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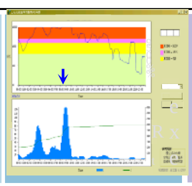
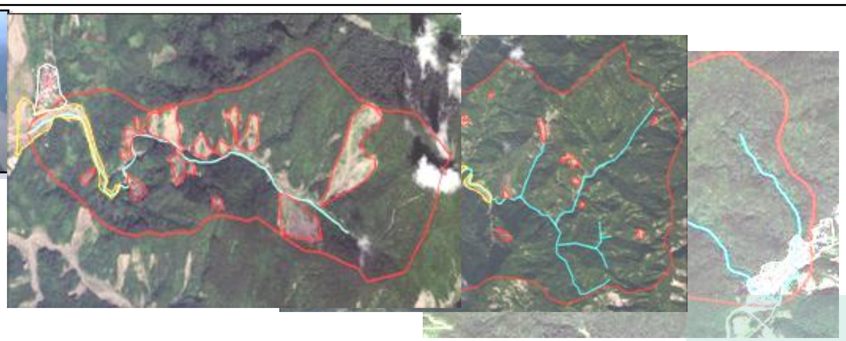
Activities on Debris-flow Disaster Reduction in Taiwan

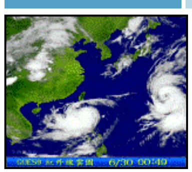
台灣土石流防減災經驗談

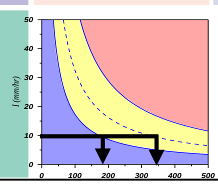
Prof. Chyan-Deng Jan (詹錢登 教授)

Department of Hydraulic and Ocean Engineering,
National Cheng Kung University, Taiwan
國立成功大學水利及海洋工程學系



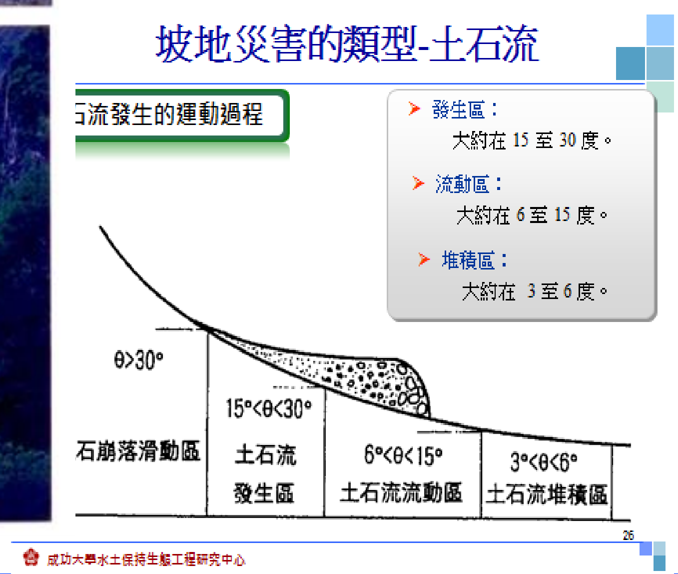


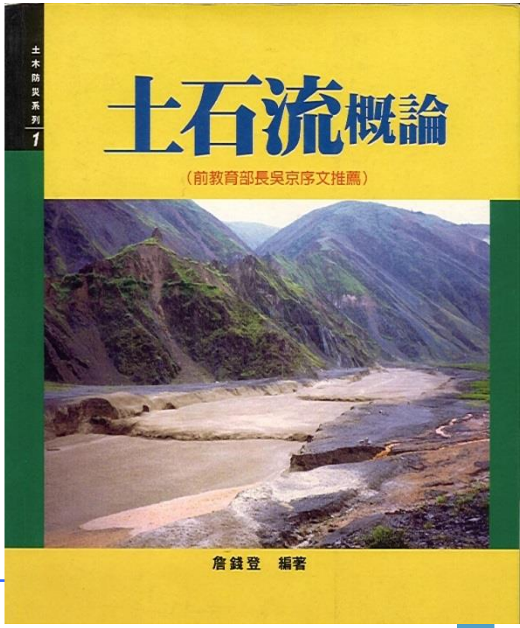




Debris Flow

- Initiation Conditions,
- Movement Characteristics,
- Hazards Prevention & Mitigation

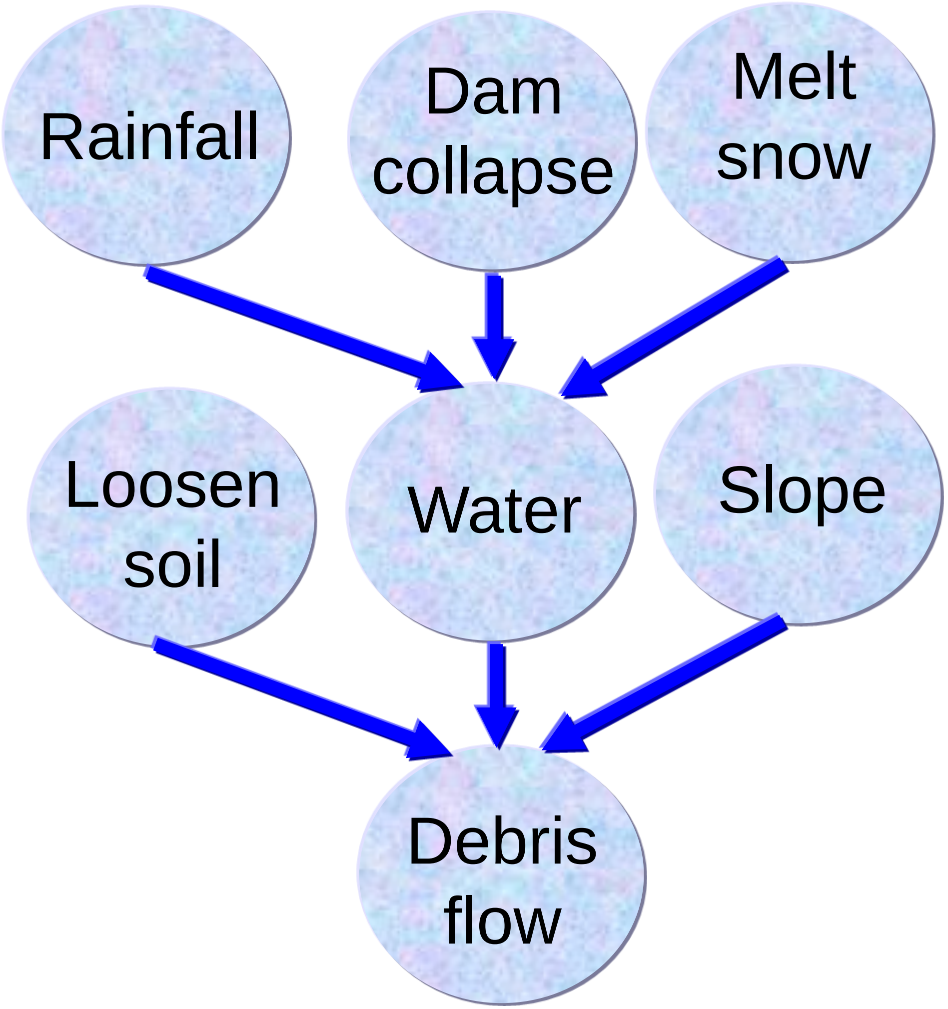




土石流災害(桃芝颱2001.7.31)

南投縣上安村土石災害

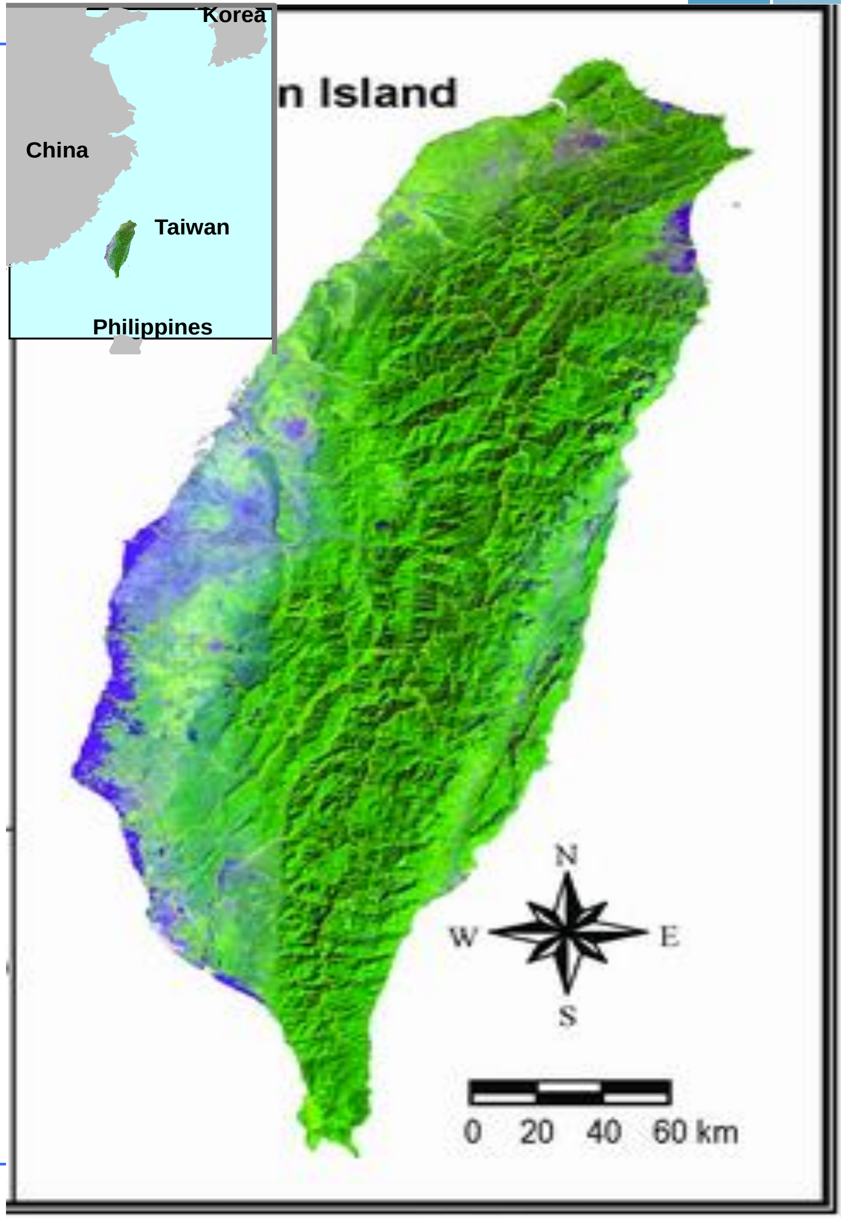
Key Factors for debris flow occurrence



- **Rainfall：**
  Provide enough water
- **Loosen soil material**
  Provide materials
- **Steep slope：**
  Provide energy

