Ensuring Stable Water Supply by Centralized Administrative Control over a Large-Scale Water Supply Network

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Abstract: The waterworks of Tokyo, which supplies water to over 13 million citizens, comprises of a large-scale and complex water network. In order to effectively operate such a network, the Tokyo Metropolitan Government Bureau of Waterworks established the Water Supply Operation Center. This center utilizes the water operation system to develop operation plans for pumps and conduct 24-hour monitoring of such things as water pressure and flow rate. Through this, it sufficiently controls the flow of drinking water. Moreover, in order to suitably control this flow, the training of personnel is essential, as well as working on improving the technical proficiency of staff through OJT, various types of training, and the preparation of response manuals. This report illustrates these roles of the Water Supply Operation Center, as well as the center's efforts in personnel training.

Keywords: Water supply network, water supply operation system, SCADA, telemeters, human resources development

1. An outline of the water supply system in Tokyo

Tokyo waterworks supplies on average 4.2 million m^3 of water per day to over 13 million citizens. The drinking water network is made up of 11 purification plants, of whose major water resources are the Tonegawa, Arakawa and Tamagawa rivers, 41 water supply stations, and distribution pipes that extend to a total length of 27,000 km. It's a large-scale and complex network. [1]

The water taken from the Tonegawa and Arakawa river sources, which accounts for 80% of these water resources, is treated at the purification plants in low altitude. Therefore, the water needs to be pumped up to water supply stations at a higher altitude. Due to this, an enormous amount of energy of around 800 million kWh (approx. 1% of the city's electricity usage) is required, and around 60% of that is due to the distribution process. Thus, efficient water operation is crucial to reduce energy usage and environmental burden.

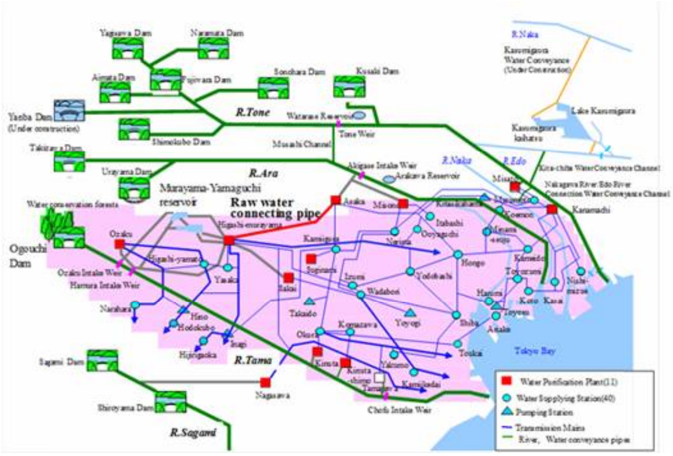

Figure 1 Water resources and major facilities

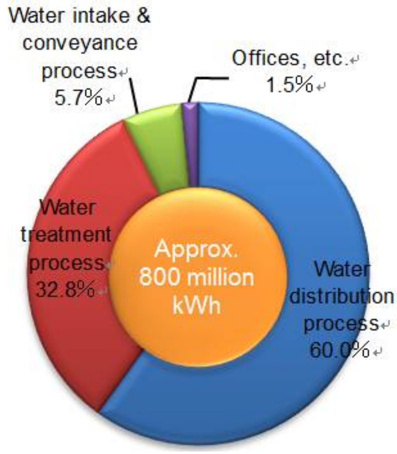

Figure 2 Breakdown of electricity usage

2. Primary roles of the Water Supply Operation Center

2.1 Integrated information management system

In order to efficiently operate the vast and complex water network and ensure stable water supply, a system that constantly monitors each facility's condition and adequately influences control of operations is indispensable. Therefore, the Tokyo Metropolitan Government Bureau of Waterworks established the Water Supply Operation Center in 1979. [2],[3]

