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URBAN SUSTAINABILITY OF WATER RESOURCES SYSTEMS IN FUKUOKA METROPOLITAN AREA

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ABSTRACT

Fukuoka Metropolitan Area, a fast growing economic and cultural center in Kyushu, Western Japan, was struck by a severe drought in 1978. 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 Fukuoka Metropolitan Area suffers from geographical disadvantage as it depends on water supply from 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.

In this paper, at first, the present situation of integrated water resources management is described, Secondly, 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 are illustrated. Finally, an assessment of the present efficiency of water resources management in terms of water distribution control is highlighted with reference to the characteristics of water distribution control for a case study of Block 12 of Fukuoka City water supply network.

KEYWORDS

Water supply network, Water resources, Water demands, Fukuoka City and Urban sustainability.

1. INTRODUCTION

Fukuoka City is located in the northern part of Kyushu, Western Japan, at $33^0 35^\backslash$ north and $130^0 24^\backslash$ east. The city area is 337 km^2 and the population is 1.33 million as of October 1999. Fukuoka Metropolitan Area consists of Fukuoka City and 20 surrounding municipalities as shown in Fig.1 [1]. The total area is 1,156 km^2. Residents living in Fukuoka City account about 62% of the total population in the Metropolitan area, in addition, another 8% are concentrated to the city during daytime. The population is, however, 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^{0}C and the annual precipitation is approximately 1,800 mm with little snow. Because of seasonal winds, there is both an early summer rain season (June to July) and a typhoon season (September to October) [2].

