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Uncertainty in Flood Risks and Public Understanding of Probable Rainfall

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1 Introduction

Flood risk data presented in hazard maps and other materials may be generally considered reliable. Such data, however, are not completely reliable, although they are obtained through calculations using methods and according to standards that are reliable to a certain extent. There also exists a gap in the understanding of data between professionals and the public. That gap may exacerbate the damage caused by floods. The Pafrics, which we developed in our project (Chapter 13), will be a useful tool for bridging this gap. In this chapter, we discuss the uncertainties involved in the determination of flood risks and the concept of risk assessment considering such uncertainties. Our present level of knowledge cannot easily accommodate such uncertainties. In relation to hydrological and hydraulic factors, numerical models are employed for such uncertainties (stochastic and/or statistical models, e.g. Bolgov *et al.*, 1998), but they are not yet perfect. We explain the existence of such uncertainties specifically using hydrological statistics as an example, which are used in flood prevention planning. The unpredictability in hydrological statistics, which is due to uncertainty and variability (Vose, 2004), and the difference between estimated probabilities of rainfall and earthquakes are also discussed. In addition, we present the results of questionnaire surveys regarding public understanding of probable rainfall, which is used in hazard maps.

2 Physical Processes of Flooding

Flooding is generally composed of four processes: (i) rainfall as input, (ii) runoff, (iii) flooding, and (iv) depth of inundation as output (Fig. 1). Each process is described below.

(i) Rainfall as input

Rain falls for certain reasons. (In grasping flood phenomena, rainfall is handled as an outright external force. The intensity of rainfall is estimated based on hydrological statistics using past rainfall data.)

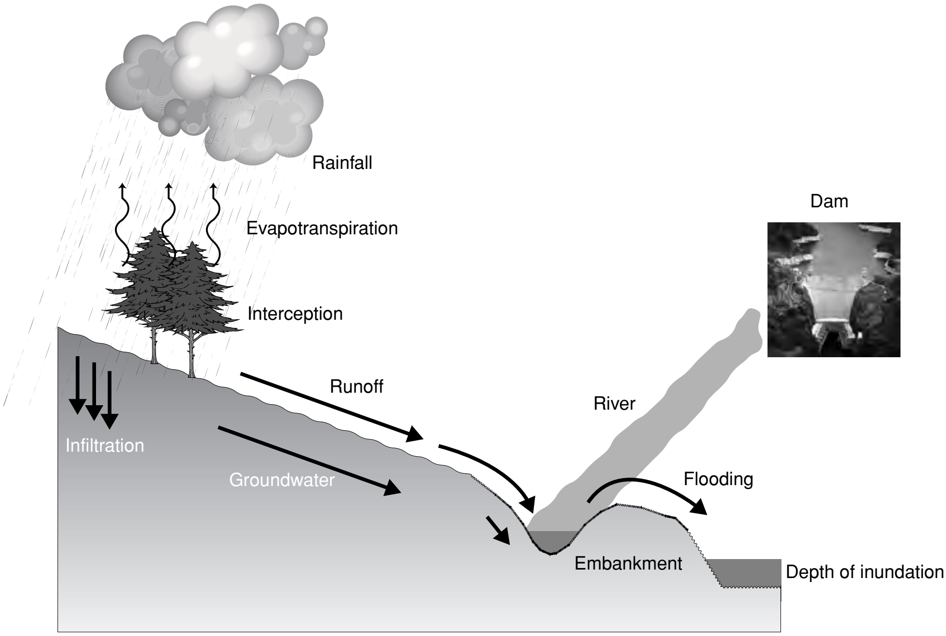

Fig. 1. Physical processes related to flooding.

(ii) Runoff

Not all of the rainfall flows off the ground surface. Some rainfall is intercepted by trees or infiltrates the ground and only some rainfall flows off the ground surface. The water infiltrating the ground also flows out to the surface some time later. Thus, rainfall does not match runoff at a given point in time. Identifying the percentage of rainfall that flows off the surface according to the characteristics of the ground surface or soil is therefore necessary.