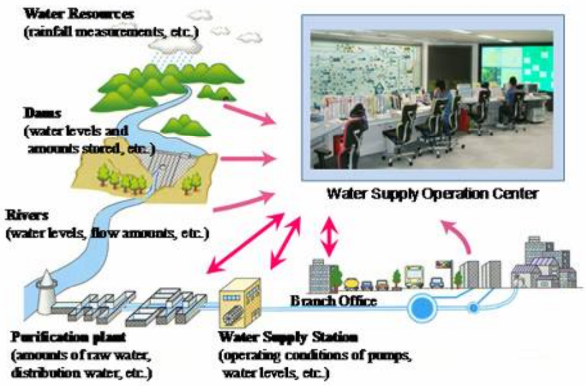

Figure 3 Relationship diagram of water supply operations

The Water Supply Operation Center sufficiently controls the flow of water whilst constantly monitoring data such as the water pressure and flow rate of each facility by using large-scale panels and monitors. This is achieved through utilizing the water supply operation system, called SCADA (Supervisory Control And Data Acquisition).

Situated at the heart of these operations is the monitoring room. It's here that the development of operation plans and monitoring of data is conducted via the utilization of the water supply operation system. Currently, around 24,000 bits of data come from 177 facilities and 313 pipelines.

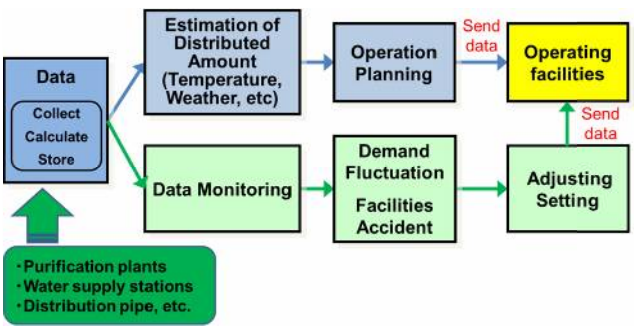

Figure 4 Roles of the Water Supply Operation Center

2.2 Development of water supply operation plans

The water supply operations in Tokyo involve preparing upon annual basic policies and monthly operation plans. Daily operations are conducted based on these plans.

Monthly plans are developed in the areas of raw water operation, transmission main operation and pump operation. They are sent online to each purification plant and water supply station, leading to the operation of pumps and other equipment.

a) Raw water operation plans are prepared monthly to determine the amounts of water intake from each source of water.
b) Transmission main operation plans are prepared as monthly basic policies for determining daily distribution amounts of water from each purification plant and water supply station. They also determine pump operation plans for each transmission main.
c) Distribution pump operation plans determine monthly basic policies for planning the operation of distribution pumps to ensure suitable water pressure in the supply area based on the area's predicted monthly average demands.

In addition to these monthly plans, distribution reservoir operation plans are prepared daily in accordance with daily water demand. Also, operation adjustment is conducted if necessary.

a) Distribution reservoir operation plans determine the pulled-in volume of a water supply station's distribution reservoirs based on the predicted demand of any given day plus the following day. Using the water supply operation system, this demand is predicted from factors such as the daily distributed water volume of the past ten weeks, and predicted weather and temperature. However, because demand fluctuates due to the day of the week and changes in the weather and temperature, the plan is reviewed five times a day.
b) In the case where operations need to be changed depending on a given day's water distribution conditions, the staff in charge adjusts operations accordingly

On the other hand, a distribution reservoir operation system has been introduced in order to maintain an appropriate storage volume in the distribution reservoirs of water supply stations. This system calculates the water levels in the distribution reservoirs based on predicted demands, and automatically adjusts the volume of water entering the reservoirs. As a result, the majority of water supply stations currently operate unmanned.

