Debris Flow Disaster Management in Taiwan

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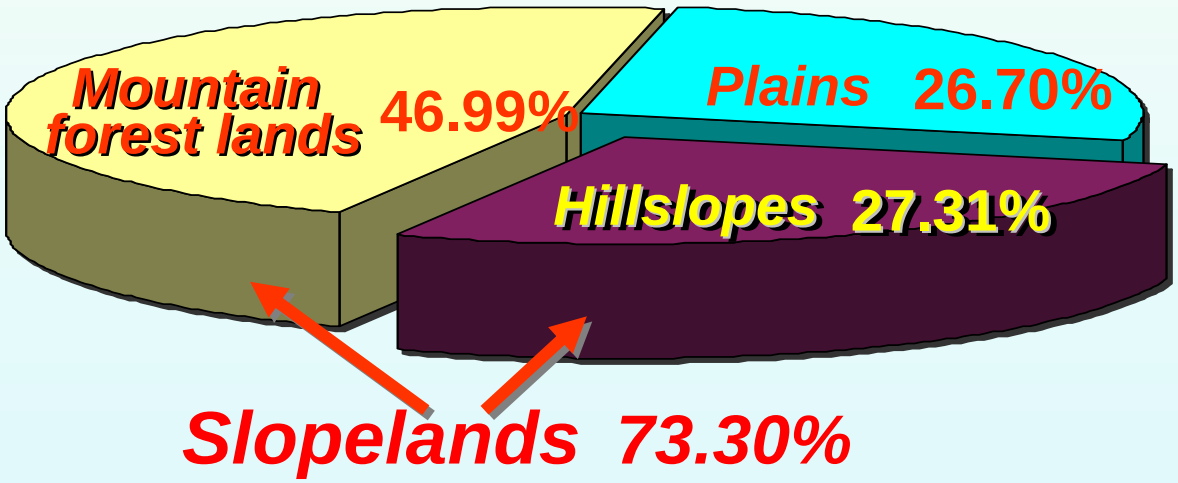
Outline

1. Background
2. Disaster Preparedness, Emergency Response and Post-Disaster Recovery
3. Identification and Zoning of Potential Debris Flow Torrent
4. Future Development and Perspective

1. Background

Introduction

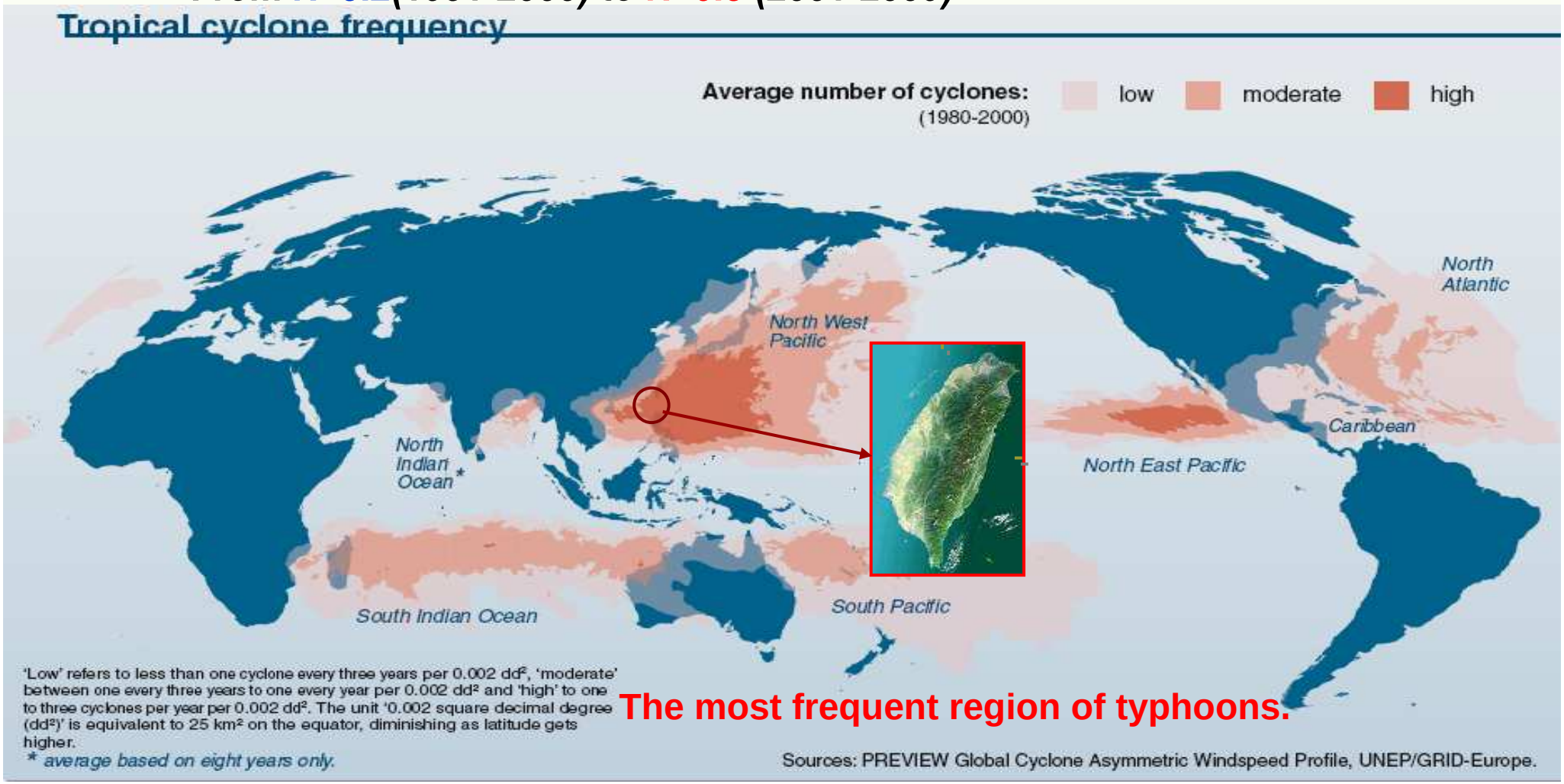
Taiwan is located at the convergent boundary of the Eurasian Plate and the Philippine Sea Plate.



Land Resources Distribution

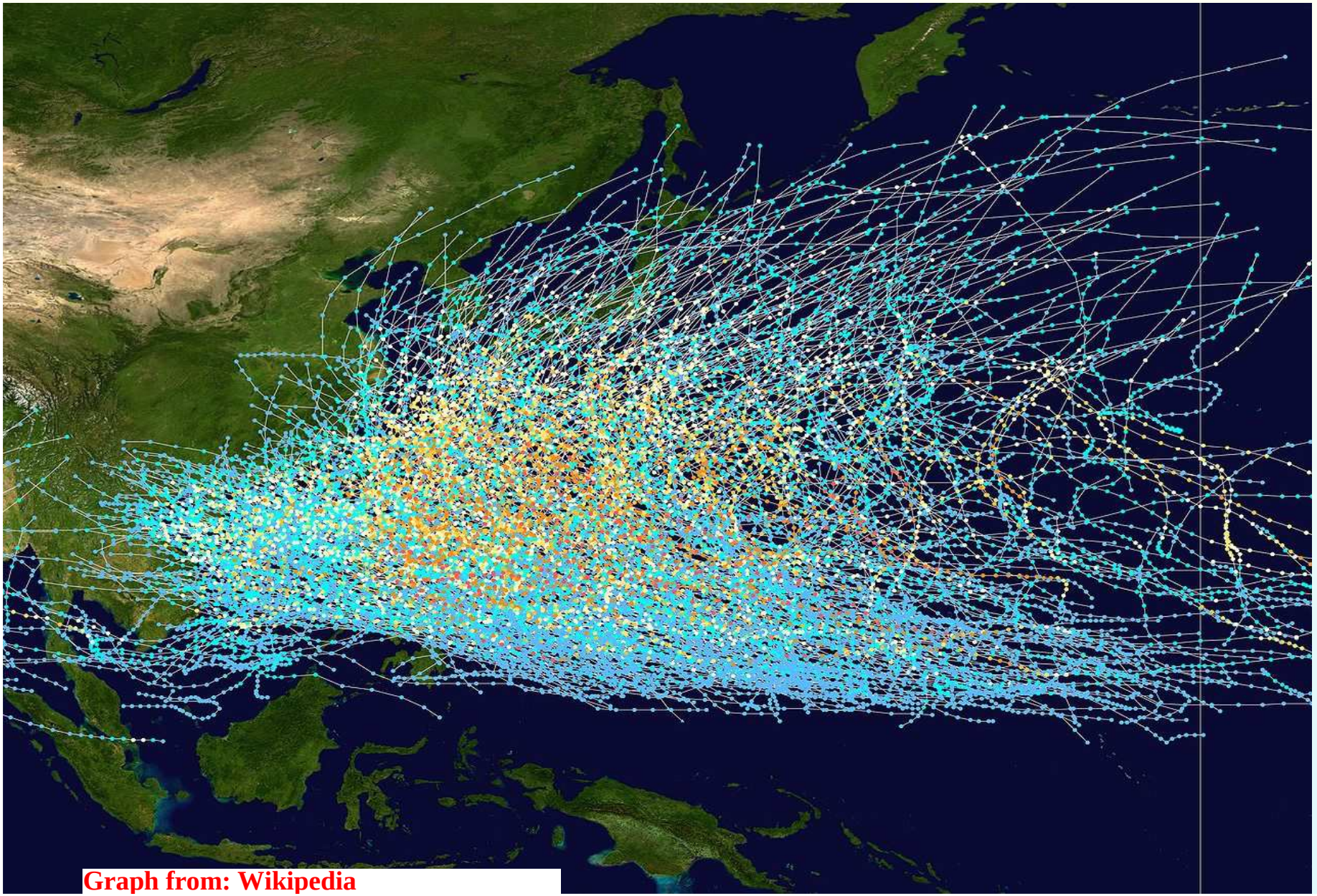
Climate Change Impact

- Temperature increases about 1.4℃ in the last 100 years (1901-2006).
- Number of typhoons per year increased dramatically after 2000.
  From N=3.2(1951-2000) to N=6.8 (2001-2009)



The most frequent region of typhoons.

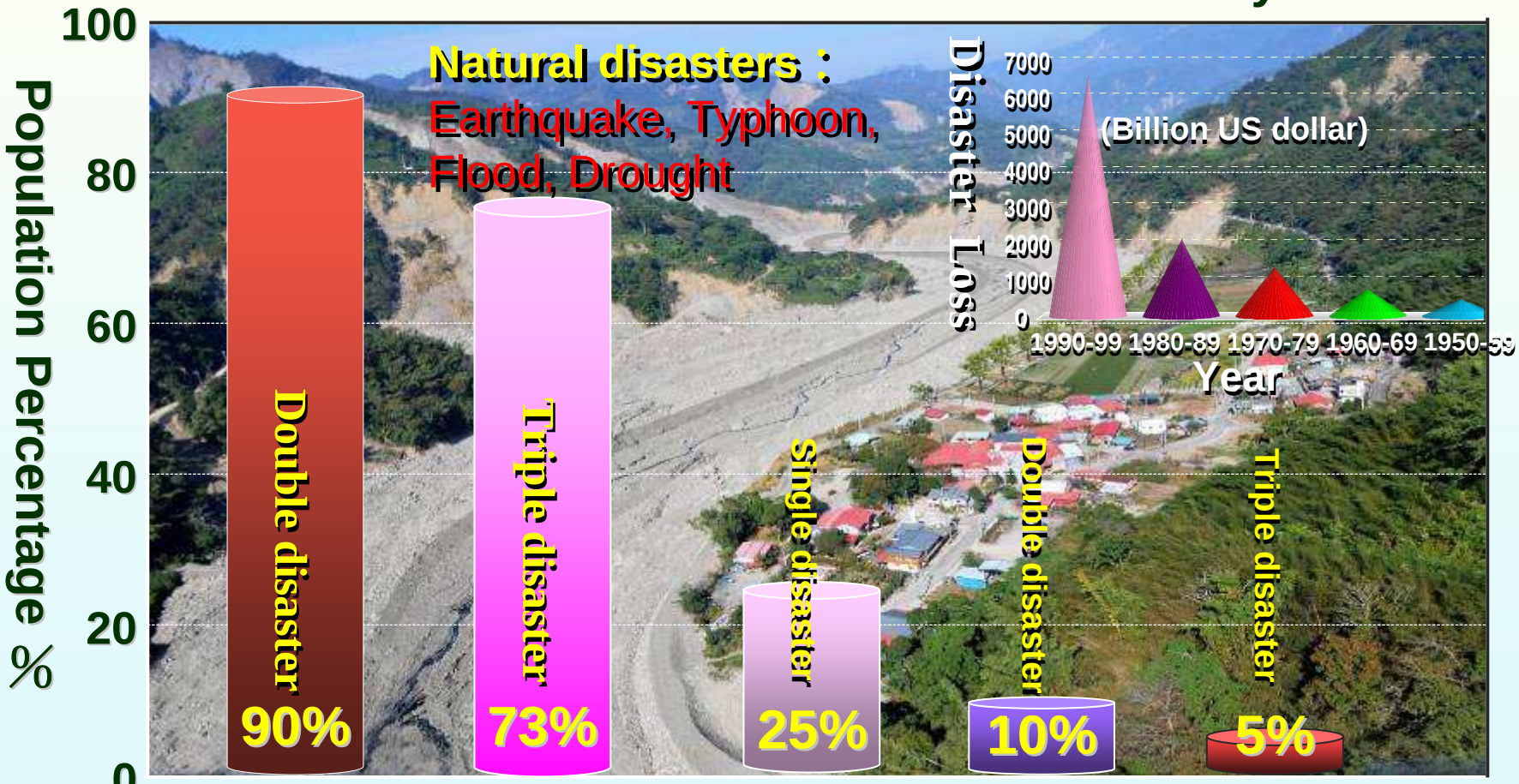
Pacific typhoon tracks 1980-2005



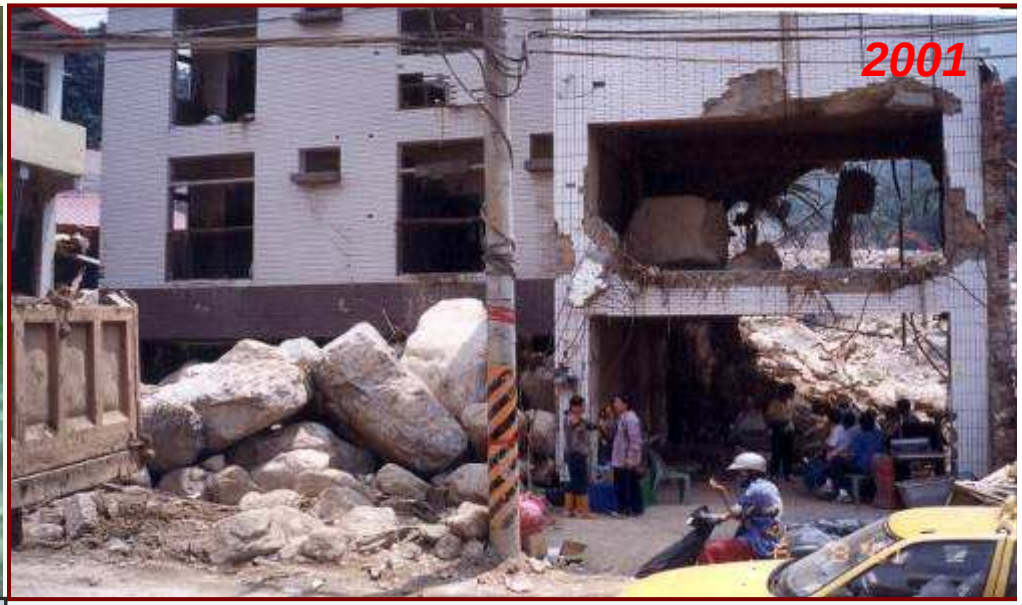
Graph from: Wikipedia

Taiwan –
Relatively High Vulnerability In the World

- World Bank (2005)：Natural Disaster Hotspots
  - A Global Risk Analysis



Debris Flow Disasters in Taiwan



Compound hazards

at Xiao-lin Village, Chia-xien, Kaohsiung County:

