

Review:

# Flood Disaster in Japan

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Progress against flood disasters since the end of World War II has shown that although human casualties have sharply decreased, material damage has not, despite improvements in flood control facilities. This is partly due to the increased concentration of buildings, infrastructures, and other assets in urban areas. Both natural and social factors are listed, and the implementation of suitable flood control policies is indispensable to saving lives and mitigating disasters in the future. Urban flood disasters are focused as a new type disaster explained in detail, stressing a combination of structural and non-structural measures and wide-area development accounting for both rivers and their entire basins to distribute the load in terms of flood control policy.

**Keywords:** flood disaster, inundation, urban flood control, countermeasure against flood disaster, river basin management

## 1. Introduction

Flood disasters are generally classified into riverside water and landside water based on water origination. Flood disasters originating from riverside water involve inundation from outside of river banks due to dike breach or overtopping of water during flooding or typhoon storm surges. Flood disasters originating from landside are caused by rainfall over the land inside dike that exceeds drainage capacity without flowing outside these dikes.

Flood disasters include storm surges and tsunamis at seashores and geohazard disasters such as debris flow, although here we mainly consider flood inundation disasters triggered from rivers.

## 2. Flood Disasters in Japan

Figure 1 shows the dead and missing and damage calculated at prices in 1955 caused by flood disasters, including storm surge inundations and geohazards, since 1945 [1]. Two factors divide results in half in the 60s.

The first half is characterized by frequent large typhoons and record heavy rainfall over wide areas resulting in high human loss and damage. Many well-known

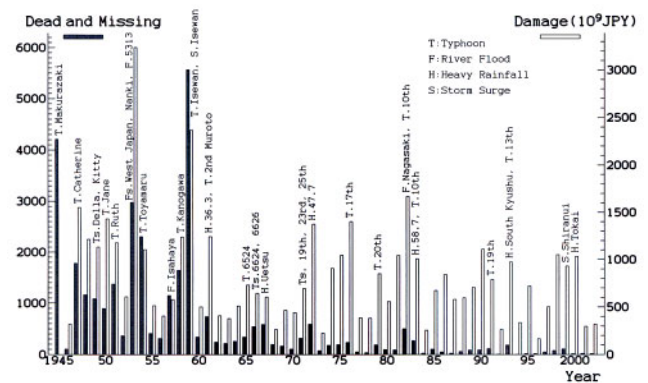


Fig. 1. Water-related hazard in Japan (including geohazards). Damage at 1995 costs.

post-WWII flood disasters occurred during this period. Examples include damage, mainly sediment-related, in Hiroshima Prefecture and western Japan caused by the Makurazaki Typhoon; bank failures along the Tone River and inundation disaster in eastern Tokyo caused by Typhoon Catherine; storm surge disasters in Osaka caused by Typhoon Jane; and the unprecedented storm surge disaster in Tokai caused by the Ise Bay Typhoon. The largest such flood disaster in dead and missing casualties was the storm surge during the Ise Bay Typhoon in September 1959, in which casualties numbered 5,098.

The second half is characterized by a dramatic drop in dead and missing, attributable to improvements in flood control facilities such as river improvement, dam reservoir and detention pond construction, advanced weather forecast technology for typhoons and heavy rainfall, and improved evacuation arrangements. Another fortunate factor is that fewer large typhoons and heavy rainfalls occurred in this second period.

In terms of damage, however, little changed in the second period except for the years of 1953 and 1959, which experienced extraordinary flood disasters. This trend has continued. Areas of inundation have been reduced as flood control policy has been implemented. The fact that Japan has grown economically and its assets have increased, including centralization in urbanization, has also contributed to this trend, suggesting that damage per area of inundation (damage density) rose, since inundations in relatively small areas could cause significant damage and openness to flood disasters increased.