(iii) Flooding

Overland water flows into rivers or onto roads. The routes of runoff are determined by elevation and obstacles such as buildings. Where rivers overflow their banks depends on the flow in the river, the shape of the river, and the strength of embankments. It is therefore necessary to identify where the runoff water concentrates and where rivers are most likely to overflow their banks.

(iv) Depth of inundation as output

The water overflowing banks flows into another area or is discharged by area drainage systems into sewers. Finally, the distributions of water level and changes in water level with time at the place of overflow and in surrounding areas are obtained. The depth of inundation determines the magnitude of flood damage.

3 Key Flood Risk Factors

Key determinants of flood risks are listed below (National Research Council, 2000).

- Hydrological factors
- Hydraulic factors
- Structural and geotechnical factors
- Material and construction factors
- Seismological factors
- Other geophysical factors
- Operation and maintenance factors

Hydrological factors include rainfall, flooding, and basin and channel data. Hydraulic factors are the characteristics of floodwater propagation and the equations and methods used to simulate such propagation. Structural and geotechnical factors refer to the geographical and geological characteristics of ground and soils. Material and construction factors mean the materials and methods used for constructing structures such as dams and embankments. Seismological factors include the destruction of dams, embankments, and other structures, as well as soil liquefaction due to earthquakes. Other geophysical factors are the behavior of ice in dam reservoirs or rivers, lightning, and tornadoes. Operation and maintenance factors refer to the operation of dams in emergencies and the maintenance of river systems.

4 Propagation of Uncertainties and the Present Response

Flood risk factors are interrelated. Uncertainties in a single factor may lead to greater uncertainties as they propagate even where other factors are perfectly modeled. Rainfall, runoff, depth of inundation, and the magnitude of damage are calculated in this order as parameters related to flooding. Small margins of errors in rainfall increase gradually as margins of error are accumulated in respective steps. The present level of knowledge has difficulty in handling such uncertainties perfectly. In relation to hydrological and hydraulic factors, models are being employed that provide for such uncertainties (stochastic and/or statistical model, e.g. Bolgov *et al.*, 1998), but they are not yet perfect.

One of the serious problems in disaster prevention planning is the lack of public understanding about the numerous uncertainties involved in flood risk estimation. The next section specifically explains how such uncertainties come about using, as an example, hydrological statistics which provide a basis for flood prevention planning.

5 Uncertainties in Hydrological Statistics

Hydrological statistics are used to estimate the intensity of potential rainfall based on past rainfall data. For example, the intensity of 100-year probable rainfall is obtained based on past rainfall data. This serves as a basis for developing flood prevention plans. In Class-A rivers, it is required that embankments can be strengthened to endure the 100- or 200-year probable rainfall expected in the area in question.

Hydrological statistics involve the following uncertainties.

(i) Uncertainty of probability

(ii) Uncertainty of data

(iii) Uncertainty owing to the use of a finite number of data

(iv) Uncertainty attributable to variation in probability estimation methods

(v) Uncertainty attributable to climate changes

Detailed explanations follow.

(i) Uncertainty of probability

There can be no assurance that 100-year probable rainfall events will occur only once in 100 years. The occurrence of such an event in any given year cannot ensure there is no 100-year probable rainfall event in the next year. Such events could occur in two consecutive years. Probability therefore involves uncertainty. There may, however, be misunderstanding among the public about this point in numerous cases. (This matter will be discussed again in following sections.)

(ii) Uncertainty of data

Data that are used to estimate probabilities always involve margins of error. The older the data is, the greater the margin of error. The probability of rainfall estimated based on error-prone data therefore involves uncertainties.

(iii) Uncertainty owing to the use of a finite number of data

Only a limited amount of data on past rainfall events is available. Those on rainfall events more than 100 years ago are particularly scarce. Probable rainfall estimated based on a limited amount of data involves uncertainties.

Table 1. Estimated probability of the Tokai heavy rainfall.

