Rainfall-Based Debris Flow Warning Model and Debris Flow Monitoring System

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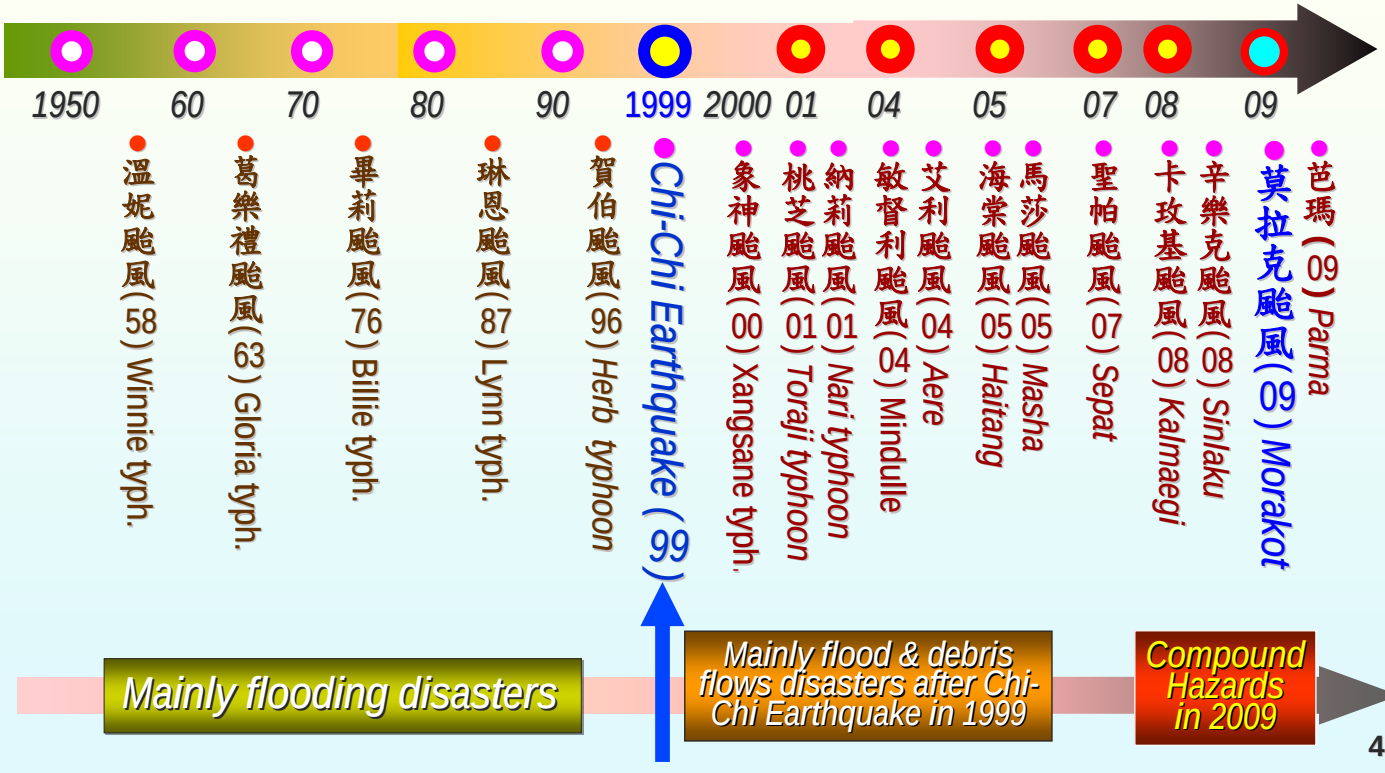
Outline

1. Type of Debris-Flow Warning System
2. Methodology of RTI Model
3. Rainfall-Based Debris Flow Warning Model
4. Debris Flow Monitoring

1. Type of Debris-Flow Warning System

Historic Typhoon Disasters in Taiwan



(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 Parameters

Rainfall Parameters	*Definition*
I (Rainfall intensity)	I_{10} *(Intensity of 10 minutes)* , I_{60} *(Intensity of 60 minutes)*, I_d *(Intensity of 1 day)*, I_a *(Intensity of rainfall event)*
R (Accumulated Rainfall)	R_{4hr} *(4 hrs accumulated rainfall)*, R *(Event accumulated rainfall)*, R_d *(Daily accumulated rainfall)*, R_{te}*(Effective Accumulated rainfall)*
T (Duration)	T_e*(Effective rainfall duration)*, T *(Event duration)*
P (Antecedent-Rainfall)	P_7 *(Previous 7 days rainfall)* P_{14}*(Previous 14 days rainfall)* P_{20}*(Previous 20 days rainfall)*

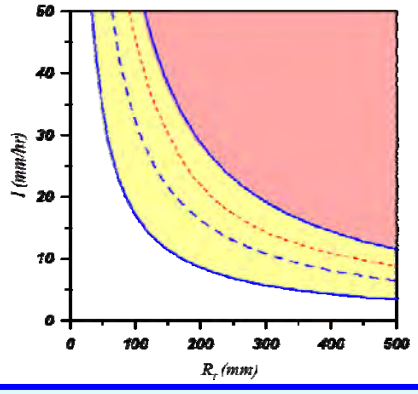
Warning Models of rainfall parameter

Type	Taiwan	Abroad
I-R	Hsieh (1995, 2000) Jiang and Lin (1991) Fang and Yao (1997) Jan (2002-2006)	Katsumi (1978) Tang (1991) Meng(1991) Kawakami (1981)
I-T	Jan (2001), Chen (2000), Huang (2000), Yao（2001）	Caine (1980) , Keefer(1987) Cannon-Ellen (1985) Wieczorek (1987), Marchi(2000)
R-T	Fang (2001,2003)	青木佑久（1980）
I-P		Wang（1972）, Wu(1990)
other		Katsumi(1973), Wilson(1997)

