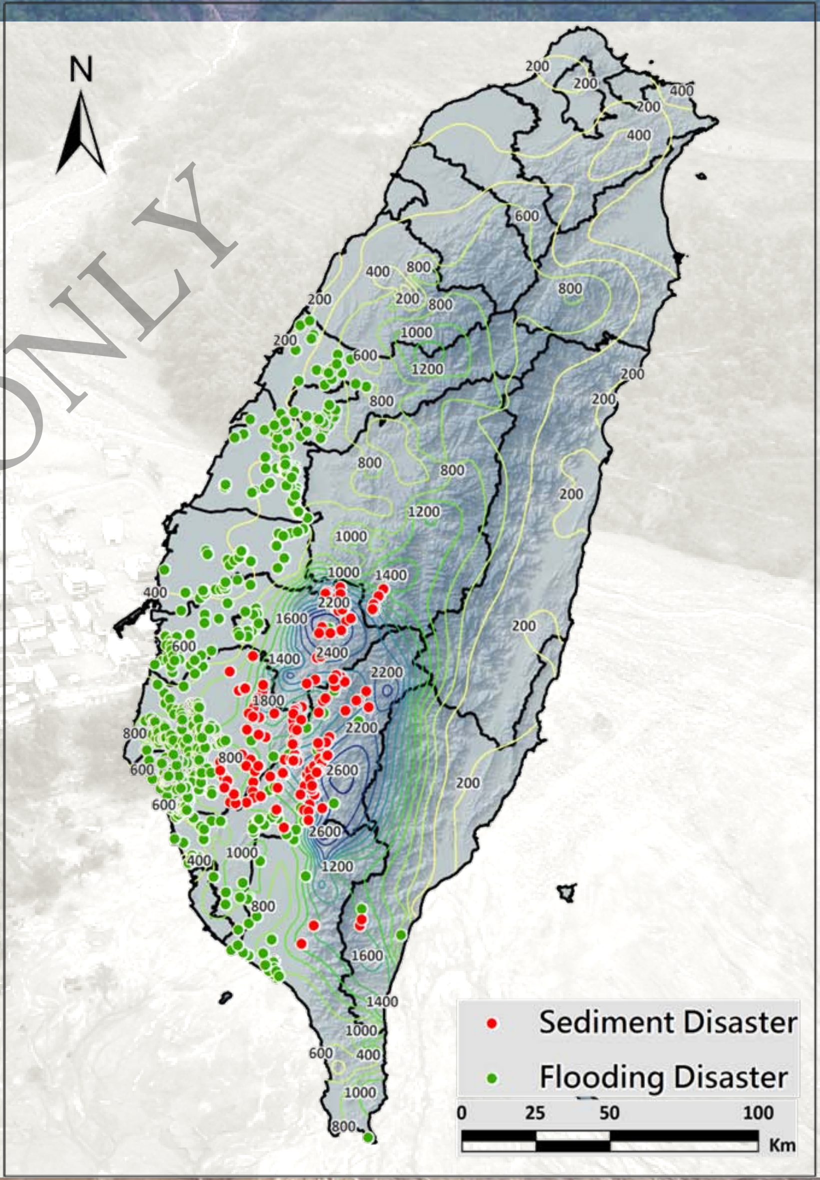
Summary of Rainfall Characteristics

- **Long duration** **(91 hours)**
- **High intensity** **(123 mm/hour)**
- **Large accumulated rainfall depth** **(3,000 mm-72 hour)**
- **Broad extent** **(1/5 of Taiwan was covered)**

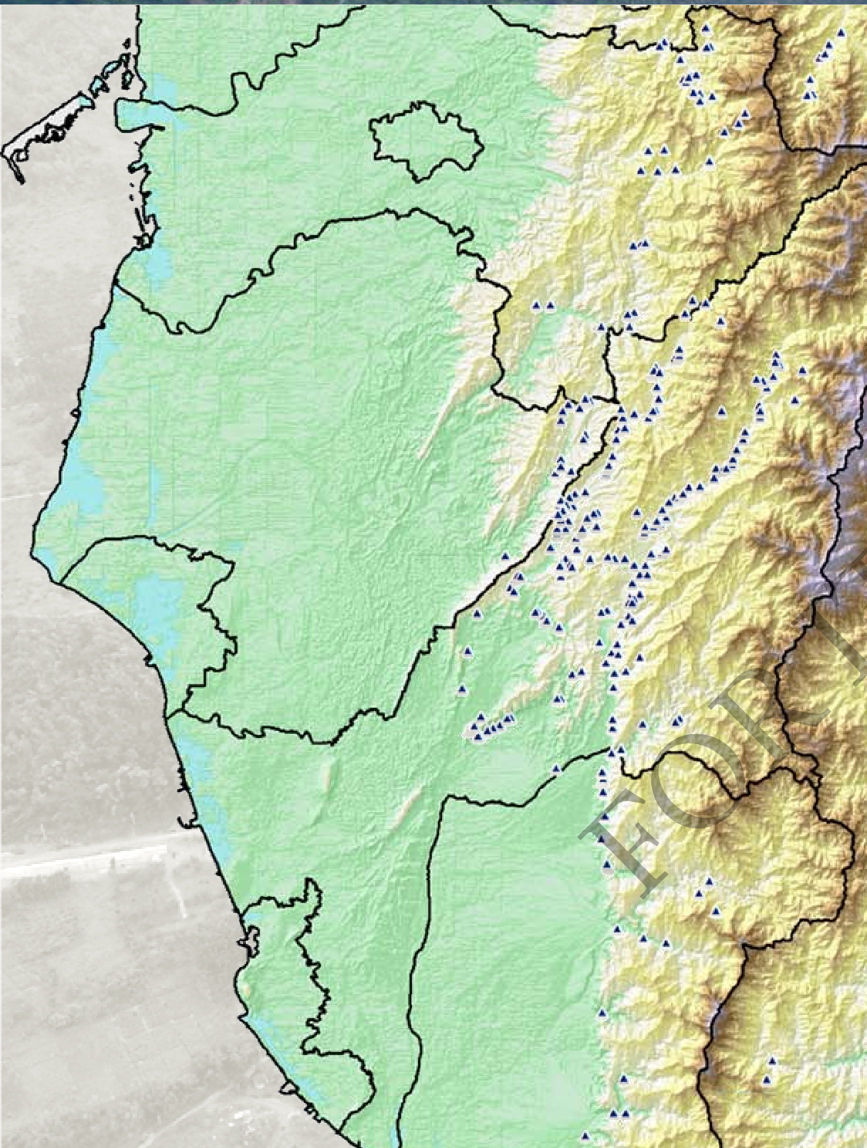
3. Disasters of Typhoon Morakot

3.1 Spatial Distribution of Hazard locations

1. Geo-hazards in the mountains located within the **range of precipitation > *1,000mm***
2. **Precipitation > 2,000mm** : the most serious area
3. Most floods located at **the downstream of rainfall center** (Chiayi, Tainan, Kaoshiung & Pingdong Counties)



3.2 Disasters in Mountainous Area

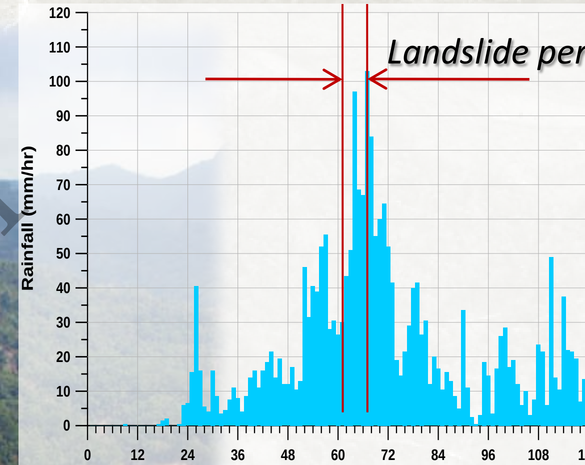


1. ***Landslide***
   ① Rapidly, Directly strike the villages
   ② Breakage of the lifeline
   ③ Provide the sediments for triggering subsequent movement
   ④ Natural Dam
2. ***Debris Flow***
   ① Strike the villages
   ② Breakage of the lifeline
3. ***Natural Dam (& Breach)***
   ① High-concentration flow (debris flow)
   ② Flood in the downstream

3.2 Disasters in Mountainous Area (Landslide)

Example for Shinkai (新開) Village

32 killed at this area



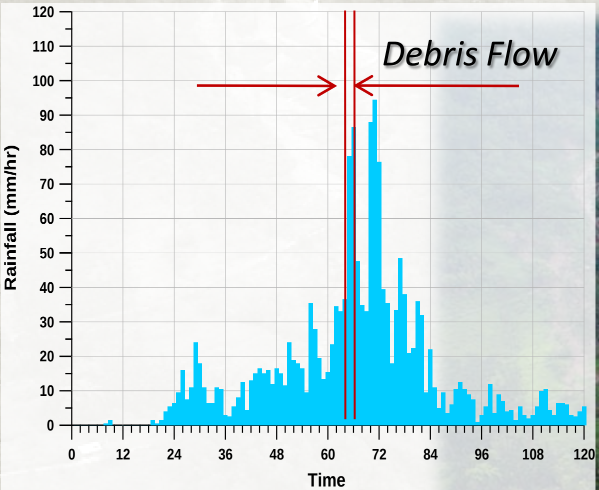
I = 98 mm/hr
R = 2342 mm
新發雨量站

3.2 Disasters in Mountainous Area (Landslide Area)

	Before Morakot		After Morakot			
Basin	Count	Area (ha)	Count	Area (ha)	New Counts	Enlarged Area
曾文溪	607	820	2,576	3,868	1,969	3,048
八掌溪	26	65	71	123	45	58
高屏溪	3,335	3,993	14,765	22,667	11,430	18,674
荖濃溪	*1,853*	*2,464*	*7,864*	*11,075*	*6,011*	*8,611*
旗山溪	*641*	*638*	*3,406*	*6,021*	*2,765*	*5,383*
隘寮溪	*841*	*891*	*3,495*	*5,571*	*2,654*	*4,680*
台東沿海	853	1,064	5,480	9,136	4,627	8,073
林邊溪	167	218	415	1,853	248	1,635
濁水溪	3,717	5,652	10,579	13,657	6,862	8,005
Total	8705	11812.18	33886	51304	25,181	36,387

1. Data collect from Forestry Bureau, Central Geological Survey & DPRC*
2. The results were just for urgent relieving disaster & needed advanced check*

3.2 Disasters in Mountainous Area (Debris Flow)



I = 88 mm/hr
R = 2074 mm
甲仙雨量站

3.2 Disasters in Mountainous Area (Debris Flow)

南沙魯 (民族村)
土石流

3.2 Disasters in Mountainous Area （Debris Flow）

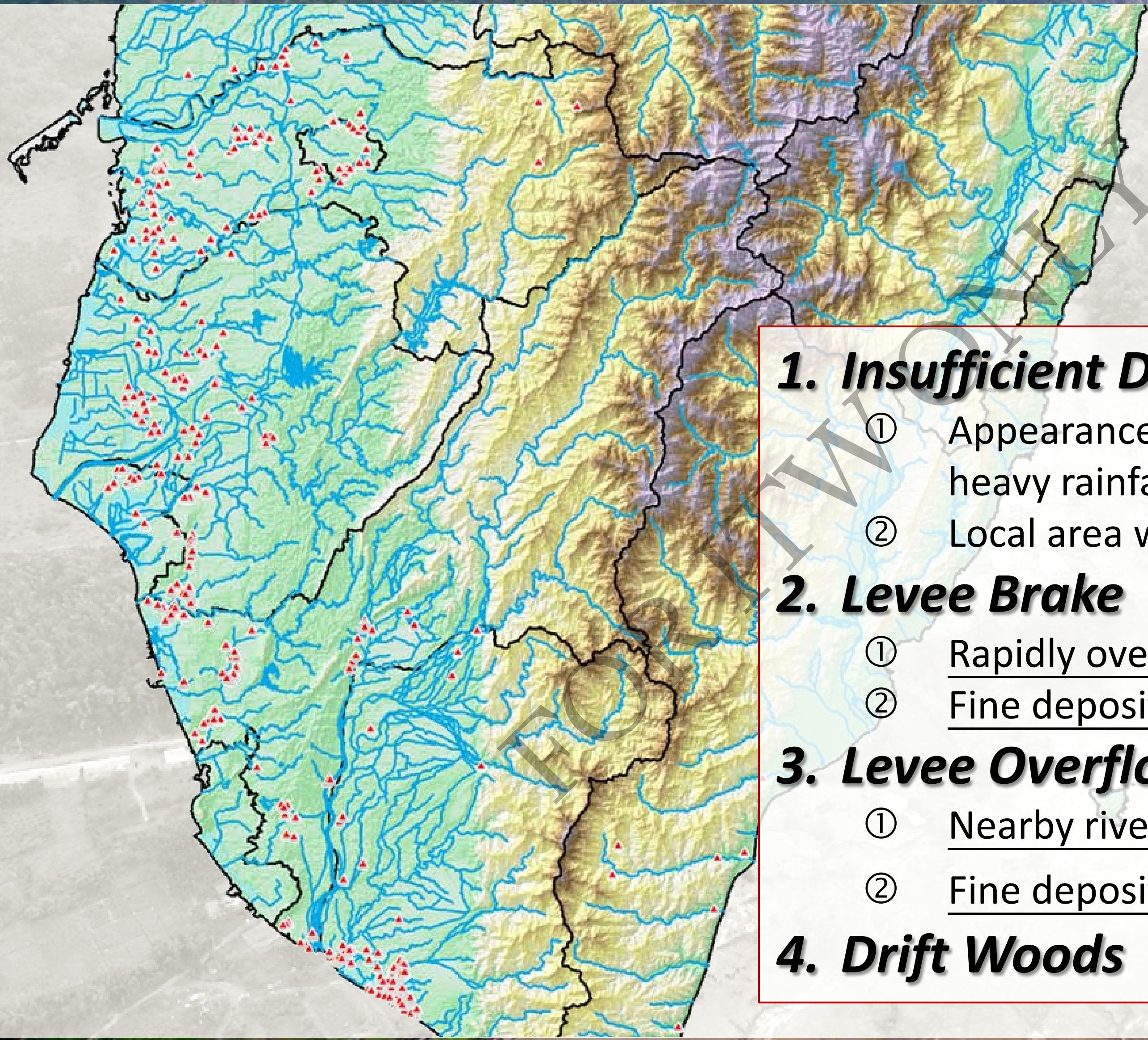
3.2 Disasters in Mountainous Area (Landslide Dam)

