特 集 3
研究解説

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Storm Water Management in Urbanizing Areas ——Practices and Directions——

都市化域における洪水対策 ——現状と課題——

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Japan has faced various problems in Storm Water management due to rapid urbanization. The direction of various measures adopted is toward integrated management of both flood flows and river low flows. The paper traces these developments and future directions.

1. Introduction

Most of the Asian countries are experiencing rapid urbanization in and around major cities. This will bring about problems in water resources as well as in drainage and flood control. Lessons from countries which have already experienced such phenomena can serve as a useful guide in policy formulation in places where the problems are just starting. This paper briefly describes the development of storm water management in Japan and the present trends.

2. Changes in Hydrological Cycle due to Urbanization

Among various aspects of urbanization, the increase in population density and the expansion of urbanized areas creating a higher building density, have the most prominent influence on changes in hydrological processes. The consequences of such changes are illustrated in Fig. 1. Items enclosed in double-lined boxes indicate problems to solve.

In many of the rapidly urbanizing countries including Japan, the installation of sewerage systems does not grow

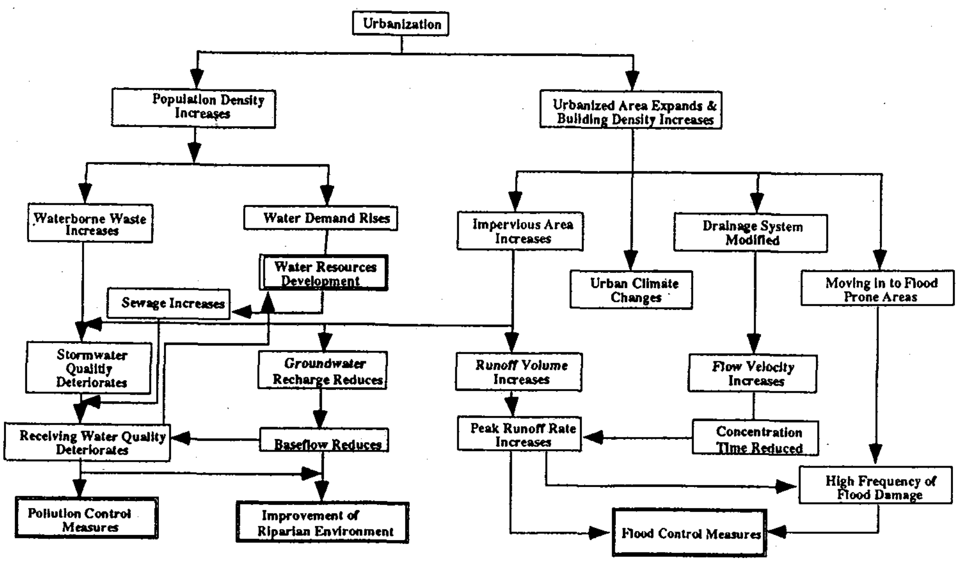

Fig. 1 Urbanization and the Associated Hydrological Changes (Modified from Hall. 1984)

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Table 1 An Example of Peak Discharge Increase due to Urbanization
—Case of a hilly basin with a catchment area of 1 km^2 located in the suburbs of Tokyo

Condition of Basin	fp	Tc	5-Year Return Period		100-Yr Return Period	
		(min)	r(mm/hr)	Qp(m^3/hr)	r(mm/hr)	Qp(m^3/hr)
Prior to Urbanization	0.2	60	59	3.3	110	6.1
Urbanized*	0.6	20	97	16.2	185	30.8

*Impervious Area: 60%, Catchment Slope: 1/80
Estimated using rational method, Qp=fp r A / 3.6. where Qp: peak flow m^3/s, fp: peak-runoff coefficient,
r: average rainfall intensity in the time of concentration Tc (mm/hr) A: catchment area (km^2)

with rapid increases in sewage amount. This inadequacy leads to the deterioration of receiving water quality. The quantity of waterborne wastes, too is increased and this contributes to the deterioration of storm water quality.

The dominant aspects of urbanization which mostly affects quantitative hydrology can be stated as,

(1) Removal of the porous surface soil and replacement with a compacted layer.
(2) Increase of Impervious areas.
(3) Modification of Drainage system.

