GUIDELINES
FOR CONSTRUCTION TECHNOLOGY TRANSFER

DEVELOPMENT OF WARNING AND EVACUATION SYSTEM AGAINST SEDIMENT DISASTERS IN DEVELOPING COUNTRIES

MARCH 2004

Ministry of Land, Infrastructure and Transport
Infrastructure Development Institute - Japan

GUIDELINES
FOR
DEVELOPMENT OF WARNING AND EVACUATION SYSTEM
AGAINST SEDIMENT DISASTERS IN DEVELOPING COUNTRIES

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GENERAL

CHAPTER 1 BACKGROUND AND PURPOSE OF THE GUIDELINES

1.1 Background of the Guidelines

Japan is blessed with rich natural environment. Such natural environment, however, presents severe natural and meteorological conditions. With complex topography and vulnerable geology, the Japanese archipelago is highly susceptible to a variety of natural phenomena, such as typhoons, torrential rainfalls, heavy snowfalls, earthquakes, and volcanic eruptions. When looking back over the 20th century alone, the Japanese people were never spared from these natural perils in any part of the country. Every year, severe flooding and sediment disasters are repeated across the country, causing tremendous damage to the lives and properties of the people. Even in July 2003 when these guidelines were being prepared, a major sediment disaster involving a number of slope failures and debris flows occurred mainly in Kumamoto Prefecture in the Kyusyu Region, under the influence of torrential rainfall at the end of the rainy season. This disaster claimed the lives of 22 persons (See Fig. 1.1).

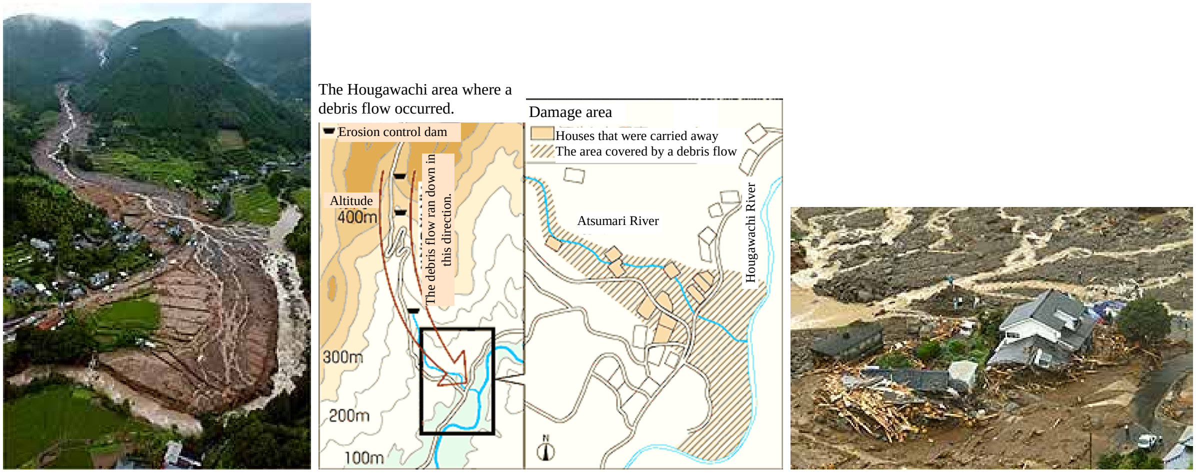


Fig. 1.1 Houses were carried away by a debris flow that occurred in Hougawachi, Minamata City, Kumamoto Prefecture (July, 2003) [1)]

When turning our eyes to the world, it is known that a myriad of people have been victimized by sediment disasters in many parts of the world. In 1985, a total of 22,000 people were killed in Columbia when a volcanic mudflow triggered by the Nevado del Ruiz Volcano eruption engulfed the town of Armero. In June 1989, more than 2,000 people lost their lives and more than 18 million people sustained damage as a result of flooding and landslides that occurred in Sichuan Province and the neighboring regions in China. In November 1991, more than 6,300 people became dead or missing in the flood and landslide disasters that occurred in Ormoc on Leyte Island in the Philippines due to a typhoon attack involving torrential rainfall. In July 1996, 238 people were killed when a landslide and the subsequent debris flow hit the northeastern part of Nepal. Even during the five-year period from 1996-2000, 46 major sediment disasters occurred, killing about 2,500 people in total. As seen, sediment disasters costing invaluable lives are commonplace in many countries in the world, but they are especially frequent in developing countries with rugged mountains and much rainfall.

To prevent such destructive sediment disasters, massive sediment disaster prevention efforts have been made not only in Japan but also in other countries in the world. But, the results are not so fruitful. Because the sediment disaster hazard area is numerous in number and extends over a vast area, an enormous amount of time and cost are required to make all the hazard areas safe with the installation of disaster prevention works. For this reason, when promoting sediment disaster prevention measures, versatile non-structural measures should be taken in addition to structural measures such as installation of disaster prevention works. Non-structural measures include the designation of a sediment disaster hazard area and the development of a warning and evacuation system appropriate for those areas. As to the highly vulnerable hazard areas, it may be necessary to implement comprehensive measures which include restrictions on building structures and new land development.

With respect to the development of a warning and evacuation system against sediment disasters, it is well known that sediment information plays a very important role in realizing a timely warning and a speedy evacuation. To best utilize this kind of information, a risk management system should be established first that enables a quick grasp of the actual damage conditions and a swift collection/delivery/transmission of disaster-related information. To keep the resulting damage to a minimum, the disaster prevention awareness of the local people should also be enhanced. In addition, to build a close cooperation between the administrative bodies and the local people, support should be extended to a variety of activities held for disaster prevention purposes. Disaster prevention drills consisting of information transmission, evacuation, and other trainings, should also be conducted to motivate the local people for active involvement.

In Japan, preventive measures against floods and sediment disasters had been carried out based on the Sabo Law, the Landslide Prevention Law, and the Law Concerning Prevention of Disasters due to Collapse of Steep Slopes (Steep Slope Law). However, taking the 1999 sediment disaster in Hiroshima Prefecture as a momentum which clearly indicated the need of integrated disaster preventive measures, another law was enacted in 2000. This law, namely, the Law Concerning the Promotion of Sediment Disaster Prevention in Sediment Disaster Hazard Area (Sediment Disaster Prevention Law) mainly concerns with the establishment of a warning and evacuation system, restrictions on new residential development, and promotion of relocation of existing houses in disaster-prone areas. With the enactment of this law, non-structural measures in Japan have been diversified and consolidated. And now, on the basis of these four laws, the disaster prevention measures in Japan are evolving toward a comprehensive approach for an overall sediment disaster prevention.

The technology that has been accumulated in Japan for the development of a warning and evacuation system is probably very effective for the developing countries suffering from sediment disasters. Japan is expected to transfer its abundant experience and knowledge on these disasters to the developing countries, and the nation is willing to accept the duty.

Sending a large number of experts and engineers to developing countries through the programs of the Japan International Cooperation Agency (JICA), Japan has long contributed to the development of the socio-economic infrastructures, technological transfer, and the education of technical experts in developing countries. What is important with this kind of technical cooperation is, not to just transfer the technologies of developed countries to the developing countries, but to transfer the technologies or install the facilities in the way best suited to the situations of the receiving countries, including socio-economic systems and social conditions.

1.2 Purpose of the Guidelines

These Guidelines are intended for use as a technical reference when Japanese technical experts dispatched to the developing countries as well as the administrators and the policy organizers in the developing countries try to develop a warning and evacuation system against sediment disasters. Through such use, the Guidelines hope to contribute to the establishment of an effective standard and an effective system for warning and evacuation in developing countries that have long been troubled with sediment disasters. These Guidelines are formulated fully incorporating the extensive technology and experiences that have been accumulated in Japan over the past several decades.

These Guidelines specifically describe the development method of a warning and evacuation system appropriate also for developing countries where observation systems for rainfall and other parameters are not yet fully established. To develop an effective warning and evacuation system, the development method cited in the Guidelines takes into account the various conditions of the target country, including a monitoring system for potential disasters, a prediction system for disaster occurrence, the social structure, and the communications system.

Prediction of disaster occurrence, or various standards for warning and evacuation, are shown using the rainfall as the main indicator. If the short-term rainfall data (10-minute rainfall, the hourly rainfall, etc.) are obtainable in real time, highly accurate prediction of disaster occurrence is possible. However, if the only data available is the daily rainfall, highly accurate prediction is difficult.

Each country should decide by itself what level of rainfall-gauging system and a warning and evacuation system are needed for each hazard area, by taking into account the social situations in the country. However, regardless of the target levels of the systems, the important thing is to build a warning and evacuation system anyway utilizing currently available rainfall data, and then to initiate an operation of the established warning and evacuation system in close cooperation with the local people.

CHAPTER 2 APPLICATION OF THE GUIDELINES

2.1 Potential Users of the Guidelines

The Guidelines are designed to be used primarily by the technical experts in developing countries who perform surveys and designs in the fields of rivers, sabo (erosion and sediment control), and disaster prevention. In brief, the following experts are considered as the potential users of the Guidelines.

1) Short-term and long-term experts sent by the JICA of Japan
2) Administrative organizations in developing countries
3) Educational institutions, such as universities, in developing countries
4) Civil engineers in the private sector in developing countries

2.2 Scope of Application

The Guidelines are intended for use in any developing countries susceptible to sediment disasters. In other words, the Guidelines are appropriate for developing countries with numbers of steep mountain streams, much rainfall in wide areas, and under constant threat of sediment disasters.

CHAPTER 3 ORGANIZATION AND FEATURES OF THE GUIDELINES

3.1 Organization of the Guidelines

These Guidelines consist of three parts - General, Basis of Sediment Disaster, and Planning of Warning and Evacuation System. The structures of the three parts are shown in Table 1.1. The second part, Basis of Sediment Disaster, covers the preventive measures against sediment disasters and the technical background for the prediction of disaster occurrence, both serving for the development of a warning and evacuation system. The third part, Planning of Warning and Evacuation System, deals with the practical steps toward the actual setting of a warning and evacuation system against sediment disasters.

Table 1.1 Organization of the Guidelines

General			
Chapter 1	Background and purpose of the Guidelines		
Chapter 2	Application of the Guidelines		
Chapter 3	Organization and features of the Guidelines		
Basis of Sediment Disaster		Planning of Warning and Evacuation System	
Chapter 1	Principles of occurrence of sediment disasters	Chapter 1	Identification of sediment disaster hazard areas
Chapter 2	Actual state of sediment disasters and preventive measures	Chapter 2	Monitoring and forecasting of sediment disasters
Chapter 3	Prediction method of occurrence of sediment disasters	Chapter 3	Delivery and transmission of sediment disaster information
Chapter 4	Actual state of warning and evacuation system against sediment disasters	Chapter 4	Evacuation plan

The flowchart showing the steps for the establishment of a warning and evacuation system against sediment disasters is described in Fig. 1.2.

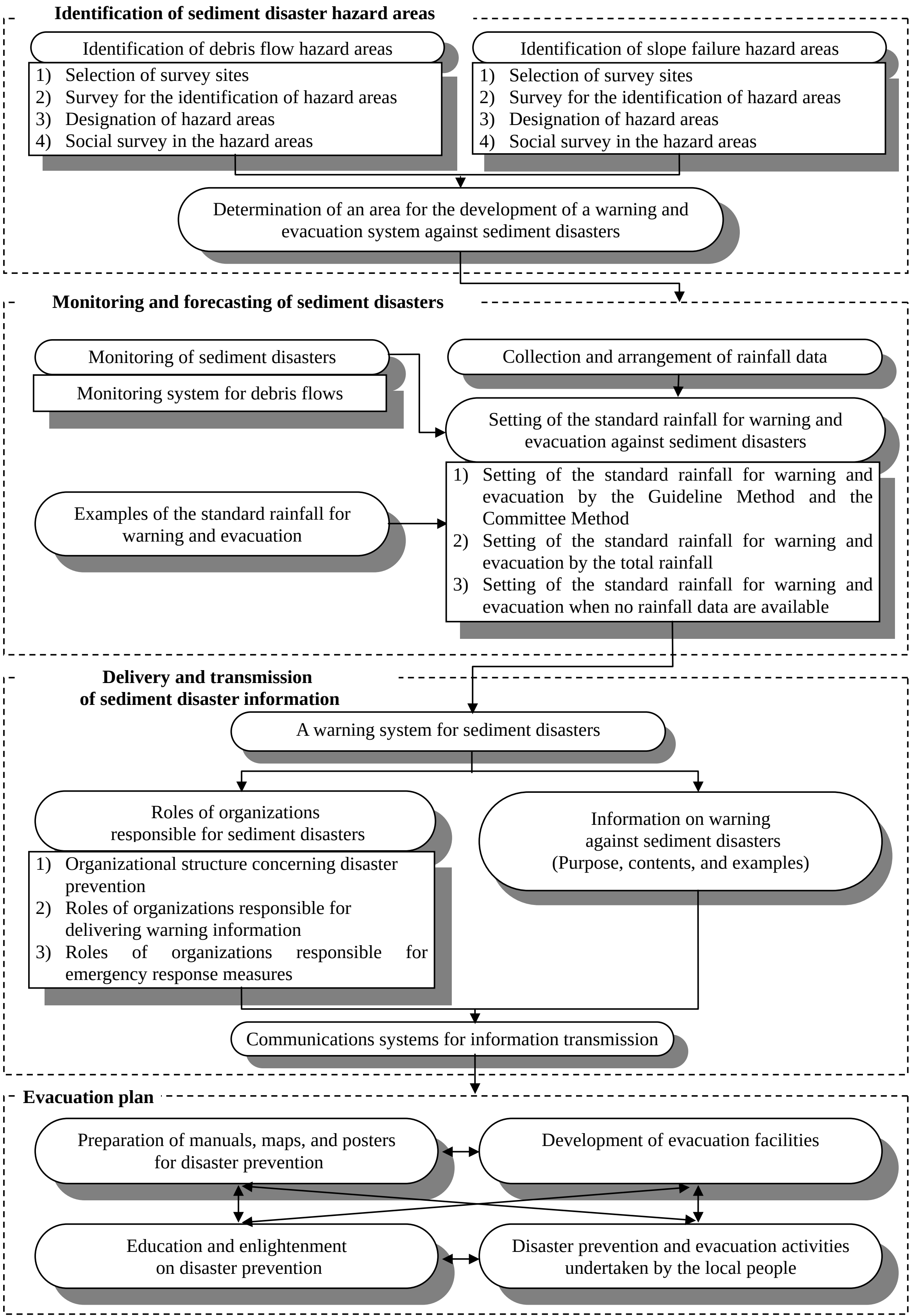


Fig. 1.2 Flowchart showing the steps for the establishment of a warning and evacuation system against sediment disasters

3.2 Features of the Guidelines

The features of these Guidelines are summarized as follows:

1) The Guidelines are expected to be used mainly by civil engineers, researchers, and scholars. But, as some officials in administrative bodies and disaster prevention organizations do not have an engineering background, care was taken to explain the ideas as simple as possible so that they can also use these Guidelines.

2) Those who are not familiar with sediment disasters can obtain a basic knowledge about this disaster and can understand the necessity of establishing a warning and evacuation system, if they read the second part "Basis of Sediment Disaster". If they continue to read into the third part "Planning of Warning and Evacuation System", they can be ready to begin an actual planning of a warning and evacuation system.

3) The Guidelines show sediment disaster prediction methods usable in any rainfall-gauging levels (hourly rainfall, daily rainfall, and no rainfall data) so that an appropriate warning and evacuation system can be set up even in areas where the necessary data, such as topography, geology, and hydrology, are not so much available.

4) The Guidelines primarily focus on the development of a warning and evacuation system among various preventive measures against sediment disasters. Hence, the data collection/arrangement, survey methods, and planning methods useful for the establishment of the system are mainly explained in the Guidelines. As a result, when a comprehensive disaster prevention plan incorporating other types of prevention measures is needed, additional survey methods or additional steps may become necessary. Relevant materials for this purpose are available from the list in References.

5) With regard to Chapter 3 - Delivery and transmission of sediment disaster information and Chapter 4 - Evacuation plan, both in the part of "Planning of Warning and Evacuation System", a variety of forms are conceivable depending on the conditions of each country or region. Therefore, only the basic concept and examples implemented in Japan are showed in the Guidelines.

BASIS OF SEDIMENT DISASTER

CHAPTER 1 PRINCIPLES OF OCCURRENCE OF SEDIMENT DISASTERS

1.1 Modes of Sediment Disaster Occurrence

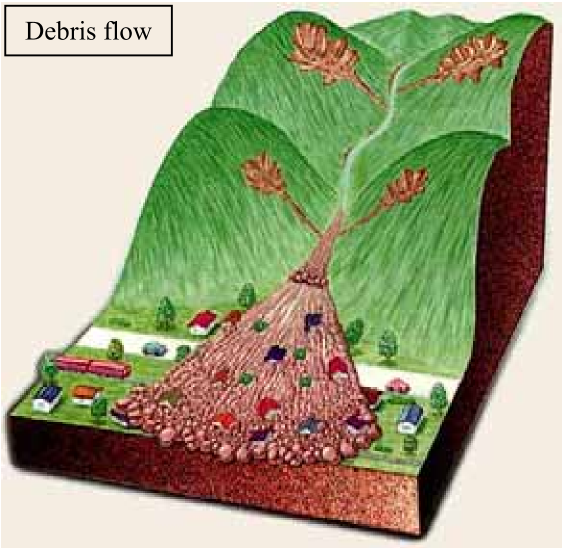
1.1.1 Phenomena to cause sediment disasters

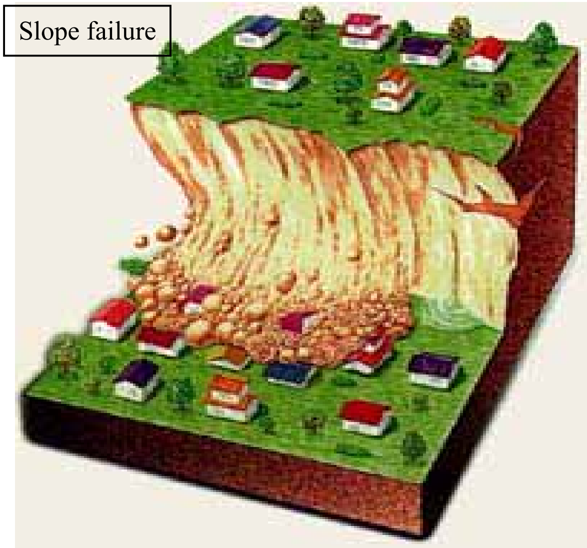
Sediment disasters are defined as the phenomena that cause direct or indirect damage to the lives and properties of people, inconveniences to the life of people, and/or the deterioration of the environment, through a large-scale movement of soil and rock. Damage due to these disasters occurs in several forms: 1) the ground on which buildings and farmland are situated are lost due to a landslide or an erosion; 2) houses are ruined by the destructive force of soil and rock during their movement; 3) houses and farmland are buried underground by a large-scale accumulation of discharged sediment; and 4) aggradation of a riverbed and burial of a reservoir are caused by sediment discharge along a river system, which may invoke flooding, disorder of water use functions, and deterioration of the environment.

Sediment disasters are roughly categorized into two types: 1) the direct type sediment disasters that cause direct damage as a result of sediment movement; 2) the indirect type sediment disasters that cause a flood or an inundation through the aggradation of a riverbed or blocking of a river course. Disasters of the latter type are not the subject of the present Guidelines. Phenomena that cause the direct type sediment disasters include debris flows, slope failures, and landslides. They are explained as follows:

Table 1.1 Phenomena that cause the direct type sediment disasters: debris flow, slope failure, and landslide [4)]

Debris flow	This is a phenomenon in which soil and rock on the hillside or in the riverbed are carried downward at a dash under the influence of a continuous rain or a torrential rain. Although the flow velocity differs by the scale of debris flow, it sometimes reaches 20-40 km/hr, thereby destroying houses and farmland in an instant.
Slope failure	In this phenomenon, a slope abruptly collapses when the soil that has already been weakened by moisture in the ground loses its self-retainability under the influence of a rain or an earthquake. Because of sudden collapse, many people fail to escape from it if it occurs near a residential area, thus leading to a higher rate of fatalities.
Landslide	This is a phenomenon in which part of or all of the soil on a slope moves downward slowly under the influence of groundwater and gravity. Since a large amount of soil mass usually moves, a serious damage can occur. If a slide has been started, it is extremely difficult to stop it.





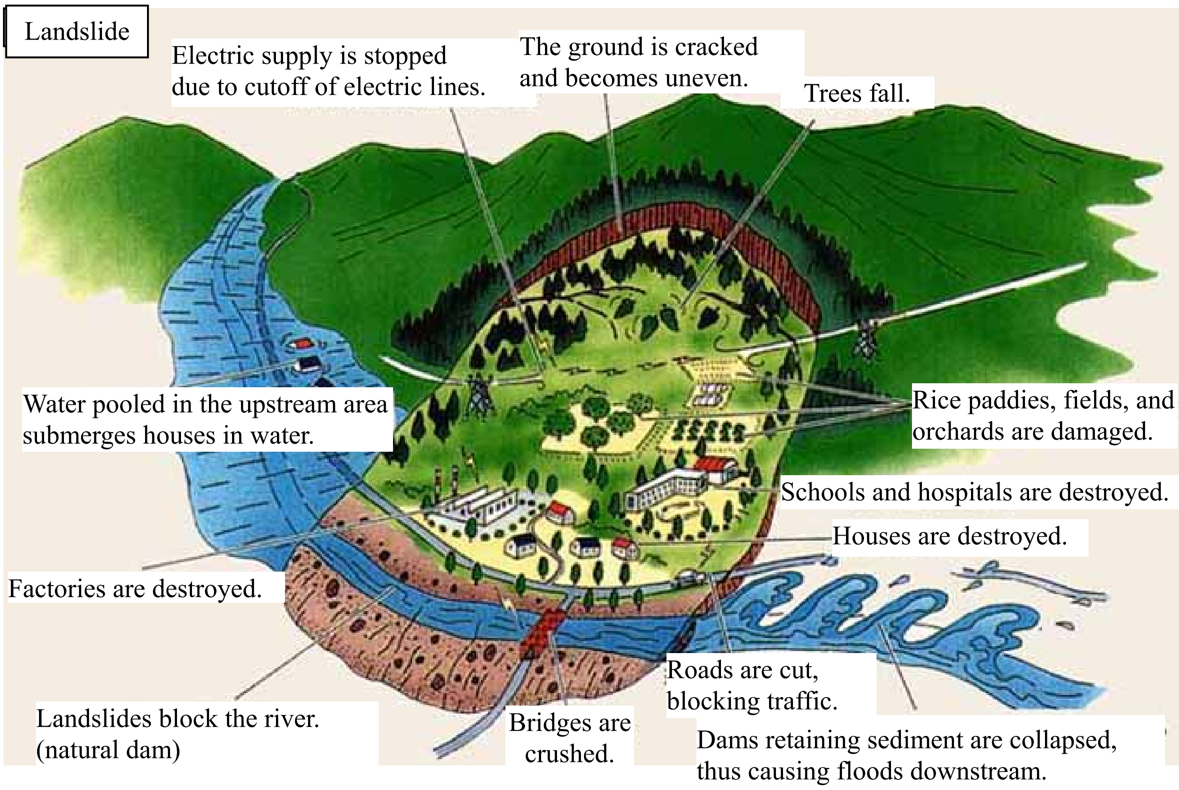


Fig. 1.1 Phenomena that cause the direct-type sediment disasters: debris flow, slope failure and landslide [2)]

1.1.2 Types of debris flows

Debris flows occur in a variety of forms depending on the conditions of the site and the factors contributing to their occurrence. When classified by the contributing factors, debris flows are roughly divided into five types, as shown in Table 1.2. Except for the natural dam collapse type, all types of debris flows are primarily related to the short-term (less than one hour) rainfall intensity.

Table 1.2 Types of debris flows classified by contributing factors [4]

Type	Features
Riverbed sediment movement type (sediment gradient type)	Mass discharge of sediment is triggered when the sediment accumulated on the riverbed exceeds the gradient made by the bed-load transport of sediment and the balance between them is lost.
Slope failure type	A slope failure directly changes into a debris flow.
Natural dam collapse type	A debris flow is caused due to the collapse of a natural dam which is formed by landslide or slope failure.
Landslide type	A debris flow occurs as the last stage phenomenon of a landslide. It occurs because the soil is almost liquefied due to extremely clayey alteration.
Volcanic activity type	In a narrow sense, this means debris flows caused by a volcanic eruption or an earthquake. But, in a broad sense, it means debris flows that occur in areas of an active volcano. A volcanic mudflow is also included in this type. Debris flows of this type are rich in fine grains, highly flowable, and readily occur even under a small rainfall.

The flow mode and flow characteristics of debris flows differ largely depending on the type, size, and concentration of stoney grains included in them. If a large amount of coarse gravel and a relatively small amount of fine grain finer than silt are contained, it is called the gravel type debris flow. In contrast, if a small amount of coarse gravel and a large amount of fine grain are contained, it is called the mudflow type debris flow. If the amount of clay and silt is especially large, it is called the viscous type debris flow.

Gravel type debris flow: a debris flow occurred at Kamikamihori Valley in Mt. Yakedake

Mudflow type debris flow (viscous type debris flow): a debris flow occurred at Jiangja Creek, Yunnan Province, China

Fig. 1.2 Examples of the gravel type debris flow and the mudflow type debris flow [2]

1.1.3 Slope failures and landslides

The Working Committee on World Landslide Inventory, which was set up in cooperation of UNESCO and international academic societies related to foundation engineering, has defined the landslide as the "movement of a mass of rock, debris or earth down a slope". It classified landslide movements into not only slide but also fall, topple, spread, and flow in terms of kinematics.

Meanwhile, the Landslide Prevention Law of Japan defined the landslide as the "phenomenon in which part of land slides or moves downward under the influence of groundwater or other factors". This law is intended to cover a phenomenon that almost never moves at high speed in a large scale at a time (therefore, this is referred to as "J-landslide" to distinguish it from a landslide in a broad sense). In another Japanese law, namely, the Law Concerning Prevention of Disasters due to Collapse of Steep Slopes (Steep Slope Law), slopes with a gradient of 30°or over are defined as steep slopes and they are assumed as hazardous slopes at risk of collapse. This law is mainly intended to cover a phenomenon in which soil and rock move downward at high speed (slope failure). The differences between j-landslides and slope failures are outlined in Table 1.3. As seen, j-landslides are different from debris flows and slope failures in that the former is slow at moving speed and difficult to predict. Therefore, j-landslide is not included in the subjects of the current Guidelines.

Table 1.3 Features of slope failure and j-landslide [5)]

Item	J-landslide	Slope failure (landslip, earth fall)
Geology	Occurs in specific geology and geological structure.	Almost no relation to geology
Topography	Occurs at a gentle slope in a so-called landslide topography	Occurs at a steep slope.
Depth of movement	Several meter to over 10 meter	Within 1-2 m
Scale of movement	Large	Small
Speed of movement	Usually slow, sometimes abrupt	Abrupt
Incitant factors	Groundwater	Torrential rainfall
Signs of movement	Tilted trees, cracks on the ground surface	Almost none
Land use	Used as arable land	Not used
Possibility of recurrence	Possible	Not possible for several years to over a decade

1.2 Mechanical Factors and Incitant Factors of Sediment Disasters

Both mechanical factors and incitant factors should be considered as the factors contributing to the occurrence of sediment disasters. Mechanical factors are the conditions of the site where a sediment disaster occurs, and incitant factors are the forces applied to the occurrence site as the external forces. The mechanical factors and incitant factors of debris flows and slope failures are summarized in Table 1.4.

Table 1.4 Mechanical factors and incitant factors of debris flows and slope failures [5)]

	Debris flow	Slope failure
Mechanical factors	**Topography of river basin:** Existence of an unstable hillside in a steep slope, ease of convergence of surface water, presence of groundwater and spring water **Topography of river:** Longitudinal gradient of riverbed, plane and longitudinal configurations of river course **Unstable sediment**: Thickness of weathered soil layer in a hillside slope, thickness and amount of riverbed sediment, volumetric concentration and grain size distribution of accumulated sediment, accumulated sediment due to slope failure	**Geology:** In addition to the strength of rocks, dominant factors are the level of weathering, alteration, fissure and fracture, direction of layers, conditions of permeable layers, and distribution of loose layers such as a surface layer. **Topography:** Failures tend to occur at slopes of 40-50°, and at slopes or locations easy to collect rainwater, such as a concave type slope, the bottom of a long slope, and the bottom of a gentle slope. **Vegetation:** Forests have a collapse prevention effect with regard to surface failures caused by infiltration of torrential rainfall.
Incitant factors	**Rainfall, snowmelt:** Sudden increase of water discharge, a large amount of rainwater discharge **Earthquake, volcanic activity:** A large amount of unstable sediment produced by slope failure (mechanical factor), collapse of a crater lake and outflow of snowmelt due to a volcanic eruption	**Rainfall, snowmelt:** The number of slope failures increases if a rainfall of strong intensity occurs when the ground is already moist. **Earthquake, volcanic activity:** The ground becomes unstable when stress conditions in the slope are altered due to an earthquake or a volcanic eruption. **Groundwater:** An increase in pore water pressure caused by a subsurface flow due to rainfall leads to a slope failure. **Artificial activities:** Deforestation, artificial changes of a natural slope by cut and fills.

[Reference: Mechanical factors and incitant factors of j-landslide]

Mechanical factors	J-landslides occur most frequently in the layer called the Tertiary formation which was formed some two million to sixty million years ago. The reason is that, as this formation is relatively new, rocks are low in the degree of solidification and less resistant to weathering. Weathering of this formation is distinctive in that soil and rock are quickly granulated and become clayey by the repetition of drying and wetting called slaking. Of the two stones - sandstone and mudstone - in this formation, mudstone contains smectite (montmorillonite) that has a property of swelling, which is one of causes of a landslide.
Incitant factors	The incitant factor causing a landslide is water. Water from rainfall and snowmelt permeates into the ground. The permeated water generates a pore water pressure and then decreases the shear strength of the soil. Therefore, landslides tend to occur in the rainy season or at the time of typhoons. In the meantime, landslides due to artificial causes are grouped into two types: landslides that occur due to cut of slopes in landslide areas; landslides that occur due to cut or fill of slopes in non-landslide areas. The former type of landslides can be predicted by the reading of landslide survey maps and aerial photographs. The latter type of landslides is difficult to predict, but not so hard to prevent if structural works are installed.

1.3 Mechanism of Occurrence of Sediment Disasters

A slope failure occurs when the balance between the shear stress and the shear resistance of the soil in a slope is lost. The former is a force to cause a slide and the latter is a force to prevent it. Slope failures can occur in any steep slopes. The incitant factors of slope failure are mainly those that work to decrease the shear resistance of the soil in a slope, such as rainfall and the rise of groundwater level.

On the other hand, landslides of the riverbed sediment accumulation type (sediment gradient type) are triggered when a soil mass loses its stability due to saturation and the resulting decrease of friction resistance. The occurrence mechanism of this type of landslide is essentially the same with that employed in the stability analysis of large slopes.

In brief, slope failures and debris flows occur when the force to move a soil mass become greater than the shear resistance derived by the Mohr-Coulomb's Equation shown below.

$$\tau = c + (\delta - u)\tan\phi \quad \cdots\cdots(1)$$

where τ: shear stress, c: cohesion of soil and gravel
δ: normal stress, u: pore water pressure
ϕ: internal friction angle

1.3.1 Mechanism of occurrence of slope failures

When a linear slip surface with a depth of h and parallel to a slope gradient θ is assumed, as shown in Fig. 1.3, the occurrence of a slope failure is determined by the relative magnitude of the force component of collapsing soil mass, τ, that works along the slope and the shear resistance of the soil, τ_L. The safety factor, F, which indicates the stability of a slope is given by $F = \tau_L / \tau$, and the slope stability is judged using the following criteria:

$F > 1$: failure is unlikely

$F < 1$: failure is likely

$F = 1$: critical state

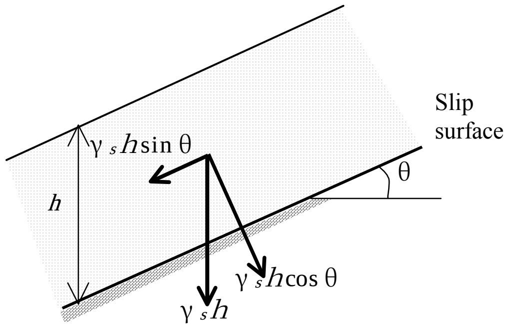


Fig. 1.3 A representation of stability analysis of a slope that has a linear slip surface parallel to the ground surface

When the density of soil is given by γ_s, F is derived by the following equation.

$$F = \frac{c + (\gamma_s gh\cos\theta - u)\tan\phi}{\gamma_s gh\sin\theta} \quad \cdots\cdots(2)$$

where g : gravitational acceleration

1.3.2 Mechanism of occurrence of debris flows

In debris flows of the riverbed sediment accumulation type (sediment gradient type), a surface water flow is generated and its weight has a significant effect on the stability conditions of a slope. Also, as the soil mass is already saturated when a surface water flow is generated, the volumetric density of soil mass, γ_s, which was also used in Equation (2) is given as shown below, using the density of soil grain, σ, the density of water, ρ, and volumetric density of sediment, C_*.

