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Survey Report:

Lessons Learned from Tokai Heavy Rainfall

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In September 2000, heavy rainfall in the Tokai district flooded Nagoya and its surroundings, wreaking heavy damage. This flood showed typical aspects of urban flood disaster. The damage expanded in a wide range and paralyzed city operations. This revealed the many problems of complex flood control systems in urbanized drainage basins and evacuation and rescue systems. The cases of the Shinkawa and Tenpaku Rivers are discussed below as typical urban flood problems.

Keywords: urban flood disaster, Tokai heavy rainfall, flood control system

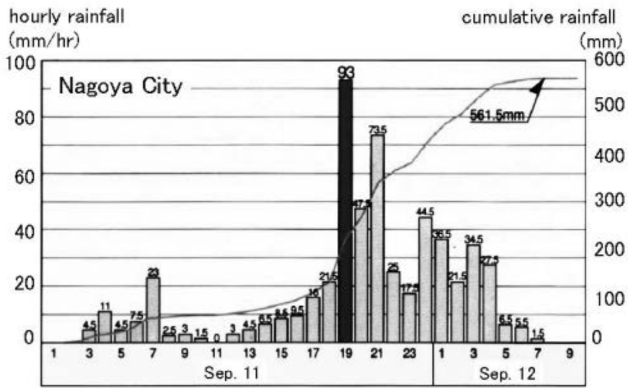

Fig. 1. Hourly and cumulative rainfall in Nagoya.

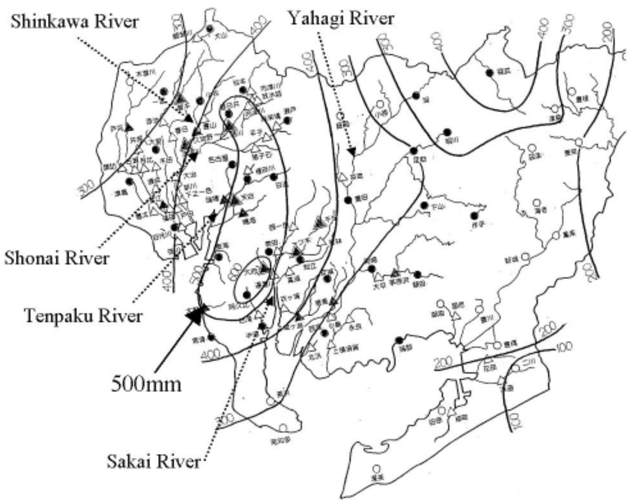

Fig. 2. Total rainfall in Aichi prefecture (mm in 27 hours).

1. Introduction

On September 11 and 12, 2000, the heaviest rainfall on record occurred in the Tokai district centering on Aichi prefecture. The daily rainfall on September 11 amounted to 428 mm – far exceeding the previous maximum of 240 mm. A maximum hourly rainfall of 93 mm was recorded at Nagoya's Local Meteorological Observatory. Total rainfall, amounting to 567 mm is equal to roughly one third of the averaged annual rainfall (**Fig. 1**). This rainfall exceeded by far the design level for flood protection. The spatial distribution of the total rainfall in Aichi prefecture is shown in **Fig. 2**.

The main rivers, Shonai and Yahagi Rivers flooded far beyond the historical record. Water levels of many medium and small rivers in Aichi prefecture exceeded the warning stage and torrential inundations were taken place due to overtopping or breaching of levees and lack of drainage ability. The number of people urged to evacuate amounted to 5,500,000 and 7 people died in Aichi prefecture. As to house damage, 23,896 houses were flooded above floor level and 39,544 below floor level. The Shinkawa River levee breached 16 km upstream from the river mouth and inundation extended widely into the southwestern Nishi-ward of Nagoya and Nishi-Biwajima town. Maximum inundation depth reached 2 m. Meanwhile, in the Tenpaku river basin, severe inundation to a maximum depth of 2.4 m occurred without levee breaching. This was caused by poor drainage ability and the fragile drainage system. As for the Yahagi River, 1.7 times the design discharge was released from the Yahagi dam, severely damaging areas downstream along the Yahagi River. Levee breach occurred in 10 places in Aichi prefecture and particularly Tokai and Obu in the Sakai river basin were widely inundated.

