JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
AUGUST AMERICAN WATER RESOURCES ASSOCIATION 2006

AN EMPIRICAL MODEL OF FATALITIES AND INJURIES DUE TO FLOODS IN JAPAN[1]

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ABSTRACT: This paper provides a framework for analyzing flood fatalities and injuries, and it describes the derivation of a generalized flood risk (i.e., flood consequences and their probabilities) function by introducing an integrated index (the number of residential buildings affected by a flood) that represents the major change in the power relation among the flood intensity, regional vulnerability, and resilience. Both the probabilities and the numbers of fatalities and injuries clearly increase significantly after the flood severity (in terms of the number of inundated buildings) passes a branch point. Below the branch point, it is still possible for fatalities and injuries to occur because of the variability in the data and the uncertainty in the predicted fatality values. The empirical models of fatalities and injuries due to floods in Japan suggested the usefulness in predicting fatalities and injuries and evaluating the efficacy of the warning or other emergency response measures.

(KEY TERMS: fatality and injury; life loss; empirical model; flash flood; rainy season flood; Japan.)

Zhai, Guofang, Teruki Fukuzono, and Saburo Ikeda, 2006. An Empirical Model of Fatalities and Injuries Due to Floods in Japan. Journal of the American Water Resources Association (JAWRA) 42(4):863-875.

INTRODUCTION

Floods are one of the oldest, most frequent, and most severe natural disasters to which human beings are exposed. According to a study by the Munich Reinsurance Company, floods killed some 11,000 people in 2002, accounting for 50 percent of human losses caused by major natural catastrophes in that year, and flood damage shows an increasing trend (MunichRe, 2003). Flooding in Central and Eastern Europe in August 2002, killed more than 100 people. Heavy rain in Japan during the period of July 17-21, 2003, caused mudslides that killed 23 people and injured 21 more (Fire and Disaster Management Agency of Japan, 2003). Reducing flood fatalities and injuries by applying not only "hard" countermeasures such as dams and levees, but also "soft" measures, such as early warning systems and strengthening the awareness of flood risk (i.e., flood consequences and their probabilities), has thus become common sense. Usually, cost benefit analysis is applied to help make decisions on the measures to be taken.

Although loss of life is seen as a major consequence of floods, there is a limited number of methods available for estimating the number of fatalities caused by floods (Jonkman *et al.*, 2002), and such a consideration is often excluded from cost benefit analyses. An important rational explanation for this exclusion is that it has been regarded as "difficult to predict the loss of life, because the loss depends on the natural elements such as the time of the flood's occurrence and social elements such as the early warning system and evacuation measures" (Ministry of Land, Infrastructure and Transport, Japan, 2000). Therefore, after reviewing the limited existing studies on flood fatalities, this work aimed to develop a framework for estimating the number of fatalities and injuries due to floods in Japan and their probabilities.

This paper is organized as follows. First, after briefly reviewing the existing studies on flood fatality

[1]Paper No. 04155 of the *Journal of the American Water Resources Association* (JAWRA) (Copyright © 2006). **Discussions are open until February 1, 2007.**

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models, an analysis framework is developed for flood fatalities and injuries. For this framework, an integrated index (the number of buildings affected by floods) is introduced, which represents the major change in the power relation among the flood intensity, regional vulnerability, and resilience. Then, the relations between fatalities (injuries) and building damage are empirically analyzed. Empirical models of fatalities and injuries are thus established for different periods and different flood types by utilizing data obtained from the annual statistics published by the Ministry of Land, Infrastructure and Transport, Japan, from 1953 to 2001. Finally, the models are evaluated by considering the recent floods occurring in Niigata and Fukushima Prefectures, Japan, in July 2004, and historical flood data.

A FRAMEWORK FOR MODELING FATALITIES AND INJURIES FROM FLOODS

Review of Existing Studies on Flood Fatalities and Injuries

Flood fatalities and injuries depend on flood characteristics and social vulnerability. Flood characteristics include water depth, rate of rise, stream velocity, wind, and temperature, while social vulnerability refers to population, land use, systems for warning and emergency assistance, preparedness, and so on. Because of the lack of data, most estimation methods for flood fatalities and injuries have been limited to considering only a few factors. The data sources differentiate the models into two types: statistics-based macro models (using data from a particular flood, or historical flood data), and experiment-based micro models.

Concerning the models derived from particular floods, Waarts (1992) established two relations between the water depth and mortality from data for a 1953 flood in which a storm surge on the North Sea inundated a large part of the Southwest of the Netherlands and caused 1800 deaths. Improvements in Waarts' functions (van Manen *et al.,* 1994) have added the rate of water rise as a factor. The models developed by the Netherlands Organization for Applied Scientific Research (TNO) (Vrouwenvelder and Steenhuis, 1997) for sea and river floods consider three causes of drowning: the collapse of buildings near a dike breach, the collapse of buildings from waves, and all other causes. The model proposed by Jonkman (2001) takes into account the effects of high stream velocities on buildings and humans.

Most models, however, have been obtained through statistical analyses of historical flood data. For example, regarding injuries and fatalities due to dam breaks, Brown and Graham (1988) proposed a model in which the numbers of fatalities and injuries are functions of the population and the time available for evacuation. DeKay and McClelland (1993) improved this model by distinguishing "high lethality" areas, such as canyons, and "low lethality" areas, such as flood plains. In 1999, Graham (1999) provided a framework for estimating the numbers of fatalities and injuries due to dam failures as functions of the flood severity, the number of warnings, and the populace's understanding of flood severity. After critiquing existing life loss models in dam safety assessment, McClelland and Bowles (2002) presented a summary of historical insights on the levels of subpopulations at risk, by using nearly 100 carefully defined variables. Their work culminated by presenting the conceptual basis for a new life loss model, which remains under development. Aboelata *et al.* (2003) have developed a modular geographical information system (GIS) model that is being developed in order to estimate the potential loss of life from natural and dam-failure floods.

Mizutani (1996) proposed fatality and injury functions for typhoons by using Japanese historical data from 1946 to 1995, which took into account the landing power and other, subordinate factors, such as the landing time, the area, and tidal waves. Stability functions have also been obtained (Abt *et al.,* 1989; Lind and Hartford, 2000) in experiments on human subjects placed in a flume to determine the velocity and depth of flow that cause instability.

All of the above methods are based on the idea that the number of fatalities and injuries are functions of the flood characteristics and social vulnerability, and they are formulated directly. A truly satisfying theoretical model has not been completed; however, this is primarily due to the lack of empirical underpinnings (McClelland and Bowles 2002). As noted by Jonkman (2005), mortality is strongly correlated with flood type. It is thus important to develop an empirical model of flood fatalities that reflects both the flood type and regional characteristics. Because dam breaks, generally considered human induced (or manmade) disasters, are rare in Japan in recent history, they are excluded from this study. The scope is limited to the most common types of floods in Japan, namely freshwater flooding (rainy season floods and flash floods).