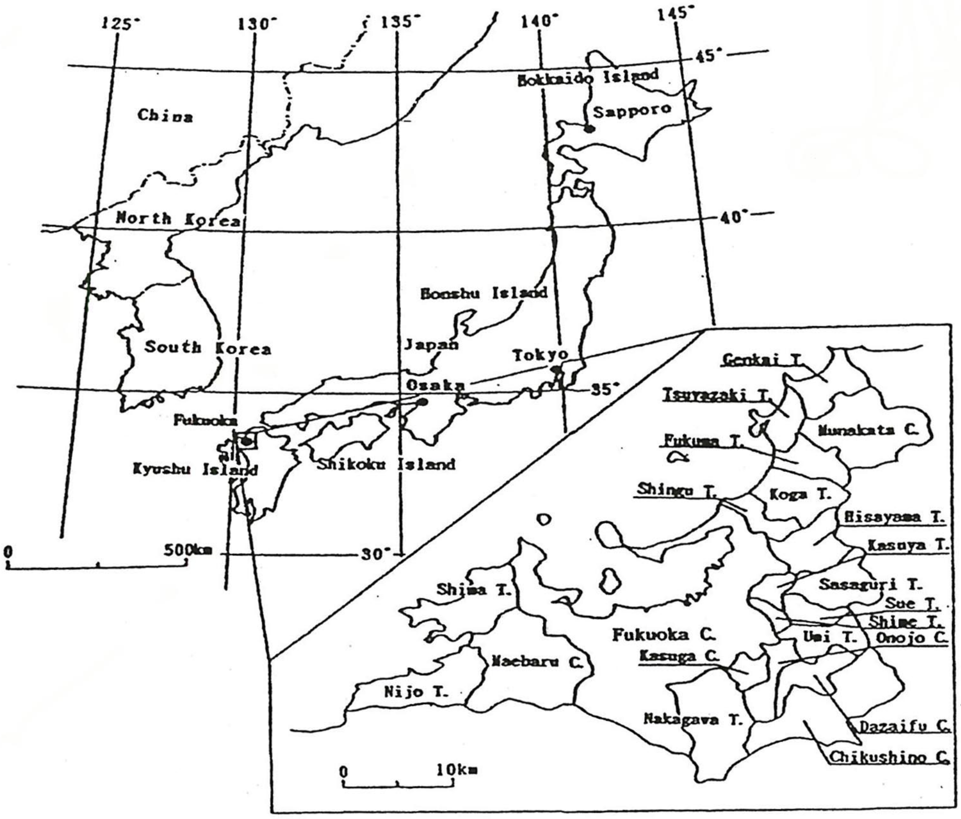

Fig.1 Location of Fukuoka Metropolitan Area

People living in urbanized areas may feel that water should be supplied as much as they need. This is usually also the case during climatic conditions. However, during drought conditions, water rationing may hamper many activities in daily life. Even urban planners are often unaware that water resources are indispensable constraints for appropriate development of a city. 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 [3]. This happened when urban citizens believed that high water consumption is a barometer of modern city life. 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. As a result, the drought provided a great challenge for the authorities to develop countermeasures to secure a stable water supply [4].

Because of the geographical location of the city, water shortage has been experienced several times in the past. In order to cope with this and an increasing demand anticipated in the future, it has been necessary to develop water resources for suburbs as well as areas outside of the city. Also, the authorities are exerting all efforts to promote water conservation in order to make efficient use of the water developed and to maintain a stable water supply.

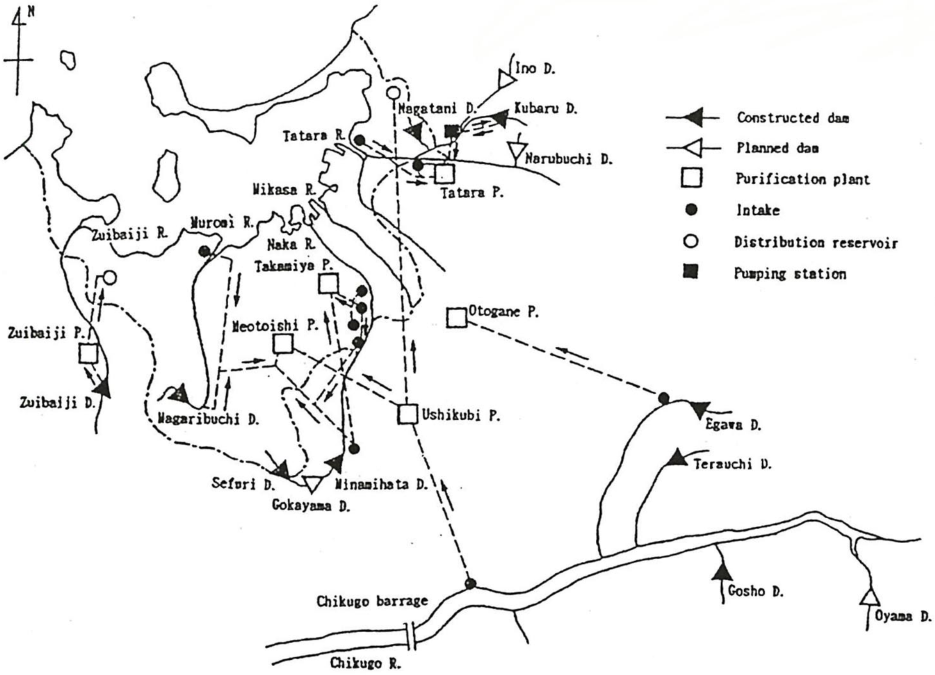

Fig.2 Waterworks facilities and water sources of Fukuoka City

2. 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. The sources of water supply in Fukuoka Metropolitan Area are surface water (87%), river-bed water (3%), and ground water (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 ratio are 66%, 1%, and 33% for the surrounding municipalities indicating fairly 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 [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

Table 1 Project list of unique water resources development and management

A. Preservation of forested infiltration areas.
B. Reservoir development.
  1. Pumping up storage reservoir.
  2. Dredging of dam beds.
  3. Reservoir for drought control.
C. Improvements of water usage and existing facilities.
  1. Increasing efficiency of irrigation water.
  2. Advanced water treatment.
  3. Water leakage prevention.
  4. Water supply control.
D. Water quality improvements.
  1. Utilization of treated sewage water.
  2. Desalination of seawater.
E. Regional water transfer.
F. Measures for controlling water demand.
  1. Popularizing water saving equipment.
  2. Increase of water saving awareness.
  3. Water cost policy.

areas, development of industries (urban infrastructure), the increase of living standard, etc. The big number of expansion projects shows the effort that the city has taken in order to develop and efficiently utilize the scarce water resources.

