Recent Advance in Landslip Warning System

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Abstract: Hong Kong is a city with rugged topography. Landslides generally occur during periods of heavy rainfall. The Geotechnical Engineering Office (GEO) of the Civil Engineering Department and the Hong Kong Observatory (HKO) of the Government of Hong Kong Special Administrative Region operate a Landslip Warning System to alert the public to landslide hazard. By using information on a combination of real-time measured rainfall and rainfall forecast, and based on our understanding of the rainfall-landslide relationship, the Hong Kong Government is able to issue Landslip Warnings as appropriate. One purpose of the Landslip Warning is to alert the public to reduce their exposure to possible danger from landslides. The GEO and the HKO manage a raingauge system of over 100 automatic raingauges distributed over Hong Kong that measures rainfall intensities at 5-minute intervals. The GEO keeps comprehensive rainfall and landslide data since 1984, which facilitates the study of correlations between rainfall and landslides. This paper outlines the key components of the GEO Landslip Warning System and presents the algorithm for predicting the number of landslides by the established correlations between landslide frequencies and maximum 24-hour rainfall using simplified GIS approach. The incorporation of short-range rainfall forecast made by the HKO into the Warning System is also described.

INTRODUCTION

Hong Kong has a long history of landslides, the majority of which were triggered by rainfall. The Geotechnical Engineering Office (GEO) of the Civil Engineering Department (CED) and the Hong Kong Observatory (HKO) of the Government of Hong Kong Special Administrative Region operate a Landslip Warning System. Landslip Warnings are issued during times of heavy rainfall when it is predicted that numerous landslides will occur. The purposes of Landslip Warning are to alert the public to reduce their exposure to possible danger from landslides and to trigger the operation of an emergency system within government departments that mobilises staff and resources to deal with landslide incidents.

The operation of the Landslip Warning System requires knowledge of the real-time and forecast of rainfall intensities, and a good understanding of the relationship between rainfall and landslides.

THE GEO RAINGAUGE SYSTEM

The GEO and the HKO operate an extensive network of automatic raingauges, providing real-time rainfall data to the Landslip Warning System. The locations of the raingauges are shown in Figure 1. This network, which dates back to 1984, was upgraded in 1999 to improve coverage in the new development areas. The network now comprises 86 raingauges located throughout Hong Kong. The data capture, control and processing system, which was also upgraded in 1999, receives data from the 86 GEO field raingauge stations and an additional 24 automatic raingauges operated by the HKO.

The hardware for the GEO raingauge system includes two major parts: (i) 86 field raingauge stations and (ii) a Central Control Centre located in the Civil Engineering Department of the Government of Hong Kong Special Administrative Region. Each field raingauge station comprises a Casella tipping bucket raingauge, a data logger module with a modem for data transmission, and a rechargeable battery powered by a solar panel, as depicted in Figure 2. The Casella tipping bucket raingauge collects rainfall, and the data logger module records the corresponding measurement in real-time. Every 5-minute the modem transmits the total rainfall amount recorded in the last 5-minute by private telephone line to the data acquisition unit in the Central Control Centre, which is equipped with computers for receiving and processing the raw rainfall data (Figure 3). The data are also transmitted to the HKO in real-time using private telephone line.

Computer programs are developed and applied together with the proprietary software to acquire real-time rainfall data, display situation of rainfall development (such as, rainfall contour maps), calculate the predicted number of landslides and check automatically the rainfall situation against the Landslip Warning criteria. As mentioned in the above section, the real-time rainfall records are transmitted to the Central Control Centre every 5-minute. The software system then checks the validity of the rainfall data, updates the corresponding rainfall data and displays