Case A	Kawata (2002)	At least once in 200 years
Case B	Mizutani (2002)	At least once in 1000 years
Case C	Ushiyama and Takara (2002)	Once in 40 137 years

(iv) Uncertainty attributable to variation in probability estimation methods

Probabilities are estimated by various methods. Logarithmic normal distributions are suitable for expressing annual extreme values over a relatively long term (a month or a season). Extreme-value distributions can properly represent annual extreme values over a relatively short term (a day or an hour). Non-annual data can be handled well using exponential distributions. The selection of the method, however, is basically arbitrary. No choice is regarded as mathematically wrong. Actually, though, results can vary greatly according to the method selected. The fluctuation is outstanding in areas of poor reliability; e.g., low-probability events such as 100-year probable rainfall events. Estimation of probable rainfall therefore involves uncertainties.

(v) Uncertainty attributable to climate changes

When estimating the amount of rainfall for a certain probability based on past rainfall amounts, it is assumed that climate remains unchanged from the past. Climate, however, does change, which in turn causes the mode of rainfall to change. Phenomena due to natural climate changes, such as cold summers and warm winters, are well known. Man-made climate changes, including CO2-induced global warming, have also become an issue. These uncertainties are inherent in the estimation of the probability of rainfall.

Finally in this section, let us consider an example of the calculation of probable rainfall. The estimated probability of the Tokai heavy rainfall that occurred on September 11, 2000 (daily rainfall: 428 mm, peak hourly rainfall: 97 mm) vary from once in approximately 200 years to once in 40,000 years according to researchers (Table 1). The variations are ascribable mainly to the duration of data collection (data volume) and the method of probability estimation. These variations cause an uncertainty of design for disaster prevention structures (e.g. embankments and dams) and a social problem of environmental destroy by the structures (Ohkuma, 2004).

6 Peculiarities and Unpredictability of the Probability of Rainfall

The probability of rainfall has different aspects from ordinary probabilities (e.g., those when rolling dice). Each face of a die is likely to come up once in six rolls, as has been true in the past and will be in the future. That is not always the case with rainfall. Suppose the probability of a certain amount of rainfall is 1/100 in a given year. If a certain amount of rainfall exceeding the expected amount occurs several times in the next 10 years, the probability of that amount of rainfall will no longer be considered to be 1/100; it will be higher. This is related to the uncertainties due to climate changes. Once the mode of rainfall changes, there will be no assurance that the probability of a certain amount of rainfall occurring in the future can be estimated based on the past rainfall amounts. Even without climate changes, calculating the probability of a certain amount of rainfall in a given year from the past rainfall amounts is not guaranteed to be accurate; it is simply based on an assumption. The issue is how to make such an assumption. This is closely related to the prior probability in Bayes' theorem in statistics. (For Bayes' theorem, refer to the Statistics Section, Department of Social Sciences, College of Arts and Sciences, University of Tokyo (1992).) Regarding the application of Bayes' theorem to stochastic prediction, Katayama (1975) and Matsumura (2004) point out some interesting considerations concerning seismic prediction.

Unpredictability is attributable to uncertainty and variability (Vose, 2003). Uncertainty means a lack of knowledge about phenomena. Variability refers to the accidental or stochastic action of phenomena. These two factors generally combine to create unpredictability. In the case of probable rainfall, uncertainty of data, uncertainty owing to the use of a finite number of data, and uncertainty due to variation of probability estimation methods are "uncertainty". Uncertainty of probability and uncertainty due to climate changes should be regarded as "variability". The unpredictability of climate changes may, however, be "uncertainty" ascribable to our insufficient knowledge. The probability of rainfall differs from that when rolling a die in these respects.

7 Difference between Probabilities of Rainfall and Earthquakes

The probabilities of earthquakes and rainfall events are based on the same concept. They, however, vary in three respects.

(i) To estimate earthquake probabilities, the Brownian passage time (BPT) distribution based on Brownian movement is frequently used. This is because earthquakes and Brownian movement share a physical property that can be described by a Markov process which depends only on the immediately preceding phenomenon. The BPT distribution, unlike other mathematical distributions, facilitates physical interpretation and exhibits an upward-sloping line, even over an infinite period of time. Rainfall is basically a Markov process independent of the past (like rolls of a die), so using the BPT distribution to estimate the probability of rainfall is not physically justifiable.

