Report of the National Research Institute for Earth Science and Disaster Prevention, No. 64 ; March, 2003

Dynamic Efficiency Analysis of Flood Prevention Investment in Japan

Guofang ZHAI *, Teruki FUKUZONO *, and Saburo IKEDA **

* *National Research Institute for Earth Science and Disaster Prevention, Japan*
** *The University of Tsukuba, Japan*
zhai@bosai.go.jp, fukuzono@bosai.go.jp and ikeda@sk.tsukuba.ac.jp

Abstract

In Japan, the need for investment in public works, including flood disaster prevention facilities, such as dykes and dams, is widely discussed at present. This paper aims to evaluate the comprehensive efficiency of flood disaster prevention investment from 1955 to 1999 by developing and applying an evaluation model that focuses specifically on relative success in the prevention of human and economic losses. Results of our analysis have clarified some important issues currently being discussed in Japan. Firstly, a one-way-layout analysis of variance shows there to be a statistically significant difference only between the period of 1955-1961 and those of 1962-1967, 1968-1983, and 1984-1999. The average values of normalized flood losses decreased greatly between the 1955-1961 period and the 1984-1999 period. Secondly, the ratio of human loss to total loss caused by floods in Japan may be less than 10%. This ratio showed an increasing trend before 1970 and then stabilized at around 8% after 1970. The proportion of intangible effect to total loss increased from less than 10% before the 1970s to approximately 20% after that period. Finally, flood prevention investment in Japan effectively reduced losses caused by flooding before the 1960s ; however, since the 1980s, investment has changed from an efficient mode to an inefficient mode, not only from the economic standpoint, but also from that of total flood loss saving. We conclude that it is necessary to explore the usefulness of new investments and to develop improved strategies for flood disaster prevention from a risk management viewpoint.

Key words : Normalization of flood loss, Flood prevention investment, Efficiency analysis, Japan

1. Introduction

Worldwide, losses from natural hazards are showing a rising pattern. Of these, flood losses account for 50% in economic terms and 66% in human terms (MunichRe 2001). The human loss from flood hazards has greatly decreased as a result of implementing various measures such as dam and dyke construction, but the economic loss has not decreased to the same extent. In Japan, the flood plains hold about 49% of the population and 75% of property, and flooding is currently a serious natural hazard. The severe recession in the Japanese economy and public preoccupations with the need to preserve the environment have recently put a brake on investment in large-scale public works, including flood disaster prevention facilities such as dykes and dams. However, the Tokai flood in 2000, which caused losses of ¥978.3 billion, 10 dead, and 115 injuries, including 9 serious injuries (Ministry of Land, Infrastructure and Transport, Japan, 2001a), may help the advocates of large-scale flood-disaster-prevention facilities. How to view the flood loss trend and how to evaluate the efficiency of past flood prevention investments are now under intense discussion.

The opponents of investment in large-scale public works believe that they destroy the ecosystems on which human beings depend (Ono 1999) ; they also maintain that since (as reported by Ministry of Land, Infrastructure and Transport, Japan) increased investment in flood-prevention public works shows no decreased flood losses, there is nothing to be gained by making any further investments in public

* Tennodai 3-1, Tsukuba, Ibaraki, 305-0006, Japan
** Tennodai 1-1-1, Tsukuba, Ibaraki, 305-8577, Japan

works. However, its proponents say that increasing investment in flood prevention is protecting Japan from even worse human and economic losses, and that in reality, human losses have decreased greatly since the 1960s, even though economic losses have not fallen so obviously ; and that with no more investments, these losses would have been much greater (Maruoka 2000). Both opponents and proponents seem to accept the fact that economic losses do not decrease while human losses greatly decrease, but draw opposite conclusions. The reason for this may be regarded as coming from diverging beliefs concerning the efficiency evaluation of flood prevention investment vs. losses.

Natural hazards such as floods may have unwanted, adverse consequences with respect to human life, health, property and the environment. In other words, the magnitudes of the losses from floods are affected not only by the magnitude of the precipitation or discharge, but are also affected by socioeconomic scale, socioeconomic vulnerability, risk perception by residents, etc. Therefore, an integrated approach that takes socioeconomic factors into account is needed to evaluate the efficiency of flood prevention investment.

Pielke and Landsea (1998, 1999) mathematically modeled an integrated approach in their hurricane studies to investigate the loss trend, but did not go further into the analysis of investment/loss and did not take into account the random patterns of natural events. There also appears to be no such previous study using an integrated approach to explore flood patterns and investment efficiency in Japan. The objective of this paper is to evaluate in comprehensive fashion the efficiency of flood prevention investment by integrating economic loss with human loss. Taking into account the fact that there are major uncertainties in the statistical estimate of the value of a human life, we will first evaluate economic loss, and then integrate human loss with economic loss.

This paper is organized as follows. Section 2 describes the integrated efficiency evaluation method of flood prevention investment, which includes the ratio of total benefits to total cost, *Elasticity*, and the marginal ratio of substitute of flood loss decreases to flood prevention investment. Section 3 lists the data sources and empirically normalizes flood losses in Japan. Section 4 empirically analyzes the economic efficiency of flood prevention investment in Japan using the proposed indices. Finally, policy implication and concluding remarks are provided.

2. The Integrated Efficiency Evaluation Method of Flood Prevention Investment

The integrated efficiency evaluation method of flood prevention investment comprises 3 steps : data collection, normalization and economic efficiency evaluation.

Natural disasters, floods in particular, are concerned with hazard magnitude, socioeconomic scale, and socioeconomic vulnerability to the event, residential risk perception and other issues. The data includes annual flood prevention investment, annual flood losses, the annual deflator index, annual population, land use patterns, social systems for flood prevention, perception of flood risks and so on. Not all data are used : we have selected data with high quality and a time series.

2.1 Normalization of flood losses

An integrated method is needed to identify patterns of natural hazards. Pielke and Landsea suggested an integrated approach model to evaluate the economic loss from hurricanes. It assumes that hurricane losses are proportional to three factors : inflation, wealth and population. However, the scale of flood losses are affected not only by inflation, wealth and population, but also include land use patterns, residential risk and public perceptions. Provided that the factors of flood losses are F_{1t}, F_{2t}, ... F_{nt}, that flood loss (current price) is Y_t, and that generally normalized flood loss of t year at B year price is NL_{tB}, here defined as shadow loss, then

$$NL_{tB} = Y_t \times \prod_{i=1}^{n} p_{itB} \tag{1}$$

$$p_{itB} = \frac{F_{it}}{F_{iB}} \quad i=1,2,\ldots,n. \tag{2}$$

2.2 Efficiency evaluation model of flood prevention investment

The efficiency of flood prevention investment involves focusing on its basic and fundamental objectives, i.e., protecting human life and property from flood loss even if the investment places a load on the socioeconomic system. In other words, it is important to find out how, under similar circumstances, losses would be different if no flood prevention investment had been made. Floods have human, economic and environmental impacts. However, here, only human losses and economic losses are estimated and compared with the investment in flood prevention, using the latest research results, while the environmental impact will be treated as a future issue due to lack of sufficient data.