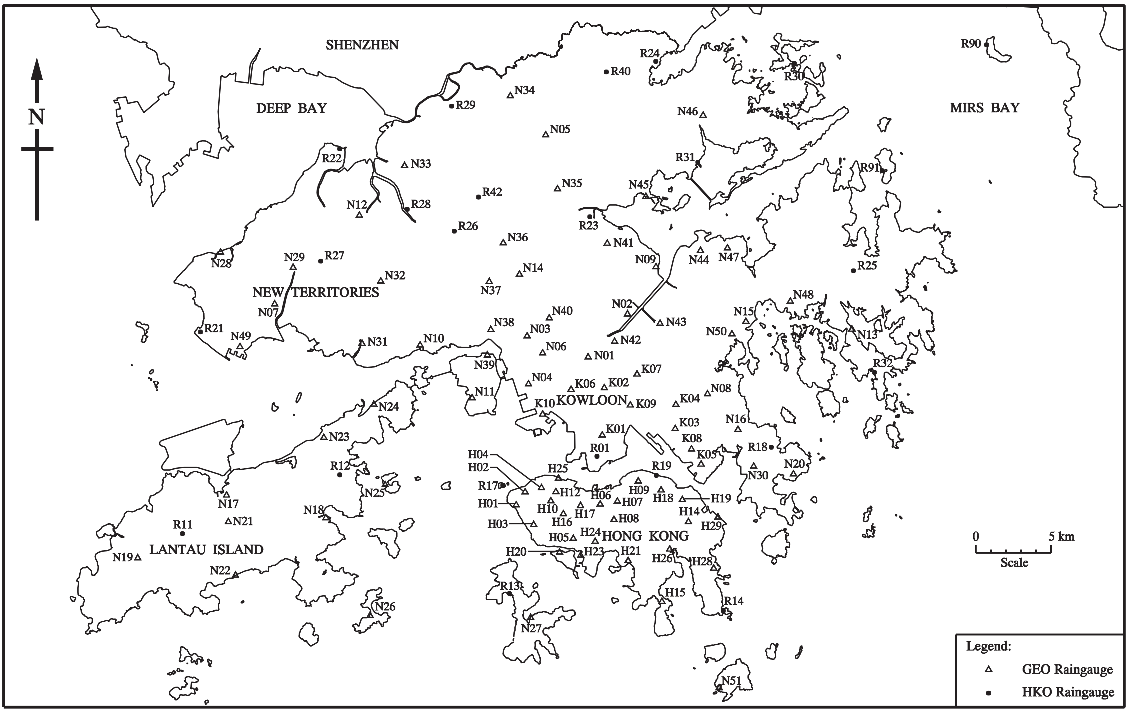


Figure 1. Locations of GEO and HKO field raingauge stations

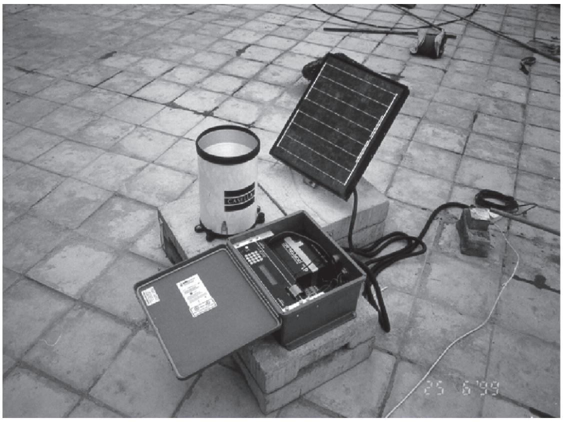


Figure 2. GEO field raingauge station

them in contour maps for different duration of rainfall (Figure 3). The Landslip Warning criteria are also automatically checked using the recorded and forecast rainfall and the rainfall-landslide correlation model. All the above processes are completed within five minutes.

CORRELATION BETWEEN RAINFALL AND LANDSLIDES

The first set of Landslip Warning criteria in 1977 was based on the work of Lumb (1975). Under the criteria, Landslip warnings would be issued when the 1-day rainfall exceeded a certain threshold value, which depended on the 15-day rainfall.

Brand et al (1984) reported on the work carried out in the early 1980s for the development of the second-generation Landslip Warning criteria. In that research, rainfall data covering a period of about 20 years were analysed. Data on the time of landslide occurrence used were based on the records of the Fire Services Department. Two thresholds values for the on-set of widespread landslides associated with 24-hour rainfall and one-hour rainfall respectively were established. The findings formed the basis of the Landslip Warning criteria in the second half of the 1980s and most of the 1990s.