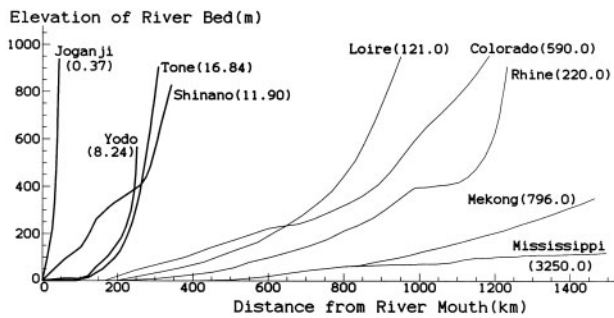


Fig. 2. Longitudinal profile of riverbed. Numbers in parentheses are  $10^3 \text{ km}^2$  river basin areas.

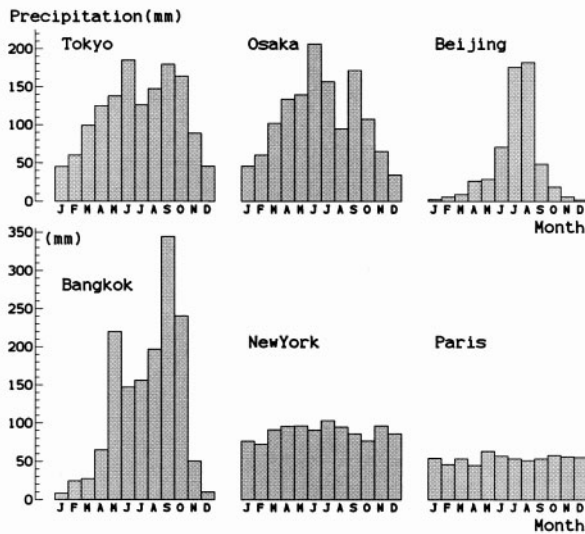


Fig. 3. Monthly precipitation.

### 3. Flood Disaster Factors

Japan has long suffered from floods due to the following factors:

(1) Steep river inclines

Japan's geography features mountain ridges running down the center of its relatively narrow islands, making rivers generally short and on steep inclines (Fig. 2 [2]). Compared to continental rivers, Japanese rivers look more like waterfalls than rivers. Because Japanese rivers reach the sea so soon, area of river basin and plains are small.

(2) High precipitation

Japan's average annual rainfall is about 1,700 mm – large compared to the world average of 970 mm (Fig. 3 [3]). Located in the Asian monsoon belt, Japan's rain tends to be concentrated in the "rainy season." Located east of the Asian continent and west of the Pacific Ocean, Japan is frequently hit by typhoons, further increasing rainfall. As mentioned later, local torrential rainfall exceeding 50 mm an hour has occurred increasingly often in recent years.

(3) Large, swift floods

Due its abrupt geography and large amounts of rainfall,

Table 1. Comparison of peak flood discharge per unit basin area.

River	Flood discharge per unit drainage area ( $\text{m}^3/\text{s}/\text{km}^2$ )
Tone R.(Kurihashi)	1.24
Shinano R.(Ojiya)	0.628
Yodo R(Hirakata)	1.09
Yangtze R.	0.0299
Mississippi R.	0.0232
Rhine R.	0.0580

Japan's floods start and end comparatively quickly. Continental river flooding, in contrast, may last several weeks to one month. Japanese rivers are characterized by "flash" floods leaving insufficient time for forecasting, warning and evacuation, hampering measures against flood disasters.

Despite small river basins and short duration flooding, peak flood discharge per unit basin area indicating flood intensity is by no means small (Table 1 [4]). Flood discharge is, in fact, significant compared to the basin area of Japanese rivers.

Another feature of rivers in Japan is the large fluctuation in discharge throughout the year. This means that discharge becomes high during floods but extremely low during droughts. Because of steep riverbed inclines, the time from rainfall to flooding is short – put succinctly, the trend is for "rainfall to equal flooding, but no rainfall to equal drought."

Take some examples of continental river flooding – The Oder River flowing through the Czech Republic, Poland, and Germany was the site of the "flood of the century" (Jahrhundertflut) in 1977, estimated to have been about  $3,000 \text{ m}^3/\text{s}$  at Frankfurt an der Oder – over 6 times the normal discharge of about  $500 \text{ m}^3/\text{s}$ .

In Japanese rivers, flood discharge may be some hundreds of times that of normal, and such a wide-range fluctuation in discharge raises problems from the viewpoint of flood control and water utilization as a resource.