Loss of life resulting from dam failure is highly influenced by three factors: (1) the number of people occupying the flood plain below the dam, (2) the amount of warning time given to the people exposed to dangerous flooding, and (3) the severity of the flooding (Graham 1999). In addition, nearly 100 quantitative or categorical variables can be considered to affect the number of flood fatalities due to a dam failure (McClelland and Bowles 2002). It would be ideal to include all of these variables (factors) into an estimation model for flood fatalities, but it could be nearly impossible because of the insufficiency and uncertainty of flood data. It would be more reasonable to first consider the most important factor to be included in the model. Then, if possible, the second, third, and subsequently most important factors can be sequentially included.

Early warning and evacuation is the best method for reducing the loss of life from floods. The percentage who evacuate (i.e., those who go to shelters), however, is always low in Japan, averaging only 26 percent and generally less than 40 percent in the case of 18 recent flood evacuations. Moreover, most residents start evacuating either after or just before a dike break, even when the evacuation was initiated several hours earlier, as in the case of the 2004 Niigata-Fukushima Flood (Katada Lab, 2004). Two of the main reasons for this is: (1) flood information is not correctly given to residents because of the short period (usually several hours) between the rise of river water and a dike break, which is quite different from the case of a continental river system (usually several days); (2) residents may not understand the intimidating situation of a flood even if they are informed of it, because of the "not me" factor noted by Joffe (1999). That is, due to the low probability of natural hazards occurring, some people tend not to consider them problems. This was also observed by Motoyoshi *et al.* (2004). Given the low evacuation rate, and the fact that most residents who do evacuate do so after or just before a dike break, it is necessary to collect data for not only the evacuation time, but most importantly, the temporal distribution of the evacuated population. Because such data is unavailable for most floods in Japan, however, including evacuation factors in the model is difficult at present, and it may reasonably be considered to not significantly influence the performance of the present model because of the low evacuation rate.

Flood severity can be regarded as a complex concept, which may be divided into two categories: the characteristics of a flood per se, such as the flood plain, flood velocity, debris, and flood duration; and the outcome of a flood, such as the numbers of inundated and collapsed buildings, economic damages, and so on. The first category also suffers from a lack of detailed data for most floods, though the outcome of a flood reflects, to some degree, the flood characteristics. Additionally, among the components of the second category, there are strong co-relationships. For example, the larger the flood plain, the greater the number of inundated buildings; the more inundated buildings, the greater the number of building collapses and the greater the economic damages. In fact, the number of inundated buildings reflects, to some extent, the flood severity.

Nonetheless, the number of people occupying a flood plain (i.e., the population at risk) is the most important factor in loss of life. In dam failure research, the population at risk is defined as the number of people who would get wet from a flood if they did not evacuate (McClelland and Bowles 2002). In the case of typical floods in Japan, however, the population at risk is more complex to define, in practice. In Japan, internal flooding results when continuous rainfall exceeds the capacities of sewage systems. Whether evacuation instructions are issued depends on whether the height of a river exceeds a warning level. If river dikes are regarded as being in danger of breaking, residents are instructed to evacuate before external flooding due to the collapse of river dikes occurs. Additionally, flooded areas do not necessarily accord with the areas in which evacuation instructions are issued. Furthermore, not all residents of a flooded area necessarily belong to the population at risk, because in multistory apartment buildings only those living on the first floor, or possibly the second, are affected by floods. Therefore, it is necessary to find an integrated index that can reflect the interrelationships among the flood intensity, regional vulnerability, and resilience.

Physical damage to buildings and property may be regarded as one of the integrated indices representing the major change in the power relation among the flood intensity, regional vulnerability, and resilience. Actually, with the aid of a computer, the number of buildings affected by a flood in any particular region can be simulated with a high degree of accuracy. If a relationship between loss of life (or injuries) and building damage can be determined, the probability and the number of fatalities or injuries can be estimated.

Generalized Fatality and Injury Functions

The number of fatalities or injuries depends on the flood magnitude and population exposure. It can be mathematically formulized as follows.

$$L = L(F,P) \tag{1}$$

$$P = P(F,N) \qquad \rightarrow F = P'(P,N) \tag{2}$$

therefore

$$L = L(P'(P,N), P) \quad \rightarrow L = L^*(P,N) \tag{3}$$

where the symbols are defined as follows: L is the number of injuries or fatalities; F is the flood magnitude; P is the population exposed to the flood; N is the regional population; $L(.)$ and $L^*(.)$ are the injury or fatality function; $P(.)$ is a function of the population exposed to the flood; and $P'(.)$ is an inverse function of the population exposed to the flood.

In a given period and region, if the total population is regarded as constant, the numbers of fatalities and injuries then become functions of the population exposed to flooding (i.e., the population remaining after evacuation of a flooded area). If the exposed population is proportional to the number of inundated buildings, including damaged buildings, the fatality and injury function may be transformed into Equation (4).

$$L = S(H) \tag{4}$$

where $S(.)$ is the function and H is the number of inundated residential buildings.

The number of buildings inundated by a given hypothetical flood can be estimated with high accuracy by applying a flood simulation. Therefore, the numbers of fatalities and injuries for such a flood can be estimated. If Equation (4) is divided by the total population P, the fatality (injury) probability per event is obtained as Equation (5). Here, n is the number of residents per building.