As a result of the first two of above, the infiltration capacity gets reduced thus creating an increase in flood runoff volume. Modification of the drainage system shortens the time of concentration. These two effects combined together causes extremely large increases in the peak runoff rate.

As an example, a case study in the suburbs of Tokyo is cited in Table. 1 . In case of both 5 year and 100 year return periods it can be observed that the peak flow of an urbanized area roughly becomes five times that prior to urbanization. The 100 year peak flow of a natural basin is equivalent to a rain of 37 mm/hr falling in 20 minutes for the urbanized basin. The Intensity-Duration-Frequency curves show that this rain has an occurrence of 2-3 times a year. Therefore a hundred year flood for a natural basin could occur twice or thrice annually when the basin is urbanized.

Next consider the 5 year peak flow of the urbanized basin which amounts to 16.2 m^3/s. This flow when converted to natural basin which has a high time of concentration and a low runoff coefficient become equal to a 290 mm/hr rain. In Japan the maximum rain recorded in an hour is 185 mm. Therefore a five-year return period flood in an urbanized basin will never occur in a natural basin.

A considerable increase in flood runoff volume due to the above mentioned factors (1) and (2) reflects a reduction in the quantity of ground water recharge and subsequently results in a reduction of ground water runoff component in stream flow.

3. Japan's Experience in Storm Water Management

A major flood disaster in a newly urbanized area was first experienced in 1958 in Tokyo-Yokohama district. This was caused by a big typhoon known as 'Kanogawa Typhoon'. Since then many newly urbanized areas which had no previous flood records were subjected to severe flooding, around big cities such as Tokyo, Osaka, Nagoya, etc.

These floods were given the name 'Urban Flood Disasters', and during 1960's and 70's this phenomenon spread from large cities to newly developing smaller cities. The primary reasons for this are the expansion of urbanization into paddy areas which previously acted as natural retarding basins, and the flooding of down stream cities by increased flood discharge due to upstream urbanization.

Throughout 1960's and 70's river-zone flood control measures such as river channel improvement, floodways, retarding basins etc., had been carried out as countermeasures against Urban Flood Disasters. However, river-zone improvement alone was not enough to cope up with the problem and the need for a comprehensive basin wide flood mitigation plan became evident. In 1978, the Ministry of Construction had prepared such a plan termed 'Comprehensive Flood Control Measures', outlined in Fig. 2.

The main purpose of river improvement works up to then had been control of flood as efficiently as possible. These measures generally gave rise to straight and lined river channels which were not aesthetically pleasing. At the same time a growing public concern arose demanding utilization of public water bodies for recreational purposes. In response, a new kind of river construction projects termed 'Water Friendly' projects were undertaken. These include expanding greenery and beautifica-

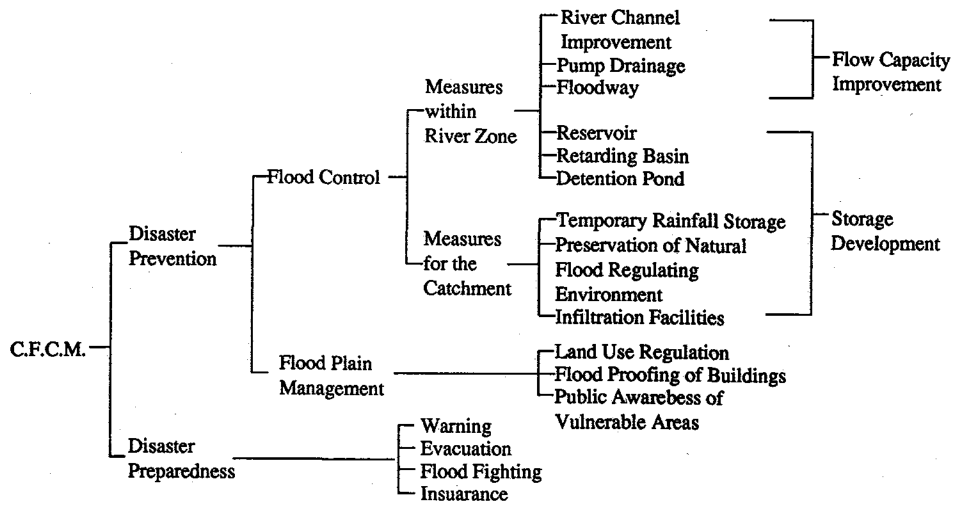


Fig. 2 Outline of Comprehensive Flood Control Measures (C.F.C.M.)

tion of urban rivers, including aesthetically pleasing embankments, revetments designed to create a suitable environment for fish to grow, etc.