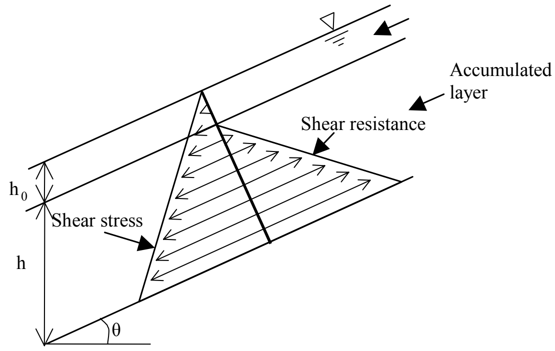


Fig. 1.4 A representation of stress distribution when a surface flow is present

$$\begin{aligned}\gamma_s &= C_*\sigma + (1 - C_*)\rho \\ &= C_*(\sigma - \rho) + \rho\end{aligned} \quad \cdots\cdots(3)$$

Accordingly, when the thickness of accumulated layer, *h*, and the depth of surface water flow, h_0, are used, the shear stress acting on the bottom of a soil mass, τ, becomes as follows:

$$\tau = \left[\{C_*(\sigma - \rho) + \rho\}gh + \rho g h_0\right]\sin\theta \quad \cdots\cdots(4)$$

On the other hand, if it is assumed that the only normal stress acting on the bottom of the soil mass is the effective stress of the soil mass, the pore water pressure existing in the soil mass can be ignored. Further, if cohesion of the soil mass is ignored by assuming it to be too small, the shear resistance, τ_L, becomes as shown below.

$$\tau_L = C_*(\sigma - \rho)gh\cos\theta\tan\phi \quad \cdots\cdots(5)$$

Then, the equilibrium equation between them becomes as follows:

$$\left[\{C_*(\sigma - \rho) + \rho\}gh + \rho g h_0\right]\sin\theta = C_*(\sigma - \rho)gh\cos\theta\tan\phi \quad \cdots\cdots(6)$$

If the value on the left side (shear force) exceeds that of the right side (shear resistance), a debris flow is caused. Hence, a critical slope gradient, θ_p, which distinguishes the occurrence and non-occurrence of a debris flow, is obtained by the following equation.

$$\tan\theta_P \geqq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + h_0/h)}\tan\phi \quad \cdots\cdots(7)$$

Takahashi considered that only the forces that work between the grains are effective as the shear resistance, and expressed the critical gradient for the occurrence/non-occurrence of debris flows as shown below, using the grain size, *d*, instead of the thickness of accumulated layer, *h*.

$$\tan\theta_P \geqq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + h_0/d)}\tan\phi \quad \cdots\cdots(8)$$

With regard to the behavior of a debris flow and the riverbed gradient, it is known that there is a relationship as shown in Table 1.5.

Table 1.5 Relationship between the behavior of a debris flow and the riverbed gradient

Behavior of debris flow	Gradient of riverbed	
	Ordinary mountain streams	Volcanic area
Section where a debris flow occurs	$20° \leq \theta$	$15° \leq \theta$
Section where a debris flow runs down and accumulates	$10° \leq \theta < 20°$	$10° \leq \theta < 15°$
Section where sediment accumulates	$3° \leq \theta < 10°$	$2° \leq \theta < 10°$

Note) Cases are reported in which a debris flow containing a large amount of fine sediment, much like a sediment flow, reached an area with a riverbed gradient less than 3° (less than 2° in case of a volcanic sabo area), when allowed by the properties of the debris flow and topographical conditions of the site. This table is usable as a reference for debris flows of riverbed sediment movement type (sediment gradient type: see Table 1.2).

1.4 Prediction of Sediment Disaster Occurrence by Rainfall

Slope failures and debris flows are most often caused by rainfall and the resulting river flow, except for the cases caused by an earthquake, volcanic activity, and snowmelt among the direct incitant factors shown in Table 1.4. It is a well-known fact that influential rainfall differs not only by the type of sediment movement such as slope failure or a debris flow but also by the kind of topography and geology in the area.

The prediction method of the occurrence of sediment disasters are roughly categorized into three types:

1) **Method utilizing the measurements of sediment movement**
A wire sensor for detection of debris flow, a vibrometer for detection of debris flow, a clinometer, observation and monitoring by humans

2) **Method used for the prediction of sediment movement in a wide area**
This is a method to predict sediment movement, like a debris flow and a slope failure, in a wide area that shares some common features, like an entire river basin.

3) **Method used for the prediction of sediment movement at a specific location**
This is a method to predict sediment movement at a specific location vulnerable to a debris flow or a slope failure, by conducting intensive surveys on topography, geology, and rainfall and constant monitoring on signs of movement.

In the case of floods, it is possible to take a warning and evacuation activity or a flood fighting operation with some preparation time, if changes in rainfall and water level have continuously been monitored. However, in the case of sediment disasters, prediction of an approaching danger is almost impossible unless the very site of soil movement has been identified and it is continuously monitored. Even though dangerous conditions are detected, safe evacuation of the local people is very difficult because a debris flow or collapsed sediment reaches their houses in such a short time. However, if the rainfall is utilized and the hourly rainfall data is obtainable, disaster occurrence can generally be predicted one or two hours before. This allows enough time for people to evacuate safely. In view of this, a disaster prediction method targeting a wide area utilizing the rainfall that is relatively easy to obtain is employed in the current Guidelines as the basic approach.

CHAPTER 2 ACTUAL STATE OF SEDIMENT DISASTERS

AND PREVENTIVE MEASURES

2.1 Actual Damage due to Sediment Disasters

A sediment disaster is not so large as an earthquake, flood, storm surge or tsunami, in terms of the size of occurrence, but its danger to human lives is very high because it occurs at multiple locations at a time. In Japan, 54% of the dead and missing by natural disasters during the 31-year period from 1967 to 1997 are accounted for by sediment disasters (excluding the victims in the Hanshin Awaji Earthquake in 1995).

In the case of sediment disasters, it is very difficult to install preventive works at every location in need of them because such locations are virtually countless. Therefore, it is important to mitigate damage by establishing an effective warning and evacuation system, which includes the grasp of hazard areas, prediction of dangerous phenomena leading to a disaster, and designation of sediment disaster hazard areas. Actually, many cases has been reported in which people were not involved in sediment disasters because they evacuated in time by detecting the disaster signs quickly. This clearly indicates that the local people have or do not have knowledge of potential disasters in their area spells the difference between their life and death.

Before modern times, few people lived in an area susceptible to sediment disasters. And if they lived in such an area, they handed down disaster experiences from generation to generation as the history of their area. However, with the rapid increase of population and the enlargement of arable land after entering the modern times, the population living in hazardous areas has increased enormously. People living in newly developed areas often do not have knowledge about sediment disasters. Such a change of the social environment is one of factors worsening the damage of disasters. Here, sediment disaster cases in Japan, Indonesia, and Nepal in recent years are introduced.

2.1.1 Examples of debris flow disasters

(1) Debris flow disaster in Kagoshima Prefecture (Japan) [2)]

In July 1997, a large-scale debris flow occurred in the Harihara area, Izumi City, Kagoshima Prefecture, killing 21 people.

[Date]
At 0:44 on July 10, 1997
[Location]
Harihara, Sakai-machi, Izumi City, Kagoshima Prefecture
River name: the Harihara River (basin area: 1.55 km^2; total length: 2.3 km)
[Damage]
Death - 21, injury - 13, building damage - 29, damage to farmland - 10.2 ha.
[Rainfall]
Continuous rainfall - 401 mm (midnight of July 6 - 24:00 of July 9), daily rainfall - 275 mm (July 9), maximum hourly rainfall - 62 mm (16:00-17:00, July 9)
[Scale of failure]
Slope length - approx. 200 m, width - approx. 80 m, maximum failure depth - 28 m, sediment volume collapsed - 166,000 m^3 (80,000 m^3 ran down to the downstream of the sabo dam), average gradient - 26°

A Sabo dam built on the upstream of the disaster-stricken area exhibited an effect by capturing over 50,000 m^3 of sediment, but the total sediment volume collapsed was far greater than the design sediment volume.

On the evening of July 9, the local people were advised to evacuate to a community center used as a refuge facility, but none evacuated to this facility.

(2) Torrential rainfall disaster in Hiroshima Prefecture (Japan) [2)]

Hiroshima Prefecture is a region susceptible to sediment disasters because of its topographical and geological features. The number of places at risk of sediment disasters in this prefecture amounts to over 30,000. On June 29, 1999, a large-scale disaster was caused by localized torrential rainfall due to a stationary front. Damage occurred not only in this prefecture but in a huge area, extending from the Chugoku and Kansai regions to the Tokai region.

In the northwestern part of Hiroshima City and in Kure City where torrential rainfall was especially serious, slope failures and debris flows were triggered at multiple locations simultaneously, killing 31 persons and missing 1 person in total.

[Date]
On the evening of June 29, 1999
[Location]
North and northwestern parts of Hiroshima City, Kure City, and other places in Hiroshima Prefecture
(Slope failure -186 locations, debris flow - 139 locations)
[Damage]
Death - 31, missing - 1, houses of total collapse - 154
[Rainfall]
Continuous rainfall - 271 mm (June 28 - 29, obtained at Toyama), maximum hourly rainfall - 82 mm (14:00 - 15:00, June 29, at the Yawatagawa Bridge)

(3) Flood and sediment disasters on Nias Island in the Province of North Sumatra (Indonesia) [8)]

Sediment disasters occur almost every year in Indonesia. Just like Japan, Indonesia is a country having both mechanical and incitant factors of disasters, such as topographical and geological features, a number of active volcanoes, earthquakes, and torrential rainfalls. More than 280 people were reported victimized in a sediment disaster that occurred in the southern part of Nias Island in the Province of North Sumatra in 2001.

[Date]
At midnight of July 31, 2001
[Location]
The southern part of Nias Island in the Province of North Sumatra
[Damage (estimated)]
Death - 77, missing - 95, houses - 325, school - 1, bridges - 5, public facilities - 2, farmland - several thousand ha.
[Rainfall]
Daily rainfall - 222 mm

(4) Debris flow disaster in Modjokerto Prefecture in the Province of East Java (Indonesia) [8)]

A total of 32 people were killed in a debris flow disaster that occurred in Modjokerto Prefecture in the Province of East Java in 2002. The victims included many children who were playing in a hot water swimming pool built on a riverbank extracting water from a nearby hot spring.

[Date]
Around 14:30 of December 11, 2002
[Location]
Pacet in Modjokerto Prefecture in the Province of East Java
River name: the Dawahan River, a tributary of the Cumpleng River (basin area: 4.5 km^2)
[Damage]
Death – 32
[Rainfall]
Daily rainfall - 222 mm
[Scale of failure]
Discharged sediment - 7,000 m^3

The biggest cause of this disaster involving a number of human lives is considered to be an artificial one. The affected site is a mountain stream that experienced another sediment disaster in the past, which is clearly known from topography around the site as well as from the sediment accumulated in the stream. However, this kind of debris flow risk was not understood among those concerned with the resort development project.

(5) Slope failure and debris flow disasters in Matatirtha (Nepal) [9)]

Natural disasters occur almost every year in Napal under the influence of monsoons as well as due to topographical and geological structures that are being formed by the still active orogenic movements. 55 sediment disasters occurred in this country in 2002, resulting in a loss of over 380 people in total.

[Date]
On the morning of July 23, 2002
[Location]
At a place about 4 km away from the western end of the loop road encircling the capital city of Kathmandu
[Damage]
Death - 16, damage to houses - 8, damage to roads - several locations, damage to farmland - approx. 1 ha
[Rainfall]
Daily rainfall - 207 mm (the largest in the past 30 years)
[Discharged sediment]
Collapsed sediment - approx. 7,000 m^3, discharged sediment - approx. 1,500 m^3

2.1.2 Examples of slope failure disasters

(1) Slope failure disaster in Kubmen Prefecture in the Province of Central Java (Indonesia) [8)]

[Date]
Around 21:30 of October 4, 2001
[Location]
Lemah Abang Hill in Kubmen Prefecture in the Province of Central Java
[Damage]
Death - 9, injury - 4, damage to houses – 4
[Rainfall]
Continuous rainfall - 190 mm (rainfall continued for abut 6 hours)
[Scale of failure]
Slope length – 200-300 m, width – 30-70 m, estimated sediment volume - 25,000 m^3, slope gradient – 30-60°

According to the results of field survey, the disaster occurred in two stages: (i) relatively slow collapse at the lower area of slope; (ii) sudden collapse at the middle to upper area of slope.

(2) Slope failure disaster at 15+050 positions of the Kathmandu-Naubise road (Nepal) [9)]

[Date]
Around 22:00-23:00 of July 22, 2002
[Location]
At a place 15 km to the west of Kathmandu, along the Tribhuvan Highway
[Damage]
Death - 9, injury - 1, damage to houses - 2, damage to roads - several locations
[Rainfall]
Daily rainfall - 93.5 mm, hourly rainfall just before the start of disaster - 13.0 mm
[Scale of failure]
Slope length - approx. 110 m, width – 30-40 m, estimated sediment volume - 1,500 m^3, slope gradient - 45°

The incitant factor of this slope failure was the rainfall, but the mechanical factor was that a gutter installed along the road was blocked with sediment from a small-scale roadside failure and the flowing water converged at the head area of this slope failure disaster.

(3) Sediment disaster at Butwal City (Nepal) [9)]

A slope failure and the ensuing debris flow occurred in three consecutive stages on August, 27, August 29, and September 5, 1998 at the suburb of Butwal City located at some 180 km to the west of Kathmandu.

[Date]
August 27-September 5, 1998
[Location]
Churia Hill in the suburb of Butwal City (the Lumbini zone in western Nepal)
[Damage]
Death - 1, injury - 2, houses of total collapse - 35
Total damage value - approx. 58 million Nepal rupee
[Rainfall]
(No data are available. Local people said in the post-disaster hearing that a rainfall with high intensity continued for long hours after the first collapse had occurred.)

2.2 Present State of Structural Measures against Sediment Disasters

2.2.1 Structural measures against debris flows

As the method to control debris flows, three methods are considered: (i) to prevent the start of debris flow movement; (ii) to prevent the growth of debris flow movement that has already started; (iii) to dissipate the energy of debris flow movement and put it under control. Preventive measures against debris flows should be determined by considering topographical conditions, subjects of conservation, and the cause and flow mode of a debris flow in each of the occurrence area, the flowing area, and the sedimentation area. Primary preventive measures to be taken in each area are described below:

- Occurrence area: soil retaining works, groundsill works, etc.
- Flowing area: sabo dam with a sedimentation reservoir, sabo dam with slits, sand pocket, etc.
- Sedimentation area: revetment works, training dike works, channel works, dam works, etc.

A sabo dam is the most principal measure to be taken against debris flows. It can provide a variety of functions, ranging from the storage function like arrest and accumulation of debris flow, control function of sediment load, erosion control function, conversion function of transportation mode, and grading function of grains. Sabo dams can provide a certain level of effect even after they are filled up with sand.

No. 1 sabo dam on the Name River in the Kiso River system: A large-scale debris flow occurred in July, 1989 due to localized torrential rainfall, but this sabo dam prevented it from reaching the downstream.

Sabo dam in mid-area of the Aratani River: A debris flow and accompanying driftwood were restrained by this sabo dam in a torrential rainfall disaster that occurred in the coastal area in Hiroshima Prefecture in June, 1999.

Fig. 2.1 Sabo dams constructed in the flowing area of debris flow [2)]

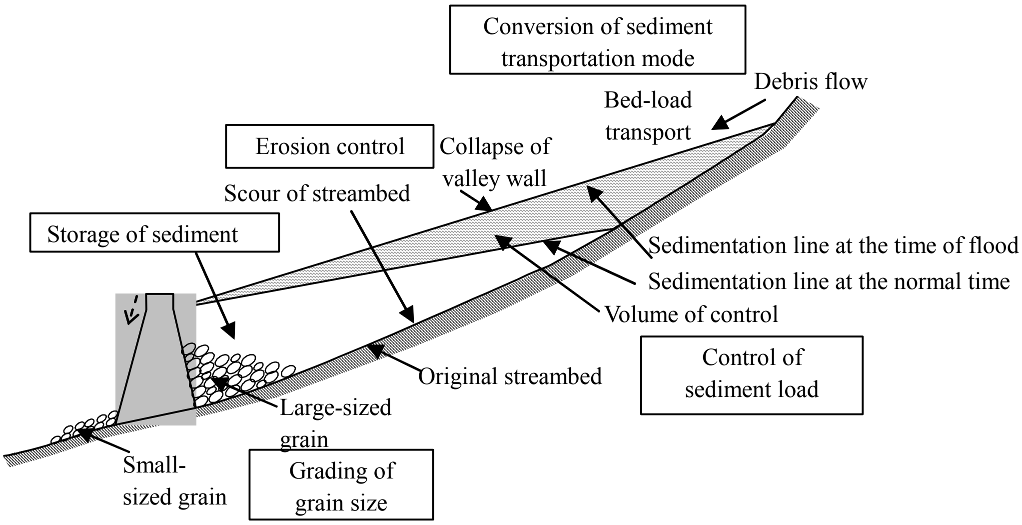


Fig. 2.2 Various functions of a sabo dam [4)]

2.2.2 Structural measures against slope failures

Broadly, structural measures against slope failures are classified into two types of works: control works and restraint works. The control works are employed to mitigate or remove the factors that may lead to slope failures, whereas the restraint works are intended to prevent failures by the installation of structures. They are summarized as shown in the table and the figure next page.

Table 2.1 Structural measures against slope failures

Type	Primary purpose	Type of works
Control works	To mitigate the effect of rainfall	Drainage works, vegetation works, slope protection works
	To remove a soil mass highly likely to collapse	Cutting of an unstable soil mass
Restraint works	To reinforce the surface soil layer in a slope	Cutting of slope to improve the form, retaining wall works, anchor works, pile works, loading embankment works

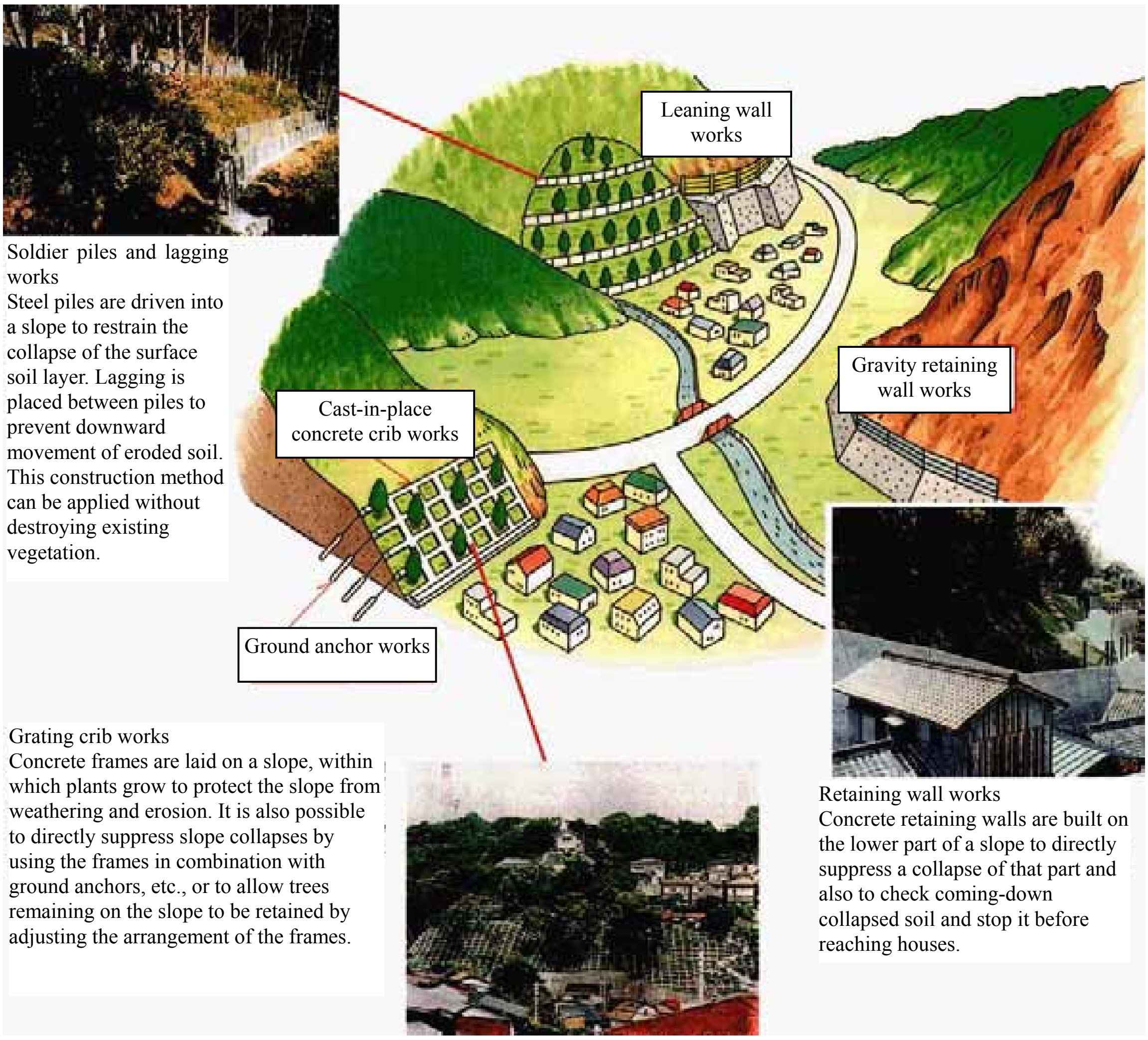


Fig. 2.3 Preventive measures against slope failures [2)]

2.3 Need for the Development of Warning and Evacuation System

Preventing the occurrence of disasters by controlling the mechanical and incident factors with the installation of structural works is the most basic approach to disaster prevention, and all who are involved in disaster prevention efforts are arduously waiting it to be realized. However, the rage of the nature sometimes attacks us with a magnitude beyond our imagination. Because it is extremely difficult to identify the disaster site and the occurrence time in advance, complete prevention of sediment disasters is virtually impossible even today when the society is enjoying highly advanced technologies.

Accordingly, together with the continuous efforts to prevent the occurrence of sediment disasters, another important aspect has to be focused which is to prevent the enlargement of damage after a disaster has occurred. It is well known that an evacuation is extremely effective in preventing and mitigating damage to humans by natural disasters.

To carry out an evacuation swiftly and adequately, the disaster prevention organizations as well as the local people need to take the activities shown in Table 2.2. It is important to establish a warning and evacuation system in which the activities shown in the table are interlinked and coordinated systematically.

Table 2.2 Activities needed for evacuation from disasters

	Normal time	Warning time
Disaster prevention organizations	- Preparation of disaster prevention plan - Dissemination of disaster prevention plan - Implementation of disaster prevention training - Establishment of information transmission system	- Collection and transmission of disaster information - Recommendation and instruction to evacuate - Guide for evacuees and rescue operation
Local people	- Voluntary disaster prevention organizations - Improvement of disaster prevention awareness - Disaster prevention training	- Grasp of the state and judgment - Actual evacuation - Mutual cooperation in community

As non-structural measures against sediment disasters, three methods are considered: (i) to develop warning and evacuation system, (ii) to restrict the land use in the area that has the risk of sediment disasters, (iii) to prepare hazard map with public involvement and to publish its map. The development of warning and evacuation system is mainly explained in the current Guidelines.

CHAPTER 3 PREDICTION METHOD OF OCCURRENCE OF SEDIMENT DISASTERS

3.1 Outline of Various Prediction Methods

Setting methods of standard rainfall for warning and evacuation used for the prediction of sediment disasters are classified into several types by different researchers. In general, however, they are divided into two types in terms of practical application: 1) methods appropriate for a wide area that includes a number of locations at risk of sediment disasters; 2) methods appropriate for a localized area. Of the two methods, the former is the mainstream at present in view of the availability of data and the convenience for administrative operation. Four methods are considered as the setting method of standard rainfall for warning and evacuation appropriate for use in a wide area.

(i) Setting method using tank model
(ii) Setting method using working rainfall
(iii) Setting method using rainfall intensity within the traveling time of runoff water
(iv) Setting method using multiple factor analysis

These setting methods are further divided into subcategories by the differences of the treatment of the details. Outline of the four methods are summarized in Table 3.1.

As the methods other than the above, four methods are mainly available: (i) the setting method that additionally incorporates the forecast of short-term rainfall. This method is employed in several prefectures in Japan; (ii) the setting method that additionally incorporates geological factors as the experimental procedure; (iii) the method utilizing the neural network; and (iv) the method utilizing the data envelopment analysis (DEA).

3.2 Prediction Method Using Working Rainfall

Explained below are four methods that are commonly used by sabo-related divisions in Japan as the setting method of standard rainfall for warning and evacuation against sediment disasters. The technical development process and features of those four methods are shown in Fig. 3.1.

(i) Method A by the tentative guidelines in 1984 (Method A)
(ii) Method B by the tentative guidelines in 1984 (Method B)
(iii) Method by Yano (Yano Method)
(iv) Method by the Committee for Studying Comprehensive Sediment Disaster Control Measures (Committee Method)

In general, sediment disasters occur under the influence of not only the rainfall at the time of disaster occurrence (causing rainfall) but also the rainfall during the period of one to two weeks before the occurrence of a disaster (antecedent rainfall). The degree of influence of the antecedent rainfall normally reduces as time becomes distant from the causing rainfall. Therefore, for the prediction of sediment disasters, use of the accumulative rainfall that takes the effect of the antecedent rainfall into account is effective. In view of this, the working rainfall defined as follows are used in the four setting methods shown above.

The working rainfall is defined as the sum of the antecedent working rainfall and the accumulative rainfall during a series of rain.

Here, one sequence of rain having more than 24 hours of non-rainfall duration before and after that rain is called "a series of rain". The total amount of rainfall during that period is called the "continuous rainfall (R_C)". The rain during the period of one to two weeks before the start of "a series of rain" is called the "antecedent rain". And, the rainfall during that period is called the "antecedent rainfall (R_A)". Also, the 24-hour rainfall one day before the causing rainfall is multiplied by the coefficient of "α_1 time". The 24-hour rainfall two days before the causing rainfall is multiplied by the coefficient of "α_2 time". In this way, the 24-hour rainfall up to "t" days before the causing rainfall, or "d_t", is multiplied by the coefficient of "α_t time ($\alpha_t < 1$)". And, the total of those rainfalls is called the "antecedent working rainfall (R_{WA})". For details, refer to Item 2.4.2 in Part III - Planning.

$$R_{WA} = \alpha_1 \cdot d_1 + \alpha_2 \cdot d_2 + \cdots + \alpha_{14} \cdot d_{14} = \sum_{t=1}^{14} \alpha_t \cdot d_t$$

Table 3.1 Classification and outline of primary setting methods of standard rainfall [10)]

Method	Method (subcategory)	Index	Target phenomena	Outline	Features
Method using tank model	Method by Suzuki et al.	(i) Storage height in 1st tank (ii) Storage height in 2nd tank	Slope failure Debris flow	This method uses a tank model in which a tank with an outlet in the bottom and another outlet on the side is vertically placed in three layers. This method makes use of good relationship seen between the water height stored in tanks against the input rainfall value and the occurrence timing of a slope failure or a debris flow.	It is desirable to determine various constants of tanks which indicate permeability characteristics of the target area by evaluating conformity with the measurement results such as the flow rate. However, measurement data are usually insufficient, which makes the determination of those constants difficult. It is said that relatively effective disaster prediction is possible even in different geological conditions, if constants in the area of granite are used.
	Method by Michiue et al.	(i) Storage height in 1st tank (ii) Total of storage height in 1st and 2nd tanks	Slope failure Debris flow		
	Method by Makihara et al.	Total of storage height in three tanks	Slope failure		
Method using working rainfall	Method by the tentative guidelines in 1984 (Method A)	Working rainfall (antecedent rainfall, half-life: daily)	Debris flow	Setting of standard and judgment are made using a rainfall index derived by adding the antecedent working rainfall to the continuous rainfall from the start of rain.	During the examination process, the hourly rainfall at a given time and the working rainfall up to one hour before a given time are treated separately, but judgment is made using only the working rainfall up to a given time. Thus, the examination process is rather difficult to understand. This method is in a sense easy to disseminate because the rainfall index used is only one and it is similar to the continuous rainfall. It is pointed out, however, that this method shows some unconformity if used for a long rain or an intermittent rain.
	Method by the tentative guidelines in 1984 (Method B)	(i) Working rainfall intensity (ii) Working rainfall (antecedent rainfall, half-life: daily)	Debris flow	Evaluation is made using a rainfall index derived by combining of the working rainfall used in Method A and the effective rainfall intensity. Because the rainfall index is a combination type index, setting of the standard and judgment is made using a X-Y graph.	Because the antecedent working rainfall used in Method A is also used, this method (Method B) is pointed out to have some unconformity if employed for a long rain or an intermittent rain. This method is recognized as a reference to be used when setting of standard by Method A is difficult. Hence, actual application is not so many compared with Method A.
	Method by Yano (Yano Method)	(i) Working rainfall (one-tank model)	Debris flow	A rainfall index is derived by improving the operation method of the working rainfall in Method A, and by making it to be harmonizing with the transition of the moisture content in the soil.	Unconformity for a long rain or an intermittent torrential rain has been improved by the change of the operation method of working rainfall. This index is also effective for the cancellation of warning. No concrete method is specified about the setting of half-life.
	Method by the Committee for Studying Comprehensive Sediment Disaster Control Measures (Committee Method)	(i) Working rainfall (half-life: 1.5 hours) (ii) Working rainfall (half-life: 72 hours)	Slope failure Debris flow *)	The operation method of working rainfall given in Yano Method and the disaster prediction method using a three-layered tank model are adopted. The rainfall index is derived using a combination of two half-lives, 1.5 hours and 72 hours.	As this method uses the working rainfall used in Yano Method, unconformity for a long rain or an intermittent torrential rain seen in Method A is improved. This index is also effective for the cancellation of warning. The general-purpose applicability of this method is confirmed through use at various locations.
Method using rainfall intensity within the traveling time of runoff water	Method by Hirano et al.	Rainfall intensity within the traveling time of runoff water	Slope failure Debris flow	The rainfall intensity within the traveling time of runoff water derived by using the occurrence model (physical model) of debris flow or slope failure, is used as the index.	Although the traveling time of runoff water differs by topographical and geological conditions, it can be obtained empirically by analyzing causing and non-causing rainfalls in the past. This empirical derivation method is showed.
Method using multiple factor analysis	Method by Araki et al.	A combination of topographical factors and rainfall factors	Debris flow Slope failure **)	Topographical factors deeply related to the occurrence of a debris flow are surveyed and measured at each mountain stream at risk of this disaster. Equations for analysis are derived incorporating these survey results and various rainfall indexes.	Laborious measurement of topographical features is required as the prior work. But, it can be done using topographical maps, and labor can be saved if the distinct element method (DEM) or other efficient method is employed. The standard value can be set for each mountain stream or for a group of similar streams.

*): This method is proposed exclusively for the precipice failure. But, as the tank model used by this method is useful for debris flows, this method is considered to be useful for debris flows.
**): In the literature concerning this method, mountain streams at risk of debris flow are mainly treated. Basically, however, the occurrence of a slope failure and the occurrence of a debris flow are assumed identical.

Method by the tentative guidelines in 1984 (Methods A and B)

- ♦ Outline
  - (i) Proposed for debris flows.
  - (ii) The working rainfall used for the derivation of rainfall index is calculated by adding the effect of antecedent rainfall to the continuous rainfall from the start of rain.
- ♦ Advantages
  - (i) In Method A, the standard value is expressed by a single index like "the working rainfall is ○ mm (the continuous rainfall is ○ mm when the effect of antecedent rainfall is excluded). This is easy to understand and simple to make known.
- ♦ Disadvantages
  - (i) When a long rain or an intermittent rain continues, the amount of rainfall may easily exceed the standard value or does not fall below it for a long time.
  - (ii) Decision for cancellation of warning cannot be made unless no precipitation for over 24 hours is confirmed.

↓

Method by Yano (Yano Method)

- ♦ Outline
  - (i) Proposed for debris flows.
  - (ii) Problems contained in Methods A and B are improved.
  - (iii) The working rainfall used for the derivation of rainfall index is calculated using a method harmonious with the changes of the moisture content in the soil.
- ♦ Advantages
  - (i) The standard value is expressed by a single index like "the working rainfall is ○ mm". This is easy to understand and simple to make known.
  - (ii) Problems contained in Methods A and B are improved.
- ♦ Disadvantages
  - (i) A problem remains with the setting of half-life.

↓

Method by the Committee for Studying Comprehensive Sediment Disaster Control Measures (Committee Method)

- ♦ Outline
  - (i) Proposed for precipice failures which were not covered by any other methods. The precipice failures to be dealt by this method are restricted to those occurring locally.
  - (ii) Problems contained in Methods A and B are improved.
  - (iii) The working rainfall used for the derivation of rainfall index is calculated using a method harmonious with the changes of the moisture content in the soil, just like Yano Method.
  - (iv) For the operation of working rainfall, a half-life determined by a sediment-related disaster forecast method using a tank model is specified.
  - (v) The tank model used in this method is also usable for debris flows. Hence, this method is also considered applicable to debris flows.
- ♦ Advantages
  - (i) Problems contained in Methods A and B are improved.
  - (ii) The half-life is such that almost any regional differences are allowed.
- ♦ Disadvantages
  - (i) The standard value is shown by a linear line like "y = ax + b", which is difficult to make known. It is better to use an easy-to-understand expression like a single index by using the intercept value on the standard line as the standard value.

Fig. 3.1 Overview of four methods for the setting of standard rainfall [10)]

CHAPTER 4 ACTUAL STATE OF WARNING AND EVACUATION SYSTEM AGAINST SEDIMENT DISASTERS

4.1 Development of Warning and Evacuation System against Sediment Disasters in Japan (A Case at Mt. Unzen-Fugen)

Since Mt. Unzen-Fugen first erupted in 1990, the occurrence of a large-scale debris flow became a real threat at rivers originating from this mountain (River Mizunashi, River Akamatsudani, River Nakao, River Yue, and River Hijikuro). Responding to this situation, the Ministry of Land, Infrastructure and Transport, Nagasaki Prefectural Government, and municipal governments around this mountain joined forces to establish a warning and evacuation system against debris flows. The monitoring system of debris flow movements is made up of a wire sensor for detection of debris flow, a vibrometer for detection of debris flow, and a rain gauge. The monitoring data are transmitted by radio to the master station placed in Nagasaki Prefecture's Shimabara Development Bureau by way of two relay stations. And then, information from this master station to relevant organizations is transmitted by telephone line.