(4) Active sediment yield

As of 1995, the sediment (alluvial) volume deposited in 750 dam reservoirs in Japan was estimated to be 1.2 billion  $\text{m}^3$ , much of which is from Chubu and Hokuriku. Some 150 million  $\text{m}^3$  of new sediment is produced every year [5].

Because this represents the amount of sediment deposited in dams, it depends both on how much sediment is produced in a region (sediment production) and on the time when a dam was constructed and the number of dams. If rivers without dams are included, much more sediment must be taken into account.

If sediment production is concentrated, this could cause

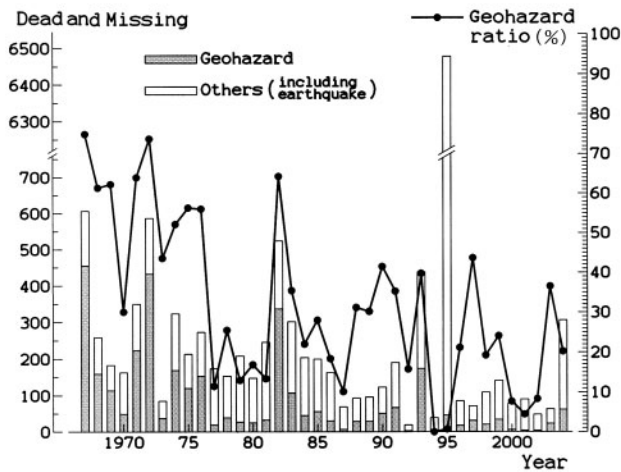


Fig. 4. Victims of natural disasters and the geohazard ratio.

sediment-related disasters such as debris flows. Such disasters, landslide and slope failure, often triggered by rainfall, are dangerous and involve human loss, many victims being elderly people living in the mountains, every year (Fig. 4 [6]). Japan's dangerous geography, with its disruptive geology of fragile soil and steep slopes, make it necessary to focus on both disaster prevention measures and reduction of damage.

The production of large amounts of sediment causes problems such as reduced effective dam reservoir effective capacity and rise of riverbed from dams. It also causes riverbeds below dams to fall and changes the configuration of shorelines. Behavior of sediment movement in rivers significantly influences the river environment of fauna and flora important for rivers, making comprehensive management of sediment control from upstream to downstream important.

#### (5) Cities on flood plain

Many cities in Japan are located on alluvial plain formed by the accumulation of river-transported sediment. As mentioned above, actively produced sediment often makes riverbeds higher than the ground between banks. A typical example is a so-called "suspended river" whose bed is higher than the neighboring plain.

Figure 5 compares the cross-sections of Osaka and London. The Thames River flows at the lowest level in London, but in Osaka, the water level of the Yodo and Yamato Rivers during flooding is highest, that of the Neya and Hirano Rivers running through the city second highest, and urban areas the lowest. Danger thus exists that large flooding from river inundation could occur during bank failure and that inundation inside dike could occur due to the difficulty of draining inner city rivers into the Yodo River. Many so-called area lower than sea level are located along the seashore.

Many cities with large populations, assets, and hub functions in Japan are thus located downstream of potential risk of flood disasters. Districts that have already sustained inundations or are at risk (both are called flood prone area) account for 10% of all land in Japan, but in-

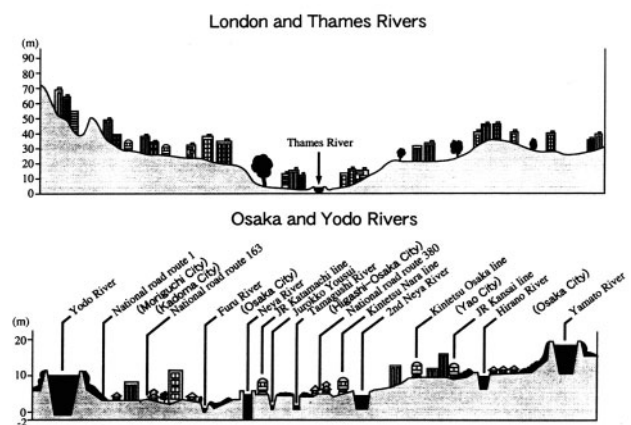


Fig. 5. Cross-section profile of typical city.

volve 50% of total population and 75% of total assets – quite a contrast to the United States, for example, where inundation districts account for 7%, involve 9% of the total population.