The natural environment in Taiwan

- Taiwan is located at the convergent boundary of the Eurasian Plate and the Philippine Sea Plate.
- Two-third of Taiwan area is covered by highly hilly mountains and hills. The steep topography, young and weak geological formations, active earthquakes, and loose soils on the slop make Taiwan highly potential for occurring debris flow.
- Taiwan receives an average annual rainfall of 2,500 mm, but exceed 5,000 mm in some high mountain regions. About 80 percent of annual rains fall in the rainy season from May to October, especially during typhoons.



Taiwan matches the conditions for debris flow occurrence

***It is natural for Taiwan having debris flows*, *due to having the three basic conditions for debris flow occurrence*:**

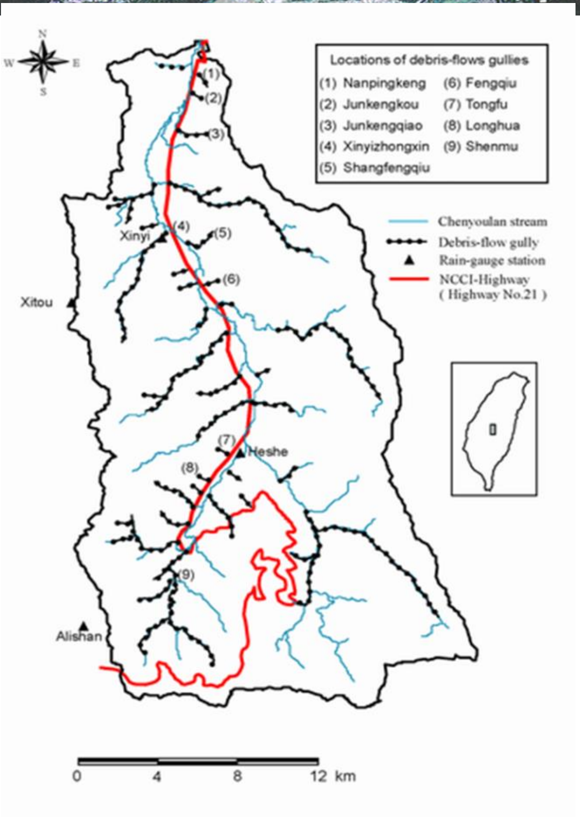
- **steep topography,**
- **abundant loose soil, and**
- **large amount of rainfall.**

Debris flow caused by Typhoon Ofelia in 1990

- Typhoons are especially important agents of debris flows in Taiwan.
- The first well documented debris flow was the one occurred in Hualian, Eastern Taiwan, during Typhoon Ofelia in 1990, with maximum rainfall intensity 106 mm/hr. This debris flow killed 35 people and destroyed 24 houses.
- Debris flow was usually just called as a "sediment disaster" instead of debris flow in Taiwan, and got less attention before 1990.
- This event pushed Taiwan government officials and researchers to initiate the study of debris flow and its countermeasures, and organize debris-flow conferences.
- After severe debris flow events caused by Typhoon Herb in 1996, they pay more and more attention on debris-flow-related studies.

Debris flow caused by Typhoon Herb in 1996

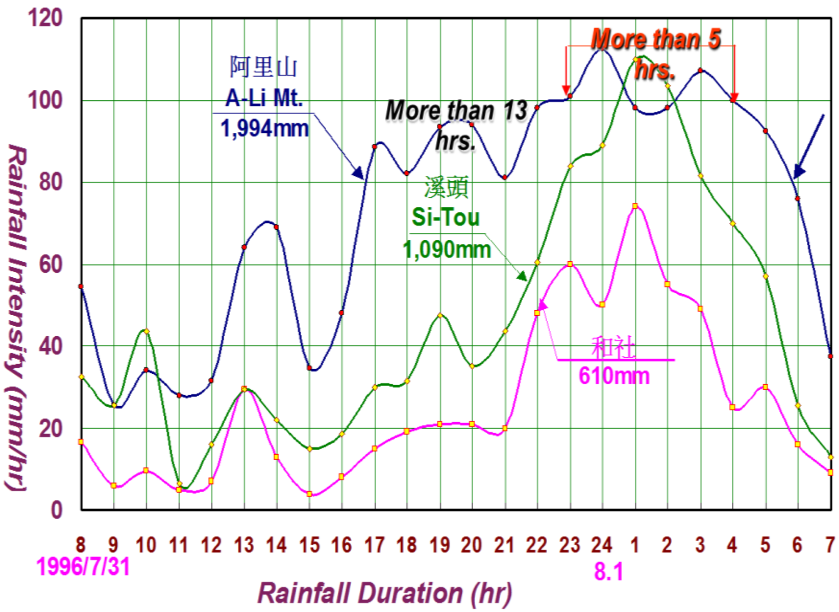
- **Typhoon Herb hit Taiwan in 1996 and triggered 52 debris flows (killed 43 people), most of them in central Taiwan.**
- **This event made people realize the severity of debris-flow hazards. Since then "debris flow" is a name of "disaster." The first Taiwan debris-flow conference was hold in 1997.**
- **The Soil and Water Conservation Bureau and the National Science Council have played a leading role in sponsoring debris-flow research and developing a comprehensive program for debris-flow hazards mitigation in Taiwan.**
- **After severe debris flow events caused by Typhoon Herb in 1996, they pay more and more attention on debris-flow-related studies.**

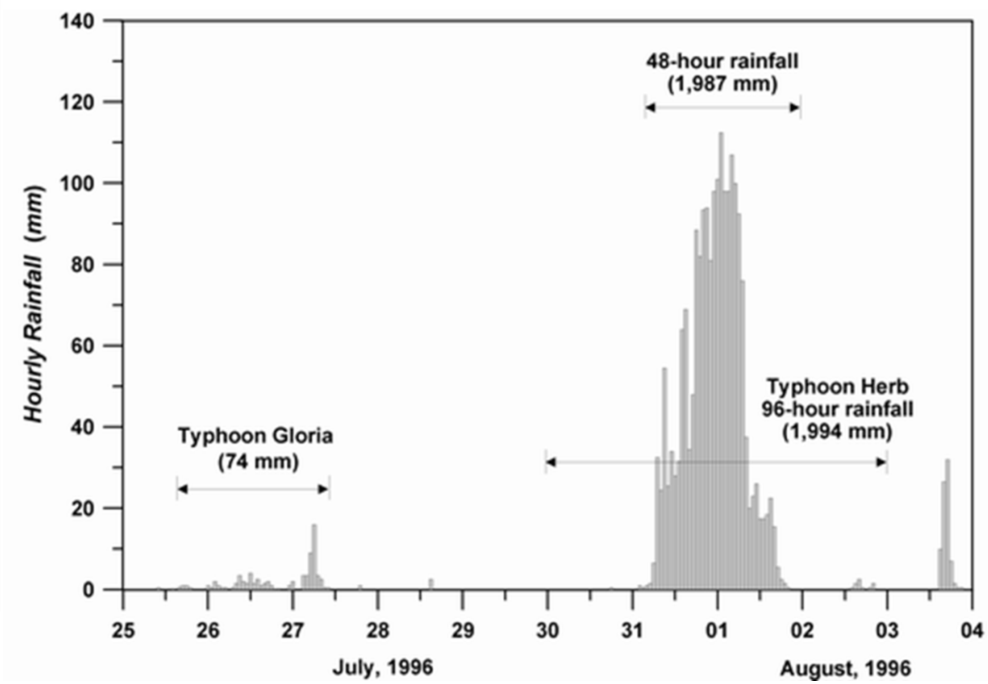


Why Typhoon Herb could cause so many debris flows?