Fig.2 illustrates present waterworks facilities, water sources and conveyance system of Fukuoka City [2]. Fukuoka City is withdrawing water from five small rivers that flow through the city and that are managed by the prefectural government. Those 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. There are five water purification plants and all of them are treating water by rapid-filtration [4].

3. 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. Those projects classified into 6 categories A to F are listed in Table 1 [5]. In this section some of the projects among the list are explained.

3.1 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.

3.2 Pumping up storage reservoir
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's areas are very small 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.

3.3 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.

3.4 Desalination of seawater
Desalination plant will be constructed aiming at around 2005 using seawater on a large scale. The capacity of this plant 50,000 m^3/day by means of the reverse osmosis method will be the largest in Japan.

3.5 Regional water transfer
Among the water resources development projects, the water withdrawn from the Chikugo River (Fig.1), which is located outside of the Fukuoka Metropolitan Area, supplies approximately one third of the total water for Fukuoka City.
The Fukuoka District Waterworks agency, which is composed of representatives from each municipality of Fukuoka Metropolitan Area, was established in 1973 aiming at water supply to the entire metropolitan area. In 1983, regional water transfer from Chikugo River started even though it was opposed by people living in the basin. This was because flow rates decreased for fishery and because of environmental issues. The agency was originally transferring water from the Chikugo River only, but now other rivers are also involved. At present, the agency is playing a very important role as a water supply administrating agency for the metropolitan area.

3.6 Regulations concerning water supply rejection
Eight small municipalities surrounding Fukuoka City, for which the water supply situation is very stringent due to rapid population increase, have introduced regulations which enable the authorities not to supply water to newly constructed large buildings.
By this regulation which was approved in 1999 by the supreme court, the authorities are no more responsible to supply water to the newly constructed large buildings.

4. WATER SUPPLY CONTROL

The setup of a water supply control system started when the great drought occurred in 1978. 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 completing the Water Control Center. 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 120 water pressure gages, 68 flow meters, and 149 electric control valves all at important points along the water distribution pipes (April, 2000). An engineer can by visual control operate electric valves by remote control in order to secure the necessary water pressure through the pipes 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 [6].

The water distribution regulation system is made up of a data transmission system and a data processing system. The data transmission system connects the various equipments (TM/TC units, etc.) installed in each water supply block, and the TM/TC parent stations located in the Water Distribution Control Center via telephone lines, while the data processing system controls the motor valves and processes incoming data. While monitoring data from purification plants, flow meters installed in distribution mains, and pressure gauges located within blocks, motor valves installed in mains and block injection points are operated by remote control, thereby controlling flow and pressure [7]. Fig.3 shows a schematic diagram of system signal pathways applied in Fukuoka City.