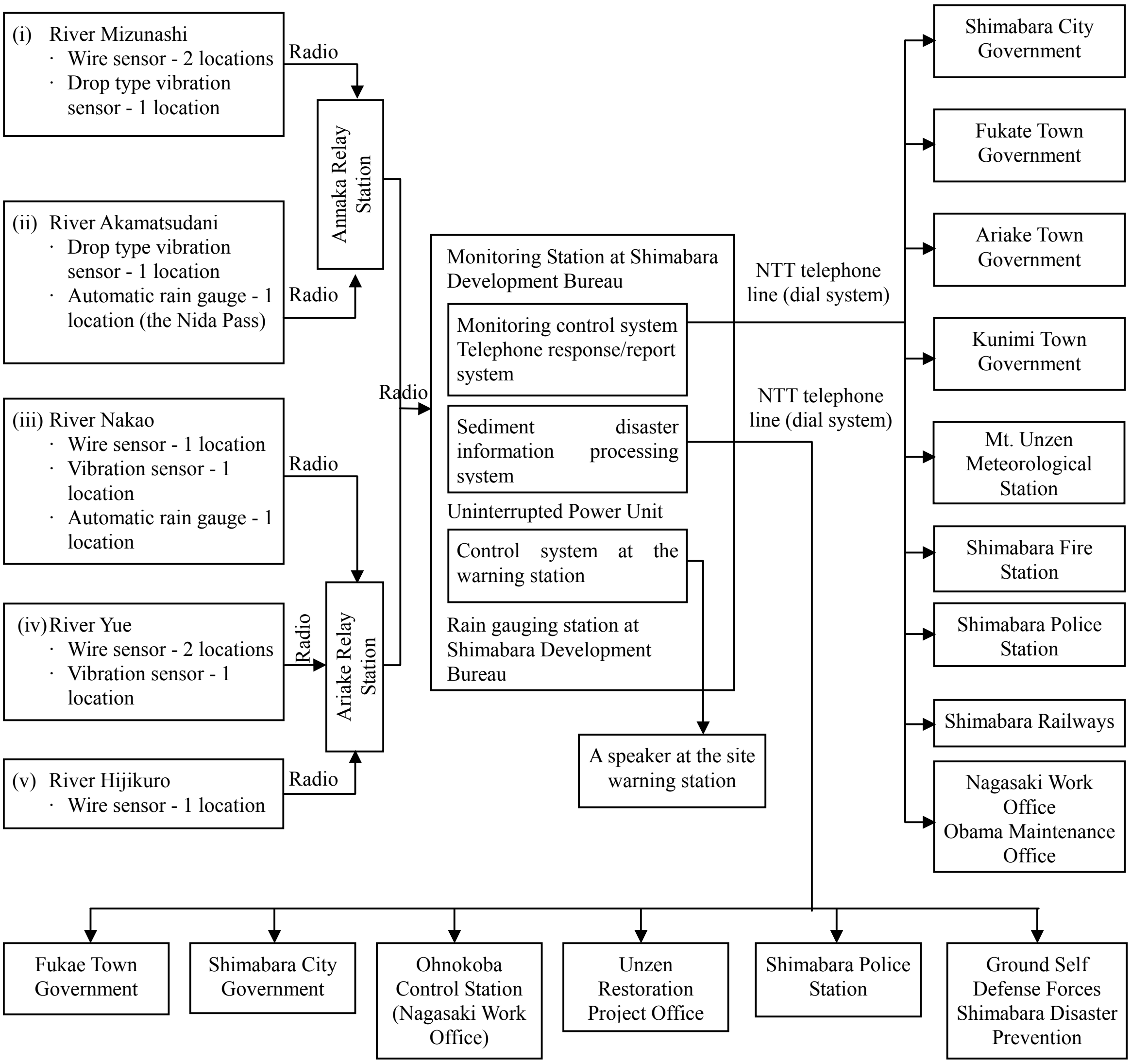


Fig. 4.1 Debris flow monitoring system at Mt. Unzen-Fugen volcano [11)]

During the three-year period from the first eruption in 1990 to June 1993, a total of 26 debris flows occurred at the five rivers mentioned above. Although the damaged buildings during those years amounted to over 1,200, the number of injured persons remained just one. This clearly indicates that a warning and evacuation system established at this volcanic mountain is highly effective.

Table 4.1 Evacuation activities taken against a debris flow on May 19, 1991

Date/time	Warnings and activities	Date/time	Warnings and activities
May 19 13:20	Evacuation was recommended to the Kami-ohnokoba area (Fukae Town).	May 20 7:31	A debris flow occurred (small scale).
13:39	A wire sensor at River Mizunashi was cut.	8:48	A debris flow occurred.
13:43	Evacuation was recommended to all households in the basin of River Mizunashi (Shimabara City).	9:51	The Ohnokoba Bridge was removed.
13:45	Evacuation was recommended to the areas in the basins of River Akamatsudani and River Mizunashi (Fukae Town)	14:32	The heavy rain and flood warning was cancelled.
14:57	The Tsutsuno Bridge was carried away.	14:46	Evacuation recommendation in Shimabara City was cancelled.
15:00	A heavy rain and flood warning was issued.	15:00	Evacuation recommendation in Fukae Town was cancelled.
15:09	A bridge for agricultural use was carried away.		
15:21	The Hirabara Bridge was demolished and removed (removal by self-decision).		
15:34	Evacuation of the North and South Kamikoba areas was completed.		

[Note] In Japan, a head of local government (a mayor or a village chief) who has close-relationship with local residence has authority and obligation to be responsible for recommendation and cancellation of evacuation.

4.2 Development of Warning and Evacuation System against Sediment Disasters in Developing Countries

4.2.1 Warning system against sediment disasters established at the Merapi volcano (Indonesia)

The area around the Merapi volcano is designated by the government of Indonesia as the most important disaster prevention area in the national disaster management program. A number of sabo projects, both structural and non-structural, have been implemented in this area as the nation’s model project against disasters due to an active volcano. Fig. 4.2 and 4.3 show the warning system against sediment disasters in this area.

On the hillside of Mt. Merapi, 16 observation posts are installed, each equipped with a telemeter system. To collect data, 6 rain gauges that can measure the 10-minute rainfall, 9 water level gauges, and 6 vibrometers and wire sensors are installed. The radar rain gauge is installed at the Sabo Technical Center (STC)/Research Center for River and Sabo (RCRS) located in Yogyakarta City. The data are transmitted to the master station placed in the STC/RCRS.

In this area, warning information against sediment disasters is transmitted to the people in hazardous areas through an operation office established in the local government after it is sent from the STC/RCRS. The transmission of warning information down to the community level is done by radio or telephone, but the delivery of it from the community level to the local people is made either by a direct notification in which some responsible person runs around by motorcycle to tell the warning, or by banging a traditional bell called Kentongan (a wooden alarm bell hung in front of a house to tell an approaching danger). The operation office in the local government also uses a siren for delivering a warning. At present, a warning system utilizing the LAN network is being introduced to the STC/RCRS. When its introduction is completed, the real-time transmission of rainfall conditions and the results of disaster prediction will become possible at various divisions and organizations in and around the Sabo Technical Center.

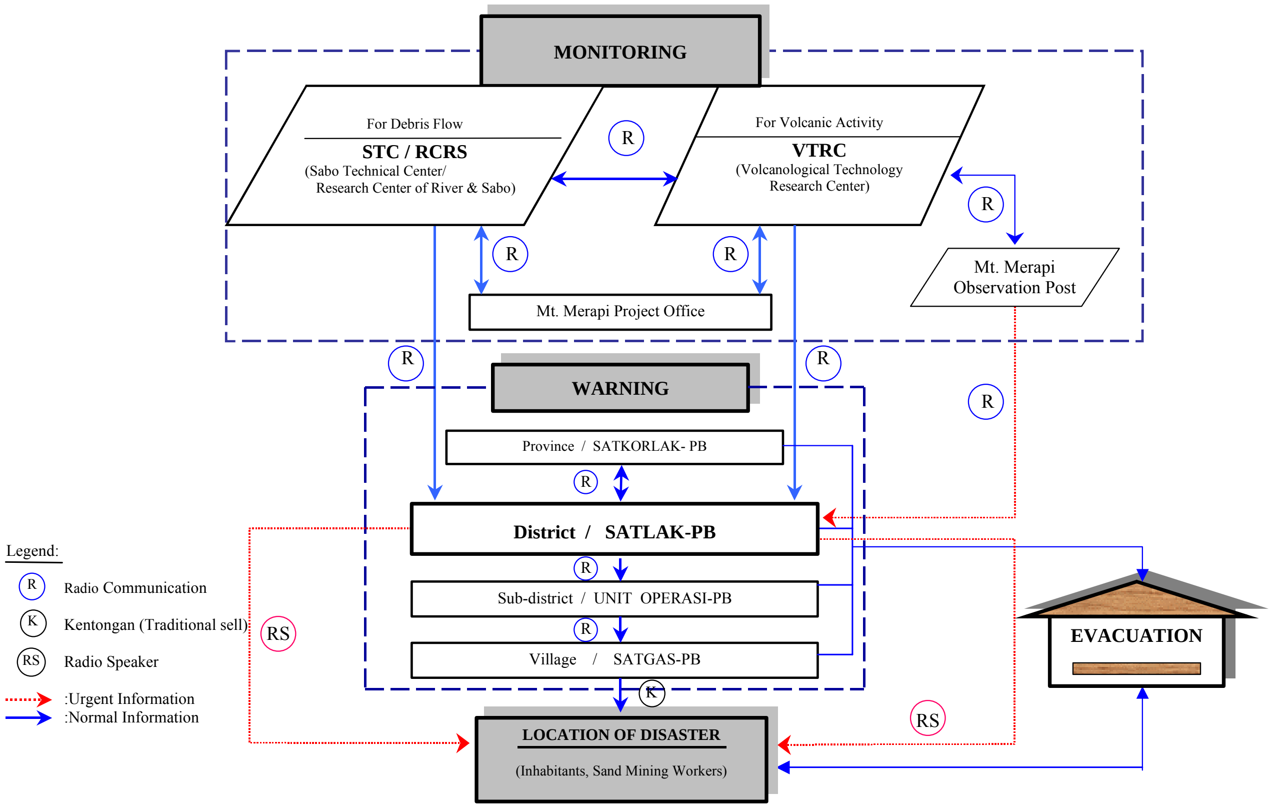
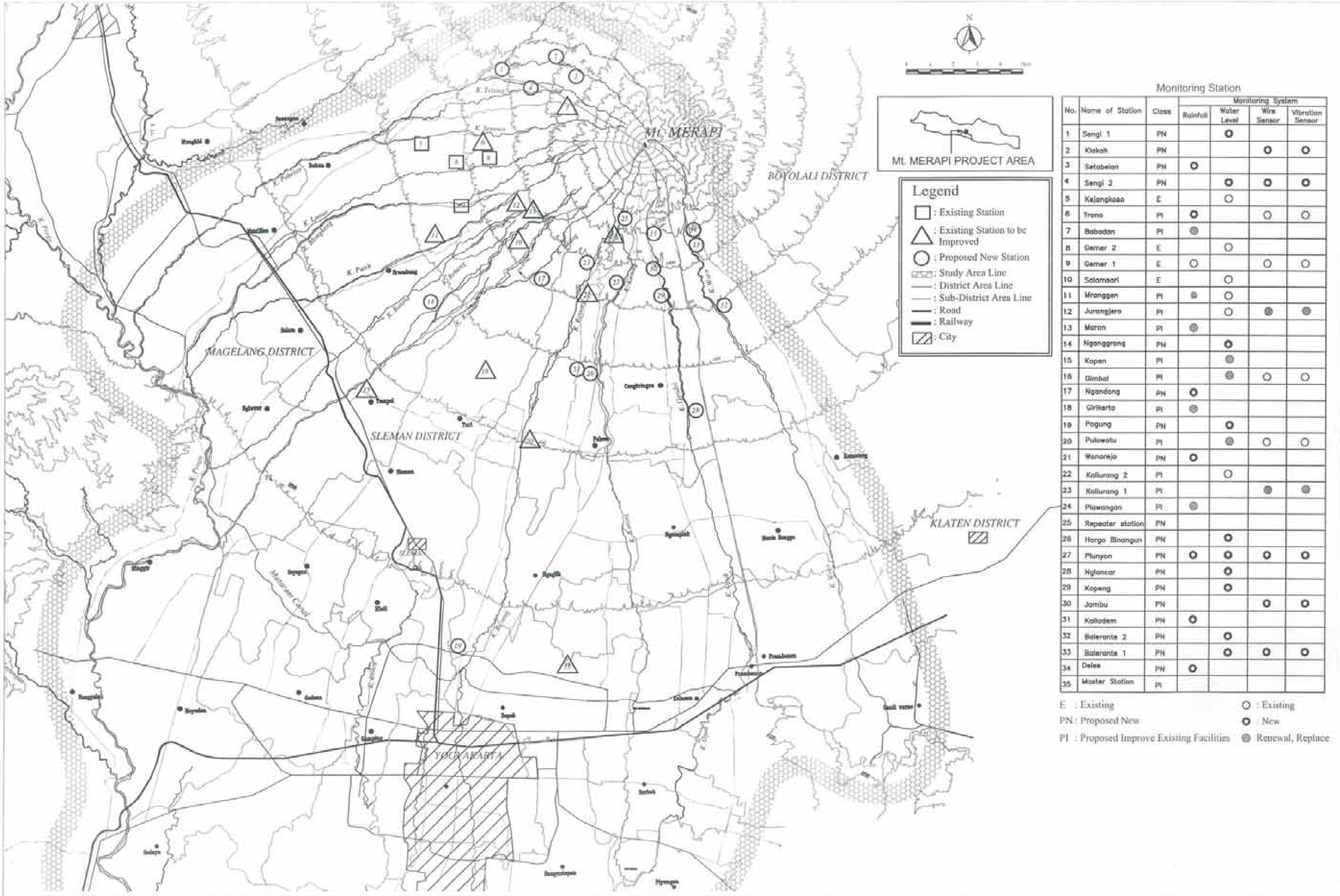


Fig. 4.2 Warning and evacuation system established in an area around the Merapi volcano [12)]



Monitoring Station

No.	Name of Station	Class	Monitoring System: Rainfall	Water Level	Wire Sensor	Vibration Sensor
1	Sengi 1	PN		**O**		
2	Klakah	PN			**O**	**O**
3	Setabelan	PN	**O**			
4	Sengi 2	PN		**O**	**O**	**O**
5	Kajangkoso	E		○		
6	Trono	PI	**O**		○	○
7	Babadan	PI	●			
8	Gemer 2	E		○		
9	Gemer 1	E	○		○	○
10	Salamsari	E		○		
11	Mranggen	PI	●	○		
12	Jurangjero	PI		○	●	●
13	Maron	PI	●			
14	Nganggrong	PN		**O**		
15	Kopen	PI		●		
16	Gimbal	PI		●	○	○
17	Ngandong	PN	**O**			
18	Girikerto	PI	●			
19	Pogung	PN		**O**		
20	Pulowatu	PI		●	○	○
21	Wonorejo	PN	**O**			
22	Kaliurang 2	PI		○		
23	Kaliurang 1	PI			●	●
24	Plawangan	PI	●			
25	Repeater station	PN				
26	Hargo Binangun	PN		**O**		
27	Plunyon	PN	**O**	**O**	**O**	**O**
28	Nglancar	PN		**O**		
29	Kopeng	PN		**O**		
30	Jambu	PN			**O**	**O**
31	Kaliadem	PN	**O**			
32	Balerante 2	PN		**O**		
33	Balerante 1	PN		**O**	**O**	**O**
34	Deles	PN	**O**			
35	Master Station	PI				

E : Existing ○ : Existing
PN : Proposed New **O** : New
PI : Proposed Improve Existing Facilities ● Renewal, Replace

Fig. 4.3 The Rainfall and Debris Flow Monitoring System in the Mt. MERAPI Volcano Areas

4.2.2 Warning system against sediment disasters established in the upstream of the Chang Jiang River (China)

The upstream area of China's largest Chang Jiang River (the Yangtze River) is an area frequented with sediment disasters, because this area contains approximately 10,000 mountain streams at risk of a debris flow and about 150,000 locations at risk of a slope failure or a landslide. These persistent threats have a serious effect on the economical development and the social stability of the area.

Since 1990, the "Water and Land Retention Committee in the Upstream Chang Jiang River" has been working to establish a warning and evacuation system against landslides and debris flows, in cooperation with other organizations. According to the "Management Policy of Warning and Evacuation System against Landslides and Debris Flows in the Special Area for Water and Land Retention in the Upstream Chang Jiang River" which was stipulated in January 2002, the warning and evacuation system in this area is made up of five aspects: (i) development of a warning and evacuation system and responsibilities of each organization (division); (ii) preparation and inspection before the rainy season; (iii) warning and evacuation activity by local people; (iv) analysis of monitoring data and reporting; and (v) survey and research.

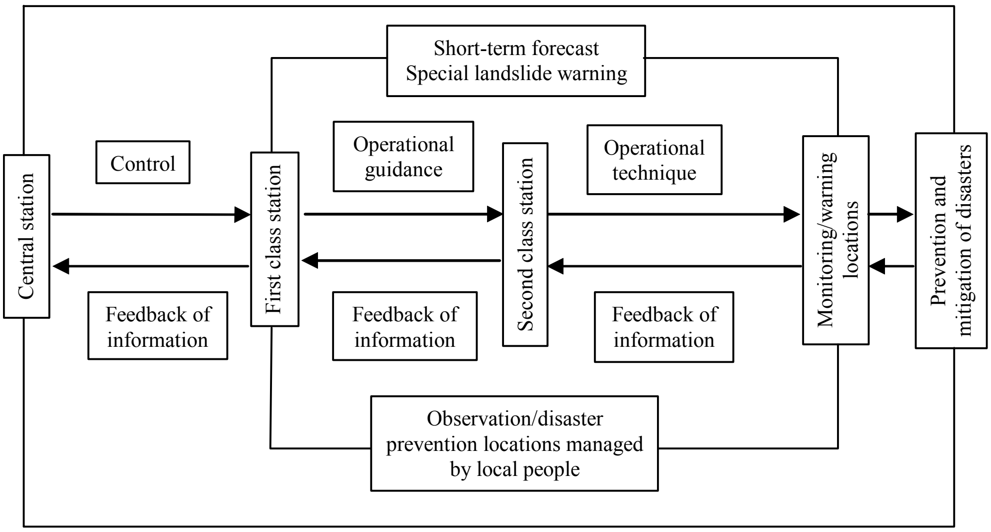


Fig. 4.4 Warning system against sediment disasters established in the upstream of the Chang Jiang River [13)]

After the establishment of the warning system in 1990, 58 monitoring locations are installed and 5 prefectures are designated as the model prefectures for warning and evacuation activity conducted by local people. They are attaining significant results.

4.2.3 Disaster prevention activities in the Provinces of Central Java and Jogjakarta (Indonesia)

In November 2000, a slope failure occurred at Menorah Hill lying across Purworejo Prefecture in the Province of Central Java and Kulonprego Prefecture in the Province of Jogjakarta, claiming the lives of about 70 people. To prevent the recurrence of such a disastrous damage, a small-scale housing relocation and a disaster prevention education were carried out in these prefectures in cooperation of the Sabo Technical Center (STC), the Research Center for River and Sabo (RCRS), and the University of Gadjah Mada (UGM), and the International Cooperation Agency (JICA) of Japan, with a grass-roots financial assistance from Japan.

The disaster prevention education was held for three days in each prefecture, inviting representatives of counties, villages, and communities, school teachers, people related to the Red Cross, and NGO groups. A lecture and a field workshop were held on such subjects as the causes of sediment disaster, locations at risk of sediment disaster, installation of a simple rain gauge and measurement, and evacuation and relief activities.

Fig. 4.5 Disaster prevention education held in local communities [8)]

4.2.4 Disaster prevention meeting and evacuation training in the Dahachowk area (Nepal)

Disaster prevention education and evacuation training were extended to the local people in the Dahachowk area in Nepal which is frequented with debris flow disasters, with the intention of enlightenment toward disaster prevention and the establishment of a warning and evacuation system as a part of non-structural measures against sediment disasters. Although the disaster prevention meeting and evacuation training were held during the daytime, about 70 local people participated, which clearly indicates the high awareness of the people toward disaster prevention. Because a deep understanding of debris flows is indispensable for proper warning and evacuation activities, the actual state of debris flows, their causes, and preventive measures, as well as the importance of warning and evacuation were explained to the people through video screening and panel discussion. After that, an evacuation training was conducted to reconfirm the evacuation route, the location of refuge facilities, and the cautions to be observed during evacuation.

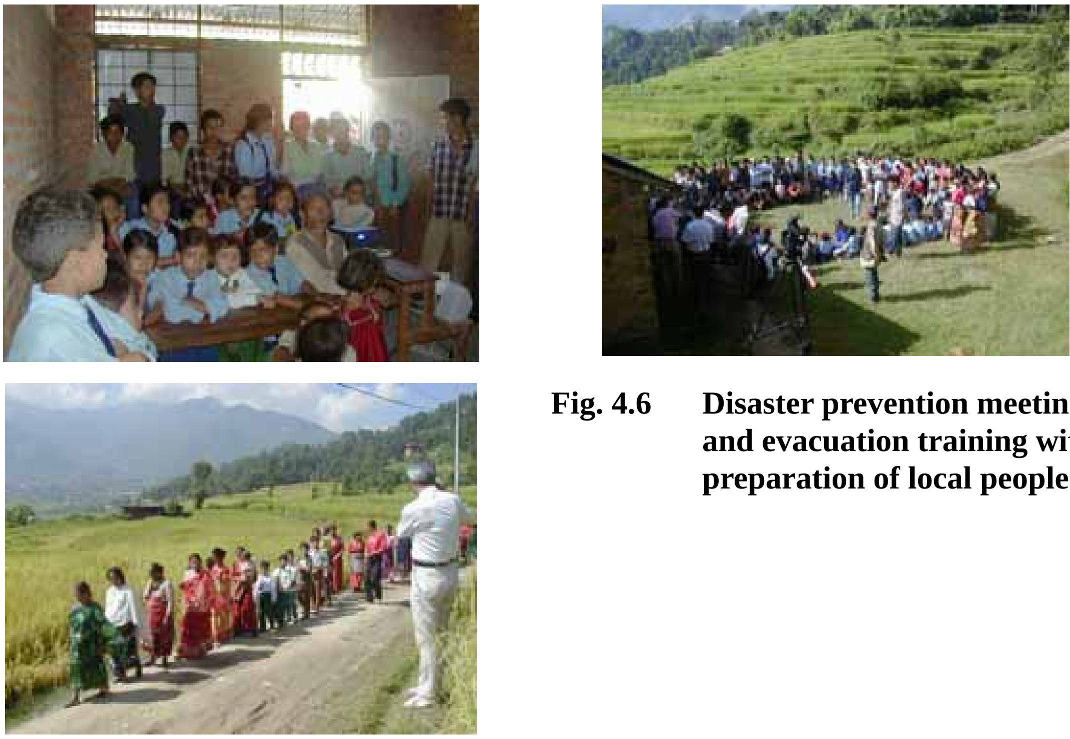


Fig. 4.6 Disaster prevention meeting and evacuation training with preparation of local people [9)]

4.2.5 Preparation of hazard map in the Bhagra area with public involvement (Nepal)

A hazard map showing potential flooding areas and areas at risk of sediment disasters was prepared in the Bhagra area along the Girubari River which is designated as the model site for the establishment of a warning and evacuation system. See Fig.-4.7.

Employing the PRA's social map preparation method which is one of the methods of the public involvement type, the hazard map was prepared based on the surveys of refuge facilities, evacuation routes, places at risk of disasters that were completed with the cooperation of local people. The information included in this hazard map is limited to that useful to the local people. Discussion was also made with the local people on what method is suited to them to transmit the information on warning and evacuation.

Traditionally, in this area where only one house owns a telephone, a messenger person was appointed to deliver the information from the representative of a community to each household. However, in an emergency situation like a flood or a debris flow, this type of information transmission is unable to save people from an approaching danger. To respond to this need, a communication system, or the use of an alarm bell, that can deliver a warning information instantly to the entire area was proposed.

As the refuge facilities, school buildings and public facilities often used by local people were selected in consideration of their accommodation capacity, location, and structure. However, a problem remained that refuge facilities themselves are situated in a disaster hazard area. To cover this weakness, it was determined to install simple structural works. Using the gabions provided by the current project, the groundsill works were installed with the hands of local people. Besides these structural works, staffs for measuring the water level in rivers and simple rain gauges for measuring rainfall were provided to this area to be utilized for warning and evacuation-related judgment.

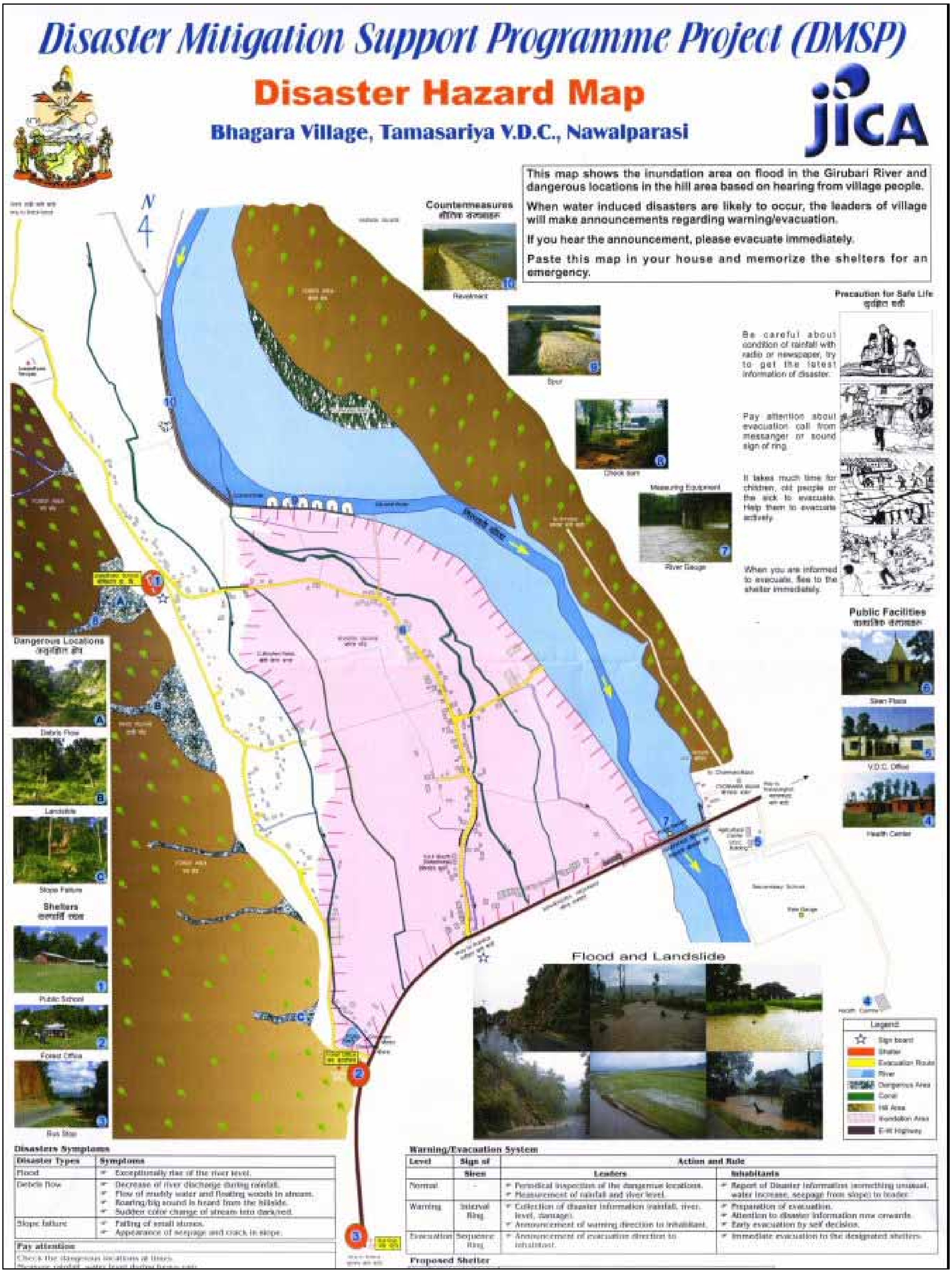


Fig. 4.7 Hazard map of the Bhagra area [9)]

PLANNING OF WARNING AND EVACUATION SYSTEM

CHAPTER 1 IDENTIFICATION OF SEDIMENT DISASTER HAZARD AREAS

1.1 Debris Flow Hazard Areas

The survey for the identification of debris flow hazard areas shall be limited to the range that needs to be considered at this moment for establishing a warning and evacuation system for the people, without including the range that needs to be considered for the future. The survey shall be conducted in accordance with the flowchart in Fig. 1.1. The details of each survey step, including the contents and the methods, are shown below.

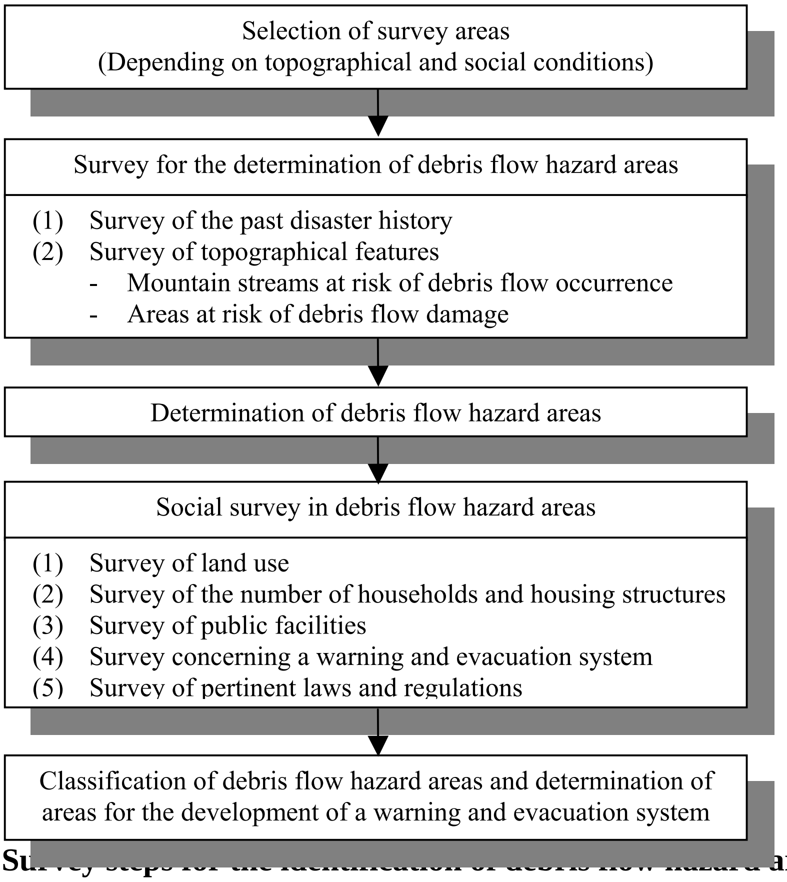


Fig. 1.1 Survey steps for the identification of debris flow hazard areas [16]

1.1.1. Selection of survey areas

The survey areas are the areas that may sustain damage due to a debris flow and the mountain streams at which a debris flow may occur. Utilizing topographical maps on a scale of 1/25,000 in principle, areas that satisfy both the topographical and social conditions shown below shall be taken out as the survey areas. If large-scale topographical maps above 1/25,000 are available, those maps shall be used. If the only maps available are small-scale maps below 1/25,000, insufficient information shall be confirmed during a field survey.

<Topographical conditions>

- **Areas at risk of debris flow damage:**
  These areas are located between the point at which a debris flow enters into a fan at the foot of a mountain (it is usually a point where a debris flow begins to flood, which is called a debris flow flooding point) and the lowermost point a debris flow will reach (this is usually the point where the ground gradient is 2°).

- **Mountain streams at risk of debris flow occurrence:**
  These mountain streams are located in the upper area than the point at which a debris flow begins to flood. To be specific, they have the following features.
  (1) Mountain streams having a valley-like configuration on a map of 1/25,000
  (2) Mountain streams at which a debris flow or a sediment flow occurred in the past. This includes mountain streams having a fan-like configuration.
  (3) Mountain streams assessed as at risk of debris flow occurrence from their topographical and geological conditions. An example is a mountain stream located in a river basin having a large devastated area or a large bare area.

<Social conditions>

Survey should be made to find if houses, public facilities, roads, and railways often used by people are located in a hazardous area or a hazardous mountain stream.