Severe Rainfall brought by Typhoon Herb

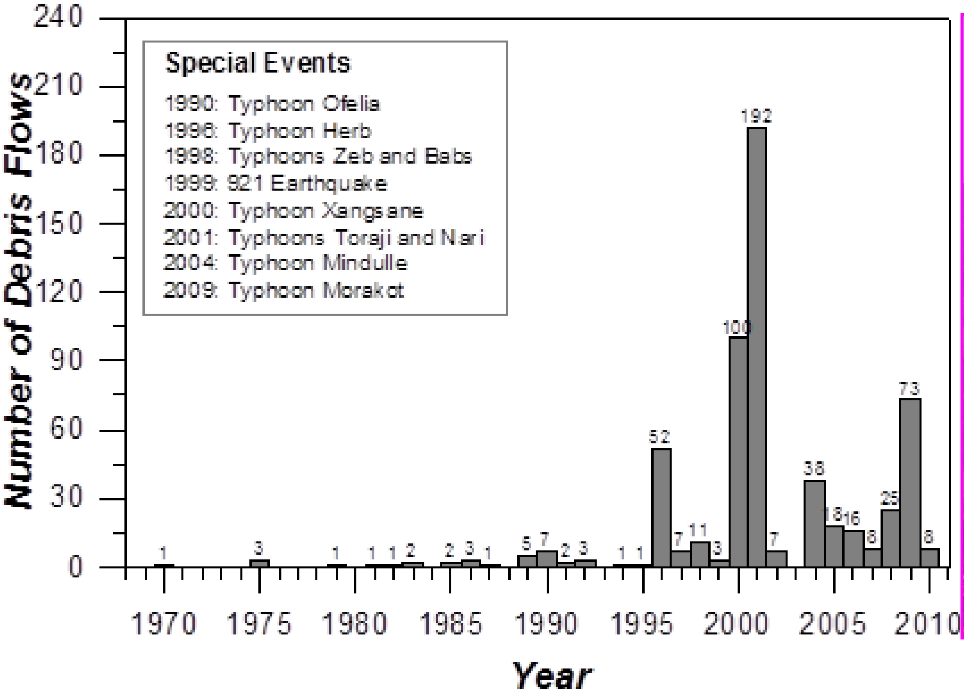
- **Total Rainfall = 1994 mm, Highest Rainfall Intensity = 112.5 mm/hr,**
- **5 hours continually having rainfall intensity larger than 100 mm/hr.**
- **13 hours continually having rainfall intensity larger than 80 mm/hr.**





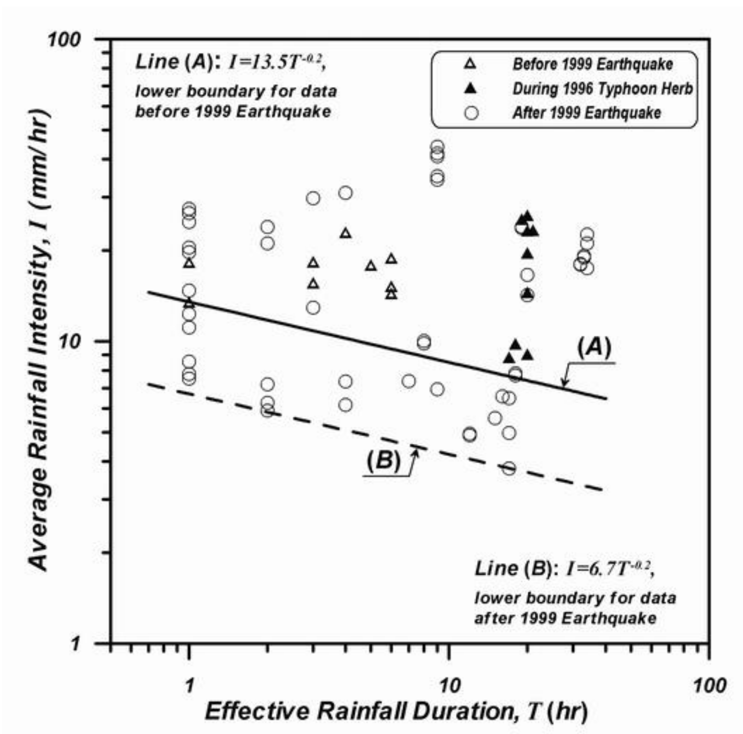
Number of debris flows in recent years in Taiwan

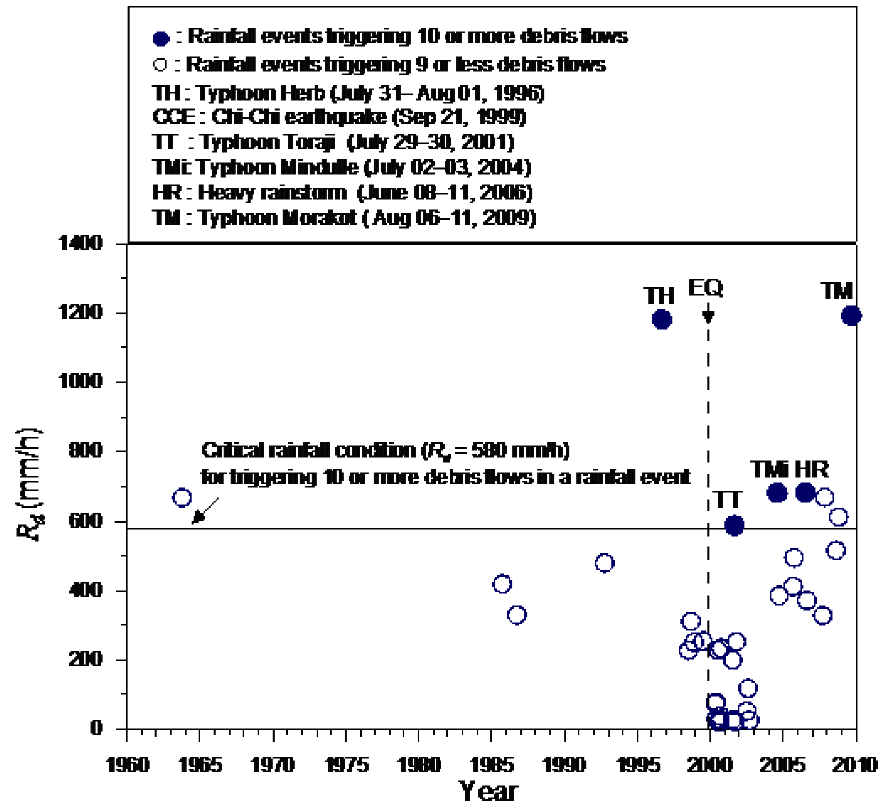
- **Typhoons are especially important agents of debris flows in Taiwan.**
- **Catastrophic earthquake with magnitude 7.3 on the Richter scale on September 21, 1999.**



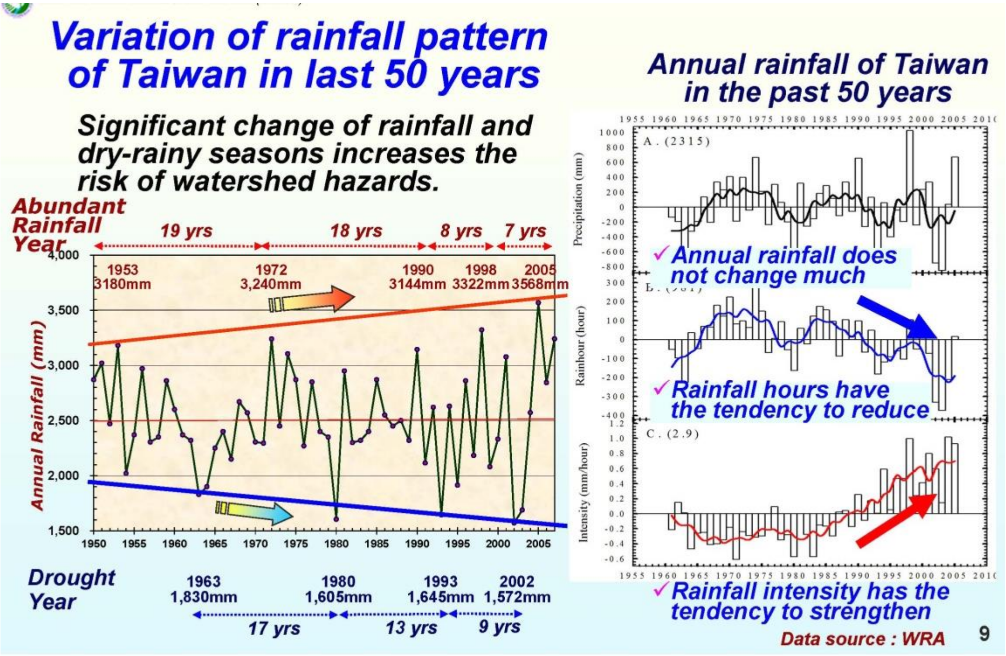
Effect of Ch-Chi earthquake on debris flow occurrence

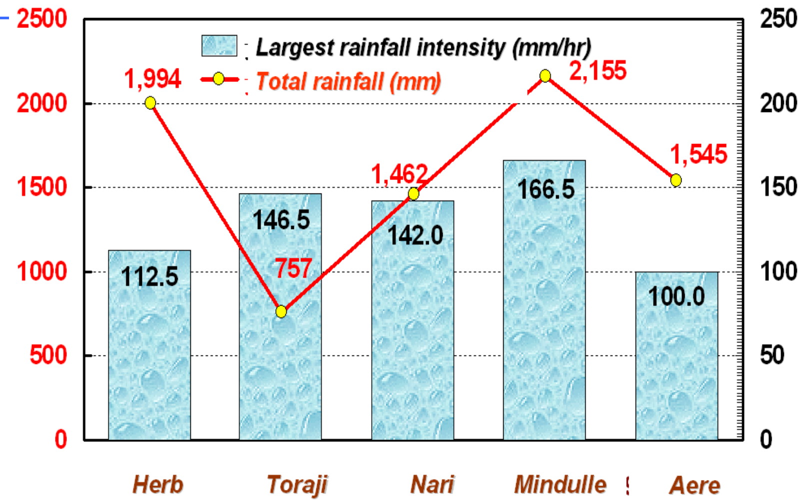
- The 1999 Chi-Chi earthquake reduced the critical rainfall condition for debris flow occurrence, and its effect on debris flow occurrence about 5 years.





More and more extreme rainfalls in Taiwan





More and more extreme rainfall events caused more and more landslides and debris flow in Taiwan

Debris-flow Disaster Management in Taiwan

- In Taiwan, **the Soil and Water Conservation Bureau** (SWCB) is the central government official in charge of debris flow hazards mitigation, including prevention, mitigation, evacuation, and emergency management.
- SWCB has developed debris-flow hazards mitigation strategies and measures, such as structural and non-structural countermeasures, after severe debris flow events caused by Typhoon Herb in 1996.