(ii) Earthquake probabilities are calculated only for selected earthquakes of intensities that are unique to the area. For example, in the southern Kanto area, magnitude-8 earthquakes occur more frequently than magnitude-7 earthquakes. The magnitude-8 earthquakes in the area contradict the power law that smaller earthquakes occur more frequently than greater earthquakes (a drop of one in the magnitude means an earthquake is likely to occur 10 times more frequently), and are regarded as earthquakes of an intensity unique to the area. The accuracy of probability is therefore increased by selecting for calculation only magnitude-8 earthquakes (which occur at an interval of approximately 200 years). This depends on the characteristic of earthquakes. That is, the intensities of past earthquakes up to approximately 600 years ago (approximately 2000 years ago in China) can be identified based on archival data on seismic motions or the destruction of buildings. Rainfall-induced runoff, on the other hand, depends on the ground surface condition at a given place in a given age, so estimating rainfall from the descriptions of rainfall or runoff in ancient documents is difficult. In addition, great earthquakes do not occur every year, so probabilities are calculated only for great earthquakes, but heavy rains occur every year, so the probabilities of rainfall are calculated every year based on the maximum annual rainfall. More accurate probabilities, however, may be calculated based on 100 leading rainfall events during the past 100 years rather than on the 100 maximum heavy rainfalls during the past 100 years.

(iii) For earthquakes, cumulative probabilities (e.g., the probabilities of magnitude-8 earthquakes occurring in 10 years, or in 30 years) are calculated based on the assumption of an underlying physical process (a process of releasing stresses and then accumulating stresses again). This is possible because earthquakes can be described using a Markov process that depends only on the state of an immediately preceding earthquake. Rainfall, on the other hand, is a Markov process independent of the past (like rolls of a die), so the idea of cumulative probability based on an assumed physical process is difficult to apply. The probability of a 100-year probable rainfall occurring in 10 years, of course, can be mathematically calculated, but no physical process is assumed. Even without any heavy rains in the next year, the probability of 100-year probable rainfall events occurring in 10 years remains the same as in the previous year (as in the case of rolls of a die). On the other hand, histories of water content in soils or groundwater volume are available, so an approach similar to that for earthquakes may be applicable to the estimation of landslide probabilities or groundwater-runoff volumes. In addition, in rainfall events, unlike earthquakes, direct observation of the source of the event (such as atmospheric conditions) is possible. For example, the probability of a typhoon causing heavy rainfall of more than x mm can be estimated based on the moisture contained in the air.

8 Flood Risks and Their Uncertainty

One of the greatest problems involved in the uncertainties of flood risks is that various flood forecasts are considered to be certain although they actually contain stochastic factors. One-hundred-year probable rainfall, for example, does not necessarily occur only once in 100 years[1]. It may occur several times in a short period of time. The occurrence of a flood therefore never guarantees relief for a certain time period. Daily preparedness therefore becomes important.

From a stochastic viewpoint, a general concept of flood risk can be expressed quantitatively as

$$\text{Risk} = (\text{Probability of the hazard}) \times (\text{Damage caused by the hazard}).$$

Note that the risk expressed above is neither a vague mood nor an abstract word, but can be expressed numerically using the probability of and damage caused by a hazard, and that knowing the scale of a risk and taking appropriate control measures help reduce the potential damage. This probability and the scale of a risk, however, contain numerous uncertainties.

Particularly when estimating the magnitude of damage, the scale and definition of damage, and the value judgment or psychological factors of the organizations or individuals evaluating risk should be taken into consideration. Numerous uncertainties are also involved in risk evaluation by organizations or individuals. It may be natural for local residents who have suffered from large-scale flood damage over a long time to demand that the government improve rivers and construct estuary barrages or seawalls. There have, however, been vigorous campaigns calling for the protection of the natural environment, leading to protests against river improvements on numerous occasions. The former group focuses on the risk of flooding while the latter group focuses on the risk of degrading the environment. Differences in viewpoints, interests, or values cause such differences in focus. In addition, even among those paying attention to the same risk, the scale of acceptable risk may vary according to individual viewpoints.

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[1] For example, the probability of a 100-year probable rainfall occurring at least once in the next 30 years is relatively high at approximately 26% ($1 - (99/100)^{30} = 0.26$), although this is contrary to common knowledge.

