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CHARACTERISTICS OF WATER DISTRIBUTION CONTROL IN FUKUOKA CITY FOR EFFICIENT WATER RESOURCES MANAGEMENT

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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 resulting in water rationing which lasted for 287 days. 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, however, has a geographical disadvantage, thus water supply has to rely on small rivers and limited groundwater resources. As a result, the area is always exposed to potential drought.

In order to meet increasing water demand in areas with scarce water resources, water resources development and management projects with innovative ideas have been carried out. As one of the project, Fukuoka city has set up water supply control system for controlling the flow and pressure from purification plants to taps. It aims to equalize tap water supply over the entire city. Also, it is designed to meet the varying demands for water on each purification plant caused by the multiple intake system.

Therefore in this study, an assessment of the present efficiency of water resources management in terms of water distribution control are highlighted with reference to the characteristics of water distribution control. A case study of block number 12 in the city water supply network is also presented.

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 338 km^2 and the population is 1.33 million as of October 1999.

Fukuoka Metropolitan Area consists of Fukuoka City and 20 surrounding. 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 1,630 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) (Kawamura and Kuzuha 2001).

The present situation of integrated water resources management and number of unique water resources developments projects which have been carried out since the 1978 drought in Fukuoka Metropolitan Area are illustrated. Secondly, the water supply control system for Fukuoka city is presented. Finally, a case study of block number 12 in the city water supply network is introduced.

PRESENT SITUATION ON WATERWORKS

In Japan, water resources planning are designed for a drought with a targeted ten-year return period. Waterworks are governed by public organizations, and in general principles each municipality is responsible for its resident water supply. By law the waterworks in each municipality are operated on a self-paying basis, so that each municipality has 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 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. 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 (Zongue *et al.* 1998)

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), 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 1 illustrates present waterworks facilities, water sources, and conveyance system of Fukuoka city. The city is withdrawing water from five small rivers that flow through the city and that are managed by the prefectural government. 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. There are five water purification plants and all of them are treating water by rapid-filtration.