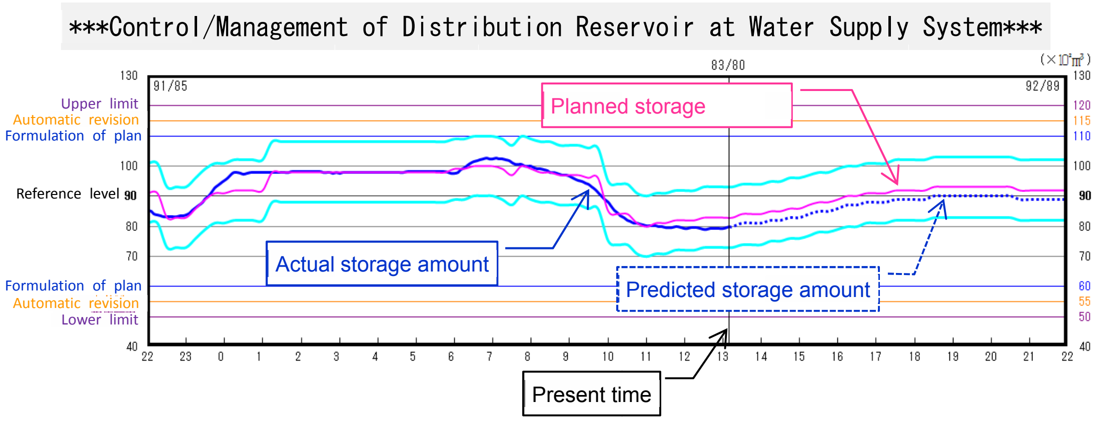

Figure 5 Prediction and Actual Record in Distribution Reservoir Operation System

In addition, the Water Supply Operation Center gathers and analyzes data on electricity by utilizing a total energy control system, and tries to reduce energy consumption within a range that ensures stable water supply.

The unit of electricity consumption per m^3 for each supply route is calculated based on historical data from electricity consumption by distribution pumps and amount of distributed water. By multiplying the amount of water flow from each unit, the total electricity consumption for a route can be calculated. Then, the route with the lowest amount of electricity consumption is selected. This way, the reduction of energy consumption is achieved.

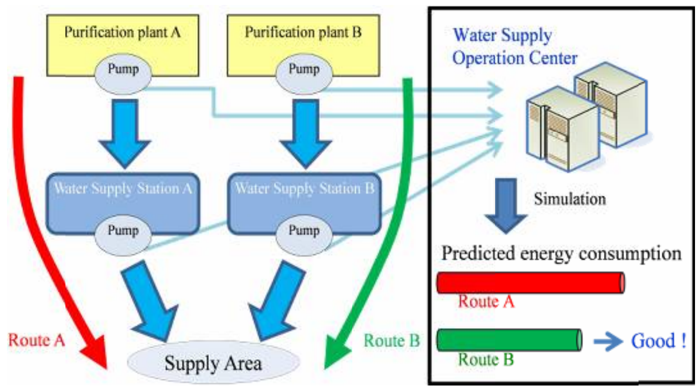

Figure 6 Conceptual diagram of the total energy control system

2.3 Data monitoring

The Water Supply Operation Center is constantly monitoring many types of data in the facilities. In cases of change in flow late and pressure due to demand fluctuations, pump operations are adjusted. In cases of accidents at facilities, supply routes are switched if necessary.

Additionally, when flow rate or pressure exceeds appropriate levels, it’s immediately detected by the system. For example, in cases of large-scale water leakage accidents in pipelines, as in **Photo 1**, water pressure and flow rate suddenly change at the same time, as shown in **Figure 7**. When these peculiarities are captured by the system, they are recognized as abnormal and a warning is sent out.

Photo 1 Leakage accident at a distribution pipe (inner diameter: 1,500 mm)

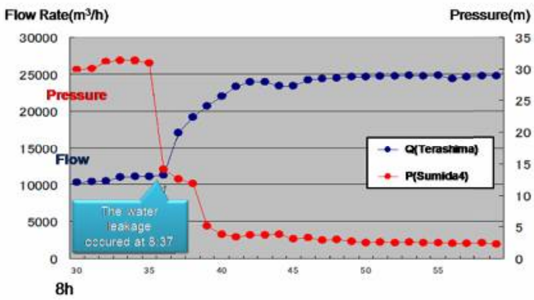

Figure 7 Changes in flow rate and pressure during an accident

Also, when water pressure and flow rate exceed the set upper or lower limits, as shown in **Figure 8**, they are perceived as abnormalities and reported upon.

Through this system, staff members have become able to instantly detect abnormalities in facilities and respond to them quickly.

