Past and Recent Developments of Flood Control in the Tone River

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1. INTRODUCTION

The Tone River has its source in Gunma Prefecture's Daiminakami mountains. Flowing through five prefectures and Tokyo, it has a catchment area of 16,840 km^3, the largest in Japan. With a length of 322 km, it has as tributaries the Watarase River, Kinugawa River and Kokaigawa River, etc.. Out of the Tone River flows the Edo River, to Tokyo Bay.

Since long ago the local inhabitants have been so fond of, and also afraid of, the Tone River that they nicknamed it Bandou Taro (Translator's note: Bandou refers to the Kanto region; and in the past the eldest sons in many Japanese families were given the name Taro). The river plays an important role in our life, providing water that is indispensable to our daily activities. On the other hand, the Tone River used to be a wild torrent, in which floods frequently occurred. Therefore, many flood control works have been constructed since long in the past Works in the Edo era involved the constructions of new channels, during the Meiji period the improvement of the levees and the sabo works. Entered the Showa era, the river has witnessed a series of improvement works, including the levees, the construction of dams in the upstream, the Watarase reservoir, river maintenance as well as environmental protection. Today the Tone River has become ever more important to the political, economical and social activities of the Kanto region, especially to Tokyo Metropolitan area It may be claimed as the most important Japanese river.

From the regional characteristics of the Tone River floodplain, this talk will first review the historical as well as present flood control measures, then discuss about the river administration and floodplain management in the future.

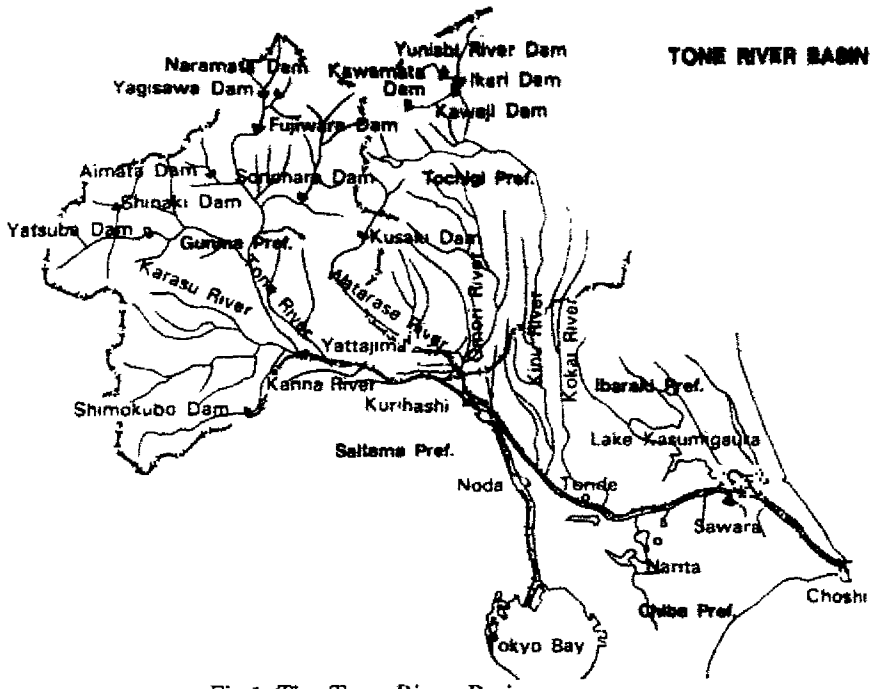

Fig.1 The Tone River Basin

2. FLOOD CONTROL IN THE TONE RIVER - River course migration and flood damages

River improvement works in the Tone River started after the first levees had been constructed in the Kamakura era. In 1457, Ohtadokan considered as the main flow course the one flowing southward from Kutsuwada (8 Km to the north of Kumagaya city), by Souka, and into Edo Bay (Tokyo Bay). It is believed that in some reaches the sectional area was enlarged. The details, however, remain unknown.

Improvement works started earnestly after the establishment of the Tokugawa Shogunate in Edo. The Tone River, until then a wild one, has been so trained as to have its main flow going to Choshi, while its main tributary - which forms the Edo River - joining Tokyo Bay. This integrates two originally different basins (Tone River basin and Hitachigawa basin which includes today's Kinugawa, Kokaigawa and Kasumigaura etc.) into a single one, creating the largest river basin in Japan. The project is now refereed to as the Tone River Easterly Diversion Work.

