**Thai J. For. 32 (1) : 35-50 (2013)**

**Original article**

# Decision Support System for a Flash Flood and Landslide Warning System in an Upper Watershed: A Case Study at Mae Wang Watershed, Chiang Mai Province

**Sutep Junkhiaw[1]**
**Wanchai Arunpraparat[1]**
**Nipon Tangtham[2]**
**Anond Snidvongs[3]**
**Chanchai Yarwudhi[2]**

[1]Faculty of Forestry, Kasetsart University, Chatuchak, Bangkok, 10900, Thailand.
E-mail: sutep28@yahoo.com
[2]Forestry Research Center, Faculty of Forestry, Kasetsart University, Chatuchak, Bangkok, 10900, Thailand.
[3]Geo-Informatics and Space Technology Development Agency (GISTDA),The Government Complex 120 Moo 3 (Building B) 7Fl.Chaeng Wattana Rd., Laksi, Bangkok, 10210, Thailand.

Received: Feb 6, 2013 Accepted: Mar 8, 2013

## ABSTRACT

To save people's lives, the Decision Support System (DSS) for a flash flood and landslide warning system in an upper catchment of the Mae Wang watershed was developed involving the development of the methodology, models, and locations of the warning system. A general package radio service (GPRS) system was determined to be the most suitable and was selected. It used GPRS technology for data transmission and remote control after evaluating the GPRS technology against a very high frequency-based system, a synchronized communication system, and a satellite system. The system prototype included four automatic rain gauges, two water level sensors and three soil moisture sensors that were installed at the four stations namely, Khun Wang (STA01), Tung Khlung (STA02), Sop Win (STA03), and Pun Ton(STA04).

The antecedent precipitation index (*API*) that was used to predict landslide warnings was determined from rainfall simulation in four land use types dry dipterocarp forest, hill evergreen forest, degraded forest, and agricultural land with *API* crisis values of 221.50, 400.00, 325.59, and 248.86 mm, respectively. The flash flood warning system used the correlation of rainfall at three stations to predict the water level at STA03and the relationship between the water level at STA03 and STA04 to define the warning area. The accumulated 24 hr rainfall critical values of STA01, STA02, and STA03 were 100.00, 145.00, and 221.50 mm, respectively. The relationship between the two water levels could be estimated by the equation: $y = 2.382\ln(x) + 1.0032$ ($r^2 = 0.763$) where y is the water level (m) at STA04 and x is the water level (m) at STA03 and the flow timing of water movement was forecast by the equation $T = 25.576e^{-0.465x}$ ($r^2 = 0.69$) where $T$ is the travel time (hr) from the STA03 to STA04 and $x$ is the water level (m) at STA03. The critical water level at STA03 was 3.58 m for warning villages located below STA04 and 3.10 m for villages located above STA04.

**Keywords:** Decision support system (DSS), Flash flood and landslide, Early warning system (EWS), Upper watershed, Mae Wang watershed

## INTRODUCTION

Over the last decade (2001–2010), more than 891 people have died in floods and landslides with 216 people in 2002, 446 people in 2006, and 229 people in 2010 (Wongruang, 2010). Flooding and landslides cause widespread damage and suffering. Bank of Thailand (2011) reported that in 2011, Thailand suffered major flooding with 63 provinces directly involved and 12.8 million people affected, involving 698 deaths and 3 missing presumed dead. More than 24 million hectares of agricultural land was damaged as well as most of the industrial estates in the central part of the country. Economic losses were estimated at 45 thousand million dollars. Flash flooding and landslides caused by heavy rainfall in the head watershed overloaded the soil carrying capacity, as its ability to absorb the heavy rainfall was reduced due to the conversion of hill slope land use from forest to agriculture.

Since historical times, in Thailand, general broad scale flooding and flash flooding have caused damage to both life and property. Engineering structures and also non-structural measures can be used to reduce flood damage. One of the non-engineering measures is a flood warning system that can immediately inform the people living downstream to take precautions before the floodwaters reach them. With this system, the people can make a decision on when the flood discharge should arrive and how much time they have to evacuate to safe locations. With new electronic technology and modern communications as well as geographic information system (GIS) techniques, decision support systems for flash flood and landslide warning have become more common and produced more reliable forecasting.

A decision support system (DSS) for flash flood and landslide warning is possible to develop and to then be used to save people's lives in the watershed. The proposed DSS for flash flood and landslide warning proposed here was intended to integrate a computer model with the people participatory approach so that the DSS can be handled by the local organization to inform when either a flood or landslide is likely to reach the village. The research used automatic data transmitting (ADT) from client stations to a server for analysis with real-time reporting by the network system. The participants could then assess a flood or landslide event and determine if warnings should be issued to the people in the watershed.

The flash flood and landslide warning system developed in this study was installed in an upland watershed where flash flooding and landslides frequently occurred to allow downstream communities to use it as a tool for making decisions following heavy rainfall events in the upstream catchment. The main target of the research was to design and verify the ADT system. The digital signal from client stations to the server was analyzed, and the process of real-time reporting by the network system was monitored and adjusted.