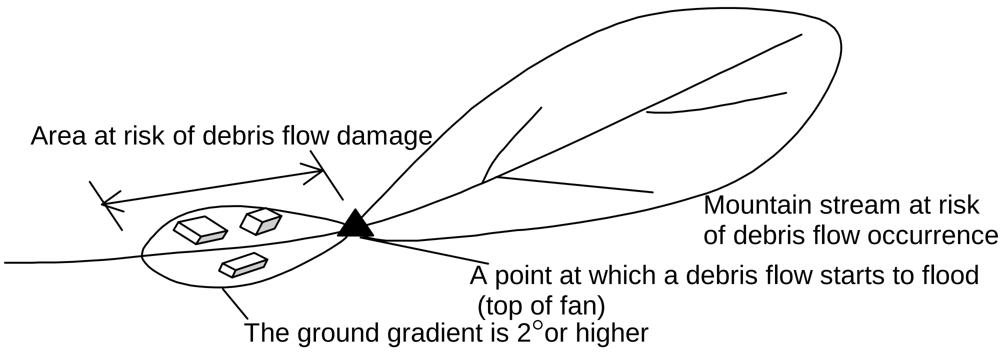


Fig. 1.2 A representation of the area for survey [16)]

1.1.2 Survey for the determination of debris flow hazard areas

To collect data needed for the determination of debris flow hazard areas, the selected survey areas shall be investigated in detail by such methods as the reading of existing topographical maps, a field survey, and a collection of reference materials. If it is a survey to find the necessary preventive measures against debris flows, the detailed survey should consist of 1) survey of past disaster history, 2) topographical survey, 3) geological survey, and 4) survey of conditions of existing preventive works. But, in the case of survey for the development of a warning and evacuation system against debris flows, 1) and 2) are needed as the minimum requirement. They are explained below.

(1) Survey of past disaster history

Survey should be made on debris flows that occurred in and around the selected survey areas in the past, and their scales and the damages shall be gasped. Survey should be performed mainly on the following items.

- Date, time, location, and causes of a debris flow
- The scale of a debris flow (total volume of sediment discharge, flooding area)
- Damage to humans (the number of persons killed or injured), damage to houses, structure of damaged houses (wooden/non-wooden), and level of damage to houses (total collapse, half collapse, partial collapse)
- Rainfall (cumulative rainfall, daily rainfall, hourly rainfall, 10-minute rainfall)

- Others (thickness of sedimentation due to flooding)

(2) Topographical survey

The topographical survey, as shown in Table 1.1, shall be conducted at mountain streams at risk of debris flow occurrence and in areas at risk of debris flow damage separately. It is best to use topographical maps on a scale of 1/2,500 or over. But, if the only maps available are small-scale topographical maps below 1/2,500, insufficient information shall be confirmed during a field survey.

Table 1.1 Survey for the determination of debris flow hazard areas

<table>
<tr><th>Mountain streams at risk of debris flow occurrence</th><th>Areas at risk of debris flow damage</th></tr>
<tr><td><Gradient of streambed></td><td><Gradient of ground and gradient of streambed></td></tr>
<tr><td colspan="2"><u>Reading of topographical maps</u>
Using large-scale topographical maps of 1/2,500 or over, the ground gradient and the streambed gradient shall be grasped.
<u>Field survey</u>
When large-scale topographical maps of 1/2,500 or over are not available, the streambed gradient that is closely related to the occurrence, flow, and sedimentation of a debris flow shall be measured at the site. During a field survey, detailed measurements shall also be performed on such matters as the changing position of streambed gradient, the streambed gradient above and below the structures, and the streambed gradient at a point where a valley becomes wider, utilizing a pocket compass (a hand level) and other devices. The ground gradient shall be measured in a similar manner.</td></tr>
<tr><td><Area of a debris flow occurrence basin>
The area of a basin above the debris flow flooding point shall be measured (this is called the area of a debris flow occurrence basin). If it is a volcanic area, the area of a basin having a gradient of 10° or higher shall be measured as the area of a debris flow occurrence basin. If it is an ordinary area, the area of a basin having a gradient of 15° or higher shall be measured as the area of a debris flow occurrence basin.</td><td><Transverse configuration>
To obtain basic data for the estimation of the flowing scale (flow rate), the flooding point, and the flooding range of a debris flow, a field survey shall be conducted on 1) transverse configuration, 2) gradient of a stream bank, 3) width of a stream, 4) relative height of a terrace, and 5) relative height of the subject of conservation and the streambed. Using these results, a transverse profile shall be prepared. The precision level of this survey shall be the level of a simple survey, as necessity calls.</td></tr>
<tr><td></td><td><Plane configuration>
To obtain basic data for the estimation of the flooding scale and flooding range of a debris flow, the plane configuration shall be grasped utilizing the results of a ground gradient survey, reading of aerial photographs, and a transverse configuration survey. Before going out for a field survey, crook and narrow sections of a stream course, plains at the bottom of a valley, flat areas (residential areas, arable land), artificial structures (roads, railways, bridges) shall be identified using maps, and they shall be confirmed during a field survey.</td></tr>
</table>

1.1.3 Determination of debris flow hazard areas

The debris flow hazard area is defined as follows.

An area located below the debris flow flooding point (top of fan) and having a ground gradient of 2°or higher. However, an area clearly admitted beyond the reach of a debris flow from its topographical conditions is excluded (See Fig. 1.3).

The debris flow hazard area shall be determined in accordance with the procedures shown below, based on the survey results mentioned in Section 1.1.2 above.

1) The debris flow flooding point shall be determined using topographical maps and the results of a field survey, with a focus on the following items.
   - Outlet of a valley: a point at which the valley width becomes large
   - Top of fan: a point at which the valley width becomes large and the streambed gradient becomes gentle
   - Point of gradient change: a point at which the gradient of a streambed abruptly changes from steep to gentle
   - Crook: a point at which the river course is bent sharply (flooding will occur on the exterior side because a debris flow flows straight).
   - Outlet of a narrow section: a point at which the valley width abruptly changes from narrow to wide
   - Debris flow flooding point: a point at which a debris flow began to flood in the past disasters
2) A point at which the ground gradient becomes 2˚shall be identified in the area below the debris flow flooding point.
3) The debris flow hazard area shall be determined by focusing on the area located between the debris flow flooding point and the lowermost point where a ground gradient is within 2˚or higher, and by taking other factors into account, including topographical features around the stream and the location/scale of artificial structures. Besides these, other factors shall also be taken into account. They include topography in the area, distribution of sediment carried by past debris flows, past disaster history, and other debris flows that occurred at nearby streams or at streams having a similar topography and geology. To determine the range of reach, attention shall be paid to the topographical features and sedimentation in the area, including 1) fan type topography 2) presence of a group of boulders, 3) presence of unlayered sediment containing both sand and gravel. The transverse profile of a debris flow hazard area (See Fig. 1.4) shall be determined based on the field confirmation of the relative height of a streambed and surrounding terrains, a river terrace, artificial structures, etc.

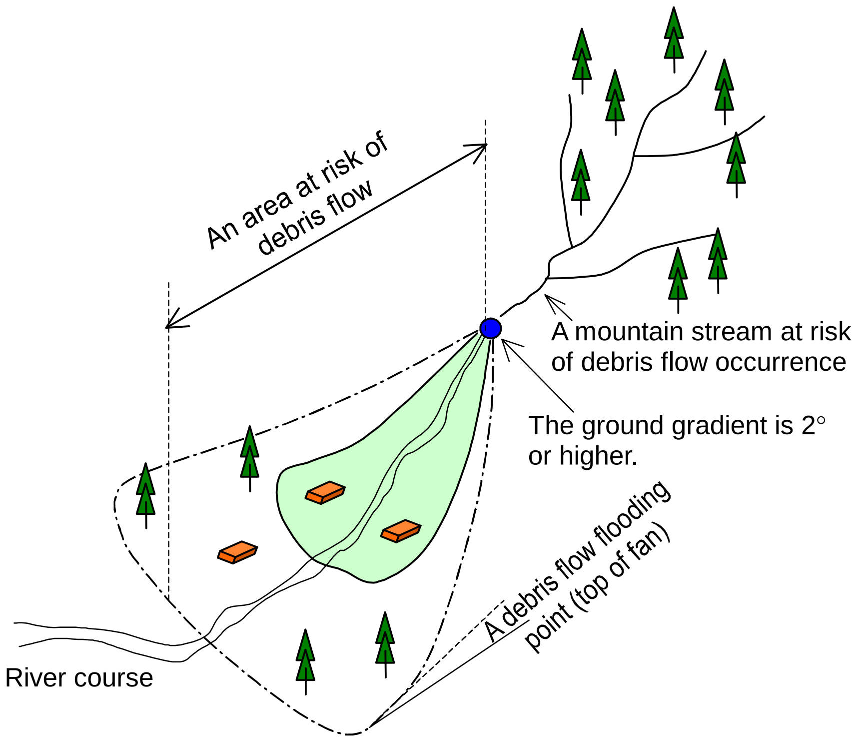


Fig. 1.3 A representation of the debris flow hazard area [16)]

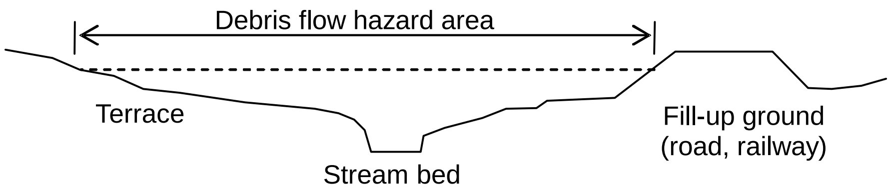


Fig. 1.4 A representation of the transverse profile of a debris flow hazard area [16)]

1.1.4 Social survey in debris flow hazard areas

(1) Survey of land use

The state of land use (roads, watercourses, ponds and marshals, residential areas, farmlands, forests, etc.) shall be surveyed in debris flow hazard areas.

(2) Survey of the number of households and housing structures

The number of households and the structure of houses shall be surveyed in debris flow hazard areas.

(3) Survey of public facilities

The conditions of public facilities and business establishments located within debris flow hazard areas shall be surveyed to grasp the region-wide potential effect of a debris flow. Survey shall also be made on the structures of those facilities and business establishments to find their safety level against a debris flow. The subjects to be surveyed are as shown below. With regard to (i), the type, length, and number of facilities located within the survey area shall be surveyed. As to (ii), the type of facilities and their structure shall be surveyed.

(i) Public facilities, like a road and a railway:

National roads, prefectural roads, municipal roads, rivers, roads, railways

(ii) Public buildings, like a post office and a social welfare facilities:

- Public buildings, such as a police station, a post office, other public offices, business establishments, hotels and inns, stations, schools
- Social welfare facilities and medical facilities used by elderly people, handicapped people, infants, and others who need special consideration in disaster prevention (these are referred to as the facilities for vulnerable people)

(4) Survey concerning a warning and evacuation system

To grasp various conditions related to the development of a warning and evacuation system in debris flow hazard areas, survey shall be made on the following items.

(i) Designation/non-designation of the debris flow hazard area

(ii) Presence/absence of voluntary disaster prevention groups

(iii) Installation of measurement devices such as a water gauge and a flow meter

(iv) Location of a rain gauge and its operator

(v) Setting of standard rainfalls

(vi) Development of a transmission system for conveying rainfall information, forecast of disaster occurrence (advisory and warning), and disaster information

(vii) Designation of evacuation routes, location of refuge facilities (located within the disaster hazard area or not), structure of refuge facilities (wooden/non-wooden),

(viii) Dissemination of disaster-related knowledge and information to the people, including distribution of disaster prevention maps

(ix) Disaster prevention training

(5) Survey of pertinent laws and regulations

Survey shall be made on laws and regulations that have been enforced concerning the areas at risk of debris flow damage.

1.2 Slope Failure Hazard Areas

The survey for the identification of slope failure hazard areas shall be limited to the range that needs to be considered at this moment for establishing a warning and evacuation system for the people, without including the range that needs to be considered for the future. The survey shall be conducted in accordance with the flowchart in Fig. 1.5. The details of each survey step, including the contents and the methods, are shown below.

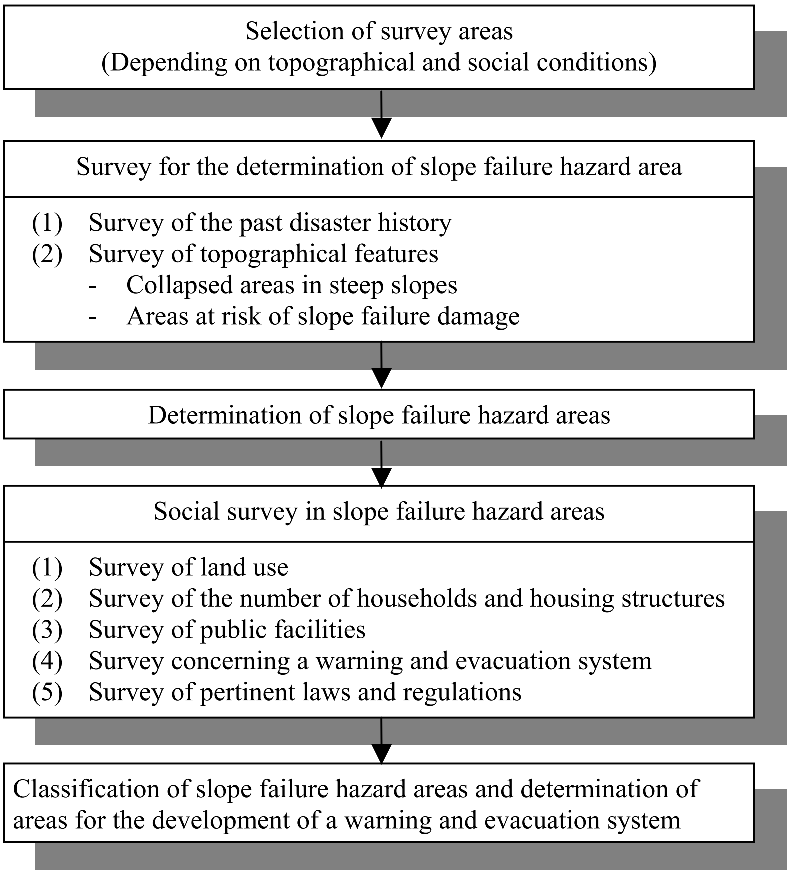


Fig. 1.5 Survey steps for the identification of slope failure hazard areas [16)]

1.2.1. Selection of survey areas

The survey areas are the areas that may sustain sediment damage due to a slope failure. Utilizing topographical maps on a scale of 1/25,000 in principle, areas that satisfy both the topographical and social conditions shown below shall be taken out as the survey areas. Each survey area shall be taken out as the area having some kind of unity so that a warning and evacuation system can be established efficiently and other administrative measures implemented smoothly. If large-scale topographical maps above 1/25,000 are available, those maps shall be used. If the only topographical maps available are small-scale maps below 1/25,000, insufficient information shall be confirmed during a field survey.

<Topographical conditions>

A slope failure hazard area is an area having a gradient of 30°or higher and a height of 5 m (See Fig. 1.6). Unlike a landslide case, it is difficult to locate the very site of slope failure in advance because a slope failure is an initial stage movement of a slope. Hence, the above definition is used to specify a hazardous slope at risk of collapse. As the average friction angle of loose sandy soil is around 30～35˚, the slope gradient 30˚ is a gradient at which a fall can occur even though excessive pore water pressure is not generated. In that sense, although it is an approximated value, the slope gradient 30˚ presented in the definition is a meaningful value. Because slopes having a gradient of 30˚ or higher are numerous, survey shall be limited to the slopes having a height of 5 m or higher in view of their vulnerability.

<Social Conditions>

A survey of social conditions shall be conducted at: 1) steep slopes, 2) slopes having houses, public facilities, and farmland around the slope, and 3) slopes around which houses, public facilities, and farmland may be built in the near future in view of current land use and land development plans.

1.2.2 Survey for the determination of slope failure hazard areas

To collect data needed for the determination of slope failure hazard areas, the selected survey areas shall be investigated in detail by such methods as the reading of topographical maps, a field survey, and a collection of reference materials. If it is a survey to find the necessary preventive measures against slope failures, the detailed survey should consist of 1) survey of past disaster history, 2) topographical survey, 3) geological survey, and 4) survey of conditions of existing preventive works. But, in the case of survey for the development of a warning and evacuation system against slope failures, 1) and 2) are needed as the minimum requirement. They are explained below.

(1) Survey of past disaster history

Survey should be made on slope failures that occurred in and around the selected survey areas in the past, and their scales and the damages shall be grasped. Survey should be performed mainly on the following items.

- Date, time, location, and causes of a slope failure
- The scale of a slope failure (height of a steep slope area, gradient of a steep slope area, height of collapse, depth of collapse, width of collapse, width of spread of soil and rock, length of collapse, range of reach of soil an rock, volume of collapsed soil and rock
- Damage to humans (the number of persons killed or injured), damage to houses, structure of damaged houses (wooden/non-wooden), level of housing damage (total collapse, half collapse, partial collapse)
- Rainfall (cumulative rainfall, daily rainfall, hourly rainfall, 10-minute rainfall)
- Others (constants of soil, etc.)

(2) Topographical survey

The topographical survey shown in Table 1.2 shall be conducted at steep slopes at risk of collapse and in areas at risk of damage due to a slope failure individually. It is best to use topographical maps on a scale of 1/2,500 or over. But, if the only maps available are small-scale maps below 1/2,500, the insufficiency of information shall be confirmed during a field survey.

Table 1.2 Survey for the determination of slope failure hazard areas

Steep slopes at risk of collapse	Areas at risk of damage due to a slope failure
The following surveys are important for the determination of a range at risk of collapse. Therefore, confirmation at the site is desirable.	Survey of hazardous areas shall be performed at the bottom of a steep slope and at the flat area. The following items shall be grasped.
<Gradient> An angle made by the horizontal line and the line linking the bottom of a steep slope and the natural inflection point of gradient shall be surveyed.	<Micro-topography> Micro-topography of the area showing a small ruggedness, such as a small hill, artificial fill, river, and irrigation channel
<Height of a steep slope> The difference of elevation between the lower end and the upper end of a steep slope shall be surveyed (this is referred to as the height). If uneven places that are not really steep exist at the midway of a steep slope, the lower end and the upper end of a steep slope can be determined in view of an entire slope (in principle, a point 5 m ahead must be viewed without serious obstruction).	<Artificial structures> Artificial structures built on excavated areas or fill-up areas, such as a railway and a road

1.2.3 Determination of slope failure hazard areas

The sloop failure hazard area is defined as follows (See Fig. 1.6).

1) An area having a gradient of 30˚ or higher and a height of 5 m or over.
2) An area located within a horizontal length of 10 m from the upper end of a steep slope
3) An area located within twice the height of a steep slope (if this exceeds 50m, the limit is 50 m) from the bottom of a steep slope (However, part of the area which is clearly admitted not within the reach of soil and rock from its topographical features is excluded).

Using data obtained from topographical survey of a steep slope, the cross sectional configuration as well as the plane configuration of the steep slope shall be grasped. Then, incorporating the results of a field survey and a disaster history survey, the slope failure hazard area shall be determined by taking the steps shown below.

1) The lower end and the upper end of a steep slope are determined.
2) The height and gradient of a steep slope are determined.
3) Three areas are determined as the slope failure hazard area: (i) a steep slope area itself; (ii) an area located above the steep slope and within 10 m from the top of the slope; (iii) an area located below the steep slope and within the twice the height of the steep slope from the bottom of the steep slope (if this exceeds 50m, the limit is 50 m). The area in these cases means the area situated between the right-side vertical plane that passes the right-end points at the upper end and lower end of a steep slope and the left-side vertical plane that passes the left-end points at the upper end and lower end of a steep slope (See Fig. 1.7).

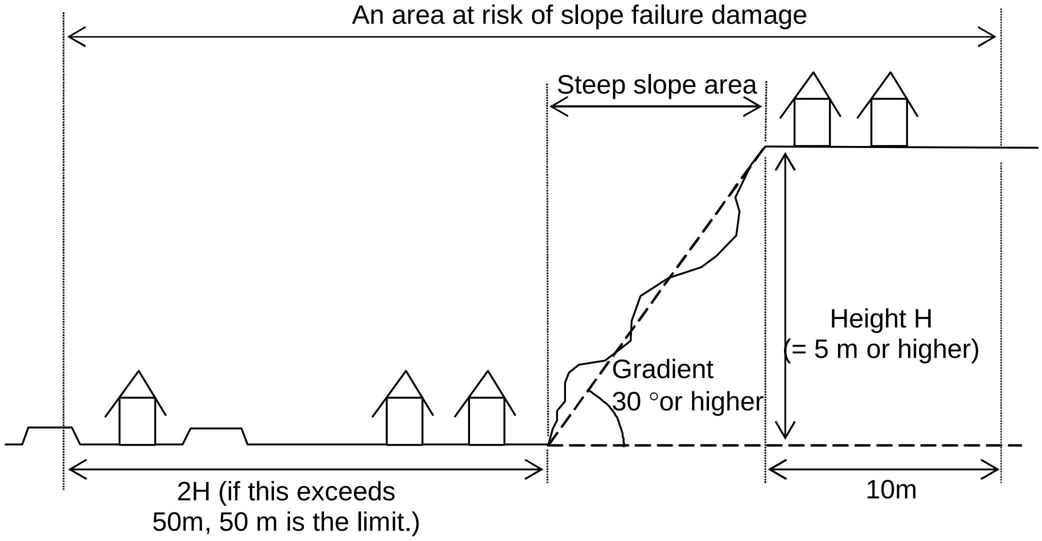


Fig. 1.6 A representation of the slope failure hazard area [16)]

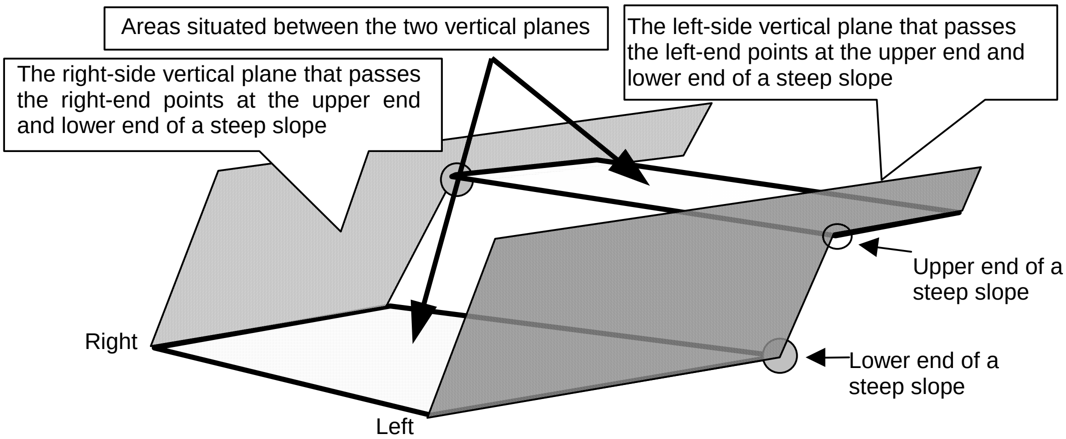


Fig. 1.7 Determination of right-end and left-end points of a steep slope area [16)]

1.2.4 Social survey in slope failure hazard areas

The Social survey in slope failure hazard areas shall be conducted in accordance with Section 1.1.4, which outlined the social survey in debris flow hazard areas. For the survey of hazardous slopes, aerial photographs are extremely useful. Aerial photographs are also very effective for the determination of hazard areas and the identification of houses. To distinguish houses by wooden or non-wooden, a picturing scale of 1/10,000 or 1/12,500 is appropriate (the picturing scale of ordinary aerial photographs is also acceptable).

1.3 Selection of Areas for the Development of Warning and Evacuation System

Although it is desirable to develop a warning and evacuation system in all the sediment disaster hazard areas, this is not always possible because of financial constraints and other reasons. Accordingly, sediment disaster hazard areas for the development of a warning and evacuation system shall be selected based on priority in consideration of various factors, including the hazard level, social and economic importance of the area, and the possibility of human damage. The classification of sediment disaster hazard areas is explained below.

1.3.1 Debris flow hazard areas

In Japan, the debris flow hazard mountain streams are classified into three groups based on the social conditions of the debris flow hazard areas (type and number of subjects for conservation).

1) **Debris flow hazard mountain stream I:** Mountain stream flowing in an area having 5 or more houses for conservation, or mountain stream flowing in an area having an important public facilities, like a public office, school, hospital, station, power plant, even though the number of houses for conservation is less than 5
2) **Debris flow hazard mountain stream II:** Mountain stream flowing in an area in which the number of houses for conservation is 1 or more but less than 5
3) **Mountain stream equivalent to debris flow hazard mountain stream III:** Mountain stream flowing in an area which has no houses for conservation at present but may be developed for housing construction later

This kind of classification shall be decided based on the social conditions of each country or each region. As a reference, the following classification is also available.

1) **Debris flow hazard mountain stream I:** Mountain stream flowing in an area having houses for conservation and a public facilities for people
2) **Debris flow hazard mountain stream II:** Mountain stream flowing in an area having houses for conservation but no public facilities for people
3) **Debris flow hazard mountain stream III:** Mountain stream flowing in an area having no houses for conservation and no public facilities for people

1.3.2 Slope failure hazard areas

The slope failure hazard areas are classified into three groups based on social conditions (type and number of subjects for conservation).

1) **Slope failure hazard area I:** Steep slope area (including an artificial steep slope) having a slope gradient of 30˚ or higher and a slope height of 5 m or higher on which 5 or more houses are located (this includes a steep slope area having a public office, school, hospital, station, inn, or a facilities used by disaster vulnerable people such as a social welfare facilities, even though the number of houses located is less than 5.)
2) **Slope failure hazard area II:** The same area as above, but the number of houses located is 1 to 4.
3) **Slope area equivalent to a slope failure hazard area III:** The same area as above, which has no houses at present, but may be developed for housing construction later.

This kind of classification shall be decided based on the social conditions of each country or each region. As a reference, the following classification is also available.

1) **Slope failure hazard area I:** Steep slope area (including an artificial steep slope) having a slope gradient of 30˚ or higher and a slope height of 5 m or higher on which houses for conservation and a public facilities for people are located
2) **Slope failure hazard area II:** The same area as above, having houses for conservation but no public facilities for people.
3) **Slope failure hazard area III:** The same area as above, but no houses for conservation and no public facilities for people

CHAPTER 2 MONITORING AND FORECAST OF SEDIMENT DISASTERS

2.1 Monitoring of a Debris Flow

As the direct monitoring methods for detecting the precursors and the occurrence of a debris flow, two methods are available: one is the use of a wire sensor, a vibration sensor, and a monitoring camera; the other is a visual observation by local people. Visual observation of debris flow movements by local people is simple but effective, and is able to be carried out even if without rainfall data. It is regarded as an important method among the debris flow monitoring systems.

2.1.1 Establishment of the debris flow visual observation system

The flow modes of a debris flow are diverse due to such factors as the gradient at the debris flow occurrence point, width of a stream or a river, materials on the streambed, thickness of accumulated sediment, and rainfall intensity. In general, however, the following modes of debris flows are observed in the upstream, midstream and downstream of a river. It is known that there are precursors of sediment disasters described in Table 2.1.

<Mode of debris flow>

- In the upstream, a debris flow occurs intermittently and it is a large-viscous flow containing a relatively small amount of water.
- In the midstream, a debris flow moves like a hydraulic bore with a small wave height. Containing relatively large amount water, the flow becomes like a liquefied flow and tends to flow in the lower direction.
- In the downstream, a debris flow becomes like a concrete mortar-like flow containing a large amount of water. Compared with an ordinary water flow, it is a viscous flow.

Table 2.1 Precursors of sediment disasters

Slope failure	Debris flow	Landslide
- Water from a precipice or a slope becomes muddy. - Cracks appear on a precipice or a slope. - Small stones fall. - A sound is heard from a precipice or a slope.	- A rumbling sound of the mountain is heard. - The water level in the river lowers, though rain is continuing. - The river water becomes muddy or includes driftwood.	- Cracks appear on the ground. - Water in a well or a valley becomes muddy. - Water gushes out from a precipice or a slope.

In the debris flow visual observation system, these precursors of sediment disasters and the occurrence of a debris flow are visually observed. The detected information is reported to the debris flow monitoring center and can be used for recommendation and cancellation of evacuation.

When the visual observation method is taken, an observer is required to grasp those debris flow modes in different areas of a river and it is important that a visual observer has an ample knowledge about the precursors of a potential disaster which can be detected by human eyes in order to judge the occurrence of a debris flow with no time to lose. Flood in river and stream is one of the important precursors of debris flow and other sediment disasters. Thus, it is necessary to monitor the water level of rivers and unusual water level of rivers must be reported immediately. If the precursors are observed, the information must be transmitted to relevant organizations. Then a warning and evacuation action should be taken immediately and an evacuation of people should be initiated. In case a large-scale debris flow is occurring, the speed of a warning transmission should be faster than the speed of the debris flow itself. If the downstream area is an important area, a visual observation point should be placed at two or three locations at least in the upstream and the midstream of a river.

2.1.2 Establishment of a debris flow detection/monitoring system

The debris flow detection/monitoring system is designed to detect the occurrence of a debris flow with a detection sensor and report it automatically. The debris flow detection equipment consists of the following devices.

1) Wire sensor: The debris flow occurrence is detected by the cut of a wire due to debris flow forces. Another type is to detect it from the contact of an electricity-charged wire to the swell of a debris flow.
2) Vibration sensor: The debris flow occurrence is detected by capturing vibration caused by debris flow movements.
3) Monitoring camera: The occurrence, the flowing state, and the scale of a debris flow are detected through a monitoring TV installed in a monitoring station or a control center.

2.2 Collection and Arrangement of Rainfall Data

2.2.1 Determination of representative rainfall gauging stations

To determine some representative gauging stations for related data collection, existing rainfall gauging stations located in and around each sediment disaster hazard area discussed in Chapter I shall be taken out, and their features as shown below shall be grasped.

- An organization in charge of management or administration
- Location of a rainfall gauging station and its altitude
- Types of rain gauges installed (gauging system: daily rain gauge/hourly rain gauge; recording system: automatic rain gauge/ordinary rain gauge)
- Availability of past rainfall data (daily rainfall, hourly rainfall, gauging period, years of data accumulation)

Based on these results, a representative rainfall gauging station that collects rainfall data of each sediment disaster hazard area shall be determined. The representative rainfall gauging station should be located in an area having similar rainfall characteristics with those of a target area, can gauge the hourly rainfall, and should have a longest possible gauging history.

2.2.2 Collection and Arrangement of Rainfall Data

The rainfall data as shown below shall be collected at a representative rainfall gauging station and then recorded in the designated data forms.

1) Daily rainfall: Daily rainfall data during a longest possible period shall be collected. Then, a chronological table of daily rainfall shall be prepared.

2) Hourly rainfall:
   - Rainfall data at the time of disaster occurrence (causing rainfall): hourly rainfall during a series of rains (a continuous rain having a period of no rainfall for 24 hours or over before and after) including the time when a sediment disaster occurred.
   - Rainfall data other than above (non-causing rainfall): hourly rainfall during a series of rain which include a rain having a continuous rainfall of 40 mm or over or hourly rainfall intensity of 10 mm or over.
3) Past maximum rainfall: Daily rainfall and hourly rainfall intensity that are ranked as the upper ten including the past maximum.
4) Results of rainfall analysis: Probability daily rainfall and probability hourly rainfall

2.3 Policy for the Setting of Standard Rainfalls for Warning and Evacuation against Sediment Disasters

It is possible to forecast the occurrence of a debris flow or a slope failure from the rainfall data, but its accuracy level differs largely depending on the level of data obtained. Although it is known that real-time gauging of hourly or 10-munite rainfall is the most appropriate for a highly accurate forecast of disaster occurrence, the available gauging level in developing countries is usually the daily rainfall. Further, gauging itself is not sometimes conducted in remote regions away from large cities. These adverse situations, or the insufficiency of rainfall data, should be duly considered when determining the setting method of standard rainfalls for the development of a warning and evacuation system in those countries.

2.3.1 Case when hourly rainfall data are accumulated

(1) When causing and non-causing rainfall data are accumulated

To make a practical prediction of the occurrence of sediment disasters, gauging of hourly rainfall is a prerequisite. Hence, the present Guidelines demand that a rain gauge that can gauge an hourly rainfall should be installed in areas where the only available data at present is the daily rainfall and in areas where the rainfall itself is not being gauged. On the other hand, in areas having both the hourly rainfall data and the past sediment disaster records, prediction of the occurrence of sediment disasters is possible if those data are analyzed. There are many methods to set standard rainfalls for the development of a warning and evacuation system. In the current Guidelines, the following three standard methods, which are mostly applied and become the practical standard, are explained.

1) Method A (Guideline Method)
2) Method B (Guideline Method)
3) Committee Method

The Method A and Method B are the methods presented in the "Guidelines for the Setting of Rainfall for Warning Issuance and Evacuation Instruction against Debris Flow Disasters (Tentative)" (1984). Of the two methods, priority is placed on Method A. Method B is used only when Method A is not adaptable well. These methods (especially Method A) are easy to use because predictions are possible with the use of only one rainfall index. Because of this advantage, they have been widely used in Japan. But, they do have disadvantages. For example, standard rainfalls established by those methods can be easily exceeded at the time of a long rain or an intermittent rain, and they do not have a standard for the cancellation of a warning.

To remedy such disadvantages of Method A and Method B, Yano Method was proposed and then came the Committee Method. The Committee Method was proposed in the Guidelines entitled “Setting Method of Standard Rainfall for Warning and Evacuation against Collectively-Occurring Steep Slope Failures (Tentative)” (1993) which was prepared by the Committee for Studying Comprehensive Sediment Disaster Control Measures set up by the Ministry of Land, Infrastructure and Transport. Though the Committee Method has corrected the disadvantages of Method A and Method B, it is in a sense difficult to understand compared with those two methods because the standard for the occurrence of sediment disasters is expressed in a line form as “Y = aX + b”.

The standard rainfalls for warning and evacuation against sediment disasters that are presently established in prefectures in Japan are shown in Appendix-2. They are mostly established based on Method A and Committee Method. As of February 2004, about 50% of debris flow prediction systems employ the Committee Method, 38% Method A, and the remaining 12% either Method B or Yano Method. With regard to the prediction of steep slope failures, although the setting ratio of standard rainfall is still about 50% at present, 90% of them use the Committee Method, 9% Method A, and 1% other method.