## 4. Recent Flood Disasters Reviewed

Recent flood disasters have been characterized by frequent torrential rains, inundation inside dike, inundation of small and medium rivers, and flood disasters in urban flood. Seen in terms of damage, elderly populations have suffered disproportionately from flood disasters.

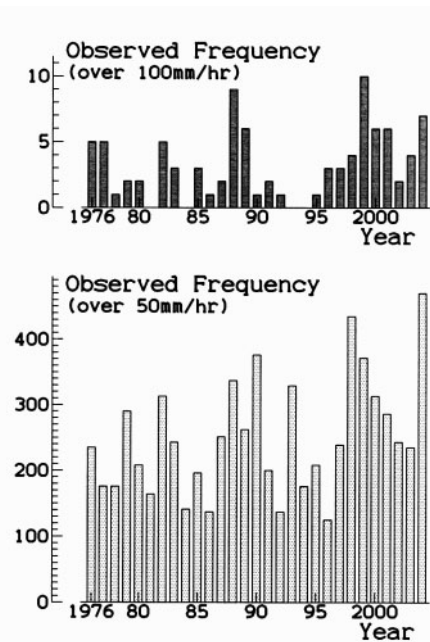
### (1) Frequent torrential rains

Much of the rainfall triggering flood disasters is due to typhoon, stagnant front over Japan or typhoons accompanied by heavy rainfall concentrated locally and continuously.

Figure 6 shows frequent occurrences of torrential rains over an hour based on data from the Automated Meteorological Data Acquisition System (AMeDAS) [6]. Rain falling at 50 mm an hour is the criterion upon which many improvement plans for sewerage systems are designed in Japan. Rain of 50 mm an hour resembles waterfalls, preventing people from see well ahead of themselves. Such heavy rainfalls are observed several hundred times a year, as are occasional rainfalls of 100 mm an hour. The highest hourly rainfall recorded in Japan is 187 mm, which fell in Nagayo during the Nagasaki flood disaster in 1982.

The degree of concentration in space depends on the cause of rain. If the cause is a thunderstorm, significant localized rainfall often occurs in the summer evening. If the cause is a weather front or typhoon, the spatial range of rainfall is not so limited. The most dramatic is torrential rain covering the whole basins of small and medium river, occurring frequently and triggering inundations in river running through cities or tributary basin.

Meteorologically, the trends in Fig. 6 cannot be directly connected to the idea that the number of heavy rainfalls is increasing. The convergence of wind, upward



**Fig. 6.** Frequency of heavy rainfall observed from about 1,300 AMeDAS sites.

current of air due to heat islands, urban geography and large amounts of aerosol as the core of raindrop particles, however, are considered to be factors in the occurrence of torrential rain in urban areas. Quantitative evaluation of these factors and torrential rain forecasts in urban areas is a projected study theme.

#### (2) Inundation inside dike

In many sewage system plannings, the objective set is to treat rain is 50 mm an hour. Sewage system dissemination barely exceeds 50% in all areas requiring protection against inundations, however. Torrential rain of 50 mm an hour appears also to be occurring quite frequently (**Fig. 6**).

These factors and urban geography cause frequent inundation inside dike, especially on lower plains when urban rainwater drainage capacity is exceeded. This is gloomy and aggravating for local residents.

The problem of inundation inside dike is not limited to urban areas. At the confluence of tributaries and major rivers, for example, where tributary banks are constructed high for backwater region, rainwater within the tributary basin is drained through pumps. If rainfall exceeds the pumping capacity, drainage cannot catch up with rainwater in the tributary basin, causing inundation inside dike.

Inundation inside dike are generally considered smaller than flooding from river, but in some cases, surrounding inundation inside dike flowing toward the lowest point geographically must be taken into consideration because such inundation could reach significant depths.