The development of this system as a part of the national response to help predict flash flooding and landslides to reduce their negative impacts on people and property involved two objectives: 1) to develop the real time flood and landslide warning system using equipment and a remote transmitting system developed in the country, and 2) to develop the DSS for the user interface of the flood warning system in the Mae Wang watershed, Chiang Mai province.

## MATERIALS AND METHODS

The Mae Wang watershed area is located in the sub districts of Mae Win, Ban Kard and Tung-Peare in Mae Wang district, Chiang Mai province. The Mae Wang watershed area is connected to the north east of the Doi Inthanon National Park. The total area is approximately 500 square kilometers and about 20 kilometers from Chiang Mai. The upper and middle steam watershed area is classified as hill slope and piedmont and the remaining is lowland in the downstream part. The area slopes to the east of Mae Wang district and the main land uses are conservation and agriculture. The Mae Wang river is very important for agriculture and the other products for consumption. This research involved the installation of four stations in this area as shown in Figure 1.

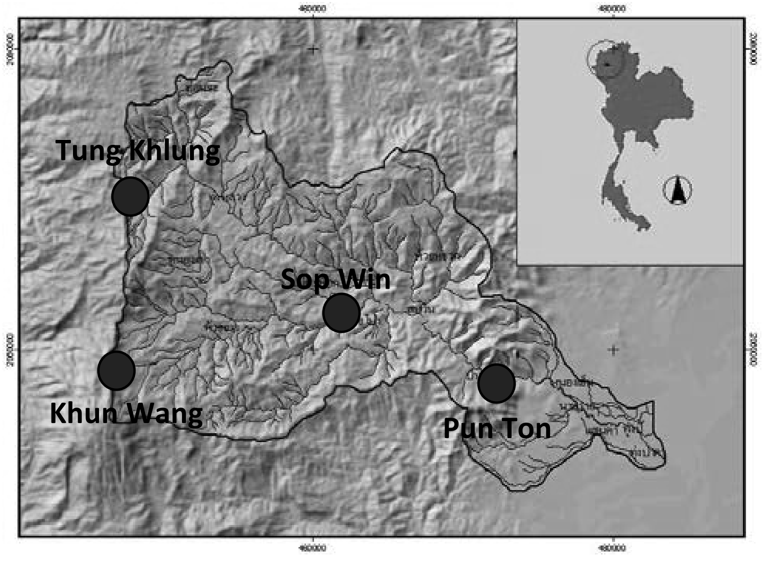



**Figure 1** Study area in Mae Wang sub-watershed, Chiang Mai province.

The warning system for the upper watershed consisted of measurement data recorded in a database, systems processing, and the system remote control components. There were five steps in creating the model to determine the critical values in decision making on flash flood and landslide warnings. First, the general watershed characteristics were taken into consideration, such as the topology (geology, slope, aspect), the natural resources (type of forest, type of land use), watershed structure (stream density, stream slope, stream distance), including historical flood and landslide information in the Mae Wang watershed. These data were used to create a flood and landslide risk map. In step 2, the early warning system (EWS) was designed and developed and the following equipment was installed to measure field data for a period of two years: two water level gauges, four automatic rain gauges, four temperature measurement sensors, and four soil moisture sensors. All data were transmitted from the field stations back to a server computer in Bangkok. Step 3 consisted of developing the model from the analysis of the collected data which was then used as input into the next step. In step 4, the landslide DSS was developed using a flash flood model based on the antecedent precipitation index (API), soil moisture and real-time processing of rainfall data. Generally, after long periods of falling rain, the runoff increases because the soil is saturated. The correlation between the water level at an upper watershed and a lower watershed point where flooding could occur was used to develop the flash flood decision making system. The last step a community alert system was developed involving three different ways of real time warning about critical levels in the prediction models namely, by website, telephone (automatic SMS messages), and by a flashing light and loud siren at the field measurement stations.

## RESULTS AND DISCUSSION

### System Designed and Development

#### Early Warning System Development

The early warning system (EWS) or automatic alarm system was designed and developed to alert residents in the Mae Wang watershed. It was created to be a functional link between the client stations and the server station. Each client station was designed to be able to operate automatically if the connection were interrupted. The client stations were set at the critical values for the decision making factors to deliver a first warning, and were activated as soon as the measured values from the field sensors exceeded the critical value or an activation command was sent from the server station. High performance computing was used in the server station to process the data and several factors together before sending the data to the alarm client stations. This resulted in an accurate and precise process.

The EWS in the client stations included the measurement data systems, data processing, data transmission systems and remote control, and alarm systems. The main computer server was connected to the GIS database, historical data, and data from other client stations to create a mathematical model and deliver a warning signal to alert the client stations, be posted on a website, and distributed via SMS.