✓*I-R* Model

with consideration of antecedent rainfall

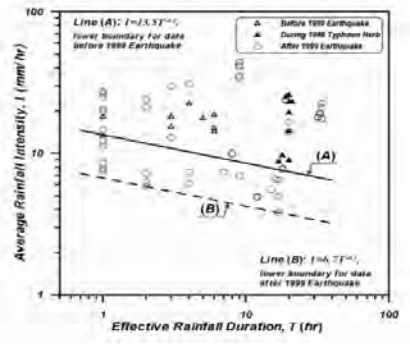
$RTI = I \times R$



✓*I-T* Model

without consideration of antecedent rainfall

$I = a \times T^{-b}$



2. Methodology of RTI Model

A. Development of RTI Model

❖Linear *I-R* model

$$R_t + aI = b$$

- Effective accumulated rainfall
- rainfall intensity

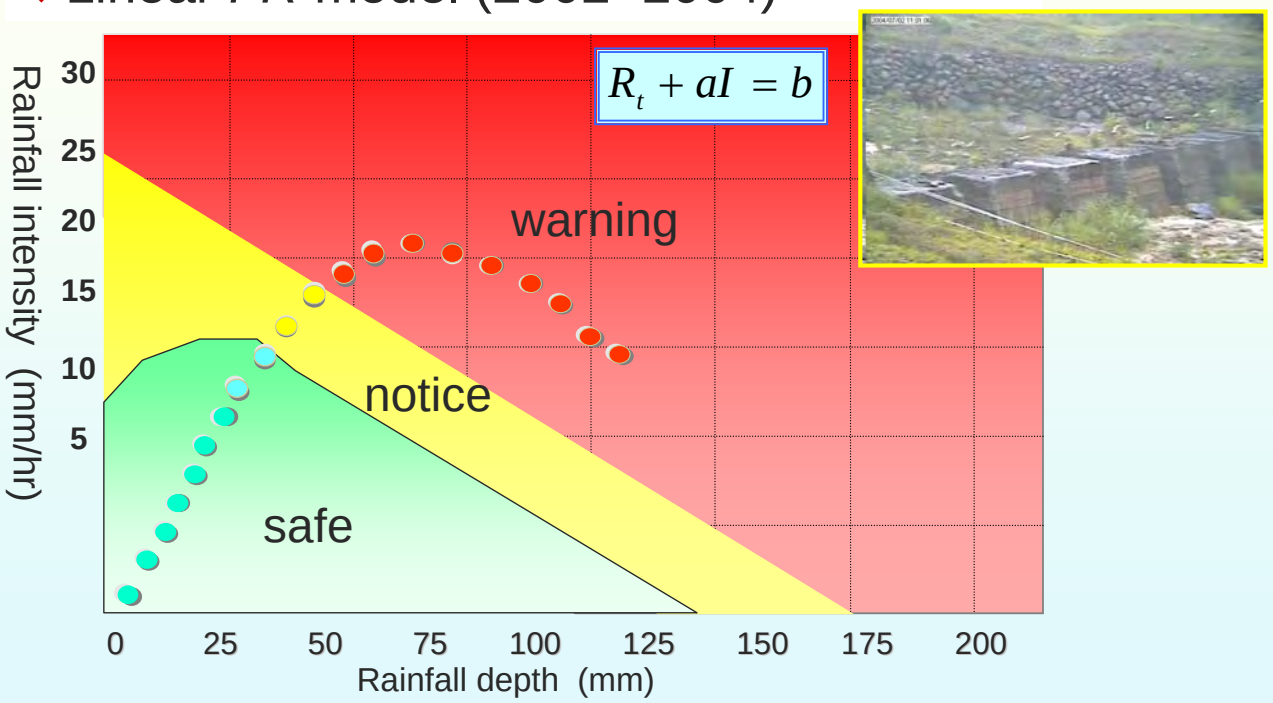
Where *a, b* are coefficient needed to be determined

❖Hyperbolic *I-R* model

$$I \times R_t = RTI$$

- Rainfall intensity (mm/hr)
- Rainfall Triggering index (mm^2/hr)
- Effective accumulated rainfall (mm)

❖Linear *I-R* model (2002~2004)



❖Hyperbolic *I-R* model (After 2004)

➢ ***Rainfall Triggering Index (RTI)***
=Rainfall intensity × Effective accumulated rainfall

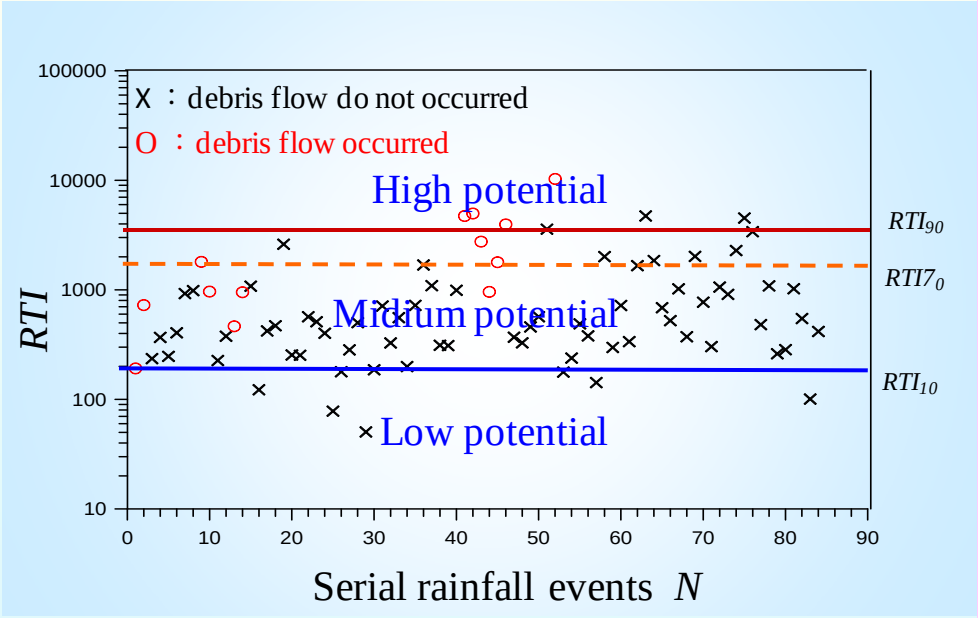
RTI = I×R_t

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

***R*(*t*) is the amount of the accumulated rainfall at time t in the considered rainfall event**
***R_i* is the amount of the antecedent *i* day's rainfall**
α is a weighting factor and is set to be 0.8

Debris-flow rainfall events : Hourly rainfall at the debris-flows occurrence time
No debris-flow rainfall events : Peak of hourly rainfall in the rainfall events

Determine the critical RTI-values for Debris-Flow Occurrence



✓ A lower critical line (RTI_{10}) is defined as the lowest *RTI*-values of rainfall events that had triggered debris flows

✓An upper critical line (RTI_{90}) is defined as that 90% of *RTI*-values for the historical rainfall events no matter with triggering and not triggering debris flows is smaller than it .