The Tone River Easterly Diversion Work is thought to have had several important objectives

a Prevention of inundation in Edo;

b Dissociate southern Kanto area from the Tone River, and had it cultivated;

c Develop navigation to enhance economic exchanges between the Kanto and other regions;

d. Military defenses, etc..

Being large scale, the Tone River Easterly Diversion Work, was carried out from 1594 to 1654, which created the present Tone River course. Before that, the main flow, tracing the old Tone River and Sumida River, poured down to Tokyo Bay. Therefore, large floods overflowed the Tone River, sometimes returned to its old course to Edo (Tokyo) Bay

For the above reason, large floods occurred and reached Edo in 1794, 1742, 1786, 1802, 1846, 1896, 1910 and 1947, with a return period of about 30 to 50 years.

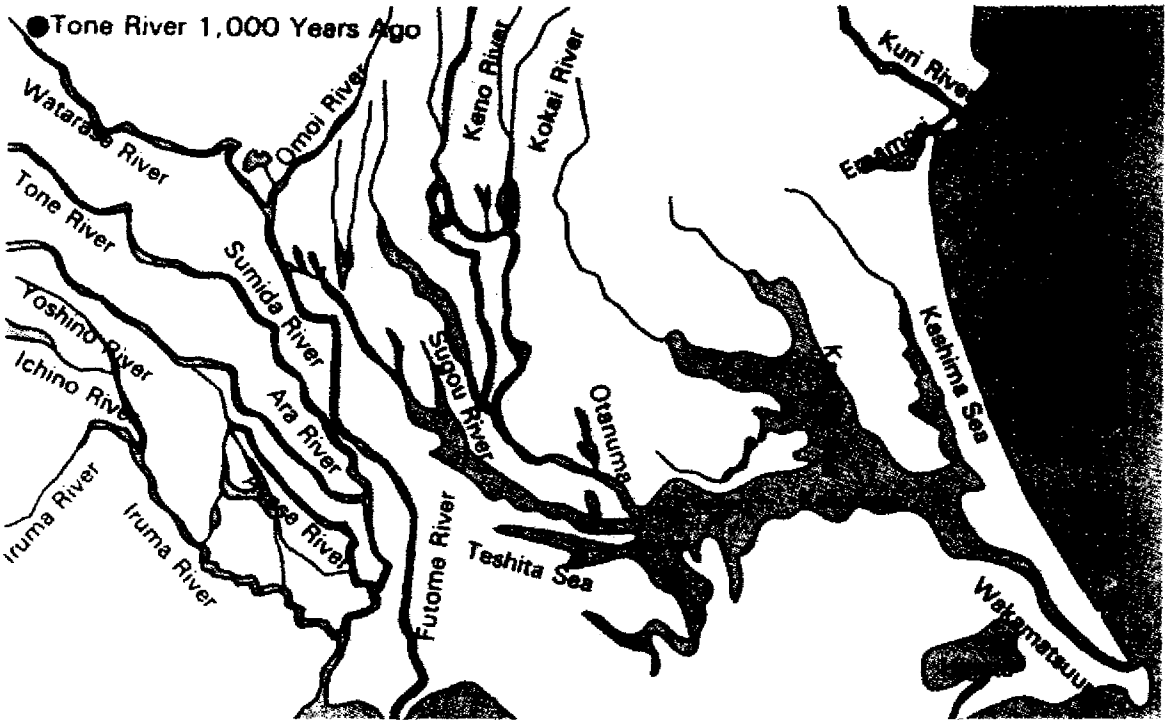

Fig.2 Migration of the Tone River Course

3. LEVEE FAILURES AND INUNDATION IN 1947

(1) Weather conditions leading to the levee failures

On September 8, 1947, Katherine Typhoon occurred east of the Mariane Islands. With a pressure of 960 mb at the center, it advanced northward at a speed of 45m/s. Along the way it rolled through east of the Boso Peninsula, pouring heavy rains down to the Kanto area. In the Tone River basin, the average precipitation was more than 300 mm.

Due to the heavy rains, debris flows occurred around Akagiyama in the upper Tone reach. In the middle Tone reach, the effects of confluence with the tributaries and backflows led to levee failures at numerous locations, and damages followed one another.

Starting from September 15, water level kept increasing at today's Shinkawadori, and the local flood fighting troops were put on alert. To make things worse, downstream of Shinkawadori there were three bridges, and works to rise the levee heights were just underway. All these factors forced the flows to spill over the levees, over a length of 1300m, with a maximum depth of 50 cm. At the end, the right bank levee broke out over a length of 340m. This immediately inundated the surrounding towns and villages, and the flood flow went southward along the old Tone River course. Near the location of levee failure, for a full month the villages were under waters of up to 5m deep.