#### (3) Inundation of small and medium rivers

An example of torrential rain covering an entire basin as mentioned earlier is the rainfall in 2004, the year when 10 typhoons struck Japan. This triggered many flood disasters, covering some hundreds of km<sup>2</sup> from some hours

to a whole day. Although no flood disasters occurred along large rivers such as the Shinano, large flood disasters occurred in rivers with basin areas of some hundreds of km<sup>2</sup>, including the tributaries of large rivers. Setting aside the magnitude, it was as if the situation before the first half of the 60s had reappeared.

The improvement in small and medium rivers and tributaries is low. Since the Tokai Region flood disaster in 2000, emphasis in flood disaster measures appears to have shifted to urban areas, but many more measures are still needed against conventional flooding.

Such rainfalls striking the basins of rivers running through large cities could cause urban flood disasters. In any case, flood control against such torrential rain is desirable from the viewpoint of whole basin.

#### (4) Damage

Damage intensity and the suffering of older populations are rising. Damage intensity is caused as assets in inundation districts, especially those vulnerable to inundation, such as automobiles, electrical goods, and computer facilities, increase. In the Tokai Region flood disaster typical of urban flood disasters, damage to private properties accounted for 96.4% and damage to general public properties – roads, bridges, etc. – for only 3.6% – an all too typical feature of urban flood disasters.

In such disasters, including sediment-related disasters, those aged 65 years and older account for 60% of all victims due in part to delayed evacuation information transmission and action and to the lack of assistance in evacuating. Measures and local community support are thus required for evacuating older populations and others who need helps.

## 5. Urban Flood Disasters

Since the high growth of the Japanese economy in the 1960s, urban flood disasters have mushroomed. This phenomenon involves two aspects – how the hydrological and hydraulic events triggering disasters change under increasing urbanization and how damage caused by flood disasters is changed by urban development.

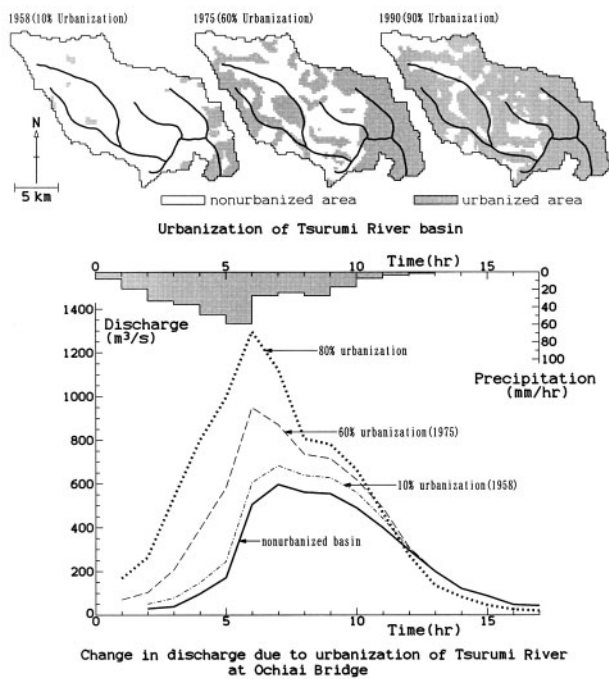
The former, in turn, involves changes in runoff accompanied by progressive urbanization, the inundation of small and medium river and inundation inside dike mentioned earlier. The latter, in turn, involves damage to centralized, complex, diverse structures and functions in urban areas.

### 5.1. Urbanization and Flood Inundation

Changes in rainfall patterns caused by progressive urbanization were referred to above. More direct influences of urbanization on flood inundation concern the following:

#### (1) Changes in flood by progressive urbanization

Progressive housing land development with increases in urban population raises the runoff percentage of torrential rain and increases the burden on urban rivers. Generally, urbanization makes flood discharge faster and peak



**Fig. 7.** Flood discharge changes due to urbanization of Tsurumi River basin at Ochiai Bridge.

discharge increases, resulting in more acute and dangerous flood. Especially in basins of small and medium river running through cities, the potential risk of flood inundation increases exponentially with urbanization. Around the Tsurumi River in Kanagawa Prefecture, for example, urbanization in 1958 was 10% but had increased to 90% by 1990. Based on trial calculations (Fig. 7), flood discharge at reference points doubled from about 600 m<sup>3</sup>/s at 10% urbanization to 1,300 m<sup>3</sup>/s at 80% urbanization (Fig. 7 [7]).