As seen, the Committee Method is becoming the mainstream setting method in Japan, but Method A is still widely used owing to its ease of use. In the present Guidelines, three methods - Method A, Method B, and Committee Method - were explained. Before determining which to use, features of each method, adaptability to a given region, and usage of standard rainfall shall be carefully studied and then the best possible setting method of standard rainfall for warning and evacuation against sediment disasters shall be chosen.

(2) When sediment disasters have not occurred (or data of causing rainfall are not accumulated)

In some regions, rainfall data related to the occurrence of sediment disasters may not be accumulated because of non-occurrence of such disasters, even though the hourly rainfall has been gauged. In this case, it is still possible to establish the standard rainfall for warning and evacuation if those non-causing rainfalls are analyzed. Also, the standard rainfall can be tentatively set up by referring to the analysis results of rainfalls in Japan or in other regions. What is important above all is to start operating a sediment disaster prediction system as early as possible. The data can be accumulated after that, and when enough data are accumulated, they can be reanalyzed using one of the setting methods shown above. Through such process, the existing system can be improved to an advanced sediment disaster prediction system with high accuracy.

2.3.2 Non-case when hourly rainfall data are accumulated

On the other hand, in an area where the only rainfall being gauged is the daily rainfall, an hourly rainfall gauge should be installed in or around the sediment disaster hazard area. If the installation of an hourly rainfall gauge takes a long time, standard rainfalls may be determined using the daily rainfall data as the tentative measures before the hourly rainfall data become sufficient. In an area where rainfall data are not available at all, the visual observation system should be strengthened as the measures against sediment disasters. As mentioned earlier, in sediment disaster hazard areas where the hourly rainfall data are not currently available, it is important to start its gauging as soon as possible and set the standard rainfalls for warning and evacuation using either the Guideline Method or Committee Method so that an efficient warning and evacuation system can be established without delay.

Fig. 2.1 shows the level-up steps of the sediment disaster forecast method with consideration for the differences in rainfall gauging levels.

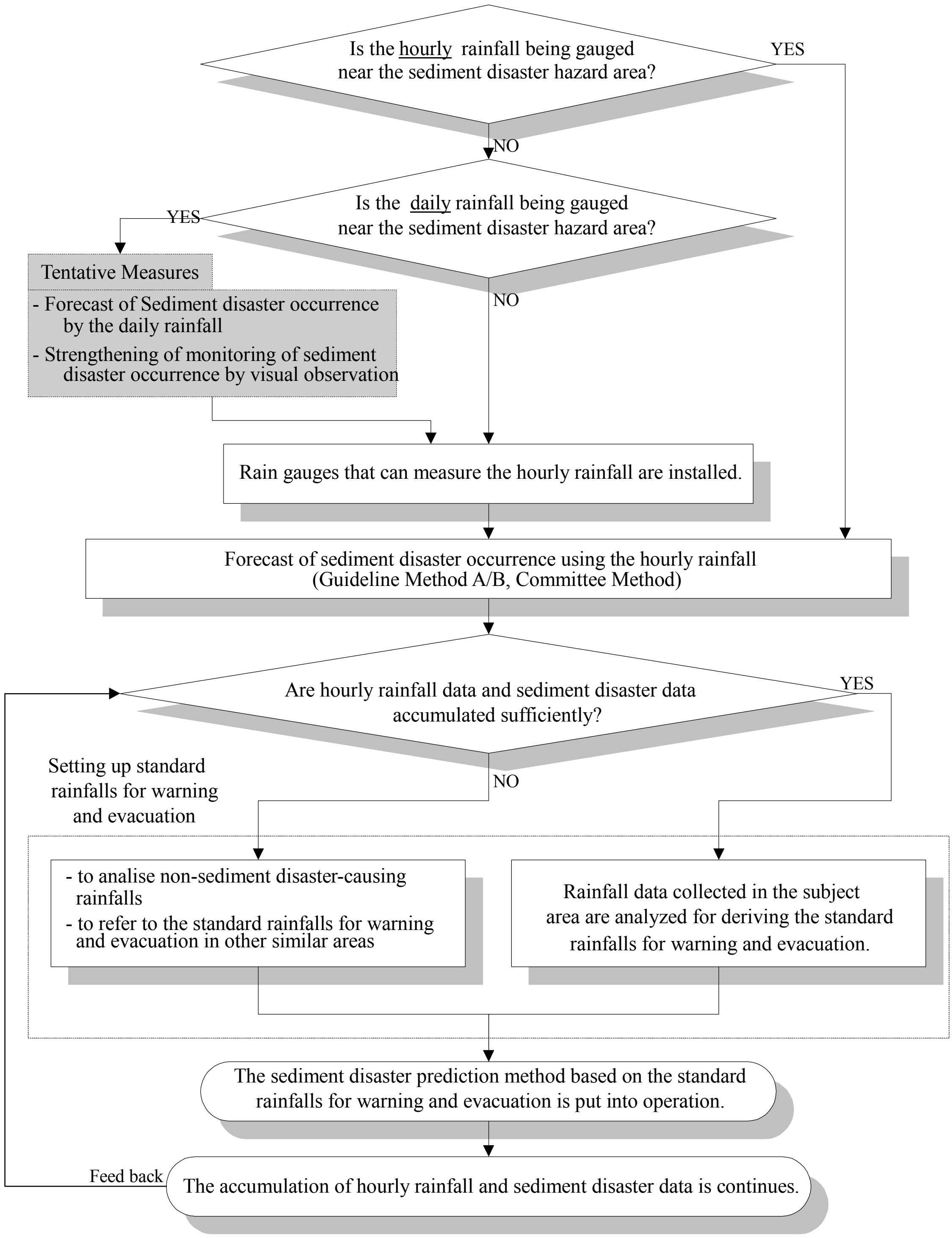


Fig. 2.1 Level-up steps of the sediment disaster forecast method in consideration of differences in rainfall gauging levels

2.4 Setting of Standard Rainfalls for Warning and Evacuation by the Guideline Method

The Guideline Method (Method A and Method B) was presented in the "Guidelines (tentative) for Setting of Rainfalls for Warning Issuance and Evacuation Instruction against Debris flow Disasters" which was prepared by the former Ministry of Construction in 1984. This method is intended to forecast the occurrence of a debris flow using rainfall indexes that are obtained by combining rainfall intensity and a total rainfall. This type of index was derived because it is known from the actual state of debris flow disasters that a debris flow tends to occur even when the total rainfall is small if the rainfall intensity is large, and that it tends to occur even when the rainfall intensity is small if the total rainfall is large. This method was originally developed for debris flows, but it is also applicable to slope failures because the occurrence process of a debris flow is similar to that of a slope failure.

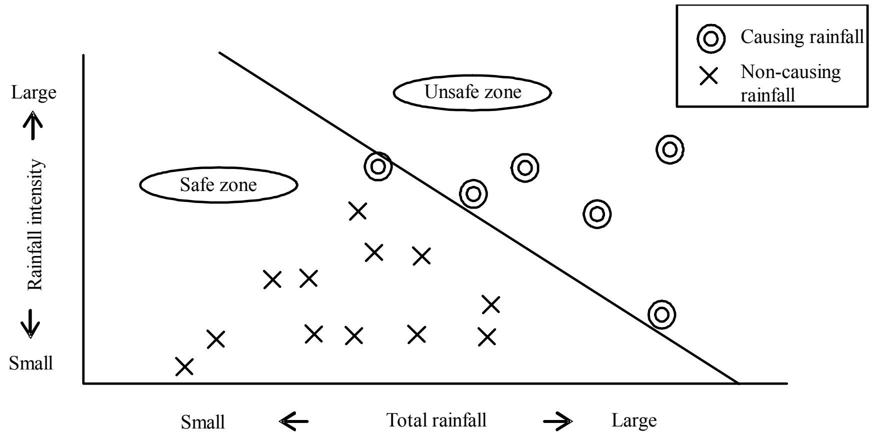
2.4.1 Outline of the Guideline Method

The application area of the Guideline Method and the rainfall indexes used are summarized as shown in Table 2.2.

The setting procedure of standard rainfalls for warning and evacuation by the Guideline Method is as follows.

1) The representative rainfall gauging station for collecting the rainfall data of the target area shall be determined.
2) The rainfall data at the time when a sediment disaster, a debris flow or a slope failure, was caused (called the causing rainfall) and the rainfall data at the time when those disasters were not caused (called the non-causing rainfall) shall be collected and recorded in Form 1 and Form 2. See Table 2.3 and Table 2.4.
3) Even when setting the standard rainfalls for debris flows, slope failure-related data should also be collected because they are an effective set of data that indicates a behavior preceding a debris flow.
4) In the Guideline Method, two kinds of setting methods (Method A and Method B) are shown which are different in the use of rainfall indexes that are derived using the data in Form 1 and Form 2. In the Guideline Method, it is mentioned that if an appropriate value is not obtainable with the use of Method A, Method B may be used as the alternative. This means that use of Method A, which is easy to use, is recommended more than the use of Method B.
    - Method A: Hourly rainfall (ordinate) - Working rainfall (abscissa)
    - Method B: Effective rainfall intensity (ordinate) - Working rainfall (abscissa)

Table 2.2 Application area and rainfall index of the Guideline Method [10)]

<table>
<tr><td>Application area</td><td>It is specified in the Guidelines that, although stream-specific setting is more desirable, the same standard rainfalls can be used for more than one debris flow-prone mountain streams located in closer areas that have a similar topography, geology, and vegetation, if the rainfall data and the past disaster records are not sufficient for stream-specific setting. In the past setting cases, areas are usually grouped by the mechanical factors and characteristics and then standard rainfalls are set for each group which is usually a city or a town.</td></tr>
<tr><td>Rainfall index</td><td>The rainfall index is expressed by a combination of the rainfall intensity and the total rainfall. As shown in the figure below, the rainfall intensity is shown in the ordinate and the total rainfall in the abscissa. Debris flow-causing rainfall and non-causing rainfall are plotted in the figure by the ◎ and × symbols, respectively. Then, those two rainfall groups are separated with a liner line or a curved line descending to the right. The lower left side of this line is the safe zone where a debris flow may not be caused. The upper right side of this line is the unsafe zone where a debris flow may be caused.

</td></tr>
</table>

2.4.2 Analysis of debris flow causing rainfall and non-causing rainfall

(1) Collection and recording of data on debris flow-causing rainfall

Using past records and through an inquiry to the local people, the occurrence time of past debris flows and slope failures shall be identified. These data and the rainfall data obtained at a representative rainfall gauging station shall be recorded in Form-1 shown in Table 2.3. Because the total rainfall differs by the time of disaster occurrence, it is very important to obtain the highly accurate information about the exact occurrence time. In the case of old disasters, it is usually difficult to distinguish if it was a slope failure or a debris flow, in addition to the difficulty of getting the exact time of occurrence. Therefore, data should be collected from many organizations. For the collection of accurate data, it is desirable that a debris flow-prone mountain stream and a rainfall gauging station are located as closely as possible. If this is not satisfied, it is better to plan the installation of a new rain gauge to improve the future data.

(2) Collection and recording of data on non-causing rainfall

From various data on a series of rain collected at a representative rainfall gauging station, the non-causing rainfall data shall be taken out. They are used to find a critical line that separates the occurrence and non-occurrence of sediment disasters. If a series of rain with a small mount of rainfall that has little effect on the incidence of a sediment disaster is included in data analysis, analysis becomes complex. Therefore, data collection should be limited in principle to the rainfalls specified below. However, this can be changed in view of circumstances, such as the amount of causing rainfall and convenience of analysis. The obtained data shall be filled in Form 2 shown in Table 2.4.

- Debris flow: a continuous rainfall of 80 mm or over or hourly rainfall intensity of 20 mm or over
- Slope failure: a continuous rainfall of 40 mm or over or hourly rainfall intensity of 10 mm or over

(3) Definitions of various rainfall indexes

When preparing Form 1 (Table 2.3) and Form 2 (Table 2.4), various rainfall indexes shall be operated. Here, the definitions of those indexes that appear in those forms are explained.

(i) A series of rain, continuous rainfall (R_C), antecedent rain, antecedent rainfall (R_A)

One sequence of rain with more than 24 hours of non-rainfall duration before and after that rain is called "a series of rain". And, the total amount of rainfall during that period is called the "continuous rainfall (R_C)" This relationship is shown in Fig. 2.2. The rain during one-or two-week period before the start of a series of rain (this relates to the half-life of the working rainfall which is mentioned later) is called the antecedent rain and the rainfall during that period is called the antecedent rainfall (R_A). Regarding the antecedent rain, the rain during 24 hours before the start of a series of rain is called the "rain of one day before," the rain between 48 hours before and 24 hours before the start of a series of rain is called the "rain of two days before". Using the same rule, the rain of n-days before can be specified. However, from the definition of a series of rain, the rainfall on one day before a series of rain is always zero.

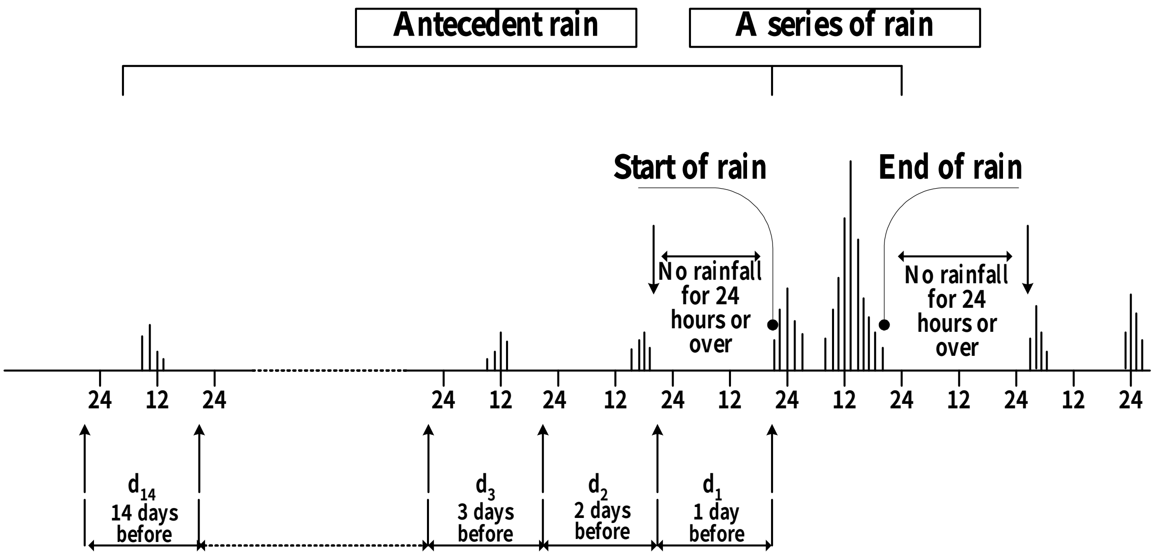


Fig. 2.2 Concept of a series of rain and the antecedent rain [10)]

Table 2.3 Form for recording the causing rainfall data (Form 1) [10)]

Municipality (Prefecture) (Representative rainfall gauging station)

(a) Reference No.	(b) Mountain stream	(c) Address	(d) No. of debris flow hazard stream	(e) Occurrence date/time	(f) Continuous rainfall (R_C) (date/time-date/time)	(g) Antecedent rainfall (RA)						(h) Antecedent working rainfall (R_{WA})	(i) Cumulative rainfall up to 1 hour before the occurrence of debris flow	(j) Working rainfall up to 1 hour before the occurrence of debris flow ((h) + (i))	(k) One-hour rainfall immediately before the occurrence of debris flow	(l) Working rainfall (R_W) up to the occurrence of debris flow ((j) + (k))	(m) Initial rainfall (R_I) (date/time)	(n) Effective rainfall (R_E) up to the occurrence of debris flow ((i) + (j) − (m))	(o) Effective time	(p) Effective rainfall intensity (I_E) ((n) + (o))	(q) Total working rainfall ((f) + (h))	(r) Distance between mountain stream and rainfall gauging station	(s) Remarks
						2 days before	3 days before	4 days before	---	14 days before	Half-life												
a		b			c					d				e			f			g		h	

Procedure for recording the causing rainfall data (Form 1).

(a) Put a reference number in chronological order.
(b) Fill in the name of a stream.
(c) Fill in the address of a stream.
(d) Fill in the stream No.
(e) Fill in the date and time when a debris flow occurred. If the occurrence time is an inferred time, show it with ( ).
(f) Fill in the continuous rainfall (R_C) and the time when the rain started and ended.
(g) Fill in the 24-hour rainfall of each day from 2 days before to 14 days before.
(h) Fill in the antecedent working rainfall (R_{WA}) for each specified half-life.
(i) Fill in the cumulative rainfall from the start of a series of rain up to 1 hour before the occurrence of debris flow.
(j) Fill in the working rainfall up to 1 hour before the occurrence of debris flow.
(k) Fill in the one-hour rainfall immediately before the occurrence of debris flow.
(l) Fill in the working rainfall up to the occurrence of debris flow.
(m) Fill in the initial rainfall (R_I) and the time of Inflection Point A.
(n) Fill in the effective rainfall (R_E) up to the occurrence of debris flow.
(o) Fill in the effective time up to the occurrence of debris flow.
(p) Fill in the effective rainfall intensity (I_E) up to the occurrence of debris flow.
(q) Fill in the total working rainfall of causing rain.
(r) Fill in the distance from stream to representative gauging station.

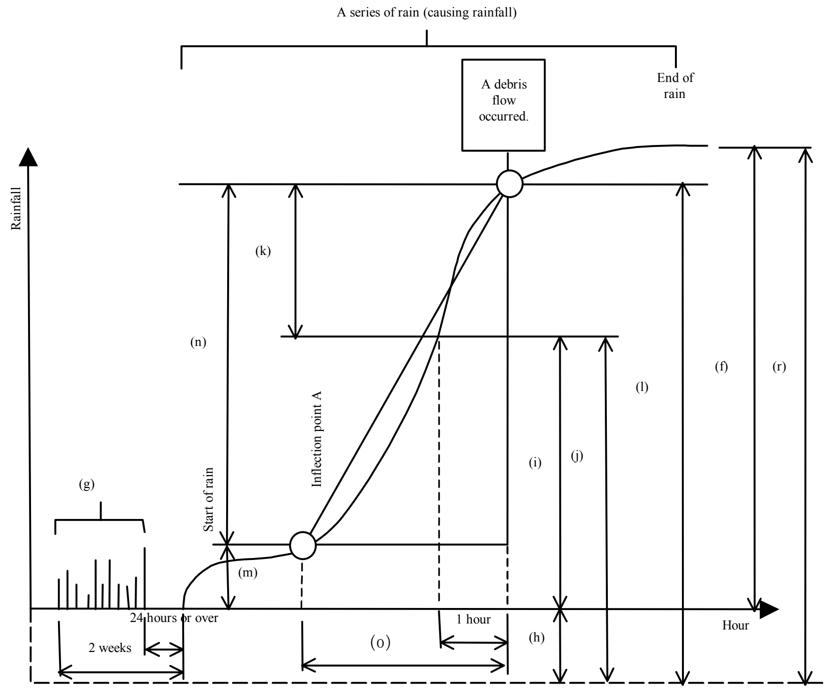


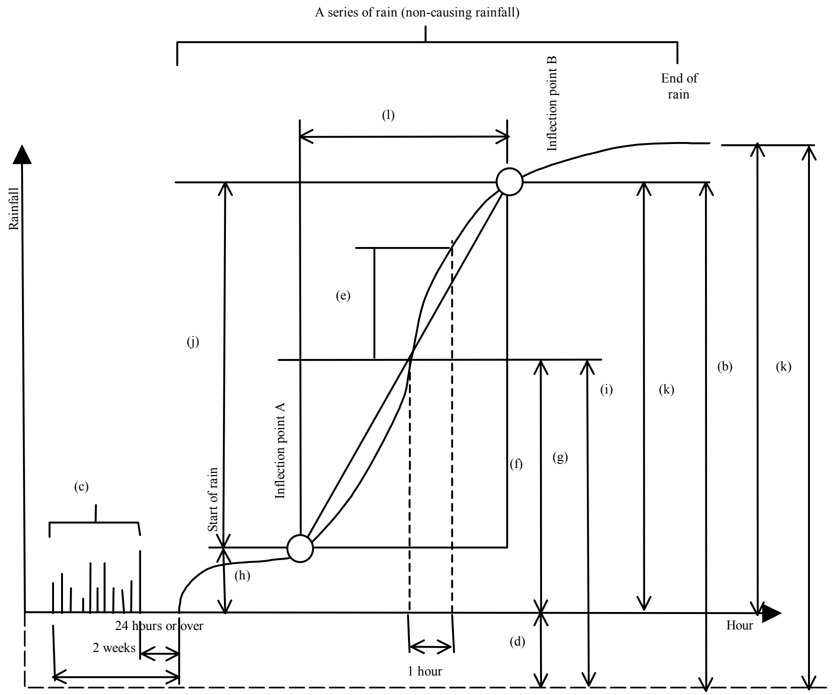
Table 2.4 Form for recording the non-causing rainfall data (Form 2) [10)]

Municipality (Prefecture) (Representative rainfall gauging station)

(a) Reference No.	(b) Continuous rainfall (R_C) (date/time-date/time)	(c) Antecedent rainfall (RA)						(h) Antecedent working rainfall (R_{WA})	(e) Maximum hourly rainfall of non-causing rain (date/time-date/time)	(f) Cumulative rainfall up to before the start of a maximum hourly rainfall	(g) Working rainfall up to before the start of a maximum hourly rainfall ((d) + (f))	(h) Initial rainfall (R_I) (date/time)	(i) Cumulative rainfall up to Inflection Point B (date/time)	(j) Effective rainfall (R_E) up to Inflection Point B ((i) – (h))	(k) Working rainfall up to Inflection Point B ((d) + (i))	(l) Effective time	(m) Effective rainfall intensity ((j) + (l))	(n) Total working rainfall ((b) + (d))	Remarks
		2 days before	3 days before	4 days before	---	14 days before	Half-life												
a	b												d			c		f	

Procedure for recording the non-causing rainfall data (Form 2).

(a) Put a reference number in chronological order of rainfall data.
(b) Fill in the continuous rainfall (R_C) and the time when a rain started and ended.
(c) Fill in as done in (g) in Form 1.
(d) Fill in as done in (h) in Form 1.
(e) Fill in the maximum hourly rainfall in a series of rain and its starting time.
(f) Fill in the cumulative rainfall from the start of a series of rain up to before the start of a maximum hourly rainfall.
(g) Fill in the working rainfall up to before the start of a maximum hourly rainfall.
(h) Fill in the initial rainfall (R_I) and the time of Inflection Point A.
(i) Fill in the cumulative rainfall from the start of a series of rain up to Inflection Point B and the time of Inflection Point B.
(j) Fill in the effective rainfall up to Inflection Point B.
(k) Fill in the working rainfall up to Inflection Point B.
(l) Fill in the effective time up to Inflection Point B.
(m) Fill in the effective rainfall intensity (I_E) up to Inflection Point B.
(n) Fill in the total working rainfall of non-causing rain.



(ii) Working rainfall (R_W), antecedent working rainfall (R_{WA}), deduction coefficient

The working rainfall is a cumulative rainfall that takes into account the effect of an antecedent rainfall. In general, debris flows occur under the influence of not only debris flow-causing rainfall but also antecedent rainfall. The degree of influence of an antecedent rainfall normally reduces as time becomes distant from a debris flow-causing rain. To derive the effect of an antecedent rainfall, the 24-hour rainfall of one day before the debris flow-causing rain is multiplied by the coefficient of "α_1 time" and a 24-hour rainfall of two days before the debris flow-causing rain is multiplied by the coefficient of "α_2 time". In this way, the 24-hour rainfall up to "t" days before, or "dt", is multiplied by the coefficient of "αt ($\alpha t < 1$)". And, the total of them is called the antecedent working rainfall (R_{WA}).

$$R_{WA} = \alpha_1 \cdot d_1 + \alpha_2 \cdot d_2 + \cdots + \alpha_{14} \cdot d_{14} = \sum_{t=1}^{14} \alpha_t \cdot d_t$$

Where, the coefficient "α_t" is called the deduction coefficient of "t" days before. There are many ways to determine "α_t". When the half-life is assumed to be one day, which means the value of α becomes 1/2 of "α_{t-1}" when one day has passed, the antecedent working rainfall (R_{WA}) is calculated as follows.

$$R_{WA} = 0.5 \cdot d_1 + 0.25 \cdot d_2 + 0.125 \cdot d_3 \cdots$$

When judging if a debris flow will occur or not, the appropriateness of judgment shall be evaluated by changing the half-life to 2 days and 3 days. The relationship between the deduction coefficient and the half-life is given by the following equation.

$$\alpha_t = 0.5^{t/T}$$

Where, T : day(s) of half-life; t : day(s) before the start of rainfall

The results of operation regarding the deduction coefficient when the half-life is 1, 2, and 3 days are shown in Table 2.5. As to the period when the deduction coefficient is less than 0.004, operation can be omitted because an effect on operation values is usually very small. But, when the antecedent rainfall is large and the values derived by multiplying a deduction coefficient are not negligible, the omission rule can be ignored.

Table 2.5 Half-life and deduction coefficient (α_t) [10)]

Days before the start of rainfall	Half-life			Days before the start of rainfall	Half-life		
	1 day	2 days	3 days		1 day	2 days	3 days
1	**0.50000**	0.70711	0.79370	13	0.00012	0.01105	0.04961
2	0.25000	**0.50000**	0.62996	14	0.00006	0.00781	0.03937
3	0.12500	0.35355	**0.50000**	15	0.00003	0.00552	0.03125
4	0.03250	0.25000	0.39685	16	0.00002	0.00391	0.02480
5	0.03125	0.17678	0.31498	17	0.00001	0.00276	0.01969
6	0.01563	0.12500	0.25000	18	0.00000	0.00195	0.01563
7	0.00781	0.08839	0.19843	19	0.00000	0.00138	0.01240
8	0.00391	0.06250	0.15749	20	0.00000	0.00098	0.00984
9	0.00195	0.04419	0.12500	21	0.00000	0.00069	0.00781
10	0.00098	0.03125	0.09921	22	0.00000	0.00049	0.00620
11	0.00049	0.02210	0.07875	23	0.00000	0.00035	0.00492
12	0.00024	0.01563	0.06250	24	0.00000	0.00024	0.00391

Note 1: The shaded area in the table shows the period when an influence on the working rainfall would not be serious.
Note 2: For example, if the 24-hour rainfall is 200 mm when the deduction coefficient is 0.004, the value added to the working rainfall becomes 0.004 × 200 mm = 0.8 mm.

(iii) Inflection point A, Inflection Point B

Inflection Point A is a point when the value in the cumulative rainfall curve of a series of rain begins to increase sharply. It is usually a point when an hourly rainfall of 4 mm or over begins to rain for the first time. Inflection Point B is a point when the value in the cumulative rainfall curve of a series of rain begins to stop a sharp increase. It is usually a point when an hourly rainfall of less than 4 mm begins to rain for 3 hours or more (See Fig. 2.3).

(iv) Initial rainfall (RI)

The initial rainfall is a cumulative rainfall from the start of a series of rain up to Inflection Point A.

(v) Effective rainfall (RE) , effective time, and effective rainfall intensity (IE)

The effective rainfall is a rainfall derived by deducting a cumulative rainfall up to Inflection Point A from the cumulative rainfall of a series of rain up to a given point. Namely, it is a cumulative rainfall after Inflection Point A. The effective time is the raining hours from Inflection Point A up to an effective rainfall. The effective rainfall intensity is a value derived by dividing the effective rainfall by the effective time (See Fig. 2.4).

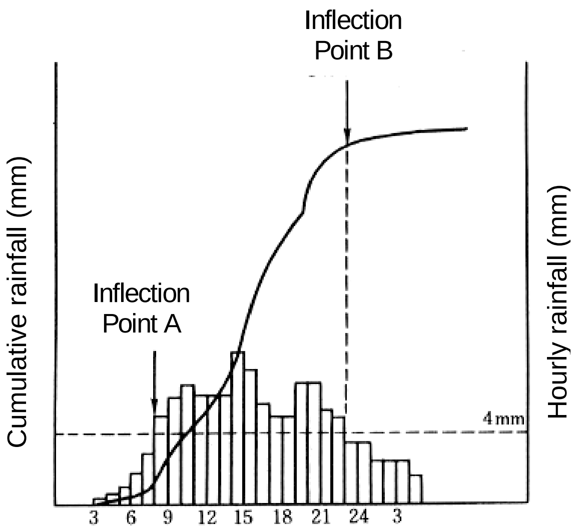


Fig. 2.3 Definitions of Inflection Point A and Inflection Point B

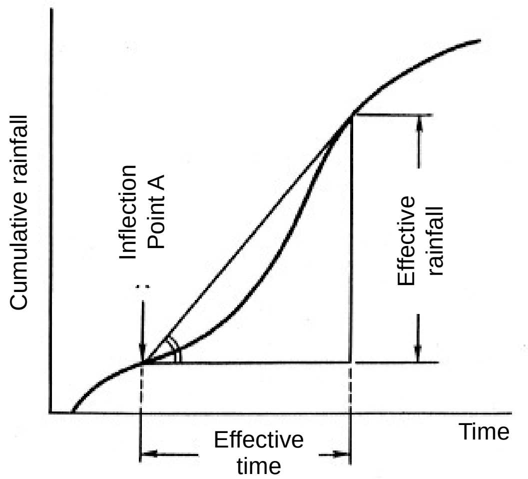


Fig. 2.4 Effective rainfall, effective time, and effective rainfall intensity [10)]

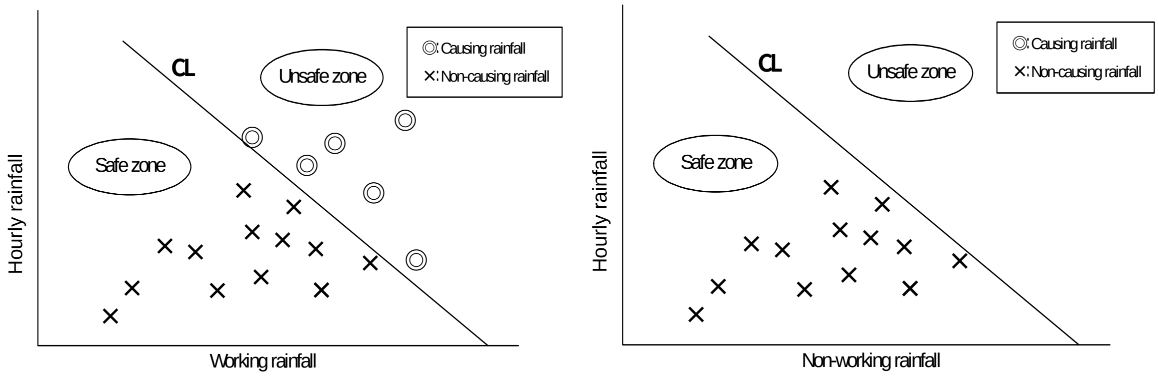
2.4.3 Setting of standard rainfalls by Method A (Guideline Method) [10)]

(1) Setting of the critical line (CL)

An X-Y graph is prepared by placing (j) and (k) in Form 1 (Table 2.3) and (g) and (e) in Form 2 (Table 2.4) in the abscissa and the ordinate as shown in Fig. 2.5. The rainfall indexes depicted in the X-Y graph are defined as shown in Table 2.6. Attention should be paid to the fact that one-hour time lag is intentionally introduced between the two axes. It is a kind of idea to express a standard rainfall for warning and a standard rainfall for evacuation (these are explained later) using only one rainfall index. In that respect, this X-Y graph is essentially different from an ordinary X-Y graph used in mathematics.

Table 2.6 Definitions of rainfall indexes depicted in a graph [10)]

	The X axis (abscissa)	The Y axis (ordinate)
Causing rainfall	(j): The working rainfall up to 1 hour before the occurrence of debris flow	(k): One-hour rainfall immediately before the occurrence of debris flow
Non-causing rainfall	(g): The working rainfall up to before the start of a maximum hourly rainfall	(e): The maximum hourly rainfall in a series of rain



(a) If causing rainfalls are available **(b) If causing rainfalls are not available**

Fig. 2.5 The X-Y graph by Method A [10)]

In Fig. 2.5, a boundary line is drawn between the debris flow causing rainfalls and the non-causing rainfalls. The upper right side of the boundary line is the unsafe zone where a debris flow may occur and the lower left side of the line is the safe zone where a debris flow may not occur. This boundary line is called the Critical Line (CL) which distinguishes the occurrence and non-occurrence of a debris flow. When the inclination of the CL is shown by "a", the inclination "a" should be gentler than "-1" and within the range of "-1 < a <0", as shown in Fig. 2.6.