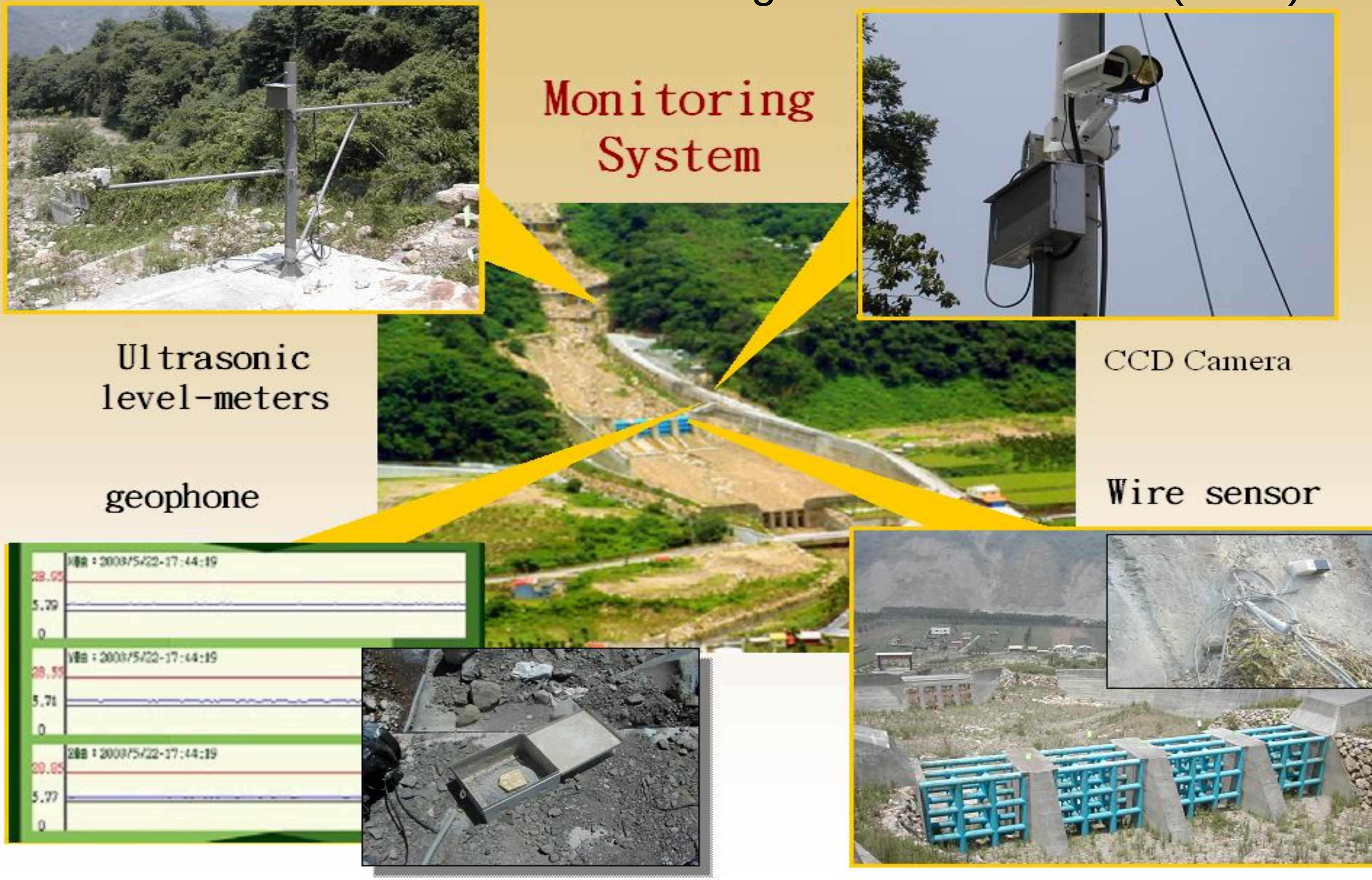
Structural debris-flow countermeasures

The structural countermeasures include the installation of debris barriers, debris breakers, debris basins, slit dams, Sabo dams in debris-flow gullies and alluvial fans.

Debris-flow prevention structures

Debris-Flow Monitoring System

22 monitoring stations in Taiwan (2009)

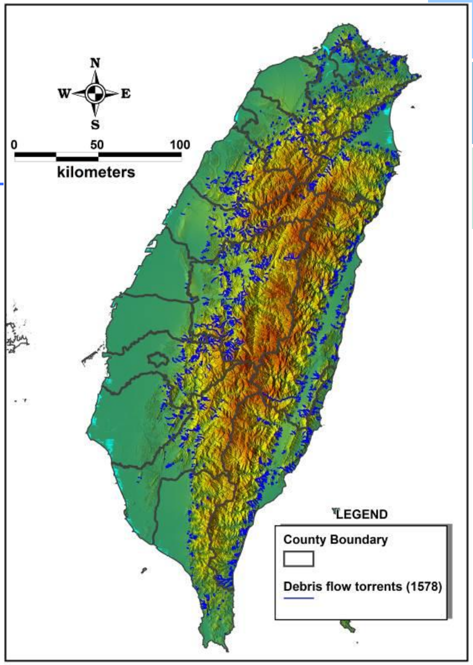


Non-structural methods

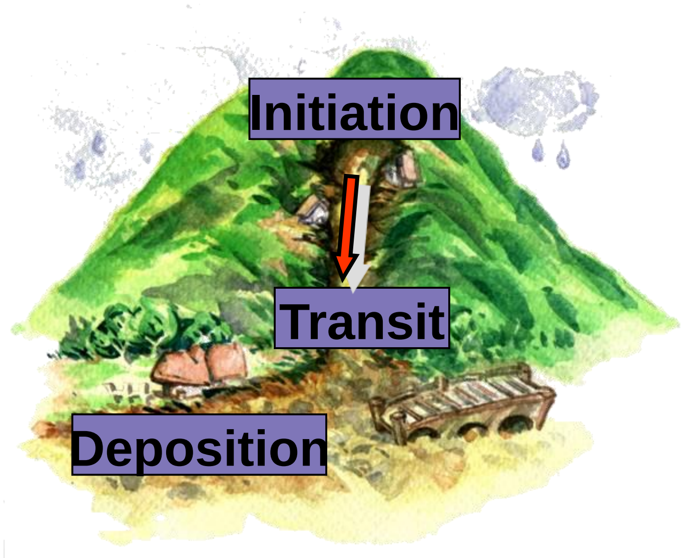
We realized that it is impractical to completely prevent debris flow hazards by structural countermeasures. Therefore, non-structural countermeasures have been also applied through:

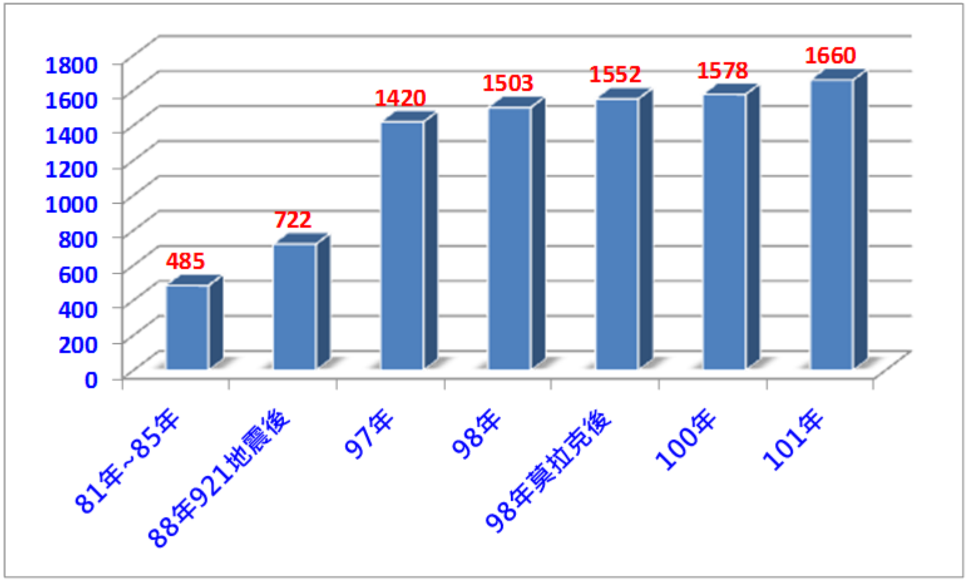
- Identification of potential debris-flow torrents.
- Zoning of potential debris-flow hazard areas.
- Rainfall-based debris flow warning system.
- Inhabitant evacuation practice for avoiding debris-flow hazards.

Identification of debris flow potential torrents



- **Total 1,701** debris flow potential torrents have been identified up to the year of 2015.



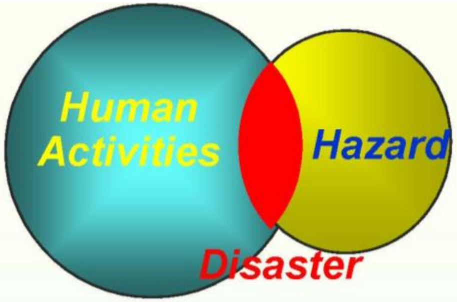


Potential debris flow flooding area and evacuation map

Identify the risk of debris flow torrents

Soil and Water Conservation Bureau (SWCB)

Investigation of 1,701 Potential Debris Flow Torrents



Risk Degree=Occurrence degree X Degree of hazards on protected targets

Occurrence Degree

- Watershed area, landslide ratio, drainage slope, sedimentation amount, geological structure, vegetation, historical events

Protected Targets

- Downstream fan areas
- People, living houses, public buildings, roads, bridges, other infrastructures

Risk Degree		Occurrence		
		Low	Mid	High
Protected Targets	Low	Low	Low	Mid
	Mid	Low	Mid	High
	High	Mid	High	High

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Setup of Debris-Flow Warning System

(1). Post-event Type

Using geophone, wire sensor, or CCD image to take the signal of debris flow after occurring.