Around the year 1985, another aspect of urban water requirements made it necessary to integrate urban water management strategies. Analysis of earthquake disaster impacts has shown that areas possessing on-site water stocks fare better than areas without on-site storage. On the other hand there is very little storage of water with central authorities which could be used in emergencies. For example, Tokyo metropolitan area has a stock of water only for 6 hours in case of an emergency, making it more desirable to have local on-site water storage in case of emergencies. The water storage requirements of the urban flood control planning, emergency preparedness and amenity enhancement, all could be integrated under a central plan. This approach resulted in the concept of "Urban Oasis".

Major urban river management measures in Japan had taken place during the last 20 years. These measures include the Water Pollution Control law, Comprehensive Flood Control Measures plan, Water Friendly Projects, Urban Oasis concept, etc. The direction of these measures over the years is towards the management of both flood and ordinary flow in rivers, by integrated planning and management of basin scale water environment.

4. Systematization of Urban Water Cycle

Urban hydrological system consists of many different components which include the natural and artificial inflows, components related to water utility and various measures adopted for flood control and amenity as described. These components are interconnected in a complex manner, and has to be systematically represented to understand the overall nature of the urban hydrology. Fig. 3 describes such a representation of urban hydrological system. The flow taking place in the system can be classified into three courses, as 1) Natural hydrological processes such as rainfall, infiltration, evapotranspiration, runoff, etc. 2) Artificial paths for the drainage of storm water such as gutters, drain pipes, drainage canals, retarding basins etc., 3) Water course arising from the municipal water supply system feeding the sewerage system. These flow paths are not fully independent but partly connected to each other. To fully understand the urban hydrological system, it is necessary to quantify each of these components and their interrelationships in the system. At present measurements or observations of these components are not being carried out systematically in order to quantify these components or their relationships. Quantification of the system components for Tokyo area with available data had been carried out by Musiake et al (1990), and used to study hydrological changes due to artificial infiltration and increase of sewerage facilities.

5. Towards Integrated Storm Water Management

As outlined in Fig. 2, the two main components of comprehensive flood management are the disaster prevention and preparedness. For prevention, in order to arrive at optimum strategies, various measures adopted in flood control should be quantified, whereas for prepared-

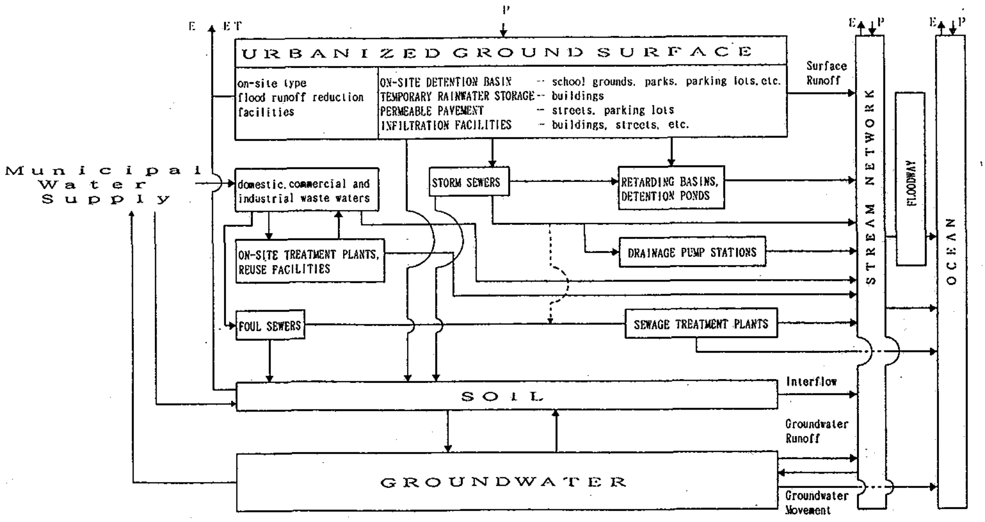


Fig. 3 Urban Hydrological System and Its Components

ness, warning and forecasting should be improved through better monitoring of storms. This section describes two examples in each category, one on modeling infiltration systems in basin scale and another on the accuracy improvements of radar rain gauges through on line calibration.