3.2 Disasters in Mountainous Area (Landslide Dam)

民生村那瑪夏堰塞湖

太麻里包盛社堰塞湖

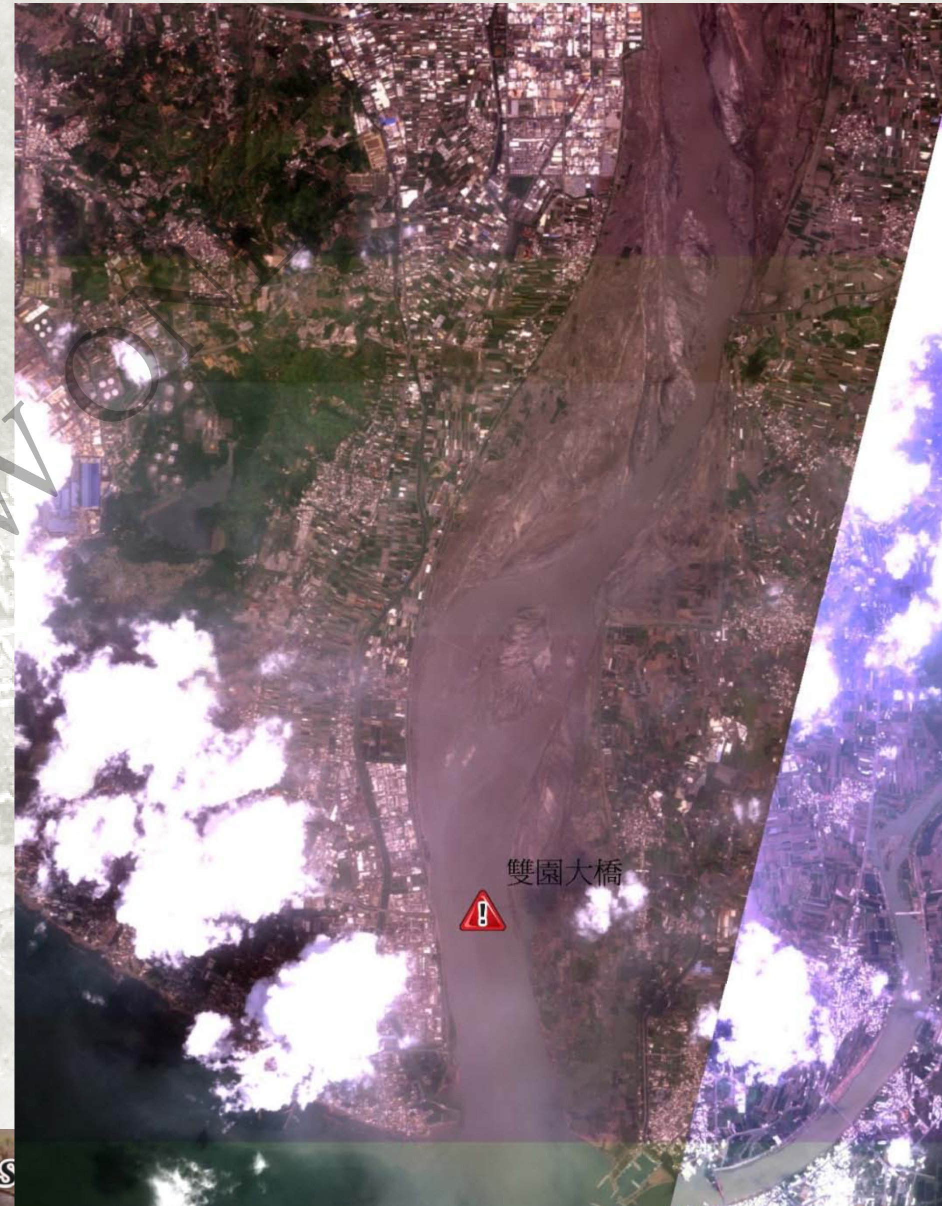
3.3 Disasters in Plain Area



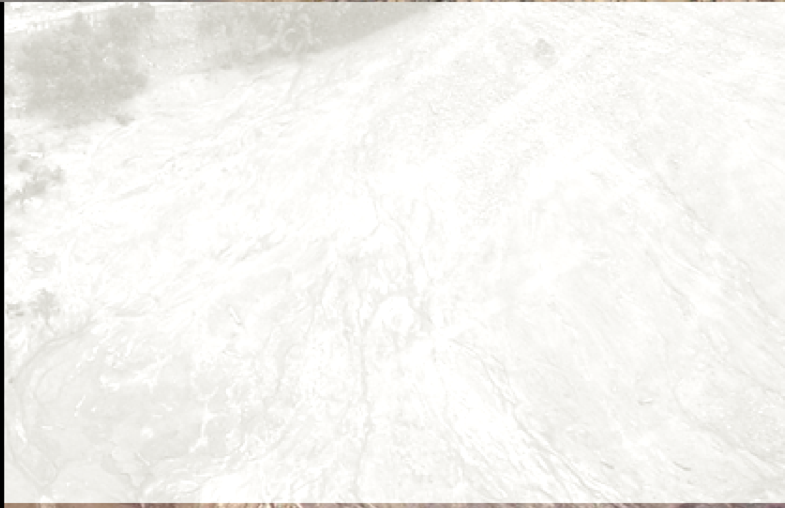
1. ***Insufficient Drainage System***
   - ① Appearance at most locations due to heavy rainfall
   - ② Local area with small scale
2. ***Levee Brake***
   - ① Rapidly over bigger living area
   - ② Fine deposits
3. ***Levee Overflow***
   - ① Nearby river area
   - ② Fine deposits
4. ***Drift Woods***

3.3 Disasters in Plain Area （ Bridge Break ）

- 雙園大橋(Swan-Uen Bridge)
- 高屏溪(Kaoping River)
- Break Length 459m
- 6 persons missing (at least)



3.3 Disasters in Plain Area (Levee Breach)



3.3 Disasters in Plain Area （Inundation）

3.4 Damages

County		Death Confirmed	Not Confirmed	Missing	Total
Major Hazard Area	屏東縣	28	6	14	48
	高雄縣	491	66	38	595
	臺南縣	25			25
	嘉義縣	17	1	2	20
	臺東縣			7	7
	南投縣	11		5	16
	Total	572	73	66	711
The Other Area	高雄市	10		2	12
	臺北縣	9	1	1	11
	基隆市			1	1
	臺中市	2		1	3
	臺南市	6		4	10
	苗栗縣	1			1
	臺中縣	7			7
	彰化縣	6			6
	雲林縣	3			3
	連江縣	1			1
	新竹縣	1		1	2
	臺北市	1			1
	Total	47	1	10	58
Total		619	74	76	769

4. Disaster Characteristics

- Disasters spread over a very large region (Over 5,000 km^2)
- Large amount of sediment yield and movement (1.2 billion m^3)
- Disasters were **compounded**
- **Secondary disasters** will easily and continuously occur in the future (10 to 20 years)
- Such kind of disasters need a new **Methodology to Make Renovation Strategy**

5. Compound Disaster (Xiaolin Village)

Before Typhoon Morakot
(2008/11)

5. Compound Disaster (Xiaolin Village)

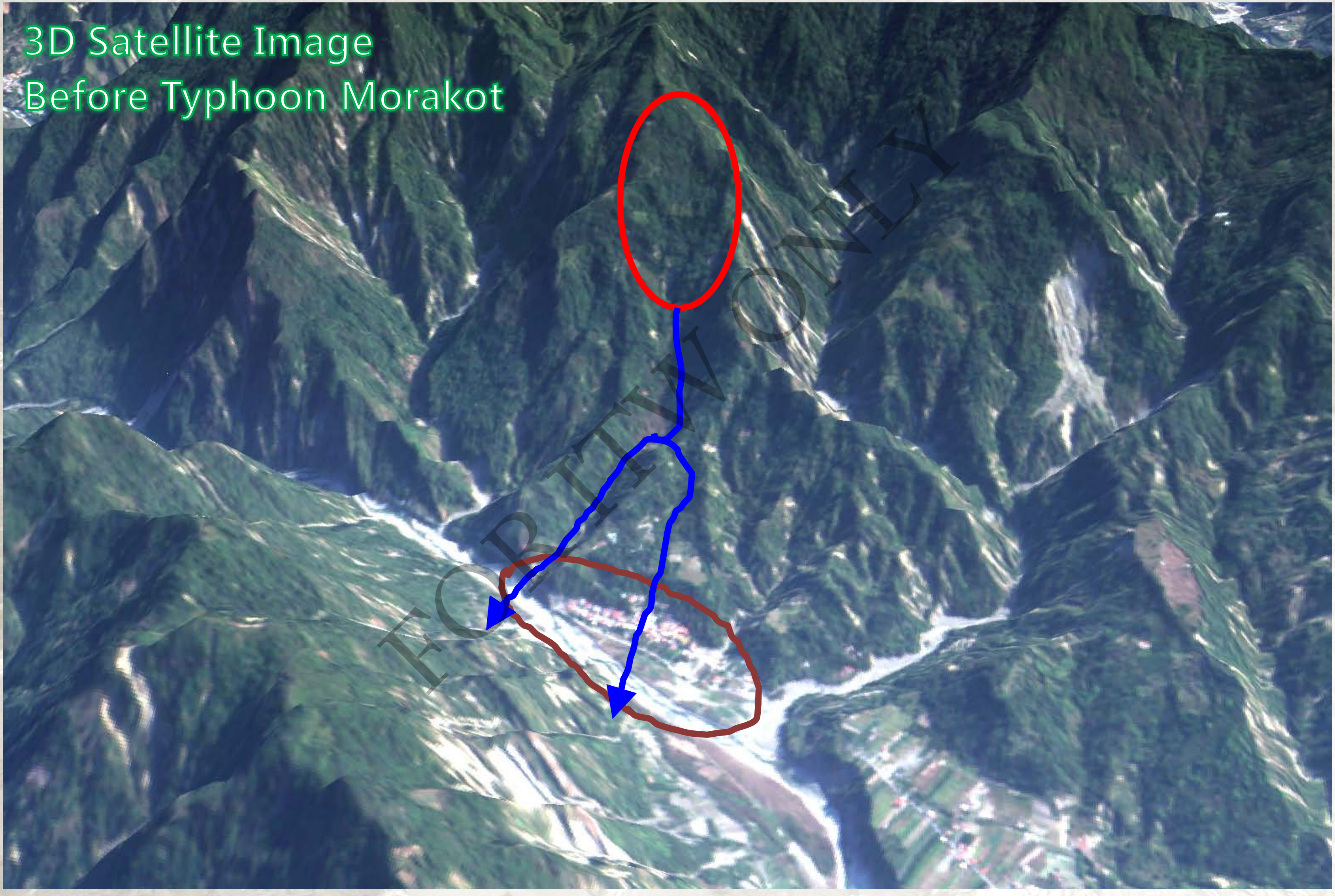
After Typhoon Morakot (2009/08)