In order to completely evaluate and comprehend the efficiency of flood prevention investment, *Elasticity* and marginal rate of substitution (*MRS*) as well as ratio of total benefit/total cost (the Ministry of Land, Infrastructure and Transport (MLIT) method) are used.

According to the Manual of Flood Control Investigation, published by the MLIT of Japan (2000), flood prevention projects should be evaluated from the viewpoint of total cost and total benefit. In line with the view that flood control projects such as dikes and dams should be evaluated based on a period of 50 years from project completion, a post-evaluation equation can be obtained (Equation 3). If the time period of data is less than 50 years, the shortfalls of investment and benefit may be estimated by model extrapolation. Here, the benefit shortfall is covered with the last year data because the flood loss seems to have become relatively stable since 1984 (the correlation coefficient between flood loss and year is 0.216 during 1984-1999).

$$R_i = \frac{\sum_{k=i}^{k=i+50} \Delta L_k}{\sum_{k=i-49}^{k=i} \Delta I_k} \tag{3}$$

Where

R_i : ratio of total benefits to total costs at time i ;

ΔL_k : decrease of flood loss at time k ;

ΔI_k : flood prevention investment at time k.

In this paper, due to flood loss data available from 1955 to 1999, Equation (3) may be transformed into Equation (4).

$$R_i = \frac{\sum_{k=i}^{k=1999} \Delta L_k + \Delta L_{1999} \times (50 - (1999 - i))}{\sum_{k=i-49}^{k=i} \Delta L_k} \tag{4}$$

At the same time that the stock of flood prevention investment is taken into consideration for efficiency evaluation, the other two important indices (*Elasticity* and marginal rate of substitution (*MRS*)) are also used here to gain a complete and thorough understanding of investment efficiency. *Elasticity* is defined as follows :

$$Elasticity_{L:I} = \frac{\Delta L_i / L_i}{\Delta I_i / I_i} \tag{5}$$

$$MRS_{L:I} = \frac{\Delta L}{\Delta I} \tag{6}$$

Here, I_i is the stock of flood prevention investment and L_i is the total loss at time i. Obviously, if *Elasticity* is less than 1, that means every 1% reduction in flood loss needs more than a 1% flood prevention investment, and vice versa. If *MRS* is less than 1, that means every 1 yen reduction of flood loss requires more than 1 yen of investment, and vice versa. Ideally, both are greater than 1, but this does not always happen. Different combinations need different flood-prevention management strategies.

3. Flood Loss Structure and Economic Efficiency Analysis of Flood Prevention Investment in Japan

3.1 Data source

Since there is no statistically significant difference in climatic conditions among several 20-year periods after 1935 (Yamamoto and Sakurai 1999), it is reasonable to assume that climatic conditions have undergone no great changes and that only socioeconomic factors affect flood losses. Therefore, the decrease in normalized flood losses can be regarded as a benefit deriving from flood prevention investment.

It is very important to note that the factors that should be taken into the model depend greatly on the time-series data availability. In fact, most countries, in particular developing countries, have such limited data that only a very few factors can be taken into the model in the event of exploring the trends in flood losses ; however, this data may still be helpful in decision-making. In the case of Japan, there is a great deal of socioeconomic data available ; however, only flood losses (at 1995 prices) adjusted for inflation after 1876, total population after 1872 and fixed producible tangible wealth after 1955 are of high quality and in a time series. Flood losses after 1955 will be normalized based on these three factors.

Flood loss data adjusted with the inflation from the Flood Disaster Statistics (Ministry of Land, Infrastructure and Transport, Japan, 2001b) shows that flood losses increased markedly before the 1950s, and then began to decrease in the 1960s. But since the 1970s, there has been no decrease in spite of a continuous increase in flood prevention investment (**Fig. 1**). The Japanese population increased from 89.27 million in 1955 to 126.68 million in 1999 (**Fig. 2**), and fixed producible tangible wealth increased from 2.12 trillion yen (1980 prices) in 1955 to 139 trillion yen in 1996 (**Fig. 3**) .

3.2 Normalized economic loss

The normalized flood loss in Japan is charted in **Fig. 4** by using Equation (1) and Equation (2). The greatest normalized flood economic loss is 101 trillion yen in 1959 when the historically disastrous Isewan Typhoon occurred, resulting in 4,697 dead, 401 missing, and 38,921 injured. The second biggest loss was 71 trillion yen in 1958 when the Kanogawa Typhoon hit, causing 900 dead, 289 missing, and 1,138 injuries. The smallest was 158.1 billion yen in 1996. A hierarchy cluster analysis (Ward method) using SPSS 10.0.7 software was used to group the normalized data from 1955 to 1999 in two steps. The first step obtained only two different groups : that of 1955-1961 and that of 1962-1999. The second step generated 3 groups : 1962-1967, 1968-1983 and 1984-1999 by clustering the data for 1962-1999. Eventually, 4 groups were clustered : (1) 1955-1961, (2) 1962-1967, (3) 1968-1983, and (4) 1984-1999. A one-way-layout analysis of variance reveals a statistically significant difference to exist only between the period of 1955-1961 and the periods of 1962-1967, 1968-1983, and 1984-1999, although the means of normalized flood losses during differ-

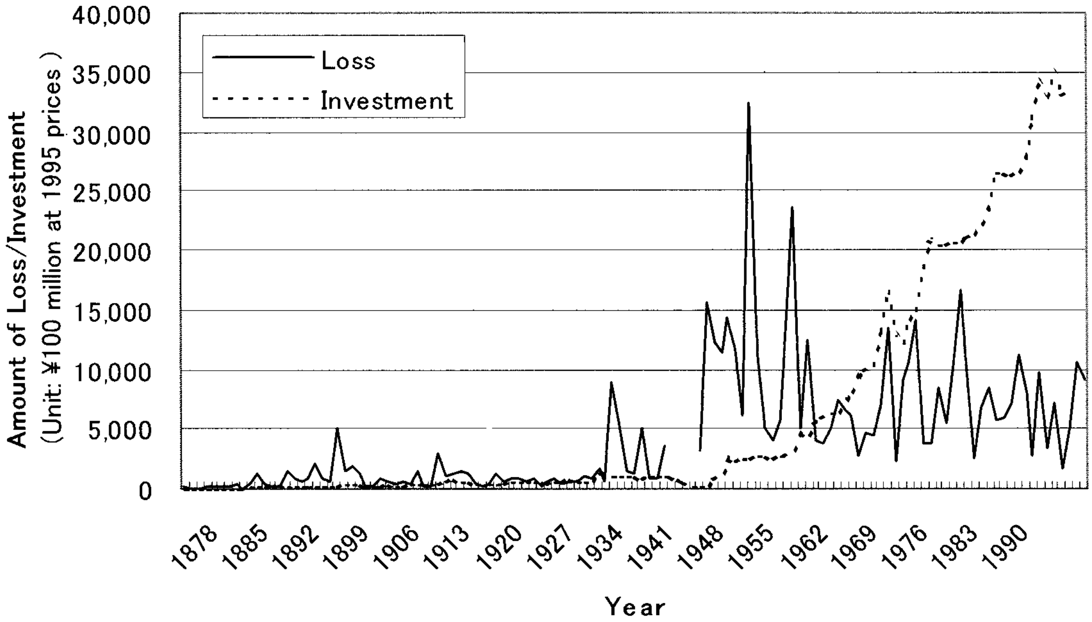

Fig. 1 Flood damage and prevention investment (Source : Ministry of Land, Infrastructure and Transport, Japan (2001b)).

ent periods appears to decrease markedly from the period of 1962-1967 to that of 1984-1999 (**Fig. 5**).