✓Other debris-flow occurrence probability

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

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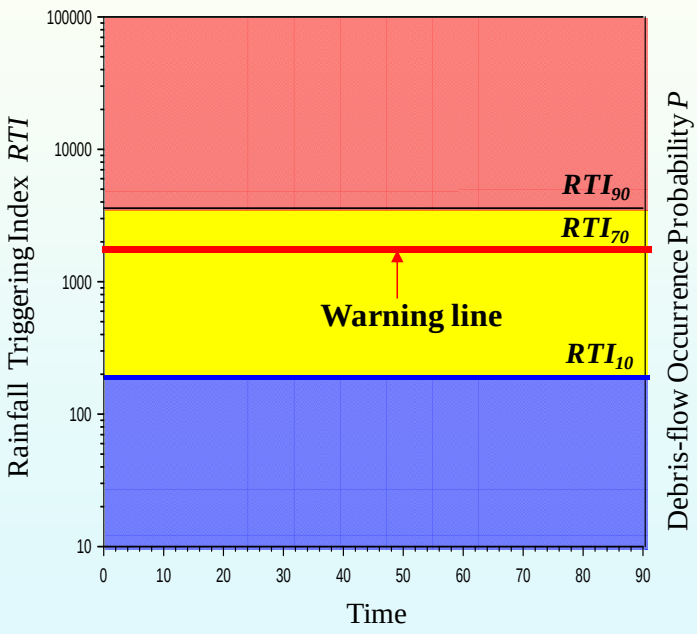
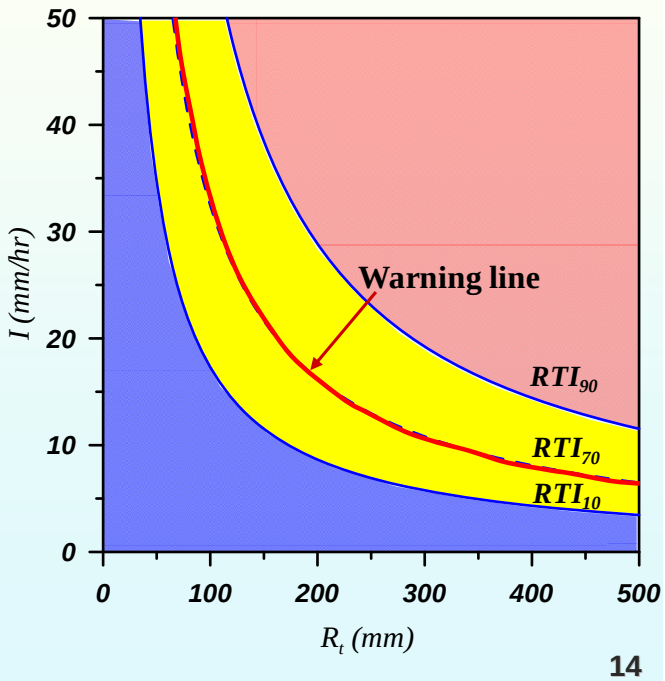
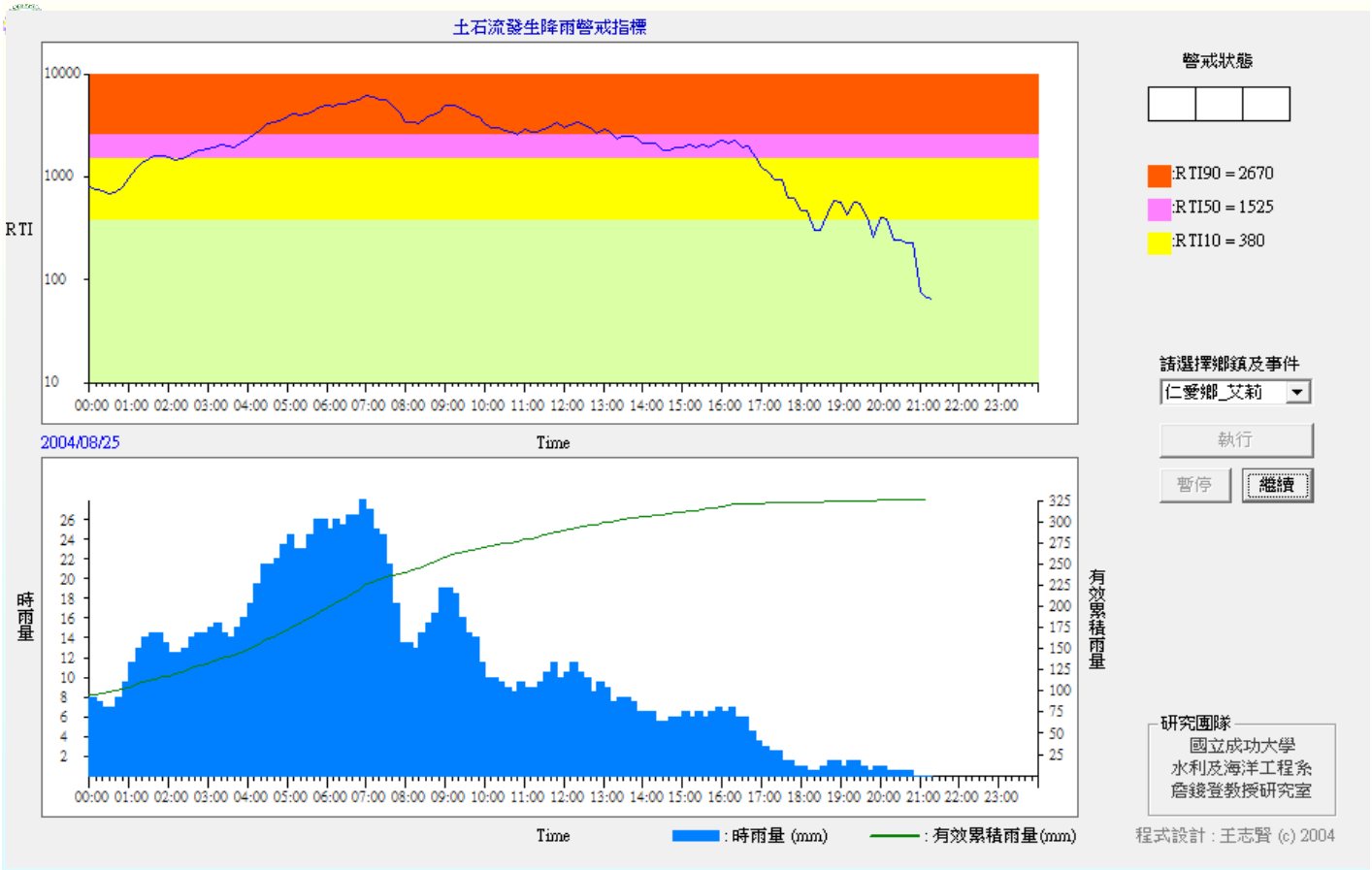
Determine the critical RTI-values for Debris-Flow Occurrence



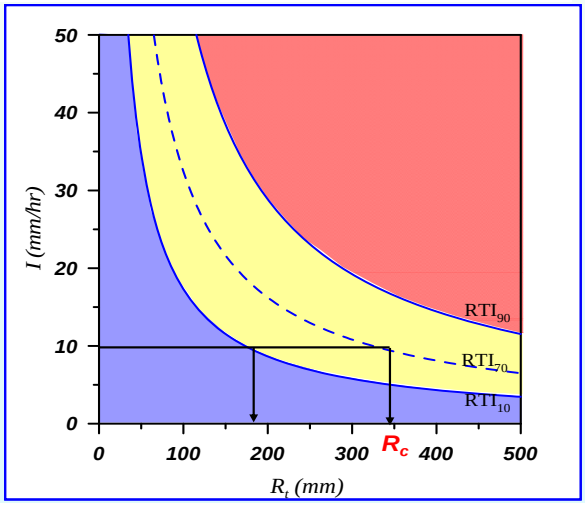




Simplified RTI model

- ✓ The critical RTI-value involves two parameters (I and R) is too academic and not easy to understand for people living in mountainous areas.
- ✓ The critical accumulated rainfall (R_c) is set for easier public understanding and application for evacuation.

Rc is estimated from the critical RTI-value with a consideration of rainfall intensity of 10 mm/hr, and rounded with 50mm as an interval of the critical accumulated rainfall. That is to say for different counties, **Rc** could be 200, 250, 300, 350, 400, 450, 500, 550, or 600 mm.



Warning criteria value Table

Village and (N) is the numbers of debrisflow gully in village

Warning Criteria

101年土石流警戒基準值明細表 101.02修訂

縣市	鄉鎮	警戒區範圍		土石流警戒基準值(mm)	參考雨量站	
		警戒區座落村里(土石流潛勢溪流總數)	土石流潛勢溪流數(條)		代表站1	代表站2
	蘇澳鎮	朝陽里(4)	4	500	南澳	東澳
		南建里(1)、永春里(2)、長安里(1)、永樂里(7)、蘇北里(1)、聖湖里(4)	16		蘇澳	冬山
	三星鄉	集慶村(1)、拱照村(3)、天山村(1)	5	600	三星	寒溪

Township

Numbers of debris flow gully in Village

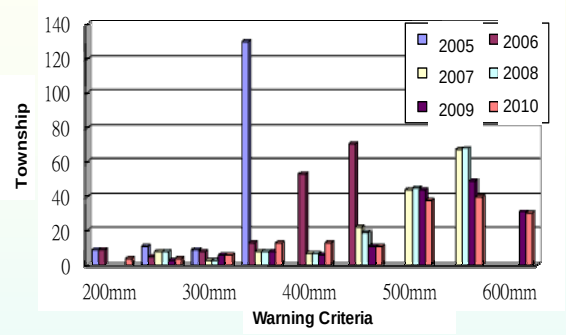
Rain gauge 1

Rain gauge 2

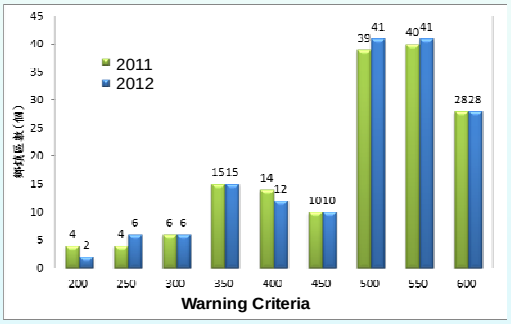
3. Rainfall-Based Debris Flow Warning Model

✓Reasons for adjustment

1. Newly added debris flow or rainfall events
2. After severe rainfall that caused severe landslides
3. Earthquake magnitude larger than 5.0
4. Others (Land-use activity changed)

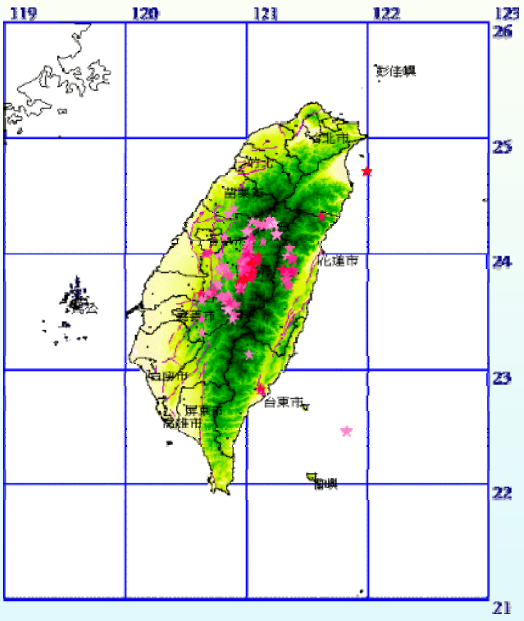


Rainfall (mm)	200	250	300	350	400	450	500	550	600
2005									
2006									
2007									
2008									
2009									
2010									