2. Characteristics of Tokai Heavy Rainfall

The Tokai Heavy Rainfall was extremely devastating disaster that occurred in a large city of Nagoya. Although human suffering was small, the total damage reached ¥850 billion, with damage to general property at 96% and

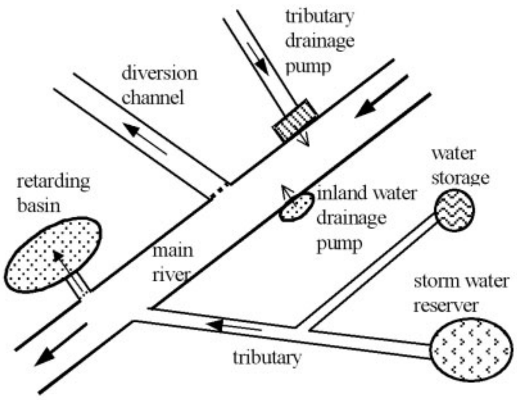

Fig. 3. Example of complex flood control system in urbanized rivers.

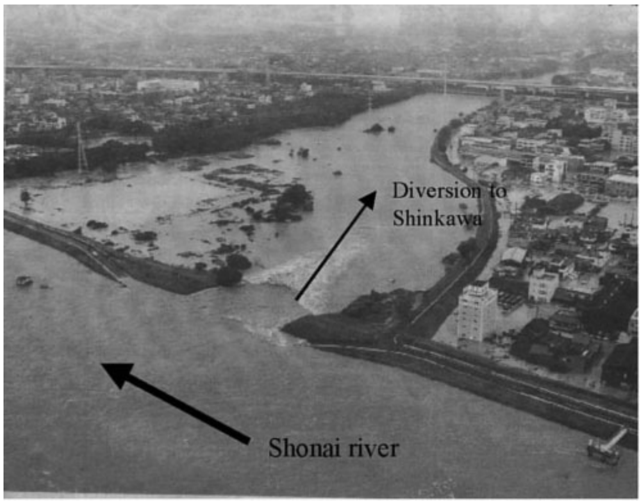

Fig. 4. Diversion discharge through the Shinkawa Overflow Weir [2].

that of public civil engineering facilities 4% of all damage. Given that the average flood disaster loss in 1999 to general property and public civil engineering facilities was 52:48, this demonstrates that flooding brings about tremendous damage when it occurs in a large city where population and properties are concentrated. In addition to housing damage, the traffic network was severely impaired, with inundated roads widely impassable, operations on a number of railway lines were cancelled, and underground railway facilities were inundated [1]. Some 74 trains were stalled on the Tokaido Shinkansen line and the effects of the disaster extended over the entire area. Lifelines such as electricity, gas and communication lines were also widely damaged. The recognition that many large cities face the same risk pointed up the need for flood disaster measures in densely populated urban areas and the need for means to deal with flood damages exceeding design values.

Furthermore, the inadequacy of regional disaster prevention systems was made all to clear in the unexpected situations. The disaster prevention plans were poor, the evacuation instructions were too late or not undertaken at all and the information was not well disseminated just in flooding. The problems of evacuation and rescue systems became disputable.

3. Problems of Complex Flood Control in Urban Rivers

Urbanized rivers involve difficulties in the degree of safety against flooding because of rapid changes in land use in their drainage basins. Most land in the Shinkawa and Tenpaku river basins had been converted to residential, commercial and industrial use in the last 40 years, replacing earlier fields and forests. This increased runoff discharge from the drainage basin. Improved drainage channels and sewers reflecting this fact reduced runoff time and brought a sharp peak to hydrograph. When storm water is collected quickly, water level rises rapidly and eventually storm water drainage becomes difficult in downstream regions. Therefore, tributaries are disconnected from main rivers and discharged forcibly by pump. In order to reduce the load on main rivers passing through important areas, diversion channels are sometimes constructed. These complex flood control factors are schematically shown in **Fig. 3**. These factors constitute complex flood drainage system but they have different levels of safety and are managed by different administrative organizations.