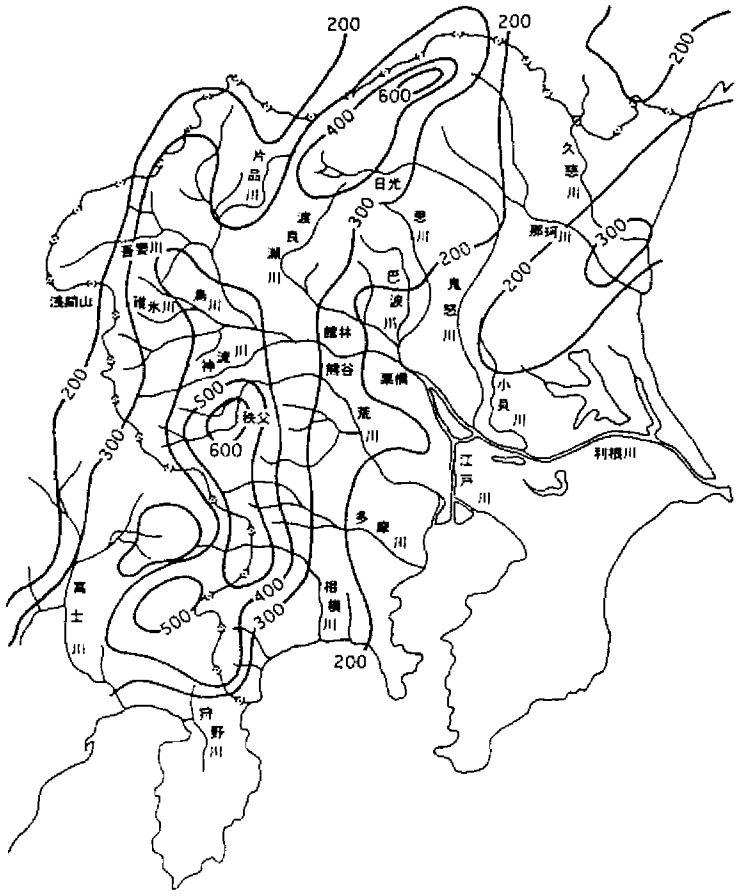

Fig.3-1 Rainfall of September 13-15, 1947

(2) The inundation

The mud flows from the Tone River subsequently destroyed houses and washed out crops. The main flood flow run further south along the Shonai River and the Nakagawa River. This southward flood flow broke out the levees of many small and middle rivers along the way, mostly of the Shonai, the old Tone and the Nakagawa.

The front of the flood flow then reached the Oubagawa levee (Sakura Zutsumi), there it stored for a while. At this time, efforts were made to divert water to the Edo River by cutting out the right bank levee near Matsudo. Before the cutting off, however, the Sakura Zutsumi levee broke out (at AM 2:20, September 19). Soon Katsushika Ward in Tokyo was in water.

Subsequently, mud flows flooded over the Jyouban rails and the national highway No.6, crippled the Soubu rails and the No.7 national highway, then arrived and stopped at the Shinkawa levees. Next, with the levees of the Nakagawa and of the Ayasegawa cut off, the water levels decreased and further levee failures prevented. Thereafter, efforts were made to divert the flood water to limit the potential inundation area.