Advantage：Highly Accurate, less false alarms

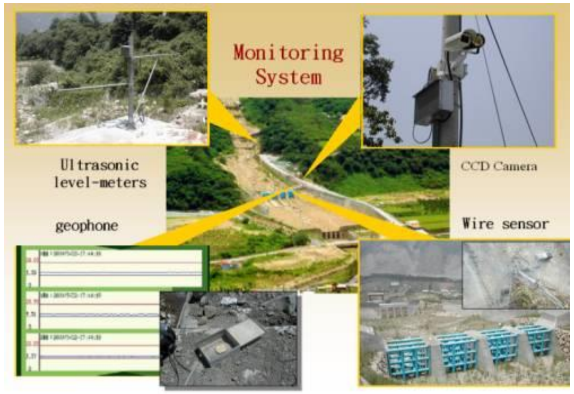
Disadvantage：Shortage of Evacuation time, Higher cost, It could not be installed entire area, so always got leakage.

(2). Pre-event Type

Using rainfall parameters to set the warning criteria.

Advantage： Lower Cost, Wide coverage, Extend evacuation time

Disadvantage： Lower Accurate, more false -alarms



Rainfall-based debris-flow warning model

Rainfall Triggering Index (RTI)

=Rainfall intensity × Effective accumulated rainfall

$$RTI = I \times R_t$$

Effective accumulated rainfall：

This accumulated rainfall + the effective accumulated rainfall of 7 days before

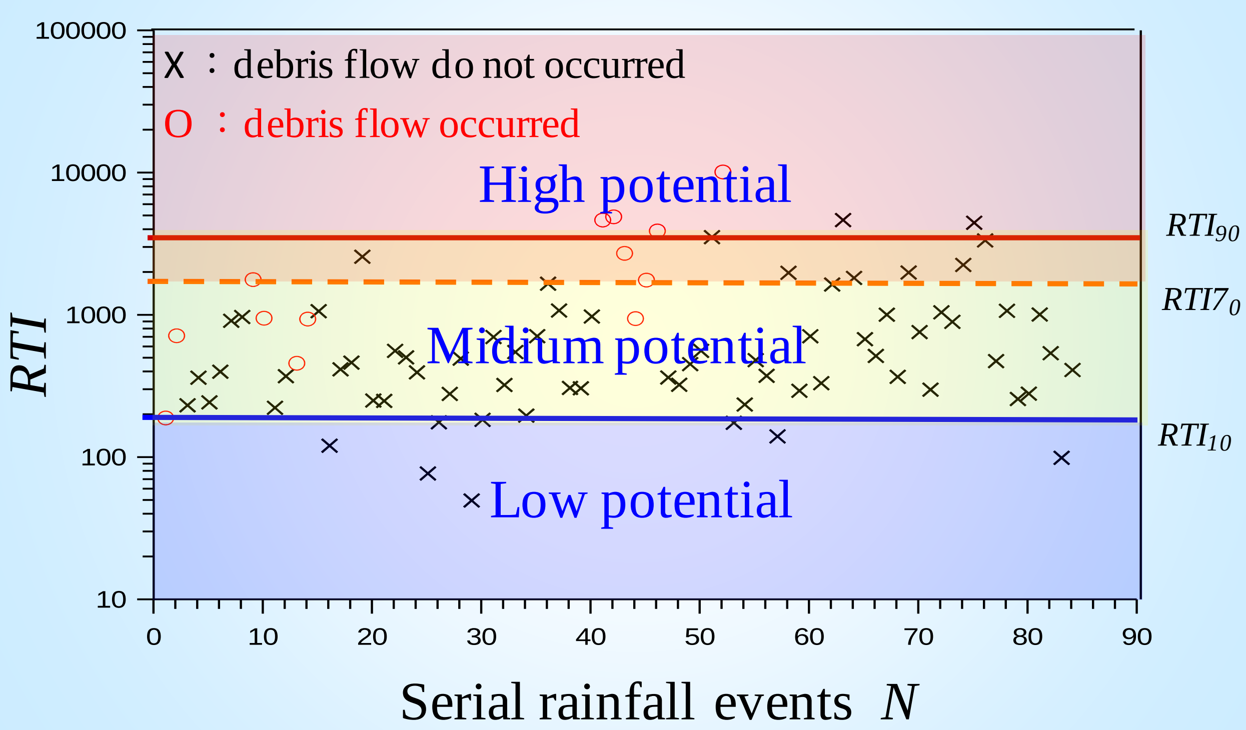
$$R_t(t) = R(t) + \sum_{i=1}^{7} 0.8^i \times R_i$$

Rainfall intensity

Rainfall Triggering Index

Determination of the critical RTI-values

The lower and upper critical RTI-values can be determined by historical rainfall data, and the occurrence potential for debris flow is classified into high, median and low potential.

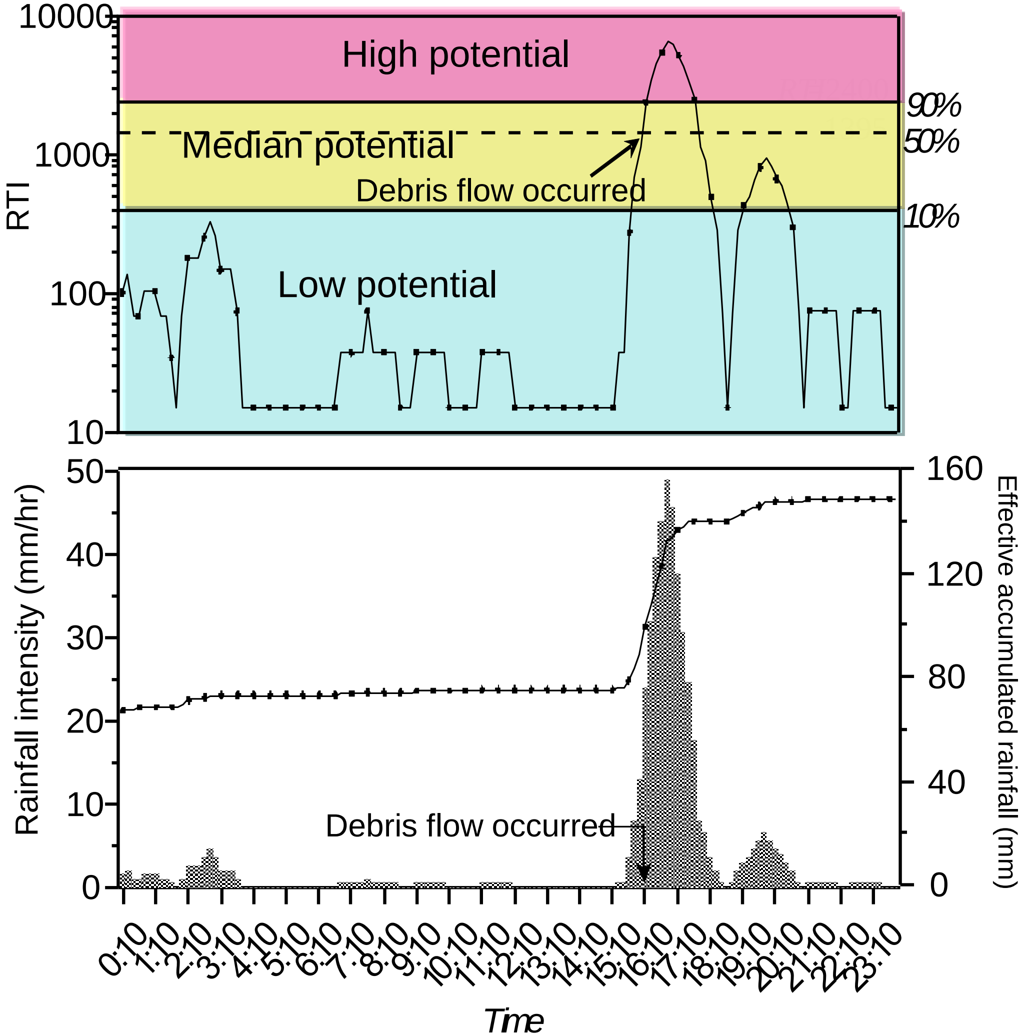


- ✓ A lower critical line (RTI_{10}) is defined as the lowest *RTI*-values of rainfall events that have triggered debris flows.
- ✓ An upper critical line (RTI_{90}) is defined as that 90% of *RTI*-values for all the historical rainfall events including have triggered or not triggered debris flows.
- ✓ The debris-flow occurrence probability within lower and upper critical lines

$$P(RTI) = 0.1 + 0.8\left(\frac{RTI - RTI_{10}}{RTI_{90} - RTI_{10}}\right)$$

Real-time assessment for debris-flow occurrence potential

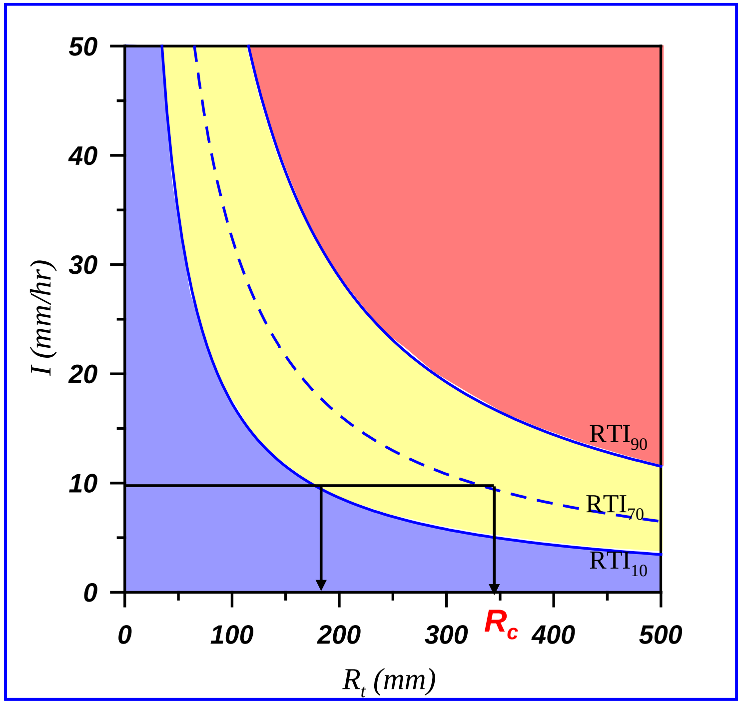
- ✓ If real-time rainfall data is available, the real-time RTI-values can be calculated and shown on the plot.
- ✓ Based on classification of high, middle and low potential for debris-flow occurrence, the real-time RTI values can express the temporal variations of debris-flow occurrence potential during a rainfall process.