3.3 Human losses and intangible effects from floods

Flood causes not only economic loss, but also human losses and intangible effects. However, the likely loss of human lives is not taken into account in the available decision models of the cost-benefit analysis (e.g. Thompson 1952 ; Murphy 1985 ; Palmer *et al.* 1999). This is mainly attributable to the ethical problems concerning human lives. Ethically, we cannot — and do not seek to — place a monetary value on our own lives or on other individuals' lives. However, society routinely places a value on life in a variety of ways. The courts provide compensation after fatalities, both to compensate families for their loss and, in some cases, to provide deterrence as well. It is, to some extent, more important in a modern society for a decision-maker to save human lives than reduce the economic loss, since the number of human fatalities is more specific and more widely reported, thereby making a greater impact on the public. Therefore, any cost-benefit analysis that ignored the impact of disasters on human lives would be publicly condemned. The total loss consists of human loss (dead and injured), economic loss, and intangible effects on residents.

Human loss, including death and injury, results not only in personal economic losses such as loss of earnings, past and future medical expenses and loss of the ability to carry out everyday tasks, but also the loss due to pain and suffering or loss of consortium (Riley 1993). Kawata and Karatani (2000) proposed an estimation method of loss of social value due to heavy casualties based on the relationship between gross regional production and average lifespan. However, this method was developed to take account of human loss seen in large-scale disasters such as the Hanshin Earthquake, in which more than 6,000 died, and may not suitable for disasters that mainly feature economic losses. Here, the human losses from death, injuries and pain and suffering or loss of consortium are estimated respectively.

The value of statistical life (VOSL) for death is introduced and integrated into the model. The underlying principle for establishing the value of a statistical life is that the focus is on the risk-money tradeoff for a small risk, not the value of an identified life (Viscusi 2000). Individuals try to strike a balance between risk and cost for themselves and society needs to seek a similar balance. Few VOSL studies for Japan are found in the literature except that of Kniesner and Leeth (1991) who estimated VOSL as \$9.2 million at 1998 prices. However, a variety of empirical VOSL studies have been conducted, mainly in the USA, showing great variation among them. However, it would appear that there is relatively little difference between several meta-analyses on VOSL. Here, two values are used. One is the average value (\$3.3 million (around 400 million Yen) per person) of the meta-analysis results. Another is the maximum value (\$9.2 million (1.1 billion Yen) per person) may be reasonably regarded.

The losses from flood injuries are estimated using the units of medical expense per injury (Saeki *et al.* 2001). We used data from the Hanshin Earthquake, which may be slightly different from data for flood injuries, but may be

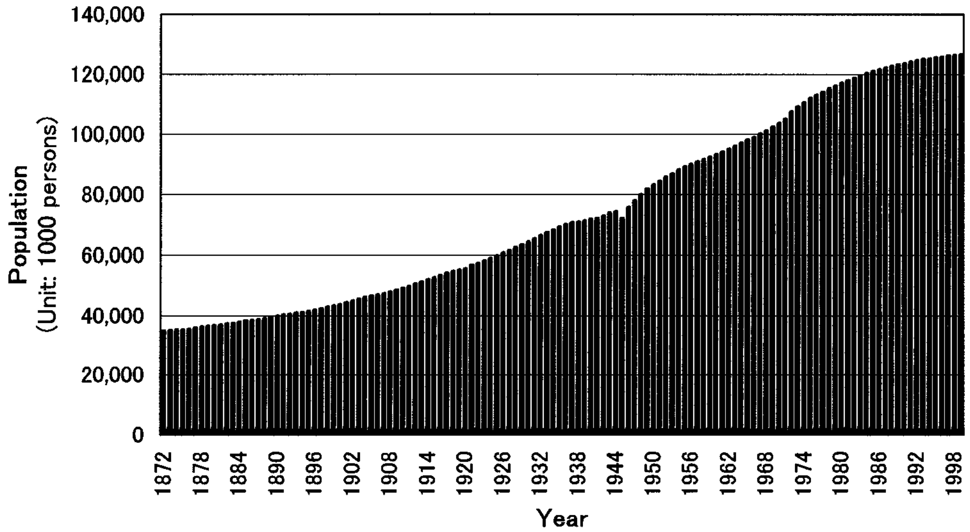

Fig. 2 Population growth in Japan (Source : Ministry of Land, Infrastructure and Transport, Japan (2001b)).

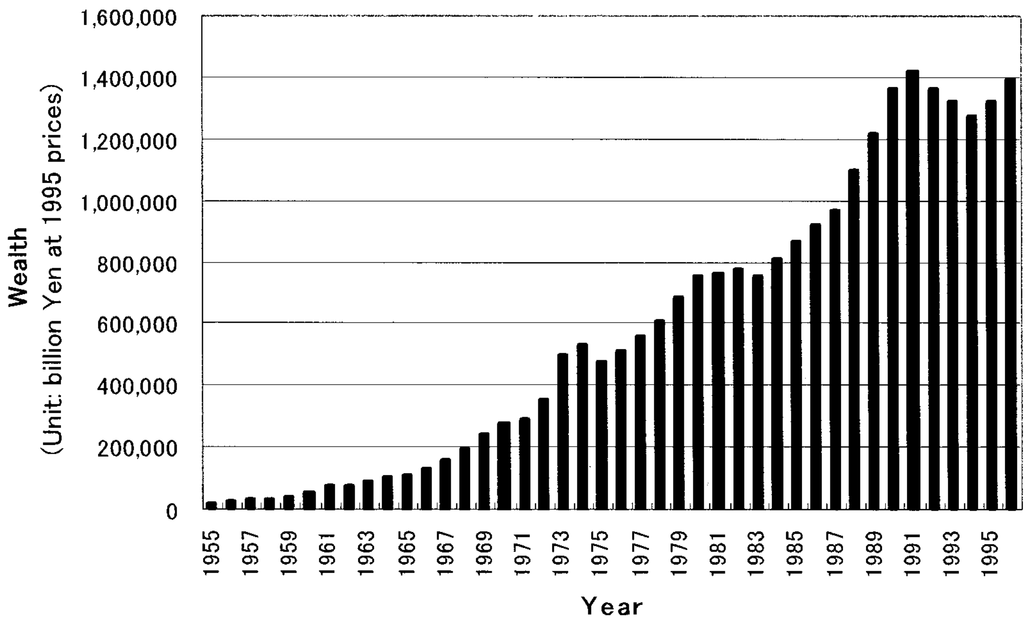

Fig. 3 Fixed producible trangible wealth (1955-1996) (Source : Fukao and Qiu (2000)).

within the range of our acceptable error.