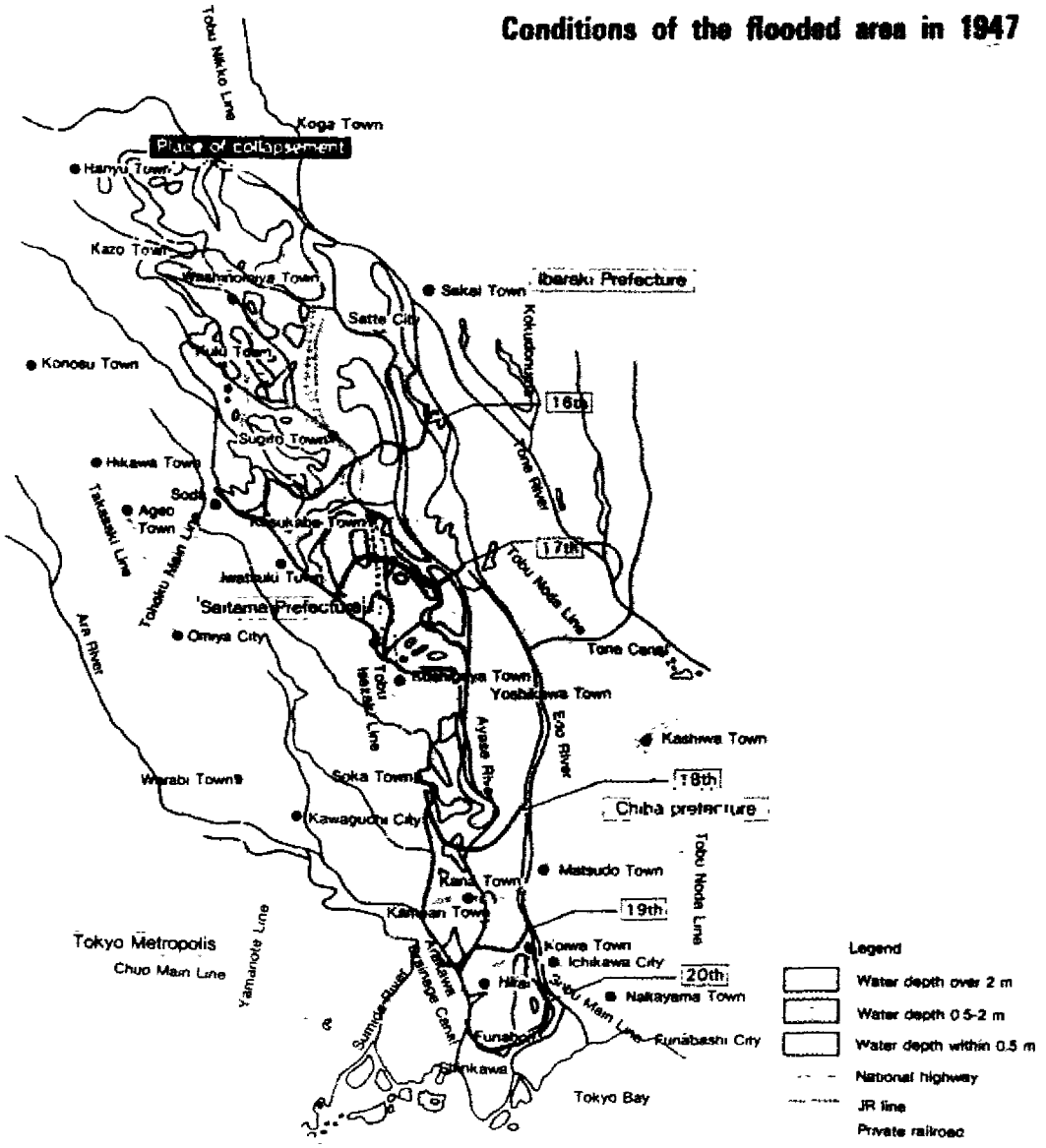

Fig. 3-2 Route of the Flood Invasion, after the Levee Failure at Azumamura

(3) Patterns of levee failures and patterns of inundation

①Inundation as influenced by topography

As can be seen from Fig 4, after the levee failure the main flood flow, running southward along the Shonaigawa and the Nakagawa, followed approximately the geographical conditions.

In fact, the area inundated is the so-called Nakagawa lowland, bordered by the Edo River and the Nakagawa River The old Tone River course, before reaching the Tokyo Bay, passed through this very same area, of which mostly were marsh lands Therefore, it may be concluded that the flood, avoiding the Ohmiya plain to the west and the natural levees, choose instead to go southward, through such lower areas as the Nakagawa and the Edo River.

② Levee failures in the small and middle rivers

The 1947 flood not only broke out the Tone River levee, but also destroyed the small and middle rivers' levees along the way, which shall be examined in the following.

Overall there were two factors leading to the failures of the small and middle rivers' levees.

1) failures due to flows inside the small and middle rivers

This type of levee failures happened in small and middle rivers of the upper Tone River basin, in which the discharge was larger than their conveyance capacities.

2) failures due to flows from the Tone River

This type of levee failures were seen in both the upper and the lower Tone River basins. In the upper river basin, the levees of small and middle rivers were destroyed directly by the mud flows from the Tone River. In the lower Tone River basin, the mud flows pouring through the broken levees in the upstream increased the discharge, which then became larger than the rivers' conveyance capacities, and the levees in the downstream collapsed.

It is considered that the inundating flood waters, while repeating the above processes, advanced down to Tokyo.