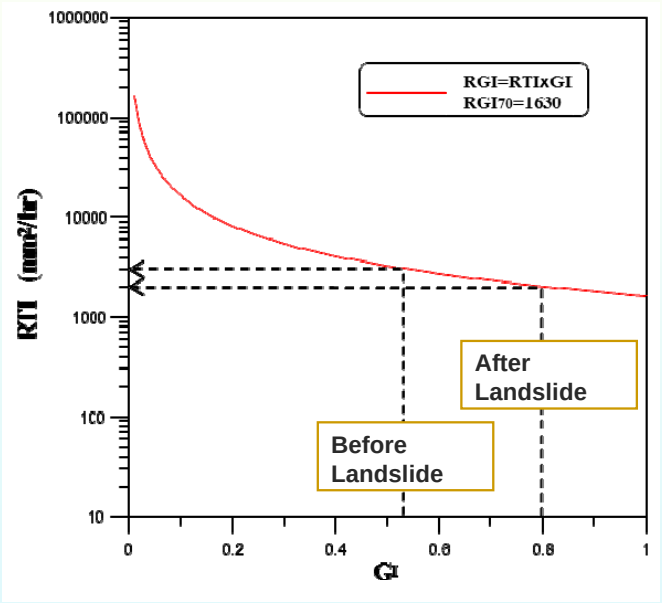
✓Affected by the earthquake

1. When magnitude of earthquake was larger than 5.0 in the township, the criteria value would be decreased from RTI_{70} to RTI_{50} , i.e. from R_{70} to R_{50} 。
2. Two years after earthquake, the criteria value would be reviewed. If the environment did not get worse, criteria value would be increased.



✓Affected by severe landslides

If somewhere had a severe landslide, the geo-conditions would be changed. Using the relationship of RTI and GI, the criteria value after landslide would be determined.



✓Announce of Debris Flow Warning in Taiwan

■ ***Rainfall Threshold for Debris Flow Warning : 200～600mm***

Predict Rainfall >Threshold

Real Rainfall > Threshold

Accumulative rainfall

-30hr. -18hr. -12hr.

Sea typhoon alarm

Sea & land typhoon alarm

Yellow warning

Red warning

Rainfall forecast

Advise Evacuation

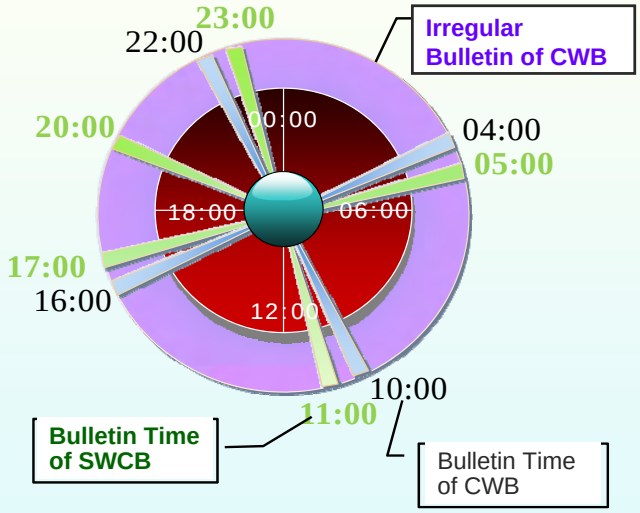
Enforce Evacuation

Local government should Advise the inhabitants evacuation.

Local government should Enforce the inhabitants evacuation.

Bulletin Time

- Regular Time:
  After the forecasting of CWB, i.e. 5:00, 11:00, 17:00, 20:00, 23:00, 5 times a day.
- Irregular Time:
  Depend on rainfall situation



Some examples of landslide and debris-flow events caused by Typhoon Morakot

Site (village)	*Hazard type*	*Occurrence time*	*Debris-flow warning time by SWCB*
Xi-an 西安村	*Debris flow*	*20: 00, August 8*	*23:00 , August 7 (21 hrs earlier)*
Dong-an 東安村	*Debris flow*	*20: 00, August 8*	*23:00 , August 7 (21 hrs earlier)*
Xin-fa 新發村	*Debris flow Landslide*	*21: 00, August 8*	*23:00 , August 7 (22 hrs earlier)*
Chi-lai 集來村	*Debris flow*	*05: 00, August 9*	*08:00 , August 8 (21 hrs earlier)*
Xiao-lin 小林村	*Landslide*	*06: 00, August 9*	*23:00 , August 7 (27 hrs earlier)*

Case of Debris flow warning

Triggering : Typhoon Morakot 2009

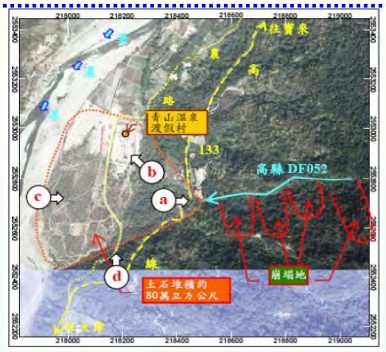
Warning time : 23:00 on Aug. 7, 2009

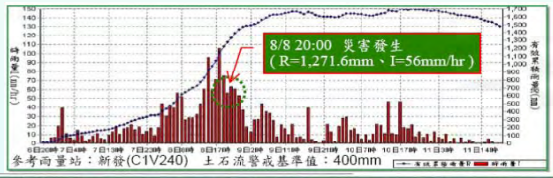
Location Xin-fa, Liugui Township, Kaohsiung County (DF052)

Rainfall station : Xin-fa station

Critical rainfla value : 400mm

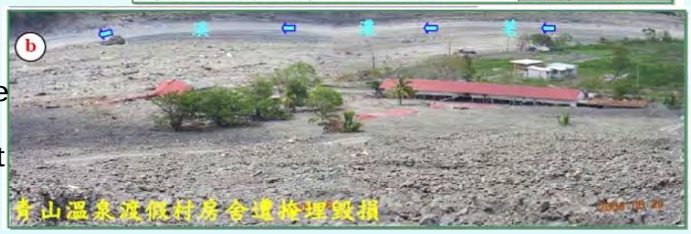
Time : 20:00 on Aug. 8, 2009





consequences

Ching-Shan Spring Resort was almost destroyed，6 houses were seriously damaged. Due to successful evacuation, no one got hurt or died.



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Case of Debris flow warning

Triggering : Typhoon Morakot 2009

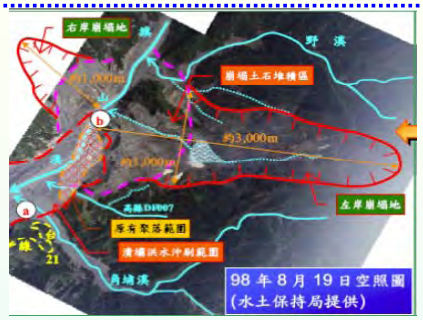
Warning time : 23:00 on Aug. 7, 2009

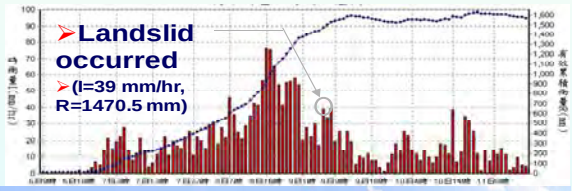
Location Xiao-lin, Village, Kaohsiung County

Rainfall station : Xin-fa station

Critical rainfla value : 450 mm

Time : 06:00 on Aug. 9, 2009





consequences

Xiao-lin, Village was destroyed，350 houses were submerged and 453 people died.