Using the data on rainfall and landslides collected in the period 1984 to 1996 through the extensive raingauge network and detailed recording of landslide incidents by GEO's professional staff, the GEO carried out a comprehensive review of the Landslip Warning criteria in 1997 and 1998. Areas with relatively high landslide density (called 'vulnerable' areas) were identified and a correlation between landslide density and rolling 24-hour rainfall was established for these areas (Pun et al, 2003). Landslide density was defined as the number of landslides reported per unit area. The correlation model was adopted for estimating the number of landslides in real time and formed the basis of the third-generation Landslip Warning criteria till 2003. Landslip Warning would be issued when the estimated number of landslides exceeded a

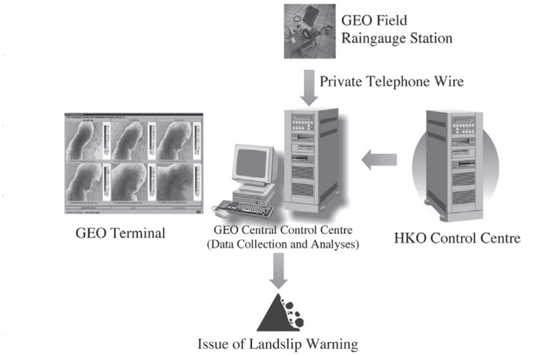


Figure 3. GEO Landslip Warning System

threshold value, currently set at 15. This value was adopted because past statistics showed that on average there was one major landslide (defined as a landslide with failure volume greater than 50 m^3) in every 15 landslides.

Pang et al. (2000) reported using a simplified GIS approach to obtain a good correlation between slope failure rate, maximum rolling 24-hour rainfall and slope characteristics for soil cut slopes. Based on this, a new model for the rainfall-landslide correlation has been developed. In the model, Hong Kong is divided into about 700 spatial grid cells, each having a plan area of 1.5 km by 1.2 km. This follows the gridding system used for 1:1000 scale maps published by Lands Department of the Hong Kong Government. In total, 118 rainstorm events with a maximum rolling 24-hour rainfall exceeding 50 mm recorded at the HKO were identified for the period 1992 to 2001. Isohyets of maximum rolling 24-hour rainfall was prepared for all the rainstorms. From the maps, the maximum 24-hour rainfall values for each grid cell during each rainstorm was determined. An example is given in Figure 4 for

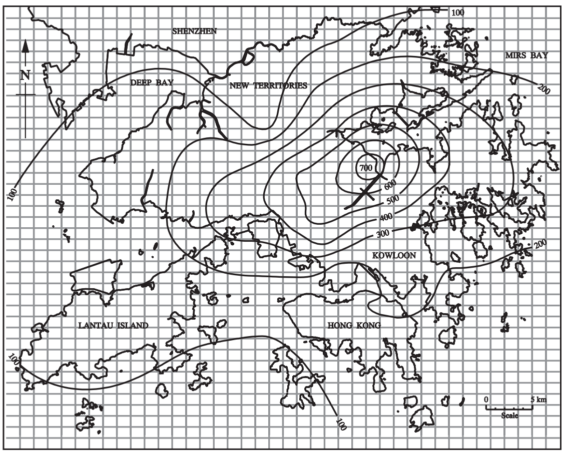


Figure 4. Rainstorm 1-4 July 1997 (Maximum 24-hour rainfall)

the rainstorm on 1-4 July 1997.

A total of 49040 man-made slope features (hereinafter referred to as 'slopes'), based on the digital data available in the GEO Slope Information System (SIS) (Lam et al, 1998), as of July 2001, were used for the study. The distribution of slopes and landslides is shown in Figure 5.

For each rainstorm, the number of landslides reported to the GEO was counted for each grid cell. As the total number of slopes in each grid cell was known, the landslide frequency could be calculated. A relationship between the amount of maximum rolling 24-hour rainfall and landslide frequency was then established by regression analysis. In light of the uncertainty in rainfall contouring, the regression analysis was performed on rainfall classes instead of the exact amount of rainfall. The rainfall classes used are 0-50 mm, > 50-100 mm, > 100-150 mm, > 150-200 mm, > 200-250 mm, > 250-300 mm, > 300-350 mm, > 350-400 mm, > 400-450 mm and >= 450 mm. Figure 6 shows the correlation models for different slope types. The landslide frequencies plotted in the figure were average values for all grid cells and all the rainstorms corresponding to each rainfall class.

The advantages of the new correlation model over the previous ones are that:

(a) It takes into account the number and types of slopes in each 1.2 km x 1.5 km grid cell.
(b) The rainfall-landslide correlation for different types of slopes can be easily updated using new data.
(c) It can easily be extended beyond areas of correlation by adding grid cells, with knowledge of the number and types of slopes within the grid cells.

The performance of the new correlation model was evaluated for rainstorms in the period 1997 to 2001. The results were found satisfactory. Figure 7 shows the estimated number of landslides in the rainstorms against the actual number.