5. Compound Disaster (Comparison)

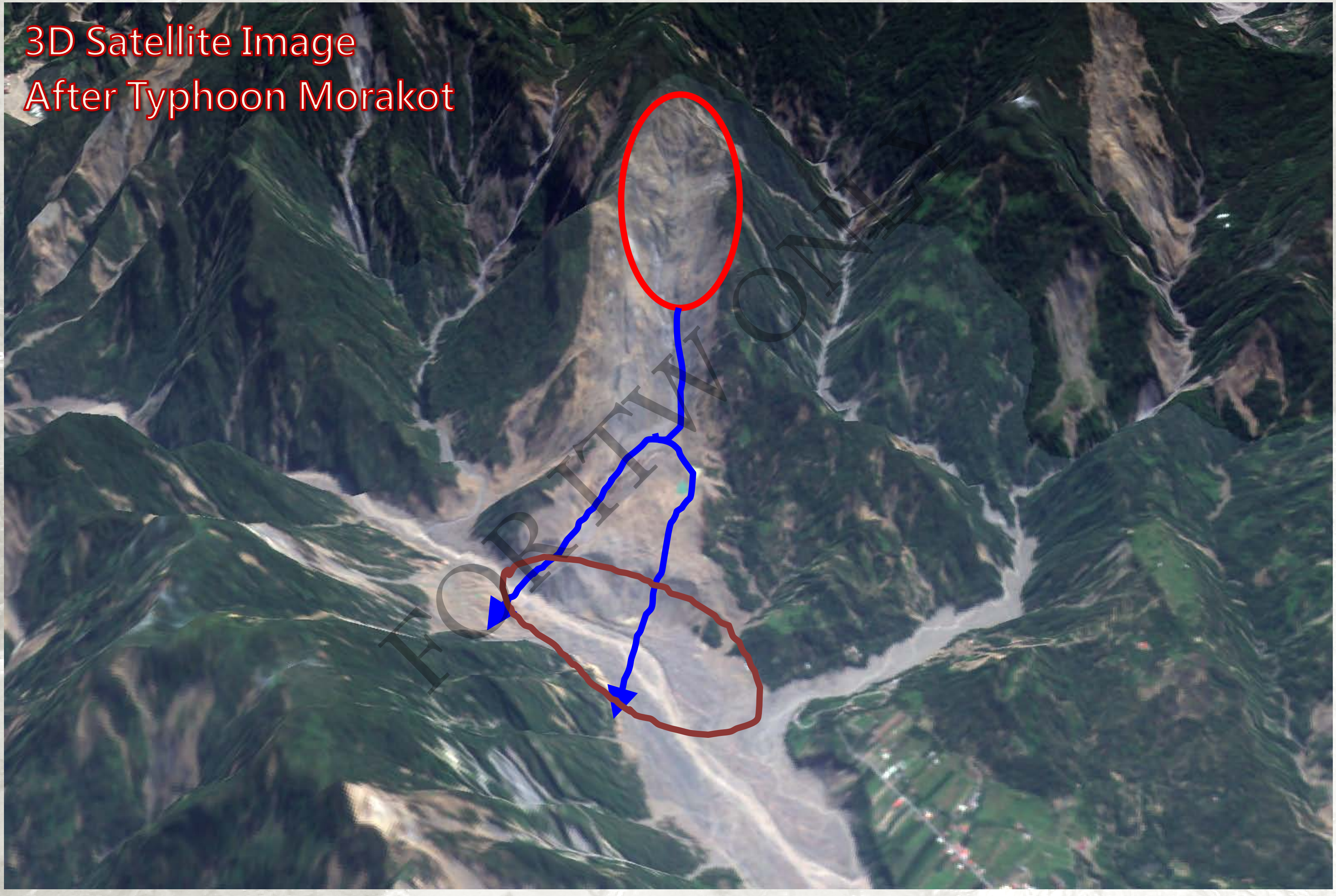
More than 400 people in xiaolin village were killed

The only remaining building in Siaolin village after the landslide

5. Compound Disaster (Xiaolin Village)

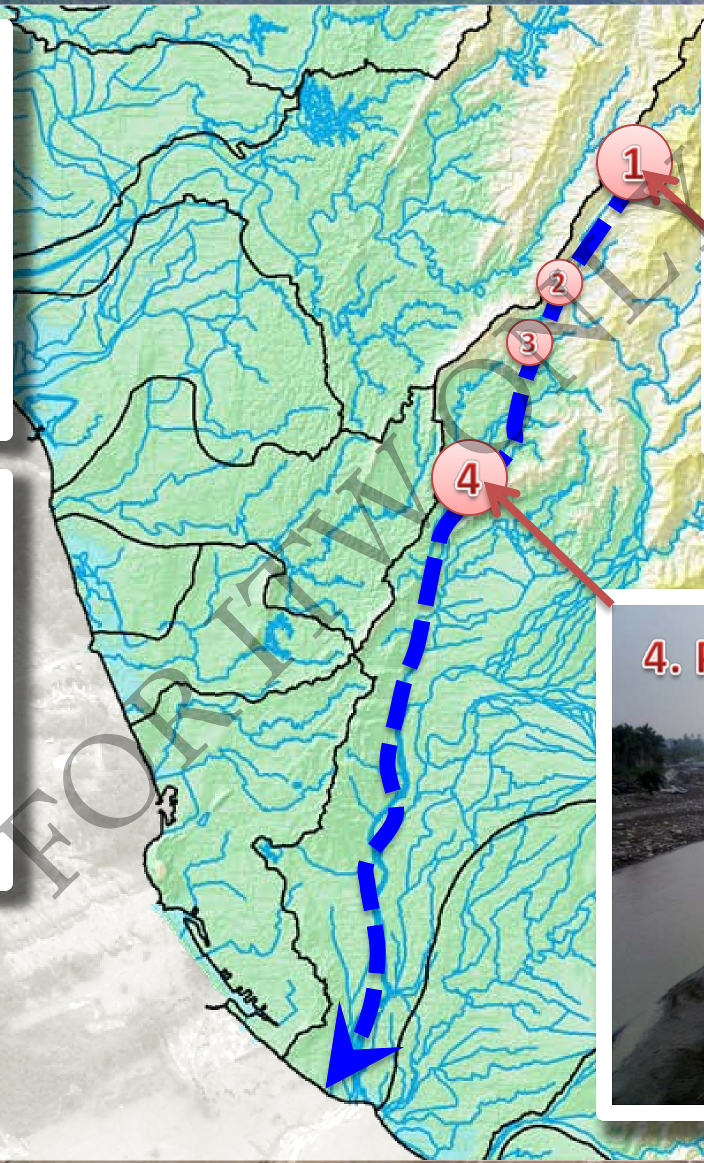


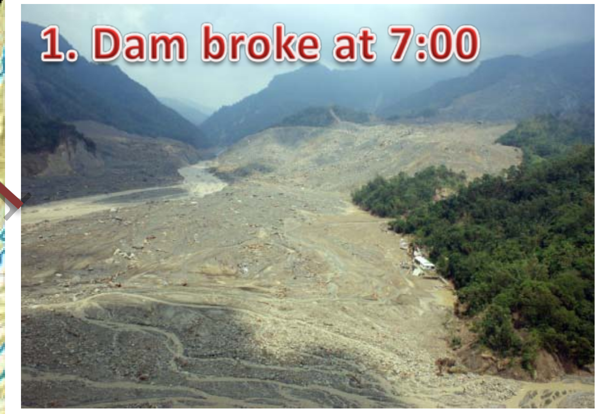
5. Compound Disaster (Xiaolin Village)

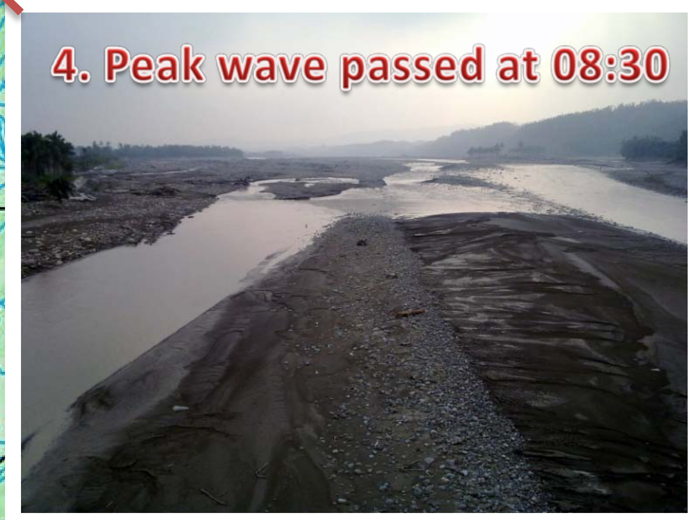


5. Compound Disaster (Landslide Simulation)

5. Compound Disaster (Dam Breach)







Riverbed gradient = 0.9%
Average Speed of Flood Wave
27.5km / 1.5hr = 5m/s

5. Compound Disaster (Flooding)

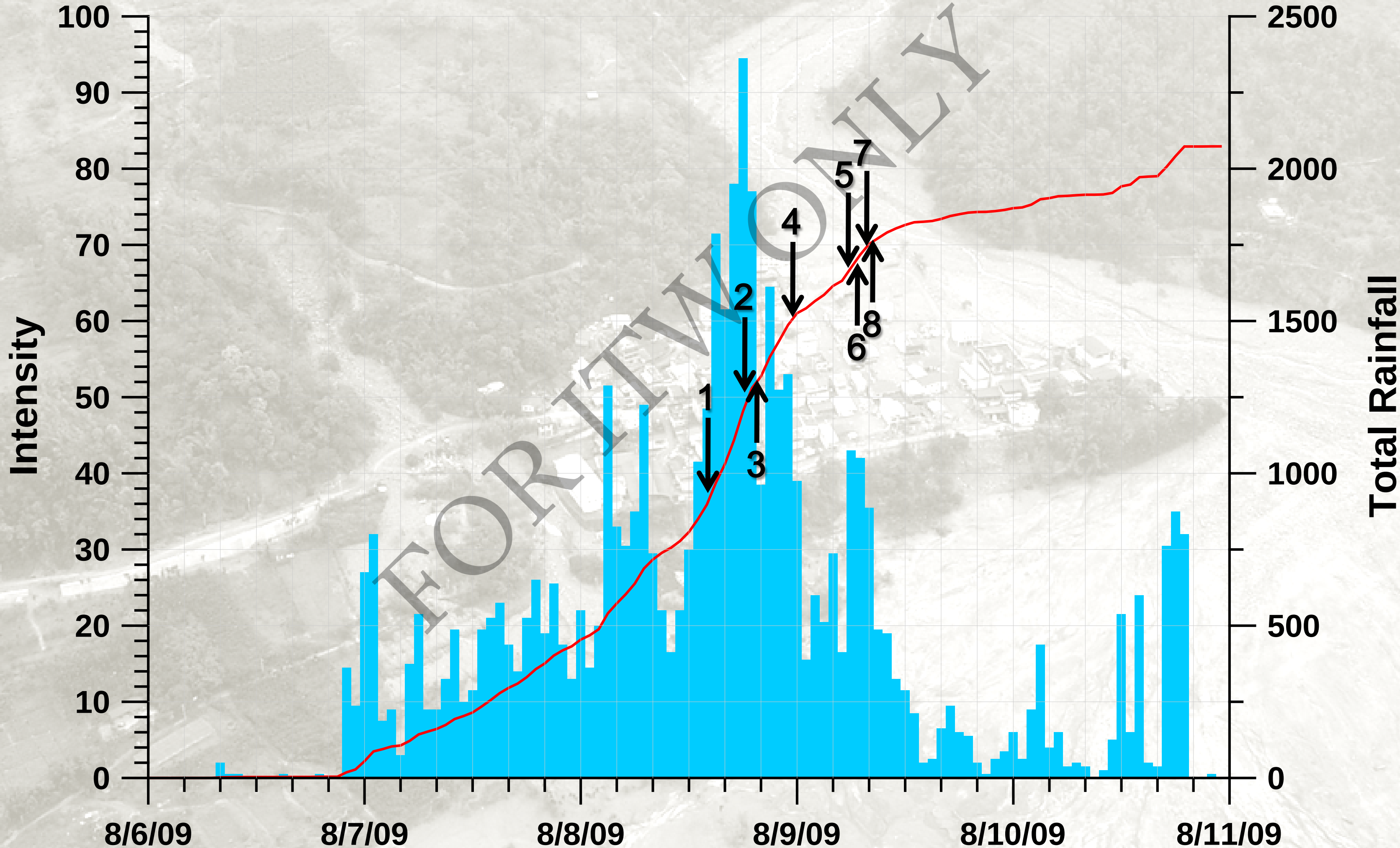
5. Compound Disaster (Xiaolin Village)