$$R = \frac{L}{P} = \frac{S(H)}{n \times H} \tag{5}$$

DATA FOR JAPANESE FLOODS

Data Sources

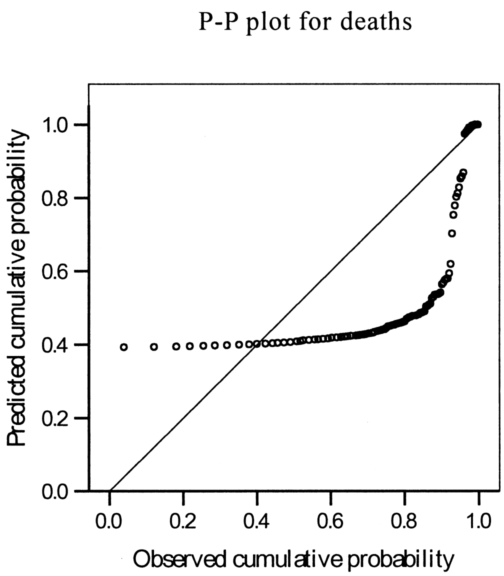
Various ministries and agencies of the Japanese government have compiled statistics on flood damage in Japan. They include the Annual Statistical Directory (*Kishou Youran*) (Central Meteorological Observatory, 1920-1956); Japan Meteorological Agency, (1957-2001); Flood Disaster Statistics (*Suigai Toukei*) (River Bureau, Ministry of Construction, 1947-2000a); River Bureau, Ministry of Land, Infrastructure and Transport (2001a); and Disaster Statistics (*Saigai Toukei*) (River Bureau, Ministry of Construction, 1947-2000b; River Bureau, Ministry of Land, Infrastructure and Transport (2001b), and the Fire Service White Book (*Shoubou Hakushuo*) (Fire and Disaster Management Agency, 1955-1965, 1966-2002). However, the data are not always in accordance with each other, mainly because of different purposes, focuses, and methods. To avoid such discrepancies, the annually published Disaster Statistics (*Saigai Toukei*) (River Bureau, Ministry of Construction, 1947-2000b; River Bureau, Ministry of Land, Infrastructure and Transport, 2001b) were used to construct a database for this analysis. The database consisted of entries of flood event statistics, compiled from 1947 to 2001, on disaster types (heavy rain, typhoon, heavy rain and typhoon), human casualties (dead, missing, injured), damage from building inundation (completely damaged, severely damaged, partially damaged, above ground inundation, below ground inundation), displaced households, displaced people, arable land damage, public facility damage, and so on. Here, according to the guidelines of the Japanese Cabinet Office (2001), a completely damaged building is defined as one whose damaged portion constitutes at least 50 percent of the building, while severely damaged and partially damaged buildings are defined as having damaged portions constituting 20 to 50 percent and less than 20 percent of the building, respectively. Therefore, the number of inundated buildings is the sum of the numbers of completed damaged buildings, severely damaged buildings, partially damaged buildings, buildings inundated above ground, and buildings inundated below ground. The number of residential buildings is used in this analysis, which is strongly related to the exposed population. Because there are no significant regional differences in terms of the types of buildings (RECPAS, 2000), the data may be considered relatively uniform, or to represent a homogeneous setting. No distinction is made between low rise, middle rise, and high rise structures in the data. A total sample number of 269 flood events was completely recorded in the Disaster Statistics from 1947 to 2001. The summary statistics about the buildings inundated and the fatalities are shown in Table 1.

TABLE 1. Summary Statistics About Fatalities, Injuries, and Buildings Inundated.

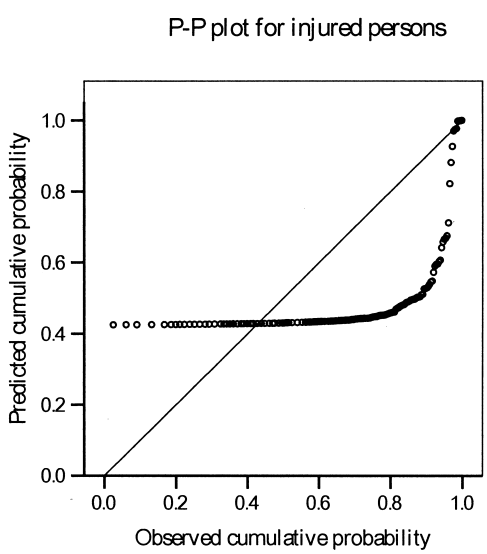
	Minimum	**Maximum**	**Mean**	**Standard Deviation**
Fatalities	0	4,987	101	383
Injuries	0	42,004	522	2,810
Buildings Inundated	2	689,623	52,704	101,402

Data Distribution

Most statistical analysis is based on the premise that the data follows a normal distribution. It is thus necessary to evaluate the data quality before proceeding with the statistical analysis. Figure 1 shows the scatter plots of the predicted cumulative probability and the observed cumulative probability for death or injury from floods before (Figures 1a and 1b) and after transformation to a base-10 logarithm (Figures 1c and 1d). Normality tests of the numbers of both deaths and injuries reject the hypothesis that the data follows a normal distribution at the significant level of 0.05 before the logarithmic transformation, but the tests accept this after the transformation. The scatter plots and normality tests show that the logarithmic transformation improves the data normality for the numbers of both injured people and deaths.



(a)



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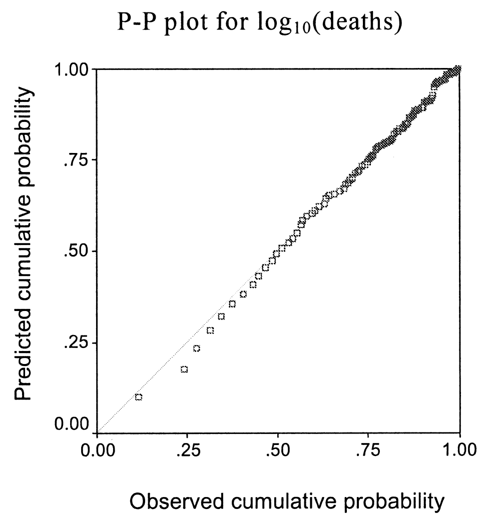
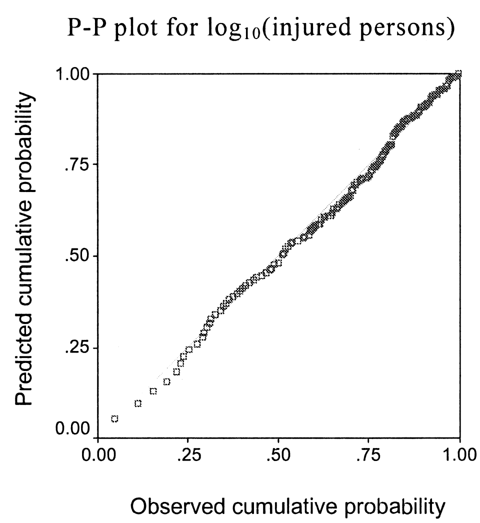


(c)



(d)

Figures 1a,b,c,d. Distributions of the Numbers of Fatalities and Injuries Before and After Logarithm Transformation.

Therefore, it is clear that the numbers of injuries and fatalities follow a log-normal distribution.

Figure 2 shows that the cumulative probability (ratio) of a flood that may cause n and less than n deaths with respect to the total number of flood events increases with the number of inundated buildings. In statistical terms, this can be described as a discrete probability function $f(x_i) = P(X = x_i) > 0$ and a cumulative probability function $F(x_i) = P(X < = x_i)$, $i = 1,2,3 \ldots$. Here, x_i is the number of fatalities due to floods. When the number of inundated buildings is less than 1,000, a flood has a 57.7 percent chance of not causing any deaths (F (*death* = 0)). If one-fatality floods are added, the probability increases to 80 percent. When the number of inundated buildings becomes more than 1,000, however, the percentage of nonfatal floods falls to 17.3 percent, and the percentage of floods causing no more than one fatality becomes 39.5 percent. Therefore, 1,000 inundated buildings are selected as the branch point indicating whether a flood causes fatalities with a high probability.