Simplified debris-flow warning model

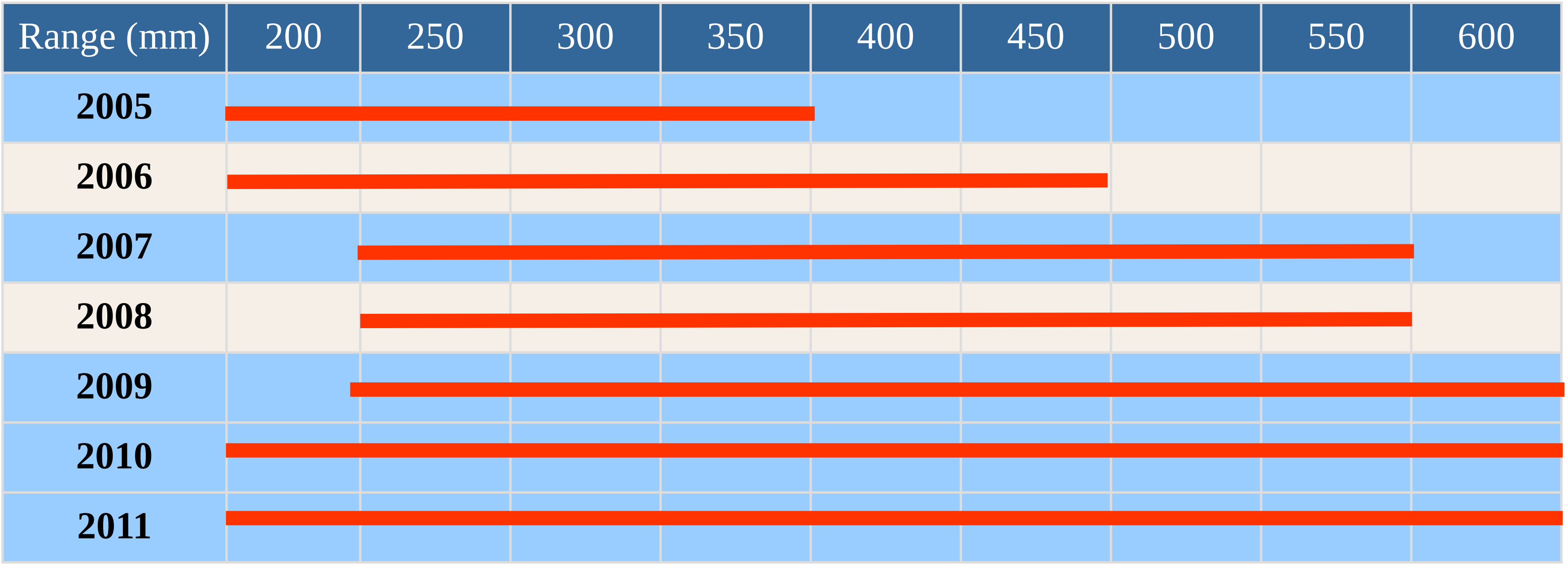
- ✓ The critical RTI-value involving two parameters (I and R) is academic and not easy be understood by the residents in mountainous areas.
- ✓ A critical accumulated rainfall is set for easier public understanding and local application for evacuation.

- Critical accumulated rainfall is estimated from the critical RTI-values with a consideration of rainfall intensity of 10 mm/hr, and rounded with 50mm as an interval of the critical accumulated rainfall.
- An upper limit of critical accumulated rainfall is set as 600 mm for safety.



Grades of debris-flow warning criteria

- ✓ The critical accumulated rainfall is applied by SWCB as the debris-flow warning criteria for every township.
- ✓ Debris-flow warning criteria for every township is classified into 9 grades which ranges from 200 mm~600 mm.



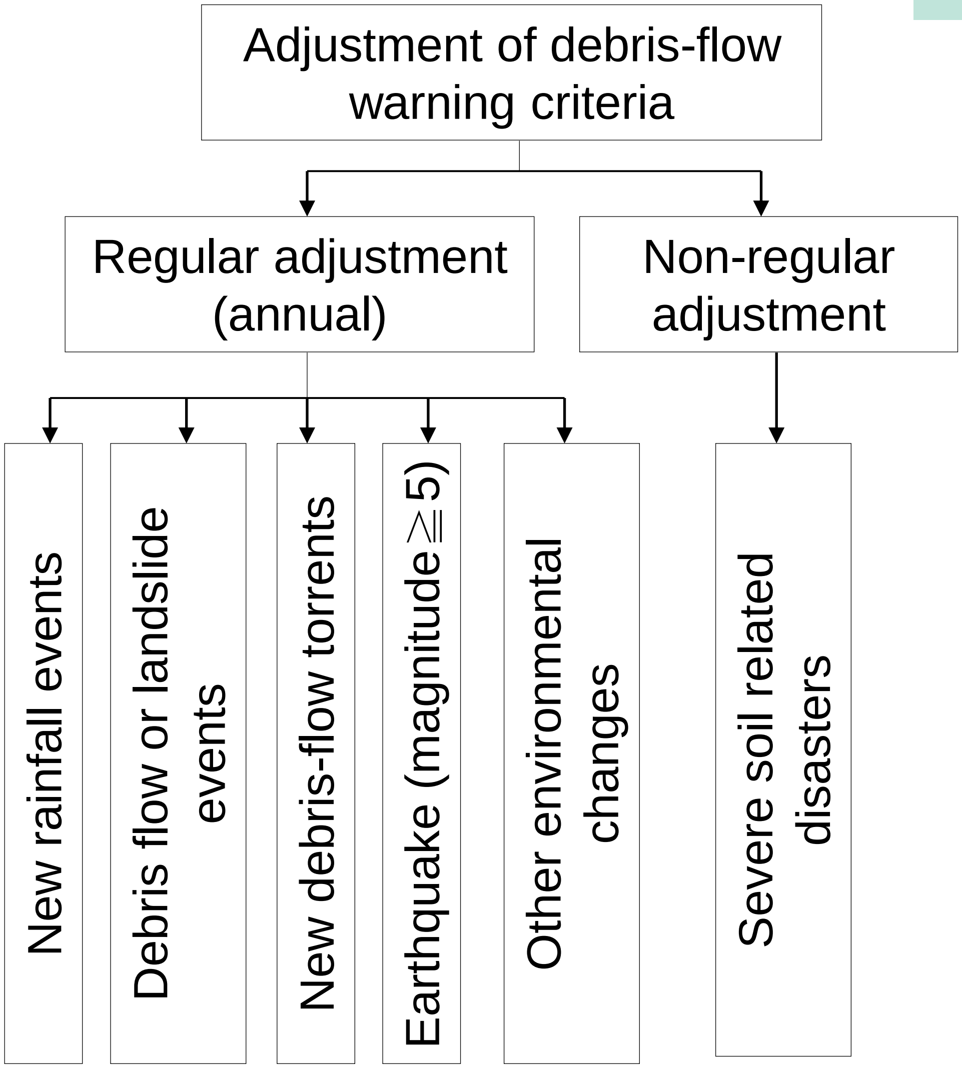
Physiographical conditions for different warning criteria

- ✓ Debris-flow warning criteria usually vary with the corresponding physiographic conditions of watershed.
- ✓ Lower debris-flow warning criteria usually represent more landslide rate or more fragile geological condition in watershed.

