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Integrated Water Management in Urban Areas

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Integrated Water Resources Management in Fukuoka Metropolitan Area

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Keywords: Integrated Water Management, Population Increase, Water Demand, Water Supply, Deforestation, Drought Control, Advanced Water Treatment, Regional Water Transfer

ABSTRACT

Fukuoka Metropolitan Area, a fast growing economic and cultural center in Kyushu, Western Japan, was struck by a severe drought in 1978 resulting in water rationing which lasted for 287 days at Fukuoka City. The drought provided a great challenge for the authorities to develop countermeasures to secure a stable water supply. Sixteen years later from the drought in 1994, another intense drought hit the area again, when the authorities had been exerting all efforts to attain the purpose. In this paper, at first, the present situation of integrated water resources management including measures to halt the rapid increase of water demand and a number of unique water resources development projects which have been carried out since 1978 drought in Fukuoka Metropolitan Area are illustrated. Secondly, natural and social situations between two droughts are compared. Finally, the prediction of water demand amount for five regions of the area is carried out aiming for the year of 2010. The estimated deficit amount of water against planned water supply capacity is calculated. The robustness of water resources system of the are is evaluated from the results.

INTRODUCTION

Fukuoka City is located in the northern part of Kyushu, Western Japan, at 33°35′ north and 130°24′ east. The city area is 337 km^2 and the population is 1.25 million. Fukuoka Metropolitan Area consists of Fukuoka City and 20 surrounding municipalities as shown in Fig. 1. The total area is 1,156 km^2 and the total population is 2.02 million as of October, 1991. Residents living in Fukuoka City account for about 62% of the total population in the Metropolitan Area, and in addition, another 8% are concentrated to the city during daytime. The population is increasing constantly. The area has mild weather and climate, and no severe earthquake or flood has ever been recorded. The annual average temperature is 15-16°C and the annual precipitation is approximately 1,800 mm with little snow. Because of seasonal winds, there is both an early

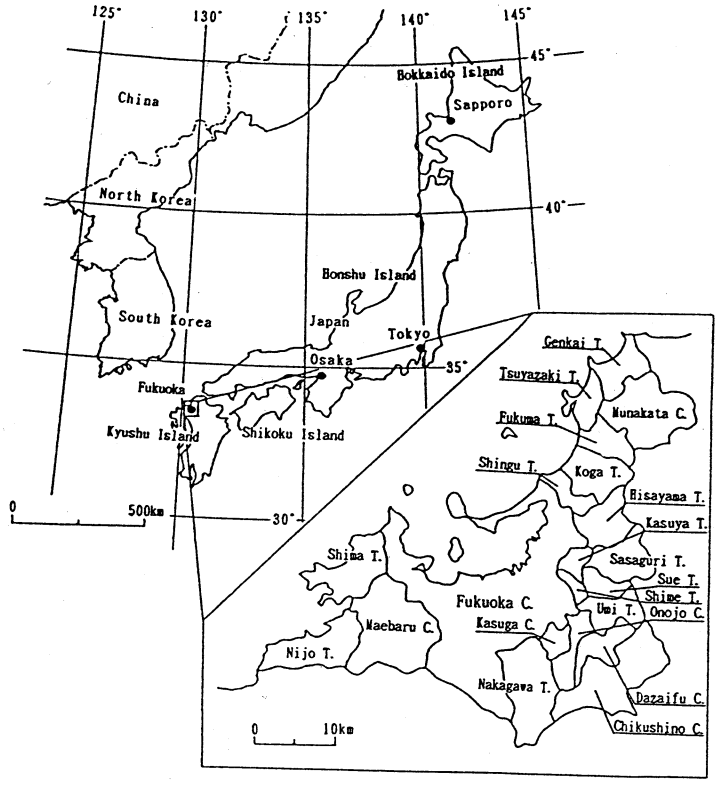

Fig. 1 Location of Fukuoka Metropolitan Area.

summer rain season (June to July) and a typhoon season (September to October).