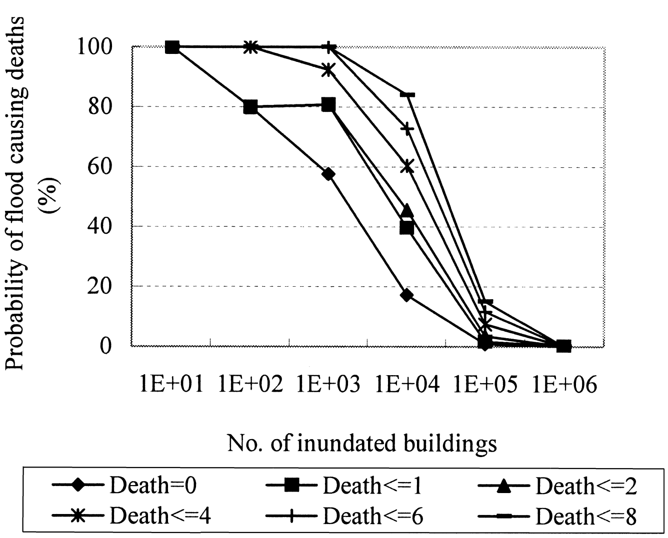


Figure 2. Probability of a Flood Causing Deaths Versus the Number of Inundated Buildings.

If a logistical model is applied to describe the probability of a fatal flood event with at least one death (Zhai *et al.,* 2002), the following Equation (6) is obtained according to the goodness of fit. The Nagelkerke R^2 is 0.419, and the correct classification rate is 93 percent, according to the classification value 0.5. The significant probability of an independent variable consisting of log10 (inundated building number) is less than 0.001.The simulation results show that for 10, 100, or 1,000 inundated buildings, the chance that at least one death occurs is 18 percent, 51 percent, or 84 percent, respectively.

$$Probability\ (fatal\ event) = 1\ (1 + exp(3.139 - 1.595 * log_{10}\ (inundated\ building\ number))) \quad (6)$$

There is a similar pattern for persons injured in floods (Figure 3). When the number of inundated buildings is less than 100, a flood has a 40 percent probability of not causing injuries. If floods causing one injury are added to this figure, the probability increases to 60 percent. When the number of inundated buildings becomes more than 100, however, the percentage of floods not causing injuries is 26.9 percent, and that of floods causing one injury becomes 30.8 percent. Therefore, 100 inundated buildings are selected as the branch point indicating whether a flood causes injuries with a high probability.

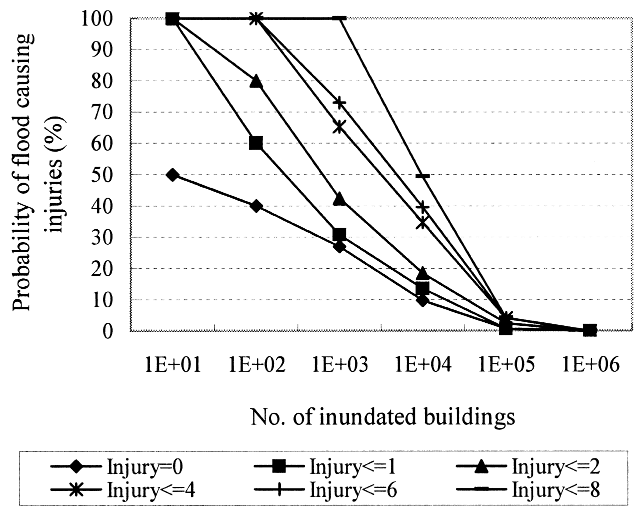


Figure 3. Probability of a Flood Causing Injuries Versus the Number of Inundated Buildings.

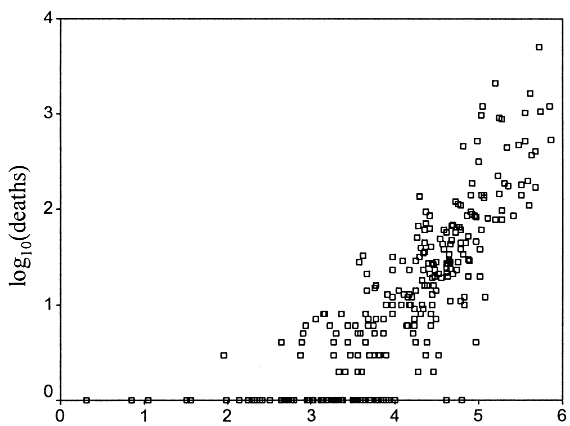
Similarly, a logistical model is applied here and the following Equation (7) is obtained for the probability of a flood causing at least one injury. The Nagelkerke R^2 is 0.298, and the correct classification rate is 94.4 percent, according to the classification value 0.5. The significant probability of the independent variable, $\log_{10}$ (inundated building number), is less than 0.001. The simulation results show that for 10, 100, or 1,000 inundated buildings, the chance that at least one injury occurs is 50 percent, 77 percent, or 92 percent, respectively.

$$Probability\ (event) = 1\ (1 + exp(1.227 - 1.212 * log_{10}(inundated\ building\ number))) \quad (7)$$

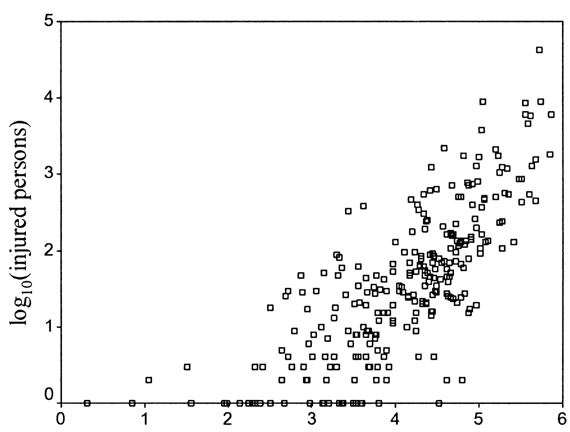
Figure 4 shows scatter plots of the relationship between the number of deaths or injuries and the flood severity (again, in terms of the number of inundated residential buildings). The plots are flat until they exceed some branch point, after which they increase with the number of inundated buildings. This implies that the relationship can be described with Equation (8) when the inundated building number exceeds the branch point (T). From Equation (5), the fatality and injury probability functions can be derived as Equation (9).

$$\log_{10}(L) = a \times \log_{10}(H) - b \tag{8}$$

$$R = \frac{H^{a-1}}{n \times 10^{b}} \tag{9}$$



(a)



(b)

Figure 4. Relationship Between the Numbers of Buildings Inundated and (a) Fatalities and (b) Injuries.

The branch point reflects whether the number of fatalities significantly increases with the number of inundated buildings, and it may be theoretically determined from the change in the slope a, which reflects the extent of regional vulnerability. For a given period, if the vulnerability is assumed constant for all floods, the slope should be constant when the sample's severity is greater than the branch point. The branch point (T) can be determined from the slope (a), intercept (b), and the model contribution ratio (R^2). Here, L refers to the number of fatalities or injuries, and H to the number of inundated residential buildings.

Socioeconomic factors, such as early warning systems and disaster response capabilities, and natural factors, such as hourly precipitation and wind strength, may greatly affect the slope (a). At first, Equation (8) is used to obtain the slopes for different periods after World War II to reveal the trend in the relationship between injuries (fatalities) and flood severity, in terms of the period and flood characteristics. Then, the fatality and injury probabilities from floods are calculated from Equation (9).