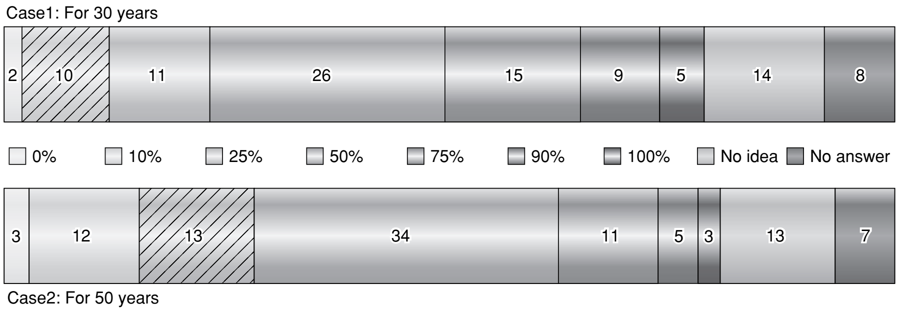

Fig. 2. What do you think is the probability of a 200-year probable rainfall occurring once in 30 or 50 years? (Nagoya City).

9 Questionnaire Surveys to Assess the Recognition of Uncertainty and the Understanding of Probable Rainfall

Questionnaires were distributed to residents to assess their understanding of probable rainfall, which is used to prepare flood hazard maps.

Questionnaires were distributed in Nagoya City and Nishibiwashima Town which suffered severe flood damage on September 11, 2000. Both of the local governments developed a flood hazard map after the flood and distributed copies to residents in 2002. Questionnaires were distributed to 3000 households in the areas expected to be inundated in the flood hazard map. Responses were obtained from 644 households.

The questionnaire included two questions about probable rainfall that residents had to understand to grasp the zones vulnerable to inundation specified in the hazard map. The questions were "What do you think is the probability of a 200-year probable rainfall occurring in the next 30 and 50 years?" (The right answers were 14 and 22%, respectively.) In Nagoya City, 10% of respondents provided the right probability for the next 30 years, and 13% gave the right answer for the next 50 years (Fig. 2). The corresponding percentages were 5 and 15% in Nishi-biwashima Town (Fig. 3).

The results indicated that residents had insufficient knowledge about the concept of probable rainfall defined by the expert although this knowledge is essential in understanding which zones are vulnerable to inundation, as shown in the hazard map.

10 Closing Remarks

Numerous uncertainties are involved in the determination of flood risks. In flood risk assessment, differences in viewpoints, interests, or values re-

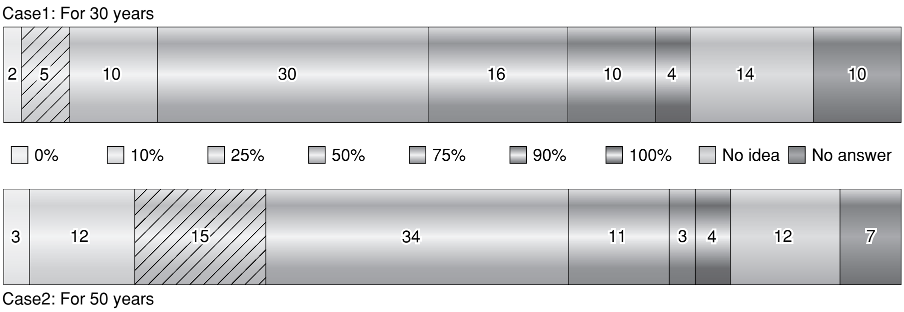

Fig. 3. What do you think is the probability of a 200-year probable rainfall occurring once in 30 or 50 years? (Nishi-biwashima Town).

sult in differences in risk focus. Each individual should determine what he or she considers an acceptable risk and take appropriate action while keeping the above in mind. The questionnaire survey results presented in Section 9 show that most residents have a poor understanding of probable rainfall. Proper knowledge about probability is indispensable to understand flood disaster risk, especially, understanding of the content on uncertinties involved in the mid/long-term probability. Support should be provided through workshops to help the public properly understand the uncertainties inherent in determining flood risks.

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