The Fukuoka drought happened in 1978. The drought index for this event was 8,160 (%•day) with 19-hour water supply cut per day at the worst. The drought showed that the region is vulnerable to water shortage unless development and management of water resources are planned properly to meet growing water demands of population and industry. The impact was so intense that citizens and authorities suddenly were forced to understand the importance of water, and realized that water is a limited resource. The Fukuoka Metropolitan Area, however, has a geographical disadvantage and water supply has to rely on small rivers and limited groundwater resources. As a result, the area is always exposed to potential drought, especially small municipalities surrounding the larger Fukuoka City. Limited water resources are now becoming one of the fundamental constraints for appropriate development of the area.

PRESENT SITUATION ON WATERWORKS

In Japan, water resources planning is designed for a drought with a targeted ten-year return period. Waterworks are governed by public organizations, and on general principles each

municipality is responsible for its residents' water supply. By law the waterworks in each municipality have to be operated on a self-paying basis, so that each municipality has to set its own water rate to make ends meet for compensating the water development and managing costs. For example, when a household uses 20 m^3 water a month in Fukuoka Metropolitan Area, the cost varies from 4,510 yen (Tsuyazaki Town) to 1,350 yen (Umi Town) with an areal average of 3,084 yen. In Fukuoka City this cost is 2,018 yen.

The sources of water supply in Fukuoka Metropolitan Area are surface water (87%), river-bed water (3%), and groundwater (10%). However, these percentages for Fukuoka City are 95%, 4%, and 1%, which indicate that groundwater as a water supply source is extremely small, whereas the ratios are 66%, 1%, and 33% for the surrounding municipalities indicating fairly high ratio of groundwater. One reason for the small use of groundwater in Fukuoka City is that the alluvial aquifer here is too thin so that salt water intrusion may occur when too much groundwater is pumped up. Another reason is recent groundwater pollution problems caused by chlorinated hydrocarbons such as trichloroethylene and tetrachloroethylene and also pesticides and herbicides reported by Jinno *et al.* [1]. Furthermore, there are no major rivers in the area of Fukuoka Metropolitan Area, only several small rivers, so that the river water utilization rate is considerably high, e.g., in Fukuoka the rate is 58% in a normal year and 67% in a designed drought year.

Since the time Fukuoka City started the water supply service in 1923, expansion projects have been carried out 18 times in order to cope with the rapid increase of water demand due to the concentration of population in urban areas, development of industries (urban infrastructure), the increase of living standard, etc. The big number of expansion projects shows the efforts which the city has taken in order to develop and efficiently utilize the scarce water resources.

Figure 2 shows the water supply and demand change with population increase for both Fukuoka Metropolitan Area and Fukuoka City. From the figure, it is seen that the increase in population of Fukuoka Metropolitan Area is larger than that of Fukuoka City, which means the population increase is more serious in surrounding municipalities being commuting towns of Fukuoka City. Also, the figure shows that mean water demand before the drought in 1978 was increasing rapidly, then it dropped drastically at the year of the drought. After the drought, the increase in daily water supply is not as big as before in spite of the large population increase. This indicates that the mean daily individual water supply has not increased since the drought. The mean daily individual water supply of about 330 liters in Fukuoka City after the drought is actually smaller than that of other large cities such as 430 liters for Tokyo Metropolis, 570 liters for Osaka City, 400 liters for Nagoya City, and 400 liters for Hiroshima City. The maximum daily water supply drops again in 1982. This is because Fukuoka City and another town carried out water supply rationing during several days that year.

Figure 3 illustrates present waterworks facilities, water sources and conveyance system of Fukuoka City. Fukuoka City is withdrawing water from five small rivers that flow through the city and that are managed by the prefectural government. They are Zuibaiji, Muromi, Naka, Mikasa and Tatara Rivers. These rivers do not have sufficient and stable discharge due to small catchment areas. The city is also receiving water (purchasing water) from the Chikugo River located outside the Metropolitan Area limits. It is the biggest river in Kyushu managed by the government. The water supply capacity as of March 1992 was 673,300 m^3/day as shown in Fig. 2. There are five water purification plants and all of them are treating water by rapid-filtration.