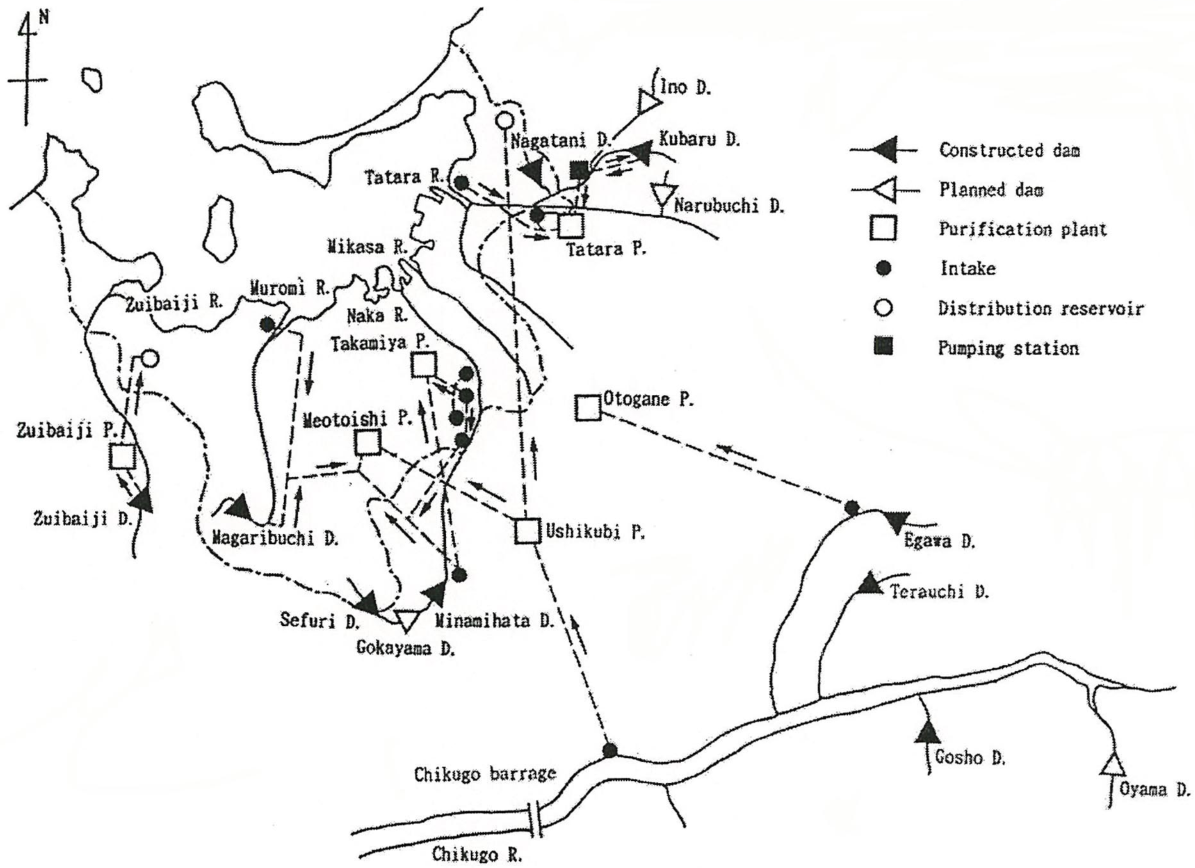

Figure 1 Waterworks facilities, water sources and conveyance system of Fukuoka City

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 (Kawamura and Jinno 1995). Those projects classified into 6 categories A to F are listed as follows:

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 sea water.

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.

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 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.

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 equipment (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 (Shinoda 1998 and Onizuka 2000). The water pressure can be controlled as seen in Figure 2.

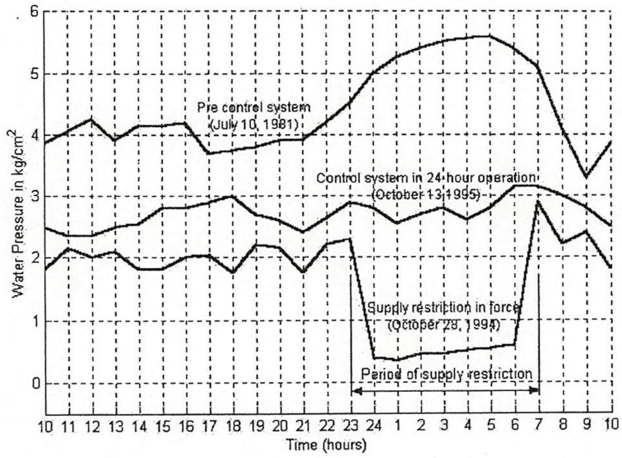

Figure 2 water pressure regulation time series graphs

Figure 3 shows a schematic diagram of the system signal pathways.

Figure 4 shows the increase of total number of water pressure gauges, flow meters, and electric control valves since the establishment of Water Distribution Control Center in 1981.