Warning criteria: 200(mm)	400(mm)	600(mm)
		
Kaohsiung DF007	Tainan DF033	Pintung DF055

Adjustment of debris-flow warning criteria

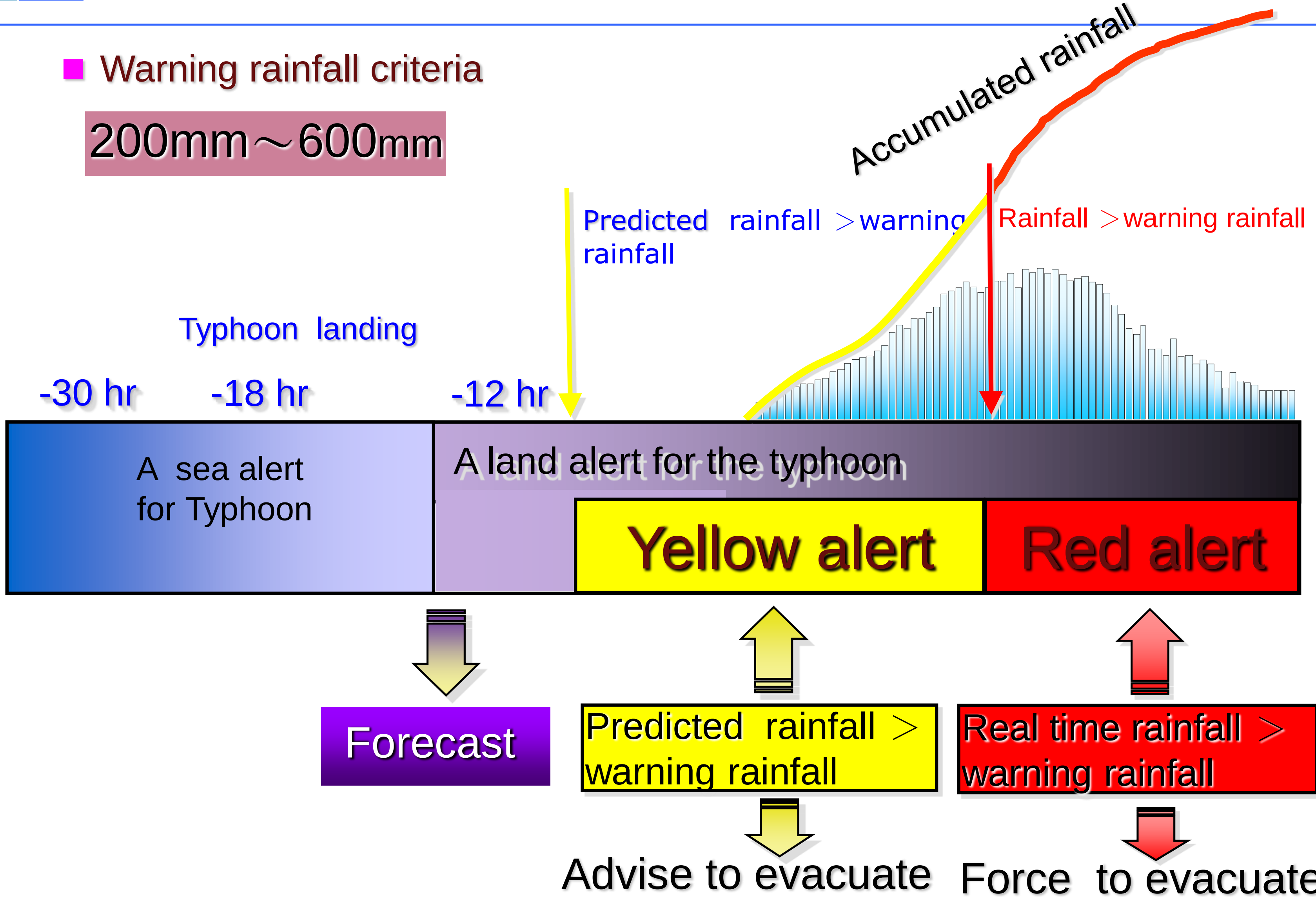
- ✓ Adjustment of debris-flow warning criteria in Taiwan can be classified into regular adjustment and non-regular adjustment.
- ✓ Regular adjustment will be carried on annually, with the considering of new rainfall events, debris-flow or landslide events, new debris-flow torrents, earthquake or the other environmental changes.
- ✓ Non-regular adjustment will be carried on after severe soil related disaster.



Announcement Debris-flow warning in Taiwan

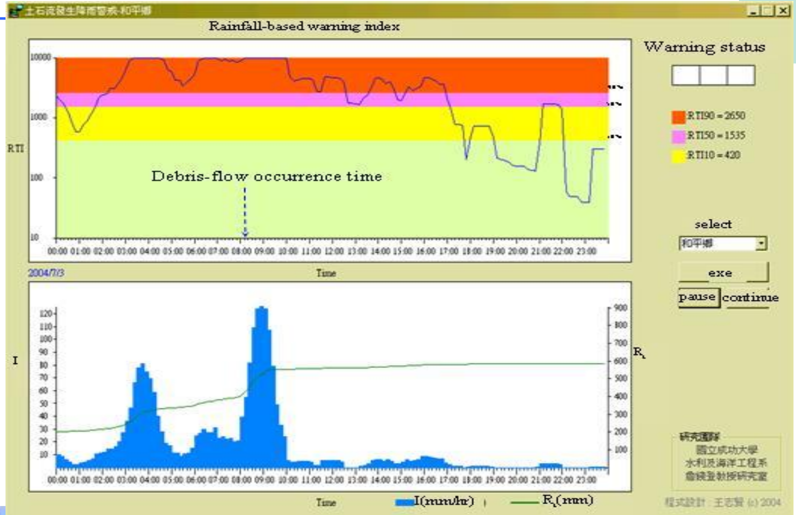
- Warning rainfall criteria

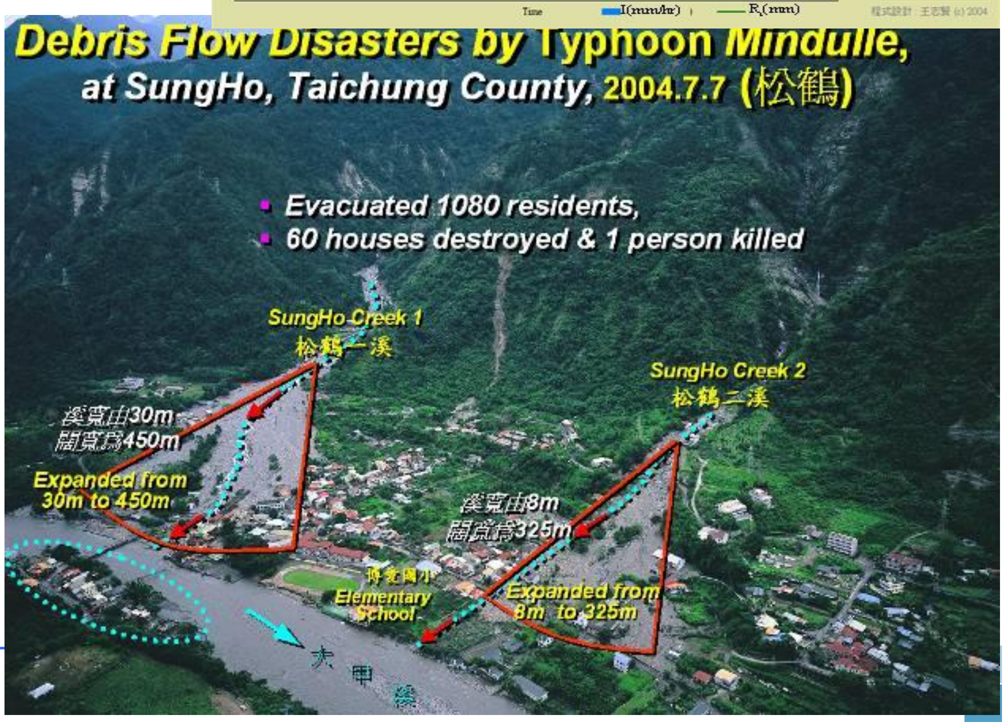
200mm～600mm



The case in Typhoon Mindulle

Event	：Typhoon Mindulle,2004
Occurred time	：About 08:30, July 3
Location	：Heping, Taichung
Warning criteria	：250mm
Pre-warning time	：10:50, July 2
Responding time	：about 21 hours

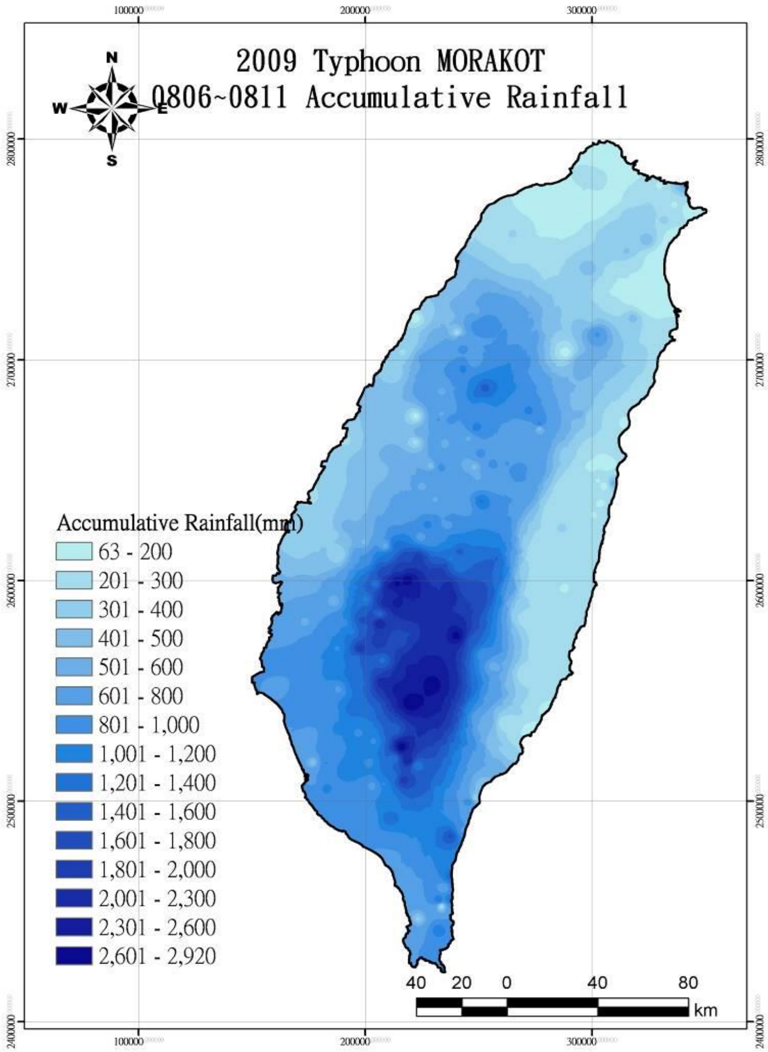




The rainfall of Typhoon Morakot in 2009

- Typhoon Morakot formed in on August 3, 2009, and struck Taiwan during August 7 to 10. The storm produced copious amounts of rainfall, peaking approached 3,000 mm, surpassing the previous record of 1,987 mm caused by Typhoon Herb in 1996.