Loss from injuries of flood
= *hospital stay (day)* × *average medical expenses per day* × *number of injuries*
= *¥4500/day* × *32.2 (day)* × *number of injuries* (7)

Intangible effects of flooding on residents have been studied since the late 1990s. It was reported by Kurigi *et al.* (1996) that the intangible effects of flooding per household were equivalent to 2.28 million yen, and as 2.85 million yen by Takagi *et al.* (2000). Here, the average of these two values (2.565 million yen per household) was used to estimate the intangible effects of flooding on residents.

The top four greatest human losses and intangible effects from flooding are 12.39 trillion yen in 1959, 5.56 trillion yen in 1958, 3.48 trillion yen in 1957, and 3.26 trillion yen in 1961 respectively, using the high VOSL estimate ($9.2 million per person), and 6.45 trillion yen in 1959, 3.79 trillion yen in 1958, 2.48 trillion yen in 1961, and 3.23 trillion yen in 1957, respectively, using the medium VOSL estimate ($3.3 million per person) (**Fig. 6**). In 1959, flooding caused 5,169 deaths, 396 missing and 41,706 injuries. The smallest value was 51.28 billion yen using the high VOSL estimate

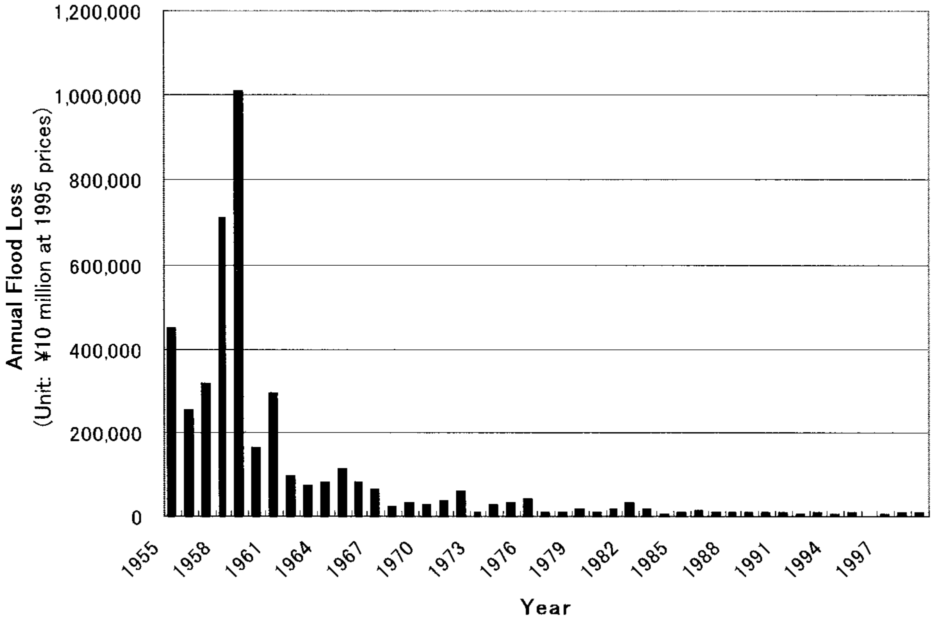

Fig. 4 Normalized flood economic loss (1955-1999).

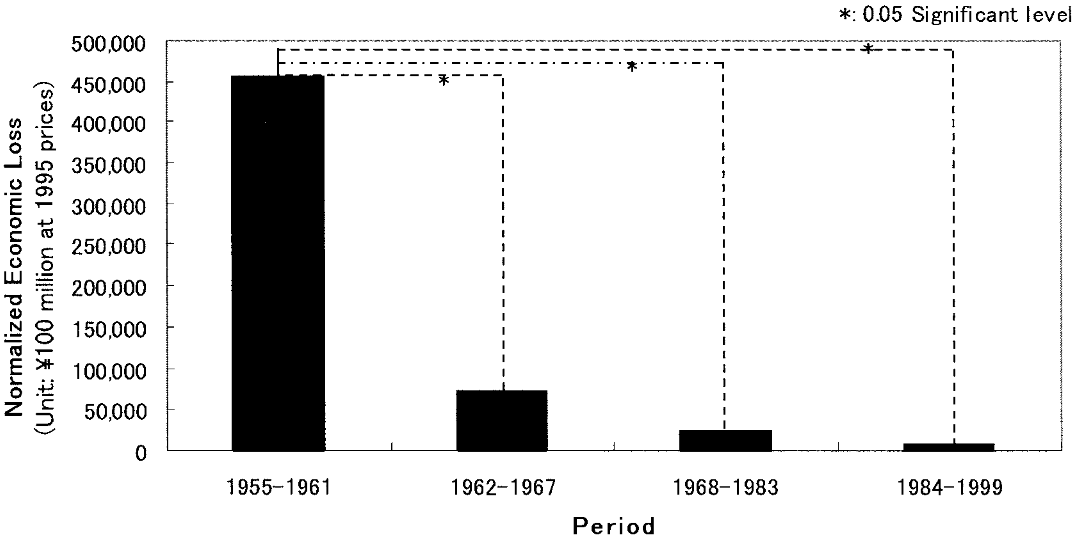

Fig. 5 Annual average economic loss from flood (1955-1999).

and 47.32 billion yen using the medium VOSL estimate in 1992 when floods caused 2 dead, 0 missing and 80 injured.

3.4 Total flood loss

Total flood loss consists of economic loss, human loss and intangible effects. The top four largest total losses from floods are 113.59 trillion yen in 1959, 76.89 trillion yen in 1958, 35.09 trillion yen in 1957 and 32.53 trillion yen in 1961, respectively, using the high VOSL estimate ($9.2 million per person) ; and 107.66 trillion yen in 1959, 75.09 trillion yen in 1958, 33.84 trillion yen in 1957 and 31.76 trillion yen in 1961 respectively, using the medium VOSL estimate ($3.3 million per person). The smallest is 229.8 billion yen using the high VOSL estimate, and 214.9 billion yen using the medium VOSL estimate, respectively, in 1992.