FATALITY AND INJURY FUNCTIONS FOR DIFFERENT PERIODS

Fatality and Injury Functions

Tables 2 and 3 list the parameters of the fatality and injury functions for different decades in Japan. All models exhibit a rather high correlation between the numbers of injuries (fatalities) and inundated buildings (i.e., more than 0.52). There is a clear difference between the periods before and after 1980 in terms of the slope (a), intercept (b), and the correlation coefficient (R^2), which all decrease with time. For example, the slopes (a) of the numbers of fatalities and injuries from floods greatly changed from more than 1.0 before 1960 to less than 0.8 after 1980, with a transition period during the 1970s. In other words, severe flooding at a particular level caused fewer deaths after 1980 than it did before 1980. The results show that the fatalities and injuries from floods may be classified into two periods: before and after 1980. This result is similar to that obtained in a study on flood prevention investment in Japan. That is, flood prevention investment effectively reduced losses in comparison with flooding before the 1960s; since the 1980s, however, the investment has changed from an efficient mode to an inefficient mode (Zhai *et al.,* 2003). The branch points for flood severity are 1,000 inundated buildings for fatalities and 100 inundated

TABLE 2. Parameters of the Fatality Function for Different Periods.

Period	1947~1959	1960~1969	1970~1979	1980~1989	1990~2001	1947~2001
a (95 percent C.I.)	1.037 (0.840~1.235)	1.103 (0.902~1.305)	0.912 (0.739~1.085)	0.778 (0.508~1.047)	0.734 (0.487~0.980)	1.011 (0.923~1.099)
b (95 percent C.I.)	-2.977 (-3.914 ~ -2.040)	-3.690 (-4.612~-2.767)	-2.810 (-3.565~-2.054)	-2.231 (-3.353~-1.110)	-2.140 (-3.086 ~ -1.194)	-3.148 (-3.533 ~ -2.764)
Adj. R^2	0.689	0.653	0.733	0.504	0.437	0.685
T	1,000	1,000	1,000	1,000	1,000	1,000
N (Sample No.)	51	64	42	34	46	237

TABLE 3. Parameters of the Injury Function for Different Periods.

Period	1947~1959	1960~1969	1970~1979	1980~1989	1990~2001	1947~2001
a (95 percent C.I.)	1.293 (1.073~1.514)	1.141 (0.888~1.395)	0.828 (0.667~0.989)	0.707 (0.460~0.954)	0.644 (0.367~0.920)	0.894 (0.802~0.986)
b (95 percent C.I.)	-3.823 (-4.871 ~ -2.445)	-3.355 (-4.509~-2.202)	-1.957 (-2.632~-1.282)	-1.419 (-2.395~-0.443)	-1.120 (-2.126 ~ -0.114)	-2.117 (-2.509 ~ -1.726)
Adj. R^2	0.734	0.555	0.693	0.448	0.270	0.583
T	100	100	100	100	100	100
N (Sample No.)	51	65	48	41	57	262

buildings for injured people, although these branch points are not absolute because of the variability in the data and the uncertainty in the predicted fatality values.

Fatality and Injury Probability Functions

Figures 5 and 6 show the results for the fatality and injury probabilities of flooded people as computed from Equation (9). The figures suggest the following: (1) the fatality and injury probabilities increase with the number of buildings inundated for the period before 1969, but decrease for the period after 1970; and (2) the differences between different decades decrease with an increase in flood severity. The main reasons may be considered due to the increasing difficulties in early warning and evacuation instruction of flash floods, which affect small area and usually have far less inundated buildings than rainy season floods, because of the increase in the strength and the decrease in the area of flash floods after 1970.

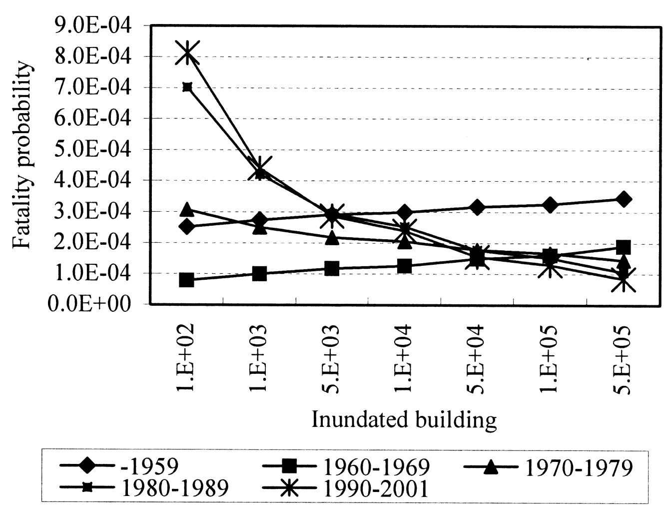


Figure 5. Fatality Probability of a Storm for Different Decades.

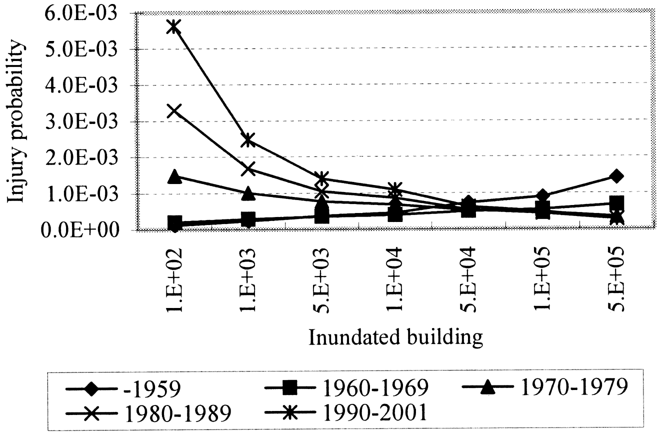


Figure 6. Injury Probability of a Storm for Different Decades.

FATALITY AND INJURY FUNCTIONS FOR DIFFERENT TYPES OF FLOODS

Floods can be categorized into different types: flash floods, those due to typhoons, rainy season floods, and so on. Although it is difficult to distinguish them precisely, for our purposes, flood events are grouped into two categories: rainy season floods, and flash floods due to typhoons or locally heavy rainfall.

Because the characteristics of fatalities and injuries from floods before 1980 are different from the characteristics for those after 1980, the fatality and injury functions for the different types of floods were obtained for three periods: 1947 to 1979, 1980 to 2001, and 1947 to 2001.

Rainy Season Floods

Table 4 shows that there is no great difference in the number of fatalities between the periods before and after 1980 in the case of rainy season floods, because the parameters a and b remain approximately the same (1.024 and -3.214, and 0.986 and -3.168, respectively). However, the numbers of injuries after 1980 were smaller than those before 1980 because the parameter a is 0.738 for the period after 1980 and 1.061 for the period before 1980 (Table 5).

TABLE 4. Parameters of the Fatality Function for Rainy Season Floods.