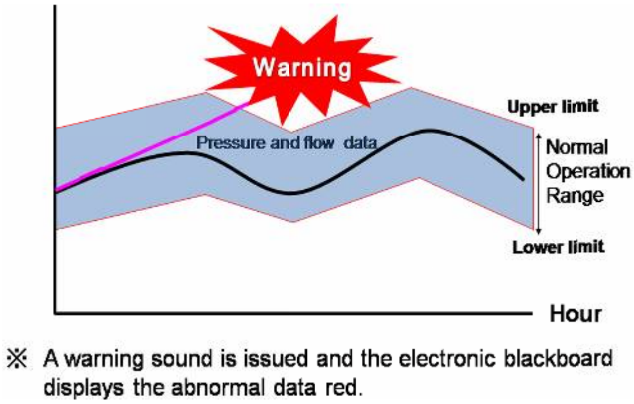

Figure 8 Upper and lower limit abnormalities

3. Examples of fluctuations in water demand

3.1 Water usage in a day

The volume of water usage in Tokyo changes depending on factors such as the season, day of the week, time period, and weather.

Figure 9 shows the hourly changes of water usage in a day. In general, water usage is greater on days with good weather, and lesser on rainy days. Additionally, on holidays the peak demand in the morning tends to be later than on weekdays. The reasons for these trends seem to be that people avoid doing laundry due to rain, and that people's activities tend to start later on holidays.

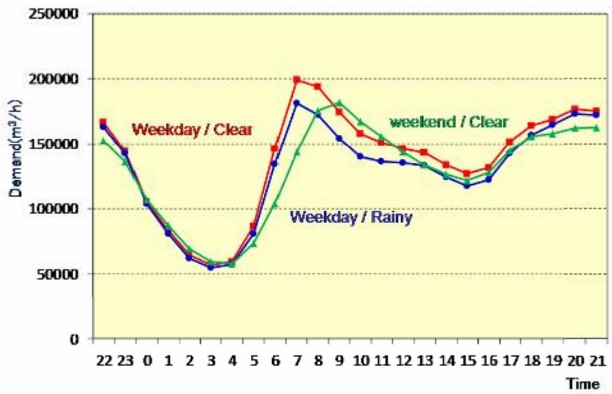

Figure 9 Changes in water usage in a day

3.2 Fluctuations in water usage during events

During events in which a high percentage of people watch television, water usage tends to fluctuate abruptly. **Figure 10** shows the fluctuations of water usage during a game of FIFA World Cup RUSSIA 2018 (Japan vs. Colombia).

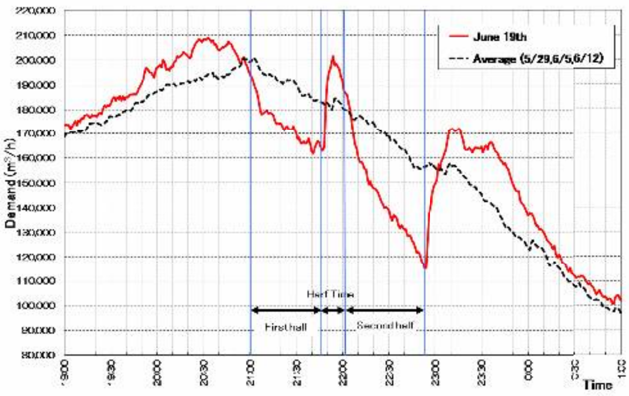

Figure 10 Water usage during a game of FIFA World Cup RUSSIA 2018 (Japan vs. Colombia)

Compared to the average usage, water usage increased just before the game began, during half time, and just after the end of the game. In particular, during halftime and just after the game ended it increased rapidly. The reason for this phenomenon seems to be that many people simultaneously start using the bathroom or doing kitchen work.

3.3 Effect of long-period ground motion

During the M7.3 Kumamoto earthquake on April 16th 2016, long-period ground motion was observed in Tokyo even though it's over 800 km away from the epicenter. [4]

Figure 11 shows the fluctuations in the total amount of supplied water and water pressures of the water mains in 23 wards during the earthquake. It can be seen here that several minutes after the occurrence of the earthquake, water pressure began to drop abruptly. Afterwards, the distributed amount increased, returning to the original condition in roughly ten minutes.