✓Evaluation of warning quality

Index	Function	Estimated method
Warning accuracy rate (C_1)	Assess the efficiencies of the warning system	C_1=A1/D A1 : The number of debris flow events after warning D: Total number of debris flow events
Critical rainfall values accuracy rate (C_2)	Assess the adequacy of the critical rainfall values	C_2=A2/D A2 : The number of debris flow events while the accumulated rainfall exceed the critical rainfall values (A2) D: Total number of debris flow events

The average index value was 70%, which was close to Japan .

2005~2010

Index / Rainfall Events	C_1	C_2
2005	12/18 = 67%	12/18 = 67%
2006	2/3 = 66%	3/3 = 100%
2007	2/6 = 33%	4/6 = 67%
2008	9/21 = 43%	14/21 = 67%
2009	25/29 = 86%	25/29 = 86%
2010	5 / 7 = 71 %	5 / 7 = 71 %

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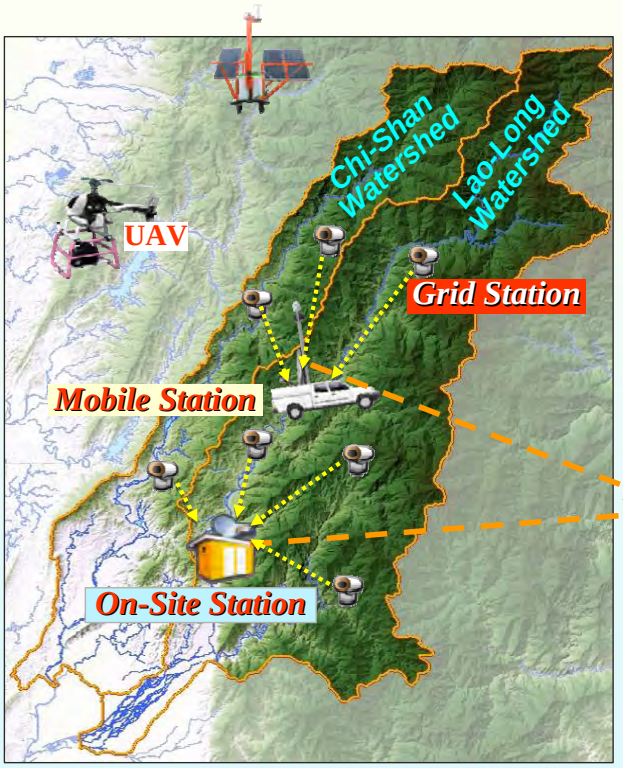
4. Debris Flow Monitoring

✓ Watershed-oriented Monitoring Network

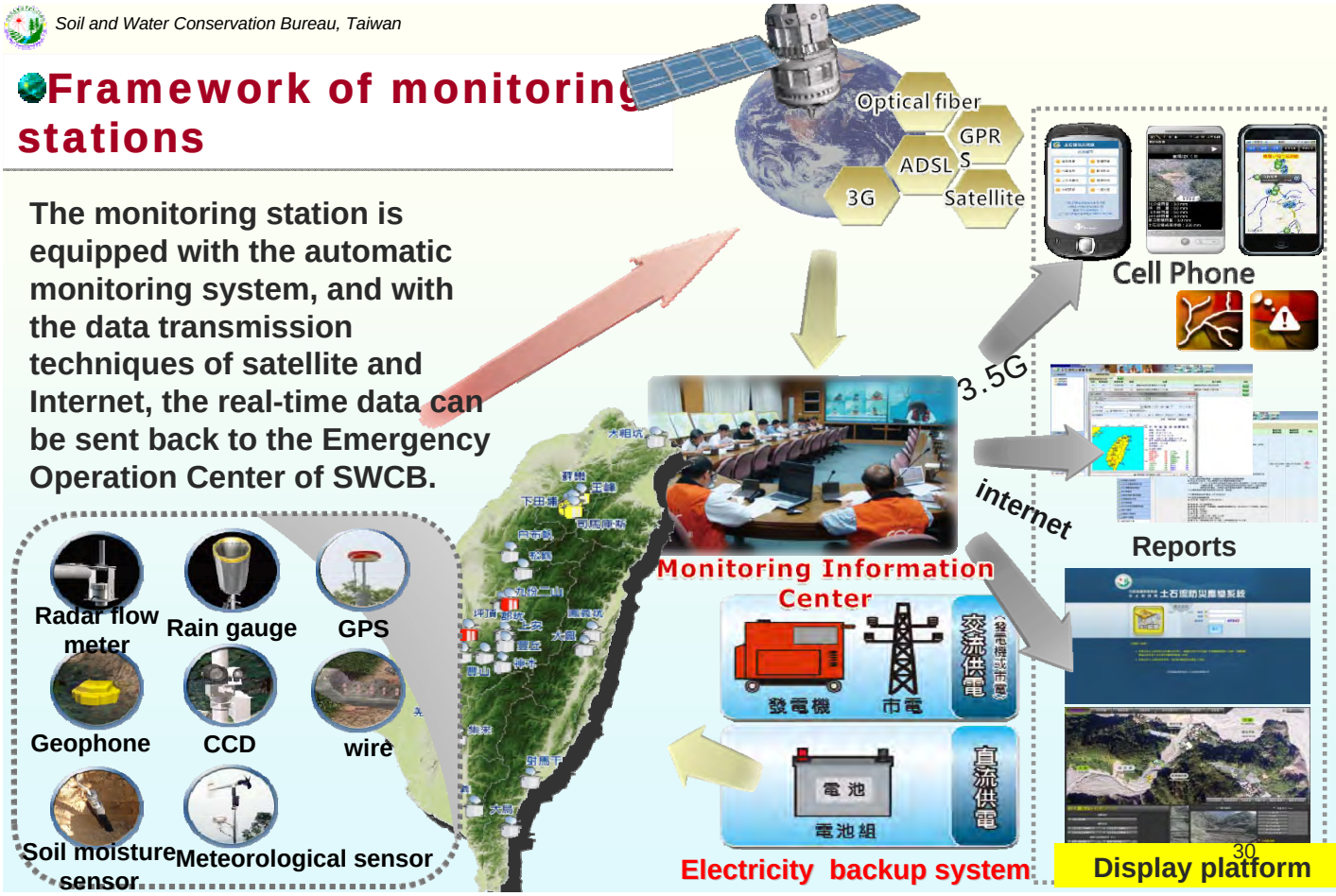


- ***Point➔Line➔Plane: extended to upper stream and the source of debris, considering a whole watershed.***
- ***Combining on-site, mobile, and grid stations.***
- ***Integrating data from different agencies.***

Emergency Operation Center

Framework of monitoring stations

The monitoring station is equipped with the automatic monitoring system, and with the data transmission techniques of satellite and Internet, the real-time data can be sent back to the Emergency Operation Center of SWCB.