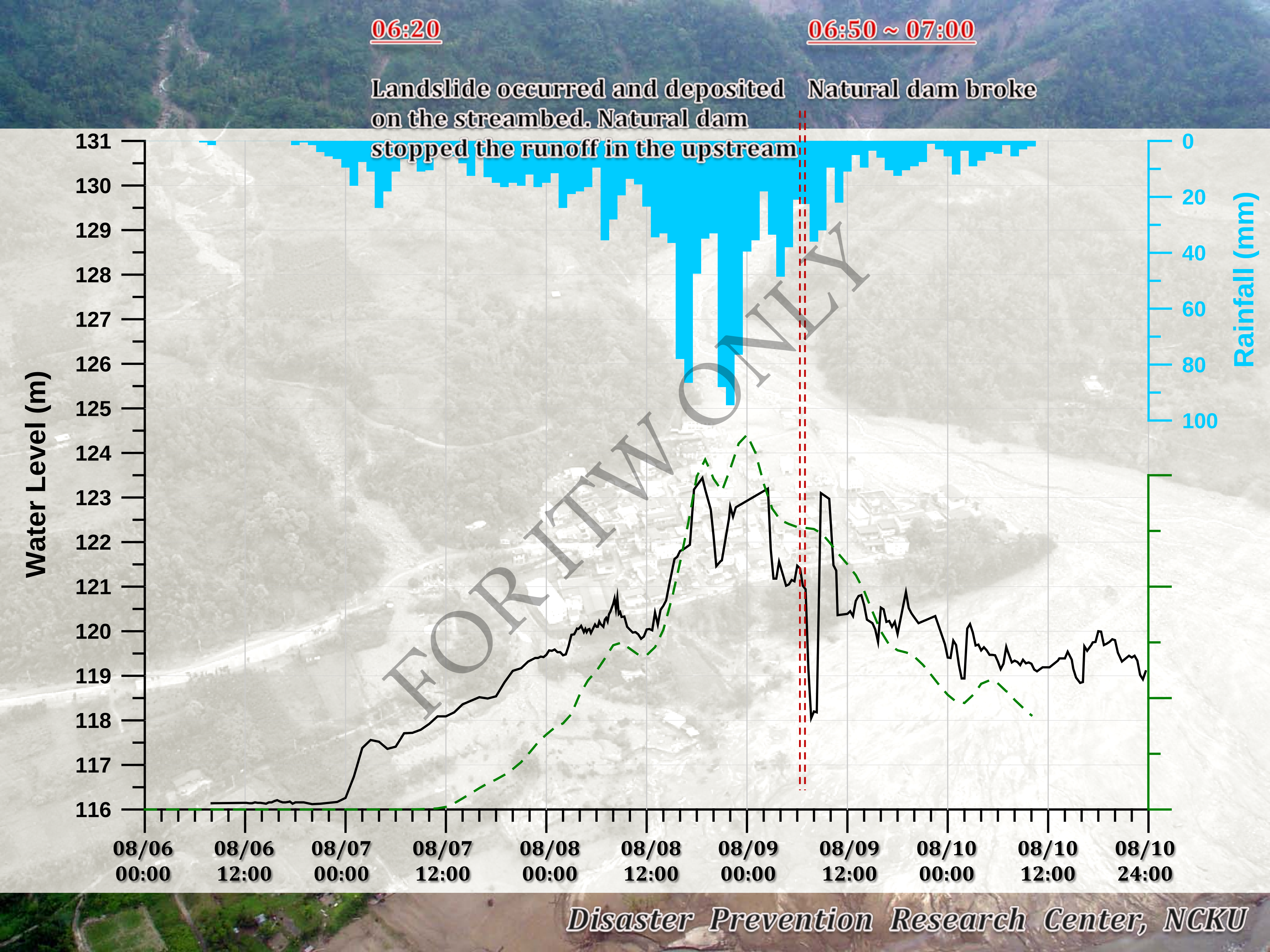
3D Satellite Image
Before Typhoon Morakot

5. Compound Disaster (Process)

Date	Time	Event	Event number
2009 /8/6	08 :30	Typhoon warning was issued.	1
2009 /8/7	17 :00	Yellow debris flow warning was issued.	2
	23 :00	Red debris flow warning was issued	3
2009/8/8	19 :00	Bridge #10 was flooded. Northward road was interrupted. Bridge #8 collapsed. Southward road was interrupted.	4
	23:00	Bridge #9 was flooded. The inundated depth was about 60cm.	5
2009 /8/9	05 :20	Bridge #9 was flooded. The inundated depth was raised from 60cm to 200 cm.	6
	05 :30	43 inhabitants moved to a hut.	7
	06 : 20	The landslide occurred. Northern part of the village was destroyed The landslide dam formed. Nanfong bridge collapsed.	8
	07 : 00	Landslide dam broke. Southern part of the village was flush out.	9
2009 /8/10	05 :30	The warning for typhoon was lifted.	10
2009 /8/11	-	43 survivors were evacuated by helicopters.	11

1. Shallow landslide occurred
2. Bridge #8 broke (debris flow)
3. Bridge #10 broke
4. Bridge #9 inundated
5. Large scale landslide ocurred, Bridge Nanfong broke
6. Natural dam breach
7. Bridge Jaishan broke
8. Wave passed Bridge Shanlin





06:20
Landslide occurred and deposited on the streambed. Natural dam stopped the runoff in the upstream
06:50 ~ 07:00
Natural dam broke
Water Level (m)
131
130
129
128
127
126
125
124
123
122
121
120
119
118
117
116
Rainfall (mm)
0
20
40
60
80
100
08/06 00:00
08/06 12:00
08/07 00:00
08/07 12:00
08/08 00:00
08/08 12:00
08/09 00:00
08/09 12:00
08/10 00:00
08/10 12:00
08/10 24:00
FOR ITW ONLY
Disaster Prevention Research Center, NCKU

6. Face the Challenge of Compound Disasters

- If we don't know the sequence of compound disasters than how to do the warning system.

- If we don't know categories of compound disasters than how to mitigate the hazards.

7. Renovation strategy (Flowchart)

Start

↓

Disaster Investigation

↓

Damage Evaluation of Villages

↓

Importance Evaluation of Villages

↓

Time Scale Choice of Renovation

↓

Compound Disasters Simulation

↓

Planning of Renovation Strategy

↓

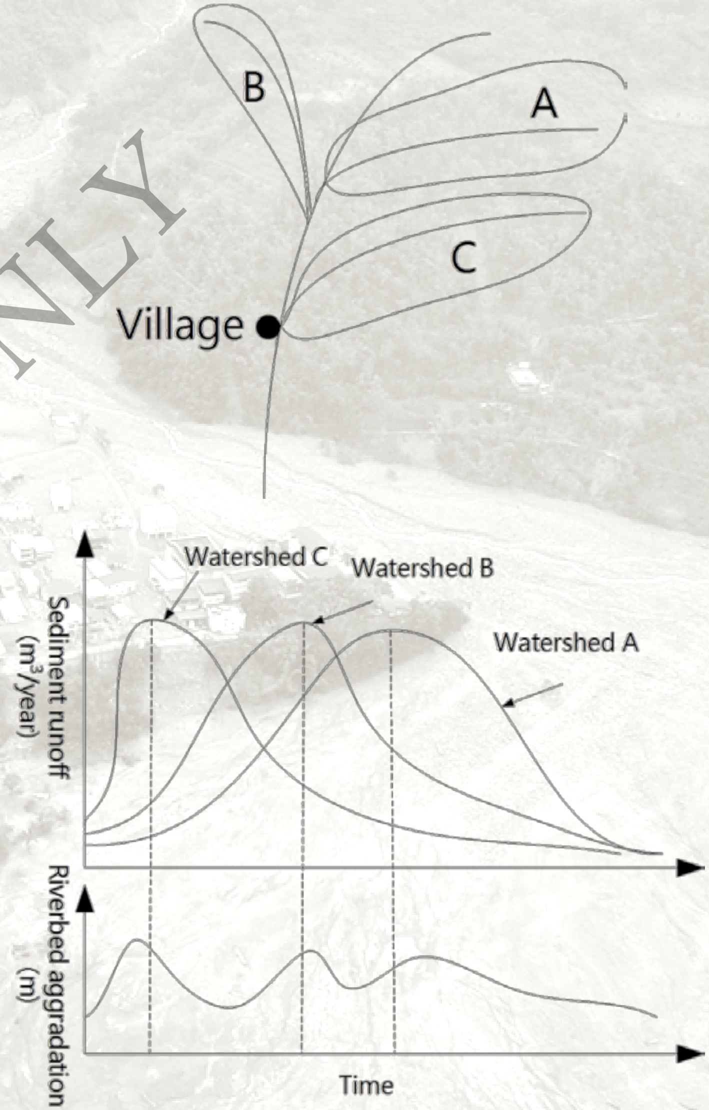
Decision Making

↓

End

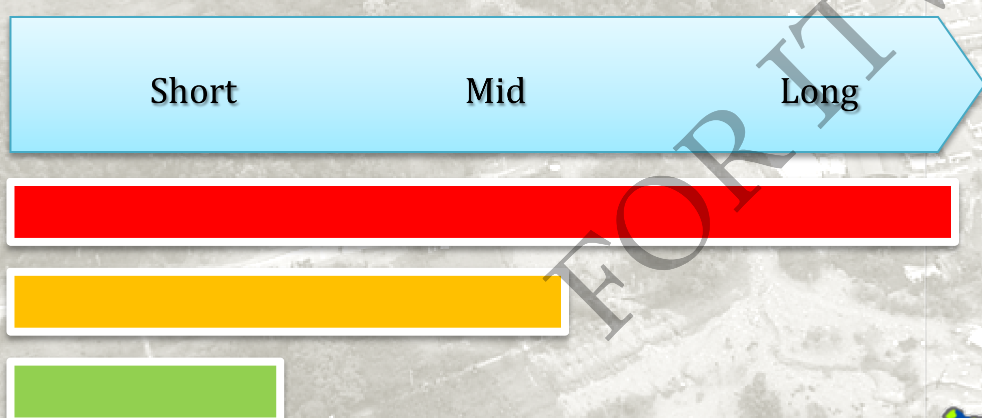
8.Time scale consideration in Renovation strategy

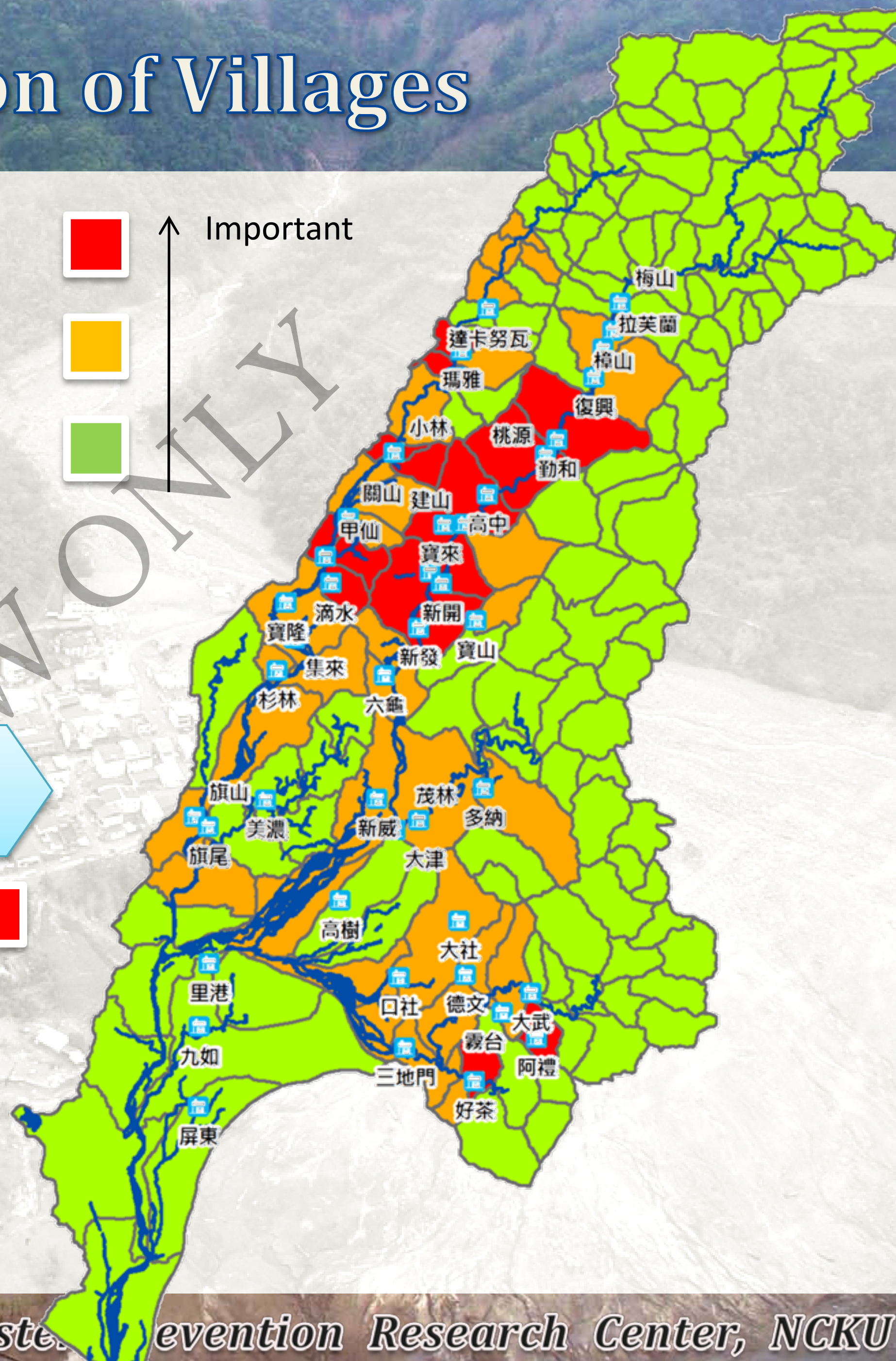
- For the village Renovation, different time scale can be considered
  - Short-term
    - Only watershed C is considered.
  - Long-term
    - Watersheds A, B and C are all considered.
- On long-term consideration, the village renovation will be expanded to a watershed management