Concerning the proportion of intangible effect to total loss, there is an increasing trend from less than 10% before the 1970s to approximately 20% after that time (**Fig. 7**). This may be explained by the fact that after 1970, when Japan had achieved its economic take-off and become a developed country, Japanese people developed an interest in less materialistic qualities of life, such as self-development, privacy, and respect for individual freedoms. The proportion of human loss to total loss has not changed markedly. The average and median values of the percentage of human loss to gross loss are 3.172% and 2.824% at the VOSL value of $3.3 million and 8.232% and 7.494% at the VOSL value of

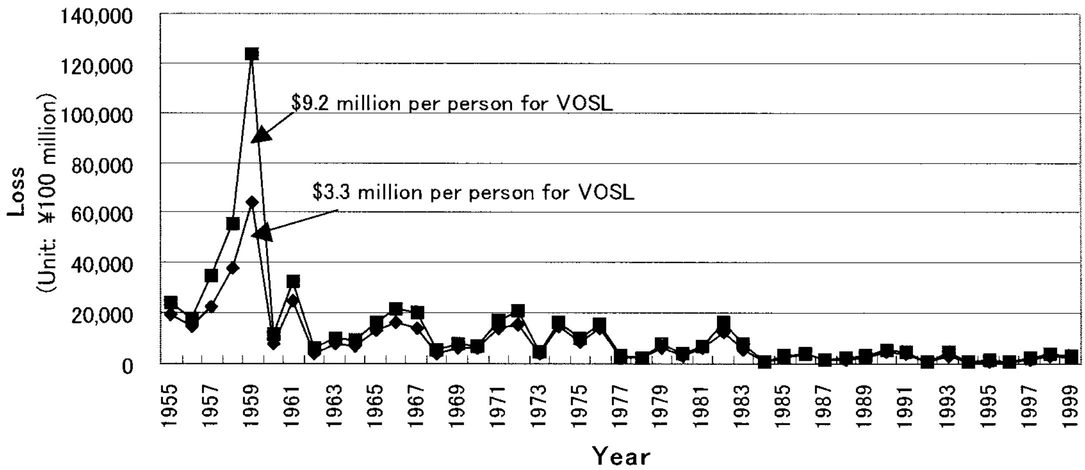

Fig. 6 Loss including dead, injured and intangible effects.

$9.2 million, respectively : the ratio shows an increasing trend before 1970 and then levels off at around 8% after 1970 (**Fig. 7 and 8**). It can also be concluded from this that the average proportion of human loss to total loss is less than 10%.

4. Economic Efficiency Analysis of Flood Prevention Investment in Japan

The ratio of total benefit and total cost, *Elasticity* and marginal ratio of substitute were used to evaluate the economic efficiency of flood prevention investment. Bearing in mind that there is much more uncertainty in the estimate of human loss and intangible effect than for economic loss, they are treated as two separate cases : economic loss and total loss.

4.1 Ratio of total benefits to total costs

4.1.1 Economic loss

An annual flood loss benchmark year is needed to estimate total benefit. However, due to the large fluctuations in annual flood losses, it is not easy to determine how relevant it might be. Here, the averages for previous times and the 5 years preceding the benchmark year are used in this paper to calculate the ratio of total benefit to total investment.

There is a smoothly decreasing line for the previous time-based average but a sharply decreasing one for the previous-5-year based average (**Fig. 9**). The lowest ratio of the former is 6.8 in 1997, and the former is much larger than the latter, since the large flood losses of the 1950s clearly have raised the average and pushed up the total benefits of flood prevention investment. The latter used the average of previous-5-year flood losses and canceled out this effect. For the latter, the ratio decreases sharply from more than 200 during the early 1960s, through 2-10 during the 1970s, through 1-2 during the 1980s, to less than 1.0 after 1988.

4.1.2 Total loss

The case of total loss is similar to that of economic loss. The integration of human loss and intangible loss (in the case of the high VOSL estimate) to the economy did not change the fundamental features of the ratio of total benefit to total investment, but did increase the ratio slightly. There is also a smoothly decreasing line in the case of the previous time-based average but a sharply decreasing one for the previous-5-year-based average (**Fig. 10**). The lowest ratio of the former is 7.6 in 1997. For the latter, the ratio decreases sharply from more than 200 during the early 1960s, to less than 1.0 after 1988. This means that since 1988, investment in flood prevention has become inefficient as measured by ratio of total benefits to total costs.

4.2 *Elasticity* of flood loss with respect to investment

4.2.1 Economic loss

Elasticity of flood economic loss with respect to flood prevention investment also decreased markedly from the 1950s to the 1990s (**Fig. 11 and 12**). *Elasticity* for clustered groups changed sharply from 39.07 during 1955-1961, 3.9 during 1962-1967, 0.91 during 1968-1983 to 0.24 during 1984-1999 and those for different decades from 53.29 during 1955-1960, 3.22 during 1961-1970, 0.95 during 1971-1980, 0.56 during 1981-1990 to 0.08 during 1991-1999.

4.2.2 Total loss

There is no significant difference between the *Elasticity* of total loss and that of total loss to flood prevention investment. The *Elasticity* of total loss from flood to investment also decreased greatly from the 1950s to the 1990s (**Fig. 11 and 12**). In the case of the high VOSL estimate, the *Elasticity* for clustered groups decreased from 38.1 during 1955-1961, 3.4 during 1962-1967, 0.86 during 1968-1983 to 0.22 during 1984-1999 and those for different decades from 52.66 during 1955-1960, 4.5 during 1961-1965, 1.8 during

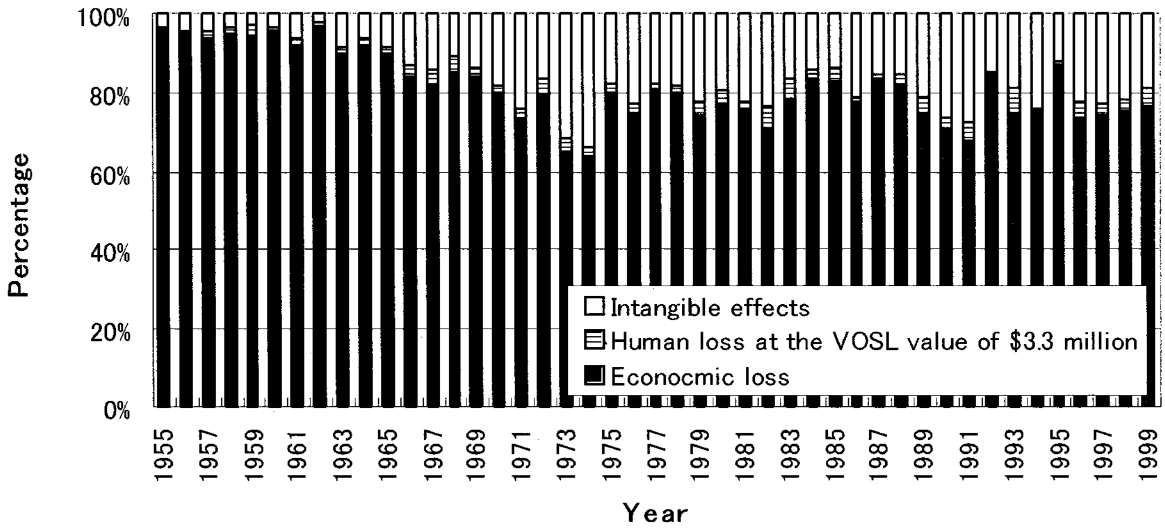

Fig. 7 Percentage of each loss in the case of $3.3 million of VOSL.