Urbanization triggers great damage if inundation occurs, i.e., the urbanization process increases potential damage. Urbanization thus doubly increases the danger of inundation disasters.

#### (2) Urban river inundation

Bedroom and satellite city burgeon in large city suburbs under progressive urbanization, which, in turn, increases and speeds up the flood discharge into rivers passing through suburban towns and large cities. Especially when new urban development is conducted upstream from an already developed city, downstream areas lack sufficient capacity to handle discharge from upstream increased by urbanization. Urbanization thus places a large burden both on developed areas and areas downstream from them, and increases the risk of inundations throughout urban river basins.

Sewage systems play an important role in draining rainwater in urban river basins. As mentioned, however, many sewage systems are set to treat an hourly rainfall of 50 mm and sewage system dissemination is yet insufficient. Changes in flood patterns and the frequent occurrence of torrential rain also raise the risk of inside dike inundation.

## 5.2. Flood Disasters in Urban Areas

### (1) Complex inundation events

Urban streets develop in the form of networks. On both sides of streets, buildings, shops and housings stretch in long lines and architectural structures are highly dense. Many use underground spaces such as basements, and in the centers of large city, underground spaces used for underground shopping centers, subways, underground warehouses and parking lots are well developed and often multi-layered structure. Structures such as embankments, railways, and roads, which would influence water flow significantly in inundations, stretch long distances. Some embankments have dike opening or seawall gates that must be shut if flood disaster are forecast. Sewage systems drain rainwater, of course, but their risk in reverse flow inundation must be also taken into account. The terminal pumping station is important in drainage facilities in inside dike inundation. When rainwater is drained into rivers, stoppage or regulation may be required, depending on how flood conditions develop. The terminal pumping station may be placed in a conflict between drainage of inside dike inundation and passage of water outside dike.

Inundation flow is greatly influenced by subtle differences in micro topography. In many urban areas, the awareness of such terrain is low and inundations may occur or become concentrated at unexpected locations.

### (2) High concentrations in cities

As mentioned earlier, many cities in Japan are located on flood plains with high population, housing concentrations and administrative, economic, and socially central infrastructures. A problem arises in flood prevention measures due to the difficulty of acquiring sites because dense concentrations of population and buildings make new large flood control projects difficult to implement. A further problem arises in the diverse damage adversely affecting both human life and properties if flood disasters occur.

### (3) Diverse damage

A noteworthy feature of urban environments is the interconnectedness of events, which often involves chains of circumstances complicating damage occurrence because of the many facilities and functions involved. The inundation of a single road, for example, may cause traffic jams adversely affecting other roads and paralyzing the entire urban transport system. The submergence of roads under water may also lead to the loss of evacuation routes.

Power supply facilities underground in building damaged by inundations could trigger a chain of locally disastrous events such as confusion caused by the loss of lighting, limitations on evacuation, the interruption of telecommunications, e.g., telephones and facsimile equipment, and the paralysis of computerized services. This, in turn, could further spread to suspended railway and road services, economic loss caused by stopped or delayed financial and other transactions – all direct damage – further complicated by indirect damage such as the suspension or termination of business and commerce.

One more point to be brought in terms of damage is

underground flood disasters. In public and private housing and buildings, the volume of underground space is generally smaller than the volume of floodwaters, meaning people should be made aware that, once flooding begins, water levels may rise faster than expected. Given the degree of high development of underground shopping centers and subways in many cities and the high numbers of people who use them, underground flood disasters become a highly important aspect of urban inundation consideration.

Concealed behind improvements in the convenience of ordinary urban life and the degree to which urban dwellers are accustomed to this convenience, cities have become increasingly vulnerable to disasters stemming from even slight flooding and the urban landscape has become much more fragile in the face of potential flooding.