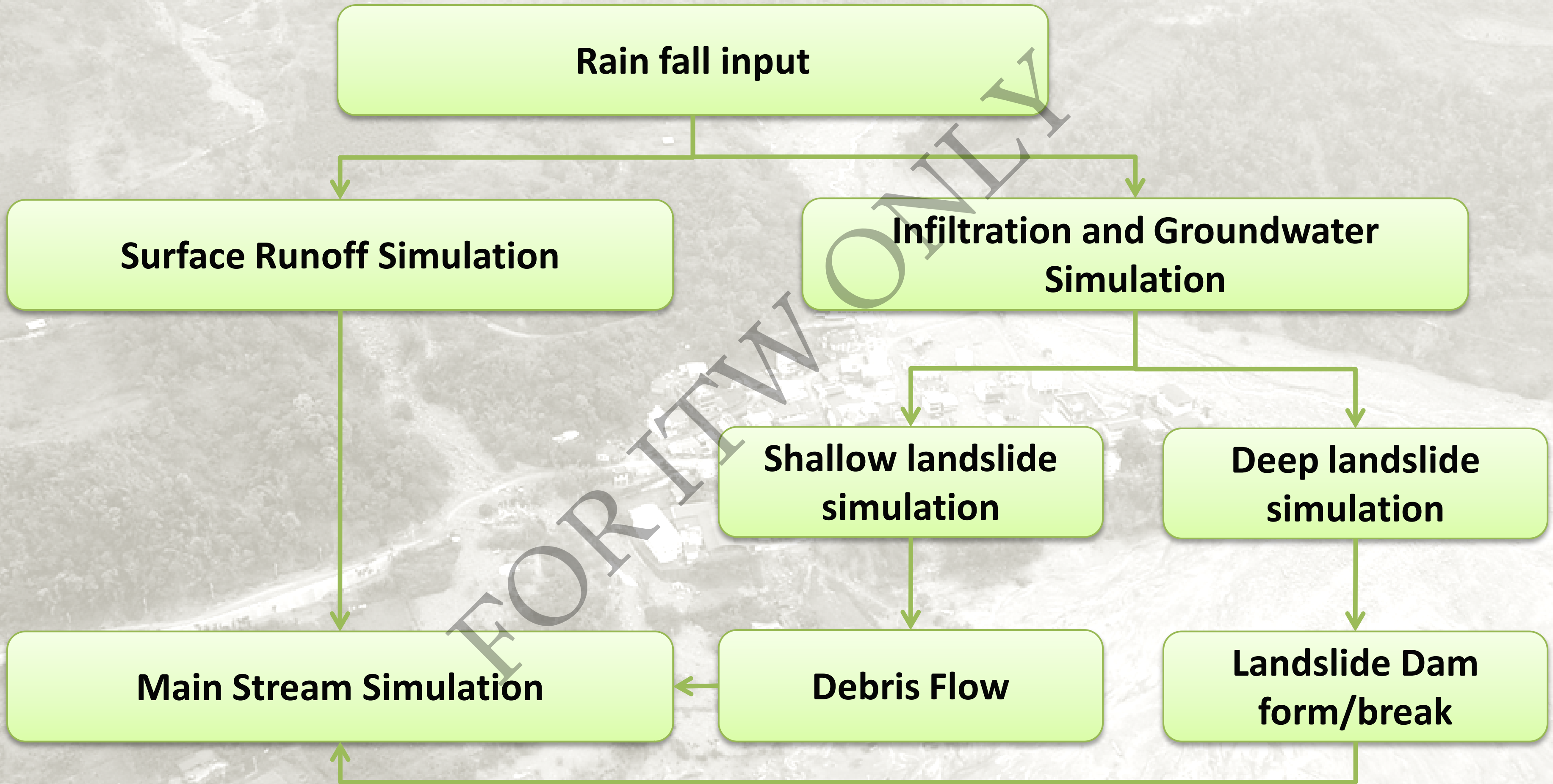
9.Importance Evaluation of Villages

- Evaluating factors
  - Population
  - Damage cost
  - Industry Structure
- Time Scale Consideration