Debris Flow Monitoring Station


CCD


Geophone


Water level meter

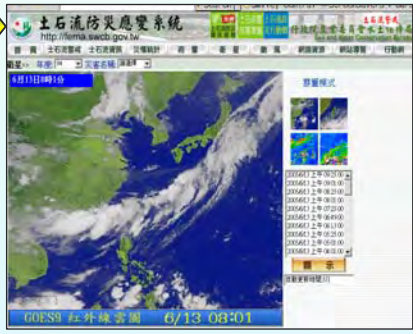

wire sensor

Satellite communication


Data-receiving center at Jiufenershan


Mobile monitoring station

Debris Flow Information System in SWCB



http://246.swcb.gov.tw

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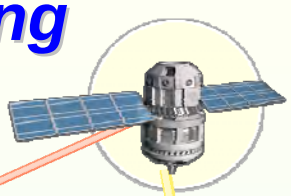
Mobile Monitoring Integration

Monitoring Information Center


Satellite Transmission

Satellite Search


Monitor in the Air

UAV


WEB

Data Obtain

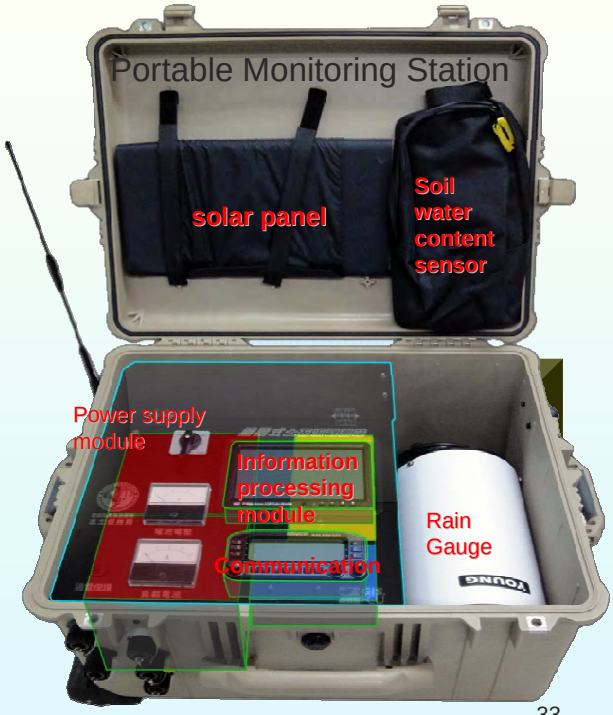
Land Monitor

Extend Monitor

Movable Monitor

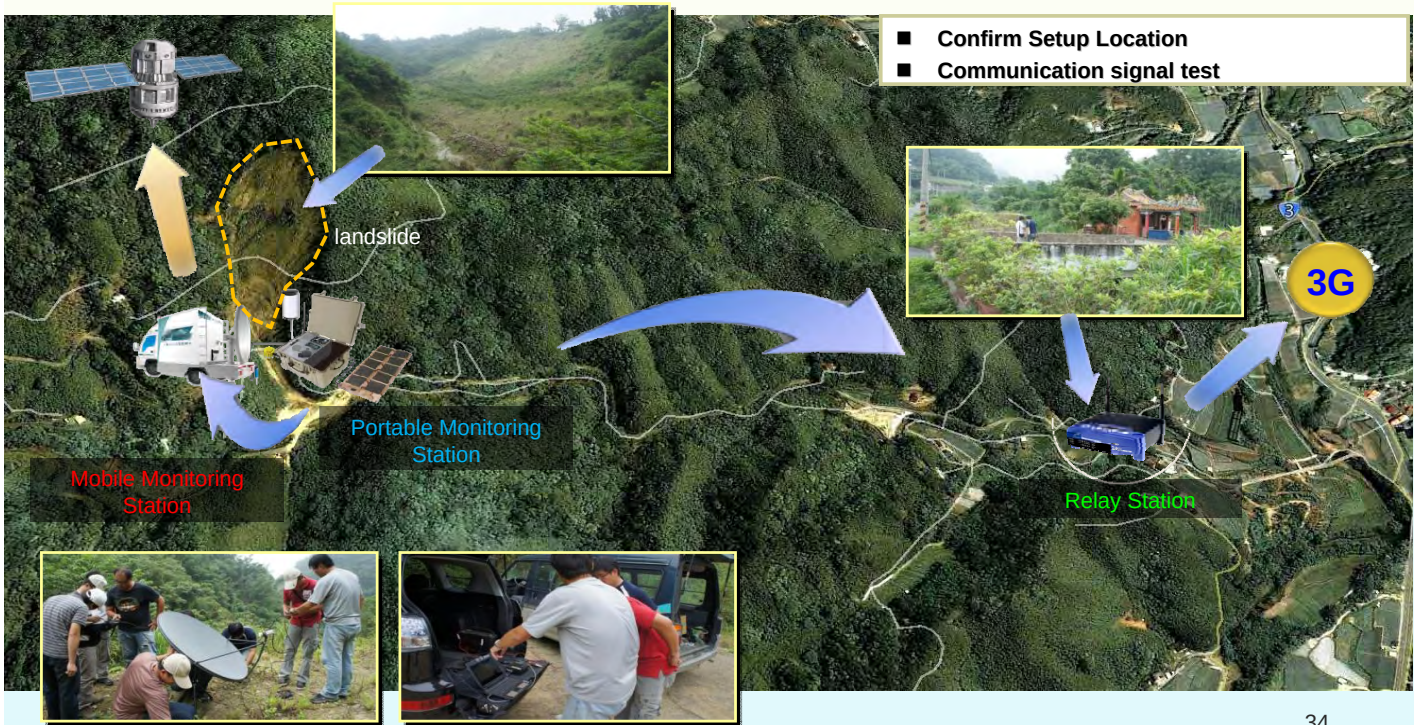
Module Monitor

The main structure of Mobile and Portable Monitoring Station



Assessment and on-site investigation

- Confirm Setup Location
- Communication signal test

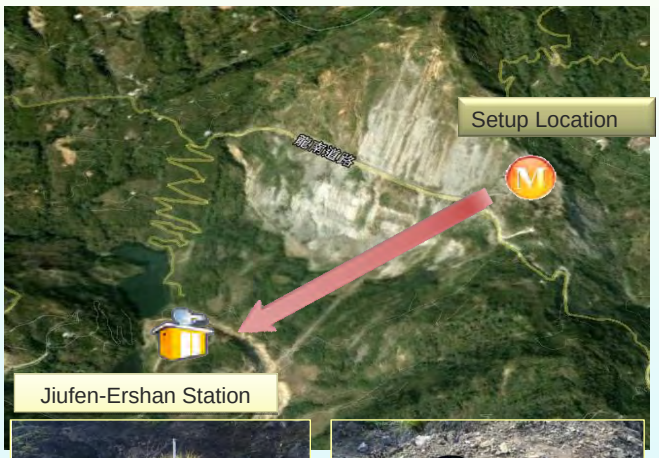


Mobile and portable station function upgrade

- *A long-term type of portable unit*

Zhu-Shan Heliport

Jiufen-Ershan bursting Point

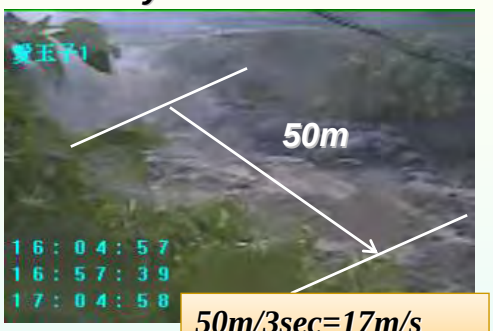


Monitoring Results – Shenmu Station 2009

CCD image (front view) of Aiyuzi downstream

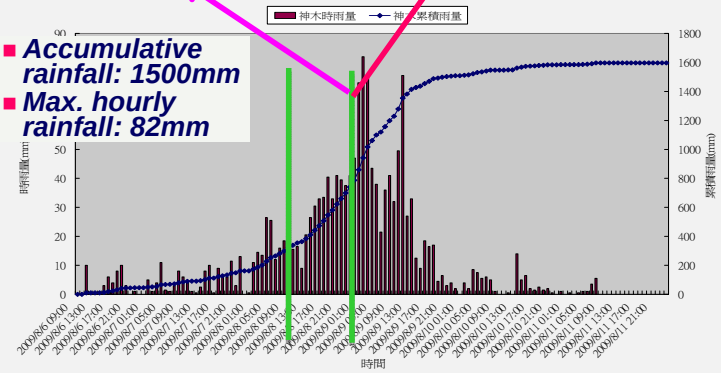
CCD image (sideview) of Aiyuzi upper stream

Velocity

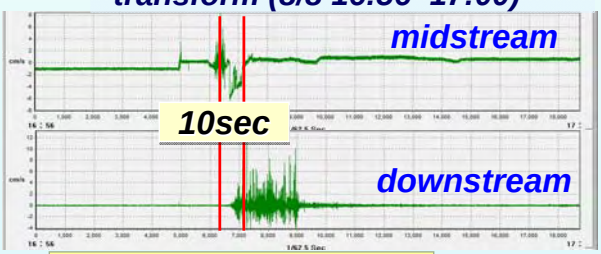


50m/3sec=17m/s

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



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



173m / 10sec =17m/s

✓Data collection and analysis

Debris Flow

At Aiyuzi Stream, Shenmu Sta.