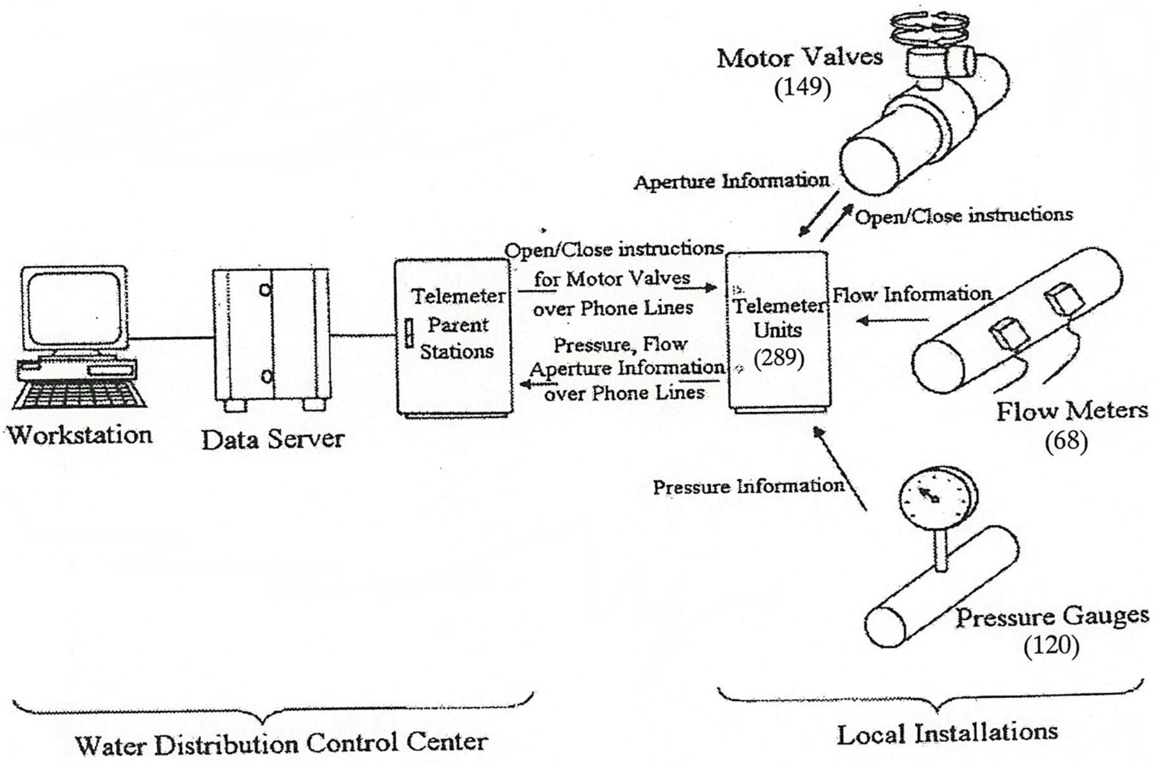

Figure 3 Schematic diagram of system signal pathways applied in Fukuoka city

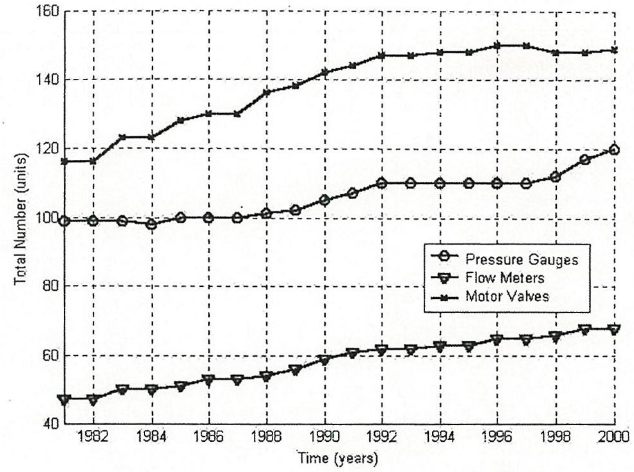

Figure 4 Increase of total number of telemeters

A CASE STUDY OF BLOCK 12

Block description

The water supply network of Fukuoka city is divided into 21 blocks. The area served by each block takes into consideration separate water distribution areas, differences in land elevation, location of rivers and railroads, as well as local differences in water usage (Miyazaki 1999).

Our case study (Block 12) is surrounded from the north by Hakata bay, from the east by Hii River, from the west by Naka River and Block 9 and from the south by an elevated area (Block 50) and also by Block 13. This block is located in the center of Fukuoka city.

Figure 5 shows the different elements of Block 12. 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 (e.g., M1, V1; M2, V15; .....). The remaining 13 motor valves are connected to the main junctions of this network (e.g., V2; V3; V5; .....) to make water distribution more efficient.

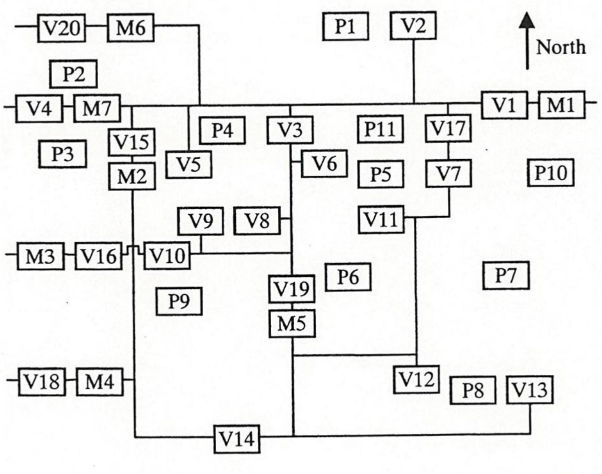

Figure 5 Block 12 of the Fukuoka city water supply network (Pipes diameters in this figure are from 45 cm and above)

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. The analyzed data of this study are for the period from April 1998 to March 2001.

Available data and data type

Hourly data are available for all flow meters, pressure gauges, and motor valves since 1st April 1998 to 31st march 2001. This makes the total number of data for each telemeter 26304 (total number of hours during this period). The percentage of missing data for this period is 6.2%.