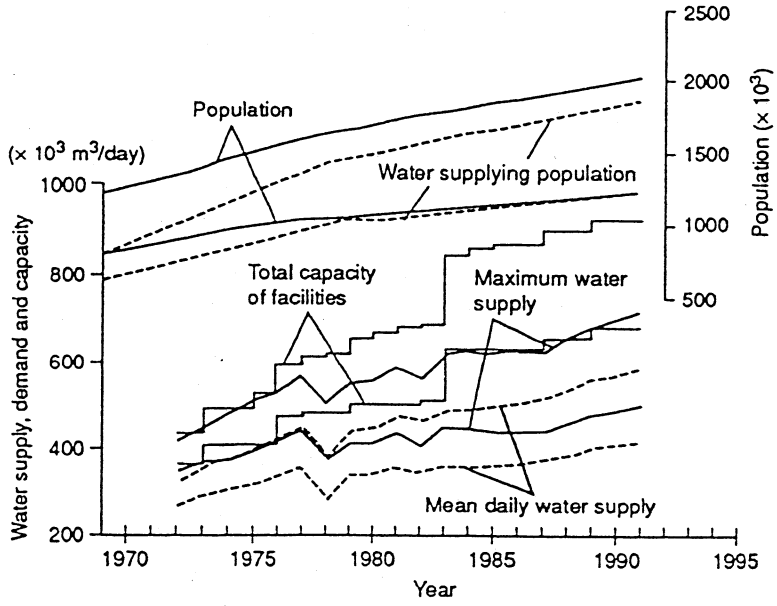

Fig. 2 Changes in water supply, water demand and population for Fukuoka Metropolitan Area and Fukuoka City.

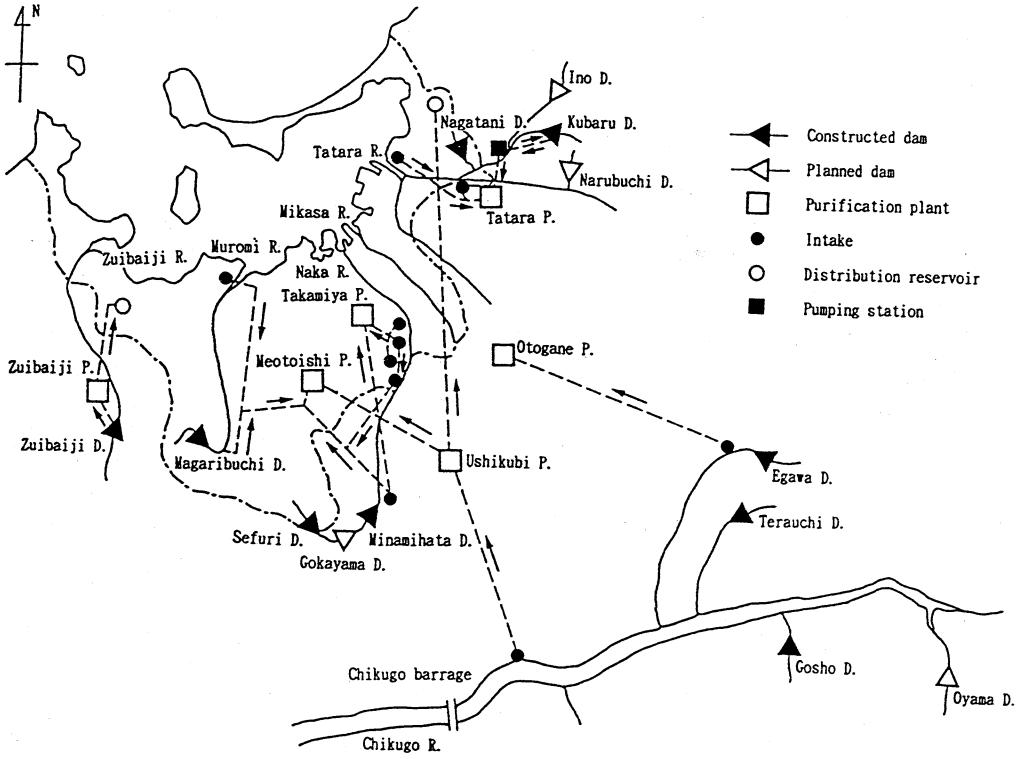

Fig.3 Waterworks facilities, water sources and conveyance system of Fukuoka City.

Table 1 Dams supplying water to Fukuoka City.