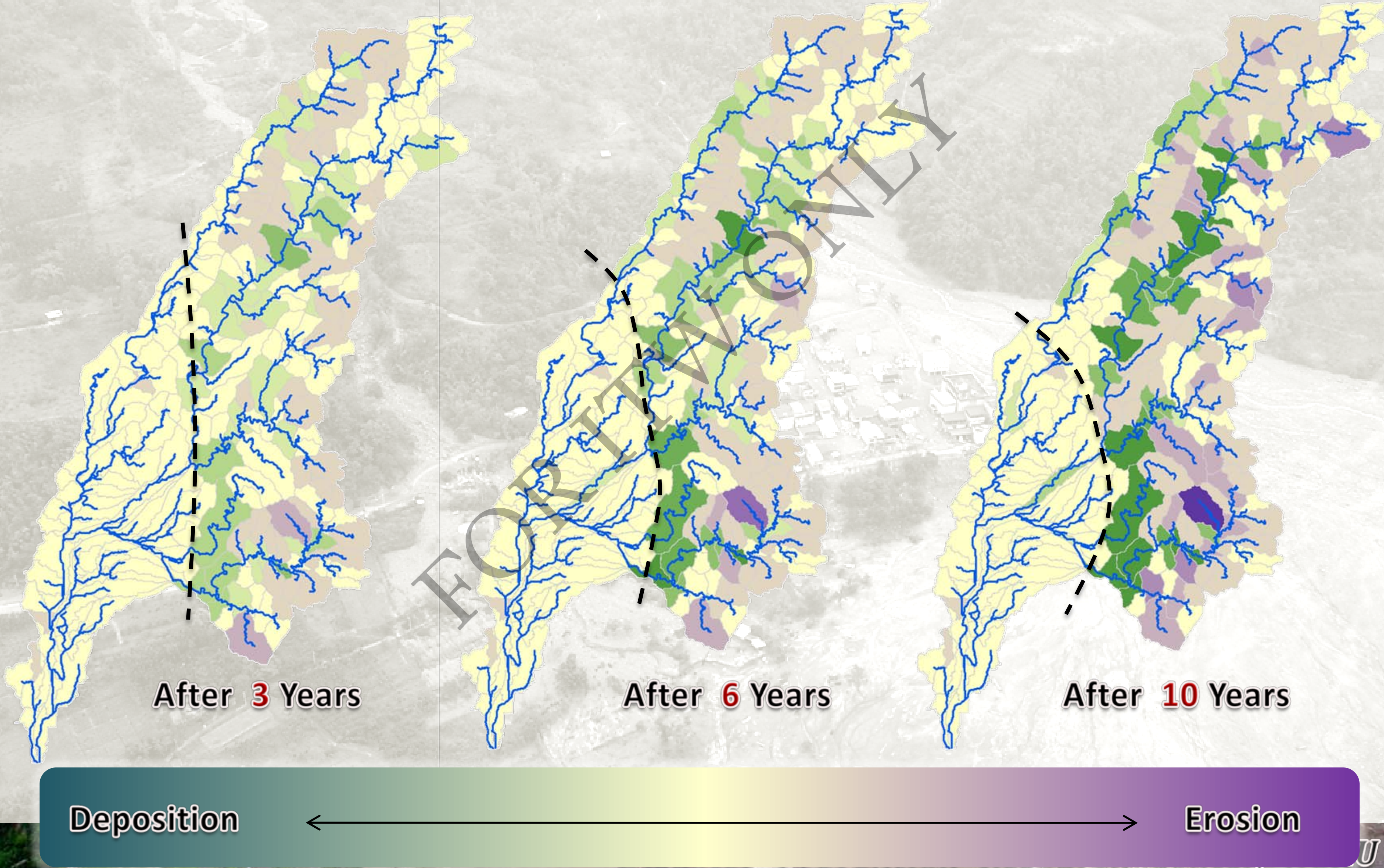


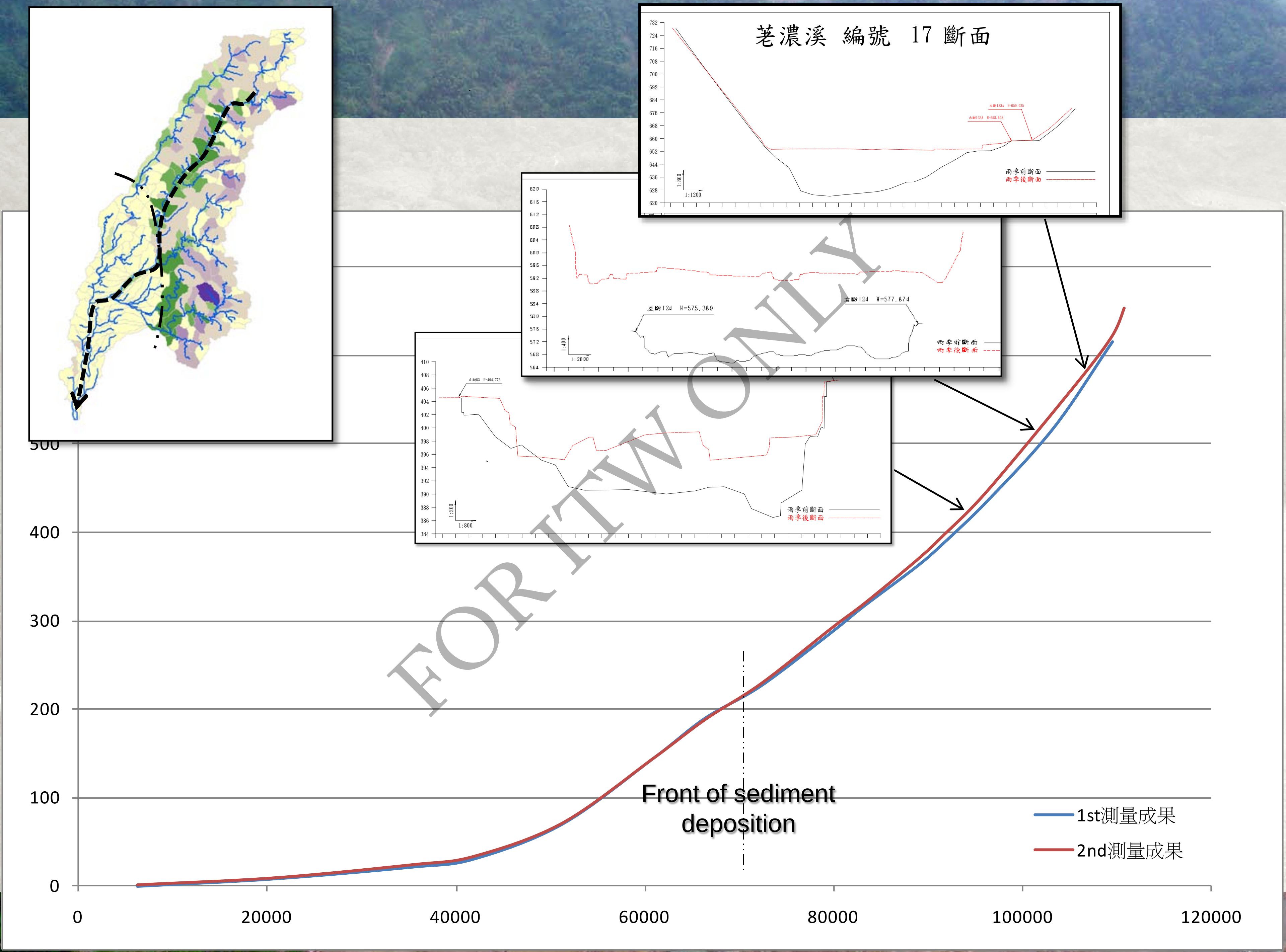


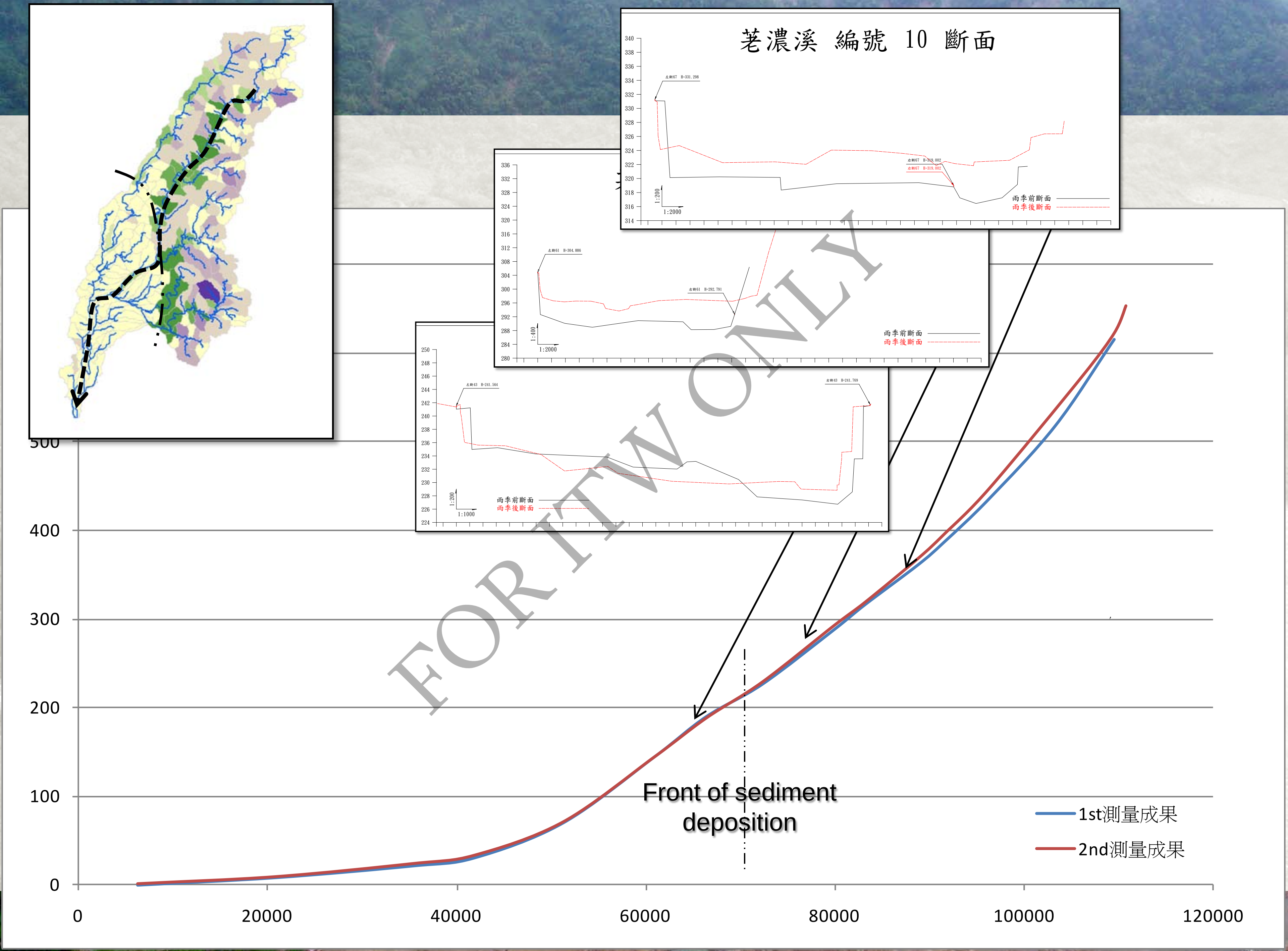
10.Simulation Model



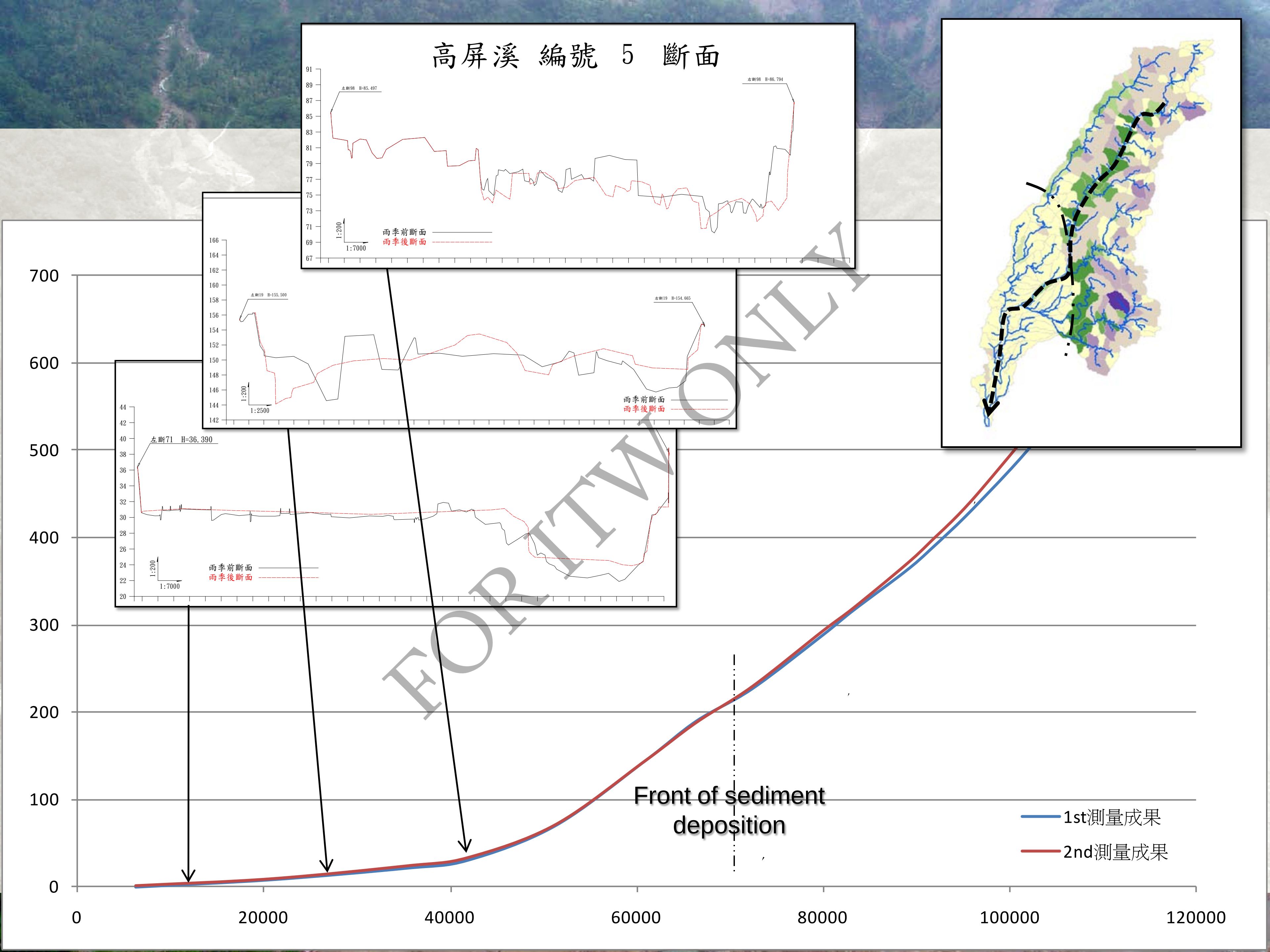
Sediment Runoff Process at Kaoping Watershed




荖濃溪 編號 17 斷面
雨季前斷面
雨季後斷面
1st測量成果
2nd測量成果
Front of sediment deposition
0
100
200
300
400
500
0
20000
40000
60000
80000
100000
120000



荖濃溪 編號 10 斷面
雨季前斷面
雨季後斷面
1:200
1:2000
1:400
1:1000
Front of sediment deposition
1st測量成果
2nd測量成果
0
100
200
300
400
500
0
20000
40000
60000
80000
100000
120000



高屏溪 編號 5 斷面
雨季前斷面
雨季後斷面
1:200
1:7000
1:2500
左斷71 H=36.390
Front of sediment deposition
1st測量成果
2nd測量成果
0
100
200
300
400
500
600
700
0
20000
40000
60000
80000
100000
120000
FOR ITW ONLY

Conclusion

- **Rainfall characteristics of Typhoon Morakot**
  - Long duration (91 hours)
  - High intensity (123 mm/hour)
  - Large accumulated rainfall depth (3,000 mm-72 hour)
  - Broad extent (one-fifth of Taiwan was covered by strong rainfall)
- **Disaster characteristics of Typhoon Morakot**
  - Disasters spread over a very large region (over 5,000 km^2)
  - Disasters were compounded
  - Large amount of sediment yield and movement (1.2 billion m^3)
  - Secondary disasters will easily and continuously occur in the future

Conclusion

- Understanding and proper prediction of disaster process can provide effective and efficient renovation strategy
- The powerful simulation model is necessary in the renovation

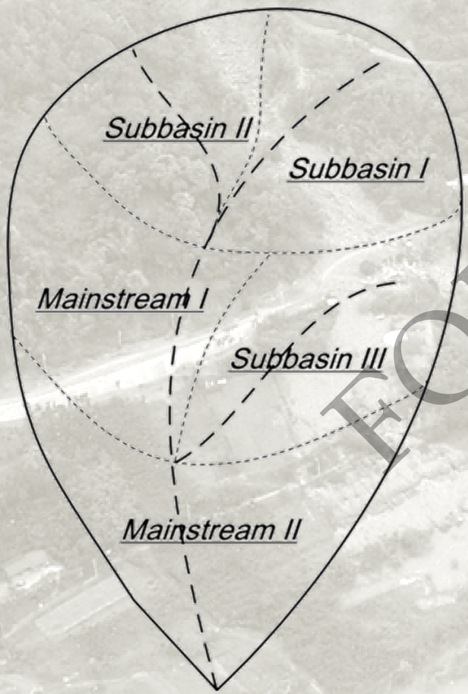
Conclusion

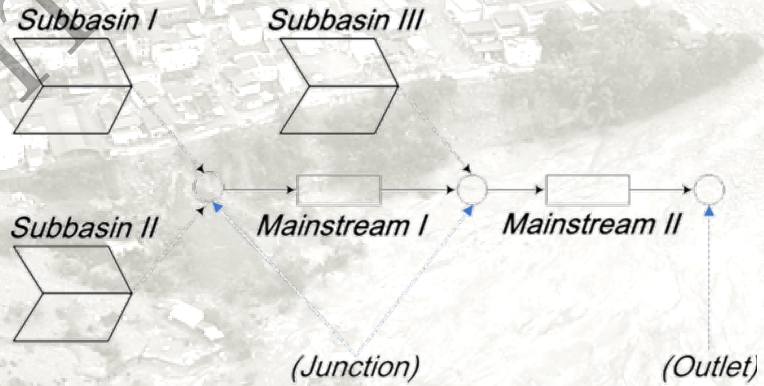
- Different time scales should be taken into account when one determines the renovation strategy.
- On long-term consideration, the village renovation will be expanded to a watershed management


Thank you
for your attention

8.Sediment Budget Model

- **Subbasin systems**
  - Watershed divide into several subbasins with joint relationships
  - Sediment yield is estimated in each subbasin
  - Sediments transport downstream, and totall at each junction
  - Remnant sediments are computed between 2 junctions





Simulation of Sediment Runoff Process

- Surface runoff

$$\frac{\partial A}{\partial t} + \frac{\partial (Q)}{\partial x} = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial h}{\partial x} = gA(S_0 - S_f)$$

- Sediment yield and transportation

Surface Erosion : USLE

$V = R_m \times K_m \times S \times L \times C \times P$

Landslide : ranged by Satellite Image

$$q_b = 8\sqrt{sgd^3}[\tau_* - \tau_{*c}]^{\frac{3}{2}}$$

$$\frac{\partial C}{\partial t} + U \cdot \frac{\partial C}{\partial x} = D\frac{\partial^2 C}{\partial x^2} + \frac{1}{h}(q_{su} - \omega_f \cdot C_b)$$

$$\frac{\partial C_w}{\partial t} + U \cdot \frac{\partial C_w}{\partial x} = D\frac{\partial^2 C_w}{\partial x^2} + \frac{1}{h}(E_w - D_w)$$