Rainfall data were automatically measured as well as the soil moisture at two levels (10 cm and 30–50 cm) and the water level in the stream. The water level sensors were installed only at Ban Sop Win station (STA03) and Ban Pun Ton station (STA04) to study the relationship between the water level at these two stations and the flood warning. All sensors were connected to the PLC (programmable logic control) units, which were the main equipment pieces of the EWS.

Warning alarms were designed to alert at three levels: level 1, a warning every 30 minutes in alarm signal lengths of 10 seconds; level 2, a warning every 15 minutes in alarm lengths of 10 seconds; and level 3, an alert every 5 minutes in alarm lengths of 10 seconds. At each level, an alarm would sound and different light codes were used. The warning levels for the client stations and the server station were also different: the client stations would alert at levels 3, 2, and 1 at 100%, 90%, and 80% of the critical values respectively. Whichever factor reached the critical value first, would initiate the appropriate alarm response level. However, the server station would alert at warning levels 3, 2, and 1 at 90%, 80%, and 70% of the critical values, respectively.

**Communication System Development**

Four communication systems were designed, developed, and tested to find the best system. 1) Very high frequency (VHF) uses voice radio wavelengths. It had a limited range and was expensive because it required an additional repeater station. Therefore, it was not considered suitable. 2) Synchronized communication system (SCS) uses a mobile phone to send data. This system had a low cost but the data had to be converted for downloading and reconverted to digital format once it had been downloaded, and data loss could occur. Furthermore, data transmission was expensive and so this system was also not considered suitable. 3) The satellite system (SAT), based on the IP-STAR satellite can be used to send data. It was very expensive and the administration process was very complicated and time consuming. The transmission was unreliable in heavy rain, which was when the data were most needed, so it was considered unsuitable. 4) General package radio service (GPRS) uses digital data transfer and there is no risk of data loss and it is not excessively expensive. Thus, GPRS was the best option and this was used in the project. The four prototypes of EWS are shown in Figure 2.

a) VHF


b) SCS

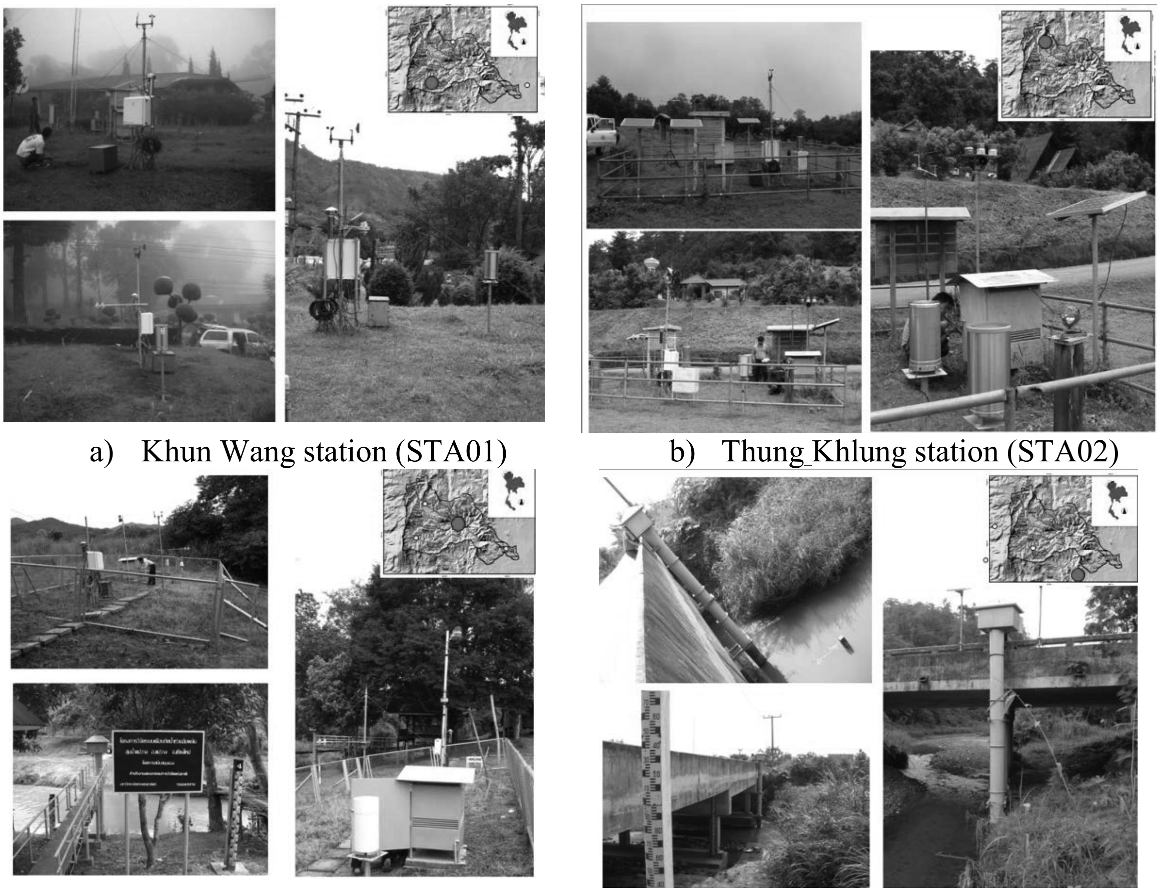
c) GPRS


d) SAT

**Figure 2** Prototypes developed for the early warning system:
a) Very high frequency (VHF),
b) Synchronized communication system (SCS),
c) General package radio service (GPRS), and
d) Satellite system (SAT).