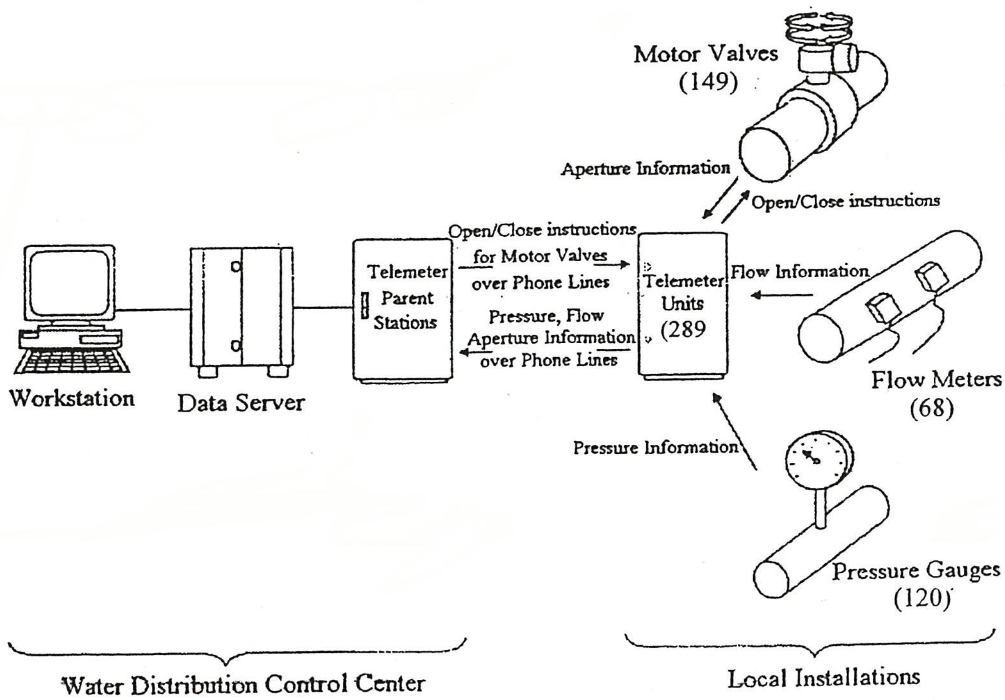

Fig.3 Schematic diagram of system signal pathways applied in Fukuoka City.