Flow characteristics

By analyzing the data of the studied three years, it is noticed that water feed 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 for preventing the occurrence of red water and also to increase the efficiency of water supply in the case of pipe breakage caused by accident or fire (Shinoda 1999).

Figure 6 shows a box-whisker plot for the statistical distribution of hourly discharge entering the block (positive sign) or leaving the block (negative sign) through all seven flow meters of this block. From this figure we can conclude that median value of flow passing through the flow meters M7 and M4 equals zero. These two flow meters are used only in the case of high water demand and also in the case to facilitate excess water for leaving this block to the other adjacent blocks.

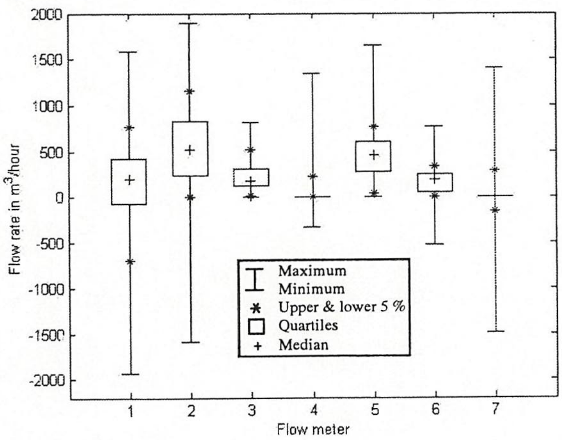

Figure 6 Box-whisker plots of flow meters of Block 12

Figure 7 shows the relation between water consumption in both of Fukuoka city and Block 12. Hourly median value of water discharge into Block 12 is plotted on the right vertical axis while the hourly demand of Fukuoka city is plotted by the box-whisker plot as the left vertical axis. Median value of water consumption in Block 12 has the same characteristics as that of the city.

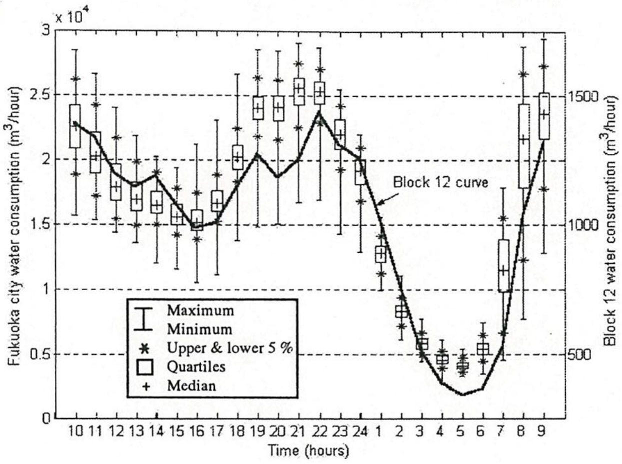

Figure 7 Water demands of Fukuoka city and Block 12

Valve control

Motor valves connected to the different pipes of this block can be classified into two types.

The first type is the valves with approximately constant percentage ratio of opening. The median value of valve opening of this type is almost constant during the different hours of the day. These valves are connected to the main entrances of this block.

The second type is valves which are completely closed during night time (from 11.00 p.m. to 6 a.m.). This type of valves is connected to the internal pipes of the block to reduce pipe-leakage through the network, and also to decrease the pressure during the night time when the water demand is at minimum.

Figure 8 shows a box-whisker plot of the statistical distribution of hourly degree of valve opening for the 20 valves of block 12. The median value of valve opening of all these valves – except valve 1 - is less than 30%. The median value of valve opening of valve 1 is 97%.

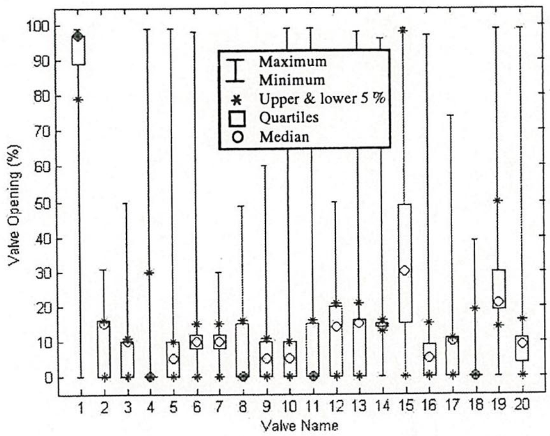

Figure 8 Box-whisker plots of motor valves of Block No. 12

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. 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%, (Fukuoka City Waterworks Bureau 1999) and (Fukuoka City Waterworks Bureau 2000).