Name of dam	Catchment area (km^2)	Capacity (thousand m^3)	Purpose *)	Jurisdiction
Magaribuchi	11.4	2,270	C	City
Minamihata	27.5	5,560	F,Ir,C,E	Prefecture
Kubaru	0.9	1,460	C	City
Egawa	30.0	24,000	Ir,C,In,E	Corp. of WRD
Sefuri	5.5	4,401	C	City
Zuibaiji	7.2	2,270	F,Ir,C	Prefecture
Nagatani	1.8	4,850	C	City
Ino[1)]	5.5	4,910	F,Ir,C	Prefecture
Narubuchi[1)]	6.8	4,160	F,Ir,C	Prefecture
Gokayama[2)]	18.9	39,700	F,Ir,C,D	Prefecture

[1)] Under construction [2)] Planned

*) F : Flood control Ir : Irrigation C : City water In : Industry
E : Electric power D : Drought measures

From these purification plants, water is distributed by gravity to areas less than 80 meters above sea level [2]. These purification plants had their own supplying areas in the city and were operated independently until the drought. After the drought, a project for an integrated water supply system was started. At present, water is distributed between purification plants and optimization of water pressure is made by a water distribution control system which consists of electrically controlled valves, flow meters and, water pressure gages. Table 1 shows the outline of the dams supplying water to Fukuoka City. As seen, the general capacity and catchment of these dams are small.

UNIQUE WATER RESOURCES DEVELOPMENT AND MANAGEMENT

As mentioned above, in order to meet increasing water demand in areas with scarce water resources, development projects with innovative ideas, unique for Japan, have been carried out. Also, various kinds of measures to halt the rapid increase of water demand have been introduced. These water resources development and management projects mainly implemented in Fukuoka City are described in the following.

Preservation of forested infiltration areas

Forested areas have a well-known function to store infiltrated rainfall in the ground and moderating rapid flood discharge. With deforestation, deterioration of water quality in reservoir and inflow of silt by erosion are also obvious. Therefore, the authorities have created a special fund to purchase and preserve forests that serve as infiltration areas since 1980 [3].

Dam development

1. Pumping up storage dam

This type of dam stores surplus water pumped up from rivers during the season when irrigation is not necessary. The Kubaru Dam and the Nagatani Dam are examples of this. These dams' catchment areas are very small as shown in Table 1 and almost correspond to their reservoir surface areas. This type of dam is not efficient for natural rainwater collection, but works well in Fukuoka City.

2. Dredging of dam beds

By this method water resources are utilized more efficiently by digging out the bottom of reservoirs to increase the usable storage capacity. An example of this is the Minamihata Dam which developed 25,000 m^3 of water per day in 1984.

3. Dam for drought control

This type of dam is designed to provide a stable supply of water during drought periods. The type of dam is planned to be constructed in the upper stream of Minamihata River as the first case in Japan. The total effective water storage capacity of this multi-purpose dam (Gokayama Dam) is 39.7 million cubic meters out of which 16 million cubic meters are to be used in case of drought, and is expected to be completed by the end of year 2000.

Improvements of water usage and existing facilities

1. Increasing efficiency of irrigation water

Generally, irrigation water is supplied by an open channel, however, there is usually great losses involved in this method. Therefore, in order to use water efficiently and to prevent losses, pipes are laid to replace open channels. As a result, excess water brought about by this system is now diverted for service water. This method was implemented at two water intakes of the Naka River in 1969 and 1980. It saved totally 50,000 m^3/day [4].

2. Advanced water treatment

A system that discharges treated sewage water (30,000 m^3/day) from a sewage treatment plant in the Mikasa River drainage area into the Naka River was introduced. The treated water is used for not only maintaining the natural river water flow (15,000 m^3/day) but also for industrial water use (15,000 m^3/day). By diverting the industrial water from the Naka River to city water, the same amount of water is taken at the upper stream for water supply to the city. This project was completed in 1985.

3. Water leakage prevention

Figure 4 shows the change in water transport efficiency in Fukuoka City [2]. Ever since the first water leakage prevention project was established in 1956, investigations have been under way. At the beginning of the project, the effective rate of water supplying was as low as 61% as shown in Fig. 4. In 1990, however, the rate reached 94%, which is considered to be very high in Japan.