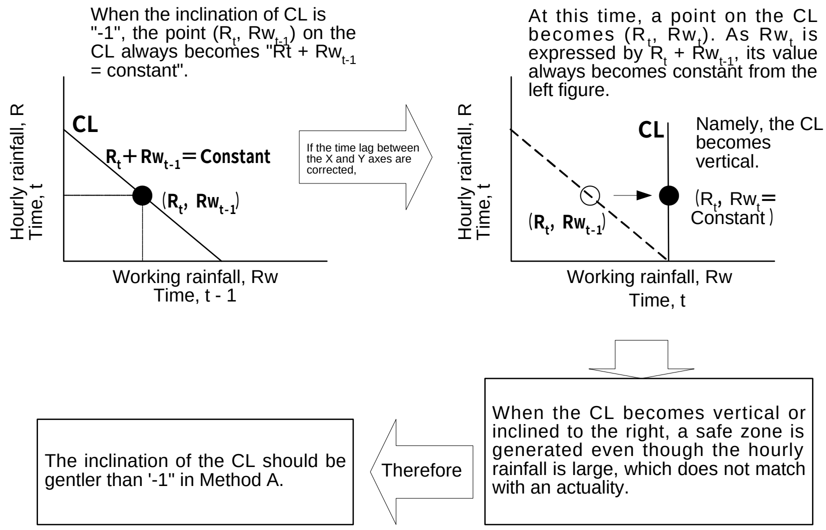


Fig. 2.6 The limit of the critical line (CL) by Method A [10)]

(2) Setting of the warning line (WL) and the evacuation line (EL)

Methods for setting the standard rainfall for issuing a warning (hereafter refereed to as the standard rainfall for warning) and the standard rainfall for instructing an evacuation (hereafter referred to as the standard rainfall for evacuation) are explained below. In the following sections, the standard line indicating the standard rainfall for warning is called the "Warning Line (WL)" and the standard line indicating the standard rainfall for evacuation is called the "Evacuation Line (EL)".

Before setting the WL and EL, it is needed to determine the timing to give a warning issuance or an evacuation instruction. It means that how many hours before the forecasted occurrence time a warning issuance or an evacuation instruction should be given so that people as well as organizations can take necessary actions for safety. After that, the WL and EL are set in consideration of an estimated rainfall during the spare hours (forecasted rainfall) and the Critical Line (CL). In the Guideline Method, a setting method using conditions in Table 2.7 is shown. But, the timing of warning issuance and evacuation instruction can be determined based on the conditions of each area. As to the estimated rainfall during the spare hours, the probable rainfall or the short-term rainfall may be used depending on conditions, such as the non-hit rate of a warning. The setting method of the WL and EL based on conditions shown in Table 2.7 is given below.

Table 2.7 The timing of a warning issuance and an evacuation instruction, and the forecasted rainfall during spare hours employed in the Guideline Method [10)]

Type	Timing of issuance/ instruction	Forecasted rainfall during the spare hours
Issuance of a warning	2 hours before reaching the CL	Past maximum 2-hour rainfall (R_{H2M})
Instruction of an evacuation	1 hour before reaching the CL	Past maximum 1-hour rainfall (R_{H1M})

<Setting of the evacuation line (EL)>

The past maximum 1-hour rainfall is shown by R_{H1M}. An interpretation of Fig.2.7 is that if the working rainfall of a given rain has reached R_2 and if the forecasted rainfall for 1 hour from now is more than R_{H1M}, then it will enter the area in the upper right side of the CL, or the unsafe zone. When R_2 is derived by assuming that the forecast rainfall for 1 hour from now, or R_{H1M}, will be the past maximum 1 hour rainfall, it will be the standard rainfall for evacuation instruction. In an actual setting of the EL, the forecasted rainfall for 1 hour from now, or R_{H1M}, is placed in the ordinate and a straight line passing that point is drawn in parallel to the abscissa. And then, a perpendicular line is drawn from the intersection point of the straight line and the CL toward the abscissa. That line is the EL.

<Setting of the warning line (WL)>

The past maximum 2-hour rainfall is shown by R_{H2M}. If one hour before reaching the EL is assumed as the WL, a straight line that is obtained by parallel displacement of the EL toward the left side by "R_{H2M} - R_{H1M}" becomes the WL (Fig. 2.7).

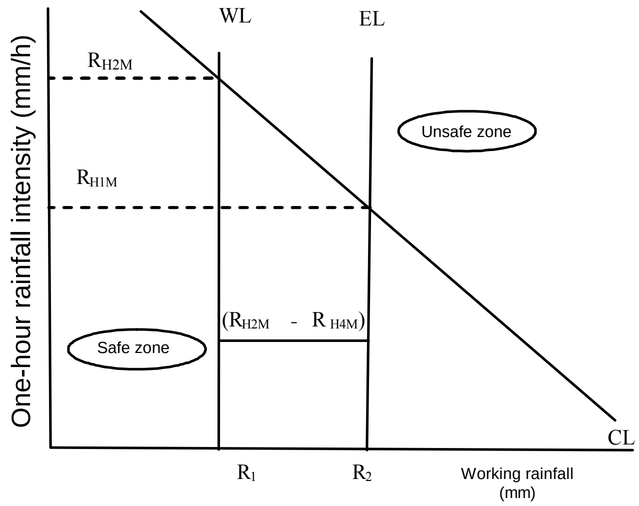


Fig. 2.7 Setting of the warning line (WL) and the evacuation line (EL) (Method A) [10)]

(3) Investigation of the adequacy of the CL, EL, and WL

An adequacy of the established CL, EL, and WL is investigated in terms of separability, frequency of issuance, and the non-hit rate.

<Separability>

If all debris flow causing rainfalls come in the unsafe zone in the upper right side and all non-causing rainfalls come in the safe zone in the lower left side taking the CL as the boundary line, it can be said that both rainfalls show a good separability. Actually, however, some of non-causing rainfalls come in the unsafe zone as seen in Fig. 2.8. Hence, the separability of the CL is investigated using the number of non-causing rainfalls. The total number of non-causing rainfalls is assumed as "Kn" and the number of non-causing rainfalls that come in the safe zone in assumed as "Knc". Then, calculation is made using an equation, $S_c = K_{nc} / K_n$. It is judged that the greater the value of S_c, the better the separability is.

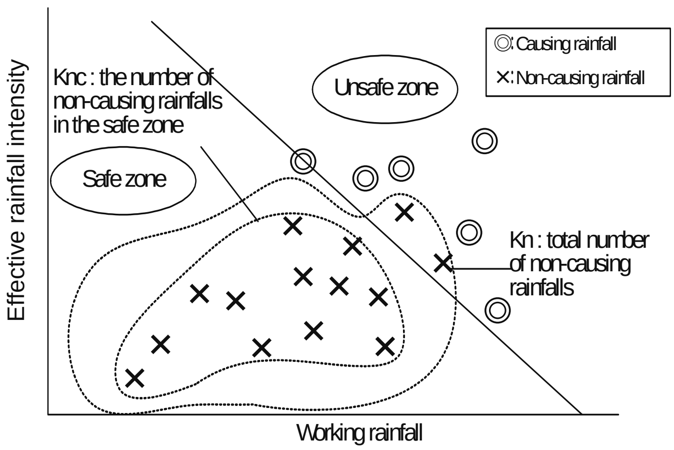


Fig. 2.8 Investigation of separability [10)]

<Frequency of warning issuance and evacuation instruction>

With regard to the established WL and EL, the frequency of warning issuance and evacuation instruction per year is investigated. The number of data in which the total working rainfall of a causing rainfall (Form 1, (q)) exceeds "R_1" and "R_2" in Fig. 2.7 is assumed as "K_{yw}" and "K_{ye}", respectively. And, the number of data in which the total working rainfall of a non-causing rainfall (Form 2, (n)) exceeds "R_1" and "R_2" is assumed as "K_{nw}" and "K_{ne}", respectively. Then, the frequency of warning issuance and the frequency of evacuation instruction are derived using the following equations, respectively.

Frequency of warning issuance: $F_w = \frac{k_{yw} + k_{nw}}{n}$ (time/year)

Frequency of evacuation instruction: $F_w = \frac{k_{ye} + k_{ne}}{n}$ (time/year)

Where, "n" is the number of years in which the data are collected.

<Non-hit rate of warning issuance and evacuation instruction>

Even though a warning is issued and an evacuation is instructed, a sediment disaster does not necessarily occur. This kind of non-hit rate is calculated using the following equations. The non-hit rate here is not intended for assessing the accuracy of the CL, but for assessing the adequacy of a forecasted rainfall used for the setting of the EL and WL.

Non-hit rate of warning issuance: $M_w = \frac{k_{nw}}{n}$ (time/year)

Non-hit rate of evacuation instruction: $M_e = \frac{k_{ne}}{n}$ (time/year)

(4) Setting of the standard rainfalls for warning and evacuation

After comparing various procedures and confirming the adequacy of the CL, EL, and WL, the standard rainfall for warning and the standard rainfall for evacuation are established as follows.

Standard rainfall for warning: R_1 (mm)

Standard rainfall for evacuation: R_2 (mm)

2.4.4 Setting of standard rainfall by Method B (Guideline Method)

(1) Setting of the critical line (CL)

To set the CL, the relationship between the effective rainfall intensity (ordinate) and the working rainfall (abscissa) is plotted in the X-Y graph using the data of debris flow-causing rainfalls and non-causing rainfalls that were filled in Form 1 and Form 2. Namely, plotted in the figure are "(l) working rainfall up to the occurrence of debris flow" and "(p) the effective rainfall intensity up to the occurrence of debris flow" which were filled in Form 1 for causing rainfalls, and "(k) working rainfall up to Inflection Point B" and "(m) effective rainfall intensity up to Inflection Point B" which were filled in Form 2 for non-causing rainfalls.

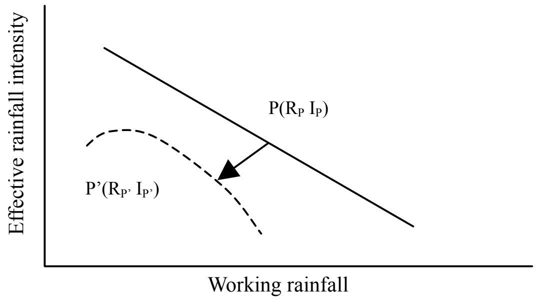
A restriction on the inclination of the CL, namely, CL> -1, which is imposed in Method A does not apply to Method B, because a time lag of one hour between the abscissa and the ordinate is not assumed in Method B.

(2) Setting of the warning line (WL) and the evacuation line (EL)

An approach to the forecasted rainfall and the timing of warning issuance and evacuation instruction of Method B is the same as that of Method A. The setting procedure of the WL and the EL by Method B using the same conditions in Table 2.7 is shown below.

<Setting of the evacuation line (EL)>

A given point on the critical line (CL) in Fig. 2.9 is assumed as Point P (R_P, I_P) and a position one hour before reaching Point P is assumed as Point P' ($R_{P'}$, $I_{P'}$). When the forecast rainfall for the evacuation instruction is the past maximum one-hour rainfall (R_{H1M}), then Point P' is a point on the evacuation line (EL). As the equation of the CL is already obtained, the unknown point P' can be obtained from the known point P. Figure 2.10 shows the relationship between the time and the accumulative rainfall of a series of rain which passed Point P' and then reached Point P.



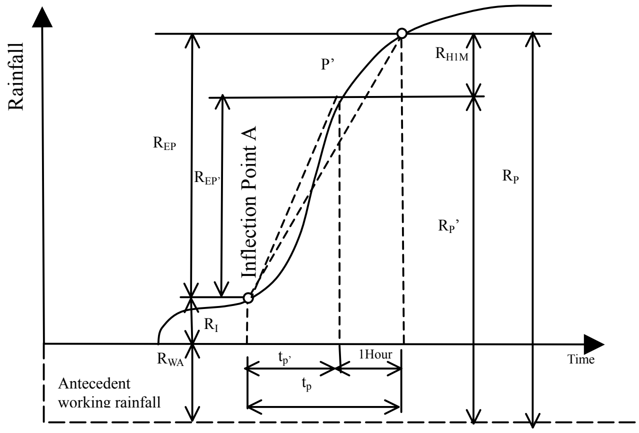


Fig. 2.9 Setting of the evacuation line (EL)[10)]

Fig. 2.10 Relationship between the time and the accumulative rainfall [10)]

From Fig. 2.10, $R_{P'}$ is expressed,

$$R_P' = R_P - R_{H1M} \quad \cdots\cdots (1)$$

The rainfall intensity, $I_{P'}$, can be can be obtained by the following equation.

$$I_P' = \frac{R_{EP'}}{t_{P'}} = \frac{R_{EP} - R_{H1M}}{t_P - 1} \quad \cdots\cdots (2)$$

Also, T_p becomes,

$$t_P = \frac{R_{EP}}{I_P} = \frac{R_P - (R_{WA} + R_I)}{I_P} \quad \cdots\cdots (3)$$

If Equation (3) is substituted for Equation (2),

$$I_P' = \frac{R_P - (R_{WA} + R_I) - R_{H1M}}{\dfrac{R_P - (R_{WA} + R_I)}{I_P} - 1} \quad \cdots\cdots (4)$$

Usually, values of R_{WA} and R_I are unknown and their values are considerably smaller than the value of R_P. Then, if $R_{WA} + R_I = 0$ is assumed, Equation (4) is expressed as follows by approximation.

$$I_P' = \frac{R_P - R_{H1M}}{\frac{R_P}{I_P} - 1} = \frac{(R_P - R_{H1M}) I_P}{R_P - I_P} \quad \cdots\cdots (5)$$

Namely, relative to Point P (R_P, I_P) on the CL, Point P' ($R_{P'}$, $I_{P'}$) which is the point one hour before can be obtained using Equation (1) and Equation (5).

Next, a general equation of the evacuation line (EL) is shown. When the equation of the critical line (CL) is expressed as Y = aX + b, Point P (R_P, I_P) is a point on this straight line and it has a following relationship.

$$I_P = a \cdot R_P + b \quad \cdots\cdots (6)$$

If R_P and I_P are eliminated from Equations (1),(5), and (6), it becomes,

$$I_P' = \frac{a(R_{P'})^2 + (b + aR_{H1M})R_{P'}}{(1-a)R_{P'} + (1-a)R_{H1M} - b} \quad \cdots\cdots (7)$$

Namely, relative to the equation of the critical line (CL) which is Y = aX + b, a general equation of the evacuation line (EL) is expressed as shown below when the Y: effective rainfall intensity and X: working rainfall.

$$Y = \frac{aX^2 + (b + aR_{H1M})X}{(1-a)X + (1-a)R_{H1M} - b} \quad \cdots\cdots (11)$$

<Setting of the warning line (WL)>

As with the setting of the evacuation line, a given point on the CL in Fig. 2.9 is assumed as P (R_P, I_P) and the forecasted rainfall is assumed as the past maximum 2-hour rainfall (R_{H2M}). If the position two hours before reaching the point P is P" (R_P", I_P"), then I_P" is expressed as follows.

$$I_{p''} = \frac{a(R_{p''})^2 + (b + aR_{H2M})R_{p''}}{(1-2a)R_{p''} + (1-2a)R_{H2M} - 2b}$$

A general equation showing the WL becomes as follows (See Fig. 2.11).

$$Y = \frac{aX^2 + (b + aR_{H1M})X}{(1-a)X + (1-a)R_{H1M} - b}$$

<Curves of the evacuation line (EL) and the warning line (WL)>

The EL and WL are the curved lines that pass the origin of the coordinate axes (0, 0) and are convex shaped toward the upside. R_u is a working rainfall value below which is usually uninfluential to the occurrence of a debris flow. That value is approximately 40 mm. But, if an appropriate value other than this is found from the collected data, that value should be used.

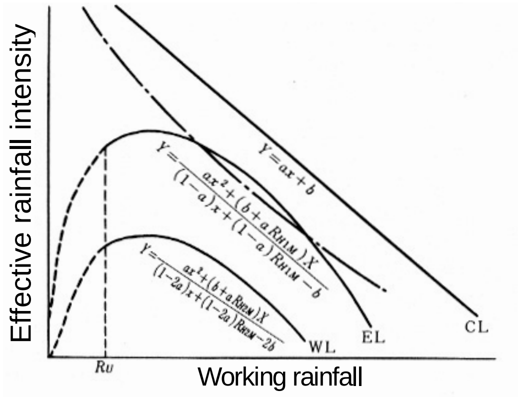


Fig. 2.11 General equations expressing the EL and the WL [10)]

(3) Investigation of the adequacy of the CL, EL, and WL

An approach to this investigation is basically the same with that taken in Method A. Focusing on the differences from Method A, adequacy of the three lines is investigated as shown below.

<Separability>

Using the same method with that in Method A, the separability of the critical line (CL) is investigated.

<Frequency of warning issuance and evacuation instruction>

With regard to the established WL and EL, the frequency of warning issuance and evacuation instruction per year is investigated. The number of data in which the total working rainfall of a causing rainfall exceeds the WL and the EL in Fig. 2.12 is assumed as "K'_{yw}" and "K'_{ye}", respectively. And, the number of data in which the total working rainfall of a non-causing rainfall exceeds the WL and the EL in Fig. 2.12 is assumed as "K'_{nw}" and "K'_{ne}", respectively. Then, the frequency of warning issuance and the frequency of evacuation instruction are derived using the following equations, respectively.

Frequency of warning issuance: $F'_w = \dfrac{k'_{yw} + k'_{nw}}{n}$ (time/year)

Frequency of evacuation instruction: $F'_w = \dfrac{k'_{ye} + k'_{ne}}{n}$ (time/year)

Where, n is the number of years in which the data are collected.

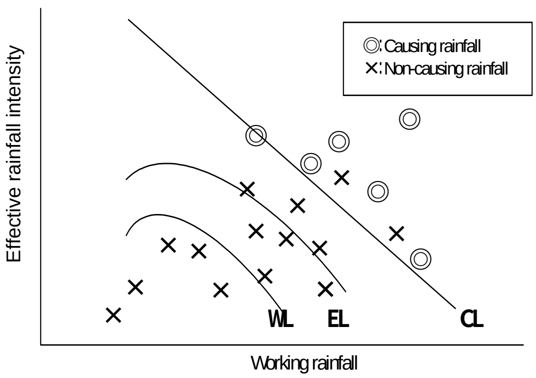


Fig. 2.12 Investigation of the frequency of warning issuance and evacuation instruction [10)]

<Non-hit rate of warning issuance and evacuation instruction>

Even though a warning is issued and an evacuation is instructed, a debris flow does not necessarily occur. This kind of non-hit rate is calculated using the following equations.

Non-hit rate of warning issuance: $M'_w = \frac{k'_{nw}}{n}$ (time/year)

Non-hit rate of evacuation instruction: $M'_e = \frac{k'_{ne}}{n}$ (time/year)

(4) Setting of the standard rainfalls for warning and evacuation

After comparing various procedures and confirming the adequacy of the CL, EL, and WL, the standard rainfall for warning and the standard rainfall for evacuation are established as follows.

Standard rainfall for warning: $Y = \frac{aX^2 + (b + aR_{H1M})X}{(1-2a)X + (1-2a)R_{H1M} - 2b}$ $(X \geq R_u)$

Standard rainfall for evacuation: $Y = \frac{aX^2 + (b + aR_{H1M})X}{(1-a)X + (1-a)R_{H1M} - b}$ $(X \geq R_u)$

Where a, b: constants

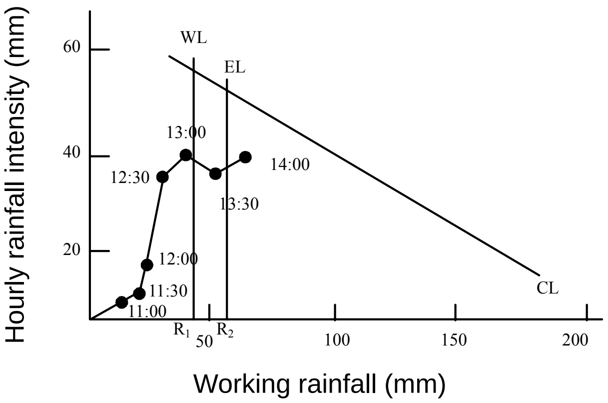
2.4.5 Features of Guideline Method and care for use

(1) Judgment by the snake line and care for use

The snake line is a line that shows the changes of two rainfall indexes with time, as seen in Fig. 2.13. In this figure, the snake line is depicted at an interval of 30 minutes. If the interval is made shorter, judgment will become more accurate.

Figure 2.13 contains several points that may easily be misunderstood. Hence, care is needed concerning the points explained hereafter. Figure 2.13 is intended to visually show how the rainfall indexes are approaching to the EL and the WL which are predetermined by Method A. This figure also contains the CL. It seems at first glance that the figure is also intended to show how the rainfall indexes are approaching to the CL. But, this is not the case. As mentioned earlier in the section of standard rainfall setting, one-hour time lag is assumed between the abscissa and the ordinate in the case of Method A. It means that when the working rainfall shown in the abscissa in the figure has reached the R_1 or R_2, the snake line will reach the CL if the past maximum 1-hour rainfall or the past maximum 2-hour rainfall which were chosen as the forecast rainfalls will rain from that time on. In other words, the ordinate should show the forecast rainfall, and should not show the rainfall intensity gauged at the same time with the gauging of the working rainfall in the abscissa. Hence, to avoid a misunderstanding, care is needed not to simply compare the snake line and the CL shown in the figure.

The EL and the WL in Method A are the standards defined by only the working rainfall in the abscissa. So, the changes of an index in the ordinate are basically needless. If it is desired to place an index in the ordinate by all means, a figure like Fig. 2.14 is good enough. The time axis in this figure is easy to understand and will not cause a misunderstanding. What is mentioned above is a problem innate to Method A only, and has nothing to do with Method B which assumes no time lag between the abscissa and the ordinate.



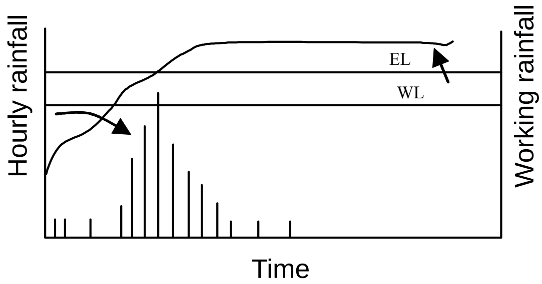


Fig. 2.13 Judgment by the snake line employed in Guideline Method [10)]

Fig. 2.14 Improvement of the judging method [10)]

(2) Characteristics of snake line movement

In Method A and Method B, the working rainfall is derived by the addition of the antecedent working rainfall to the continuous rainfall. Hence, the snake line in the figure always goes upward relative to the abscissa during the period of a series of rain. As a result, if a small amount of rainfall continues for a long time or an intermittent rain continues, the snake line will easily exceed the WL and the EL or the exceeding period will drag on. This causes a problem especially when attempting to cancel a warning or an evacuation instruction.

2.5 Method Proposed by the Committee for Studying Comprehensive Sediment Control Measures (Committee Method)

The Committee Method is the method proposed by the Committee for Studying Comprehensive Sediment Control Measures which was organized by the Ministry of Land, Infrastructure and Transport. It was originally proposed as the "Setting Method of Standard Rainfall for Warning and Evacuation against Collective Precipice Failures (Tentative)". But, it is rated as effective for debris flows because the tank model used for this derivation is found to be effective for the forecast of debris flow occurrence.

2.5.1 Outline of the Committee Method

Table 2.8 summarizes the applications area and the rainfall index with regard to the setting method of standard rainfalls for warning and evacuation by Committee Method.

The setting procedure of standard rainfalls for warning and evacuation is as follows.

1) A representative rainfall gauging station for collecting the rainfall data of the target area shall be determined.
2) The rainfall data at the time sediment disasters (debris flows and slope failures) were caused (called the causing rainfall) and the rainfall data at the time those disasters were not caused (called the non-causing rainfall) shall be collected and recorded in forms.

3) The data on the precipice collapse that occurs collectively and the data on other disasters shall be separated and filled into respective forms. The X-Y graph shall be prepared for the causing rainfalls and the non-causing rainfalls by placing the working rainfall with a half-life of 72 hours in the abscissa and the working rainfall with a half-life of 1.5 hours in the ordinate. Using this graph, various standard lines are determined.

Table 2.8 Application area and rainfall index of the Committee Method [10)]

Application area	This is applicable to the areas at risk of slope failures, such as steep slope hazard areas. In view of the fact that the rainfall data and slope failure cases are not sufficient, the same standard rainfalls may be employed in closely-located areas having a similar topography, geology, and vegetation.
Rainfall index	It is known from past researches that the timing of slope failure occurrence can be explained from the changes in the water storage height of the tank model. It is verified that there is a good agreement between the changes of the water storage height of the 1st layer tank which indicates the changes in the surface water and the changes in the working rainfall with a half-life of 1.5 hours, as well as between the changes in the water storage height of the 2nd and 3rd layer tanks which indicate the changes of groundwater and the changes in the working rainfall with a half-life of 72 hours. Hence, it is determined that the working rainfall, which is easy to use, shall be used as the rainfall index to evaluate the critical rainfall between the occurrence and non-occurrence of slope failures.

The operation method of the working rainfall in the Committee Method is different from that in the Guideline Method which calculated the working rainfall by the unit of day. Namely, all the rainfalls up to one hour before the occurrence of a sediment disaster (debris flow or slope failure) are assumed as the antecedent rainfall. Those rainfalls are multiplied by the deduction coefficient and then integrated using the equations shown below. In the case of non-causing rainfalls, the working rainfall is operated at the time of a maximum hourly rainfall during a series of rain, in the same way as done in the Guideline Method.

$$R_W = \sum \alpha_{1i} \times R_{1i} \quad \alpha_{1i} = 0.5^{i/T}$$

where R_W : working rainfall

R_{1i} : one-hour rainfall at the time i -hours ago

α_{1i} : deduction coefficient at the time i - hour ago

T : half-life (hour)

In the Committee Method, two types of rainfall indexes are operated. Namely, the working rainfalls at the time sediment disasters occurred and did not occur are operated employing the half-life of 1.5 hours and 72 hours. When calculating the working rainfall, the problem is that the rainfalls of how many hours before should be included in the calculation. In general, the desirable retroactive calculation period is the period when the deduction coefficient remains 0.004 or over considering from the effect on the working rainfall, as mentioned in the working rainfall calculation of the Guideline Method. The time when the half-life becomes less than 0.004 is approximately 12 hours before when the half-life is 1.5 hours and about 574 hours (24 days) before when the half-life is 72 hours.

2.5.2 Collection and recording of the data on causing/non-causing rainfalls of sediment disasters

(1) Collection and recording of the data on causing rainfall

Utilizing past records and through an inquiry to the local people, the occurrence time of past sediment disasters and other related data shall be grasped. These data and the rainfall data obtained at representative rainfall gauging stations shall be recorded in a form shown in Table 2.9.

Because the total rainfall differs by the occurrence time of a disaster, it is very important to gather highly accurate information about the occurrence time. In the case of old disasters, it is usually difficult to distinguish if it was a slope failure or a debris flow, in addition to the difficulty of getting the exact occurrence time. Therefore, data should be collected from as many organizations as possible. For the collection of accurate data, it is desirable that debris flow-prone mountain streams and rainfall gauging stations are located as closely as possible. If this is not satisfied, it is better to consider the installation of a new rain gauge to improve the accuracy of future data.

Table 2.9 Form for recording the data on causing rainfall [10)]

Item	Application
(a) Reference No.	
(b) Type of failure	Precipice failure (collective occurrence), precipice failure (individual occurrence), debris flow, etc.
(c) Hazard area/mountain stream	
(d) Address/lot	
(e) No. of hazard area /hazard stream	
(f) Amount of sediment moved	
(g) Damage	
(h) Date/time of occurrence	
(i) Representative gauging station	
(j) Distance to the representative gauging station	
(k) Working rainfall one hour before a disaster occurred (half-life: 72 hours)	Depicted in the X-Y graph.
(l) Ditto, above (half-life: 1.5 hours)	
(m) Working rainfall at the time a disaster occurred (half-life: 72 hours)	
(n) Ditto, above (half-life: 1.5 hours)	
(o) Remarks	

(2) Collection and recording of the data on non-causing rainfall

Rainfalls that did not cause sediment disasters shall be selected from among a series of rains having a 24-hour non-precipitation period before and after. The data collected are filled in the form as shown in Table 2.10. Basically, the data collection should be limited to the rainfalls shown below, because analysis becomes complex if rainfalls with a small amount of precipitation are included. However, this can be changed depending on the amount of causing rainfalls or for convenience of analysis.

- Debris flows : a continuous rainfall of 80 mm or over, or an hourly rainfall intensity of 20 mm or over

- Slope failures : a continuous rainfall of 40 mm or over, or an hourly rainfall intensity of 10 mm or over

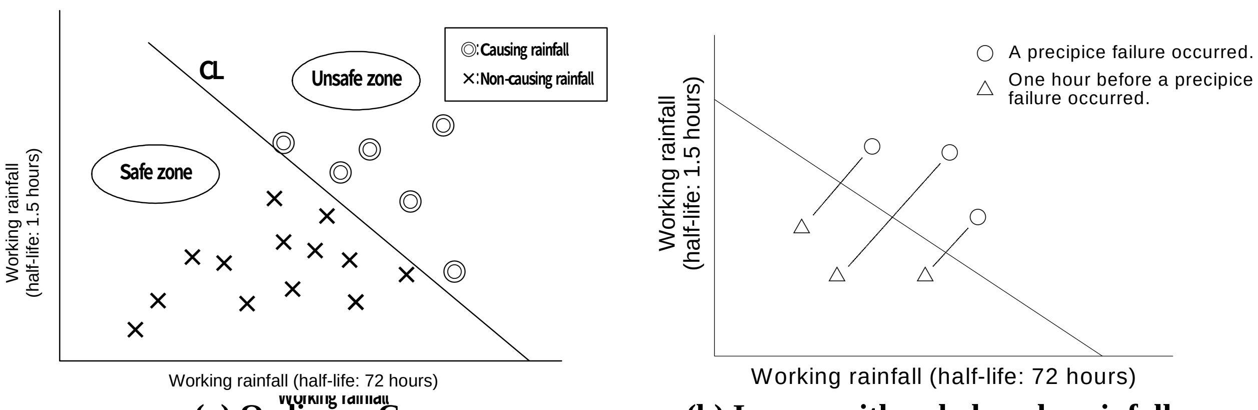
Table 2.10 Form for recording the data on non-causing rainfall [10)]

Item	Application
(a) Reference No.	
(b) Representative gauging station	
(c) Continuous rainfall (date/time-date/time, total rainfall)	The same as the Guideline Method
(d) Maximum hourly rainfall during a continuous rainfall (date/time, rainfall value)	
(e) Working rainfall at the time of a maximum hourly rainfall (half-life: 72 hours)	
(f) Ditto, above (half-life: 1.5 hours)	
(g) Time at which a maximum working rainfall occurred	The time when $\sqrt{x^2 + y^2}$ is at its maximum during a series of rain. (Time when the distance from the origin becomes the largest.)
(h) Working rainfall at the time of a maximum working rainfall (half-life: 72 hours)	Depicted in the X-Y graph.
(i) Ditto, above (half-life: 1.5 hours)	
(j) Remarks	

2.5.3. Setting of standard rainfalls

(1) Setting of the critical line (CL)

Using the data of slope failures or debris flows that occurred collectively in the target area, the rainfalls up to the time those disasters occurred and the rainfalls up to the time those disasters did not occur shall be evaluated by the working rainfall (half-life: 72 hours and 1.5 hours). Then, the critical line (CL) is drawn at the boundary of those two rainfalls. See Fig. 2.15(a). If the only available data is the hourly rainfall data, the CL can be drawn between the working rainfalls one hour before the occurrence of disasters and the working rainfalls at the time those disasters occurred. See Fig. 2.15(b).



(a) Ordinary Case **(b) In case with only hourly rainfall**

Fig. 2.15 Setting of critical line (CL) [10)]

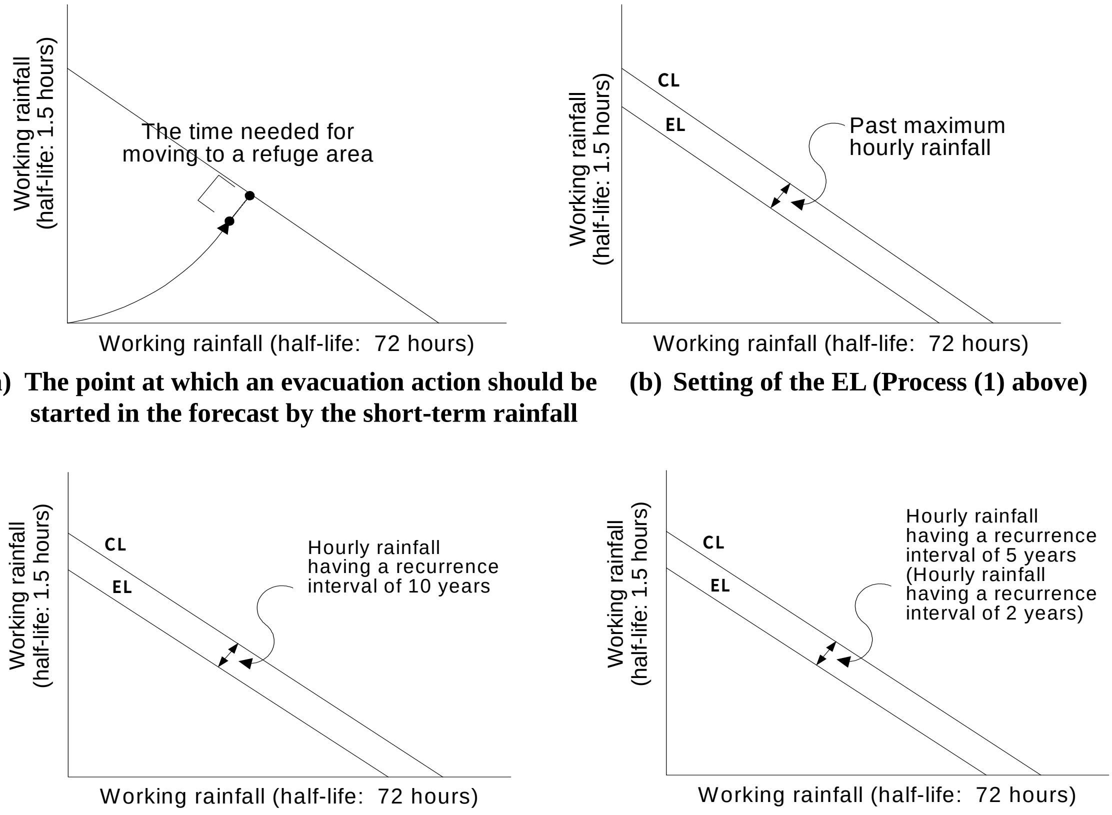
(2) Setting of the evacuation line (EL)

If, in view of the amount of forecast rainfall, the snake line obtained by the working rainfall is expected to reach the CL after some hours needed for evacuation has passed, an evacuation action should be started immediately. And, this boundary line is called the evacuation line (EL). See Fig. 2.16(a).