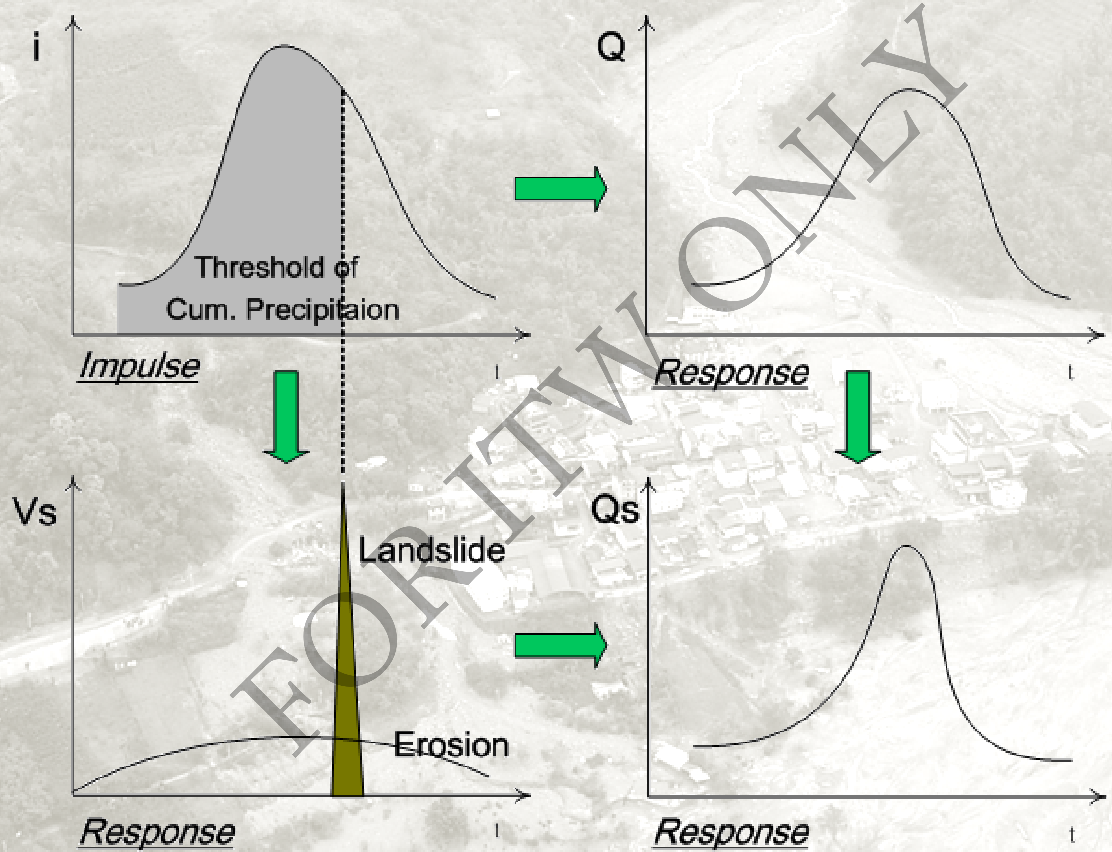
$$\frac{\partial z}{\partial t} + \frac{1}{(1-\lambda)}\left[\frac{\partial q_b}{\partial x} + (q_{su} - \omega_f C_b)\right] - D_w + E_w = 0$$

- Sediment particle size variation
- (Engineering) constructions

Sediment Yield & Transportion Simulation

Input

- Rainfall
- Topography
- Geo-parameters
- Landslide



Output

- Hydrograph of water
- Hydrograph of sediment
- Deposition/Erosion of sediments

7. Renovation strategy

- The resources must be allocated reasonably so that the renovation can be managed effectively and efficiently.

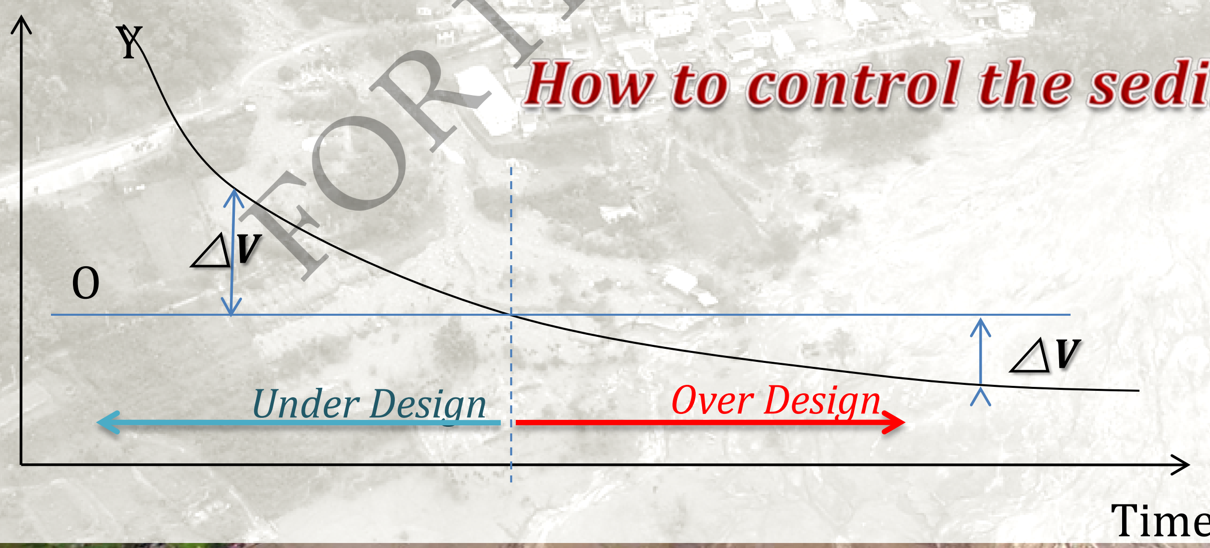
7. Renovation strategy

Traditional Methodology of Making Renovation Strategy in Sediment-Related Disasters is

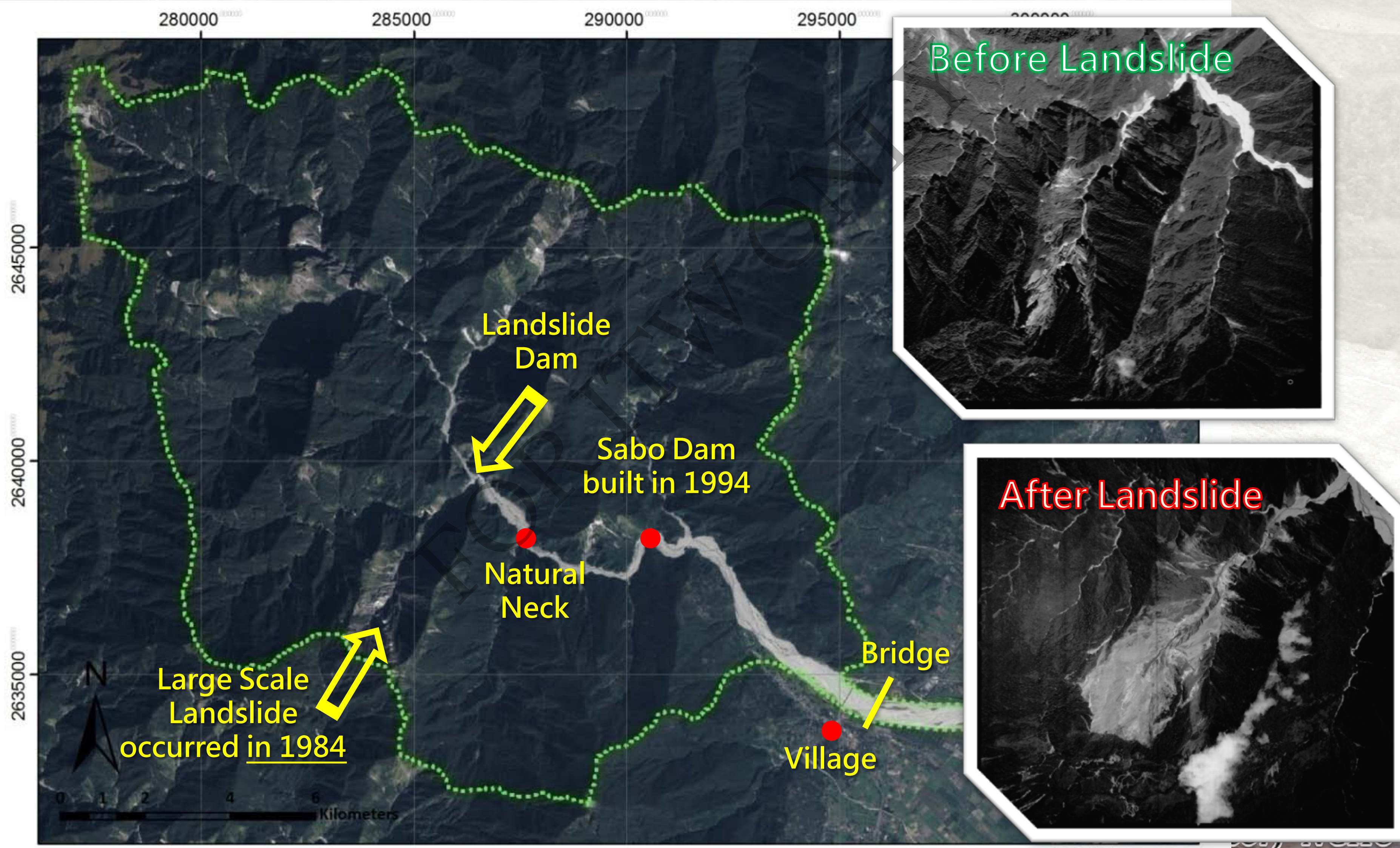
$$Y - O = \triangle V$$

Y = Sediment Yield after extreme event (varied with time)
O = Designed Sediment Runoff (constant)
△V = Amount of Sediment Control

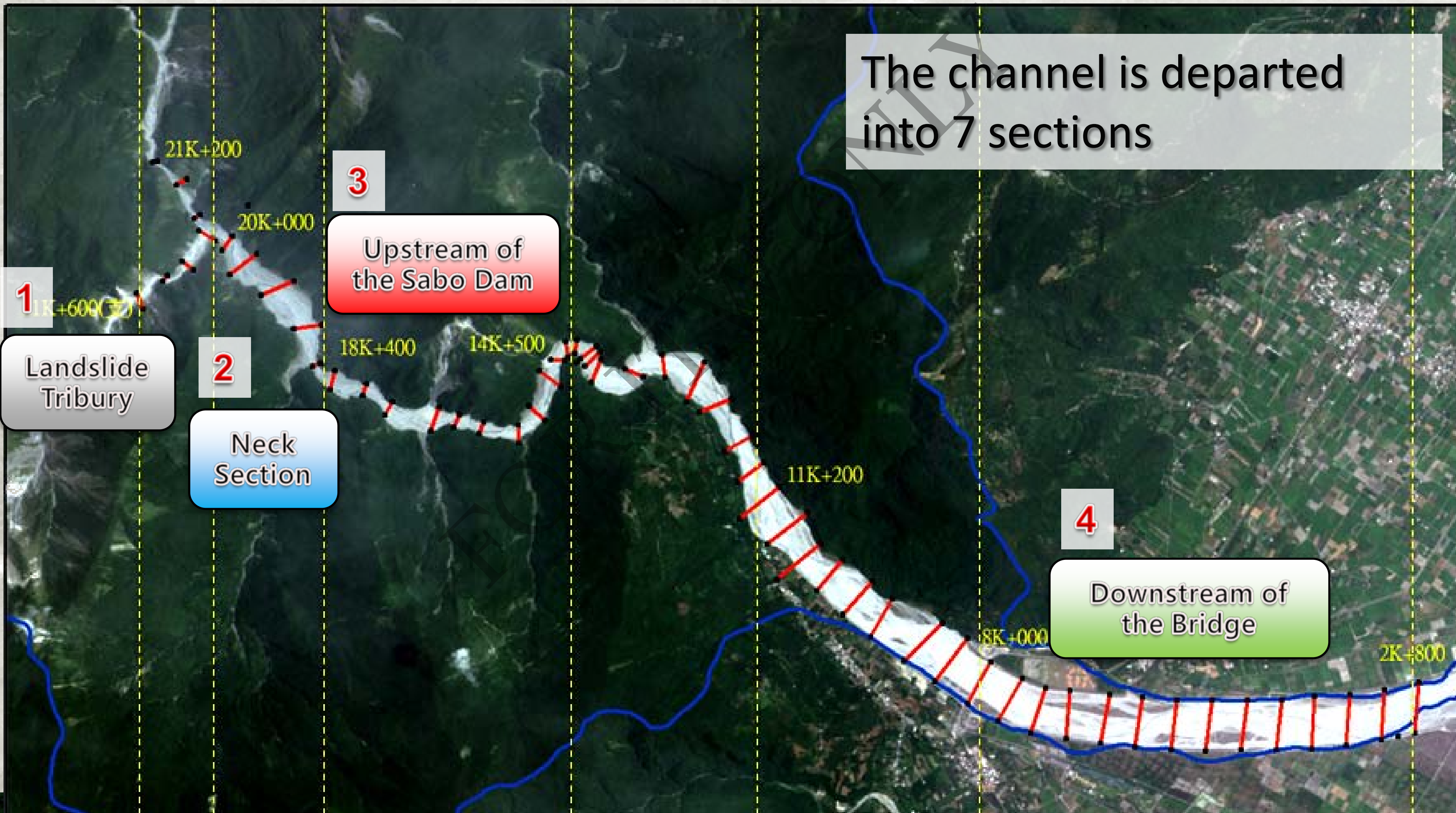
How to control the sediment ?