**System Installation**

The GPRS system was installed in the Mae Wang watershed. The four stations of the EWS were set up to represent the entire watershed, which consisted of the upper watershed basin on the left and right sides, the central basin, and the lower basin. The four stations were: Kun Wang station (STA 01), Tung Khlung station (STA02), Sop Win station (STA03) and Pun Ton station (STA04). Automatic water level sensors were only installed at STA03 and STA04. Soil moisture sensors were installed at all stations excluding STA04. The EWS consisted of measurement data, recorded data, data processing, and data transmission to the server every 15 minutes. System installations are shown in Figure 3.



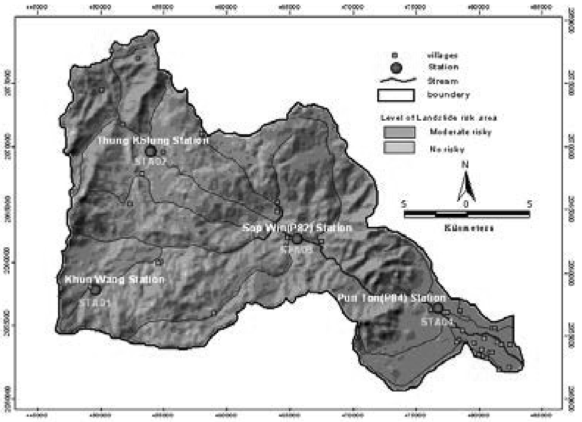
a) Khun Wang station (STA01)
b) Thung Khlung station (STA02)
c) Sop Win station (STA03)
d) Pun Ton station (STA04)

**Figure 3** Station installations, sensors, and warning system in Mae Wang Watershed.

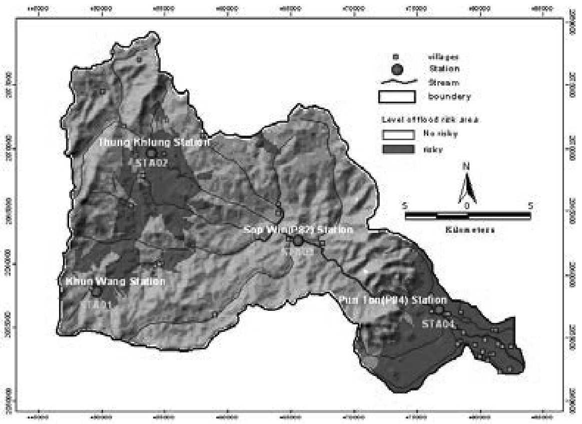
**Flash Flood and Landslide Decision Making for Early Warning System**

**Flash flood and landslide hazard map**

A landslide hazard area map was created using GIS data consisting of slope, elevation, geology, soil characteristics, and land use types, which were superimposed by weighted importance (Junkhiaw, 2003; Junkhiaw *et al*., 2004: a, b). The flood risk map was created using GIS data and historical information on flooding events. The landslide and flash flood hazard area maps are shown in Figure 4.




a) Landslide hazard area map




b) Flash flood hazard area map

**Figure 4** Emergency warning system mapping in Mae Wang watershed.

**DSS for landslide warning system**

The factor of safety (F) is proportional to the resistance force and active force which influence the moisture in the soil and can be estimated from the ratio of the current API ($API_t$) and API crisis ($API_c$) values. The evaluation model $API_t$ was obtained from Equation 1:

$$API_t = (K_t . API_{(t-1)}) + P_t \quad (1)$$

Where $API_t$ is the current API for today (mm), $API_{t-1}$ is the API of yesterday (mm), $P_t$ is today's precipitation (mm), and $K_t$ is the recession coefficient implying an effect of the amount of yesterday's evaporation. The value of $K_t$ was determined from the data collected from field soil samples that were analyzed in the laboratory. The samples were collected from each of the major categories land use in the landslide risk area-namely, hill evergreen forest (HEF), mixed deciduous forest (MDF), and agricultural land (AL). The K values were obtained from the average ratio of soil moisture recession or the proportion of soil moisture at any time with no rain as the initial moisture values. The monthly $K_t$ values are shown in Table 1.