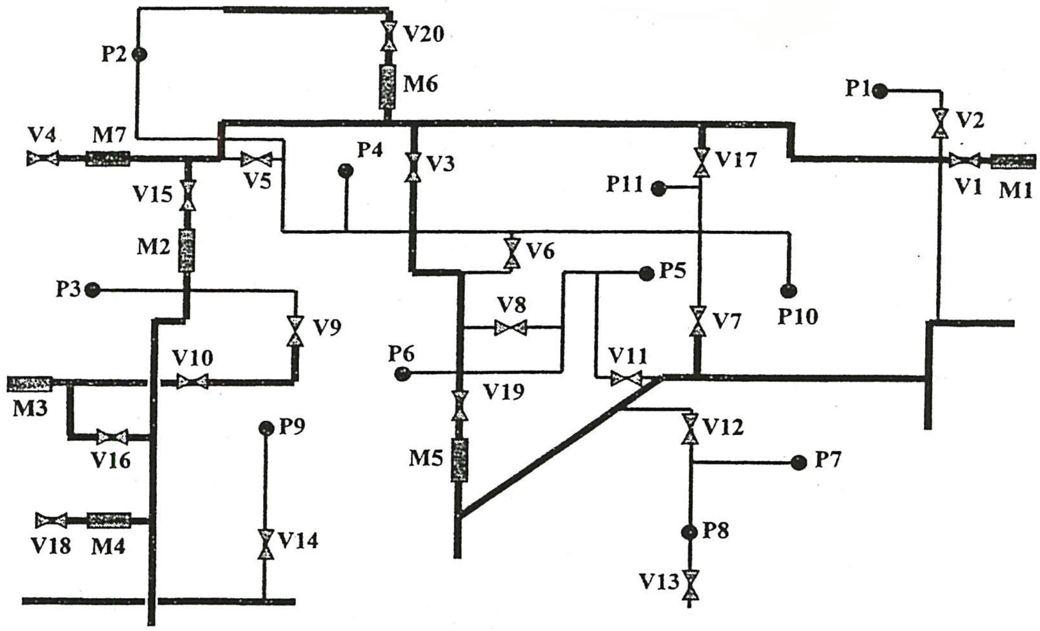

Fig.4 Block 12 of the Fukuoka city water supply network

5. A CASE STUDY OF BLOCK 12

5.1 Block description

The water supply network of Fukuoka city is divided into 21 blocks. The area to be served by each block depends on water distribution areas, differences in land elevation, location of rivers and railroads, as well as local differences in water usage. Fig.4 shows the different elements of Block 12 which is located in the center of Fukuoka city. In this block, there are 20 motor valves, 7 flow meters, and 11 pressure gauges. It is noticed from the figure that flow meters are connected in the main inlets and outlets and a valve is connected adjacent to each flow meter in order to control the flow entering or leaving the block. The remaining 13 motor valves are connected to the main junctions of this network to make water distribution more efficient. Motor valves are operated by remote control while pressure gauges and flow meters fitted to distribution pipes are monitored. The values of flow rate passing each flow meter, the opening percentage of each motor valve, and the pressure intensity at each pressure gauge are recorded every minute. Hourly data are available for all telemeters since 1[st] April 1998 to 31[st] march 2001. This makes the total number of data for each telemeter 26304 (number of hours during this period).

5.2 Flow characteristics

By analyzing the data of the studied three years, it is noticed that water feeds the block through flow meters M1, M3, M4, and M6. It is noticed also that M2 is an internal flow meter. The direction of flow through all pipes can be changed to prevent the occurrence of red water and to increase the efficiency of water supply in the case of pipe breakage caused by accident or fire.

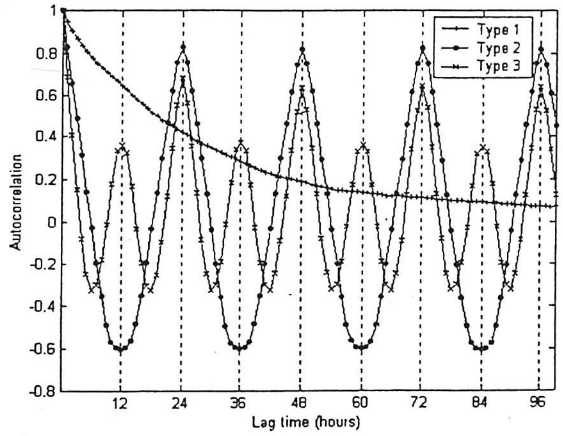

Fig.5 Autocorrelation function of the typical three types of motor valves

5.3 Valve control

Motor valves connected to the different pipes of this block can be classified as shown in Fig.5 into three typical types according to the collection of correlation coefficient computed for various lags which is named autocorrelation function (ACF) [8].

The followings are the main characteristics of the three types of valves.

Type 1: Six valves of this network fall in this type and they are Valves 1, 4, 14, 15, 18 and 19. All these valves are connected to the main entrances of the network and have approximately constant percentage of opening through out the day.

Type 2: Valves 2, 3, 13 and 17 are classified under this type. This type of valves is completely closed during night (from 10.00 p.m. to 6.00 a.m.) and they have approximately constant percentage of opening during the rest hours of the day. This type is connected to the internal pipes of the block to reduce pipe-leakage through the network, and also to decrease the pressure during night when the water demand is at minimum.

Type 3: The remaining 10 valves are considered of this type. This type of valves is used to maintain the pressure value between 2.5 kg/cm^2 and 3.0 kg/cm^2. Therefore those valves are slightly opened around the rush-hours (7.00 a.m. and 8.00 p.m.) and they are completely closed during the late night hours.

5.4 Water pressure variance

With full-scale operation of the water distribution control system commencing in October of 1981, pipe pressure began gradually to be reduced. In March of 1982, effects began to manifest, motor valve operations targeted to a standard pressure in the range 2.5 to 3.0 kg/cm^2 were carried out around the clock [9]. With regulation carried out at pressures approximately 2 kg/cm^2 lower than before introducing the system, it is calculated that the system is responsible for water savings of about 4000 to 5000 m^3/day, while incidents of natural leakage from distribution pipes have fallen by around 30% [10].