Period	1947~1979	1980~2001	1947~2001
a (95 percent C.I.)	1.024 (0.849~1.199)	0.986 (0.680~1.293)	1.043 (0.904~1.182)
b (95 percent C.I.)	-3.214 (-3.979 ~ -2.450)	-3.168 (-4.362~ -1.973)	-3.324 (-3.914 ~ -2.735)
Adj. R^2	0.647	0.576	0.675
T	1,000	1,000	1,000
N (Sample No.)	75	32	107

TABLE 5. Parameters of the Injury Function for Rainy Season Floods.

Period	1947~1979	1980~2001	1947~2001
a (95 percent C.I.)	1.061 (0.871~1.252)	0.738 (0.482~0.994)	0.992 (0.853~1.131)
b (95 percent C.I.)	-2.969 (-3.797 ~ -2.142)	-1.856 (-2.805 ~ -0.907)	-2.709 (-3.285~ -2.133)
Adj. R^2	0.616	0.465	0.633
T	100	100	100
N (Sample No.)	77	39	116

Flash Floods Occurring at Other Times

Regarding floods caused by rainstorms occurring at other times (including typhoons), there are great differences in the numbers of fatalities and injuries occurring before and after 1980 (Tables 6 and 7). For example, the slopes (a) of the numbers of fatalities and injuries from floods greatly changed from more than 1.099 and 1.04 before 1980 to 0.661 and 0.595 after 1980, respectively. These differences may be due to improved weather forecasting and early warning systems.

Fatality and Injury Probabilities for Different Types

Figures 7 and 8 show the changes in the fatality and injury probabilities, respectively, estimated from the model for floods of different types and periods.

The injury probability has a larger variation than the fatality probability between rainy season floods and flash floods. The average difference ratios (= probability difference/probability of rainy season floods*100 percent) are 27 percent for fatalities and 170 percent for injuries.

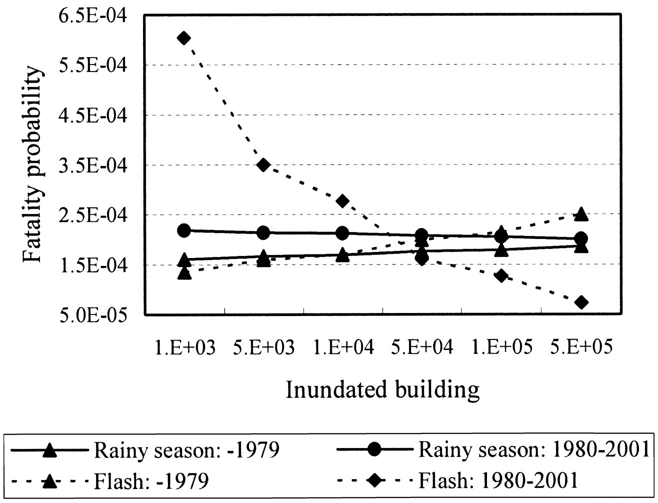


Figure 7. Fatality Probabilities for Different Storms in Japan.

For the temporal changes with different flood types, rainy season floods have less variation than flash floods in the numbers of fatalities and injuries. The temporal difference ratios (= probability difference/probability of previous period*100 percent) for

TABLE 6. Parameters of the Fatality Function for Flash Floods.

Period	1947~1979	1980~2001	1947~2001
a (95 percent C.I.)	1.099 (0.927~1.272)	0.661 (0.455~0.867)	0.974 (0.856~1.092)
b (95 percent C.I.)	-3.512 (-4.333 ~ -2.692)	-1.753 (-2.582 ~ -0.925)	-2.952 (-3.483~ -2.422)
Adj. R^2	0.663	0.465	0.673
T	1,000	1,000	1,000
N (Sample No.)	82	47	129

TABLE 7. Parameters of the Injury Function for Flash Floods.

Period	1947~1979	1980~2001	1947~2001
a (95 percent C.I.)	1.040 (0.879~1.201)	0.595 (0.383~0.807)	0.809 (0.693~0.926)
b (95 percent C.I.)	-2.720 (-3.470~ -1.971)	-0.717 (-1.526~ 0.092)	-1.604 (-2.108~ -1.099)
Adj. R^2	0.656	0.345	0.565
T	100	100	100
N (Sample No.)	87	59	146

rainy season floods average 26 percent for the fatality probability and 54 percent for the injury probability. In contrast, the ratios for flash floods are 217 percent and 433 percent, respectively.

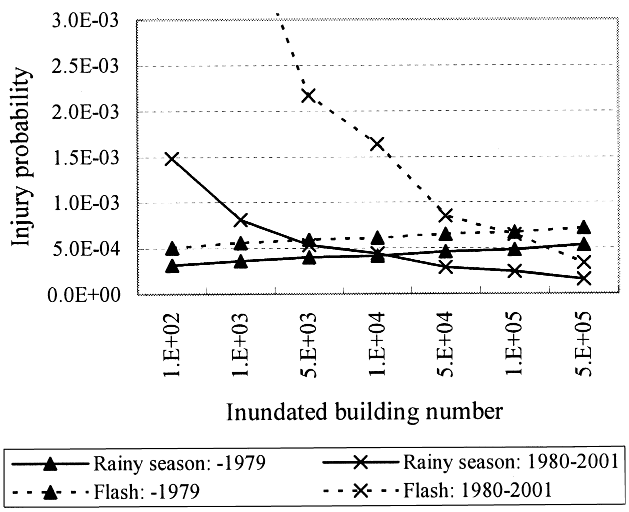


Figure 8. Injury Probability of a Storm for Different Decades.

EVALUATION OF THE FLOOD FATALITY FUNCTIONS

The above statistical analyses on flood fatalities were performed for different time periods and different flood types. Further analyses using three dummy variables for the time period, flood type, and branch point also show that their significant probabilities are less than 0.001 for both flood type and branch point and 0.011 for time period, at a statistically significant level of 0.05. This result also statistically justifies the classifications of the three issues. Next the flood fatality functions are evaluated in terms of two real cases: the 2004 Niigata-Fukushima flood, and the historical flood data from 1949 to 2001.

Evaluation for the 2004 Niigata-Fukushima Flood

Beginning on July 13, 2004, the seasonal rain front produced a heavy storm over the southern part of Niigata Prefecture and the western part of Fukushima Prefecture, Japan. The resulting Niigata-Fukushima Flood caused serious casualties and property damage. According to the report of the Fire Defense Agency, of the Ministry of Public Management, Home Affairs, Posts and Telecommunications, released on July 22, 2004, the storm resulted in 16 dead and missing. Residential building damage included 22 completely damaged, 156 severely damaged, 85 partially damaged, 4,022 inundated above ground, and 22,620 inundated below ground. The ratio of the number of flood refugees to that of those who were instructed to evacuate was low, at no more than 15 percent.