4. Water supply control

The setup of a water supply control system started when the great drought occurred in 1978.

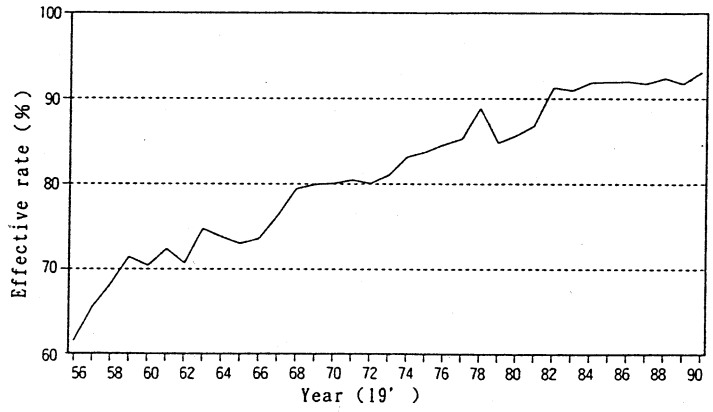

Fig. 4 Changes of effective rate of water supply in Fukuoka City.

Manual valve operation during the drought caused an extremely hard work and optimal pressure control was impossible without a water supply control system. Water pressure control by this system commenced in 1981 after completion of the Water Control Center [2]. As a part of this project, old distribution pipes were replaced and new networks were set up to make transfer of water possible among different water purification plants. Fukuoka City was the first city to introduce this system in Japan. This system includes 107 water pressure gages, 61 flow meters, and 143 electric control valves at all important points along the water distribution pipes (April, 1992). An engineer can by visual control operate electric valves by remote control in order to secure the necessary water pressure through the pipe system. By utilizing this system, it has become possible to reduce excessive high water pressure and to secure a proper and constant water pressure in order to provide better service and reduce water leakage from the pipes.

Water quality improvements

1. Utilization of treated sewage water

From the standpoint of water use efficiency, the authorities of Fukuoka City have established an "Outline of Measures for Conservation Type Use of Water in Fukuoka City" through the lessons obtained during drought in 1978. As a part of this outline, the re-use of treated sewage water has been introduced. This system recycles the non-potable highly treated waste water mainly for flushing toilets. This system uses the following three methods [2], *i.e.*, 1) Individual circulation, 2) District circulation, 3) Regional circulation. Individual circulation means that individual disposal facilities circulate their own treated water at each individual building such as offices, schools, and hotels. The method is applied to large-sized buildings of a total floor space above 5,000 square meters or with service pipes of 50 mm in diameter or more which are constructed after December 1978. Developers are obliged to install the system in spite of high investment and operation/maintenance costs.

2. Desalination of sea water

At present, research and surveys for the feasibility of desalination are conducted using sea water

on a large scale. On a smaller scale, however, a desalination plant has already been constructe at a small island of Fukuoka City. This plant has been in operation since September 1991. Th capacity is 20 m^3/day by means of the reverse osmosis method.

Regional water transfer

Among the water resources development projects, the water withdrawn from the Chikugo Rive (Fig. 3), which is located outside of the Fukuoka Metropolitan Area, supplies approximately on third of the total water for Fukuoka City. The Fukuoka District Waterworks Agency, which i composed by representatives of each municipality of Fukuoka Metropolitan Area, was establishe in 1973 aiming at water supply to the entire metropolitan area. In 1983, regional water transfe from the Chikugo River started even though it was opposed by people living in the basin. This wa because flow rates decreased for fishery and because of environmental issues. The agency wa originally transferring water from the Chikugo River only, but now other rivers are also involvec At present, the agency is playing a very important role as a water supply administrating agency fc the metropolitan area.

Measures for controlling water demand

1. Popularizing water saving equipment

Every municipality is promoting water saving equipment such as special taps, water saving toilets and so on. Water saving taps have a gadget to control water flow. By using this tap, one cubi meter can be saved per month [3]. This equipment was introduced from 1978, and the usage rat is now 92%. Water saving toilets are units designed to use 8-10 liters of water each time fo flushing, whereas a normal one uses 12-16 liters. Other water saving equipments are also bein actively promoted.