- Flooding
- Shallow landslide
- Debris flow
- Deep landslide
- Landslide barrier dam
- Dam bursting

- Dead and missing: 457 people
- Rainfall accumulated: 2,076mm
- landslide coverage area: 350 ha
- Sediment yield of Landslide:$9.5 \times 10^6 m^3$

2. Disaster Preparedness, Emergency Response and Post-Disaster Recovery

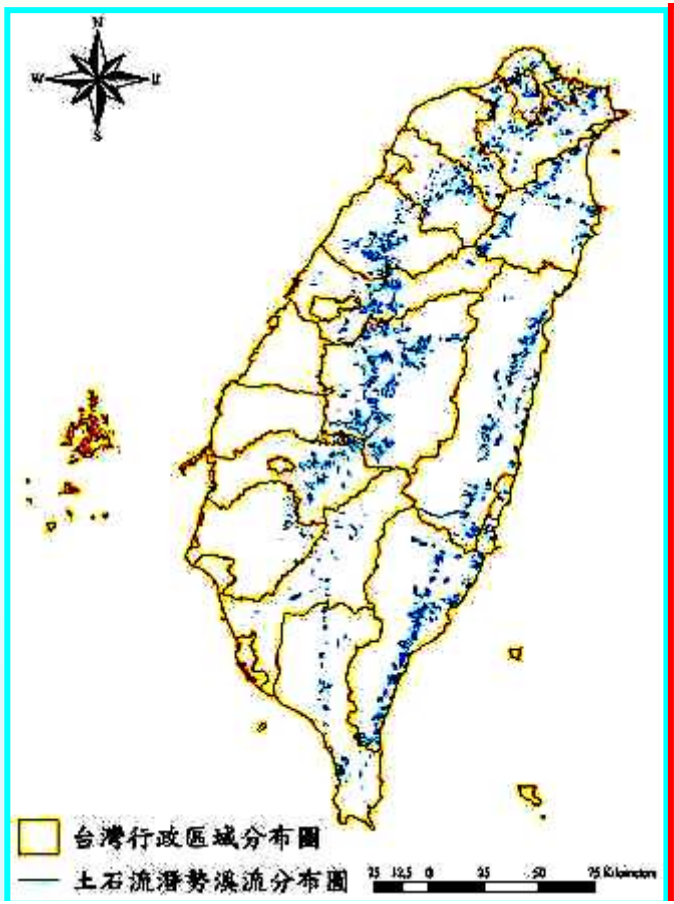
Debris Flow Disaster Management

Hazard Response and Prediction

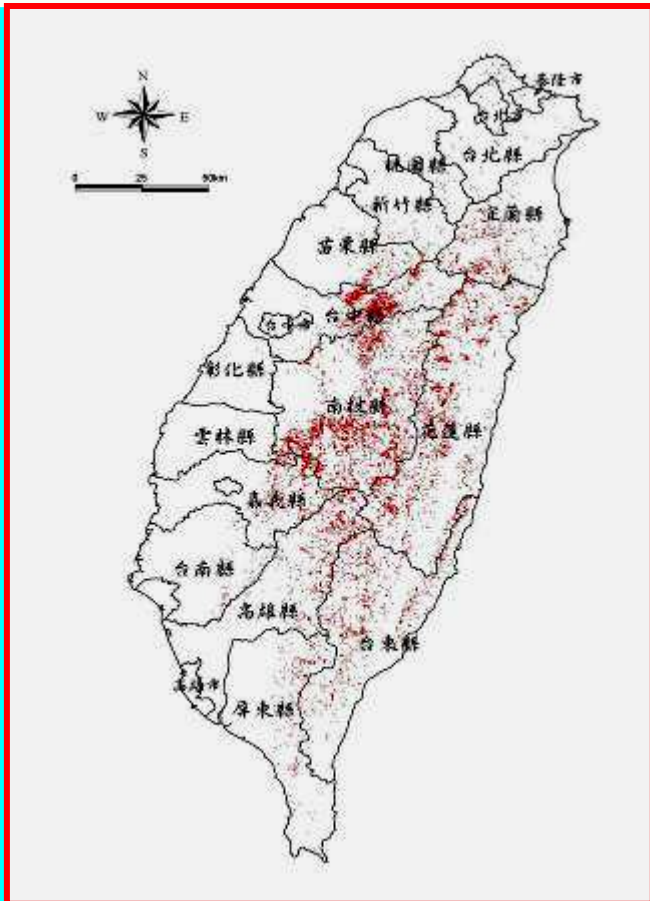
Investigation of Potential Debris Flow Torrents & Landslides

- **Potential Debris Flow Torrents**
  1,660 Torrents
- **Landslide Areas**
  58,944 ha

Potential Debris Flow Torrents



Historic Landslides Distribution



Investigation & Evaluation of Vulnerability of Village

✓ Village-based Investigation

- Village-based investigation to delimit the coverage of all types of hazard.
- The hazard of village often take place on different topographical interface.

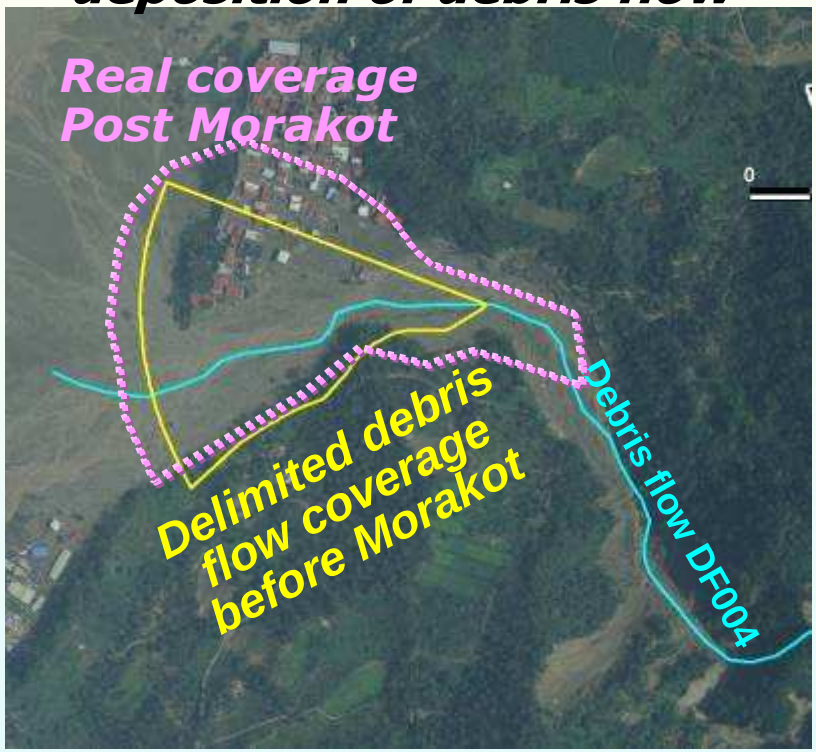
✓ Vulnerability Factors

- Types of Hazard:
  - Valley-wise: Debris Flow
  - Slope-wise: Landslide
  - River Terrace: Erosion

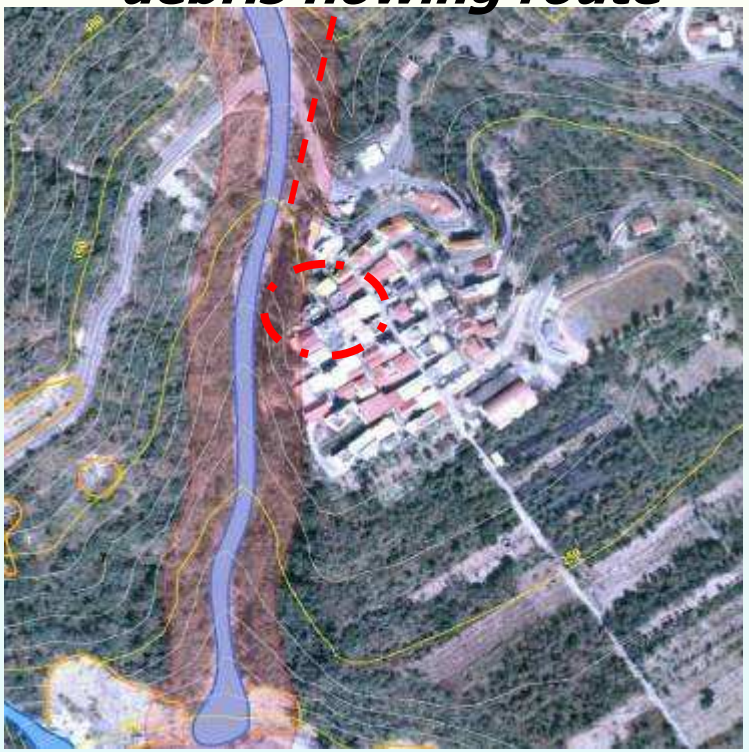
✓ Influential Area Estimate

✓Vulnerability Factor of Debris Flow

To check the coverage of deposition of debris flow



To evaluate the coverage of debris flowing route



✓**Coverage Area of debris flow Disaster:**

- After Typh. Morakot: By satellite image processing, 49 additional debris flows (44 caused by Typh. Morakot) are identified and there will be 1,552 debris flows in total in Taiwan.

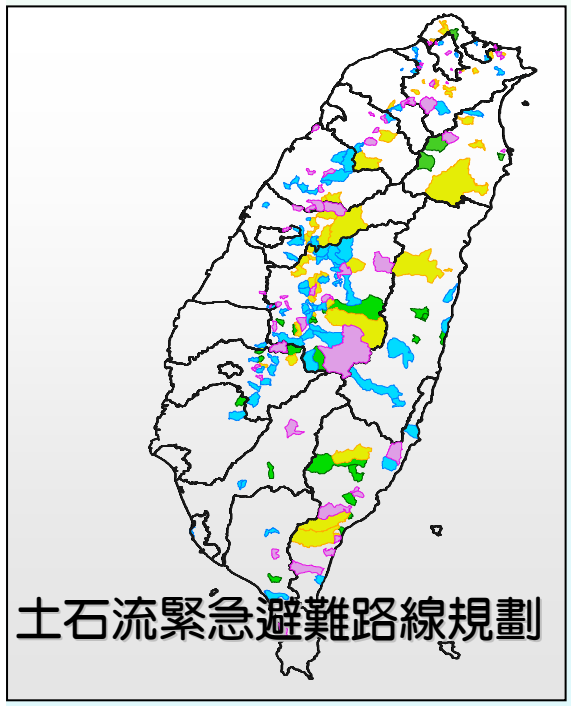
✓**Potential hazard area:** determined by geology investigation and site reconnaissance.

Evacuation Routes and Drills for Debris Flow Disaster Mitigation

- 662 Evacuation routes planned
- 600 debris flow evacuation drills held
- 1336 Debris Flow Volunteer Specialists

Debris Flow Volunteer Specialist

Location of Evacuation Projects



Evacuation Route Map

Debris Flow Disaster Prevention in Education

Localized Rainfall-based Debris-flow Warning Model

➢ Rainfall Triggering Index (RTI)

＝Rainfall intensity × Effective accumulated rainfall

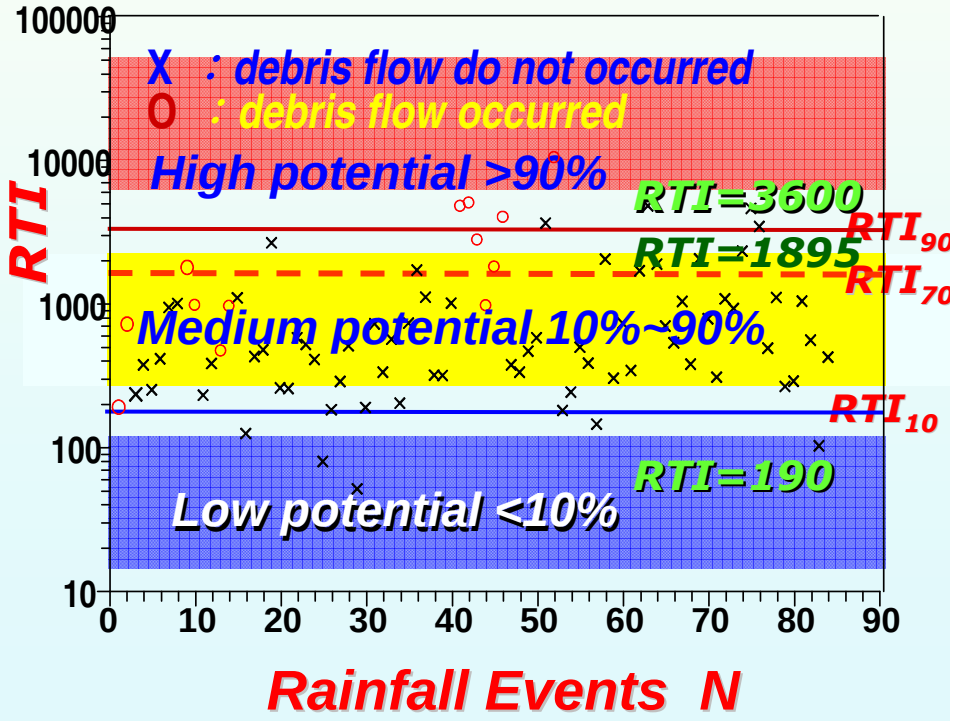
$$RTI = I \quad R_t$$

R_t : Effective accumulated rainfall
= Accumulated rainfall
Preceding rainfall for 7 days

I : Rainfall intensity (mm/hr)