#### (4) Weak local intercommunity connections

In addition to structural measure, non-structural measure have taken on increasing importance. Such nonstructural aspects include weather forecasting, warning systems, evacuation arrangements, and flood prevention activities.

Meteorological and river information transmitted via broadcasting play an important role in people's preparedness against disaster and judgment in the face of evacuation. Many urban residents, however, are only marginally interested in flood disasters. This is due to a lack of direct experience leading them to conclude that such problems are the concerns of other people and not their own. Ironically, the more that flood control policies such as river-bank improvements are implemented, the lower the risk recognition and interest in flood disaster potential! The traditional sense of local neighborhood awareness has declined decidedly over the last decades, but the function of mutual local assistance in situations such as evacuation and flood fighting has grown glaringly great, especially in a fast aging society.

## 6. Protection Against Flood Inundation Disaster

### 6.1. Improvements of River and Sewage Systems

The basic key to implementing measures for flood control and preventing inundation in urban areas is the improvement of river and sewage systems.

For rivers, the designed rainfall of the following probability of exceedance is set based on the importance of river, then flood prevention plans for rivers are drafted.

- Class A: return period in 200 years
- Class B: return period in 100 to 200 years
- Class C: return period in 50 to 100 years
- Class D: return period in 10 to 50 years
- Class E: return period within 10 years or less

The importance of a river is decided based on its size, the region's social and economic importance, the amount and degree of damage, and the local disaster history. Generally, main reaches of first-class rivers are designated as class A or B, followed by other reaches and the river classes involving C, D, and E.

Improvements in sewage systems are important both for its function to treatment of sewer and for urban flood prevention through drainage of rainwater. The hourly rainfall of 50 mm generally set as an improvement target in rainwater drainage plans corresponds in many cases a disaster of return period within 5 to 10 years.

The problem is that this probability differs greatly from that of the case of rivers improvement. This difference is also associated with the significant difference in the assumed scale of damage between water outside dike inundation and water inside dike inundation.

Another problem arises. As mentioned, if rainwater is drained into a river through a pumping station, if the river reaches a dangerous level due to flooding, drainage from sewage systems must be regulated, complicating the operation of drainage the pumping station. This is basically a problem of coordinating river plans and sewage system plans together with the above problem of potential disaster occurrence. These issues make it necessary for the concerned authorities to consult and cooperate and reach a consensus among residents on the results of such cooperation and coordination.

It must also be remembered that events could exceed the designed flood because the torrential rains and typhoons are essentially natural phenomena. In addition, improvement in river and sewage systems remains low compared to the scale of required planning.

Yet another important factor in promoting improvement is the need for mutual cooperation among municipalities located along rivers. Conflicts of interest are bound to arise between upstream and downstream interest and among those on opposite banks.

In addition to improvements in river and sewage system plans and storage facilities of rainfall, the wide-area exchange of information and cooperation on flood disasters is crucial in both ordinary times and in evacuation and relief activities during flood disasters.

### 6.2. Structural Measures

The followings are the main structural measures against flood disasters.

- River improvement – improvement of river course, embankment, widening, excavation, dike height increase, reinforcement of dike, revetment, groin
- Diversion channel – flood bypass
- Storage – detention pond, dam reservoir
- Reduction of runoff – detention pool, regulating pond, storage of rainfall, infiltration, permeable pavement

- Drainage – improvement of sewerage system, prevention of accident at manhole or drainage ditch
- Underground channel – increase of drainage capacity in dense urban area
- Protection of facilities – center of disaster prevention shelter, refuge basement, pumping station, lifeline, piloti house, prevention of underground inundation

Concerning these structural measures, in addition to the structures themselves, it is important how rules are made for their operation and use.

In addition to the above measures, considerations should be made for implementing “super levee” – those so wide that they are not breached by floods even if they may be overtopped – for the flood exceeding the designed level.

Further steps should include the control of inundation by secondary dike and other measures for lowlands such as heightening of house and ring dike, polder (“waju”) to enclose and protect communities from floods both to improve rivers by stages and to permit inundation to acceptance. This goes beyond river control to river basin flood control to take some of the burden off rivers themselves. Comprehensive flood control measures mentioned later are one type of basin flood control.