LANDSLIP WARNING

The new rainfall-landslide correlation has been adopted since April 2004 for predicting the number of landslides in the existing Landslip Warning System. As the predicted landslide frequencies are averaged frequencies for the different slope types over Hong Kong, the correlations are not specific to any area. When there is a rainstorm, the 24-hour rainfall is calculated for all spatial grid cells. The predicted number of landslides in each grid cell is obtained by multiplying the landslide frequency determined by the past 24-hour rainfall and the number of slopes within the grid cell. The total number of predicted landslides in Hong Kong is the sum of predicted landslides of all the spatial grid cells. Figure 8 shows the distribution of predicted number of landslides for the rainstorm on 1-4 July 1997.

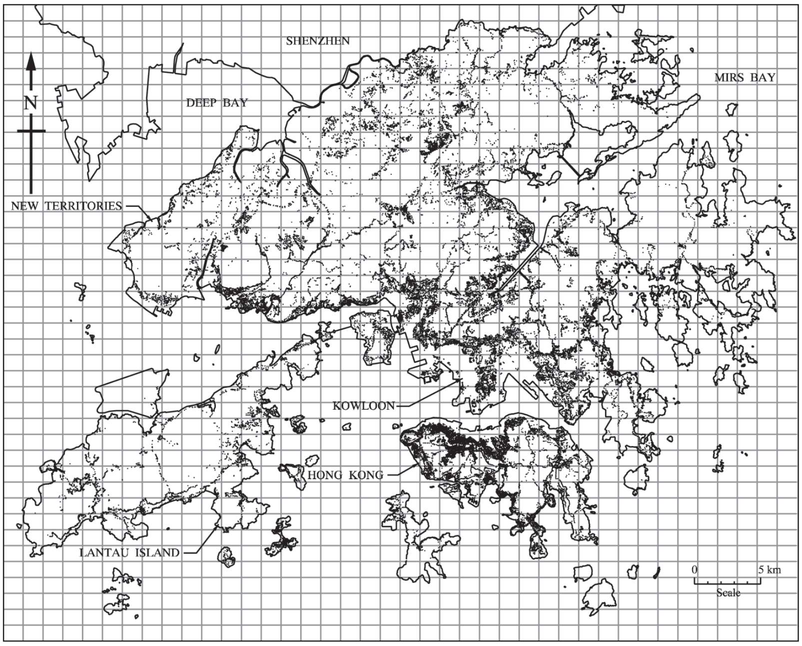


Figure 5a. Man-made slope features in Hong Kong (49040 nos.)

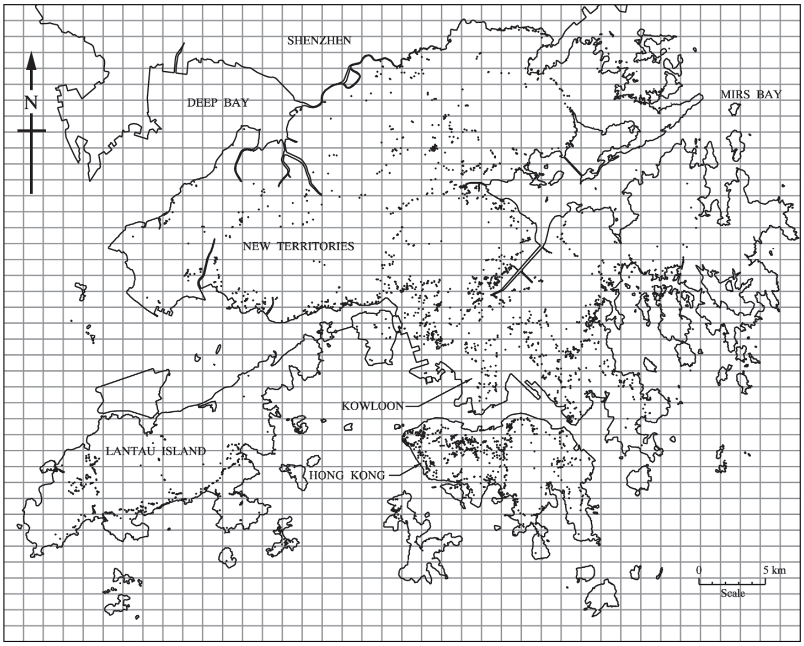
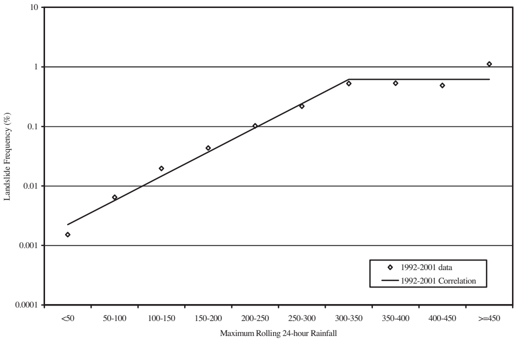
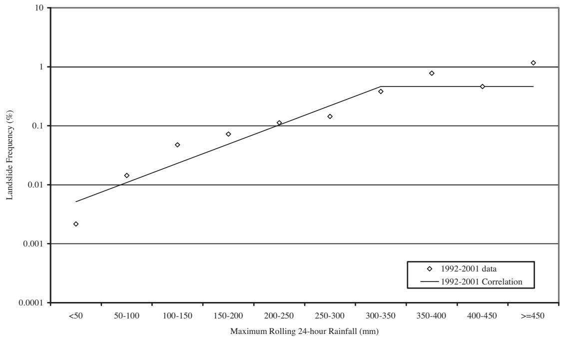