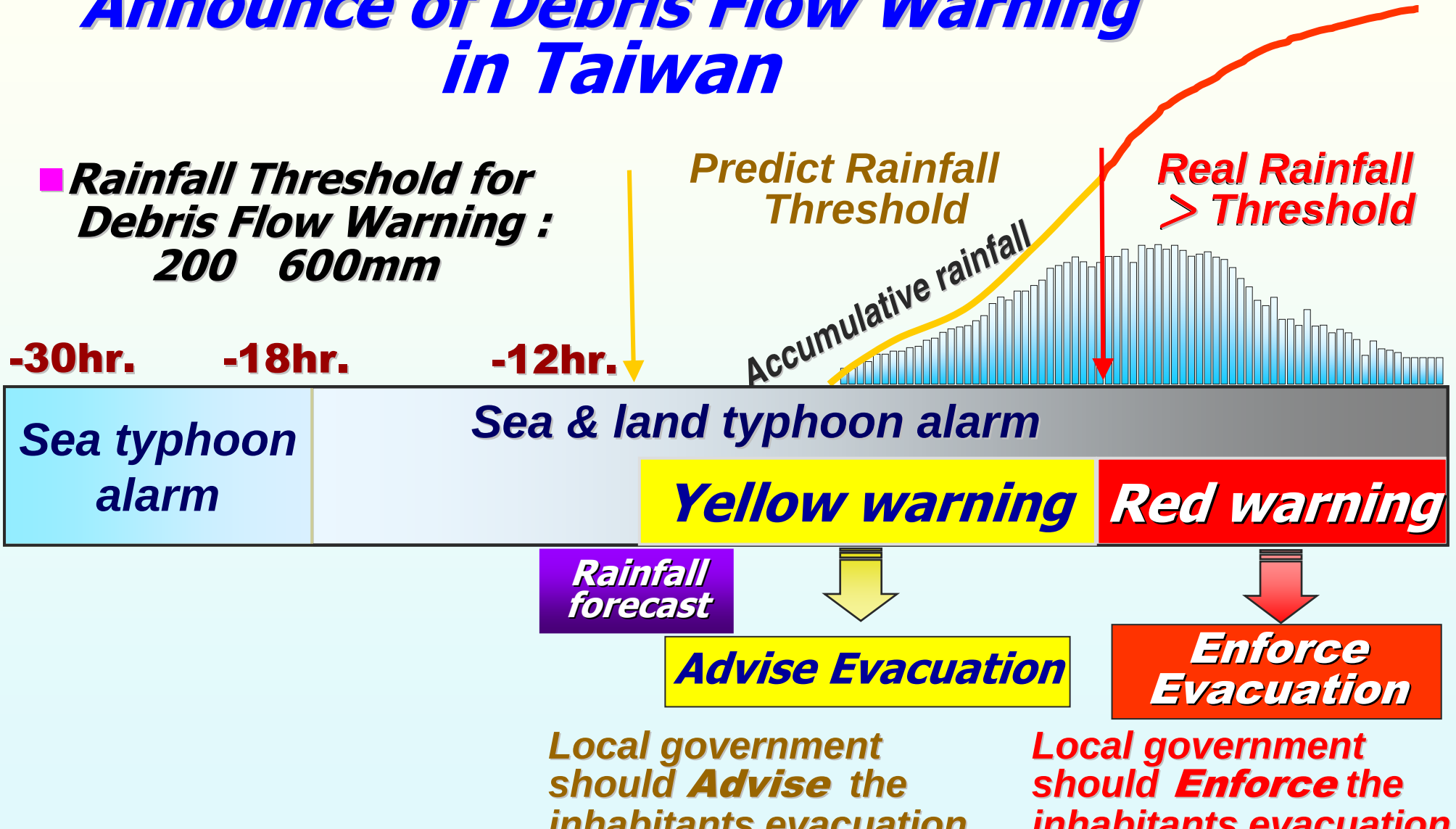
RTI_{70} : RTI at 70% of probability that debris flow occurred

- The critical accumulated rainfall for evacuation (Rc) is set for easier public understanding and local application



Announce of Debris Flow Warning in Taiwan

- **Rainfall Threshold for Debris Flow Warning : 200 600mm**



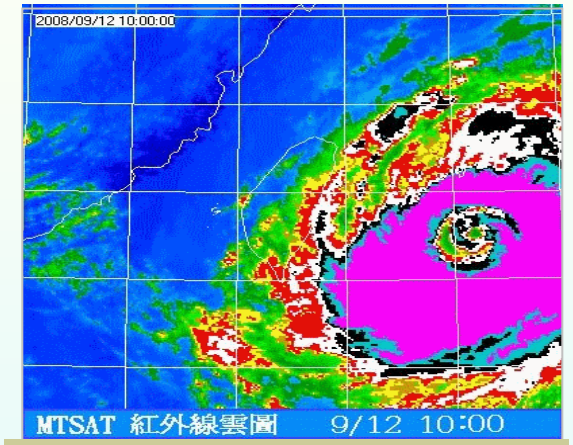
Debris Flow Emergency Operation Center of SWCB

Emergency Response during Typhoon

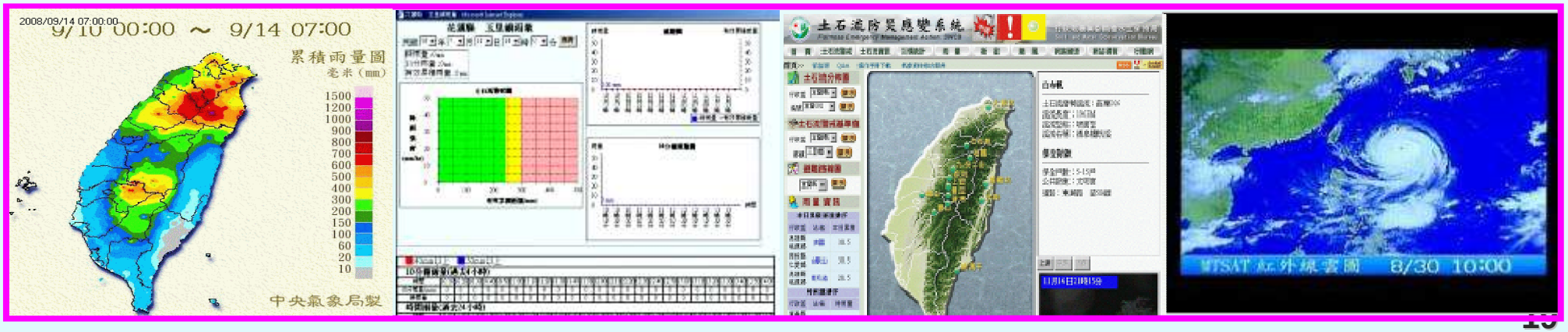
Toll-free Hotline

0800-246-246

- **Rainfall monitoring: Every 10 min.**
- **Typhoon: Cloud satellite image**
- **Announce: Debris Flow Warning**
- **Inform emergency messengers**
- **Heavy equipments standby at dangerous areas**

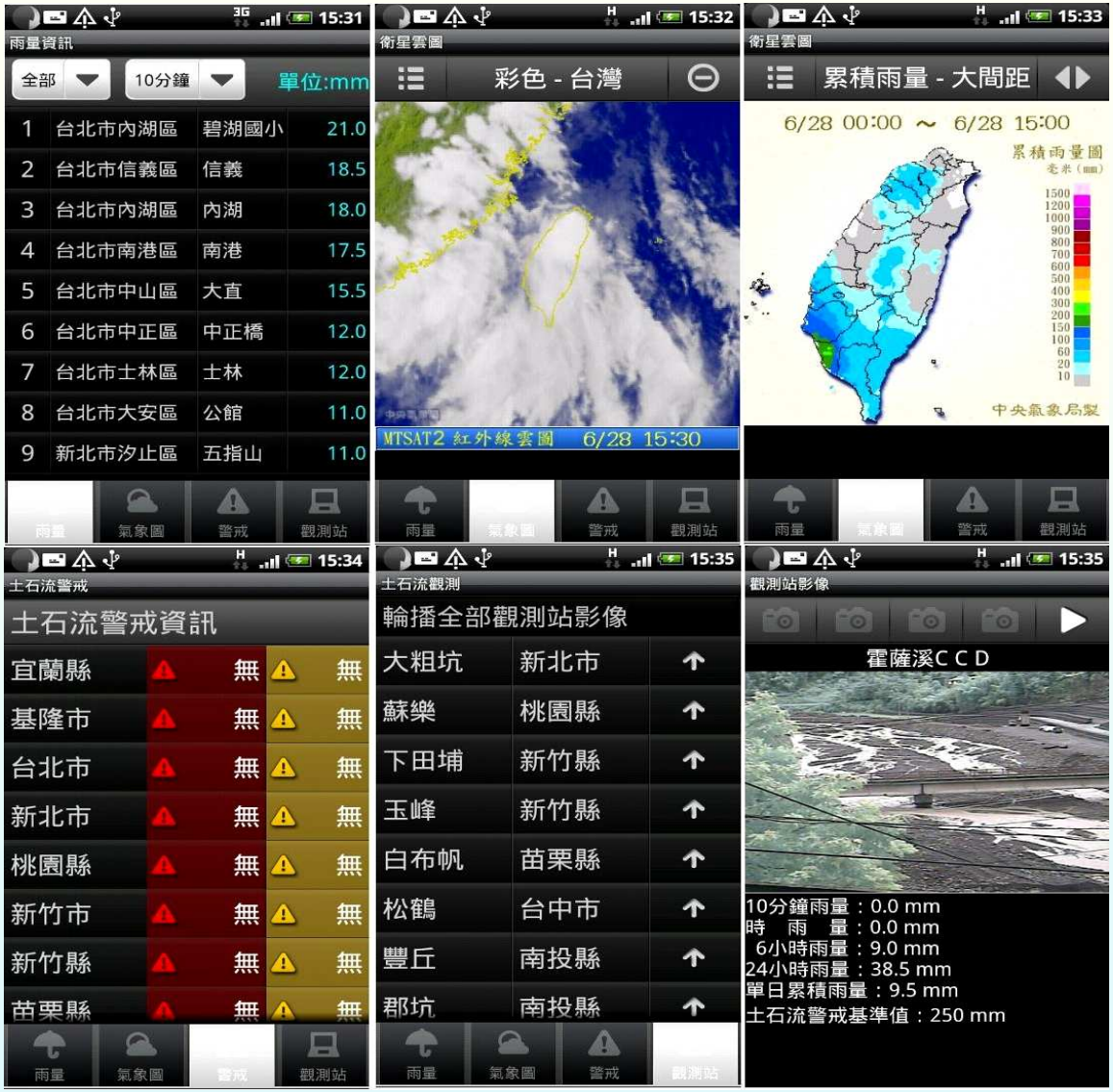


Cloud Satellite Image of Sinlaku Typhoon



Application of Smartphone (APPs for iOS & Android system)

- Realtime information :
  - Rainfall
  - Satellite image
  - Announce of Debris Flow Warning
  - Data of debris flow monitoring stations
- It lets residents easily know when to evacuate, and helps government to making decision anywhere



Debris Flow Warning and Evacuation

- During the typhoon Morakot period, 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.

Successful Evacuation

Shinshan village, Nantou County

*Although **21 houses** were destroyed by flash flood and debris flows, the **village head Ms. Mei-Ling Lin** (**also the debris flow volunteer specialist**) successfully evacuated **135 villagers** according to the red alarm issued by the COA (SWCB). No one got hurt. At least **63 people** escaped from the possible casualties.*

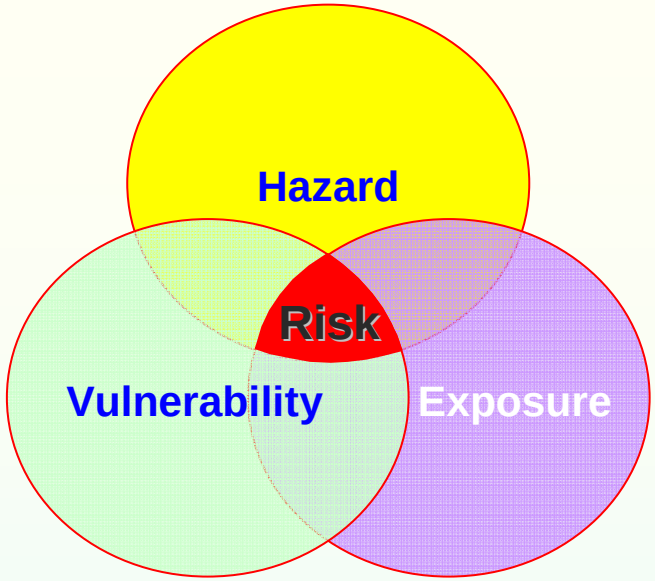
President Ma highly praised the village head

3. Identification and Zoning of Potential Debris Flow Torrent

✓ DEBRIS FLOW

Water and mixture of sand, gravel, cobbles and boulders, driven by gravity

Look just like ready-mixed concrete



■Safety: acceptable risk

Debris flow≠Debris flow hazard

- Debris flow: **natural phenomenon**
- The phenomenon could not be **eliminated**
- Only when hazard likely to occurred that **mitigation** should apply
- Still long way for **accurate forecast**

Conditions of debris flow triggering

Rain

Debris

Slope

Debris Flow

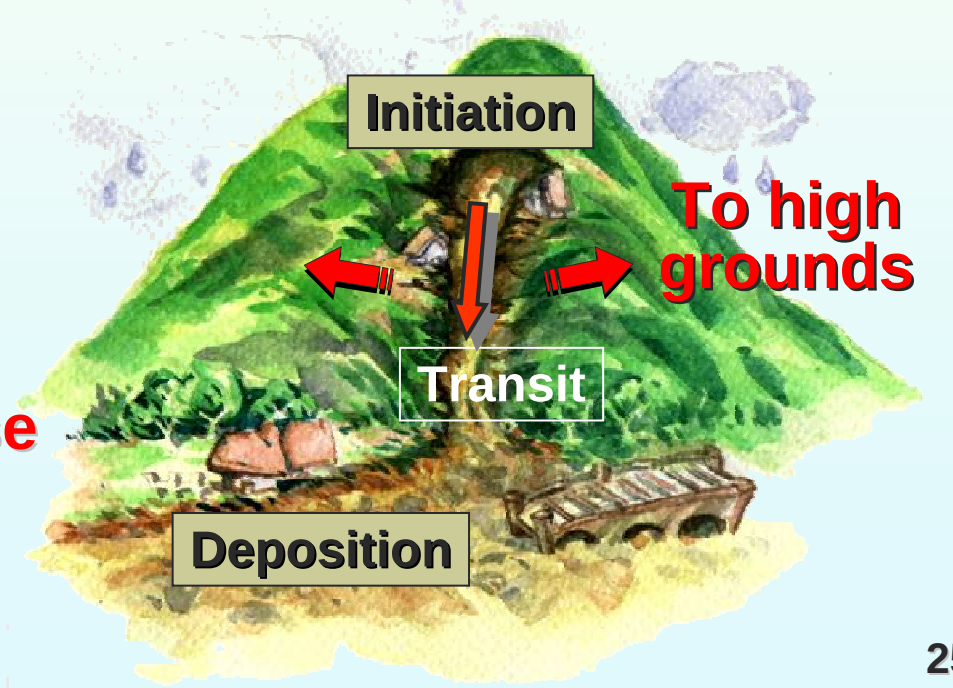
Water and mixture of sand, gravel, cobbles and boulders, driven by gravity

Danger zones

- Landslide area
- Torrent banks
- Alluvial fan

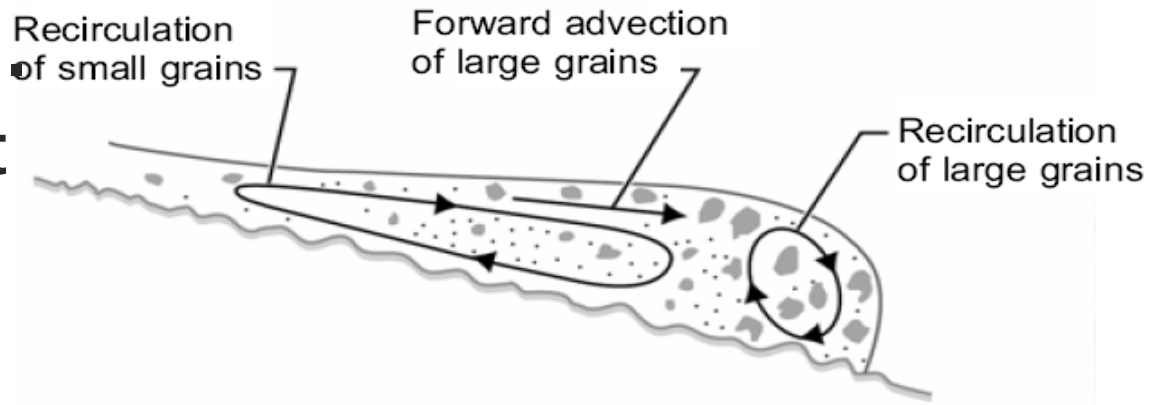
Signs of debris flow

- ✓ Strange humming in the mountains (Listen)
- ✓ Extremely muddy (Visual)
- ✓ Water level sudden decrease (Visual)
- ✓ Stinky smells (Smell)
- ✓ Ground vibration (Feel)

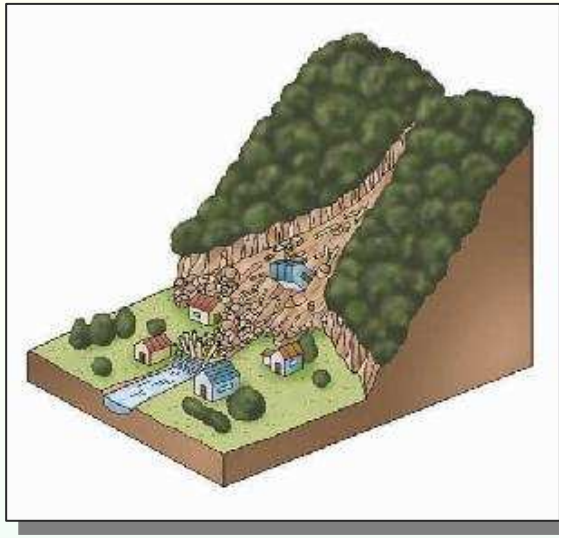


Characteristic of debris flow

- **High velocity** (2~20m/s), high impact force.
- **Head with boulder front,** followed by hyper-concentrated flow.
- **Larger size at top, smaller size at bottom**
- **Initiation** area mostly at slope above 15~30 , deposition area 3~6
- **Alluvial fan** formed at torrent exit, gentle slope area.