Estimation of the effect of Infiltration systems

Recently infiltration facilities were incorporated in the flood control measures to be adopted within catchment. They reduce direct storm run-off through infiltration and at the same time increase low flow in rivers. Infiltration capacities of trenches and wells can be estimated through numerical simulation of Richards' equation,

$$\nabla \bullet [k(\varphi) \nabla (\varphi+z)]=c(\varphi)\, \delta\varphi/\delta t \qquad (1)$$

For a limited range of water head, the infiltration capacities of the facilities can be expressed as

$$\inf(h)=K_0(ah+b) \qquad (2)$$

where inf(h) is the infiltration rate, K_0 is the soil saturated conductivity, h is the water head of the trench and 'a' and 'b' are coefficients determined by fitting a straight line to the infiltration rate water head curve. Combined with continuity equation it provides a model that could be coupled with a basin hydrological model to asses the effectiveness of infiltration systems (Herath and Musiake, 1991).

Infiltration facilities installed in a residential area in Akishima city in the suburbs of Tokyo had been in operation for several years. Another residential area of the same size but not served by infiltration facilities also has been monitored for comparison. The above mentioned model for infiltration areas was coupled to a runoff model and applied to this area. Layout of the area and the infiltration systems are described in Fig. 4. Fig. 5 shows the observations and model computations for a single rain, with the quantities expressed in mm.

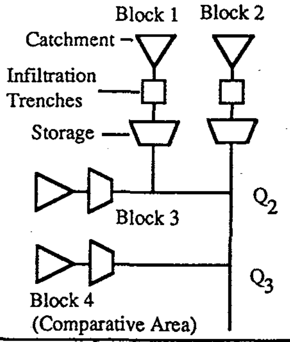
The results confirm the adequacy of modeling procedure and the effectiveness of the infiltration systems. Fig. 6 shows the comparison of total discharge volume from areas with and without infiltration systems. The available data does not cover intense and heavy rains. For such cases simulation shows that peak discharge reduction is not much once the infiltration systems function at full capacity. However, they can be coupled with onsite retention storage facilities to obtain effective peak discharge reductions.

Accuracy Improvement of radar raingauges through on-line calibration

Radar raingauges are widely used in Japan for a number of hydrological operations. One important utilization is to mobilize operators make pumps ready for operation at the beginning of severe rainfalls in urban pump-drainage river networks. Currently the empirical Z-R relation,

$$Z=BR^{\beta}$$

is generally used to convert the observed radar reflectivity (Z) to rainfall intensity (R) using the radar parameters B and ß. In the present usage, the parameters B and ß are



Item	Block 1	Block 2	Block 3	Block 4
Area(m^2)	2522.8	10674.9	2963.1	15596.1
Trench Length(m)	585	504	0	0
Storage within trenches(m^3/ha)	245.5	212	0	0
Other Storages (m^3/ha)	74.16	74.35	0	0

Fig. 4 Layout of Site and Description of Facilities

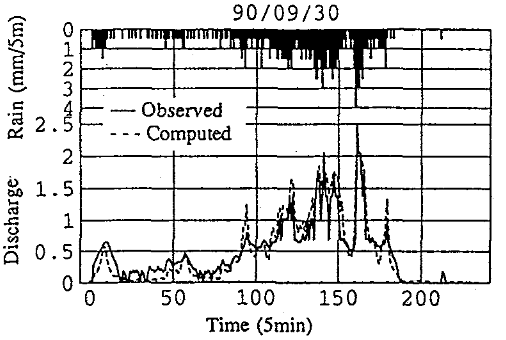


Fig. 5 A Sample of Observed and Computed Hydrographs at Q_2

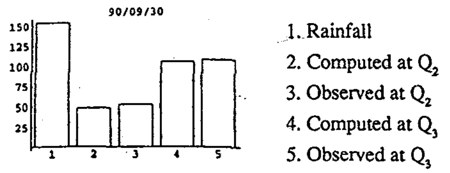


Fig. 6 Observed and Computed Total Discharges for Areas with and without Trenches