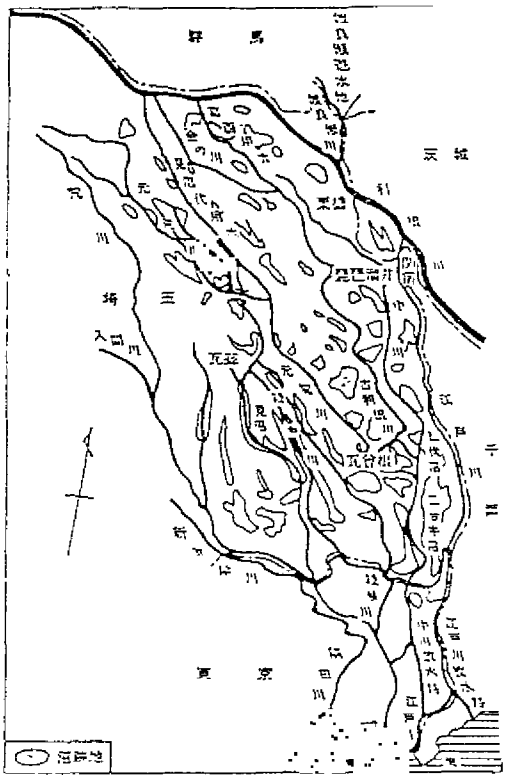

Fig.3-3 March Land in the Saitama Plain

(4) Damages

The flood destroyed the small and middle rivers' levees and inundated large area of the Saitama Prefecture, and even invaded Tokyo. It is reported that the flood stroke an area of 440 Km^2, affected the lives of 600,000 inhabitants, with a loss of about 7 billion Yen (at the 1947 prices). Shown in the following tables are more details.

Photo 3-1 A Scene of the Inundated Area

Table 1 Number of Victims

	Tokyo	Saitama Prefecture
Dead	8	70
Injured	138	1368

Table 2 Number f Houses Damaged

	Tokyo	Saitama Prefecture
Water above ground level	72945	29910
Water below ground level	15485	20514
Washed out or collapsed	56	930
Half destroyed	0	1795

Table 3 Farmland Inundated

Tokyo	Saitama Prefecture
23.3 km^2	328 km^2

Source: Katherine Flood (September 1947) and Levee Failure at Azumamura, the Tone River
Kanto Regional Bureau of the Construction Institute, January 1948

4. BASIC PLAN OF TONE RIVER SYSTEM

(1) Background of the plan

The 1947 flood occurred immediately after World War II. Therefore the conditions for field observations were so bad that the flow discharge was not measured at Yattajima.

Hence the first problem is how to determine the flow discharge at Yattajima. Using the water level records from the upper Tone reach, at Kamifukushima, Karasugawa and Kannagawa, as well as other exiting hydrological data, the unregulated peak discharge at Yattajima was estimated as being 17,000m^3/s. Accordingly, the design discharges for the tributaries downstream of Yattajima were determined.

The gist of this plan is as follows:

① Construct dams in the upper mountains for flood regulation, to reduce the design discharge at Yattajima by 3,000m^3/s, to 14,000m^3/s;

② Integrate the Watarase, Tanaka and Sugou-Inadoi retention reservoirs, to increase the overall regulating capability;

③ Increase the conveyance capability with large scale improvement works, such as setting back of levees, dredging and lowering the bed level, etc..

The plan of 1965, following the New River Act promulgated in 1964, also followed the main frame of the Tone River improvement plan. as established after the 1947 flood.

However. with the economic and social developments in the Tone River basin, the design peak discharge at Yattajima was set to 22,000m^3/s in December 1980, considering the hydrological conditions of the Tone catchment. The present plan also increased the regulating capability of the upper reach's dams to 6,000m^3/s.

Table 4 Successive Revisions to the Tone River s Basic Plan

Year of work (or revision)	Project	Unregulated Peak Discharge (design discharge), m^3/s	Grounds for the Determination of the Unregulated Peak Discharge
1901	Tone River Improvement Plan	3,750 (3,750) up to Kurihashi	1897 flood
1912	Tone River Improvement Plan	5,570 (5,570) at Yattajima	1911 flood
1939	Tone River Expansion Plan	10,000 (10,000) at Yattajima	Sept 1935 and June 1938 floods
1949	Revised Tone River Improvement Plan	17,000 (14,000) at Yattajima	Sept 1947 flood
1980	Basic Plan of the Tone River System	22,000 (16,000) at Yattajima	Largest historical flood (1947) or the one with 1/200 probability

(2) Determination of the Design Flood Discharges

If the conveyance capacity is to be increased by enlarging the cross-sectional area without any setting back of levees, then the following may be observed:

① Levee safety depends not only on its strength but also on the width of the adjacent floodplain; an examination of the past flood damages shows that a minimum width of 50m on each side of the river should be guaranteed;

② Since a sufficient floodplain width should be kept, the river's bed level then needs to be lowered to increase the conveyance capacity However, to maintain the stability of the bed and the river mouth, the design bed level must be lowered within certain limits,

③ Bearing the above on mind, the conveyance capacities and subsequently, the design discharges, may be set forward.