Types of debris flow

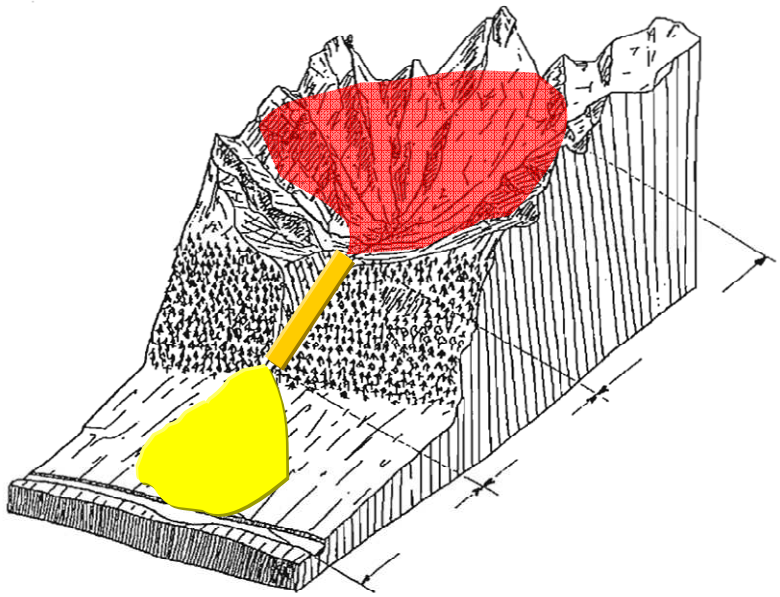


- **Mud flow:** 2~20m/sec (72km/hr)
- **Granular flow**: 3~10m/sec (36km/hr)

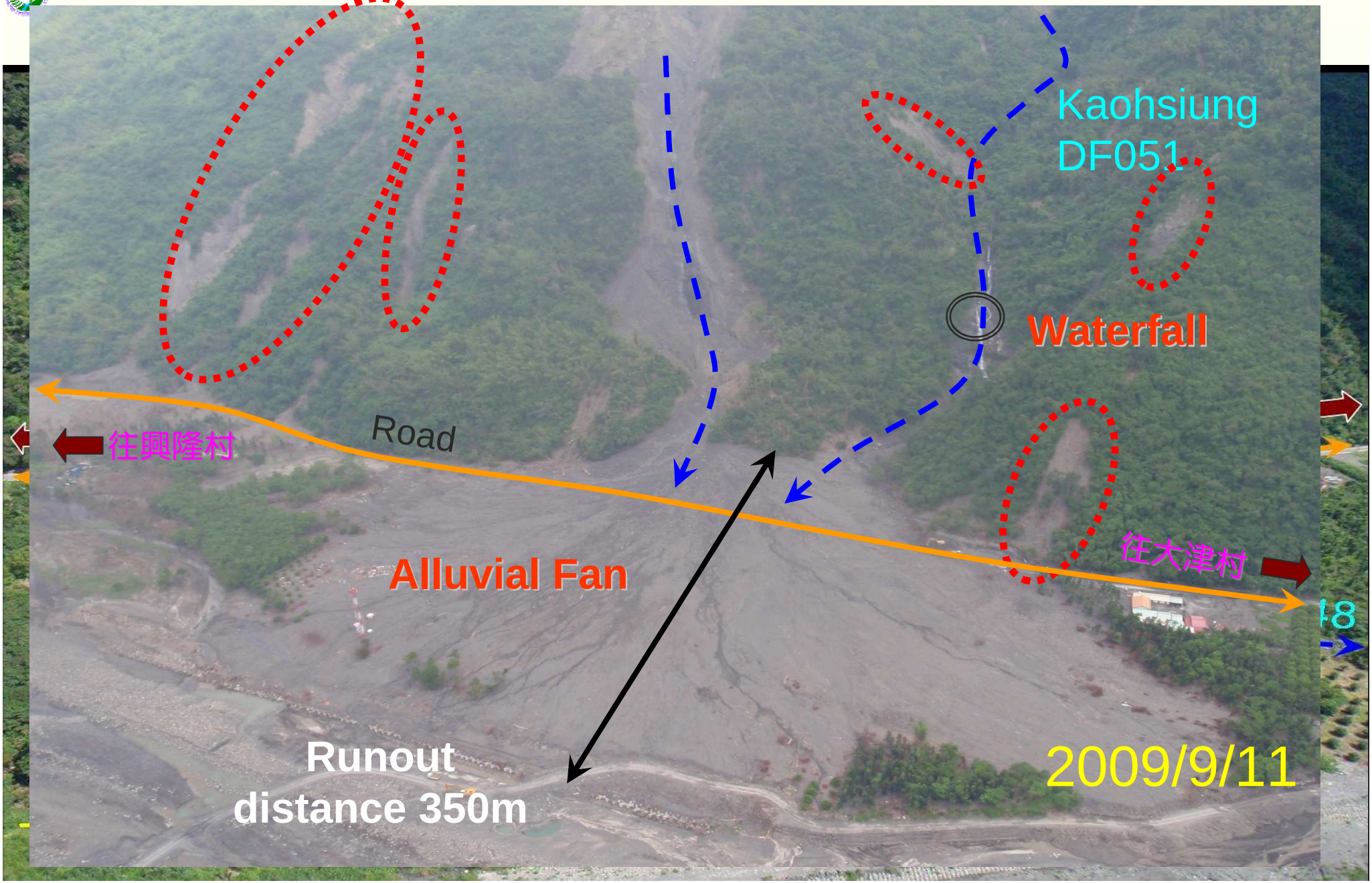
Development of Debris Flow System

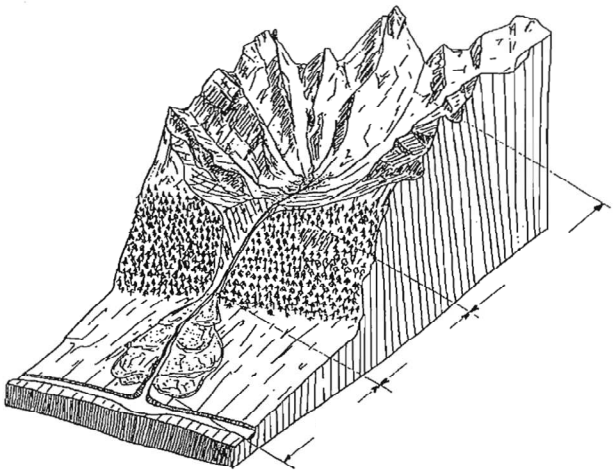
- ✓**Initiation zone:** **Steep slope failure in the headwall or side slope of a gully or stream channel. Mostly forms a V-shape; the vegetation around often appear sparse, for a large amount of landslide fragments accumulate here.**

- ✓**Transit zone: U-shape, usually located in the valley or the middle and lower reaches of the river, and there are debris that collapsed from both side of the valley on the riverbank.**
- ✓**Deposition zone: Once the flow reaches a flatter or less confined area, it will spread out, lose speed and deposit.**



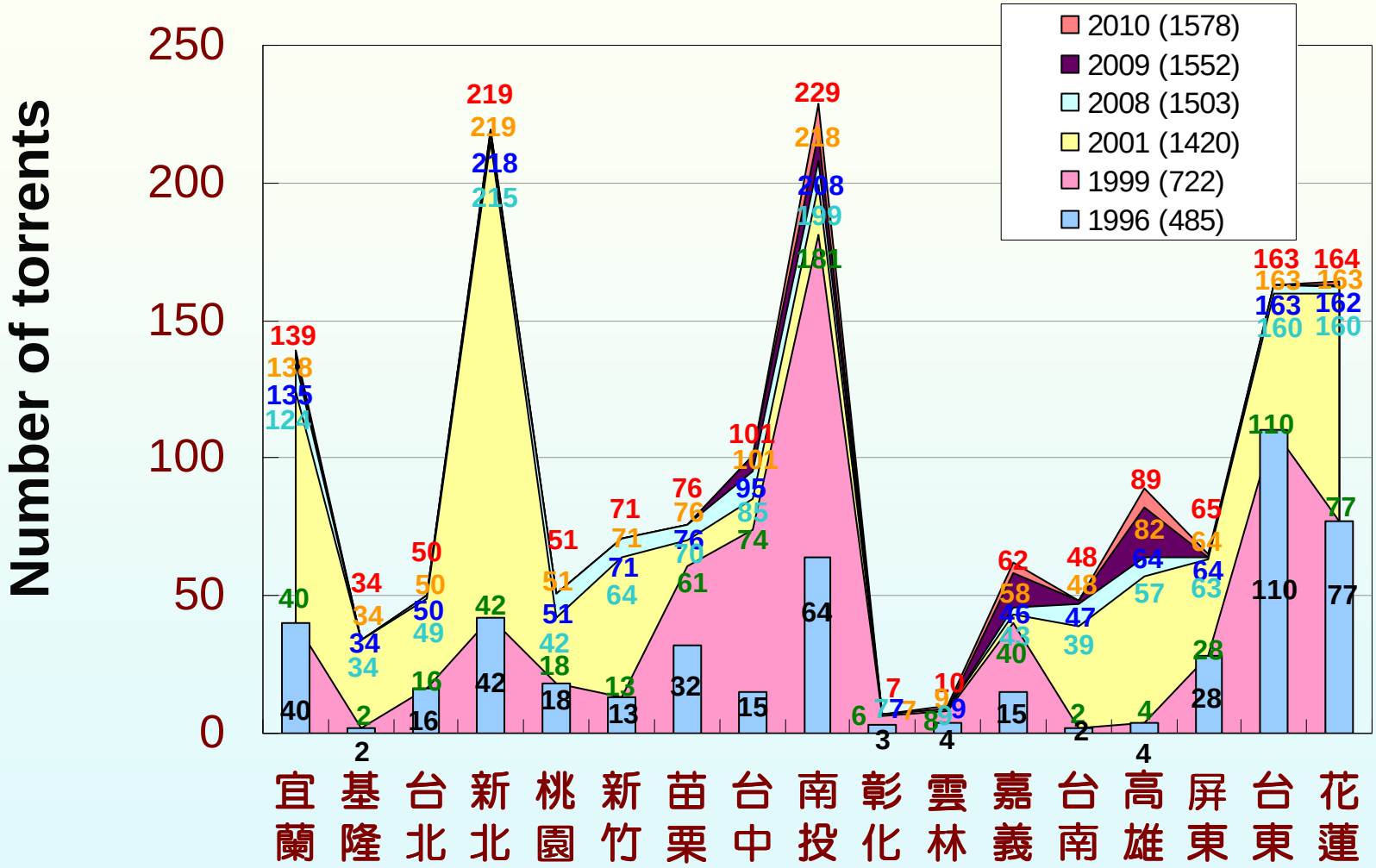
(redraw from Weber, 1964)


Kaohsiung
DF051
Waterfall
往興隆村
Road
往大津村
Alluvial Fan
Runout
distance 350m
2009/9/11