Now the fatality functions are applied to evaluate this disaster from the exposure damage functional viewpoint and to examine these functions' validities. The estimates and the errors of the different functions from the real fatalities, listed in Table 8, show that the estimates are very close to the actual number, and the errors with respect to the actual number of victims are less than three people (20 percent). Here, Models 1~3 were obtained from the data for the periods of 1970 to 1979, 1980 to 1989, and 1990 to 2001, respectively, from Table 2, while the model for rainy season floods was obtained from Table 4. When the seasonal rain front model was used, the same number of fatalities was estimated as the number of victims of this heavy rain. Therefore, in terms of the meaning of the exposure damage relation of heavy seasonal rain, it turns out that the loss of life from the Niigata-Fukushima flood was the national average.

General Evaluation for Flood Data from 1949 to 2001

Here, the ratios of the minimum to the maximum observed and predicted values for precipitation are used for the evaluation, which is developed for operational evaluation of the Japan Meteorological Agency.

TABLE 8. Evaluation of the Proposed Models for the Niigata-Fukushima Flood of 2004.

	Model 1 (1970 to 1979)	**Model 2 (1980 to 1989)**	**Model 3 (1990 to 2001)**	**Model for Rainy Season Floods (1980 to 2001)**
Model Estimate (deaths)	17.0	16.4	12.9	15.9
Error (percent)	6.2	2.5	-19.2	2.2

In addition, the correlation coefficient between the observed and predicated values is applied.

Figure 9 shows the distribution of these ratios during the period of 1949 to 2001. The frequency proportions are 5.4 percent, 15.7 percent, 26.4 percent, 29.3 percent, and 23.1 percent for the intervals of 0-0.1, 0.1-0.25, 0.25-0.5, 0.5-0.75, and 0.75-1.0, respectively. The percentage of fits is 94.5 percent at the same orders of magnitude for the observed and predicted values (one is less than 10 times as large as the other). The median value is 0.75. The average ratios during the periods of 1949 to 2001, 1970 to 1979, 1980 to 1989, and 1990 to 2001 are 0.54, 0.61, 0.55, and 0.48, respectively, at the same level of current precipitation prediction (0.50) (Japan Meteorological Agency, 2004). In addition, the correlation coefficients between them are relatively high, at 0.5 for 1949 to 2001 and 0.72 for 1970 to 2001. Taking into account that the model has the form of a log-log domain, the confidence intervals (uncertainties) for estimates of the numbers of fatalities and the number of injuries would be quite large. Therefore, the model performance may be regarded as good and suggests the usefulness in predicting fatalities and evaluating the efficacy of the warning or other emergency response measures.

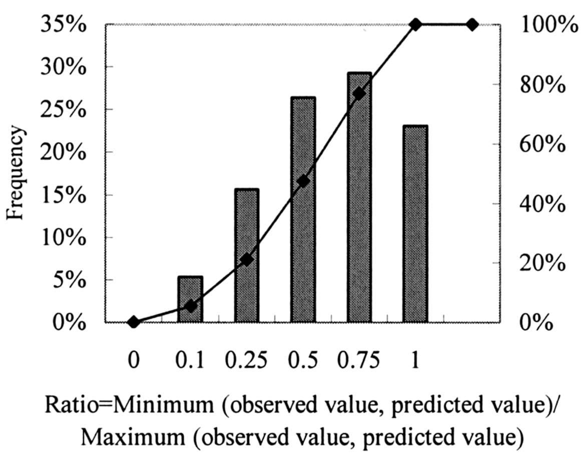


Figure 9. Model Performance Evaluation.

CONCLUDING REMARKS

This paper has provided a framework for estimating the numbers of flood fatalities and injuries and derived generalized fatality and injury functions. By using this framework, fatality and injury functions for floods in Japan occurring in different periods were obtained from statistical data. The main findings can be summarized as follows.

First, both the probabilities and the numbers of fatalities and injuries clearly increase significantly after the flood severity (in terms of the number of inundated buildings) passes a branch point. Below the branch point, it is still possible for fatalities and injuries to occur because of the variability in the data and the uncertainty in the predicted fatality values. In Japan, the branch point value is approximately 1,000 inundated buildings for flood fatalities and 100 inundated buildings for flood injuries.

Second, in Japan, there are distinguishable difference in the numbers of fatalities and injuries before and after 1980 because of changes in the social resilience and vulnerability. However, the numbers of fatalities and injuries from floods caused by rainstorms have greatly decreased since 1980, except for floods that have occurred during the rainy season. The fatality and injury probabilities for the population exposed to floods are on the orders of 10^{-4} and 10^{-3} per event, respectively. Finally, model performance evaluation in Japan suggests the usefulness in predicting fatalities and evaluating the efficacy of the warning or other emergency response measures.

The R^2 values for the 1980 to 2001 relationships shown in Tables 4 through 7 are less than 50 percent in three out of four cases and lower than those for the period of 1947 to 1979 in all four cases. This indicates that much of the variability in the numbers of fatalities and injuries has not been explained by the model, and that less is being explained for the current period (1980 to 2001). The variability may mainly result from greater uncertainty in the current period because of progress in early warning and evacuation systems and regional socioeconomic differences. The most important step for improving the accuracy of model prediction depends on the early warning and evacuation systems, since they were treated as random factors because of insufficient data. It will be necessary to first study the differences in evacuation behaviors for each flood type, and then to examine how and how much they affect the fatality and injury probabilities in a more realistic manner. Natural and socioeconomic characteristics, including building structures and flood risk perceptions, should also be taken into account in predicting the loss of life from floods.

ACKNOWLEDGMENTS

This research is a part of the Social Systems Resilient to Natural Disasters project implemented by the National Research Institute for Earth Science and Disaster Prevention (NIED), Japan. The authors thank three anonymous referees for their valuable comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect the views or policies of the NIED or the project team. Any errors are the sole responsibility of the authors.

LITERATURE CITED

Aboelata, M., D.S. Bowles, and D.M. McClelland, 2003. GIS Model for Estimating Dam Failure Life Loss. *In:* Risk-Based Decision Making in Water Resources, Y.Y.Haimes and D.A. Moser (Editors). American Society of Civil Engineers. *Available at* http://www.engineering.usu.edu/uwrl/www/programs/water/Publications/GIS_Model_for_Estimating.pdf. *Accessed on* March 17, 2006.

Abt, S.R., R.J. Wittler, A. Taylor, and D.J. Love, 1989. Human Stability in a High Flood Hazard Zone. Water Resources Bulletin 25(4):881-890.

Brown, C.A. and W.J. Graham, 1988. Assessing the Threat to Life From Dam Failure, Water Resources Bulletin 24(6):1303-1309.

Central Meterological Observatory, 1920-1956. Annual Statistical Directory (Kishou Youran). Central Meteorological Observatory (CMO), Tokyo, Japan (in Japanese).

DeKay, M.L. and G.H. McClelland, 1993. Predicting Loss of Life in Cases of Dam Failure and Flash Flood. Risk Analysis 13(2):193-205.

Fire and Disaster Management Agency of Japan, 1955-1965. The Current Status of Fire Disasters and Fire Fighting in Japan. Fire and Disaster Management Agency of Japan, Tokyo, Japan (in Japanese).