Figure 5b. Genuine landslides at man-made slope features within the period 1992 - 2001 (3765 nos.)

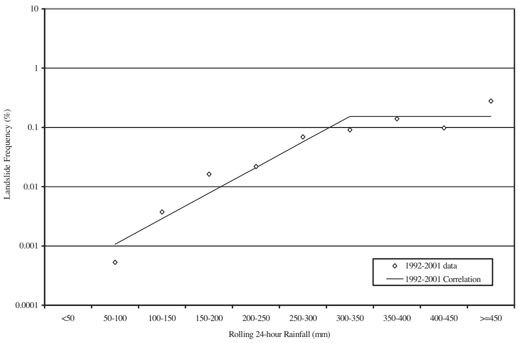
Every 5 minutes, the GEO Landslip Warning System automatically calculates the total predicted number of landslides using the 24-hour rainfall data. As the use of the GEO Landslip Warning System is to issue timely warnings to the public and to mobilize Government staff and resources to deal with landslide incidents, Landslip Warning should be issued when the Landslip Warning Level (i.e. when the estimated number of landslide is 15 or more) is expected to be reached. Rainfall thus need to be forecasted. Under the current system, the estimated total number of landslide is made up of two components (i) landslide calculated for the past 21-hour and (ii) landslide calculated for the next 3-hour rainfall forecast. With this approach, a 3-hour lead-time can be allowed for emergency preparedness.