Exam

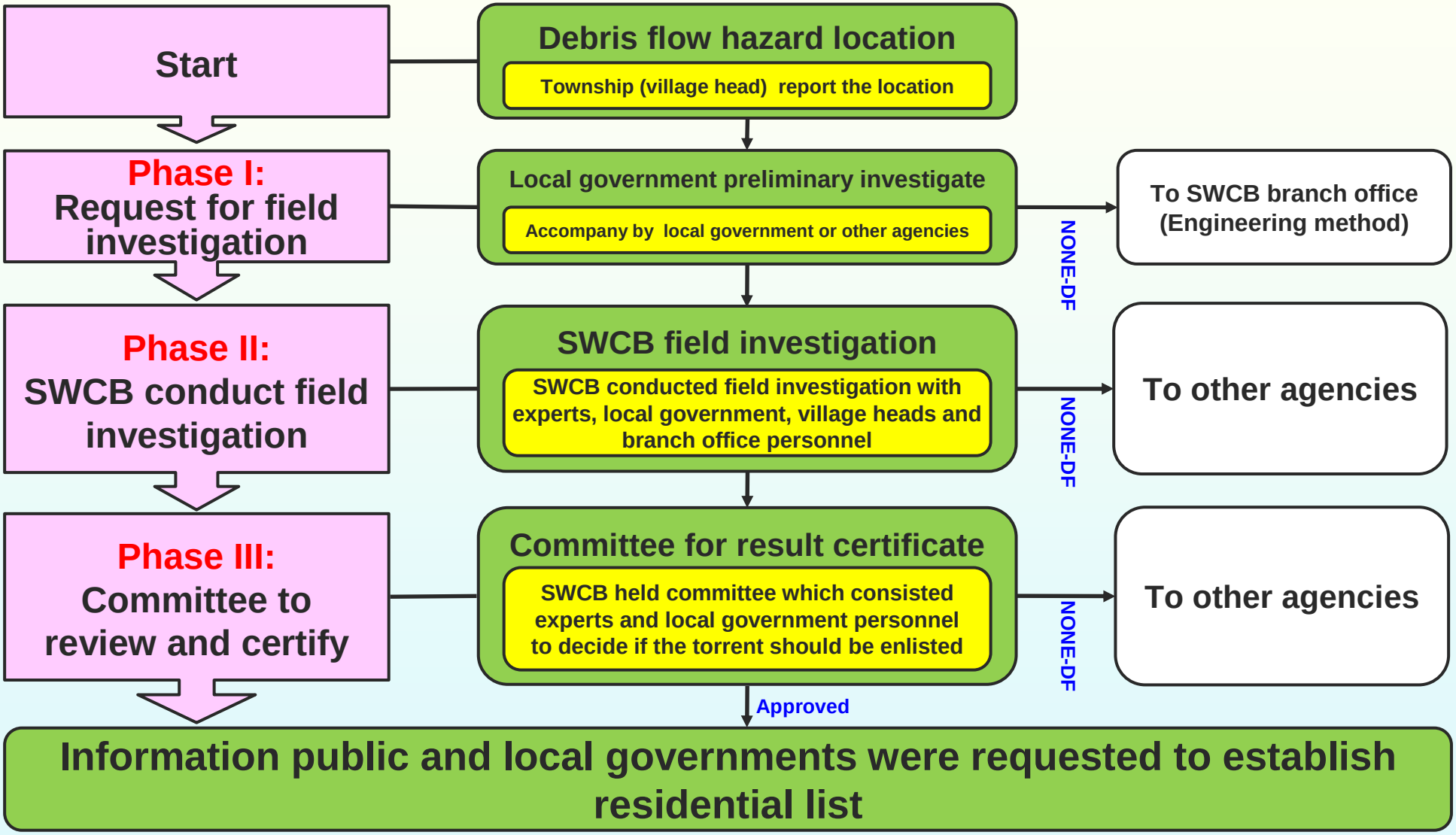
✓Distribution of debris flow torrents



Procedure of identify potential debris flow torrents

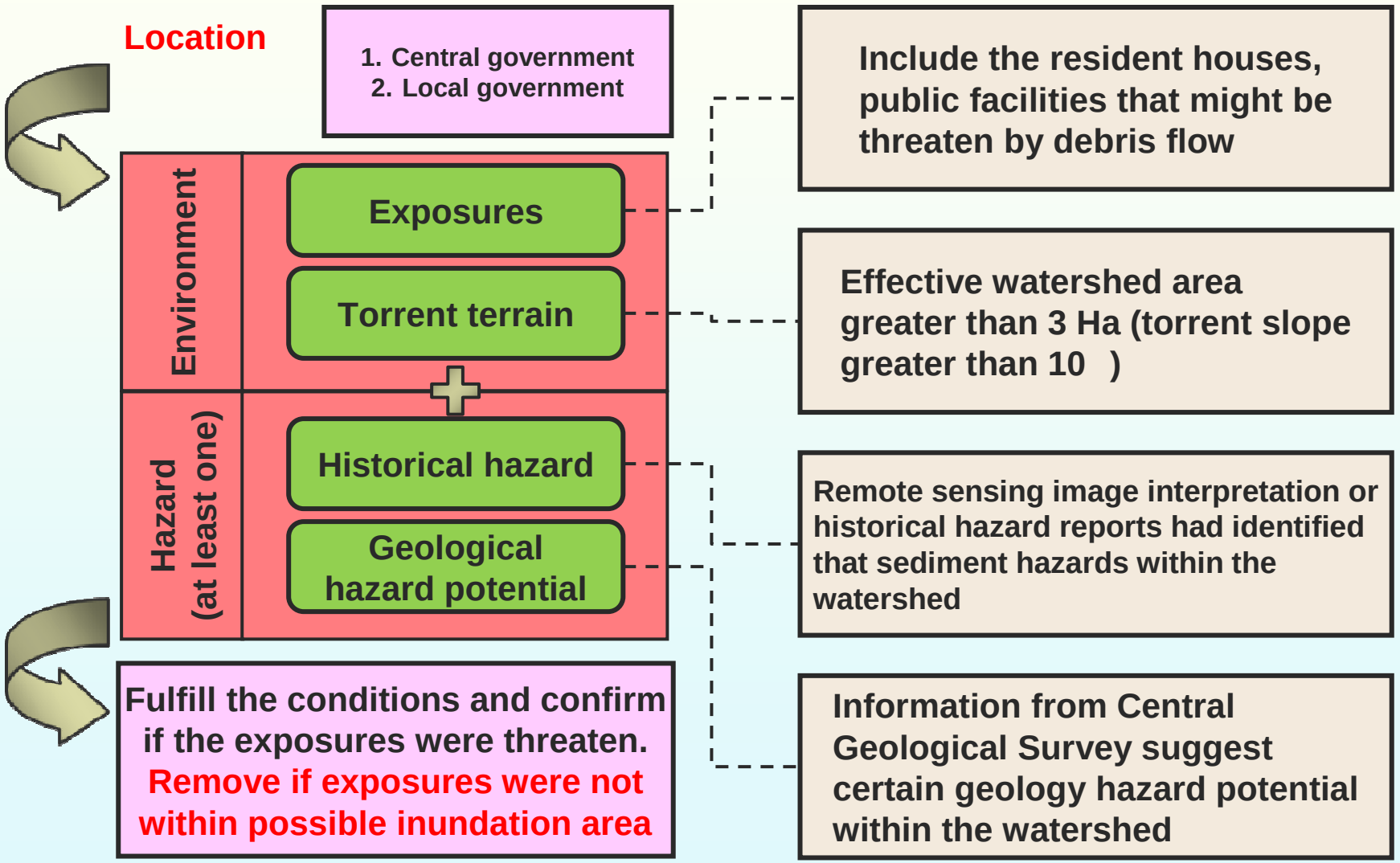
- ***Debris flow investigation and analysis procedure:***
  - ***New ones: Not yet public torrents but with debris flow hazards.***
  - ***Update: For torrents already public, request for adjustment of potential information.***
- ***Investigation request:***
  - ***Central government: Bureaus or agencies could provide the debris flow hazard locations.***
  - ***Local government: Sign up at SWCB website for providing the location of debris flow hazards.***

Procedure of identify potential debris flow torrents



Requirements of potential debris flow torrent (1/3)

Phase I



Requirements of potential debris flow torrent (2/3)

Phase I

- **Include the residential houses, public facilities that might be threaten by debris flow**
- **Buildings consider as resident house**
  - **With address plate**
  - **With utilities and inhabitants (from the fact of residential)**
- **Buildings NOT include**
  - **Local temples (no residential area)**
  - **Warehouse or temporarily rest location**

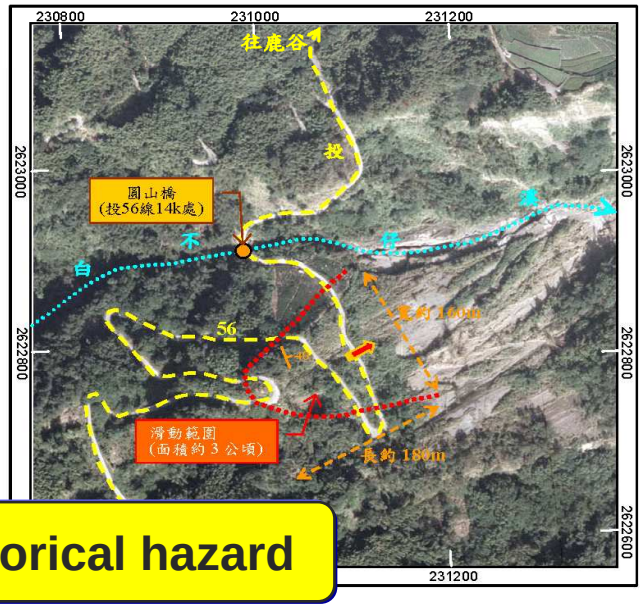
Requirements of potential debris flow torrent (3/3)

Phase I

97 年其他重大土石災例複勘報告

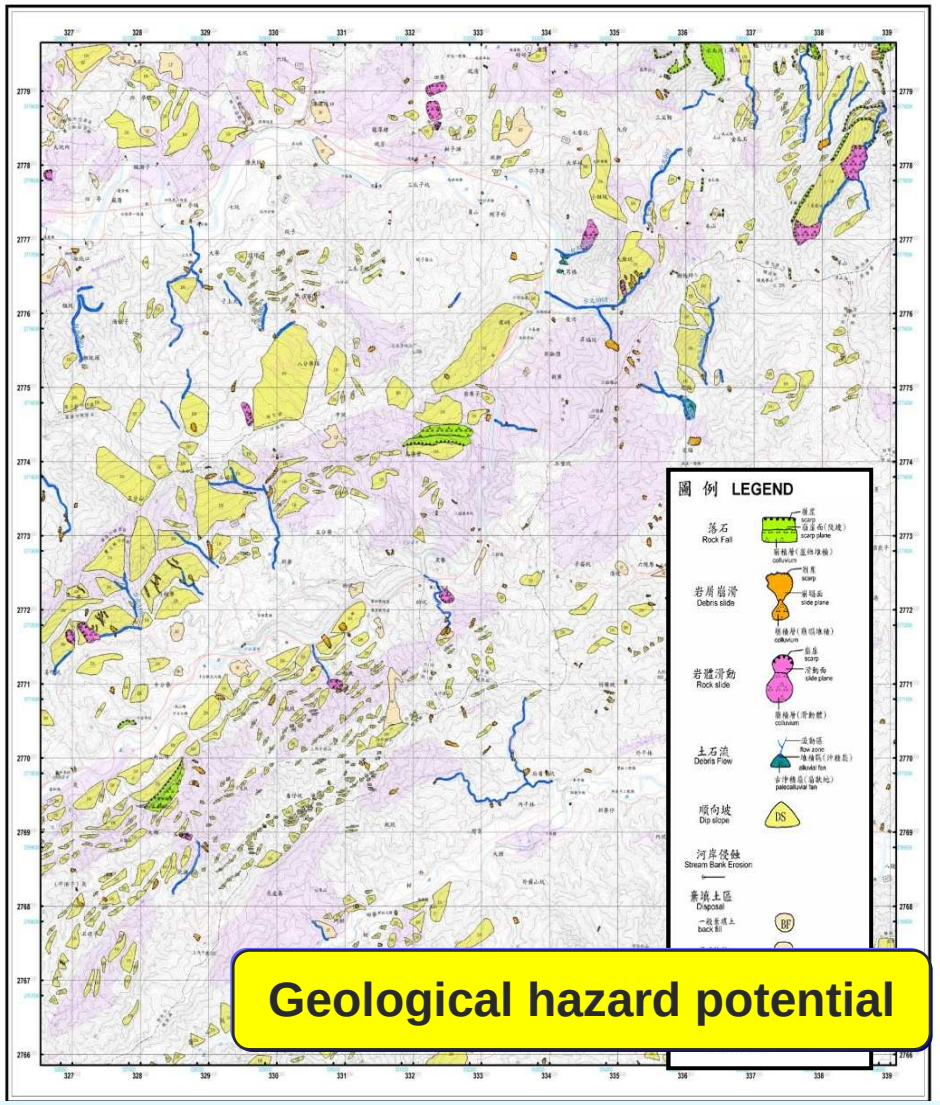
97 年其他-南投鹿谷-001　　複勘日期：98 年 7 月 3 日

一、災區複勘現況(1/2)		
災害案件編號	97 年其他-南投鹿谷-001	
災區行政區域	南投縣鹿谷鄉鳳凰村	
災害類型	地滑	
災害發生時間	97 年 6 月 13 日 13 時	
複勘日期	98 年 7 月 3 日	
植被覆蓋情況	崩塌地仍為裸露狀況。	
現有工程改善措施	執行機關	南投縣政府
	執行期間	—
	工程內容概述與執行情況	於鹿谷鄉及信義鄉交界上之投 56 公路，有多處地滑及崩塌狀況迄未處置，其中目前信義鄉鳳凰五號橋上游路段已發包進行設計中，而鹿谷鄉鳳山橋一帶則尚未進行處理。



Historical hazard

坡地環境地質基本圖　　雙 溪　SHUANGSI

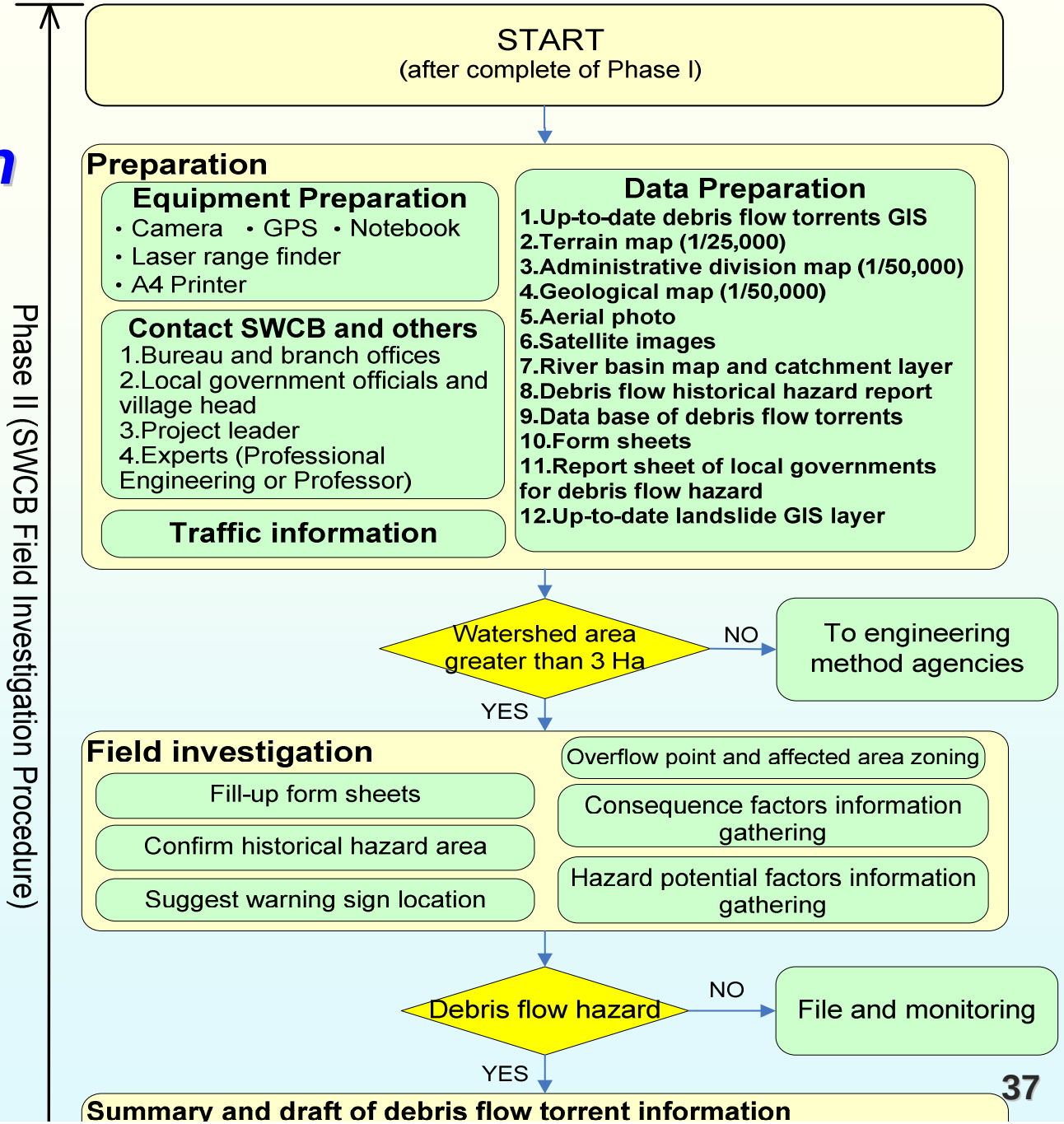


Geological hazard potential

Phase II

Field investigation SOP

- ***Procedures established by SWCB and refined regularly.***
- ***Accompany by experts, local government and SWCB personnel, conduct investigation, measurements and fill the form.***