The Shonai River was designed for the rainfall of 200-years return period by national government while the Shinkawa River is designed only for the rainfall of 5- to 10-years by Aichi Prefectural government. Drainage pumps for the Shinkawa River are managed by municipal governments and will have to work together in future planning, but their safety levels disagree with each other in the present situation. In fact, the Shonai River enables water diversion to the Shinkawa River through the Shinkawa Overflow Weir due to the delay in improvement work on the Shonai River, but the Shinkawa River is not designed to accept diversion discharge from the Shonai River. As a result, diversion discharge was a critical factor in the levee breach on the Shinkawa River (**Figs. 4** and **5**). The conflicted flood-control system has abided by grading the regional safety levels. In fact, the Shonai River overflowed its levee and flooded into residential areas 4.3-4.5 km upstream from the river mouth. The water level topped the levee for about three hours, so many sand bags were stacked on the parapet wall. Inundation depth was about 30 cm in residential areas. If discharge of about 270 m^3/s was not diverted to the Shinkawa River, the situation must have been worse (the peak discharge of the Shonai River was estimated at 3,500 m^3/s). As for the drainage pump system, when the levee was in danger, the pump station was still working at the opposite side of the levee-breached section. Pump discharge must be regulated because rivers under improvement cannot meet all pump station requirements at the present time.

Fig. 5. Levee breach in the Shikawa River [2].

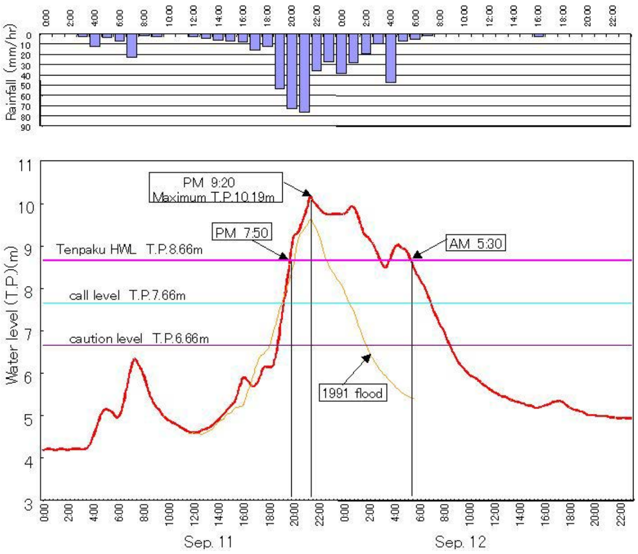

Fig. 6. Hydrograph and hyetograph in the Tenpaku River.

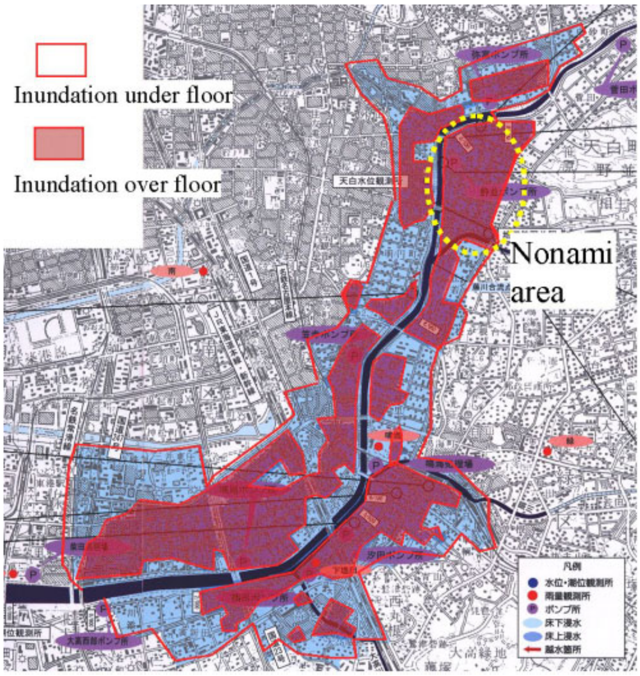

Fig. 7. Inundation area in the Tenpaku river basin.