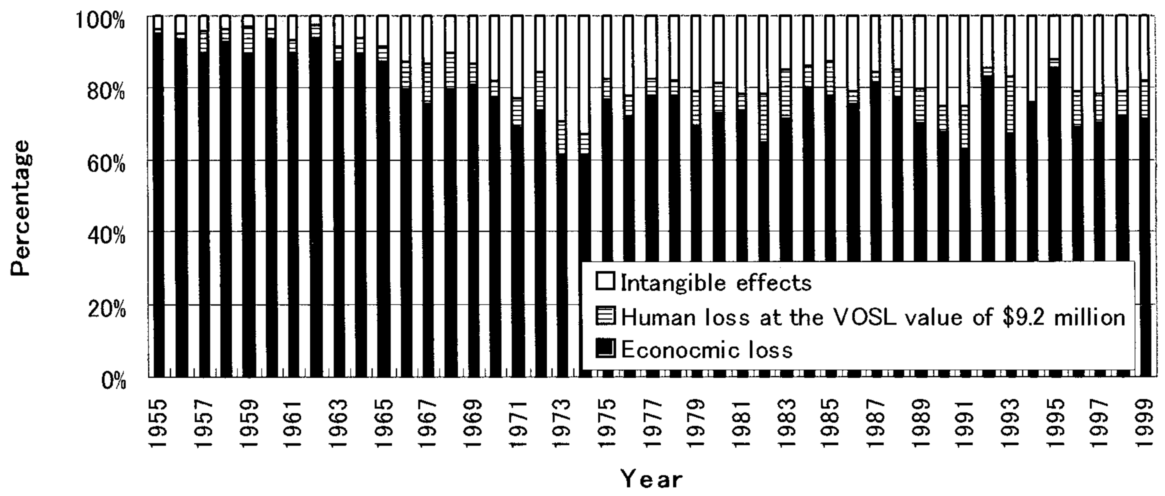

Fig. 8 Percentage of each loss in the case of $3.3 million of VOSL.

1966-1970, 1.2 during 1971-1975, 0.5 during 1976-1980 to 0.1 during 1991-1999. This implies that since the 1970s, flood prevention investment has become inefficient in terms of *Elasticity*.

4.3 Marginal ratio of substitute (MRS) of flood loss to investment

4.3.1 The economic case

The marginal ratio of substitute (MRS) of flood economic loss with respect to flood prevention investment decreased greatly from the 1950s to the 1990s (**Table 1 and 2**). MRSs for clustered groups changed markedly from -476.1 during 1955-1961, 9.2 during 1962-1967, 0.49 during 1968-1983 to 0.05 during 1984-1999 and those for different decades from -476.2 during 1955-1960, 4.79 during 1961-1970, 0.58 during 1971-1980, 0.167 during 1981-1990 to 0.06 during 1991-1999.

4.3.2 Total loss

Concerning the maximum likely total loss, including death, injuries, and intangible effects, the MRSs for clustered groups changed markedly from -416.6 during 1955-1961, 11.3 during 1962-1967, 0.99 during 1968-1983 to 0.096 during 1984-1999 and those for different decades from -500 during 1955-1960, 4.95 during 1961-1970, 0.66 during 1971-1980, 0.21 during 1981-1990 to 0.07 during 1991-1999. This suggests that since 1970, investment in flood prevention has become inefficient in terms of the marginal ratio of substitute.

Here, the negative MRS signals during 1955-1961 can be explained by the fact that under extreme conditions, in which society is completely overwhelmed by natural forces, investment in flood prevention has no effect even if the investments are increased. This phenomenon may often occur

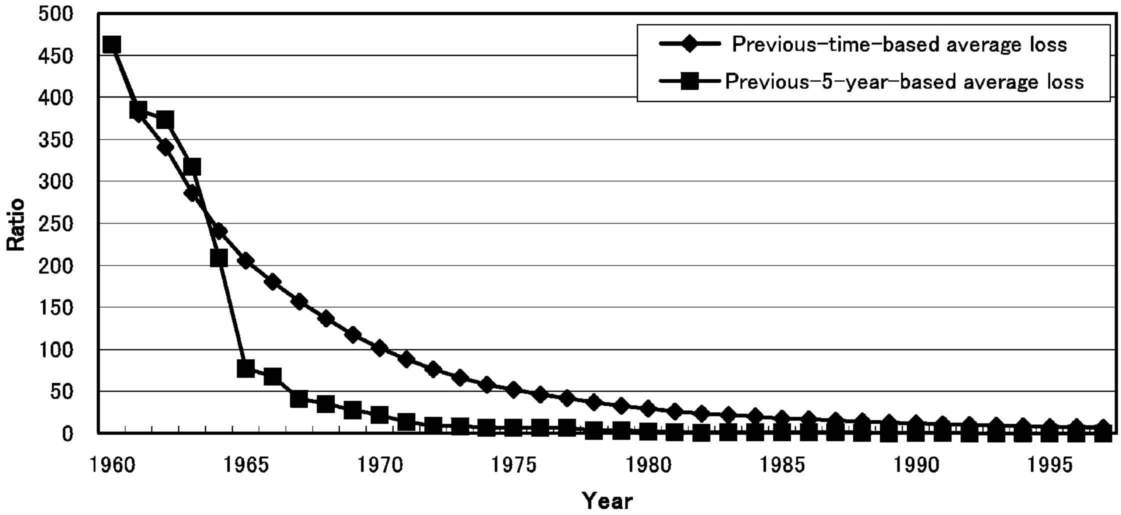

Fig. 9 Ratio of total benefit to total investment in the case of economic loss.

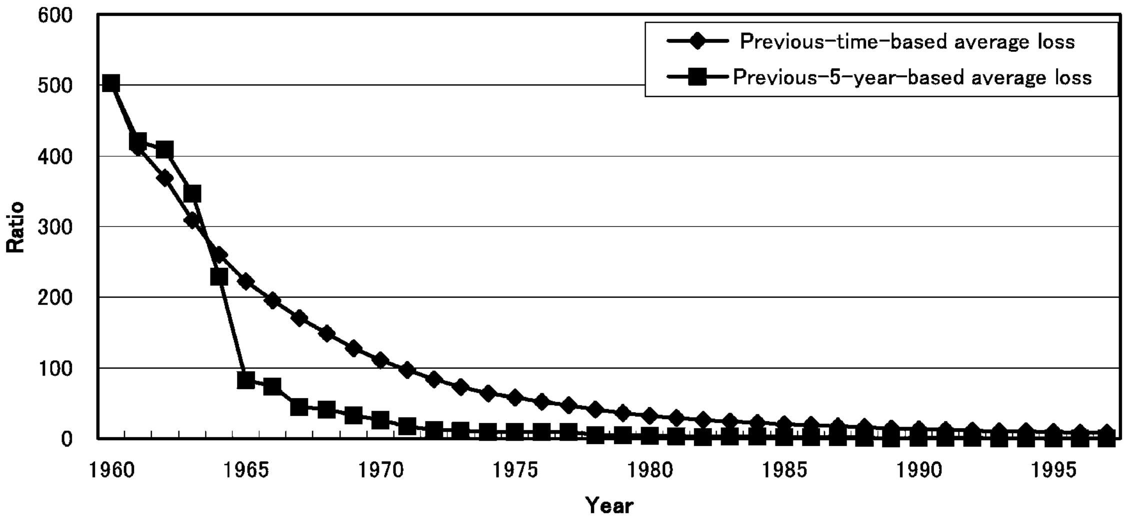

Fig. 10 Ratio of total benefit to total investment in the case of high-level estimate of VOSL ($9.2 million per person).

in developing or undeveloped countries. Historically, the MRS may change from -, 1-, 1+, to a value exceeding 2 in parallel with economic development.