Form sheets of potential debris flow torrents basic information

Basic information

土石流潛勢溪流基本資料現地調查表

填表人：_____ 填表日期：_____ 天氣：_____

一、基本資料

行政區域		縣（市）		鄉（鎮）	村（里）
溪流編號		溪流名稱			
溪流定位	坐標系統：□67 □97 X： Y：	原評定處理順序等級	□高 □中 □低		
土石流災害歷史(致災原因與時間)	1.有無歷史災害發生：	□有 □無			
	2.發生原因	□颱風 □豪雨 □其它【請加描述 】			
	3.發生時間	____年____月____日____時 事件名稱：			
	4.災害敘述				
保全對象所在行政區域說明	同行政區域：□是 □否				

Torrent current condition

二、溪流現況描述

溪流災害類型	□土石流 □岩屑崩滑 □侵蝕溝 □淺層滑動 □其它【請加描述 】				
發生區上游坡度	□≧50 度 □30 度～50 度間 □≦30 度				
集水區面積(公頃)	是否達 3 公頃以上(計算至整數)：□是(　　公頃) □否(　　公頃)				
集水區內崩塌率*1	□崩塌率≦1% □1%＜崩塌率＜5% □崩塌率≧5%				
集水區內崩塌規模*2	□無明顯崩塌 □小規模崩塌 □明顯大面積崩塌				
堆積區土石材料破碎情形(DM)	□土石材料平均粒徑≧30 公分 □土石材料平均粒徑 7.5~30 公分 □土石材料平均粒徑≦7.5 公分 □無明顯堆積材料				
集水區內主要植生種類(可複選)	□裸露地 □草地 □人造林【請加說明 】 □自然林				
集水區內主要植生生長狀況(DP)	□裸岩 □落石堆積（無植被，或植被面積＜10%） □植被稀疏：10% ≦ 植被面積 ＜30% □植被中等稀疏：30% ≦ 植被面積 ＜80% □植被密集：植被面積 ≧ 80%				
保全對象可能受危害方式(可複選)	□淤埋 □撞擊 □漫流改道 □擠壓主河道 □其它【請加描述 】				
現場初估發生潛勢因子	□高□中□低	現場初估保全危害度因子	□高□中□低	現場初估優先處理順序等級	□高□中□低
溪流照片	位置	照片編碼	位置	照片編碼	位置 照片編碼
	1.上游		2.中游		3.下游
現場初估發生潛勢因子說明：					
現場初估保全危害度因子說明：					
現場初估優先處理順序等級說明：					

註 1：按水保局提供資料判定，無資料記載採用現地判定，並填寫現地判定欄位。
註 2：該資料由現地判定取得。

Affected area

三、影響範圍修正

鄰近溢流點之保全對象：□無，「影響範圍修正」與「保全對象及防治設施」部份可免填
□有，請填寫「影響範圍修正」與「保全對象及防治設施」部份資料

溢流點位	□1 點 □多於 1 點*1			含保全對象之溢流點總數	共　處
溢流點位置	□上游 □中游 □下游		溢流點編號		
溢流點定位	X： Y：	溢流點之照片編號			
溢流點之地形位置(可複選)	□坡度陡變處 □地形開闊處起點 □谷口 □障礙物處 □河道轉彎處 □其他位置【請加描述 】				
鄰近保全住戶之修正影響範圍簡圖	□無 □見附圖(以具坐標之彩色航照圖或相片基本圖為底圖之附圖)				

註 1：需重覆填寫影響範圍修正(第三項)以及保全對象及防治設施(第四項)，每處溢流點位填寫一份。

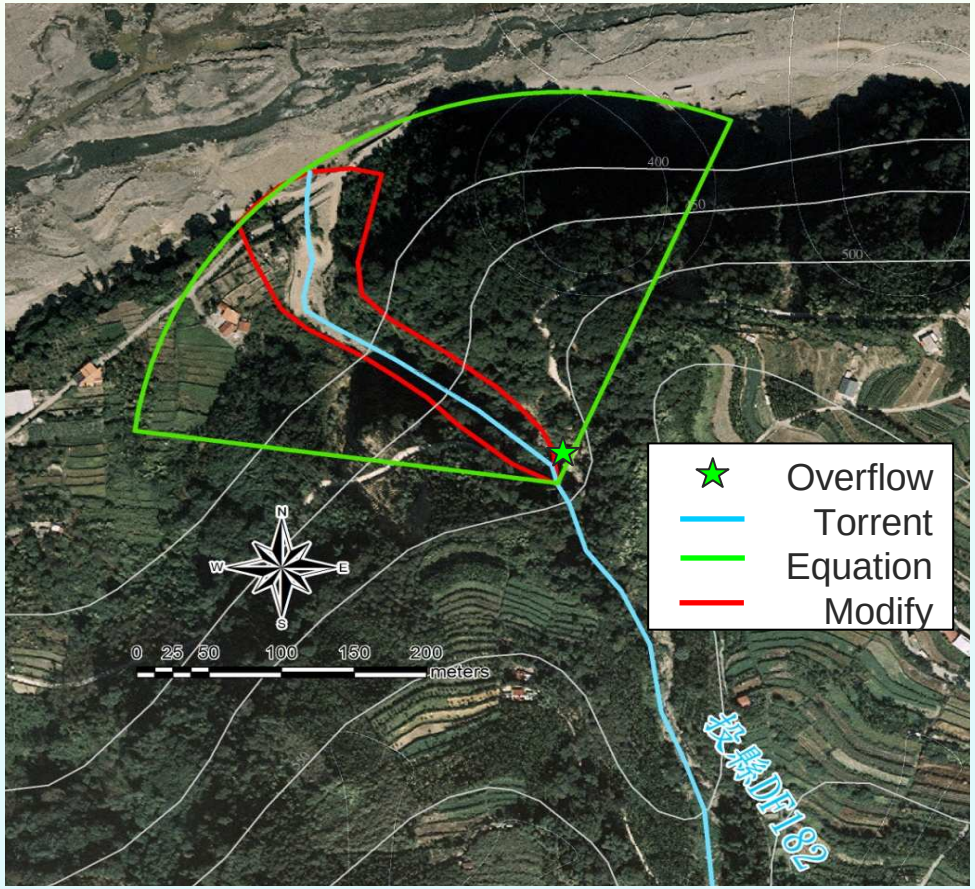
Exposures and engineering works

四、保全對象及防治設施

保全對象	1.住戶	□無	□1～4 戶	□5 戶以上	
	2.公共建築	□無	□學校	□醫院	□活動中心
	2.交通設施	□無	□橋梁【 】	□道路(含鐵路)【 】	
保全對象照片編號	□無				
保全對象住戶地址	□無				
鄰近保全對象之工程設施	□上游 □中游 □下游	GPS 定位 □無 □有	X： Y：	工程設施照片編號	□無
	□無整治設施 □防砂壩 □潛壩 □固床工 □護坡工程 □擋土牆 □沉砂池 □整流工 □其他(　　)				
其他位置之工程設施	□上游 □中游 □下游	GPS 定位 □無 □有	X： Y：	工程設施照片編號	□無
	□無整治設施 □防砂壩 □潛壩 □固床工 □護坡工程 □擋土牆 □沉砂池 □整流工 □其他(　　)				
現地整治成效評估	□暫不需整治 □良好 □尚可 □待改進				
警告標誌設置位置評估	□合適 □不合適 □暫不需設置 □編號錯誤、牌面毀損【待改進情形說明： 】				
警告標誌設置位置簡述	□無 □有，(　　)	□無 X： Y：	設置照片編號	□無	
危險聚落評估(住戶≧5 戶)	□無 □有				
危險聚落照片編號(說明)	□無	建議處置設施(可複選)	□無 □遷住 □加強治理 □臨時避難 □暫不需處理		

Affected area zoning

- The apex of the affected area was selected at valley exit or overflew point with **105 degree fan area**, the runout-distance (radius of the fan) was calculated by Takahashi equation.
- Eliminate the un-passable areas, for example if banks were **10~12m** higher than channel.



Hiroshi equation

$$\log(L) = 0.42 \log(V \tan_d) + 0.935$$

$$V \quad 70{,}992\ A^{0.61} \quad \text{(Hsieh, 2000)}$$

L=run out distance (m)
A=watershed area (km^2)
$_d$=Slope of torrent
V=estimated debris volume (m^3)

Overflow point

- ✓ Opening
- ✓ Obstacle
- ✓ Bending point
- ✓ Valley exit
- ✓ Slope changing

	1 1 *1		1
			BD01
	X：229478 Y：2654768		M100-51_MDF10DSC00485
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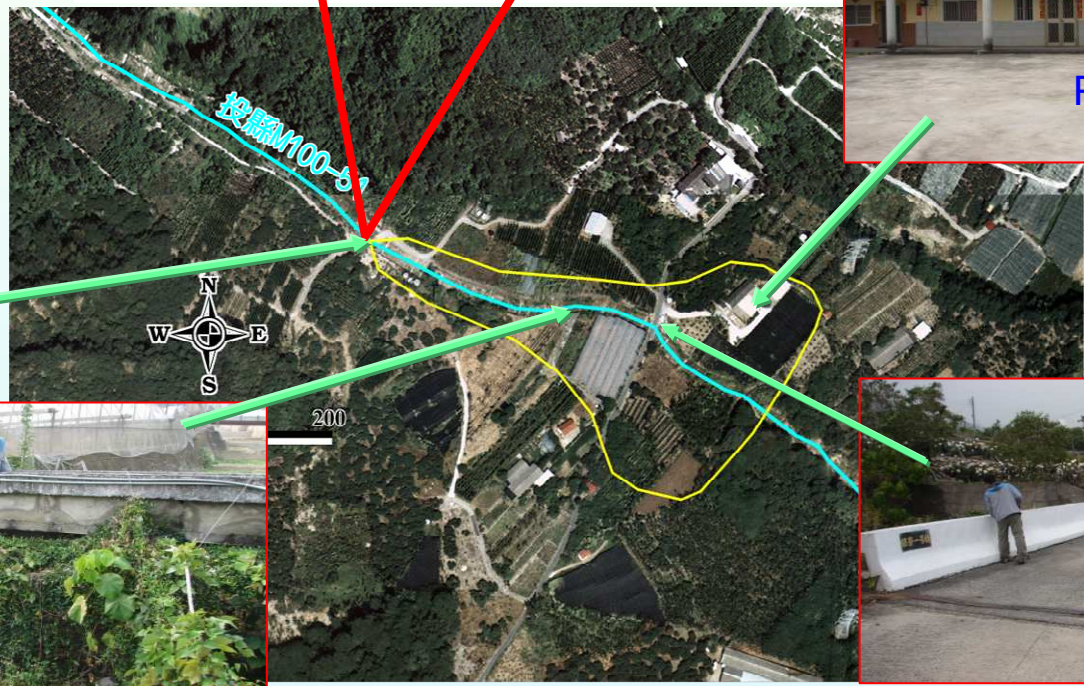
1：



Residential house

Overflow point at begin of opening

Yin-Liao bridge

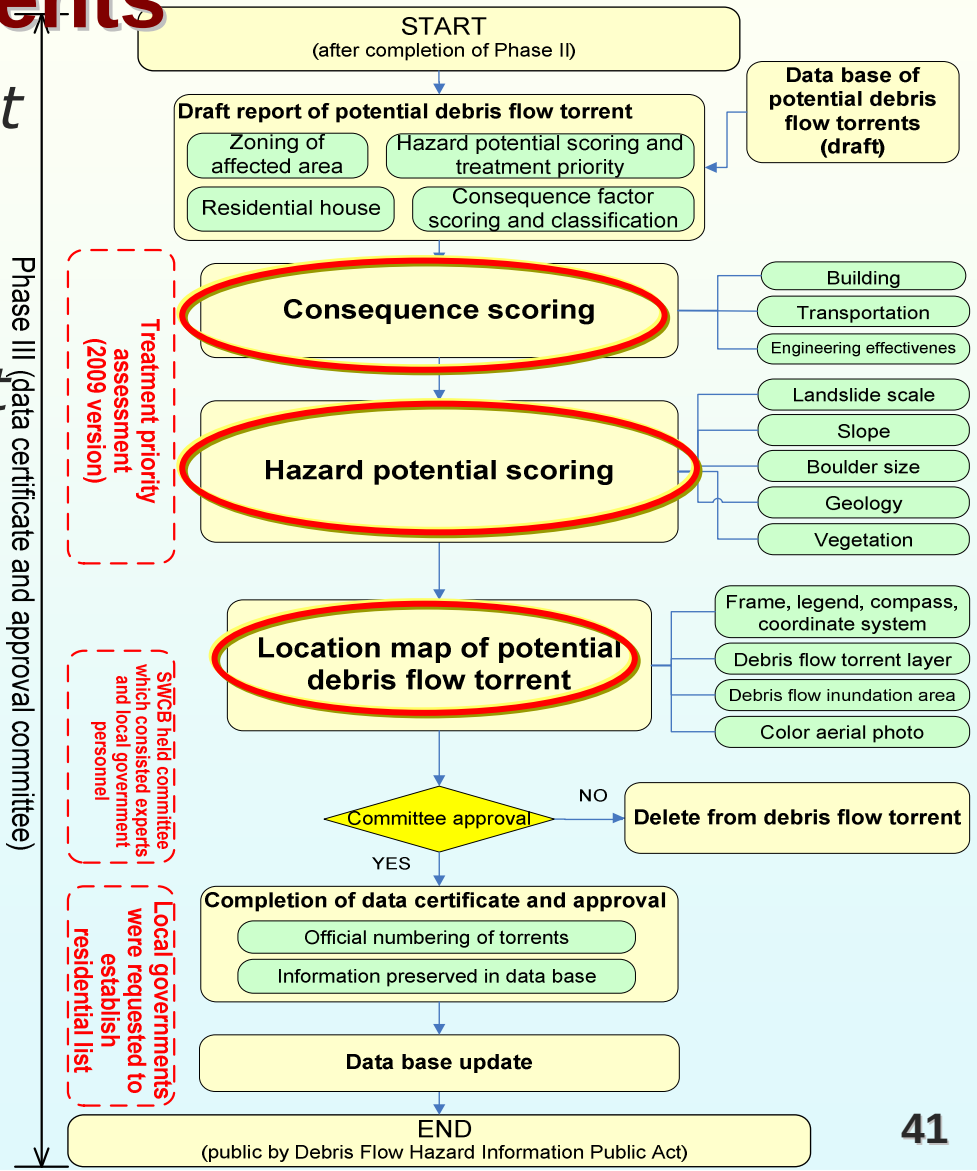
Yin-Liao 1st bridge

Potential analysis of debris flow torrents

- ✓ *Risk matrix of SWCB assessment method*
  1. *Consequence (2009)*
  2. *Hazard (2008)*
  3. *Treatment priority assessment*

Treatment priority assessment risk matrix (2009)

Priority		Hazard: Low	Hazard: Medium	Hazard: High
Conse-quence	Low	**Low**	**Low**	**Medium**
	Mediu m	**Low**	**Medium**	**High**
	High	**Mediu m**	**High**	**High**



Potential analysis of debris flow torrents

- ✓ ***Hazard potential analysis***
  1. ***Landslide scale***
  2. ***Slope***
  3. ***Boulder size***
  4. ***Geology***
  5. ***Vegetation***
- ✓ ***The summation of 5 factors become hazard potential score***