FLOOD DISCHARGE DISTRIBUTION (unit : m^3/sec)

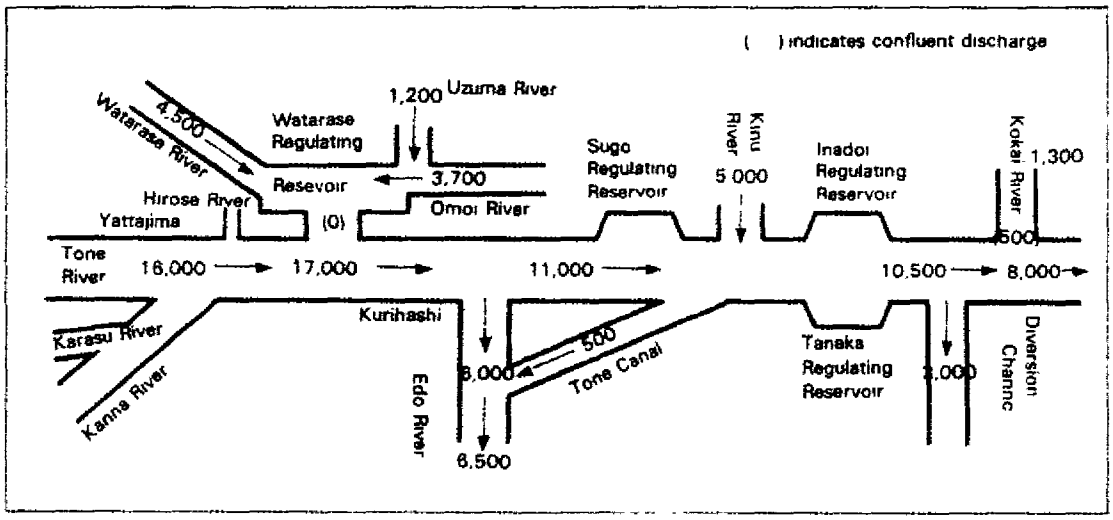

Fig.4 Design Flood Discharges for the Tone River System

5. PRESENT STATE OF THE TONE RIVER

Since Katherine Typhoon in 1947, major efforts have been made, including dam constructions, in the river's improvements. The Tone River now faces, among others, the following problems.

(1) Though greatly improved, the Tone River is still unsafe

Sine the 1947 flood, a series of measures have been taken to regulate floods. These include: dam constructions in upper mountain region; retention reservoirs in the middle reach; dredging, lowering of the river bed level, setting back of levees in the middle and lower reach (from Toride to the river mouth). Despite all these efforts, the Tone River at the present is still not safe in case large floods with 1/30 to 1/40 probabilities occur.

As shown in Fig.5, even with similar rainfalls as experienced in 1947, the flow dischange(particularly the peak value)in today's Tone River would be larger,and the hydrograph would become shaeper.

The main reason is that developments have reduced the river basin's flow retarding effect. After rainfall more water would soon accumulate and would flow rapidly into the Tone River. The improvement works in the tributaries have also made them less prone to floods and inundation, thus further increase the flow discharge in the Tone River.

On the other hand, due to the extremely concentrated population and properties in the Tokyo Metropolitan area,with the same rainfalls and levee failure conditions as in 1947, the damages and losses would be too huge to becompared with those in 1947.

(2) Further improvements of the dams and the retention areas are necessary

Although a group of 6 dams have been completed upstream of Yattajima, the dam group flood regulating capability is in sufficient.

On the other hand, works are being undertaken to use the Watarase retention reservoir as a regulating one, which would decrease flood discharges in both the Tone River and the Edo River. Of the Tanaka-Sugou-Inadoi group of retention reservoirs, two of these-Tanaka and Sugou retention reservoirs are in temporary service, the one at Inadoi is yet to be completed.