**Table 1** Monthly differences in recession constant ($K_t$) of soil by land use type in the Mae Wang watershed.

| Month | Land use type | | |
|---|---|---|---|
| | **Hill evergreen forest** | **Agricultural land** | **Mixed deciduous forest** |
| Jan | 0.9023 | 0.6872 | 0.7785 |
| Feb | 0.8997 | 0.6799 | 0.7729 |
| Mar | 0.9227 | 0.7457 | 0.8221 |
| Apr | 0.9250 | 0.7524 | 0.8271 |
| May | 0.9317 | 0.7725 | 0.8417 |
| Jun | 0.9297 | 0.7665 | 0.8374 |
| Jul | 0.9311 | 0.7706 | 0.8404 |
| Aug | 0.9420 | 0.8041 | 0.8645 |
| Sep | 0.9467 | 0.8189 | 0.8751 |
| Oct | 0.9453 | 0.8143 | 0.8719 |
| Nov | 0.9342 | 0.7801 | 0.8473 |
| Dec | 0.9111 | 0.7120 | 0.7972 |
| Average | 0.9268 | 0.7587 | 0.8313 |

Evaluation of $API_C$ was carried out by simulating the rainfall in the four types of land use namely, dry deciduous forest (DDF), HEF, MDF, and AL on hill slopes and calculating the $API_C$ on soil saturated with water or surface water runoff, which is shown in Table 2. The results were transformed into a critical isohyet-API map (Figure 5) that could be used for landslide warning.