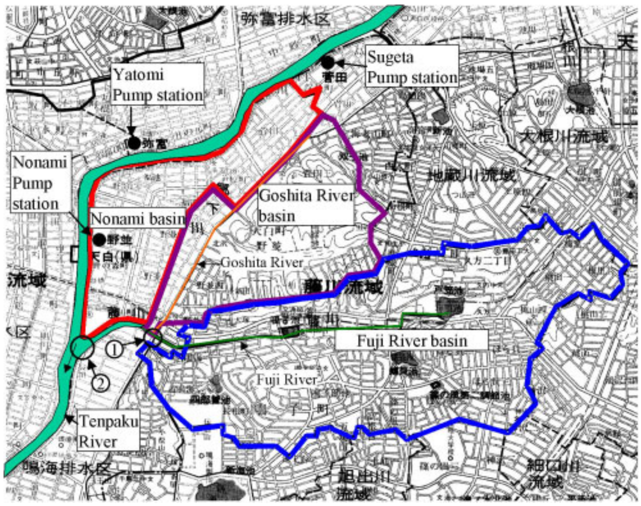

Fig. 8. Drainage basin map in Nonami area.

On the other hand, in the Tenpaku river basin, tributaries were improved to suit the future planning for the main river where improvement work was in progress. This disagreement of improvement stage between the main river and its tributary caused severe inundation in Nonami area. In addition, the basin's fragile system for storm drainage tended to concentrate the whole storm water into a lowland area. We consider this case in detail as typical case of incidental disasters.

The bed level of the Tenpaku River was higher than the surrounding ground level, and river improvement work was not executed 4 km upstream from the river mouth. This river basin was covered by the maximum rain zone shown in **Fig. 1**. **Fig. 6** shows the hyetograph at Tenpaku Civil Engineering Office and the water level hydrograph at Tenpaku Measurement Station in the Tenpaku River. The previous maximum hydrograph in 1991 is superposed in this figure. The water level rose very quickly and remained high stage for a long time, so inundation extended widely in the lowland area along the Tenpaku River as shown in **Fig. 7**. Nonami, the most deeply flooded, is indicated by circle.

Most inundations are caused by the lack of drainage-pump ability. However, in Nonami area, a serious problem existed in flood control system for the drainage basin. **Fig. 8** shows the drainage basin map in Nonami area. The Nonami basin is low-lying land and storm water in this area should be discharged into the Tenpaku River by pumps. The pump station was designed only to handle storm water in this area. The Goshita and Fuji Rivers are the tributaries of the Tenpaku River, and they join at point 1 in **Fig. 8** and then the Fuji River flows into the Tenpaku

Fig. 9. Inundation at Nonami area [2].

River at point 2. These two basins are hilly urbanized area. In Tokai Heavy Rainfall, because the water level of the Tenpaku River exceeded the embankment level of these tributaries near junction point 1, both the tributaries overflowed through the back water. More likely, a reverse flow occurred from the Tenpaku River. As a result, the two tributaries became unable to discharge water and eventually storm water in all these areas converged in the low-lying Nonami area. The maximum inundation depth reached 2.4 m (**Fig. 9**). Nonami station on the Nagoya municipal subways is located near the junction of the tributaries. Flood waters on the surface flowed through subway entrances onto subway lines. These tributaries had been improved corresponding to future planning for the Tenpaku River, which involved excavating the riverbed and lowering the levee height. This catastrophic disaster had not been assumed yet by the city government.

4. Conclusions

The Tokai Heavy Rainfall disaster clarified lessons in assuming damage when the flooding exceeds design levels. Recent climate change is likely to exacerbate heavy rainfall exceeding design values. Once excess flooding occurs, damages expands rapidly in a wide range. At that time, most people were unaware of the hazardous level of their land. After this event, however, this has become well recognized and hazard maps for flood event have been made by many municipal governments. It is also clear that flood disasters cannot be prevented river control alone and comprehensive flood management measures are needed. However, river improvement work and restrictive measures on runoff from drainage basins are still important countermeasures. The Shonai and Tenpaku Rivers narrowly withstood the record heavy rainfall. If these rivers had breached, damage would have been tremendously worse. We must therefore continue to develop mitigation measures for excess flooding with a heightened awareness of risk.

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- "Numerical Evaluation of Secondary Flow Effects on Lateral Momentum Transfer in Overbank Flows," River Flow 2004, Vol.1, Balkema, pp. 353-361, 2004.

Academic Societies & Scientific Organizations:
- International Association of Hydraulic Engineering and Research (IAHR)
- Japan Society of Civil Engineers
- Japan Society of Fluid Mechanics