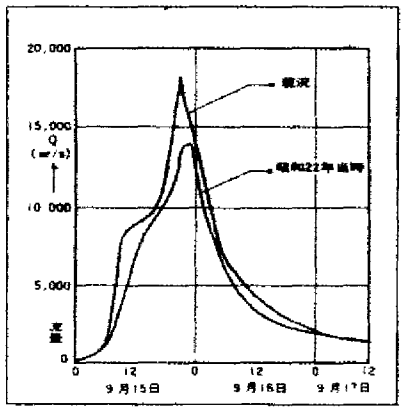

Fig 5-1 Discharge of the 1947 Flood and the One with the Present Conditions

Table 5 Estimated Losses due to A Flood as Experienced in 1947

Location of levee failure	135km, right bank levee	Estimate dinundation area	about 555km2
Peak discharge in the river	18,245m^3/s	Population affected	about 2,100,000
Peak overflow discharge	8,158m^3/s	Estimated loss	about 15,000 Bn. Yen
Total volume of inundation	655 x 106 m^3	*Properties+agriculture etc.:at 1992 price	

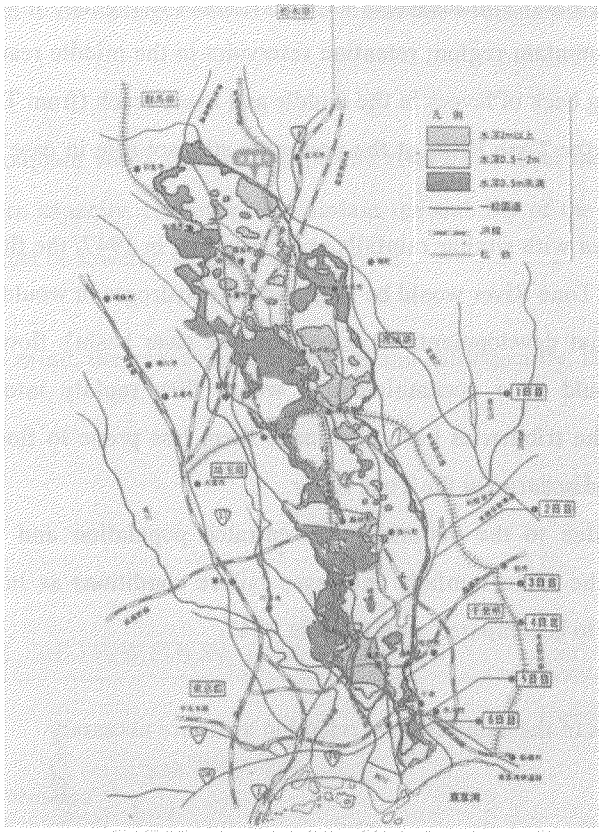

Fig.5-2 Predicted Route of the Flood Invasion,with the Present Channel Conditions

(3) Ground-level sinking and small and weak levees

Along the Tone River, 10% of its total length is not covered by any levee, and 50% have the so-called small and weak levees (too small as compared to the design levee). Leakage and slope sliding, which could lead to levee failure, sometimes occur during floods.

In the middle reach, since 1970 the ground level has been sinking in, as a consequence the levees on the right bank are about 1m lower than the design levee. This further threatens the Tokyo metropolitan area, where are concentrated a large population as well as properties.

From the Edo River s mouth to Toride the levees are extremely small, having thus the most serious safety problem. From the regulating weir to the river mouth (18.5km long), the Tone River remains without levees

(4) Part of the river basin frequently under water and dangers due to outdated structures

Developments accelerated thanks to the convenient transport systems. The development in turn has led to frequent immersions under water in some areas, which is partly due to the fact that many outdated facilities in the levees have now lower drainage capability.

(5) Construction of Super-Levees that are strong to earthquakes and to floods

It is planned that the Super-Levees will be constructed from the river mouth up to the confluence at Koyama. The total length on both sides amounts to 325km. Of the total, about 1% has been completed.

(6) Creation of waterfronts rich in nature

An environment along the river rich in nature means that it should be a friendly one to both fauna and flora, as well as one with beautiful scenery. Plans are under way to plant cherry blossom trees, and call for the rebirth of navigation.

6. RIVER ADMINISTRATION AND FLOODPLAIN MANAGEMENT IN THE FUTURE

It is our firm determination to carry out the basic plan for the Tone River. However, the present levees may fail due to the following reasons.

- the safety level, corresponding to floods with 30 to 40 years' return period, is rather low;
- it is difficult to construct the dams and retention reservoirs as planned, since the local population have become more environmentally concerned,
- since floods with 50 years return period have occurred in the past, which caused enormous damages, it is absolutely necessary to prepare for the eventual break down of the levees.