Event	Wire broken	Max. Hourly Rainfall (mm)	Accumulated Rainfall (mm)	Upstream Accumulated Rainfall (mm)	Flow Rate (m/s)	Sediment (m^3)
0713	07/13 14:33	10.5	11	21	4.3	4,984
0719 Heavy Rain	07/19 03:19	28	126	314.5	-	-
1110	11/10 13:29	17	66	100	1.77	5,891
					1.07	8,513

2011/0713

2011/1110 First Wave

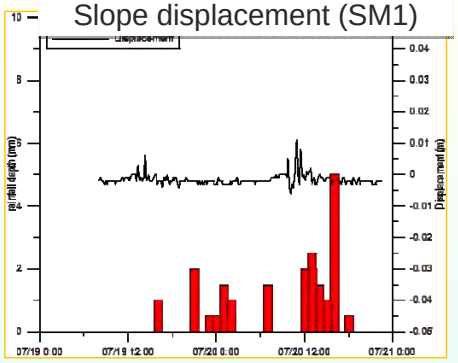
2011/1110 Second Wave

Landslide Monitoring

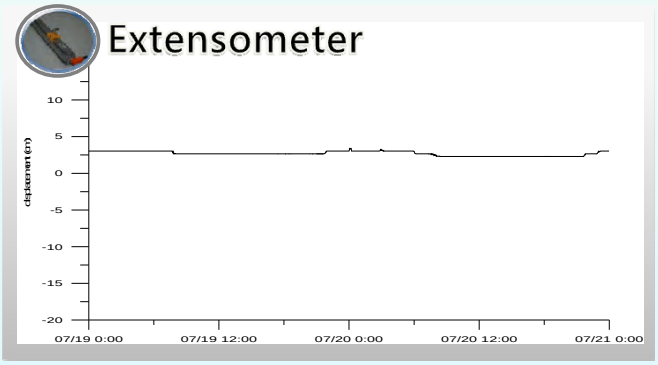
0719 Heavy Rain

Sta.	Instrument	Function
Pingting	GPS, extensometer, tiltmeter	Normal
JiuFen-ErShan	Extensometer, water level meter, groundwater level meter	Normal

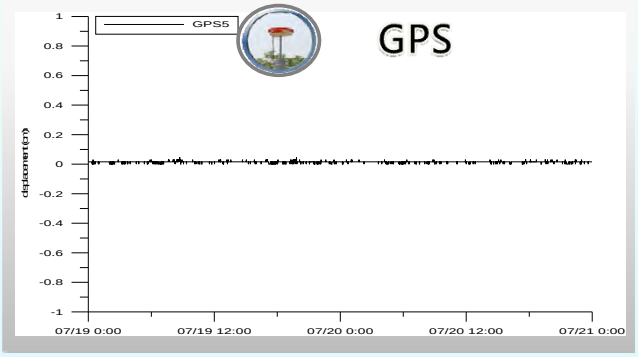
Slope displacement (SM1)



Extensometer

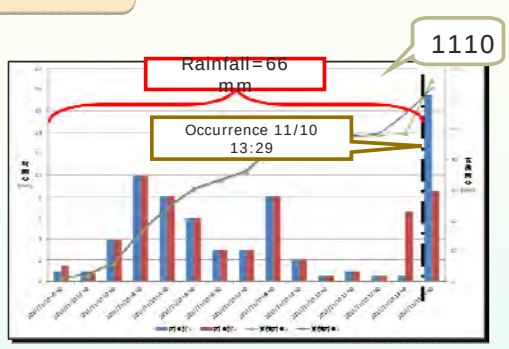


GPS



Rainfall Warning Revision

Debris Flow Event	Accumulated Rainfall by occurrence (mm)
0719	78.5
1110	66



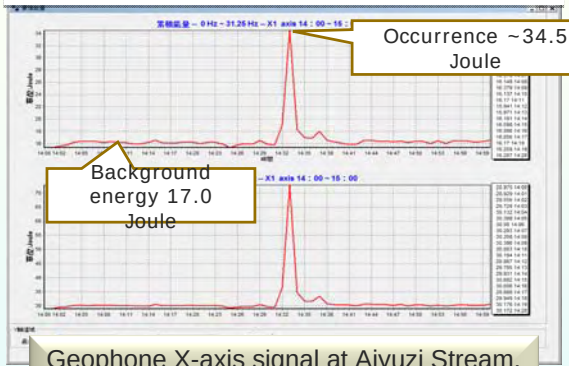
Based on the data of this year, the rainfall warning of Shenmu Sta. was suggested to lower from 250 mm to 200 mm.

- **The construction of slope protection had been completed. The rainfall warning for landslide was suggested to modified to a higher value.**
- **The rainfall warning value can use the criteria of Highway Bureau.**

Rainfall Criteria of Highway Bureau	
Warning	· Hourly rainfall >50mm or · 24hr accumulated rainfall >200mm
Action	· Hourly rainfall >60mm · 24hr accumulated rainfall >290mm

Geophone Warning Revision

Energy Analysis in Time Domain



Geophone X-axis signal at Aiyuzi Stream, Shenmu Sta.
2011/07/13 14:00~15:00

Line damaged

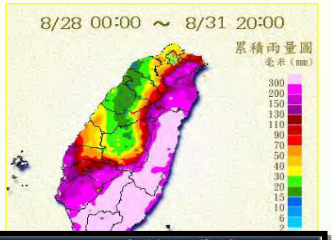
0713 Accumulated Energy (Joule)	X	Y	Z
Max.	34.5	39.7	76.7
Background	17.0	28.0	46.7
Max/Background	2.0	1.4	1.6
0719 Accumulated Energy (Joule)	**X**	**Y**	**Z**
Max.	18.4	29.1	49.0
Background	17.0	28.0	46.7
Max/Background	1.1	1.0	1.1
1110 Accumulated Energy (Joule)	**X**	**Y**	**Z**
Max.	242.5	242.4	226.3
Background	19.7	18.1	53.1
Max/Background	12.3	13.4	4.3

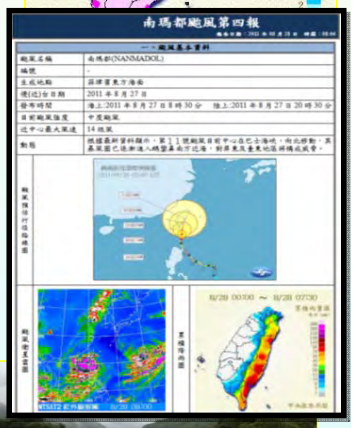
Warning Value

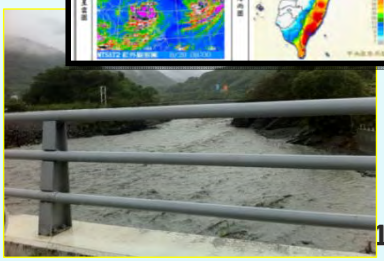
Status	Occurred	Warning
Amplitude	>3cm/s	>1cm/s
Duration	13 sec	---
Frequency	10~100Hz	---
Accumulated energy greater than the background	~~>10~~ >5	~~>5~~ >3