The forecast rainfall shall be estimated from the short-term rainfall forecast obtained from a radar rain gauge. It should be used after its adequacy to the target area is confirmed. When the short-term rainfall forecast is not available, the forecast rainfall during the time needed for evacuation should be determined from the past rainfall records of the area, and using it the EL shall be established.

The time needed for evacuation shall be determined in consideration of the actual conditions of each area. The following is a setting example of the EL when the time needed for evacuation is assumed as one hour.

1) As with Method A and Method B in the Guideline Method, the past maximum hourly rainfall of the area shall be used as the forecast rainfall (See Fig. 2.16(b).
2) If the frequency of issuance and the non-hit rate become excessive when the forecast rainfall is set according to 1), the hourly rainfall having a recurrence interval of 10 years, which is often used for the setting of standard rainfalls for warning and evacuation against debris flows, shall be used (See Fig. 2.16(c)).
(3) If the frequency of issuance and the non-hit rate become excessive even when the forecast rainfall is set according to 2), the hourly rainfall having a recurrence interval of 2 years shall be used as the minimum (See Fig. 2.16(d)).



(a) The point at which an evacuation action should be started in the forecast by the short-term rainfall

(b) Setting of the EL (Process (1) above)

(c) Setting of the EL (Process (2) above)

(d) Setting of the EL (Process (3) above)

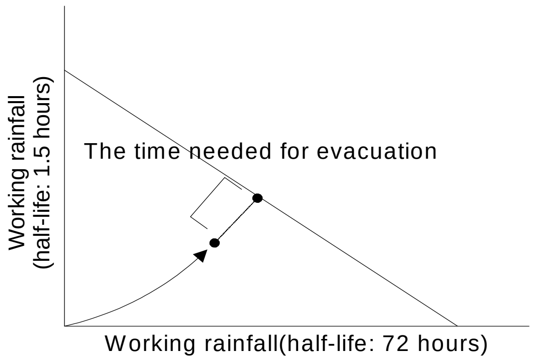
Fig. 2.16 Setting of the evacuation line (EL) [10)]

(3) Setting of the warning line (WL)

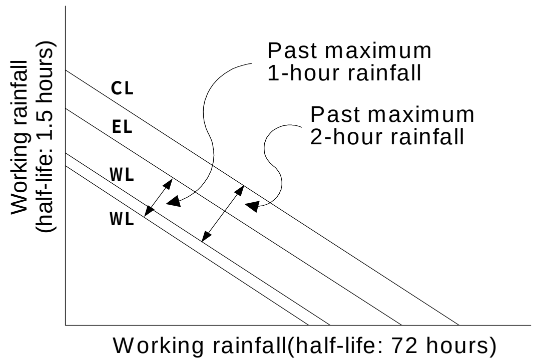
As with the setting of the EL, if the snake line obtained by the working rainfall satisfies the following conditions in view of the amount of forecast rainfall, a warning action should be started immediately. And, this boundary line is called the warning line (WL). See Fig. 2.17(a).

> When the snake line obtained by the working rainfall is expected to reach the CL after some hours needed for evacuation has passed.
>
> When the snake line obtained by the working rainfall is expected to reach the EL after some hours needed for the preparation of evacuation has passed.
>
> Note) [Time needed for evacuation] = [time for evacuation preparation] + [time for moving to a refuge area]

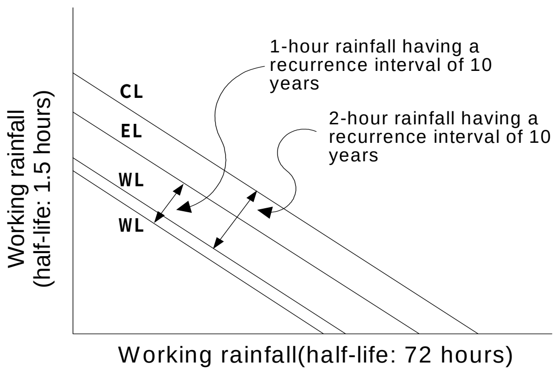
The forecast rainfall shall be estimated from the short-term rainfall forecast obtained from a radar rain gauge. It should be used after its adequacy to the target area is confirmed. When the short-term rainfall forecast is not available, the forecast rainfall during the time needed for evacuation should be determined from the past rainfall records of the area, and using it the WL shall be established.



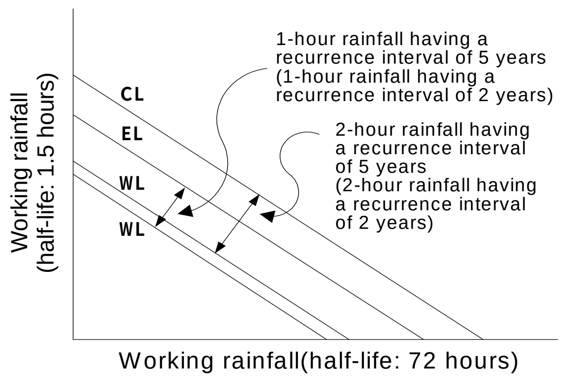
(a) The point at which an evacuation action should be started in the forecast by the short-term rainfall



(b) Setting of the WL (Process (1) above)



(c) Setting of the WL (Process (2) above)



(d) Setting of the WL (Process (3) above)

Fig. 2.17 Setting of the warning line (WL) [10)]

The time needed for evacuation shall be determined in consideration of the actual conditions of the area. The following is a setting example of the WL when the time needed for evacuation is two hours - one hour for preparation to evacuate and one hour for moving to a refuge area.

1) As with Method A and Method B in the Guideline Method, the past maximum 1-hour rainfall or the past maximum 2-hour rainfall of the area shall be used as the forecast rainfall (See Fig. 2.17(b)).

2) If the frequency of issuance and the non-hit rate become excessive when the forecast rainfall is set according to (1), the 1-hour rainfall having a recurrence interval of 10 years or the 2-hour rainfall having a recurrence interval of 10 years shall be used (See Fig. 2.17(c)).
3) If the frequency of issuance and the non-hit rate become excessive even when the forecast rainfall is set according to (2), the 1-hour rainfall having a recurrence interval of 2 years or the 2-hour rainfall having a recurrence interval of 2 years shall be used as the minimum (See Fig. 2.17(d)).

(4) Investigation of the adequacy of the CL, WL, and EL

Adequacy of these lines shall be evaluated in the same way as done in Method A and Method B. The most appropriate time to evaluate the frequency in which non-causing rainfalls exceed each line is at the time when the maximum working rainfall is obtained (this is shown in (g) and (h) in Table 2.10), although it may be changed depending on the gradient of lines.

(5) Setting of the standard rainfalls for warning and evacuation

After comparing various procedures and confirming the adequacy of the CL, EL, and WL, the standard rainfalls for warning issuance and evacuation instruction shall be established.

2.5.4. Features of Committee Method and care for use

(1) Determination of the half-life

The half-life is considered as an index to describe the water storage/discharge characteristics of the area. A half-life of 1.5 hours that indicates the ground surface characteristics is probably not so much different in any areas. But, a half-life of 72 hours that indicates the underground characteristics may be different in areas. Therefore, in the case of a half-life of 72 hours, some adjustment can be made in accordance with regional characteristics. Adjustment may be done on a trial and error basis using the results of tank model-based discharge analysis or using the empirically obtained half-life value that can separate causing rainfalls and non-causing rainfalls readily.

(2) Characteristics of snake line movement

The standard rainfalls set by the Committee Method are effective for situations like a long rain and an intermittent rain or for judgment of cancellation of evacuation. Although the snake line derived by this method is a valuable criterion for deciding the cancellation of evacuation, actual cancellation must be determined based on an overall judgment of meteorological information, forecast rainfall, ground surface conditions in and around the area, and the conditions of hazardous mountain streams. Especially, when attempting to cancel an instruction or a recommendation of evacuation, not only rainfalls but also the conditions around the hazardous mountain streams shall be fully checked before deciding an actual cancellation.

2.6 Setting of Standard Rainfalls in Case When Hourly Rainfall Data are not Accumulated

2.6.1 Setting of standard rainfalls using the total rainfall

(1) Recording of rainfall data using rainfall indexes

The Guideline Method (Method A and Method B) and the Committee Method are the methods to establish the standard rainfalls for warning and evacuation based on the working rainfall and the rainfall intensity. However, if the only rainfall being gauged is the daily rainfall, the rainfall intensity cannot be obtained. In that case, the standard rainfalls must be set using only the total rainfall which is obtainable from daily rainfall data. The following are available as the rainfall indexes usable for the setting of standard rainfalls for warning and evacuation based on the total rainfall.

1) 1-day rainfall: Rainfall on the day a sediment disaster occurred.
2) 2-day rainfall: The total of the rainfall on the day a sediment disaster occurred and the rainfall on the previous day
3) 3-day rainfall: The total of the rainfall on the day a sediment disaster occurred and the rainfalls on the previous two days
4) Cumulative rainfall: Cumulative rainfall of a series of rain including the day a sediment disaster occurred
5) Working rainfall: The total of the cumulative rainfall and the antecedent rainfall (the basic idea is the same with that in Guideline Method)

A rainfall gauging station located in or around the target area is selected as the representative rainfall gauging station and the data of causing rainfalls shall be taken out. Then, the values of the five rainfall indexes shall be calculated and filled into the form as shown below. If the number of disaster occurrence is few, rainfalls that had large 1-day, 2-day, and 3-day rainfalls shall be taken out from among non-causing rainfall data. Assuming that a sediment disaster occurred on the day of the largest 1-day rainfall, the values of the five rainfall indexes shall be calculated and filled into the form in the same way as done with the causing rainfalls.

Table 2.11 Form for recording the rainfall indexes used for the total rainfall-based setting method

No. of a series of rain	1-day rainfall	2-day rainfall	3-day rainfall	Cumulative rainfall	Working rainfall
Causing rainfalls					
1					
2					
:					
Non-causing rainfalls					
1					
2					
:					

(2) Setting of standard rainfall indicating the critical state

Regarding each rainfall index shown in Table 2.11, the lowest value of causing rainfalls and the highest value of non-causing rainfalls shall be compared. And, the rainfall index exhibiting the highest separability between the two rainfalls shall be used to establish the standard rainfall showing the critical state preceding the occurrence of sediment disasters. In general, however, the separability between the causing rainfalls and non-causing rainfalls is not so good in the case of setting method using the total rainfall. Hence, the standard rainfall showing the critical state shall be established based on the overall consideration of the non-hit rate, the frequency of warning issuance and evacuation instruction, etc.

(3) Setting of standard rainfalls for warning and evacuation

When the standard rainfalls for warning and evacuation are set based on the total rainfall, the underlying rainfall data is basically the daily rainfall. Hence, a forecast for warning issuance and evacuation instruction must be done using the rainfall index value up to the previous day. But, if a warning is issued based on the forecast maximum one-day rainfall and if the spare time before disaster occurrence is one day, a warning will be issued very often, almost every time when it rains, because the forecast one-day rainfall becomes very large. This is not practical.

The past rainfall data obtained from a daily rainfall gauge is naturally the daily rainfall only. But, if some ideas are taken, it is possible to gauge the rainfall intensity when a sediment disaster is feared due to heavy rain. They are, for example, to gauge the water stored in a daily rainfall gauge every hour or read the scale of the stored water every hour. See Fig. 2.18.

Hence, presupposing that the rainfall can be gauged every hour during the warning period using some means as shown above, the standard rainfalls based on the total rainfall can be set in the same way as done in Guideline Method and Committee Method. The setting conditions are shown in Table 2.12. However, in areas where the only available data is the daily rainfall, the past maximum 1-hour/2-hour rainfall and the probable 1-hour/2-hour rainfall as shown in the table may not be obtainable from their data. In that case, they can be specified from the hourly rainfall data obtained in other areas which have similar the daily rainfall characteristics.

Table 2.12 Timing of warning issuance and evacuation instruction and the forecast rainfall during the spare hours in the setting method based on the total rainfall

Type	Timing of warning/evacuation	Forecast rainfall during the hours shown left
Issuance of a warning	2 hours before reaching the critical rainfall	Past maximum 2-hour rainfall / probable 2-hour rainfall
Instruction of an evacuation	1 hour before reaching the critical rainfall	Past maximum 1-hour rainfall / probable 1-hour rainfall

2.6.2 Setting of standard rainfalls when rainfall data are not available at all

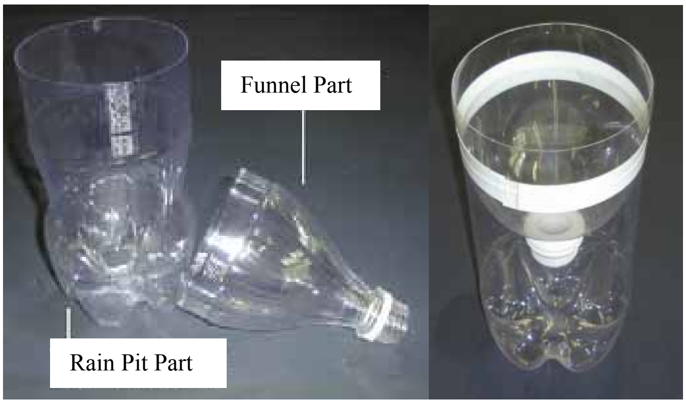
In areas where appropriate rainfall data are not available at all but regarded as at risk of sediment disasters, an hourly rain gauge must be installed as soon as possible and data accumulation must be started so that they can be used for judgments related to warning issuance and evacuation instruction. Until an hourly rainfall gauge is installed, efforts should be made to catch the precursors and forecast the occurrence of sediment disasters as quickly as possible so as to enable safe evacuation of the local people and to keep the resulting damage to a minimum.

(1) Location of rainfall gauging station and accumulation of data

A rainfall gauging station shall be installed in or around the area at risk of sediment disasters. It can be installed near the office of a disaster prevention organization if the disaster hazard area is relatively small and the rainfall characteristics of the area is roughly identical to that around the office. A rain gauge installed should be able to measure the hourly rainfall by real time. Even though this type of rain gauge is not installed for some reason, it is still important to try to obtain the daily rainfall and the rainfall intensity by using a simple daily rain gauge or a hand-made rain gauge such as a cup. Figure 2.18 shows the example of simple rain gauges.

A cup rain gauge

The easiest method of rainfall measurement is to use a container with the bottom with cylinder forms, such as a tea canister, and to collect rain water. Rainfall can be calculated by the depth of collected rain by ruler.



A plastic bottle rain gauge

The center of a bottle is cut and the top portion is attached inside out. Rainfall (cm) can be calculated by the amount of rainfall (cm^3) divided by the cross-section area of a bottle (cm^2).

A storage type rain gauge

The rain water which collected into the storage bottle is moved to a graduated cylinder, and rainfall is calculated. Hourly rainfall can also be measured by measuring for every hour.

Figure 2.18 Examples of simple daily rain gauges

(2) Setting of standard rainfalls for warning and evacuation

If a rainfall gauging station is installed near the sediment disaster hazard area and the hourly rainfall becomes gaugeable, a disaster forecast can be started using the standard rainfalls currently employed in other areas (including Japan) having a similar topography, geology, and weather conditions as the tentative measures. As the disaster forecast method, either Guideline Method or Committee Method shall be used. As the standard rainfalls for warning and evacuation, the most appropriate rainfalls for the target area shall be selected from various standard rainfalls currently employed in other areas having a similar topography, geology, and hydrology. The example of standard rainfalls for warning and evacuation against sediment disasters in Japan is shown in Appendix-2. According to this, there is no clear tendency between topography, geology and rainfall condition in the standard rainfalls for warning and evacuation. However, it is important to set up the standard rainfalls for warning and evacuation by using standard and safety values and to establish the tentative standard rainfalls.

In this way, by establishing tentative standard rainfalls for warning and evacuation and concurrently starting the gauging of hourly rainfall, the disaster forecast system as well as the warning and evacuation system can be launched. As time advances, the rainfall data will increase, a warning or an evacuation instruction may be issued, and a sediment disaster may occur. Accumulation of these sediment disaster-related data is extremely important. Based on these data, the standard rainfalls established by either Guideline Method or Committee Method are reviewed, revised, and upgraded to a highly sophisticated sediment disaster forecast system.

2.6.3 Tentative measures before a rainfall gauging station is installed

Before slope failures, debris flows, or landslides that cause serious sediment disasters occur, particular precursors are sometimes observed. In the case of debris flows, a rumbling sound is heard from the mountain or the water level in the river lowers even though the rain is continuing. In the case of slope failures, a sound is heard from the precipice or the slope, or small stones fall.

Until the day when a new rainfall gauging station is installed and the sediment disaster forecast system is put into operation, local people or voluntary disaster prevention groups should acquire knowledge about these precursors and keep a watch on the state of sediment disaster hazard areas. It is also needed to prepare a plan about the measures to be taken in case some precursors are detected, such as strengthening of a patrol or initiation of an evacuation action. See Fig. 3.3.

2.7 Preparation and Utilization of Country Watching Map (CWM)

2.7.1 Outline of country watching map (CWM)

The setting method of standard rainfalls for warning and evacuation against sediment disasters with the use of rainfall data was explained in Chapter 2 above. However, it may take a long time before a warning and evacuation system based on those standard rainfalls becomes fully established. In some case, the establishment of a warning and evacuation system itself may not be easy if the rainfall data is insufficient or the data itself is not at all available.

To prevent the occurrence of sediment disasters in situations like this, it is needed to set up a disaster prevention system that can respond to the local nature of disasters on the basis of disaster prevention units formed by community or similar scale. The system should be such that the local people participate in the development process and assume their roles in disaster prevention based on a common vision with administrative organs. This kind of disaster prevention system based on the area-wide cooperation is called the Everyone Watching System (EWS). As shown in Fig. 2.19, the EWS is a system that administrative organs as well as the local people share the roles of disaster prevention, cooperate for enhanced preparedness against disasters from ordinary times, and join forces to conserve people in case a disaster is feared under a torrential rain or others.

One of the measures supporting the EWS is the Country Watching Map (CWM). The CWM is a basic material that helps establish the EWS through the consistent devotion to disaster prevention from normal times to disaster times.

2.7.2 Preparation of Country Watching Map (CWM)

(1) Roles of administrative organs

Prefectural governments and municipal governments are required to set up disaster prevention units and, on the basis of those units and in cooperation with local people, they collect data on past sediment disasters, prepare an easy-to-use CWM, and distribute them to local areas. When a torrential rain hits their area, they gather disaster-related information from the local people and, if necessary, instruct them to evacuate to safe areas in close cooperation with them.

(2) Roles of the local people

Based on the CWM prepared in cooperation with administrative organs, the local people are required to set up a disaster prevention structure and should be prepared for potential disasters through activities, such as the gauging of hydrological conditions, disaster prevention education, grasp of hazardous locations, and disaster prevention training even from normal times. When a torrential rain hits their area, they should judge the area's hazard level by comparing with past sediment disaster records or relevant documents and, if necessary, begin to evacuate or take some actions in close cooperation with administrative organs.

(3) Preparation of Country Watching Map (CWM)

Two kinds of information should be included in the Country Watching Map (CWM): 1) information necessary to judge the danger level in case of a torrential rain; 2) information necessary for evacuation

1) Information necessary to judge the danger level in case of a torrential rain

   The information for the practical judgment of the degree of danger which has never been dealt in this kind of maps shall be included in the CWM utilizing past disaster records and empirical knowledge accumulated in each area. Namely, hearings shall be conducted and the data collected on a variety of subjects related to disasters, ranging from precursors of torrential rains, flood damages, and sediment disasters. To be specific, phenomena caused by torrential rains (gush of water from slopes, overflow of water from roadside gutters, inundation below and above floor level, blocking of rivers by bridges, flooding of rivers, debris flows, precipice failures, slope failures, and landslides) and the rainfalls at those times shall be summarized clearly, together with their temporal and spatial changes. These data are called the Disaster Integrated Watching Rainfall (DIWR) and shall be used as the criteria for judgments related to warning and evacuation.

2) Information necessary for evacuation

   As the information needed for evacuation, the refuge facilities and evacuation routes which are determined in each unit, dangerous locations during evacuation (overflows, precipice failures, slope failures, debris flows), and resident-related information (disaster vulnerable people: infants, elderly persons, handicapped persons; housing conditions: temporary vacant houses, etc.) shall be surveyed and included in the CWM. See Fig. 2.20.

(4) Survey items for the preparation of CWM

The following items shall be surveyed before preparing the CWM.

- Survey of natural features (topography, geology, and vegetation)
- Survey of social features (disaster vulnerable people, housing conditions, etc.)
- Survey of disaster history
- Survey on the present state of the disaster prevention system
- Survey of dangerous locations
- Survey of points that need inspection (spring water and water paths on hillside)
- Survey of indexes for the judgment of danger level and relevant standards
- Survey of refuge facilities and evacuation routes

2.7.3 Effect of Country Watching Map (CWM)

The Disaster Integrated Watching Rainfall (DIWR) compiled in the CWM is a familiar topic and easy to understand for the local people because it is prepared from past rainfalls in their own area and they themselves are involved in the formulation of the map. The joint efforts between the residents and the administrative organs during the preparation process of the map also work to enhance communication between the two parties and strengthen their cooperative relationship, besides a deeper understanding of the contents of the map itself. These effects serve to arouse stronger disaster prevention awareness in the area which will result in a more active development of disaster prevention efforts.

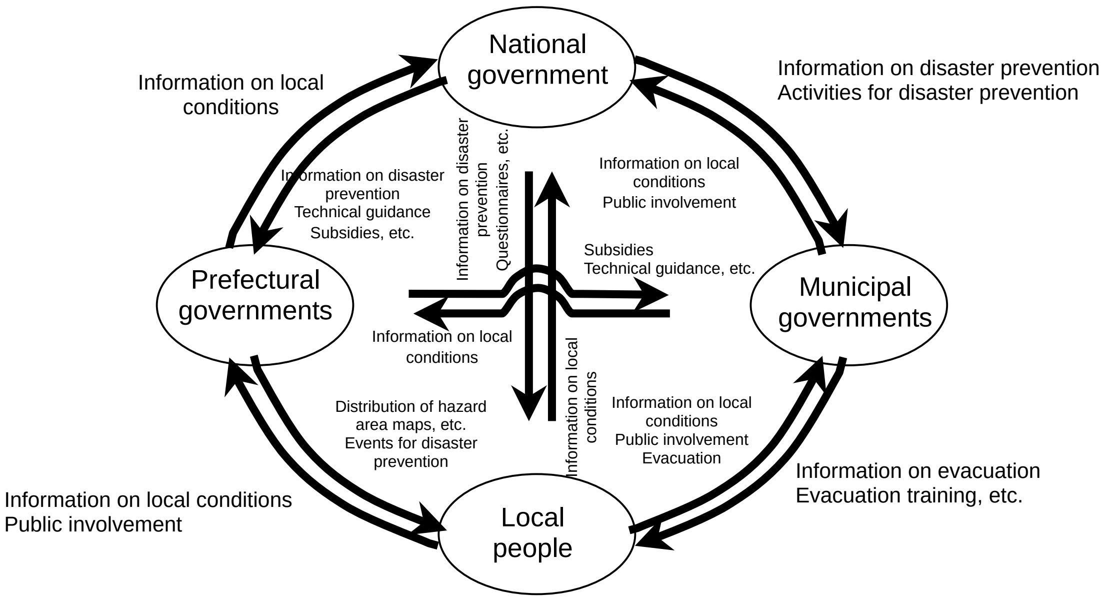


Fig. 2.19 Basic structure of the Everyone Watching System (EWS) [20]

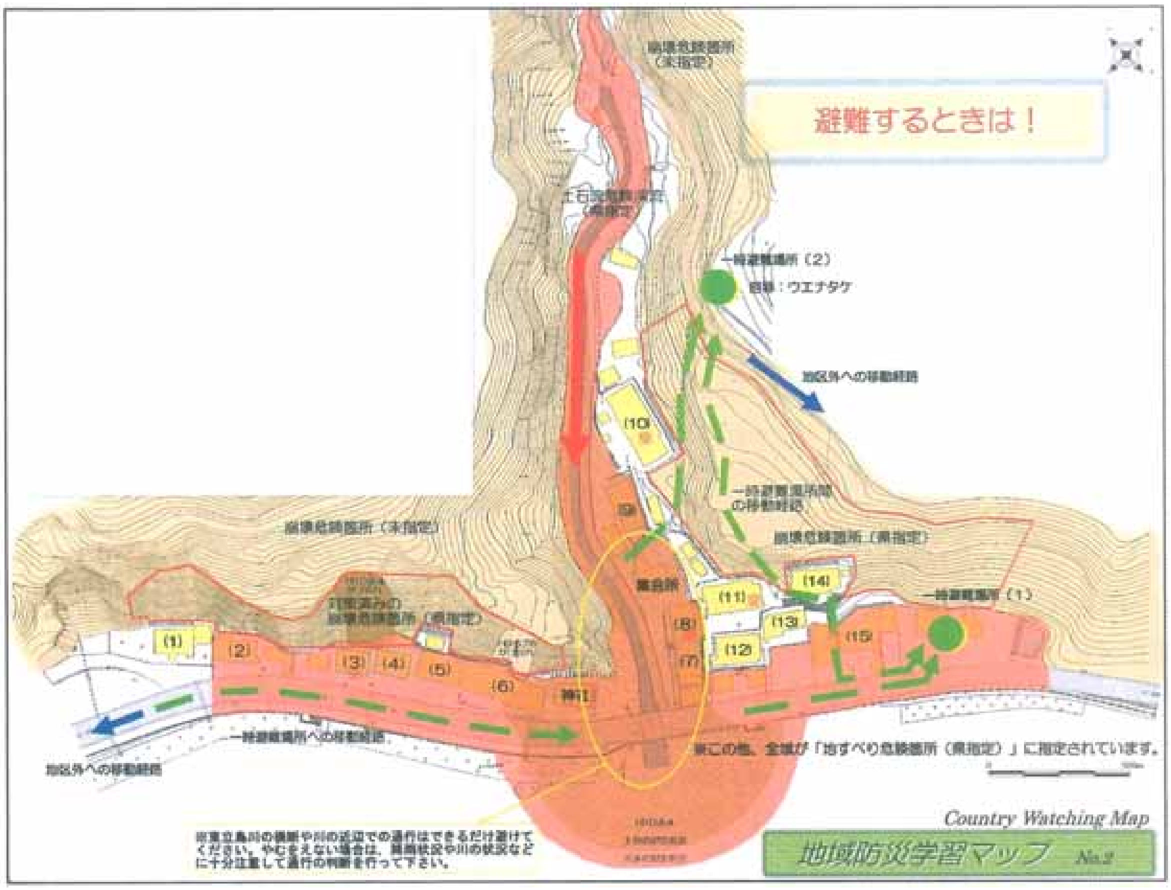


Fig. 2.20 Country Watching Map (CWM)
showing information necessary for evacuation

CHAPTER 3 DELIVERY AND TRANSMISSION OF SEDIMENT DISASTER INFORAMTION

3.1 Structure of the Sediment Disaster Warning System

The structure of the sediment disaster warning system is shown in Fig. 3.1. The system consists of the following elements.

1) **Sediment disaster monitoring system:** A system to detect the precursors and the occurrence of sediment disasters
2) **Rainfall gauging system:** A system to gauge and record the rainfalls for the forecast of sediment disasters
3) **Sediment disaster forecast system:** A system to forecast the occurrence of sediment disasters from rainfall data
4) **Information transmission network:** Two types of networks are available: 1) transmission network of gauging information; 2) transmission network of disaster information
5) **Organizations responsible for the delivery of warning information on sediment disasters:** Organizations in charge of the delivery of warning information on sediment disasters
6) **Organizations responsible for the emergency measures against sediment disasters:** Organizations in charge of emergency measures against sediment disasters to be provided to the local people
7) **Organizations concerned with sediment disasters:** Organizations related to the lifeline systems which may be damaged due to sediment disasters and organizations related to disaster prevention and emergency retrofit. The lifeline systems include four types of systems: the utility systems supplying water, electricity, gas; treatment systems handling sewage and wastes; traffic-related systems such as roads and bridges; and communications systems for telephone lines and data transmission.
8) **Local disaster prevention organizations:** Organizations that transmit disaster-related information to the local people directly and engage in the guidance of people during evacuation. These organizations include the local offices of the prefectural governments and the organizations responsible for the delivery of warning information on sediment disasters, as well as the voluntary disaster prevention groups set up by the local people.
9) **Local people:** Residents who suffer direct or indirect damage due to sediment disasters

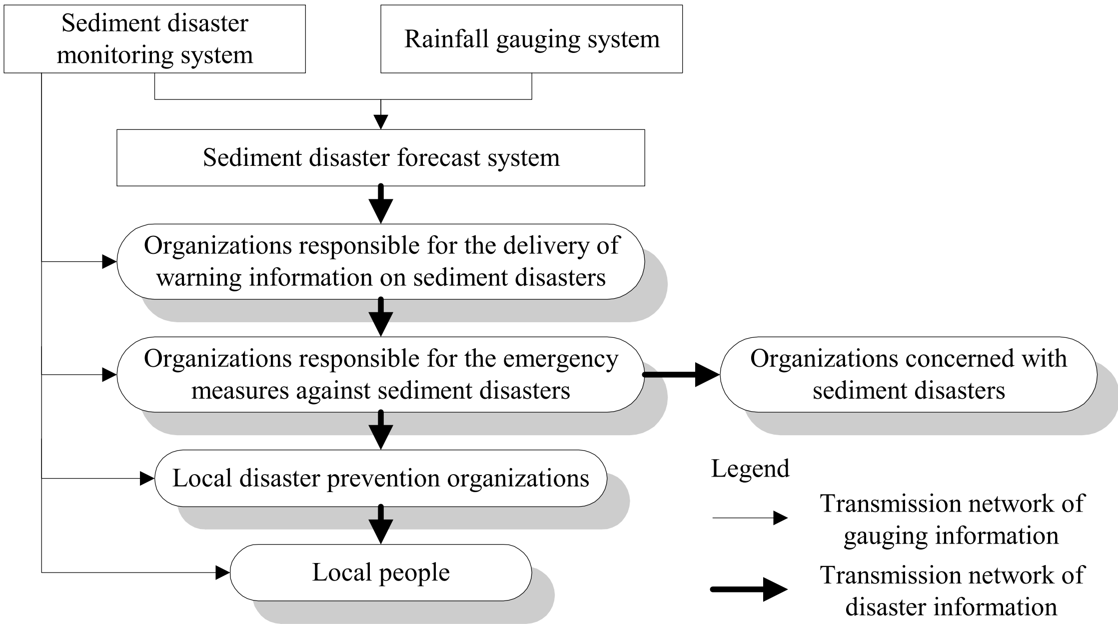


Fig. 3.1 The structure of the sediment disaster warning system [3)]

3.2 Roles of Organizations Responsible for Sediment Disasters

3.2.1 Organizational structure on disaster prevention

Sediment disasters are just one of many disasters. Therefore, organizations responsible for sediment disasters should be regarded as just one of functions of the overall structure having a mission for disaster prevention. The following is the outline of the organizational structure on disaster prevention currently in effect in Japan. It is usable as a reference when countries in the world attempt to establish a disaster prevention structure or to strengthen their existing structures.

The Disaster Prevention Basic Measures Law which is regard as the constitution of disaster prevention in Japan was enacted in 1961. The principal objectives of this law are: 1) to define the administrative responsibility for disaster prevention; 2) to promote comprehensive administrative disaster prevention; 3) to promote systematic administrative disaster prevention; 4) financial assistance to major disasters; and 5) measures for disaster-related emergency situations. As the disaster prevention system in Japan, the Disaster Prevention Basic Measures Law stipulates that prefectural and municipal governments should formulate their own prefectural/municipal disaster prevention plans, together with detailed accounts on the structure and the contents of those plans. The prefectural/municipal disaster prevention plans are the plans that define the prevention of disaster occurrence (disaster prevention measures), emergency responses in case of disaster occurrence (emergency response measures against disasters), and an approach to post-disaster recovery (retrofit and restoration measures), with a goal to conserve the land, life and properties of the Japanese people from natural disasters, large-scale fires, and other calamities.

The disaster prevention structure and the disaster prevention plans defined by the Disaster Prevention Basic Measures Law are shown in Fig. 3.1. In this law, the national government, prefectural governments, municipal governments, and designated public organizations are specified as the core disaster prevention organs that bear the prime responsibilities of conserving the land, life and properties of the Japanese public from disasters. Among those organs, the national government bears the largest responsibility and its aggressive leadership in disaster prevention is emphasized. On the other hand, as the most basic administrative unit directly connected to the local people, municipal governments are expected to perform a very important role and responsibility in such fields as 1) transmission of warnings; 2) preparatory measures and evacuation; 3) emergency response measures.