Therefore, river administration should always prepare for the worst. Particularly, floodplain management is very important regarding flood defense activities and crisis management

Furthermore, today better floodplain management may be possible using the latest information technologies.

(1) Characteristics of floods in the middle reach of the Tone River

①Social-economical situation of the potential inundation area

It can be easily imagined that levee failures due to large floods would cause such huge damages in the potential inundation area that the government nerves in Tokyo would even be crippled At the present state, if levees failed due to a flood as large as the one caused by the Katherine Typhoon in 1947,

the total loss is estimated at 15,000 billion Yen (at 1992 prices).

②Patterns of inundation

Inundation patterns along the Tone River's middle reach can be recognized in two types. Of the left bank side it is the retention type, the flooding area being limited between the Tone River's upper reach and the Watarase River. On the right bank side, it is the diffusion type, with which once a flood occurs it will invade a vast area including Tokyo.

1) Retention type floods---on the left bank side, the inundated area includes such typical areas as Kitakawabe-cho and Itakura-cho. During the September 1947 flood, the areas remained under water for more than 20 days.

2) Diffusion type flood---on the right bank side, once the levees break out between the confluence with the Edo River and the confluence with the Fukukawa River, floods would reach the Tokyo metropolitan area. During the September 1947 flood, the levee failed in Azumamura (135km from the river mouth), and Tokyos Katushika Ward was also inundated.

(2) Measures for the floodplain management

For the Tone River, floodplain management including structural measures and flood defense policies may be summarized in the follows.

(3) Inundation predictions at the present stage

Of the floodplain management measures, regarding disaster prediction methods (predictions and flood information supply) in the Tone River, a simulation model dealing with both the river and the inundated area is being developed. In the meantime, we are also examining how to supply flood-related information to the local population and concerned organizations.

■Model for flows in the river

The model considers the Tone River as well as its tributaries. It calculates the flow discharges and the water levels during a flood, evaluates the discharge corresponding to the levee failures, renders the overflowing discharge's temporal variation data, and further it is linked with the model for the inundation area. It is a one dimensional and non-steady flow model.

■Model for flows in the inundation area

When inundation occurs, the overflows out of the rivers can be considered as two-dimensional, which are influenced by the topography, railways and other obstacles, pumping facilities in the inundation area, etc..

The Tone inundation area has mild slope, thus the inertial term can be drooped and the Pond floodplain model is used. Meshes of 500m x 500m are used, and the actual geographical conditions as well as the drainage characteristics can be reasonably well taken into account in the model.

(4) Flood disaster predictions in the future

Flood disaster predictions in the future will help establish the basin database, and improve floodplain management.

Once levees break out, the behaviors of the inundating flows vary with the road and railway conditions, as well as the development level of the underground. These conditions should be reflected in the simulation model, used in flood defense and crisis management, and reflected in urban planning. To do these, it is necessary to develop a GIS tool for disaster prevention, which should be easy to use. Such a GIS tool should be able to collect the land use data and other economic development data, which could be easily updated.

Remote sensing should be employed in order to easily analyze the land use and developments underway. Once this becomes possible, the data can be used to determine hydrological parameters, which in turn will be used to predict short- and middle- term surface runoffs, and finally the flood discharge.

All these, if integrated into a GIS tool, will allow for prediction of the possible inundation area that depends on the changes of external forces and land use. It will also establish a flood evacuation system. Finally, floodplain management or crisis management would be on a more solid basis.

The following five subjects shall be studied. The aim is to summarize the obtained results and put them into a single system.

1) Establish a basin information data base, using remote sensing;

2) Develop a runoff prediction method, using the established database;

3) Put forward a flood disaster prediction model, using the established database;

4) Establish an evacuation system;

5) Draw up a detailed hazard map.

7. CONCLUSIONS

The Tone is the largest Japanese river in terms of catchment size. Along the river live more than 10 million inhabitants, including those in the Tokyo metropolitan area. The society and the local inhabitants have deep concerns in the river. Although the improvement works, including the Super-Levees, are being implemented, the present safety level has not reached the planned target.

Huge damages are to be expected should the Tone River's levees fail, which unfortunately may actually happen. To minimize and mitigate eventual damages, disaster prevention measures including structural as well as policy measures are being developed by the river administration office. At the present, using modern information technologies, we are mapping out a disaster prevention plan in cooperation with the local municipalities. In the meantime, for crisis management, a floodplain management system is being developed, using the LandSat and the basin information database

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