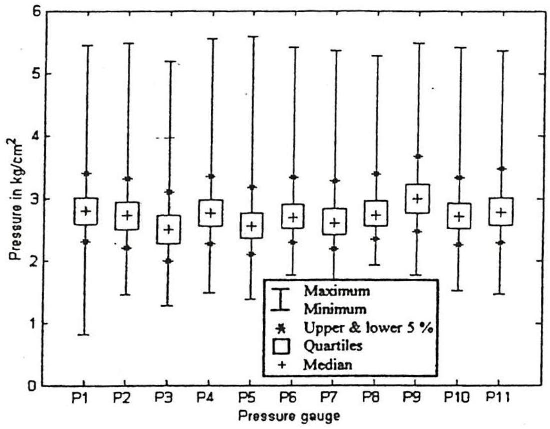

Fig.6 Box-whisker plot of pressure gauges of Block No.12

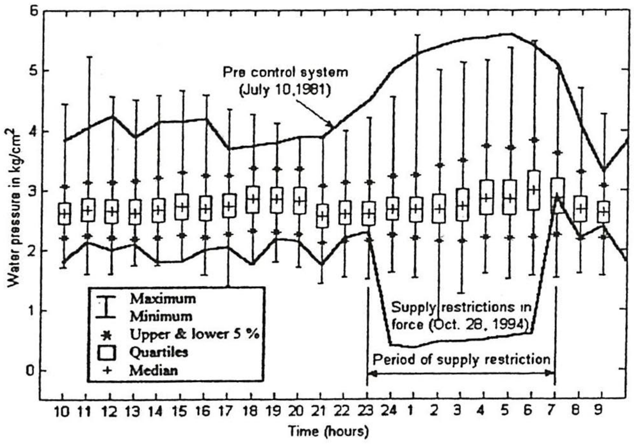

Fig.7 Box-whisker plot of pressure gauges of Block 12 compared with the cases of pre-control system and 1994 drought

In order to test the efficiency of water distribution control for Block 12, Fig.6 outlines the pressure monitored in all the 11 pressure gauges of this block. The box-whisker plot shows the median, upper and lower quartiles, upper and lower 5% of events and also the maximum and lower pressure recorded for each pressure gauge. From this chart it is seen that the median value of pressure at all nodes varied from 2.50 kg/cm^2 to 3.00 kg/cm^2, while for the upper 5% of all events, the pressure exceeds the value of 3.25 kg/cm^2 and the maximum pressure value could reach the value of 5.5 kg/cm^2. On the other hand for less than 5% of all events, the pressure is less than 2.25 kg/cm^2 and the minimum pressure value reached 1.5 kg/cm^2. This means that 90% of pressure value events are well controlled to target values. To compare the pressure control of Block 12 with the pressure values of the pre-control system and the case of 1994 drought, Fig.7 shows the box-whisker plot of all 11 pressure gauges of Block 12 compared with the cases of pre-control system and 1994 drought. This plot shows that regulation of the pressure between the upper and lower quartile for a value falls in the range 2.5 to 3.0 kg/cm^2.

CONCLUSIONS

The municipalities in Fukuoka Metropolitan Area are making comprehensive efforts for supplying a stable amount of water as mentioned in this paper.

With the assistance of Water Supply Control System, and comparing the current situation with the situation of the pre-control system, a large amount of water has been saved. A decrease of 30% of leakage from distribution pipes was achieved. An early discovery of distribution pipe abnormalities and rapid response by remote control, gathering and analyzing information to make water distribution more efficient and also an excellent regulation of pressure value through the distribution network were also accomplished.

With the ever-increasing complexity of the city-wide distribution pipe network, motor valve operation to regulate pressure and flow came to depend more and more on the experience and skills operators. For this reason, an improvement of valve operations support functions should be done. This aims to prevent the events of pressure regulation falls outside the target pressure range.

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