2008 version	Hazard potential	Score
	High	62
	Medium	46< X <62
	Low	46

Hazard potential factors table

Factor	Classification	Score
Landslide scale (25)	Massive (landslide ratio 5%)	25
	Minor (1%< landslide ratio <5%)	15
	Non-significant (1%)	5
Slope of source area (25)	Source area slope > 100%	25
	Slope between 60%~100%	15
	Slope smaller than 60%	5
Boulder size (20)	Average size > 30cm	20
	Between 8cm~30cm	13
	Smaller than 8cm	2
	Non-significant	2
Geology (15)	Type I (A, D, F Geology zones)	15
	Type II (C, E Geology zones)	15
	Type III (B, G Geology zones)	5
Vegetation (15)	Bared with rock falls	15
	Less vegetation	15
	Medium vegetation	6
	Dense forest	3
Summation of hazard potential factors		

Potential analysis of debris flow torrents

- ✓ ***Consequence factor scoring for torrents with exposures***
  - ***1. Building***
  - ***2. Transportation***
- ✓ ***Engineering effectiveness as weighting***
- ✓ ***Summation of all factors for consequence factors scoring***

2009 version	Consequence	Score
	High	60
	Medium	40< X <60
	Low	40

Consequence factors score		
Factor	Classification	Score
Building (65)	Public buildings related with hazard mitigation	65
	(Residential house) >5	60
	(Residential house) 1~4	30
	None	0
Transpor-tation (35)	Bridge	35
	Road	20
	None	0
Maximum scores		100
Weighting		
Engineering effectiveness	None or improvement required	1
	Good	0.8
	Fine or no improvement required	0.6
Result of consequence factors scoring (Building+Transportation) x Weighting		

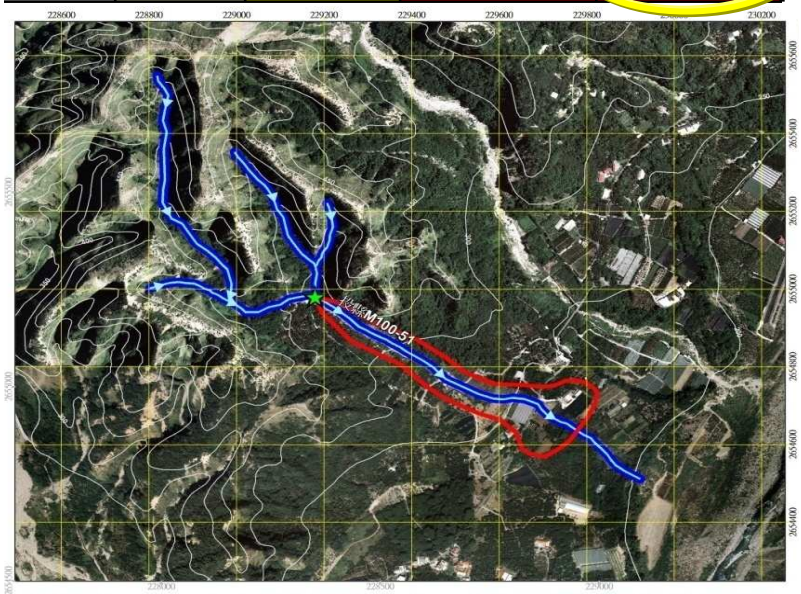
Potential analysis of debris flow torrents

Scoring Result

Treatment priority assessment risk matrix

Priority		Hazard: Low	Hazard: Medium	Hazard: High
Conse-quence	Low	**Low**	**Low**	**Medium**
	Medium	**Low**	**Medium**	**High**
	High	**Medium**	**High**	**High**

Hazard potential factors and scores			Consequence factors scores		
Torrent type	Creek		Building	Resident house:1~4 (1) Public building: 0	30
Geology	D (Sedimentary rock)	15	Transportation	Bridge: Yes Road: Yes	35
Slope of source area	60%~120%	15	Engineering effectiveness	Engineering treatment: Yes Effectiveness: Good	0.8
Landslide ratio	None-significant (0.97%)	5			
Boulder size	Average size 8~30cm	13			
Vegetation	Scattered	6			
Summation	**54**		Summation	**52**	
Classification	Medium		Classification	Medium	
Treatment priority (from Risk Matrix)					
Treatment Priority			Medium		



投縣M100-51建議新增土石流潛勢溪流位置圖

4. Future Development and Perspective

Restrictions of Rainfall-based Debris-flow Warning Model & Solutions Thinking

Restriction A.

Debris flow events are not enough:

1. Establishment of debris flow events database.
2. Deployment of debris flow monitoring systems.
3. Correlation analysis between physiographical factors and rainfall-based debris flow warning criteria.

Restriction B.

Shortage of rainfall stations in the mountain area:

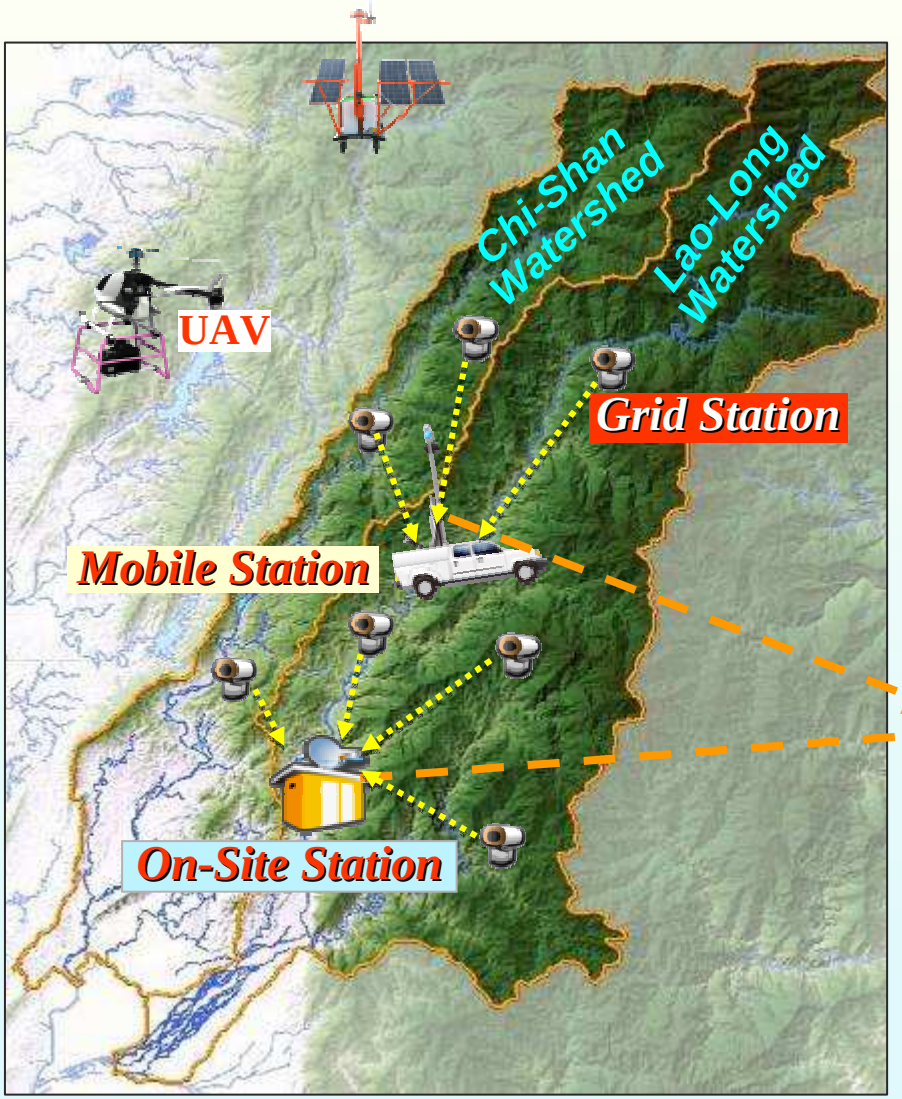
1. Enhance the spatial resolution of rainfall distribution using the QPESUMS
2. Distribute DIY rain gauges to local residents

Restriction C.

Uncertainty of the sequel rainfall:

1. Taking the QPESUMS rainfall prediction into consideration when issuing the debris flow warning

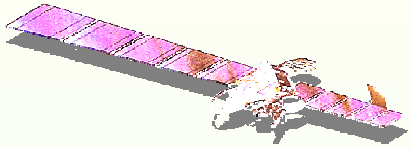
Watershed-oriented Monitoring Network



- ***Point→Line→Plane: extended to upper stream and the source of debris, considering a whole watershed.***
- ***Combining on-site, mobile, and grid stations.***
- ***Integrating data from different agencies.***

17 On-site (fixed) debris flow monitoring station

Monitoring Sensors



Satellite Transmission

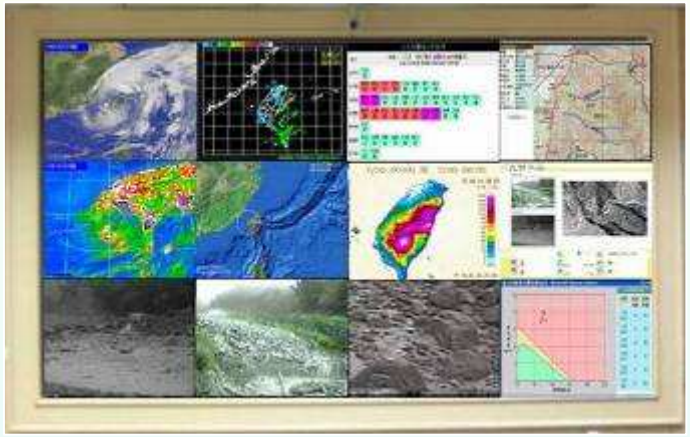
Instrumental cabin

Data-processing

Power-Supply

Information Display

http://246.swcb.gov.tw



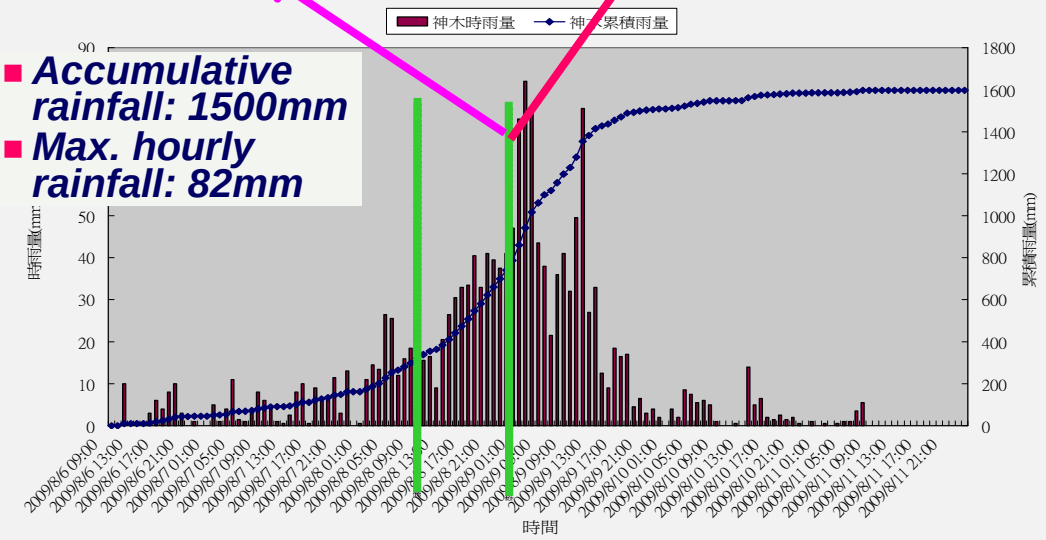
Monitoring Results – Shenmu Station 2009

CCD image (front view) of Aiyuzi downstream

CCD image (sideview) of Aiyuzi upper stream

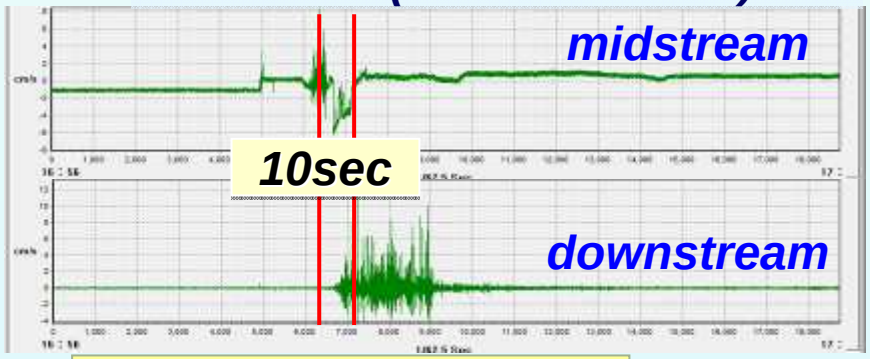
Velocity

50m/3sec=17m/s



- Accumulative rainfall: 1500mm
- Max. hourly rainfall: 82mm

- Geophone signal after wavelet transform (8/8 16:56~17:00)