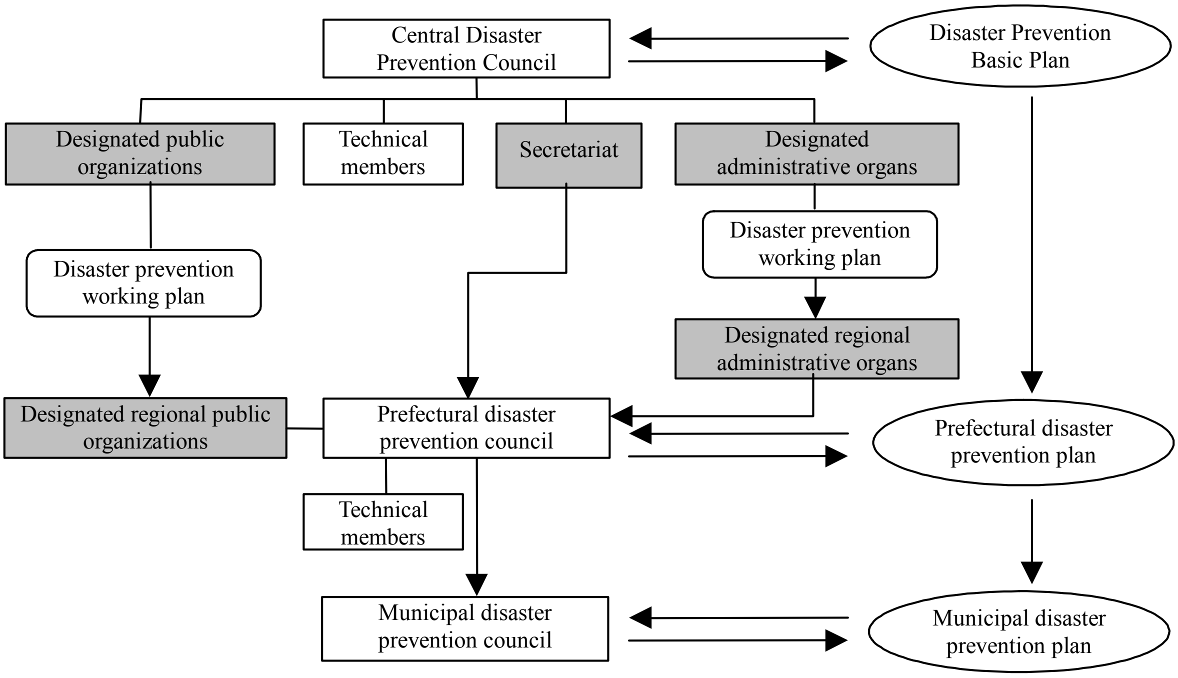


Fig. 3.2 Disaster prevention structure and disaster prevention plan in Japan stipulated in the Disaster Prevention Basic Measures Law

3.2.2 Roles of organizations responsible for the delivery of warning information on sediment disasters

Organizations responsible for the delivery of warning information on sediment disasters shall: 1) formulate plans for the sediment disaster monitoring system, the rainfall gauging system, and the sediment disaster forecast system; 2) operate and maintain those systems; and 3) deliver warning information on sediment disaster to the organizations responsible for emergency measures, based on the monitoring results and disaster forecast results. In Japan, the sabo section of the civil works department of each prefectural government usually serves as the responsible organization for the delivery of warning information on sediment disasters, and regional weather stations of the Meteorological Agency supplement insufficient information from the rainfall gauging system.

3.2.3 Roles of organizations responsible for emergency measures

It is important to clearly specify the responsible organizations that undertake emergency measures when a sediment disaster is forecasted. In Japan, it is specified that prefectural governments and municipal governments take on an important role to execute emergency measures against disasters. As to warning and evacuation against disasters, it is stipulated in Article 60 of the Disaster Prevention Basic Measures Law that the mayor of each municipal government bears the authority and responsibility for evacuation instruction and other relevant actions. It is advised that each country in the world should make clear what organization is responsible for emergency measures in case sediment disasters occur in their country, in consideration of their own laws and social situations. Those countries are also required to secure some form of communication systems that can convey disaster-related information such as warnings and evacuation recommendations. The principal roles of responsible organizations for emergency measures against sediment disasters are as follows:

1) Collection and transmission of disaster-related information
2) Transmission of warnings on sediment disasters
3) Establishment of sediment disaster hazard areas
4) Order to take emergency response against sediment disasters
5) Evacuation instruction for emergency response against sediment disasters
6) Emergency measures for emergency response against sediment disasters

3.3 Operation of Warning and Evacuation System against Sediment Disasters

A warning and evacuation system against sediment disasters must be based on monitoring and observation of sediment disasters or forecast by standard rainfalls for warning and evacuation, which is explained in Chapter 2. Then the system shall be used for the prediction of sediment disasters. Warning information by the system must be informed to residents, and it must be used for residents' evacuation preparation and its action. In developing countries, a telemeter system is not usually established. Therefore, an observer must collect the information on rain gauge installed near the area, and visual observation of sediment disasters. Then an observer must contact to the disaster monitoring center and must report the detected information to the center. A warning and evacuation system can be operated as follows: See Fig. 3.3.

1) Observers of rainfall and sediment disasters must contact to the disaster monitoring center with a radio or a cellular phone when the risk of sediment disasters is detected.
2) In response, a center predicts sediment disasters and judges the necessity of evacuation recommendation.
3) When an alarm or evacuation recommendation is given, residents carry out the evacuation preparation or the evacuation.

In operation of warning and evacuation system, it is necessary to build staff arrangement and organization required for sediment disasters information, and carry out the suitable operation.

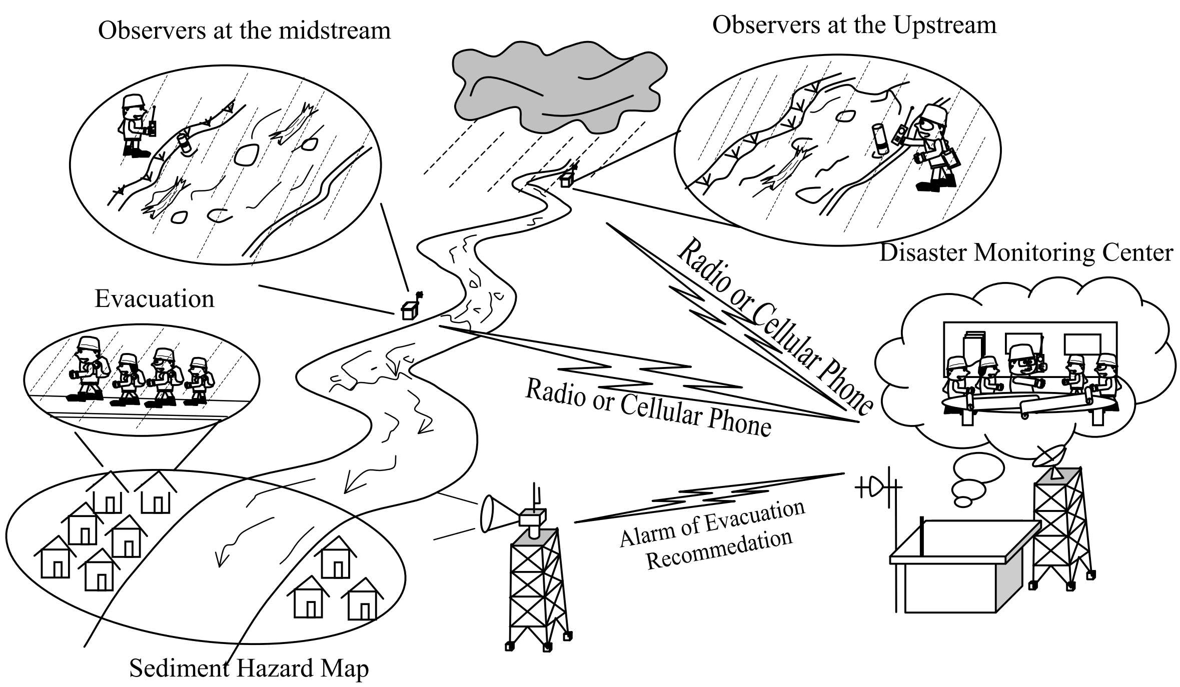


Fig. 3.3 Examples of operation of warning and evacuation system against sediment disasters

3.4 Warning Information on Sediment Disasters

3.4.1 Objective of warning information on sediment disasters

The objective of warning information on sediment disasters is to support organizations responsible for emergency measures so that they can make adequate judgments at any time concerning emergency measures, such as an evacuation instruction given to the local people, when sediment disasters are forecasted. The contents of the warning information should be such that the local people can also utilize it for their own judgments.

3.4.2 Contents of warning information on sediment disasters

(1) Contents of warning information

The warning information on sediment disasters shall include the following six items as the minimum requirement to condense all the information necessary for quick judgment, because information from a sending organization to emergency response organizations is sometimes transmitted via fax or orally.

1) Time of announcement and division announced
2) Target area (municipal name, etc.)
3) The current danger level due to antecedent rainfall (warning issuance/ evacuation instruction)
4) Predicted time of disaster occurrence and the forecast rainfall up to that time
5) Recent events that may increase the potentiality of sediment disasters (earthquakes, volcanic eruptions, ash falls, forest fires, typhoons, heavy rains, or snowmelts)
6) Other information that an organization responsible for warning information considers important for disaster prevention

(2) Care when announcing warning information

The principal objective of announcing warning information is to support disaster prevention efforts to save people from disasters by measures such as evacuation. Hence, the decision to announce warning information or not shall be made well in advance so that protective measures can be taken during that spared time. For that purpose, it is desirable that the announcement of warning information should be done approximately two hours before the expected disaster time by forecasting the rainfall of approximately two hours ahead, although it depends on the accuracy level of the rainfall forecast system.

(3) Care when canceling warning information

Special care is needed when canceling warning information because the danger of sediment disasters continues even after the rain has stopped. When canceling warning information, care should be taken not to cause a misunderstanding. An expression indicating that a caution against a sediment disaster is still necessary should be used to avoid a misunderstanding. It is something like "the heavy rain has weakened and the possibility of occurrence of multiple sediment disasters has decreased".

3.4.3 Examples of warning information on sediment disasters

Aim of warning information on sediment disasters is to be understood the contents of information at a glance, and the information sheet consists of the text and the figure. Fig. 3.4 shows an example in the case of receiving information in XX town.

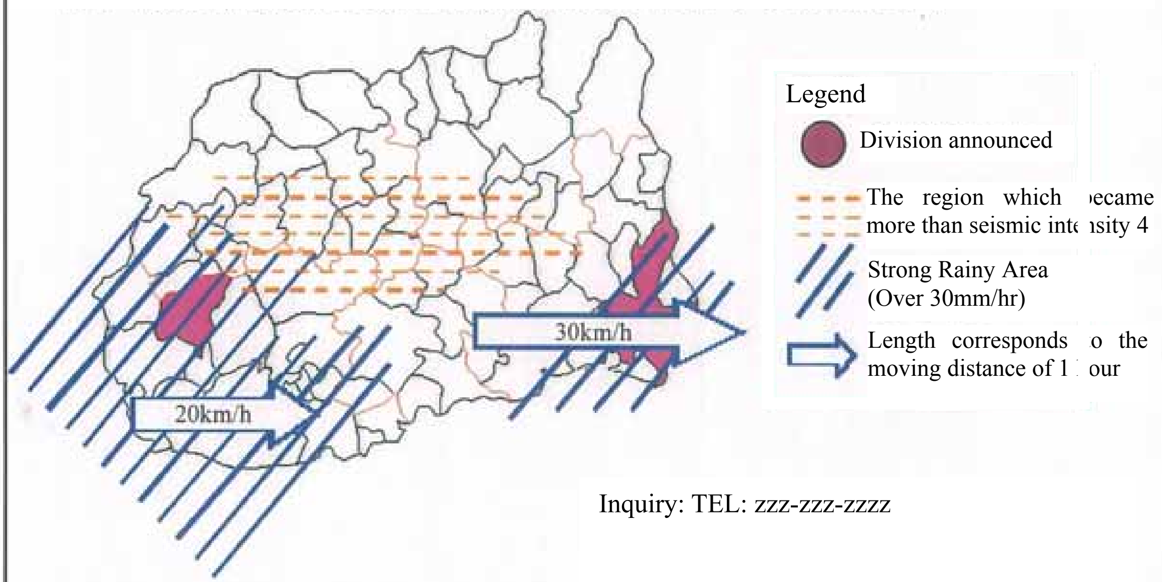
No.## Warning information on sediment disasters in □□ Prefecture

Date&Time: yyy/mm/dd, TT:MM

Announced by: Joint Statement of ΔΔMeteorological Office, □□Prefectural Government

Warning area: ○○ City, ×× Town,

Within 2 hours from now, the danger level of a sediment disaster due to heavy rain will rise to high level. Strict watch is needed in and around the sediment disaster hazard areas. The maximum hourly rainfall within 3 hours from now is expected to reach 60 mm at some locations in the warning area.



Inquiry: TEL: zzz-zzz-zzzz

Figure 3.4 Examples of warning information on sediment disasters [21)]

3.5 Communication Tools for Information Transmission

The following two information networks are available for the sediment disaster warning system.

1) Transmission network of gauging information: this is a transmission network to collect gauging information from the sediment disaster monitoring system and the rainfall gauging system.
2) Transmission network of disaster information: this is a transmission network to convey warning information on sediment disasters to responsible organizations, concerned organizations, local disaster prevention organizations, as well as to the local people.

Various tools are available to transmit this kind of information, as shown in Table 3.2. The most appropriate tools should be selected in consideration of the purpose of use, social situations, and economic conditions as well as their function and precision, so that the necessary information can be collected and transmitted swiftly and accurately even during a bad weather and a disaster.

Table 3.2 Communication tools for information transmission [22)]

Communication tools	Transmission network of gauging information	Transmission network of disaster information	
		Concerned organizations/local disaster prevention organizations	Local people
1) Radar rain gauge	○	-	-
2) Telemeter (radio system)	○	○	-
3) Special telephone line	○	○	-
4) Public telegram and telephone line	○	○	○
5) Information service vehicles	○	○	○
6) Warning signal (siren, etc.)	-	○	○
7) Verbal transmission	○	○	○
8) Mass media (radio, TV, etc.)	-	-	○

Note: the ○ symbol indicates that those tools are applicable.

CHAPTER 4 EVACUATION PLAN

The evacuation activities are recognized as the important measures in disaster prevention, because they are not only very effective but also the last resort to escape from disasters. It means that even though sediment disasters are adequately forecasted and warning information and an evacuation instruction are duly given, disaster prevention is not fruitful if the local people cannot be evacuated to safe places. In this chapter, the following subjects are explained so that an adequate evacuation plan can be formulated against sediment disasters.

1) Tools for the evacuation of the local people
2) Development of evacuation facilities
3) Education and enlightenment on disaster prevention and evacuation
4) Disaster prevention and evacuation activities taken the local people

4.1 Tools for Evacuation of the Local People

To involve the local people in the disaster prevention efforts and encourage them to make an adequate evacuation by themselves, it is essential that both the disaster prevention organizations and the local people clearly know their own roles and have a close cooperative relationship between them. To complete an evacuation successfully when a disaster has actually occurred, it is required to predetermine how the evacuation supervisor guides the people and how the people themselves are going to evacuate. For that purpose, disaster prevention maps, disaster prevention manuals, and disaster prevention posters shall be prepared in advance. See Fig. 2.20

4.1.1 Disaster prevention maps

To mitigate damage resulting from sediment disasters, it is important that the local people themselves know various dangers existing in their areas. One of the measures for this purpose is to prepare maps containing accurate and easy-to-understand disaster prevention information and present them to the local people. Through the distribution of such a handy disaster prevention information, the potential damage can be prevented or kept to a minimum.

The disaster prevention maps shall be prepared in such a way to improve the disaster prevention awareness of the local people and to be usable as a guide for evacuation. The disaster prevention maps should include the following information:

<Information to be included in the disaster prevention maps>

1) Sediment disaster hazard areas in each area
2) Locations of safe and adequate refuge facilities
3) Evacuation routes, evacuation directions

To prepare this kind of disaster prevention maps, the following surveys shall be carried out.

<Surveys needed for the preparation of disaster prevention maps>

1) Survey of sediment disaster hazard areas in each area: This survey is conducted to indicate the disaster hazard areas clearly and to find the potential obstructions during evacuation.

2) Survey of refuge facilities: This survey is made to find the safe refuge facilities located in the vicinity. The refuge facilities shall be examined in terms of the refuge period, a gathering place for evacuation, temporary refuge, and long-term refuge.
3) Survey of evacuation routes: Adequate and safe evacuation routes shall be determined in each area by considering the road conditions and the range of hazard areas showed on hazard maps.
4) Survey of vehicles usable for evacuation: Availability of vehicles to carry disaster vulnerable people during evacuation and the conditions of those vehicles are surveyed.

As an example of the disaster prevention map, the map prepared for sediment disasters by Kagoshima City, Japan is shown in Fig. 4.1.

4.1.2 Disaster prevention manuals

Two types of disaster prevention manuals are considered: one is for those responsible for disaster prevention and the other is for the local people. Main contents are as follows.

< Contents of disaster prevention manuals>

1) Conditions of sediment disasters in each area
2) Conditions of disaster prevention works and their effects
3) Sediment disasters in the past
4) Preparation of evacuation by warning levels
5) Detailed evacuation methods and instructions for evacuation
6) Disaster prevention maps (hazard areas, evacuation routes, refuge facilities)

To prepare this kind of disaster prevention manuals, the following surveys shall be performed.

<Surveys needed for the preparation of disaster prevention manuals>

1) Survey of natural conditions and disaster-related conditions: Survey shall be made on topography, geology, rainfalls, river conditions, sediment disaster hazard areas.
2) Survey of people's awareness on disasters: Survey shall be made on the disaster prevention awareness of the local people against sediment disasters and problems during evacuation.
3) Survey of social characteristics in areas: The number of residents and disaster vulnerable people (infants, elderly people, handicapped people, females) living in areas where evacuation may become necessary; social problems at the time of evacuation
4) Survey of past disaster history: Locations, disaster scale, and damage of past sediment disasters and behavior of people at the time of disasters
5) Survey of the current state of disaster prevention systems: Survey shall be made on the present conditions of voluntary disaster prevention groups, evacuation systems, warning systems, and information transmission systems.

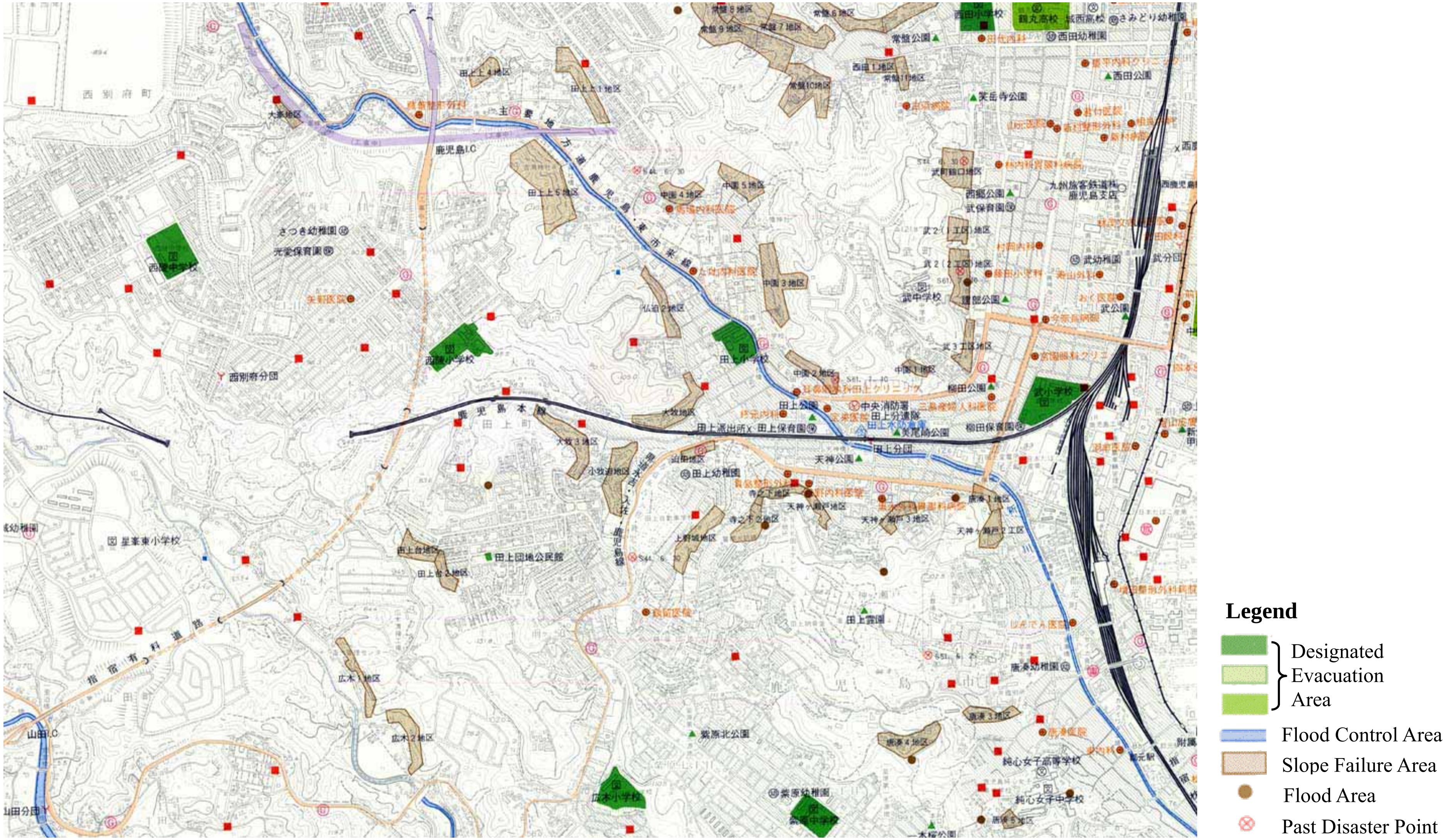


Fig. 4.1 An example of the disaster prevention map prepared for sediment disasters (Kagoshima City, Japan) [23]

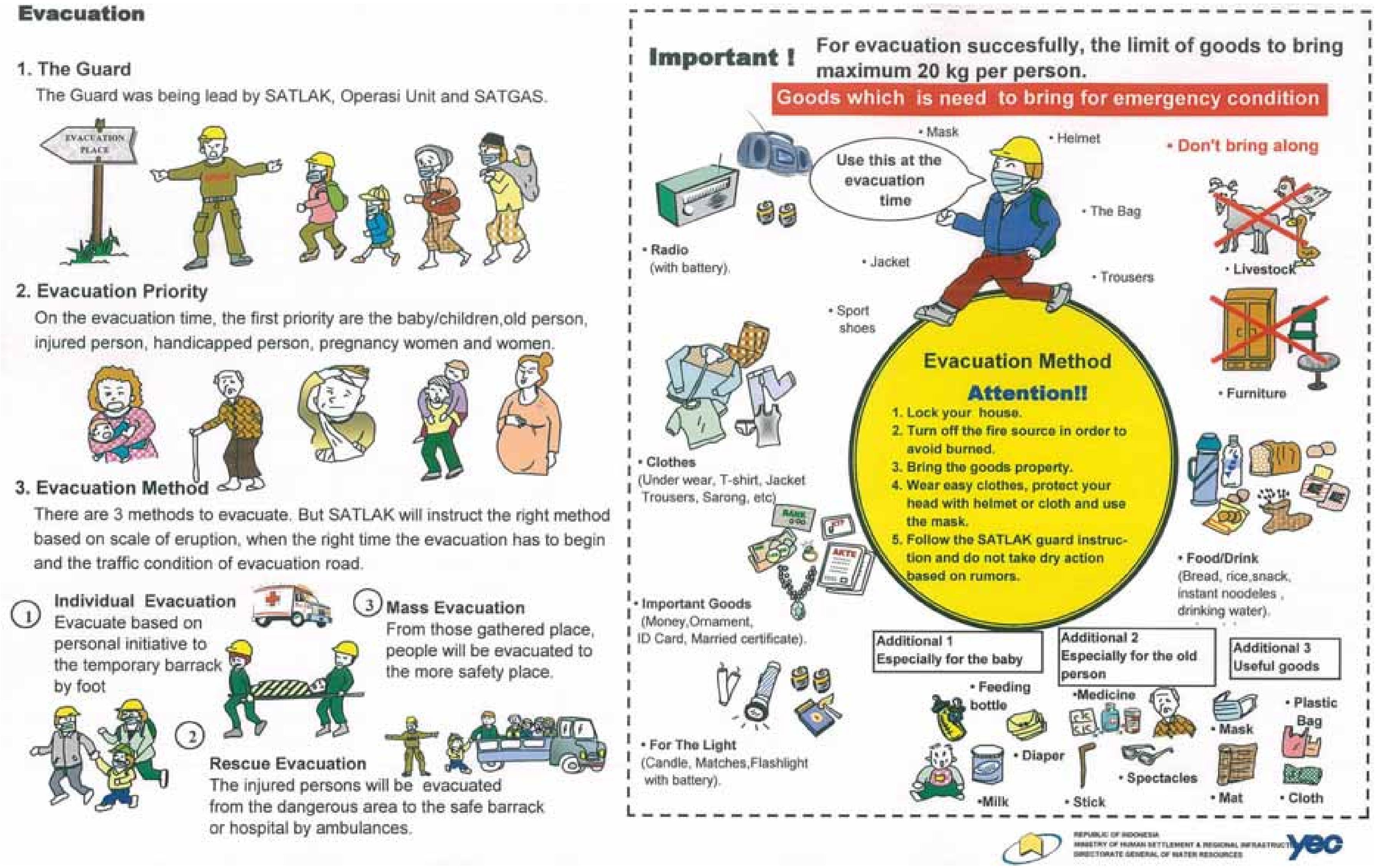


Fig. 4.2 An example of the disaster prevention poster (Merapi Volcano, Indonesia) [12)]

4.1.3 Disaster prevention posters

Disaster prevention posters for the people shall be prepared by extracting important points that should be kept in mind for disaster prevention or during evacuation. Those posters shall be put up at schools, churches, mosques, a village office, or other public facilities to enhance disaster prevention awareness of the local people and their knowledge for safe evacuation.

Various disaster prevention posters have been prepared in many countries in the world. Fig. 4.2 is an example prepared in Indonesia for sediment disasters (a pyroclastic flow, a debris flow) at volcanic Mt. Merapi.

4.2 Development of Evacuation Facilities

The roads and signs used for evacuation should be adequately developed and maintained to enable quick and safe evacuation when a disaster is forecasted and people are instructed to evacuate. Also, refuge areas and refuge facilities should be adequately established so that people can conserve themselves from sediment disasters and lead a life for some in safety. This kind of evacuation facilities is explained below.

<Evacuation roads and evacuation signs>

The evacuation road at sediment disasters must be selected a safe road to disasters. In addition, the conditions of roads existing on the evacuation routes shall be surveyed and narrow or poor roads have to be widened or repaired so that vehicles for evacuation can go through smoothly. Together with the development of evacuation roads, evacuation signs to show adequate evacuation routes and evacuation directions to people shall also be improved.

<Refuge areas and refuge facilities>

The refuge areas shall be not only safe against sediment disasters but also safe against every kind of adversities. The refuge areas include temporary gathering places before evacuation, temporary refuge areas, short-term and long-term refuge areas. Depending on social conditions and forecasted disaster levels, appropriate refuge areas shall be selected and secured. In general, schools, community centers, park grounds, public facilities are used as the refuge areas.

Living in tents in the refuge area is one form of refuge life, but it is important to set up refuge facilities when the refuge life may drag on. It is good to use these refuge facilities as the public facilities at normal times.

<Provision and stockpiling of emergency goods>

To conserve the life and heath of the people during disasters, the principal foods and the water must be stockpiled. As the emergency, food has to be kept in stock. As to the principal foods, the stocks in a wider area must be grasped and shall be supplied to a disaster-stricken area smoothly when a disaster has occurred. Also, presupposing that water works will fail if a disaster occurs, emergency water tanks shall be set up in safe places and emergency water supply vehicles shall be made available beforehand.

4.3 Education and Enlightenment on Disaster Prevention

4.3.1 Education and enlightenment for the local people

To enhance the disaster prevention awareness of the local people and make them quickly evacuate when a disaster has occurred, it is very important to provide education and enlightenment on disaster prevention and evacuation to those people. The methods to be taken for such an education and enlightenment are explained below.

<Dissemination of disaster prevention knowledge>

To promote disaster prevention activities, the self-consciousness and cooperation of each resident is essential. For that purpose, the disaster prevention knowledge must be distributed and the disaster prevention awareness must be improved through school education and community activities.

<Events on disaster prevention>

To enhance the disaster prevention awareness of the local people and make them understand the danger of sediment disasters, a variety of events, such as a lecture and a fair for disaster prevention, shall be held utilizing disaster prevention manuals, disaster prevention maps, disaster prevention posters, and disaster prevention videos.

<Warning and evacuation training>

Simulating that a sediment disaster is occurring or has occurred, warning and evacuation training consisting of a warning transmission, an evacuation, and a disaster relief shall be carried out in cooperation of disaster prevention-related organizations, voluntary disaster prevention groups, and the local people. In particular, it is desirable to designate something like the Disaster Prevention Day or Disaster Prevention Week in areas and carry out a large-scale disaster prevention/evacuation training approximately once a year with the cooperation of the national government, prefectural and municipal governments, and disaster prevention-related organizations. The disaster prevention training shall be carried out according to the disaster prevention manuals and under the instructions of a supervisor charged with regional disaster prevention.

4.3.2 Human resources development, organizational strengthening, and public consultation

To enable smooth and adequate evacuation, quick and appropriate instructions to the local people, a cooperative relationship between the local people and the local officials in charge of disaster prevention, and the mental and financial support extended to the evacuees are all indispensable. For that purpose, human resources development, organizational strengthening, and public consultation as shown below are of prime importance.

- Training to improve an ability of the officials in charge of disaster prevention at prefectural/municipal governments
- Organizational strengthening of disaster prevention organizations (organizations responsible for the delivery of warning information, organizations responsible for the emergency response against sediment disasters, and local disaster prevention organizations) so that they can execute their disaster prevention measures effectively.
- Public consultation meetings relative to disaster prevention and evacuation

4.4 Disaster Prevention and Evacuation Activities Taken by the Local People

Disaster prevention and evacuation activities against sediment disasters shall be undertaken not only by disaster prevention organizations of the national and local governments but also by an active participation of the local people. Both of them should join forces to execute flood-fighting activities, evacuations, guidance as well as the relief of disaster-affected people. These activities are particularly important to prevent the enlargement of damage and to execute disaster prevention activities without impediments. For that purpose, establishment of voluntary disaster prevention groups by the local people themselves based on the solidarity in the area and their awareness to conserve one's own life and properties by oneself, shall be promoted actively.

To mitigate damage due to sediment disasters as the disaster prevention efforts by the local people, they should understand the types of sediment disasters, their precursors, and the measures that need to be taken. It is important to keep eyes on rainfalls, earthquakes, and other abnormal phenomena from ordinary times and prepare every possible countermeasure. As presented in Table 2.1 in Chapter 2, sediment disasters exhibit various precursors which can be detected by humans. When those precursors are captured before or after a long rain, a heavy rain, or an earthquake, the local people are encouraged to report it to an organization in charge of disaster prevention.

REFERENCES

GENERAL

CHAPTER 1

1) アサヒ･コムホームページ http://www.asahi.com/

BASIS OF SEDIMENT DISASTER

CHAPTER 1

2) 国土交通省河川局ホームページ http://www.mlit.go.jp/river/sabo/index.html
3) 防災学ハンドブック：京都大学防災研究所編集，朝倉書店
4) 新砂防工学：塚本良則・小橋澄治編，朝倉書店
5) 砂防学概論 土木教程選書：高橋精二著，鹿島出版会
6) 砂防学講座 第 6 巻－１「土砂災害対策－扇状地対策・土石流対策等(1)」：社団法人砂防学会監修，山海堂

CHAPTER 2

7) 自然災害と防災の科学：水谷武司著，東京大学出版会
8) インドネシア共和国 火山地域総合防災プロジェクト
9) ネパール王国 自然災害軽減支援プロジェクト

CHAPTER 3

10) 土砂災害警戒避難基準雨量の設定手法：国土技術政策総合研究所資料 No.5、2001 年 9 月

CHAPTER 4

11) 雲仙・普賢岳噴火と火山噴火対策砂防事業：建設省・長崎県，1993 年 8 月
12) Consulting Services for Mt. Merapi and Mt. Semeru Volcanic Disaster Countermeasures Project (Phase II) <Mt. Merapi Project>, Main Report for Review Master Plan Study: KIMPRASWIL and Yachiyo Engineering Co., Ltd., October 2001
13) 中華人民共和国 水利人材養成プロジェクト
14) フィリピン共和国 治水・砂防技術力強化プロジェクト
15) マレーシア 農業省灌漑排水局 派遣専門家

PLANNING OF WARNING AND EVACUATION SYSTEM

CHAPTER 1

16) 土石流危険渓流および土石流危険区域調査要領(案)：建設省河川局砂防部砂防課，平成 10 年 12 月
17) 土砂災害防止に関する基礎調査の手引き：財団法人砂防フロンティア整備推進機構，平成 13 年 6 月
18) 土石流危険渓流カルテ作成要領(案)：建設省河川局砂防部砂防課，平成 11 年 6 月
19) 急傾斜地崩壊危険箇所等点検要領：建設省河川局砂防部傾斜地保全課，平成 11 年 11 月

CHAPTER 2

20) 地域住民にわかりやすい防災システムについて－地域防災学習マップ(Country Watching Map)による防災システムの構築－：瀬尾克美ほか，砂防学会誌 Vol.53(No.5), 2001

CHAPTER 3

21) 平成 14 年度 土砂災害警戒情報のあり方と今後の施策に関する報告書：土砂災害警戒情報に関する検討委員会
22) 平成 8 年度 建設技術移転指針策定調査（土砂災害予警報・水資源管理・緊急通信システム）報告書：建設省／社団法人国際建設技術協会，平成 9 年 3 月

CHAPTER 4

23) 内閣府防災部門のホームページ http://www.bousai.go.jp/map/kagosima.html
24) 防災工学：石井一郎編著，森北出版株式会社