2. Increase of water saving awareness

The authorities have run extensive advertising campaigns to maintain and increase the water savin awareness of citizens. For instance, "Water Saving Day" on June 1, "Waterworks Week" durin June 1-7, "Water Day" on August 1 and "Water Week" during August 1-7 were introduced fo that purpose. Many events aiming at increasing water saving awareness are performed during thes periods. Also, various kinds of leaflets, pamphlets, and videos are produced and circulated amon school children and public.

3. Water cost policy

The system used means that the cost increases rapidly as the amount of water usage increases Most of the municipalities of Fukuoka Metropolitan Area have introduced this system.

4. Regulations concerning water supply rejection

Eight small municipalities surrounding Fukuoka City, for which the water supply situation is ver stringent due to rapid population increase (commuting towns for Fukuoka City), have introduce regulations which enable the authorities not to supply water to newly constructed large building In one of the municipalities, however, a housing developer has brought a suit against th

Table 2 Waterworks situation in the previous year of the droughts

Year	1977	1993	Rate of increase (%)
Water supply population (thousand)	985	1,243	26.2
Capacity of facility (thousand m^3/day)	478	705	47.4
Maximum daily water supply (m^3/day)	443	491	10.9
Mean daily water supply (m^3/day)	357	411	15.1
Maximum daily individual water supply (liter/day/capita)	450	395	-12.2
Mean daily individual water supply (liter/day/capita)	363	331	-8.8
Spread rate of sewerage (%)	36.1	94.7	162.3

regulations to court. The point of this lawsuit is whether the authorities have to obey the water supply responsibility as stated in the waterworks law or if they can decide their own regulations. The judicial dispute is still going on.

Table 3 Descending order of annual precipitation.

Order	Year	Precipitation(mm)
1	1994	891.0
2	1939	999.8
3	1894	1025.1
4	1978	1137.5
Normal year		1604.3

COMPARISON BETWEEN 1978 AND 1994 DROUGHT

In 1994, high temperature and less precipitation were very dominant all over Japan resulting in severe drought. Many municipalities were forced to go water rationing, especially in Fukuoka Metropolitan Area, 14 municipalities out of 21 carried out water rationing, whereas 9 ones placed water rationing in 1978 drought. Water rationing of Fukuoka City lasted 295 days in 1994 drought and 287 days in 1978 drought.

Table 2 shows the situation of waterworks in the previous year of each drought. From the table, mean daily individual water supply of 331 liters in 1994 decreased by 8.8% in spite of the rapid increase of spread rate of sewerage and water supply population. The quantity of 331 liters is much smaller than that of other large cities in Japan. The capacity of waterworks facilities increased by 47 % resulting in enough capacity of water supply in reserve for the target ten-year return period drought. Sixty-two percent of the increase of the capacity was owing to the regional water transfer from the Chikugo river. Above decrease of water demand and increase of capacity were due to all the efforts of promoting integrated water resources development and management as presented in the former section.

Annual precipitation in 1994 was, However, extremely low as shown in Table 3. The amount of precipitation of 891 mm easily broke a ever lowest record by 109 mm, which means the lowest among 105 years since 1890. As a result of the low precipitation, water from the Chikugo river was cut by 55 % at the worst, and the total effective storage of 7 dams of Fukuoka City drastically decreased from full storage in June to a quarter in September as shown in Fig.5.

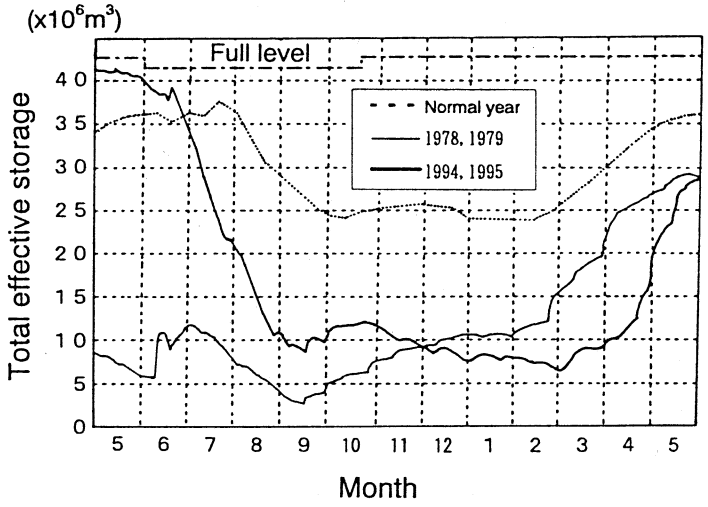

Fig. 5 Total effective storage of dams of Fukuoka City.