173m / 10sec =17m/s

3 Mobile debris flow monitoring station (since 2004)

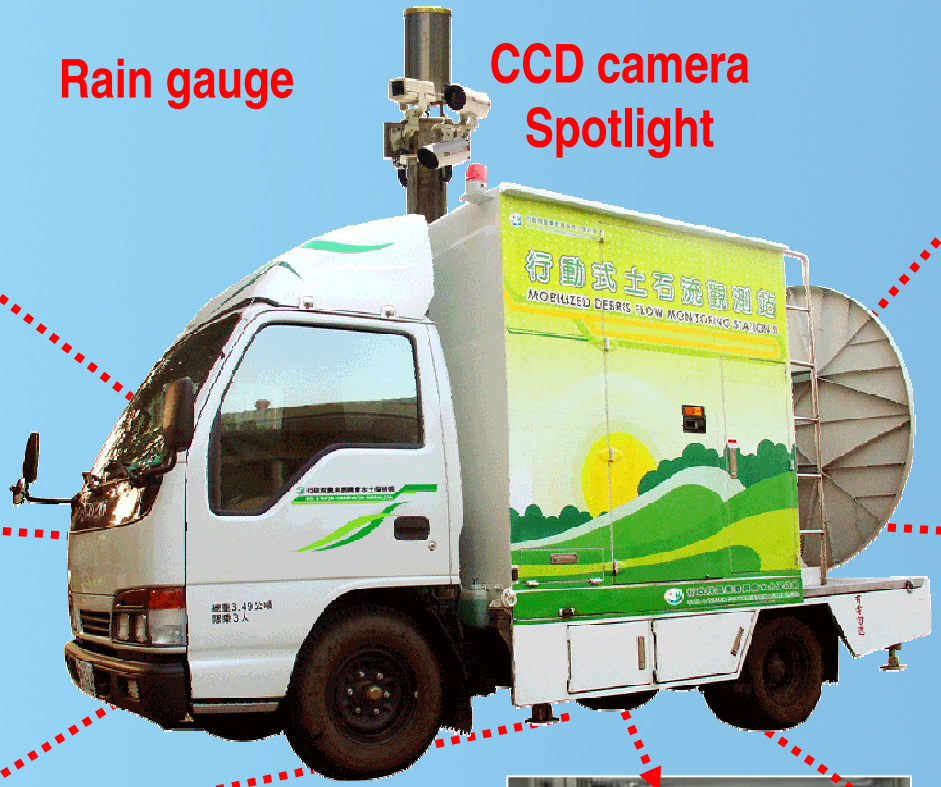
Generator

Inventor

Battery sets

Rain gauge

CCD camera
Spotlight



Geophone

LCD

IPC

GPS

Spectrum analyzer

14 Grid debris flow monitoring station (since 2010)

CCD camera

Rain gauge

Data logger and battery

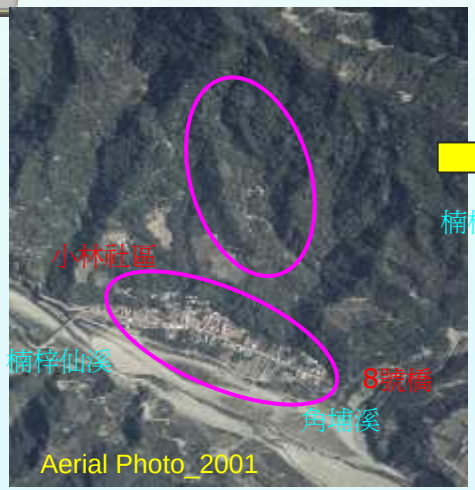
Solar panel

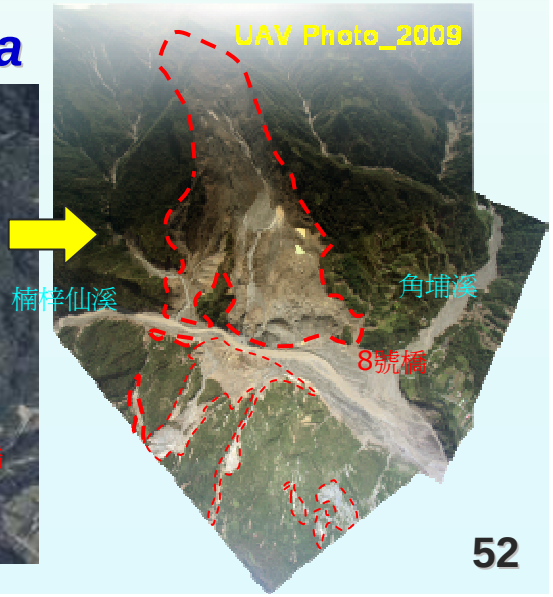
Geophone

Soil moisture probe

Unmanned Aerial Vehicle (UAV) to Collect and Analyze Disaster Information

UAV Video Data



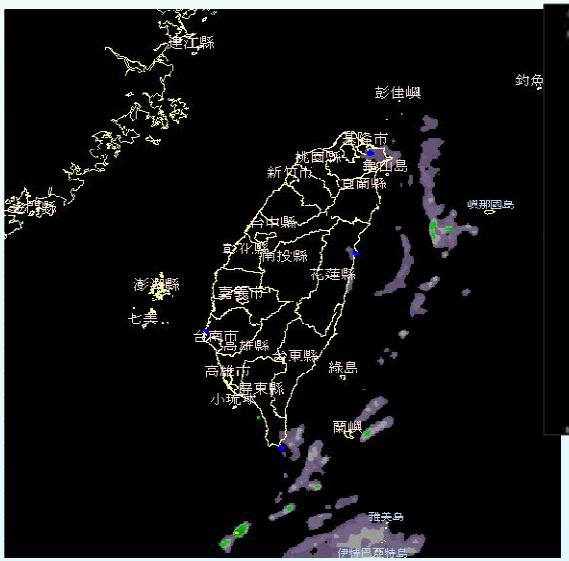


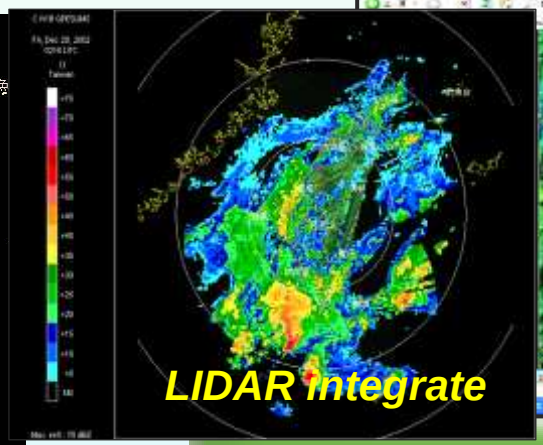
Apply QPESUMS for Rainfall Estimate

- Forecast 1 and 3 hour rainfall
- Data analysis: compute the rainfall value in the villages and rainfall stations
- Assess the timing of warning declaration

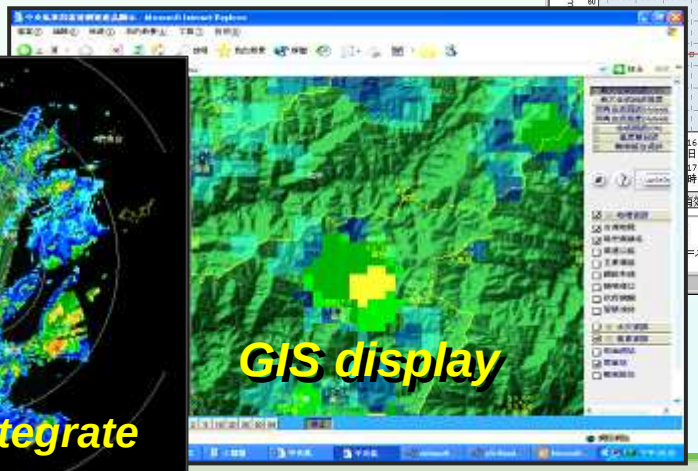
Shorten Evacuation time

Cooperation with NOAA, Water Resources Agency & Central Weather Bureau





LIDAR integrate



GIS display

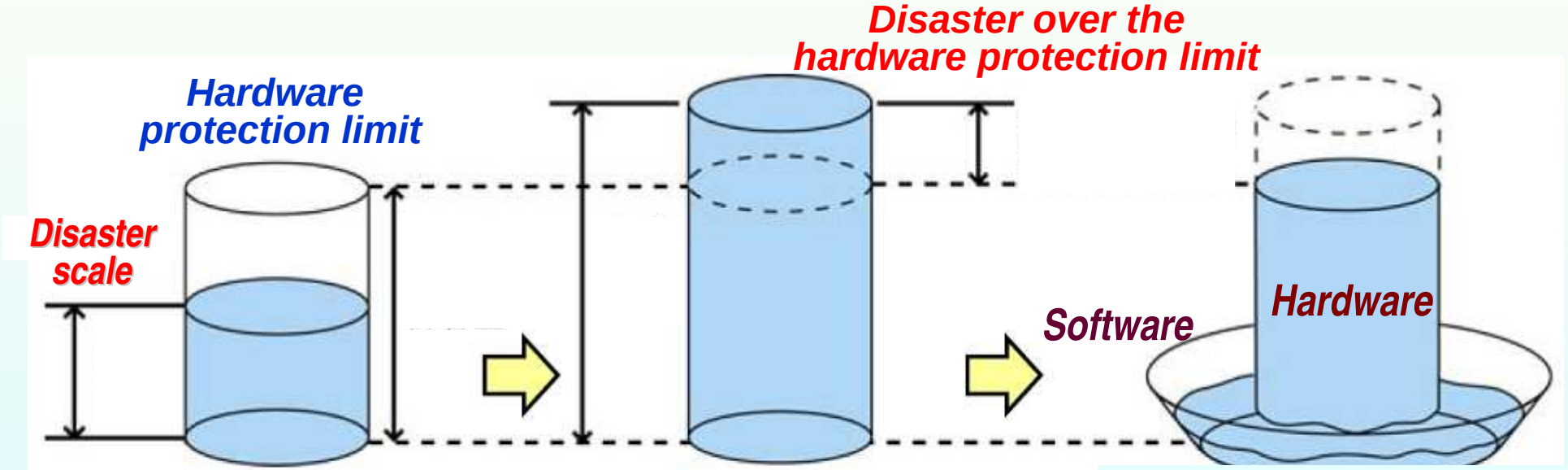
Forecast rainfall

Spatial resolution ：1.3km
Time resolution ：10min

Data reception → Analysis → Applications

Integration of Software and Hardware

- Under climate change impact, strategy of disaster precaution should be considered from hardware to software.
- Non-engineering measures should combine with mitigation works.



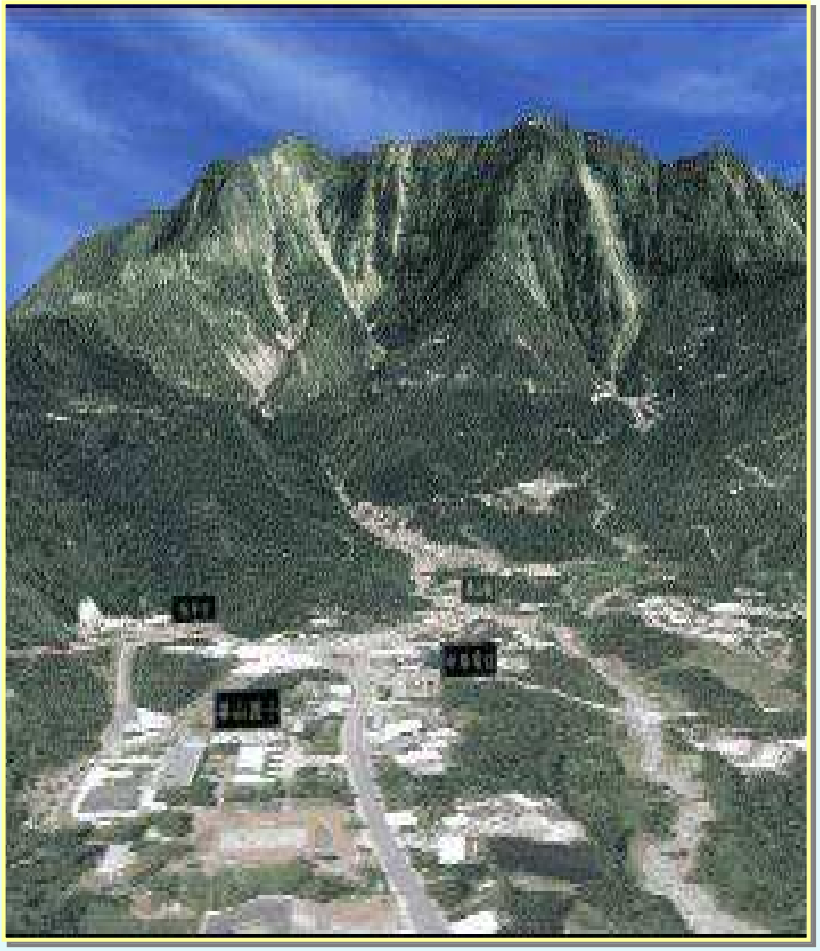
Integration of Debris Flow Disaster Mitigation & Rural Regeneration

in Hua-shan, Ku-keng, Yunlin

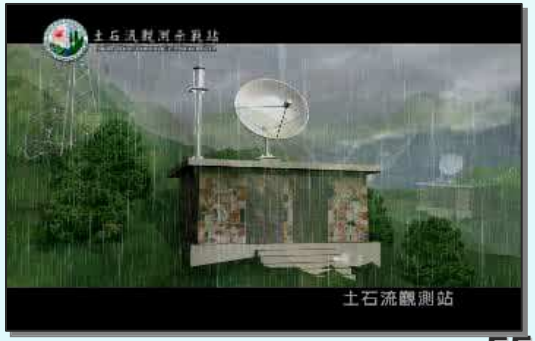
A Debris flow outdoor classroom established after debris flow mitigation

Villagers participation

Community Empowerment



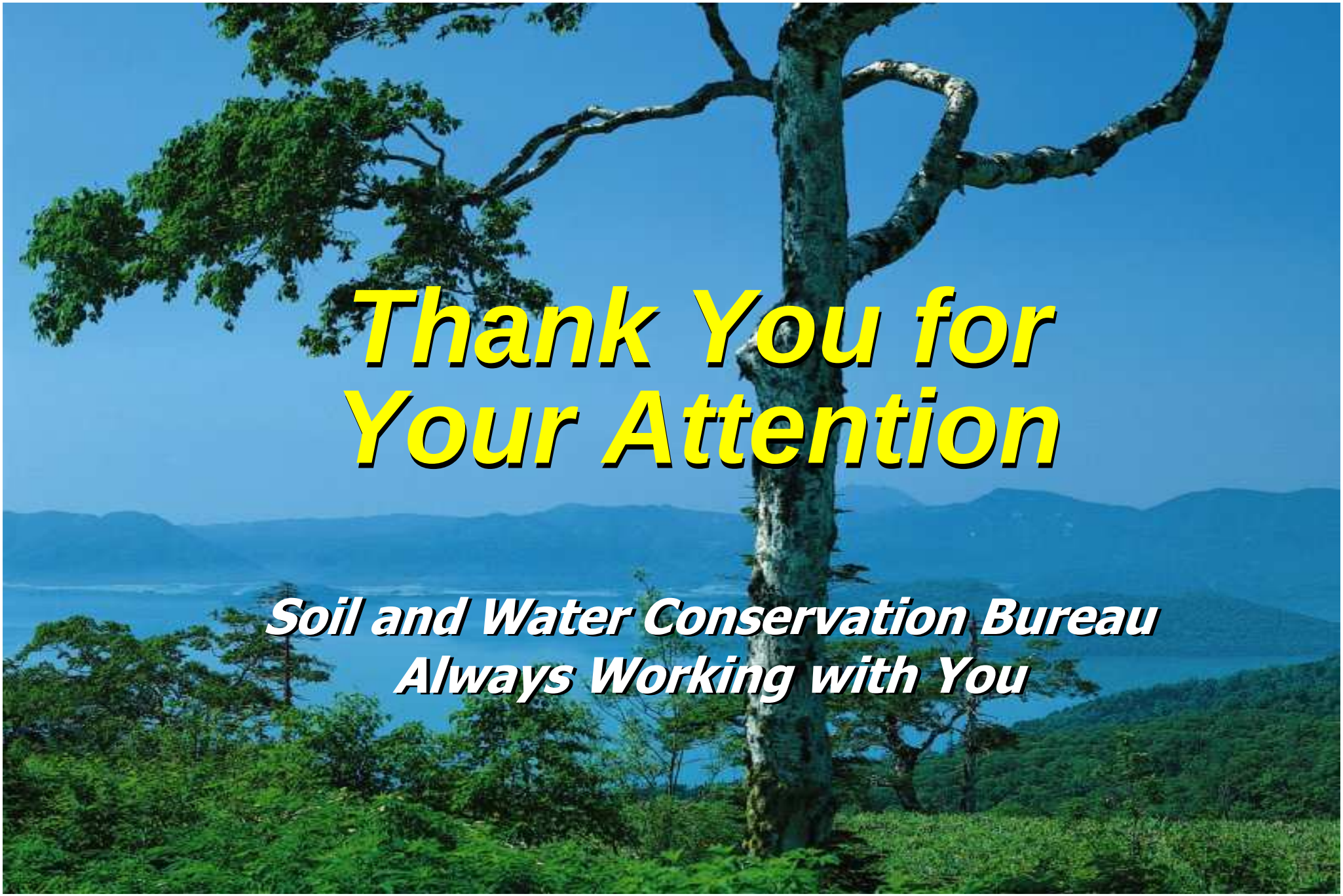
Post Typhoon Nari, 2001



Debris flow monitoring

Debris Flow Disaster Mitigation with Integrated Rural Development

in Hua-shan, Ku-keng, Yunlin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Your Attention
Soil and Water Conservation Bureau
Always Working with You