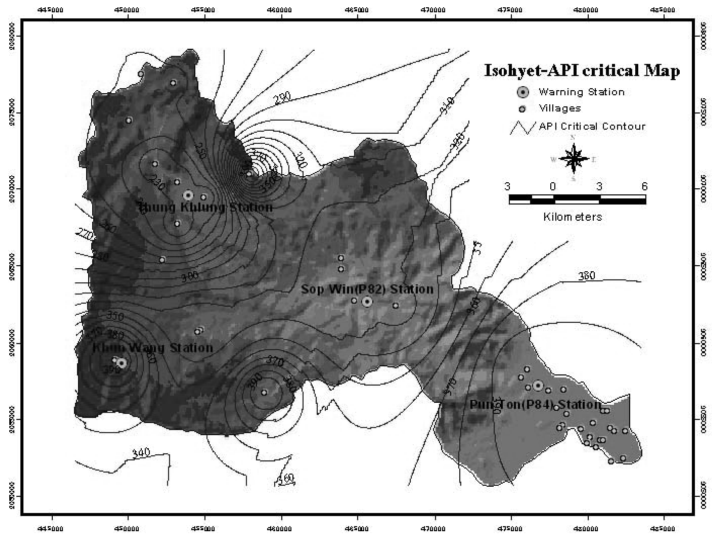


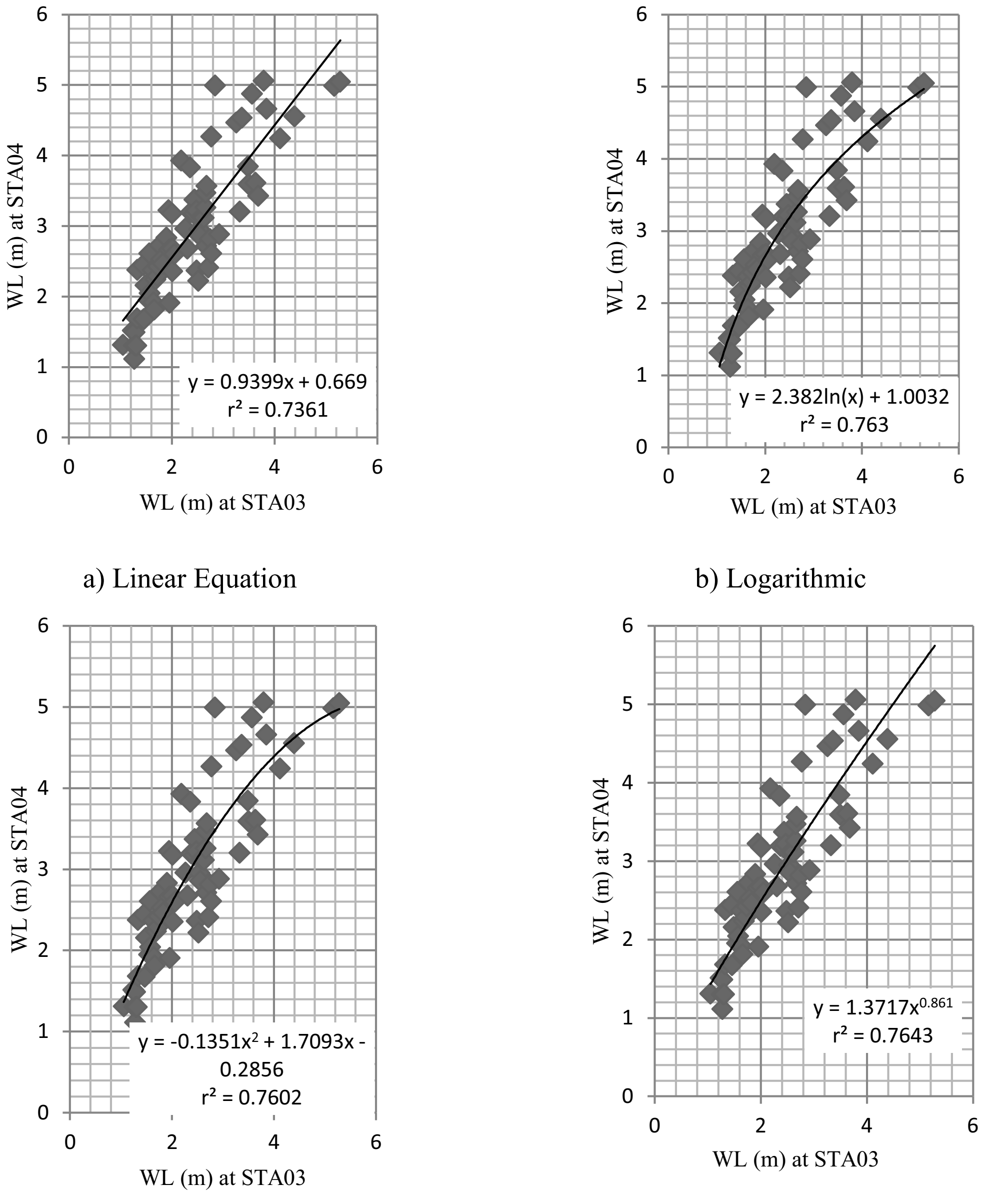

**Figure 5** Isohyet-*API* critical map for landslide warning in Mae Wang watershed.

The $API_c$ values that were used to alert all stations with a slope greater than 30% by the type of land use for DDF, HEF, DF, and AL were 221.50, >400.00, 325.59, and 248.86 mm, respectively, which were determined by the level of alert for landslides in client stations at 1, 2, and 3 as shown in Table 3.

**DSS for flash flood warning system**

There were three flood events during the two years of the study period (2006–2007): 1) 9–12 September 2006, 2) 17–22 September 2007, and 3) 27 September–1 October 2007. The collected data during these events were used to create a model for flood warning by studying the relationship of past rainfall on the current day or the past 24 hr ($d_0$), rainfall with a lag time of 1 day ($d_1$), rainfall with a lag time of 2 days ($d_2$), rainfall with a lag time of 3 days ($d_3$), rainfall with a lag time of 4 days ($d_4$), and rainfall with a lag time of 5 days ($d_5$) that influenced the water level at STA03. The results showed that the cumulative rainfall of $STA02_{d1}$ or $STA01_{d1}$ or ($STA01_{d1} + STA02_{d1}$) or ($STA01_{d1} + STA02_{d1} + STA03_{d0}$) were related to the water level at STA03, with a coefficient of determination ($r^2$) value of more than 75%.The minimum rainfall at $STA02_{d1}$ or $STA01_{d1}$ or ($STA01_{d1} + STA02_{d1}$) or ($STA01_{d1} + STA02_{d1} + STA03_{d0}$) that would constitute a risk of flooding at STA03 was 65.5, or 67.5, or 91.0, or 145.0 mm, respectively.

Another model (the relationship between the two water levels at STA03 and STA04) was used to develop alarm levels for the lower areas in the catchment. From the three cases of flooding in the Mae Wang watershed, the relationship of the water level at STA03 and at STA04 (the lower station) had an $r^2$ value of more than 70%, with the correlation of the four types of equations shown in Figure 6.




a) Linear Equation b) Logarithmic

c) Polynomial d) Power

**Figure 6** Relationship of water level (WL) between two stations (STA03 and STA04) based on four equations.

The suitable equation for water level prediction can be selected based on the sum of squares error (SSE) and the coefficient of determination ($r^2$) values in Table 2.The $r^2$ values for the linear, logarithmic, polynomial, and power equations were 0.7361, 0.763, 0.7602, and 0.7643, respectively, as shown in Table 2. Three models were developed for prediction and forecasting of water levels in the lower areas of the catchment. The model for the prediction of water in the lower areas of the Mae Wang watershed is shown by Equation 2:

$$y = a \times ln(x) + b \qquad (2)$$

Where: a = 2.382, b = 1.0032, $y$ is the water level (m) at STA04 and $x$ is the water level (m) at STA03. The parameters $a$ and $b$ are different in each basin and depend on several factors, such as any forking in the river, the stream slope, and the distance between the upper and lower stations. The water level relationship between the upper and lower stations of the Mae Wang watershed is shown in Figure 7.

**Table 2** Various relationships between the water level of the two stations (STA03 and STA04) constructed using four types of relationship.

| | **Type of equation** | | | |
|---|---|---|---|---|
| | **Linear** | **Logarithmic** | **Polynomial** | **Power** |
| $r^2$ (observed versus simulated) | $r^2 = 0.7361$ | $r^2 = 0.763$ | $r^2 = 0.7602$ | $r^2 = 0.7643$ |
| Equation | $y = 0.9399x + 0.669$ | $y = 2.382\ln(x) + 1.0032$ | $y = -0.1351x^2 + 1.7093x - 0.2856$ | $y = 1.3717x^{0.861}$ |
| SSE | 18.954 | 17.023 | 17.224 | 20.263 |
| Logical model | No | Yes | Yes | No |

**Remarks:** SSE = Sum of squares error
$R^2$ = Coefficient of determination
Logical models = the main sense of the variability of the data.