### 6.3. Non-Structural Measures

Because many structural measures are expensive and time-consuming until completion and are thus staged in their construction, additional measures are needed to compensate for these measures and for potentially unpreventable flooding and other occurrences. Among these non-structural measures are the following:

- Land use – regulation, transfer
- Announcement and recognition of flood risk – inundation map, flood risk map, risk zoning map
- Establishment of emergency management
- Forecasting and warning system – collection of meteorological and flood information, forecasting of flood, information to governmental and residential organization
- Transmission of information – measure for transmission, wireless transmission, publicity and broadcasting, telephone
- Evacuation – contents, timing and transmission of evacuation, refuge site, path of refuge, support of refuge site
- Regional flood-fighting – organization, volunteer
- Insurance and compensation – risk sharing system

Among the above nonstructural measures, for example, are regulations to development to prevent increasing the burden on rivers during flooding. Information provision in ordinary times is important and the expectations of hazard maps (risk zoning maps) is high. Information must be provided and disseminated so that residents receiving such information understand how they have to act. In evacuation, problems could arise in only limited numbers of residents evacuating despite announcements of evacuation, insufficient numbers of evacuation shelters, and risks encountered while evacuating to shelters. Insurance, compensation, risk sharing and risk assignment are problem requiring solutions in the future.

### 6.4. Comprehensive Flood Control

Increased flooding caused by progressive urbanization upstream cannot always be handled by measures in the downstream, e.g., widening of rivers or raising of riverbanks in the downstream is seldom possible. Limitations exist if only river measures are taken to manage floods, so floods should be regulated using river basins as a whole.

With this in mind, Comprehensive Flood Control Measures focusing on basin measures have been implemented in some river basins since 1977. In addition to conventional flood control measures, these focus on maintenance and promotion of water reservation and water adjustment in the whole basins, measures for lowlands, and nonstructural measures for damage mitigation.

In 2003, a new law was enacted to promote measures mitigating inundation damage in urban areas in line with river and sewage system plans.

### 6.5. Hazard Map (Risk Zoning Map)

To centralize knowledge on flood disaster risks, maps have been published on historical record of inundation and hazard area maps based on flood inundation simulation. The purpose of these maps is (i) to recognize the possibility of inundation disaster, (ii) to promote interest in flood disaster prevention and to be used for evacuation, and (iii) to anticipate flood-resistant lifestyles. In combination with these maps and information on shelters and evacuation during inundations, called flood hazard maps are to be drafted and distributed by municipalities bound by the revised Flood-Fighting Act.

One aspect of hazard maps is to help residents recognize flood disaster risks right where they live. Hazard maps must also be concretely linked to evacuation plans. Such maps often include warnings, precautions to be observed during evacuation, and the locations of shelters, but should also be designed to advise evacuation based on anticipated inundation depth.

Another point is that matters other than those shown on hazard map could be left out despite their importance and relevance. In addition to showing inundation depths, for example, potential bank failures washing away housing, water flow rates, and other such risks must be anticipated that cannot be recognized by inundation depth information alone. Because hazard maps are based on simulation

under assumed conditions so information on large disasters going beyond planned assumptions is also necessary.

## 7. Concluding Remarks

We have reviewed trends in occurrences in recent flood disasters. Important problems remaining involves changes in flood disasters and where they occur due to global environmental change, especially global warming, and social changes in Japan involving an aging society and changing population and industrial structures.

Global warming could intensify fluctuations in rainfall in time and space. Increased uneven distribution of rainfall causes larger floods in some cases and serious droughts in others. As indicated at the World Water Forum security of irrigation water and stable provision of clean drinking water take top priority, droughts occur worldwide and cause much hardship. Studies on changes in global environment influences are needed.

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• "Inundation Analysis of Complicated Underground Space," Journal of Hydrosience and Hydraulic Engineering, JSCE, Vol.22, No.2, pp. 47-58, 2004.  
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### Academic Societies & Scientific Organizations:

- Japan Society of Civil Engineers (JSCE)
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