In order to test the efficiency of water distribution control for Block 12, Fig. 9 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 between 2.50 and 3.00 kg/cm^2, while the other 10 % of values fall outside this range.

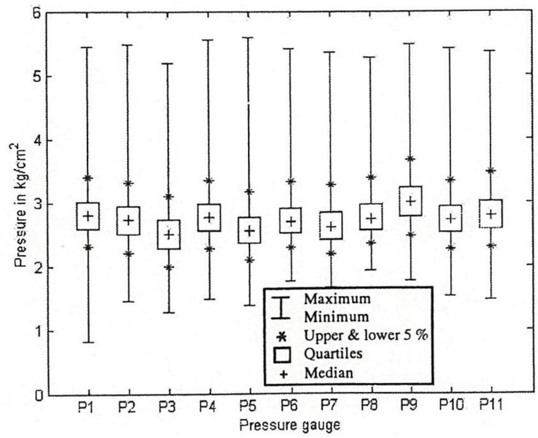

Figure 9 Box-whisker plots of pressure gauges of Block No. 12

To compare the pressure control of Block 12 with the pressure values of the pre-control system and also the values in the case of 1994 drought, Figure 10 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.

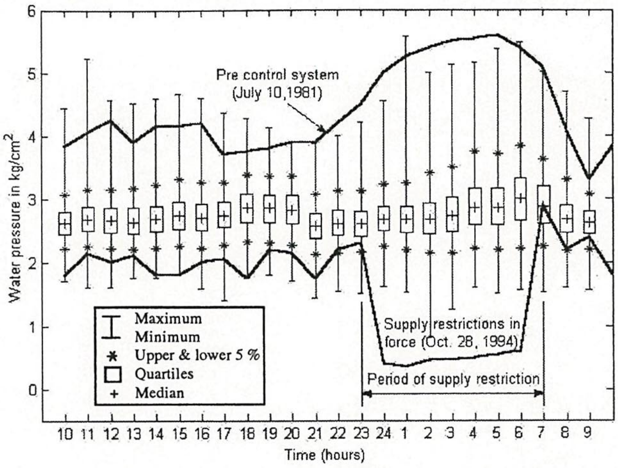

Figure 10 Box-whisker plots of pressure gauges of Block 12 compared with the cases of pre-control system and 1994 drought

For testing the efficiency of water distribution control during different hours of the day, figure 11 shows the variance between the upper and lower quartile, the upper and lower 5% of events, and the maximum and minimum value of all pressure gauges of Block 12. This figure shows an increase of pressure variance during the night hours (from 2.00 a.m. to 7.00 a.m.). The increase of pressure variance is about 0.3 kg/cm^2 when we compare the upper and lower quartile and about 0.6 kg/cm^2 when we compare the upper and lower 5% of events.

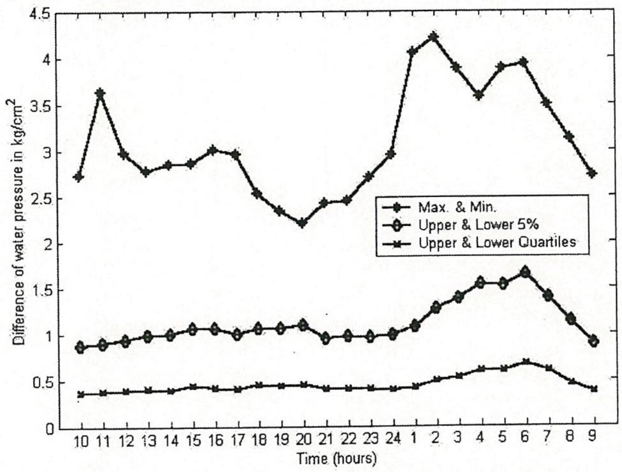

Figure 11 Variance of all pressure gauges of Block 12 for different hours of the day

CONCLUSIONS

With the assistance of Water Supply Control System, and comparing the current situation with the situation of the pre-control system and the situation during 1994 drought, much less people were called out to manually close and open the valves during water shortages. 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 based on valve operation planning for flow and pressure regulation, and the operation knowledge database which is constructed on the basis of past experience. This aims to prevent the events of pressure regulation falls outside the target pressure range and also to reduce the effort of investigator operators.

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