Several implications may be drawn from the above analysis. (1) Flood prevention investment in Japan effectively reduced the flood loss before the 1960s. (2) Flood prevention investment switched from efficient mode to inefficient mode after the 1980s. (3) The integration of human losses and intangible effects with economic losses does not greatly affect the fundamental characteristics of each evaluation index such as MRS, *Elasticity*, or the ratio of total benefits to total costs. This may be due to the much larger base than the change and to the proportionally small human loss and intangible effects on total loss.

5. Concluding remarks

This paper describes the development of a comprehensive efficiency evaluation model that takes both human losses and intangible effects of flooding into consideration in an efficiency analysis, and discusses the overall efficiency of Japan's flood prevention investments by focusing on human and economic loss savings and the prevention of intangible effects. Our analysis results clarified some important issues concerning the flood prevention investment at present being discussed in Japan. Firstly, one-way-layout analysis of variance reveals a statistically significant difference only between the period of 1955-1961 and those of 1962-1967, 1968-1983, and 1984-1999, although the mean of normalized flood losses during different periods appears to decrease sharply from the period of 1962-1967 to that of 1984-

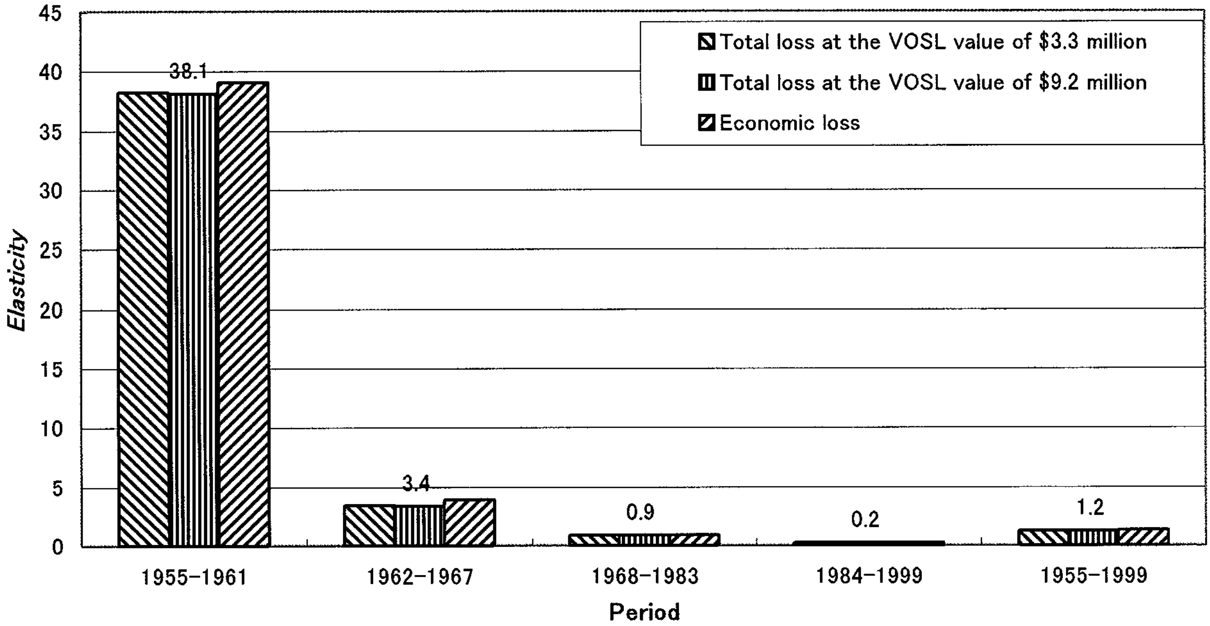

Fig. 11 *Elasticity* of flood loss decrease to flood prevention investment.

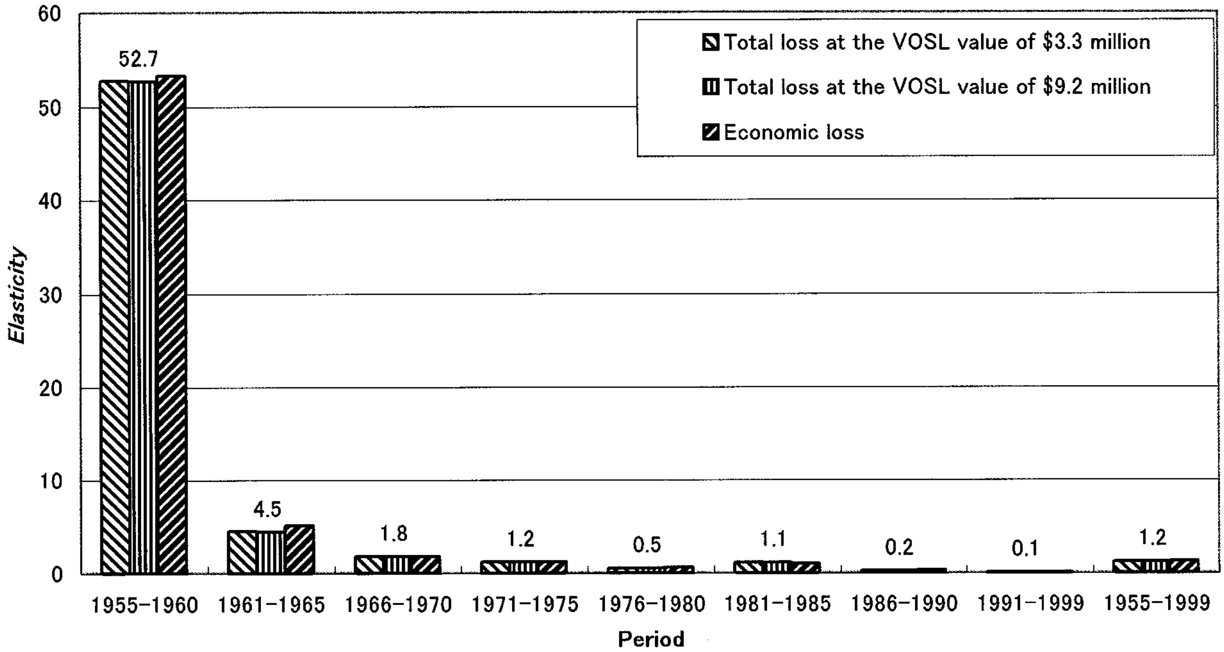

Fig. 12 *Elasticity* of flood loss decrease to flood prevention investment.