2011 debris flow warning list

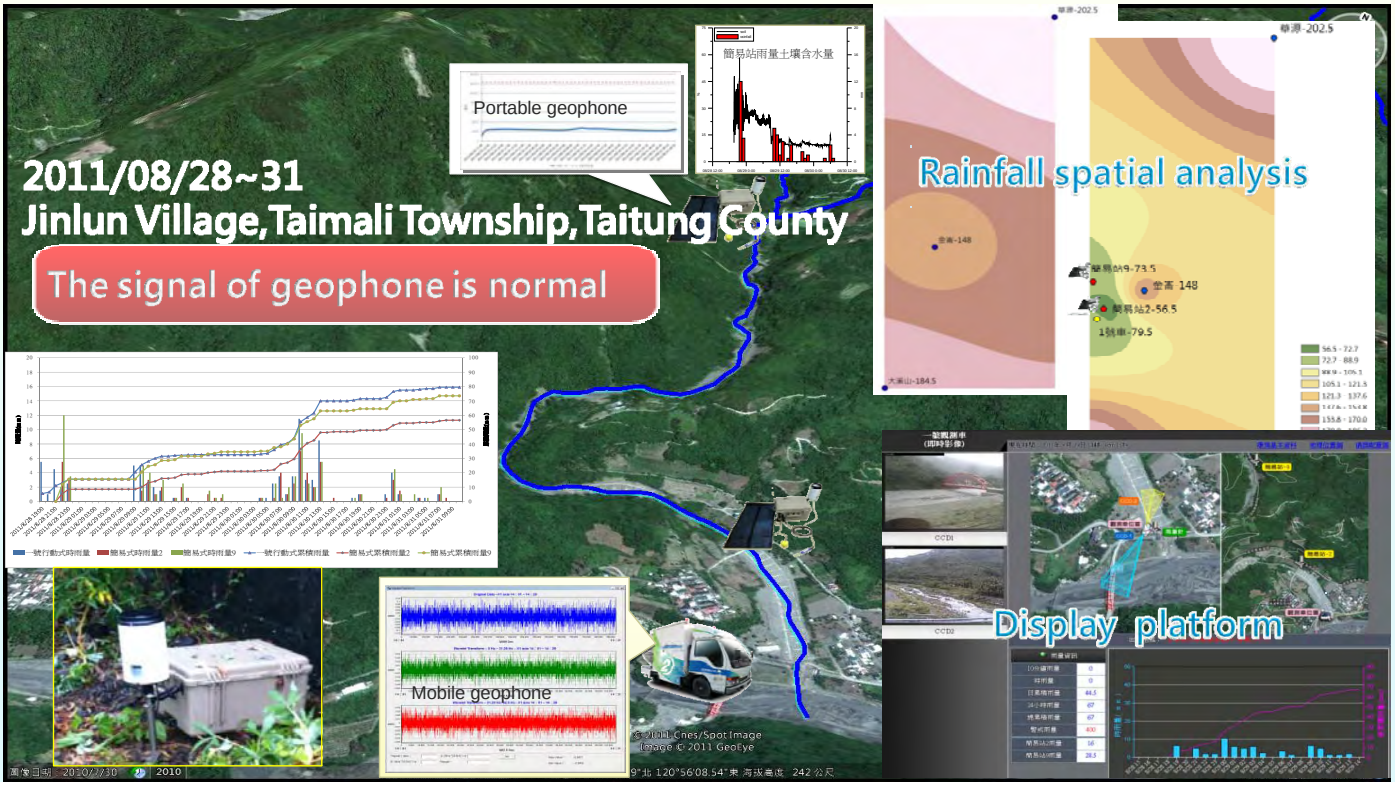
Name1	Starting time	Closure time	days	Red warning	Yellow warning	deployment
AERE	100/05/09 08:00	100/05/10 17:54	2	0	0	no
SONGDA	100/05/27 08:00	100/05/28 14:39	2	0	0	no
MEARI	100/06/24 08:00	100/06/25 14:48	2	0	0	no
0719 rainfall	100/07/19 08:30	100/07/20 22:15	2	45	146	no
MUIFA	100/08/04 17:30	100/08/06 11:53	3	0	0	no
NANMAD-OL	100/08/27 09:00	100/08/31 20:25	5	46	421	yes
1001 rainfall	100/10/02 08:00	100/10/04 14:51	3	33	227	no
1117 rainfall	2011/11/17 12:40	100/11/18 13:38	2	0	96	no







NANMADOL typhoon monitoring –mobile station NO.1



Maintenance of mobile and portable station

Schedule and Tasks

Regular

1. May to Nov. (rainy season) :Every half month
2. Dec. to April (non-rainy season) :Every month

→ Mobile station

On-call

1. After typhoon warning announced
2. After typhoon warning cleared

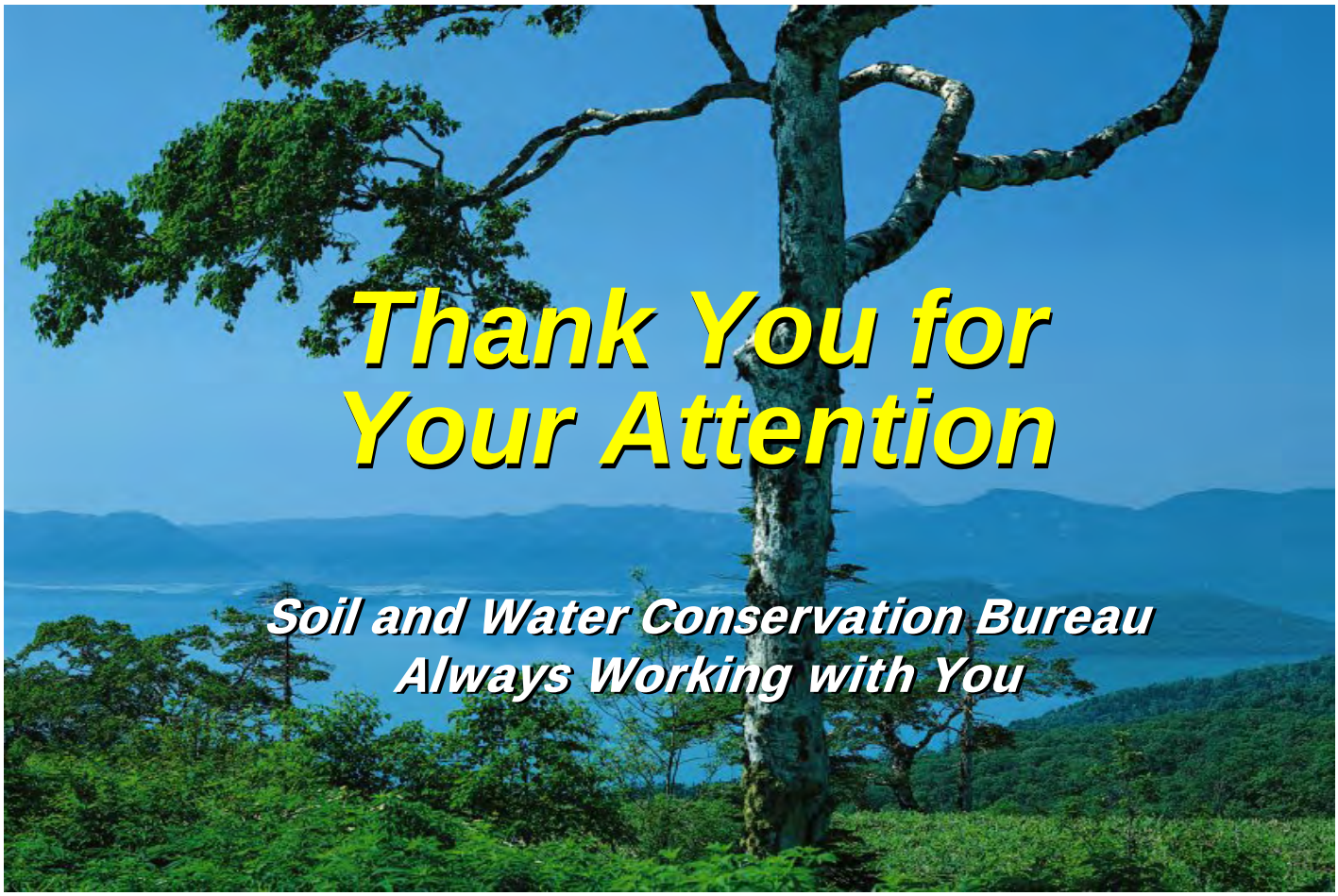
→ Portable station

Deployment of mobile and portable station

Mobile station display

Mobile station display	*Portable station display*
14 times	*25 times*

Portable station display


Thank You for
Your Attention
Soil and Water Conservation Bureau
Always Working with You