calibrated from a previous rainfall for which both radar measurements and ground rainfall had been measured. While the relative intensity may be obtained from such transformation, it is well known that radar measurements have a low accuracy, mainly due to parameterization problems.

The rainfall intensity (R) and radar reflectivity (Z) can be estimated, if the rain drop size distribution, N(D), is known for a given rainfall through the equations (3) and (4) below.

$$R=\int_0^\infty \frac{\pi}{6} D^3 N(D)\, V(D)\, dD \tag{3}$$

$$Z=\frac{\lambda^4}{\pi^5}\left|\frac{\varepsilon+2}{\varepsilon-1}\right|^2 \int_0^\infty \sigma(D) N(D)\, dD \tag{4}$$

where D, ε and λ are the diameter of raindrop, the complex index of refraction and the wave length of the radar microwave. V(D) is the terminal falling velocity of the diameter D raindrops and σ(D) is the cross section.

The variation of parameter B and ß with the rainfall are shown in Fig. 7. Here, raindrop size distribution is measured using Disdrometer and the parameters are calibrated from estimated Z and rainfall measurements. Re curve in the figure indicates the predicted rainfall using the most recent estimations of B and ß parameters (Oki and Musiake, 1993). The results show that parameters are not constant even within a rainfall event, and that it is possible to use on-line calibration techniques to improve the accuracy of rainfall estimations from radar measurements. In the on-line calibration method, B and ß parameters calibrated with Disdrometer data can be used to convert the Z, measured through radar, to obtain better rainfall estimates.

6. Conclusion

Japan has experienced various problems in storm water management due to rapid industrialization and urbanization since World War II. From the 1970's, actions for intensified countermeasures regarding each problem were commenced by respective authorities.

Nowadays, appropriate adjustments and combinations of such various measures have become necessary. Although the importance of this concept is well recognized in Japan, the inertia of existing fragmented administrative system for water management makes the transformation difficult.

Nevertheless, urbanizing countries where the urbanization has not yet started or is just beginning to start have room to introduce such an integrated management.

In future, Integrated Water Management would make use of physically based hydrological process models representing various components of the urban hydrology, utilizing spatially distributed data obtained through remote sensing and other sources, and synthesized through GIS technology. Rainfall data with high resolution both in space and time would help in utilizing these models for forecasting and warning against disasters, as well as for better management of water resources in urban areas.

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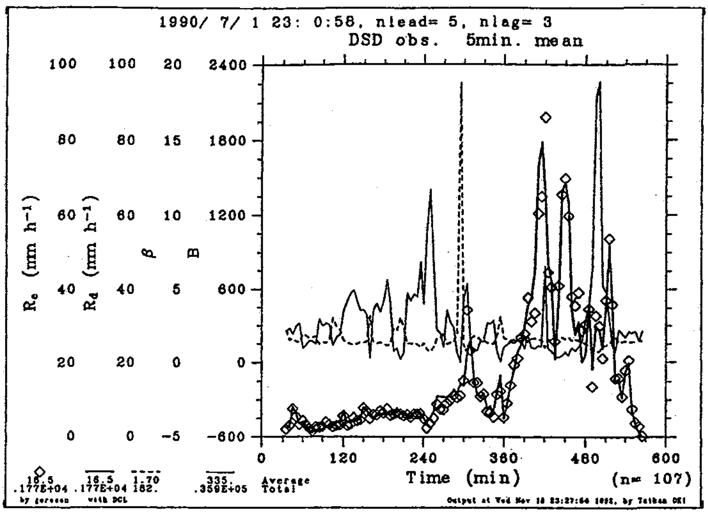

Fig. 7 Variation of B and β Parameters Obtained through Optimization of Disdrometer Measurements

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