- The extreme amount of rain triggered enormous mudslides, debris flow and severe flooding throughout southern Taiwan, especially the Kauhsiung county.



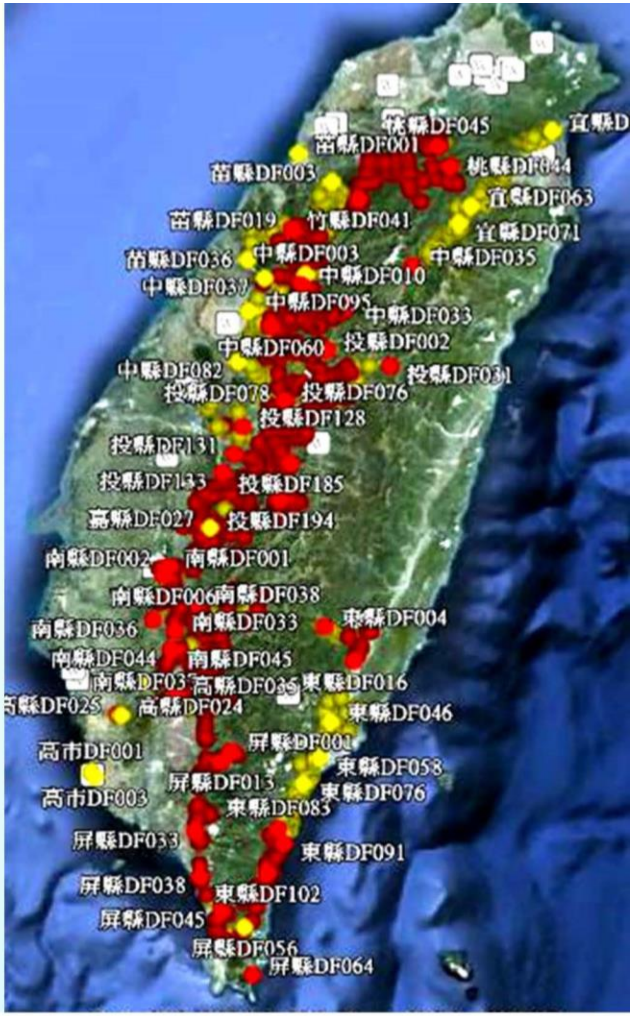
The cases in Typhoon Morakot

Debris Flow Warning and Evacuation

- During the **typhoon Morakot** period (2009), the SWCB had issued 21 debris flow warnings to the public and local governments based on the real-time weather information from CWB.

Debris flow warning	Warning ravines	County (City)	Town	Village
Red alarm	519	12	61	230
Yellow alarm	338	14	58	163

***9,100* people** were evacuated by local governments according to the warning. Among them, ***1,046* people** escaped from the possible casualties.



Debris flow warning efficiency

Efficiency of Debris Flow Warning Model

Warning Accuracy (%)

$$= \frac{\text{NO. of warning township with debris flow events}}{\text{NO. of warning township}}$$

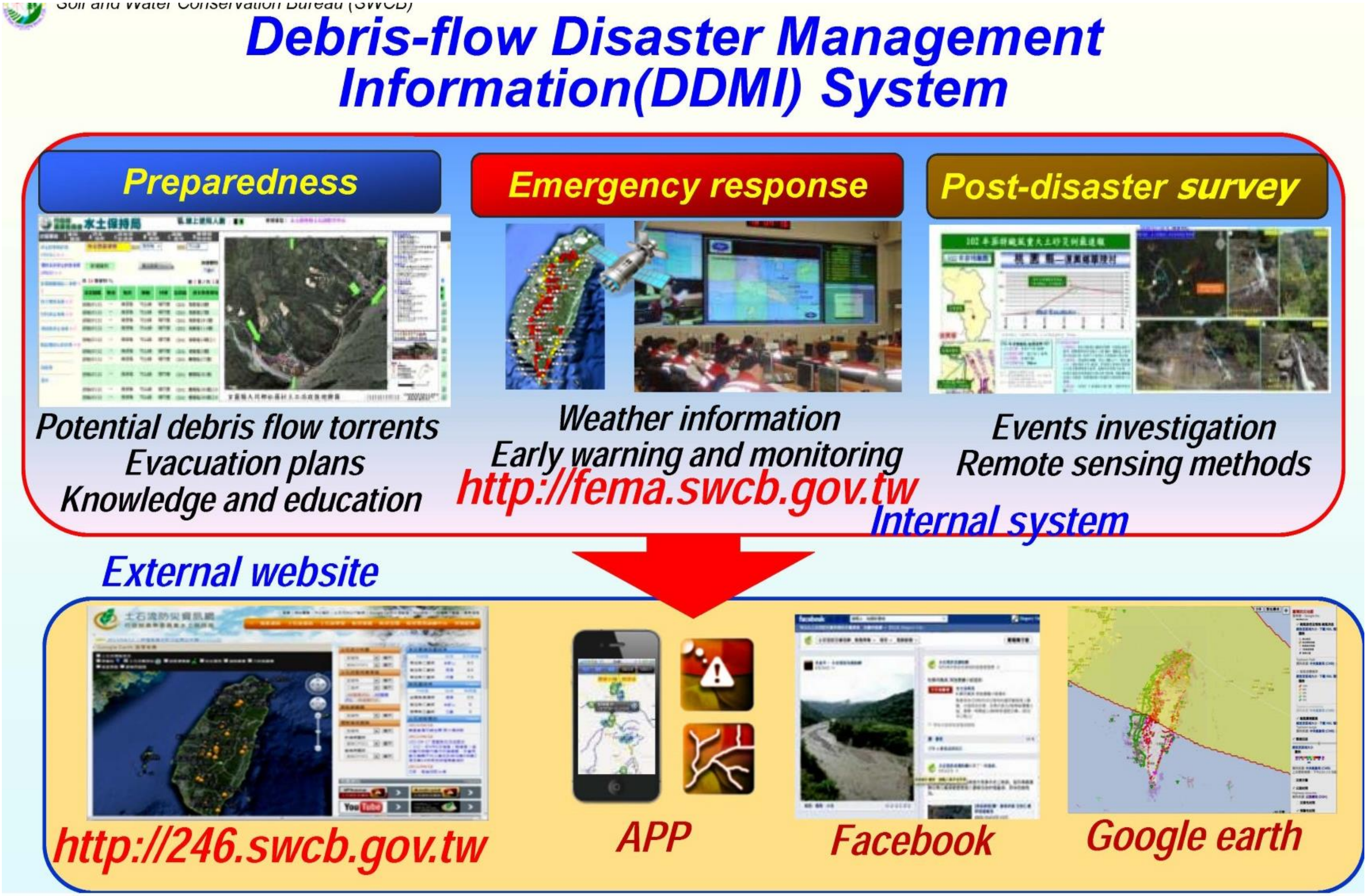
Warning Coverage (%)

$$= \frac{\text{NO. of debris flow events in warning areas}}{\text{NO. of debris flow events}}$$

From the historic statistics, the warning accuracy of typhoons is higher than torrential rain because of the different rainfall patterns.

Year	Accuracy (%)	Coverage (%)
2005	6.4	100
2006	9.1	100
2007	6.3	66.7
2008	9.1	100
2009	20.6	85.7
2010	11.5	81.8
2011	10.5	72.7
2012	7.2	92.3
2013	2.7	100
Average	9.3	89.0

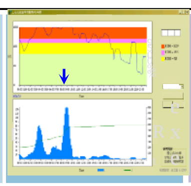
A Web-based Decision Support System for Debris Flow Disaster Management in Taiwan

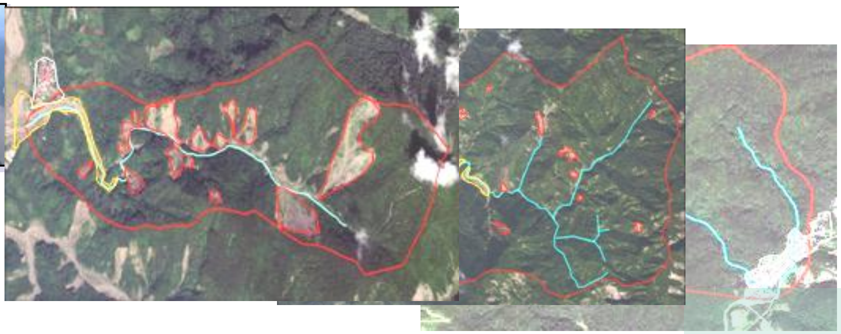


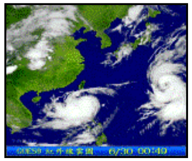
Conclusions

1. Activities on debris-flow disaster reduction have been started since 1990 after severe debris flow caused by Typhoon Ofelia.
2. The web-based decision support system for Debris-flow Disaster Management has been developed. The system integrates various kinds of information and provides the most important decision-making support for various levels of governments in Taiwan.
3. The rainfall-based debris flow warning model has been proved to be effective for evacuation operation. The warning coverage is high but the accuracy is still needed to be improved.
4. Education and evacuation practice are very important in debris-flow disaster reduction.
5. The up-to-date rainfall prediction techniques such as QPESUMS and ETQPF have been tried to be adopted for improving debris flow warnings and evacuation practice in Taiwan.


Thank You for
Your Attention







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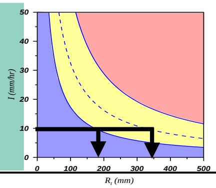
I (mm/hr)
R_t (mm)
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10
20
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