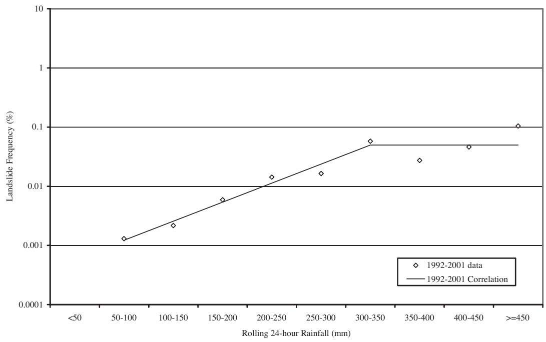
(a) Soil cut slopes



(b) Rock cut slopes



(c) Fill slopes



(d) Retaining walls

Figure 6. Correlation between landslide frequency and rolling 24-hour rainfall

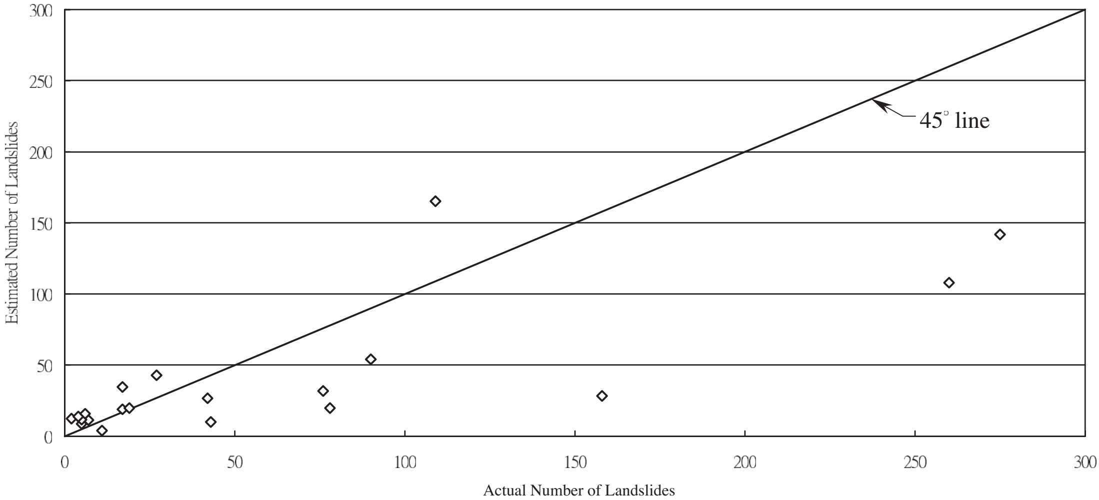


Figure 7. Estimated and actual number of landslides for rainstorms occurred between 1997 and 2001

SHORT-RANGE RAINFALL FORECAST

Rainfall forecast is provided by the HKO. A recent technical development is called the Short-range Warning of Intense Rainstorms in Localized Systems (SWIRLS) by the use of weather radars (Li et al. 2000). This system relies on real-time correlation between radar echo intensity and rainfall amount recorded on the ground by raingauges and prediction of rain cloud movement. As indicated by Lam and Lam (2003), the system has the capability to provide reliable guidance to forecasters for making decision in respect to the issue of Landslip Warning. The rainfall forecast given by SWIRLS has been incorporated

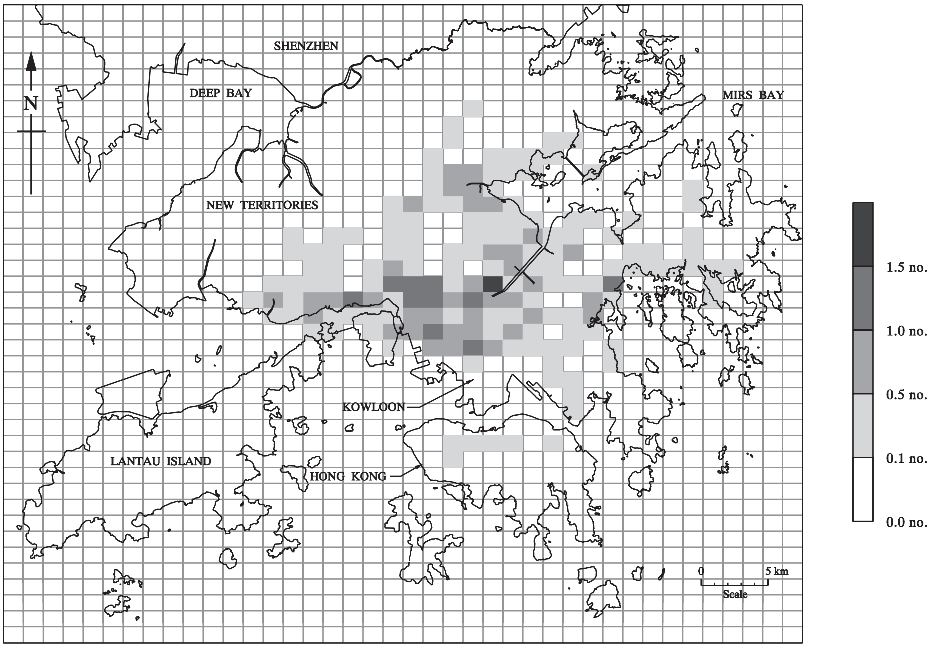


Figure 8. Predicted number of landslides for the rainstorm on 1-4 July 1997

into the GEO Raingauge System to provide reference information for deciding the issue of Landslip Warning.

CONCLUSIONS

The methodology for predicting number of landslides by the established correlations between landslide frequencies and maximum 24-hour rainfall using a simplified GIS approach is given. The incorporation of the short-range rainfall forecast using SWIRLS developed by HKO into the Warning System is also discussed. On average, there are about three hundreds landslides reported to GEO and 3 to 4 Landslip Warnings issued each year. Continuous improvements to the GEO Landslip Warning System are essential for timely issuance of reliable warnings to the public.

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