From Figure 7, the relationship between the water level at the two stations, STA03 and STA04 can be determined; for example, a level of 3.58 m at STA03 (warning level) will cause flooding at the lower station to the level of 4.0 m. The water level at the lower station (STA04) will be reduced substantially by overflowing of the stream bank and by spreading down to the lower areas.

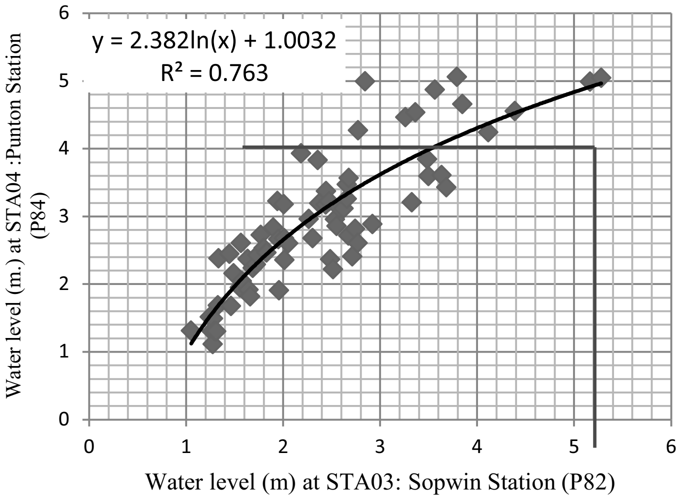



**Figure 7** Relationship between the water level at the upper station (STA03) and the lower station (STA04). The red line shows the level at STA04 (3.5 m) when the level at STA03 is 4 m.

A more effective warning was provided by modeling the travel time of water from the upper station (STA03) to the lower station (STA04) using the time between the peak of the storm runoff at STA03 to determine the maximum of water level at STA04. The relationship is shown in Equation 3:

$(r^2 = 0.6888)$ (3)

Where $y$ is the travel time (hr) of water from the upper station to the lower station and $x$ is the water level at STA04 as shown in Figure 8. The studied results are summarized in the values of landslide and flash flood warning levels by separate alarm levels for the server and the client stations as shown in Table 3.

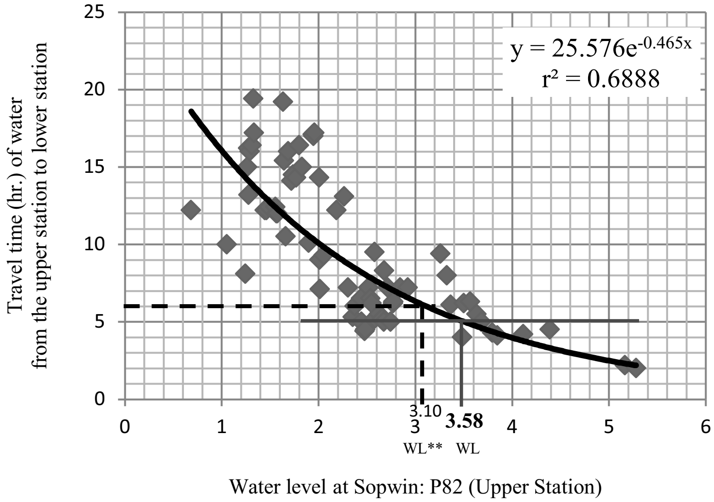



**Figure 8** Relationship between water level (WL) at the upper station (P82) and travel time (hr) of water from STA03 to STA04 that resulted in the maximum water level at STA04 (risk area).

From Figure 8 and Table 3, it can be seen that the critical water level ($Wl_c$) for the area located below STA04 has warning alarm levels 1, 2, and 3 of 2.86, 3.22, and 3.58 m, respectively, while the area located above STA04 has alarm levels1, 2, and 3 of 2.48, 2.79, and 3.10, respectively. The two cases require a period of not less than five hours warning.