1999.

Secondly, the ratio of human loss to total loss caused by flooding in Japan appears to be less than 10%. The ratio shows an increasing trend before 1970 and then stabilizes at around 8% after 1970. The proportion of intangible effect to total loss increased from less than 10% before 1970s to approximately 20% after that time.

Thirdly, flood prevention investment in Japan effectively reduced flood losses before the 1960s. However, since the 1980s, the investment has changed from an efficient mode to an inefficient mode. This suggests that it is necessary to explore the usefulness of new investments and strategies for flood disaster prevention from a risk management viewpoint.

However, the impacts of flooding are extensive, and not every item, such as environmental impact, could be explored here. Japanese values of VOSL and the intangible effects are borrowed from other research and need to be empirically checked using CVM or the wage-risk method in future.

Table 1 MRS of flood prevention investment in japan for clustered groups.

Clustered Group	MRS for economic loss	MRS for Total loss	
		\$3.3 million/person	\$9.2 million/person
1955-1961	-476.1	-416.6	-416.6
1962-1967	9.2	10.8	11.3
1968-1983	0.49	0.87	0.99
1984-1999	0.05	0.086	0.096

Table 2 MRS of flood prevention investment in japan for different decades.

Period	MRS for economic loss	MRS for total loss	
		\$3.3 million/person	\$9.2 million/person
1955-1960	-476.2	-416.6	-500
1961-1970	4.79	5.38	4.95
1971-1980	0.58	0.84	0.66
1981-1990	0.167	0.33	0.21
1991-1999	0.06	0.11	0.07

Acknowledgements

The authors wish to acknowledge the kind encouragement of Prof. K. Kobayashi at Kyoto University, Prof. Y. Ono at Hokkaido University and participants in the 2002 Annual Spring Meeting of the Japanese Geographers' Association. Last but not least, the authors would also like to kindly thank the reviewer(s) for the invaluable comments. Any remaining errors are the responsibility of the authors.

References

1) Fukao, K. and Qiu, X. (2000) : Economic Convergence and Productive Factor Input of Japanese Postwar - applicable to Solow Growth Model? Economic Research, **51**-2, 136-151, (in Japanese).
2) Kawata, Y. and Karatani, Y. (2000) : Study on Loss Estimation of Social Value due to Heavy Casualties. Papers in Engineering Planning, **17**, 393-4000.
3) Kniesner, T.J. and Leeth, J.D. (1991) : Compensating Wage Differentials for Fatal Injury Risk in Australia, Japan, and the United States. Journal of Risk and Uncertainty, **41**, 75-90.
4) Kurigi, M, Y. Imamura and H. Kobayashi (1996) : Economic Evaluation of Intangible Effect of Flooding. J. JSNDS, **15**-3, 231-240, (in Japanese).
5) Maruoka, N. (2000) : The Keywords of Flood-Prevention Projects are Communication. Efficiency and Environmental Protection, Construction Club, March 2000.
6) Ministry of Land, Infrastructure and Transport, Japan (2000) : Manual of Flood Control Investigation, (in Japanese).
7) Ministry of Land, Infrastructure and Transport, Japan (2001a) : Flood Loss in 2001. http : //www.mlit.go.jp/kisha/kisha01/05/050524_.html, (in Japanese).
8) Ministry of Land, Infrastructure and Transport, Japan(2001b) : Statistics of Flood. Ministry of Land, Infrastructure and Transport, Japan, (in Japanese).
9) MunichRe (2001) : Topics : Annual Review : Natural Catastrophes 2000. MunichRe Group.
10) Murphy, A.H., (1985) : Decision making and the value of forecasts in a generalized model of the cost-loss ratio situation. *Mon. Wea. Rev.*, **113**, 362-369.
11) Ono, Y. (1999) : River Science for Citizen. Science, **69**-12, 1003-1012, (in Japanese).
12) Palmer T.N., Brancovic, C. and Richardson, D.C. (1999) : A probability and decision-model analysis of PROVOST seasonal multi-model ensemble integrations :

the economic value of seasonal forecasts. Abstracts of 4th international conference on modelling of global climate change and variability, Hamburg, Germany.
13) Pielke, Jr., R.A. and Landsea, C.W. (1998) : Normalized Hurricane Damages in the United States : 1925-1995. Weather and Forecasting, **13**, 621-631.
14) Pielke, Jr., R.A. and Landsea, C.W. (1999) : La Nina, EI Nino and Atlantic Hurricane Damages in the United States. Bulletin of the American Meteorological Society, **80**, 2027-2033.
15) Riley, S.T. (1993) : The Economics of Hedonic Damage. Forum, Consumer Attorneys of California.
16) Saeki, T, *et al* (2001) : Evaluation Method of Medical Expense of Death and Injuries from Earthquake. Papers on Social Safety Science, **3**, 133-140, (in Japanese).
17) Takagi T., Ookuni, S. and Sakai, N. (2000) : Practical Study on Structural Analysis and Economic Evaluation of Mental Damage by Flood. Papers on River Technology, **6**, 225-230, (in Japanese).
18) Viscusi, W.K. (2000) : The Value of Life in Legal Contexts : Survey and Critique. American Law and Economics Review, **2**-1, 195-222.
19) Yamamoto, R and Sakura, Y. (1999) : Extremely Heavy Precipitation has Intensified over Japan. Proceedings of IDNDR Symposium on Mitigation of Water-related Disasters, 23-28.

(Accepted : October 25, 2002)

日本治水投資の効果分析

翟　国方*・福囿輝旗*・池田三郎**

*独立行政法人　防災科学技術研究所　総合防災研究部門
**筑波大学社会工学系

要　旨

低成長期の現在，従来のように増えつづける水害防災への投資方針を見直す動きも始まっている．本報告は，日本の水害被害額を標準化することによって，日本の水害被害額の傾向及び治水投資の経済効果を調べ，以下の結果を得た．

①水害による被害額の絶対値は減っていないが，標準化した被害額は大幅に減少し，70 年代から緩やかな減少傾向にある．

②洪水による総損失を経済被害，人的被害と精神的被害の総和と考えた場合，1955 ～ 1997 年における経済被害が大部分で , 通年の平均で 77% にのぼっている．人的被害の割合は，1970 年以前には増加傾向にあったが，それ以後は，そのような傾向は見られず，変動幅は大きいものの，平均 8% 程度であった．
精神的被害の割合は，1970 年代以前は，平均 7.8% であったが，その後 20.7% に増加している．

③総便益対総費用比，限界代替率と弾力性を用いて治水投資の効果を評価したところ，80 年代以降は，治水投資は効率的ではなかったことが明らかになった．

キーワード：水害被害額標準化，治水投資，効果分析，日本