Fig.6 shows the shut-off hours of water supply for both droughts. In 1978 drought, water supply restriction started suddenly on May 20th with 9-hour shut-off when the storage rate of total effective volume of dams fell below 20 %. The restriction was tightened sharply within a short period into 19-hour shut-off on June 1st. As the result, many waterworks staff members and self-defense officials were urged to deliver water with water supply wagons. At that time, It really caused a panic. In 1994 drought, on the other hand, the authorities began water supply restrictions much earlier than 1978 drought when the storage rate still maintained 50 %. Thanks to the great

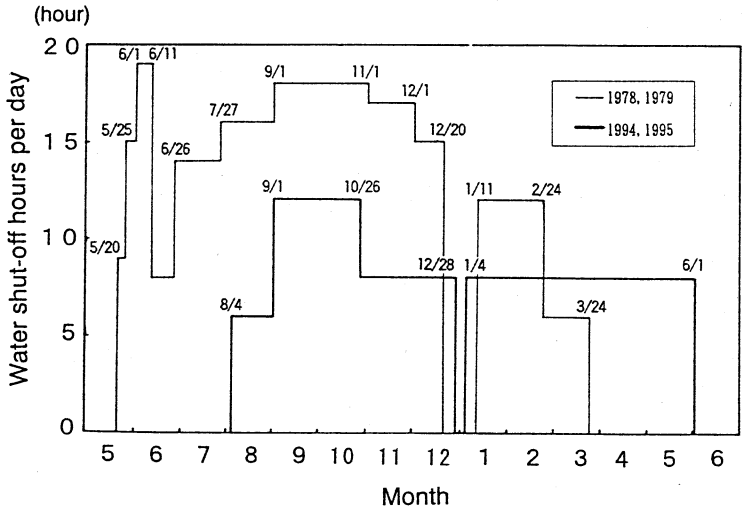

Fig. 6 Shut-off hours of water supply per day.

efforts on integrated water resources development and management as mentioned in this paper, especially with assistance of water supply control system, much less people were called out to manually close and open the valves, and no water supply wagons were used. In spite of strict precipitation situation, 2,452 hours of total shut-off of water supply were much shorter compared with 4,054 hours in 1978 drought. With the citizens' trying experience in 1978 drought and calm attitudes, no panic situation happened among the citizens this time.

As one of the remarkable problems in 1994 Fukuoka Metropolitan Drought, the vulnerability against drought in surrounding municipalities was highlighted. On the contrary of less drought damage in Fukuoka City, the number of surrounding municipalities which were forced to go water rationing increased and the drought damage itself was much severer in surrounding municipalities this time. This is because not only less precipitation but almost no room of water resources development is left within each small municipality. With this drought as a momentum, the policy is strongly expected in which the total robustness of water resources system in whole Fukuoka Metropolitan Area is strengthened.

WATER SUPPLY-DEMAND BALANCE IN THE FUTURE

In order to estimate the robustness of water resources system in the future of Fukuoka Metropolitan Area, firstly the prediction of water demand amount for five political regions in the Metropolitan Area is carried out aiming for the year of 2010. Five political regions are Fukuoka City, Chikushi Region (Chikushino C., Kasuga C., Onojo C., Dazaifu C. and Nakagawa T.), Kasuya Region (Umi T., Sasaguri T., Shime T., Sue T., Shingu T., Koga T., Hisayama T. and Kasuya T.), Munakata Region (Munakata C., Fukuma T., Tsuyazaki T. and Genkai T.) and Itoshima Region (Maebaru C., Nijo T. and Shima T.). In this prediction model, ratio method is used considering future population to be the basic frame. Daily water consumptions per head for two purposes (i.e. domestic use and urban activity use) are estimated using multiple regression analysis. The explanatory variables are the number of family members in each household, gross citizen product, spread rate of sewerage, tertiary industries' output per head and elapsed year from the reference year. The details of this water demand prediction model are described by Kawamura [5].