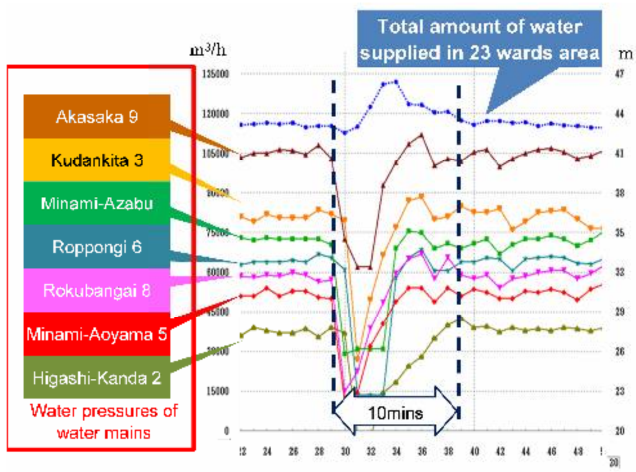

Figure 11 Changes of water supply and water pressure during the Kumamoto earthquake

It seems that these fluctuations were caused by the sloshing of receiving tanks installed within buildings, which caused malfunctions of devices that control water levels in tanks, resulting in abrupt increase of water flow into the tanks.

Through 24-hour monitoring of fluctuations in water demand and subsequent adjustments when needed, the Water Supply Operation Center ensures a stable water supply.

4. The succession of techniques and personnel training in water supply operation

In order for the water operation system to properly function, it is essential to have skilled personnel. As large-scale accidents have occurred less and less in recent years in Tokyo due to qualitative improvements of materials, the number of staff with no experience in responding to accidents is increasing. Therefore, improving technical proficiency in staff is becoming crucial. This includes measures such as strategic job rotation, simulation training for accidents, and the preparation of response manuals.

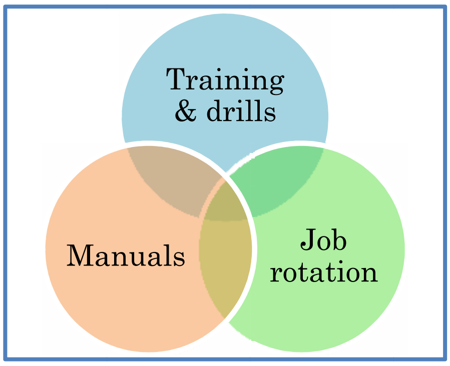

Figure 12 Technique succession and personnel training

The staff engaged in monitoring work at the Water Supply Operation Center is made up of a total of 20 members, who have backgrounds in the field of civil engineering, electricity or mechanics. Senior staff members are assigned because a high judgment ability is required in the event of an accident. Among those staff, four members are constantly on a two-shift system for monitoring 24 hours a day, 365 days a year.

There are fixed rules on how to choose these four staff. First of all, staffs with over three years of operational experience are put in charge, and experienced staffs are grouped with those with less experience. Also, staff members with different backgrounds are put together to become able to respond appropriately to accidents related to both pipes and facilities. Having staff from different backgrounds working together also helps them mutually improve their technical proficiencies.

In addition, soon after moving to the Water Supply Operation Center, the staff is given intensive on-the-job training in order for them to learn fundamental skills and knowledge.

Photo 2 Discussions during simulation training

Simulation training is conducted for staff in their first year on the job. Information about damage in facilities is assigned to them by senior staff members and they analyze it and consider how to respond to such situations through discussion with other trainees. The damage information given out by the senior staff members is based on past accidents, giving the training content a sense of reality. Senior staff members give comments and advice on countermeasures devised by trainees and explains the ideal countermeasure. In this way the succession of operation techniques is being carried out.

Various manuals for water supply operation have been developed based on past accident case studies and the know-how of experienced staff. However, it's crucial to constantly revise these manuals.

Concerning job rotation, we have been strategically securing experienced staff in order to pair them up with staff of lesser experience. We also work to get other staff outside the monitoring team to be engaged with supplementary work, in order for them to gain experience in monitoring.

5. Conclusion

The introduction of the water supply operation system has been extremely effective for the efficient control of water supply network that have become more complex due to the growth of the city.

Tokyo Waterworks has established the Water Supply Operation Center, has effectively developed the water supply operation system and is centrally controlling in real-time the whole of Tokyo's large-scale water supply network. This water supply operation system is highly effective on ensuring a stable water supply, the efficient operations of facilities, the reduction of energy consumption, and the speeding up of accident responses.

On the other hand, there are issues that need to be tackled concerning the succession of water operation techniques. Such issues include the decrease in experienced staff and the assignment of less experienced staff due to personnel changes.

We will continue to reform the system to improve the accuracy of water demand prediction and the efficiency of water supply operation. Also, we will keep working on human resource development.

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