**Table 3** Critical values to trigger a warning alert at the server station and client stations.

| STATION | Factor | Critical values | Critical warning at server station | | | Critical warning at client stations | | |
|---|---|---|---|---|---|---|---|---|
| | | | Level of warning | | | Level of warning | | |
| | | | 1 | 2 | 3 | 1 | 2 | 3 |
| STA01 | R 12 hr | 100.00 | 70.00 | 80.00 | 90.00 | 80.00 | 90.00 | 100.00 |
| | R 24 hr | 145.00 | 101.50 | 116.00 | 130.50 | 116.00 | 130.50 | 145.00 |
| | API* | 221.50 | 155.05 | 177.2 | 199.35 | 177.2 | 199.35 | 221.50 |
| STA02 | R 12 hr | 100.00 | 70.00 | 80.00 | 90.00 | 80.00 | 90.00 | 100.00 |
| | R 24 hr | 145.00 | 101.50 | 116.00 | 130.50 | 116.00 | 130.50 | 145.00 |
| | API* | 325.59 | 227.91 | 260.47 | 293.03 | 260.47 | 293.03 | 325.59 |
| STA03 | R 12 hr | 100.00 | 70.00 | 80.00 | 90.00 | 80.00 | 90.00 | 100.00 |
| | R 24 hr | 145.00 | 101.50 | 116.00 | 130.50 | 116.00 | 130.50 | 145.00 |
| | API* | 248.86 | 174.20 | 199.09 | 223.97 | 199.09 | 223.97 | 248.86 |
| | WL | 3.58 | 2.50 | 2.86 | 3.22 | 2.86 | 3.22 | 3.58 |
| | WL** | 3.10 | 2.23 | 2.48 | 2.79 | 2.48 | 2.79 | 3.10 |
| STA04 | R 12 hr | - | - | - | - | - | - | - |
| | R 24 hr | - | - | - | - | - | - | - |
| | API* | - | - | - | - | - | - | - |
| | WL | 4.00 | 2.80 | 3.20 | 3.60 | 3.20 | 3.60 | 4.00 |

**Remarks:** R12 hr = Cumulative rainfall in 12 hr (mm)

R 24 hr = Cumulative rainfall in 24 hr (mm)

API = API critical values (API* was used only for landslide warning)

WL = Critical water level (m) for villages lower than STA04

WL** = Critical water level (m) for village higher than STA04

## CONCLUSION

The results of the research in the Mae Wang watershed can be summarized as follows.

1. The GPRS system was the most suitable system compared to VHF, SCS, and SAT and was selected for the Mae Wang watershed. GPRS technology was used for data transmission and remote control. Early warning systems were installed at four stations Khun Wang (STA01), Tung Khlung (STA02), Sop Win (STA03), and Pun Ton (STA04). Each station was equipped with a sensor for automatic recording of rainfall, while automatic recording of water level was only installed at STA03 and STA04, soil moisture sensors were installed at all stations except STA04 and a set of flashing lights and sirens was installed at every station. There were three alarm levels: level 1 activated a green flashing light and an alert every 30 minutes, level 2 activated a yellow flashing light and an alert every 15 minutes, and level 3 involved a red flashing light and an alert every 5 minutes.

2. API was used to predict landslide warning. The critical value ($API_c$) was determined by rainfall simulation in the four land use types of DDF, HEF, DF, and AL with values of 221.50, 400.00, 325.59, and 248.86 mm, respectively.

3. The flash flood warning system used the correlation of rainfall at three stations to predict the water level at STA03 and the relationship between the water level at STA03 and STA04 to determine the extent of the warning area. Critical levels for STA01 STA02 and STA03 of accumulated rainfall for 12 and 24 hr were 100.00 and 145.00 mm, respectively.

The relationship between the two water levels could be estimated by the equation $y = 2.382\ln(x) + 1.0032$ ($r^2 = 0.763$) where y is the water level (m) at STA04 and x is the water level (m) at STA03 and the timing of water movement was forecast by the equation $T = 25.576e^{-0.465x}$ ($r^2 = 0.69$) where T is the travel time (hr) and x is the water level (m) at STA03. The critical water level at STA03 for warning villages located below the station was 3.58 m while the level was 3.10 m for villages located above STA04.

## ACKNOWLEDGEMENTS

The authors are grateful to Mr.Thada Sukapunnapan, Director of the Hydrology Division, Royal Irrigation Department (RID) who fostered the initial idea to develop warning system research in Thailand.

## REFERENCES

Bank of Thailand. 2012. **Thailand floods 2011: Impact and recovery from business survey**. Bangkok. Available Sources: www.bot.or.th/Economic-Conditions/ Thai/BLP/Documents/ ThaiFloodSurvey2011_eng.pdf, January 17, 2013.

Junkhiaw, S. 2003. **Forecasting Flash Flood of Mae Cheam Watershed Using GAME-T Data and Artificial Neural Network (ANN)**. In Proceedings 2003 International Symposium on the Climate System of Asian Monsoon and its Interaction with Society. 11–13 November , 2003. Sofitel Raja Orchid Hotel, Khon Kaen, Thailand.

Junkhiaw, S. and N. Tangtham. 2004 (a). **Determining Landslide of Northern Thailand Watershed Using GAME-T Data and Artificial Neural Network (ANN).** Proceeding in 2nd APHW Conference, Suntec International Convention and Exhibition Center, July 5–8, 2004. Singapore.

_____. 2004 (b). **Developing Flood Warning System for Upland Watersheds of the Chao Phraya Basin**. Proceedings of 6th International Study Conferences on GEWAX in Asia and GAME. Publication No.11. December, 3–5. 2004 at Kyoto International Community House. Japan.

Wongruang, P. 2010. **Special report: Master plan looks good, on paper**. Bangkok Post. Sunday, November 21, 2010, pp.3–5