The predicted water demand amounts were compared with the planned water supply capacity for a target ten-year return period, and the estimated surpluses or deficits are calculated shown in Fig. 7. In this figure, the values in 1990 are the records of actual water demand, and values from 1995 to 2010 are estimated ones. From the figure, Fukuoka City will be able to maintain enough surpluses, even if the surpluses will decrease hastily from 190 thousand m^3/day in 1990 to 50 in 2010. In Chikushi and Kasuya Regions, on the other side, deficits will arise after 1995, especially they will be a large amount in 2010. In the year of 2010, 3 regions out of 5 will go into the red in water supply-demand balance. As the total of Fukuoka Metropolitan Area (solid line in the figure), the surplus of 240 thousand m^3/day in 1990 will drastically decrease resulting in a little deficit in the target year of 2010. This means that water will be in short supply in 2010, even if the project of interchanging water among the Metropolitan Area is translated in reality. This water network system covering the entire Fukuoka Metropolitan Area is regarded as one of the keys for establishment of stable water supply and increasing the robustness of the system. As one of other keys for stable water supply other than the water network system, a desalination plant

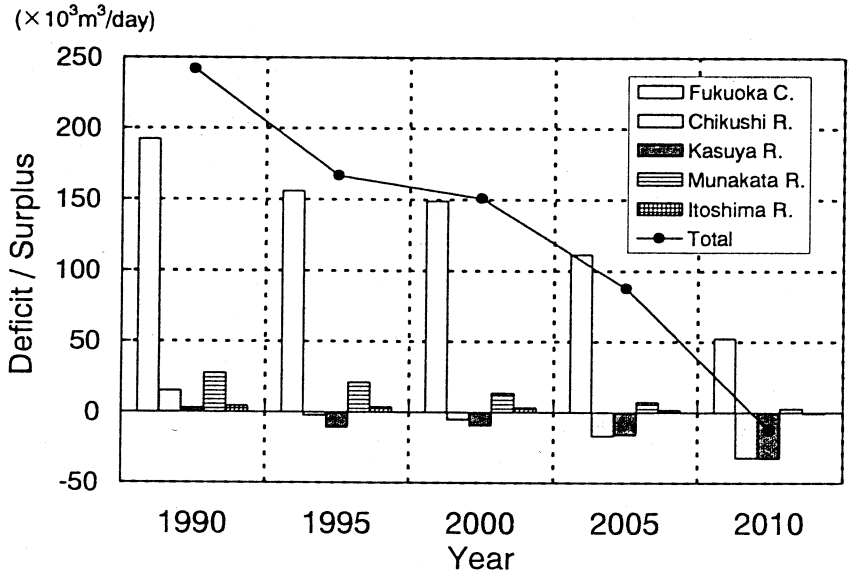

Fig. 7 Water deficit/surplus in the future.

is expected to be introduced on a large scale for the drought beyond the target ten-year drought.

CONCLUSIONS

The municipalities in Fukuoka Metropolitan Area are making comprehensive efforts for supplying a stable amount of water as mentioned in this paper. Drought is caused by an imbalance in water demand and supply, which depends on rainfall and climatic situation. At present existing water resources are highly developed and water utilization is becoming more and more complex and countermeasures against droughts beyond the designed scale is becoming a great concern.

Because of small excess reserves, effects of droughts may be tremendous. The establishment of water networks covering the entire Fukuoka Metropolitan Area and introduction of desalination of sea water are the part of those keys for stable water supply and increasing the robustness of the system. Water supply simulation also takes an important role in order to optimally allocate the limited water resources to reduce damages by drought where limited water resources have to be shared by Fukuoka City and the neighbouring communities when drought occurs. In this sense, the authors have already been applying risk analysis for the planning and operation of water supply system in Fukuoka Metropolitan Area [6].

Urbanization has meant population centralization, which is one of the important factors for water supply and demand imbalance. This is of importance not only in the city areas but also in surrounding towns. Future development plans have to consider the constraints brought about by the limited water resources in the area in order to make the robustness of water supply system become high.

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