Fire and Disaster Management Agency of Japan, 1966-2002. Fire Service White Book (Shoubou Hakushuo). Fire and Disaster Management Agency of Japan, Tokyo, Japan (in Japanese).

Fire and Disaster Management Agency of Japan, 2003. Damage Situation of Heavy Rain From July 17 to 21 (22nd Release). *Available at* http://www.fdma.go.jp/html/infor/030722 Kyushyu2.pdf. *Accessed on* July 25, 2003 (in Japanese).

Graham, W.J., 1999. A Procedure for Estimating Loss of Life Caused by Dam Failure. Report No. DSO-99-06, Dam Safety Office, U.S. Bureau of Reclamation, Denver, Colorado.

Japanese Cabinet Office, 2001. Guidance for the Certification of Building Damage Due to Disasters. *Available at* http://www.bousai.go.jp/hou/pdf/shishinall.pdf. *Accessed on* January 16, 2005 (in Japanese).

Japan Meteorological Agency, 1957-2001. Annual Statistical Directory (Kishou Youran). Japan Meteorological Agency, Tokyo, Japan. (in Japanese).

Japan Meteorological Agency, 2004. Report of Japan Meteorological Agency. *Available at* http://www.kishou.go.jp/hyouka/index.html. *Accessed on* January 16, 2005 (in Japanese).

Japan Ministry of Construction, 1947-2000. Flood Disaster Statistics (Suigai Toukei). River Bureau, Ministry of Construction, Japan, Tokyo, Japan (in Japanese).

Japan Ministry of Construction, 1953-2000. Disaster Statistics (Saigai Toukei). River Bureau, Ministry of Construction, Japan, Tokyo, Japan (in Japanese).

Japan Ministry of Land, Infrastructure and Transport, 2001a. Flood Disaster Statistics (Suigai Toukei). River Bureau, Ministry of Land, Infrastructure and Transport, Japan, Tokyo, Japan (in Japanese).

Japan Ministry of Land, Infrastructure and Transport, 2001b. Disaster Statistics (Saigai Toukei). River Bureau, Ministry of Land, Infrastructure and Transport, Japan, Tokyo, Japan (in Japanese).

Joffe, H., 1999. Risk and 'The Other.' Cambridge University Press, Cambridge, United Kingdom.

Jonkman, S.N., 2001. Food Risk: An Analysis of the Applicability of Risk Measures. Delft University of Technology (in Dutch).

Jonkman S.N., 2005. Global Perspectives of Loss of Life Caused by Floods. Natural Hazards 34:151-175.

Jonkman, S.N. P.H.A.J.M. van Gelder, and J.K. Vrijling, 2002. Loss of Life Models for Sea and River Floods. *In:* Flood Defense 2002, B. Wu *et al.* (Editors). Proc. from the Second International Symposium on Flood Defense, Beijing, China, pp. 196-206.

Katada Lab, 2004. Report on the 2004 Niigata-Fukushima Flood. *Available at* http://www.ce.gunma-u.ac.jp/regpln/katada/kataweb/atop.htm. *Accessed on* January 16, 2005 (in Japanese).

Lind, N. and D. Hartford, 2000. Probability of Human Instability in a Flooding: A Hydrodynamic Model, *In:* Proceedings Application of Statistics and Probability, R.E. Melcher and M.G. Stewart (Editors). Balkman, Rotterdam.

McClelland, D.M. and D.S. Bowles, 2002. Estimating Life Loss for Dam Safety Risk Assessment – A Review and New Approach. July 2002 IWR REPORT 02-R-3. *Available at* http://www.iwr.usace.army.mil/iwr/pdf/loss_life_report.pdf. *Accessed on* January 14, 2005.

Ministry of Land, Infrastructure and Transport, Japan, 2000. Economic Investigation Manual for Flood Control (Draft), 70 pp (in Japanese).

Mizutani, T., 1996. Causative Factors of Typhoon Disasters and Secular Changes in the Damage Ratio During 1946-1995. Geographical Review of Japan, Ser. A 69(9):744-756.

Motoyoshi, T., K. Takao, and S. Ikeda, 2004. Determinant Factors of Residents' Acceptance of Flood Risk. Japanese Journal of Social Psychology 20(1):58-67 (in Japanese).

MunichRe, 2003. Topics: Annual Review: Natural Catastrophes 2002. MunichRe Group, Germany. *Available at* http://www.munichre.com.

RECPAS (Research Center for Property Assessment System), 2000. Residential Building Assessment. *Available at* http://www.recpas.or.jp/jigyo/report_web/pdf/H.12/kaoku_h1303.pdf. *Accessed on* January 16, 2005 (in Japanese).

River Bureau, Ministry of Construction, 1947-2000a. Flood Disaster Statistics (Suigai Toukei). River Bureau, Ministry of Construction, Japan, Tokyo, Japan (in Japanese).

River Bureau, Ministry of Construction, 1947-2000b. Disaster Statistics (Saigai Toukei). River Bureau, Ministry of Construction, Japan, Tokyo, Japan (in Japanese).

River Bureau, Ministry of Land, Infrastructure and Transport, 2001a. Flood Disaster Statistics (Suigai Toukei). River Bureau, Ministry of Land, Infrastructure and Transport, Japan, Tokyo, Japan (in Japanese).

River Bureau, Ministry of Land, Infrastructure and Transport, 2001b. Disaster Statistics (Saigai Toukei). River Bureau, Ministry of Land, Infrastructure and Transport, Japan, Tokyo, Japan (in Japanese).

Van Manen, S.E., G. Hartsuiker, P. van Gelder, and A. Kraak, 1994. Inundatie in Limburge; eenrisico-beschouwing, Deelrapport 9, Schademodellering, Onderzoek Watersnood Maas. Ministry of Transport, Public Works and Water Management, The Netherlands (in Dutch).

Vrouwenvelder, A.C.W.M. and C.M. Steenhuis, 1997. Secondary Flood Defenses in the Hoeksche Waard, Calculation of the Number of Fatalities for Various Flood Scenarios. TNO 97-CON-R0332, The Netherlands (in Dutch).

Waarts, P.H., 1992. Method for Determining Loss of Life Caused by Inundation, September 1992. TNO, The Netherlands (in Dutch).

Zhai, G., T. Fukuzono, and S. Ikeda, 2003. An Empirical Model of Efficiency Analysis on Flood Prevention Investment in Japan. Review of Urban and Regional Development Studies 15(3):238-254.

Zhai, G., T. Sato, K. Seo, T. Fukuzono, and S. Ikeda, 2002. Risk Factor Analysis and Evaluation of Natural Disasters: Application of the RIFAE Framework to the 2000 Tokai Flood Disaster in Japan. *In:* Computational Intelligent Systems for Applied Research, Da Ruan, Pierre D'hondt, and Etienne E. Kerre (Editors).World Scientific Publisher, Singapore, pp. 208-217.