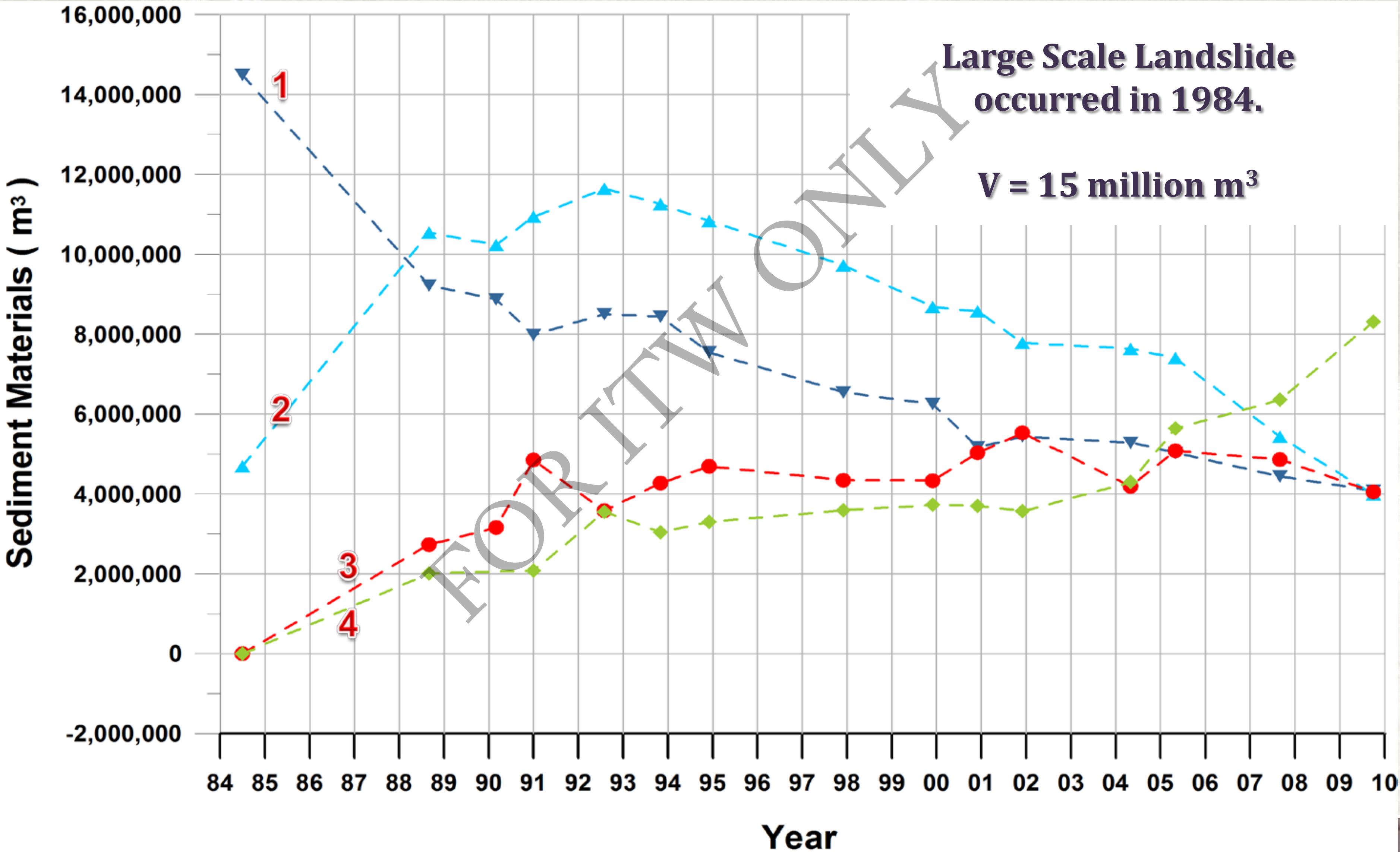
Example 1 ~ the Shoufeng Watershed



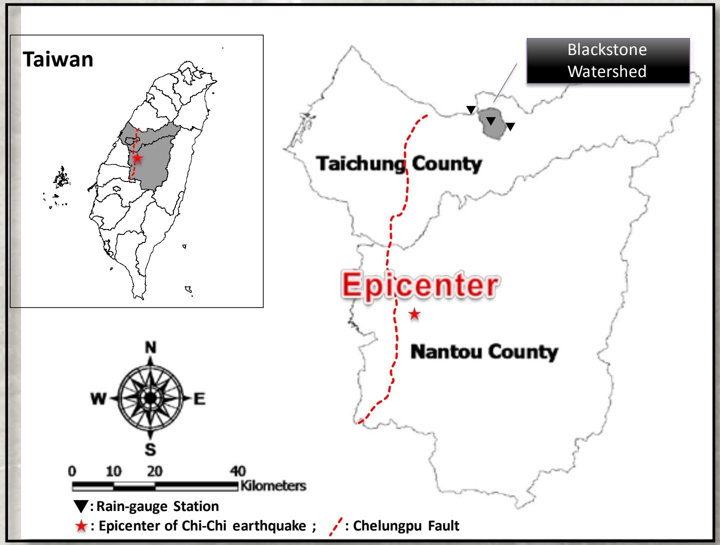
Example 1 ~ the Shoufeng Watershed



Example 1 ~ How to determine Y and △V?



Example 2 ~ the Blackstone Watershed

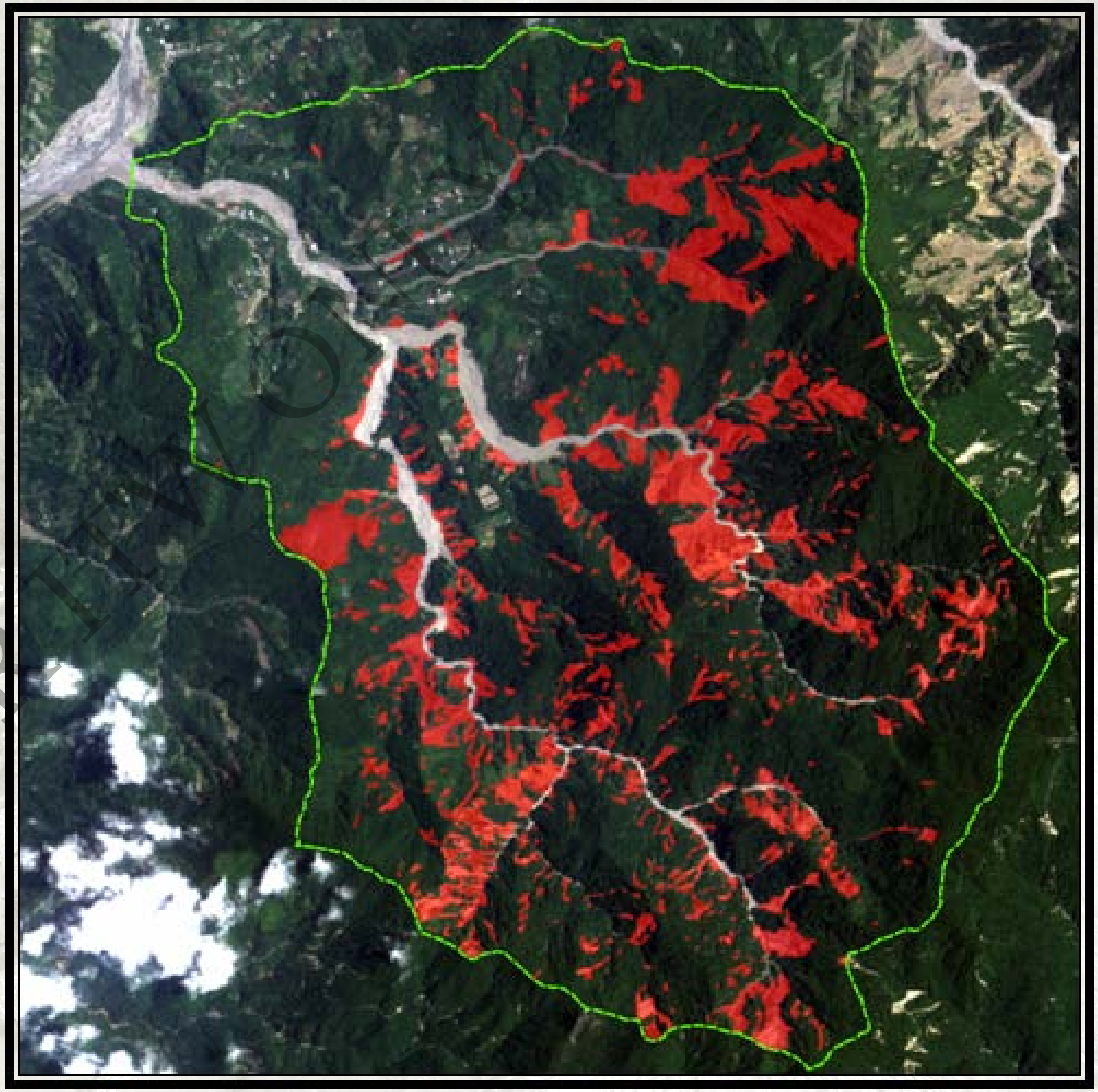


Before the Chi-Chi earthquake

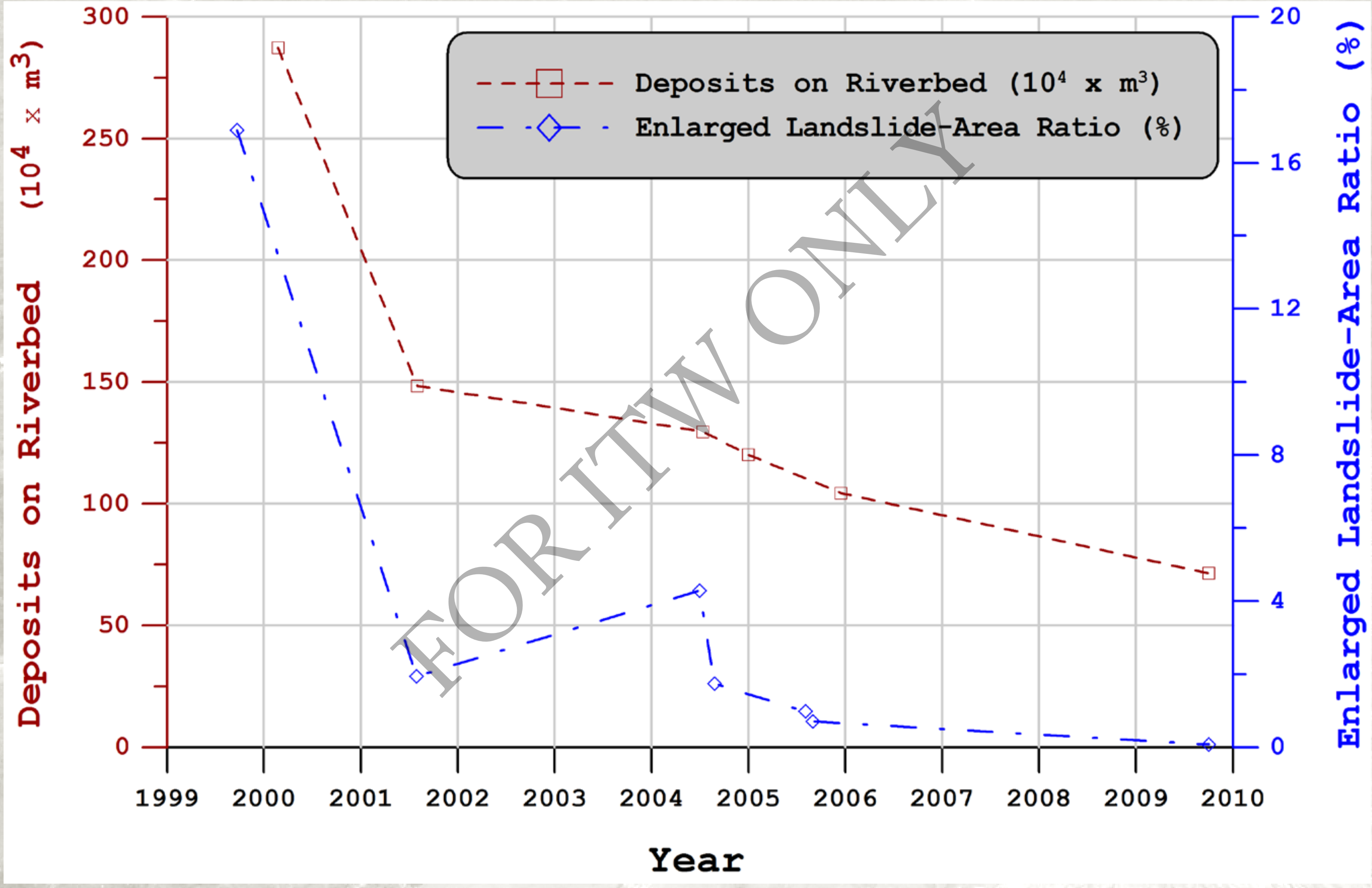
$$\frac{\text{Landslide area}}{\text{Catchment area}} = 1.4\%$$

After the Chi-Chi earthquake

$$\frac{\text{Landslide area}}{\text{Catchment area}} = 18.2\%$$



Example 2 ~ the Blackstone Watershed



Example 2 ~ How to make the criteria of debris flow warning?