Countermeasures against a Long-term Blackout in Sendai City Waterworks Bureau Passed Through the Great East Japan Earthquake

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ABSTRACT

On March 11, 2011, the Great East Japan Earthquake (hereafter referred to as GEJE), the most powerful earthquake (Mw 9.0) ever recorded in the country struck. At Sendai City Waterworks Bureau, we lacked fuel for emergency power generation equipment because of an unanticipated long-term blackout that continued for 98 hours. In particular we had 60 water distribution facilities with emergency power generation equipment such as pump stations, however we were unable to secure fuels or refuel before the power outage occurred due to a shortage in human resources. Therefore, operation and monitoring for all of the facilities became impossible, resulting in suspension of water service over a wide area.

Before the GEJE, we had installed equipment as countermeasures against a blackout of up to 24 hours in water purification plants and facilities with large impacts during a blackout, based on the Design Criteria for Water Supply Facilities edited by JWWA. However, after the GEJE, we reconsidered the policy for installation of equipment for countermeasures against a blackout, using the lessons learned from the GEJE and the long-term blackout. In the policy, installation of equipment for countermeasures against a blackout more than 72 hours in main water purification plants and important facilities roles of disaster recovery and water distribution control are denoted.

Countermeasures against a long-term blackout in Sendai City Waterworks Bureau are as follows:

(1) Improving fuel efficiency by upgrading gas turbine generators to diesel generators
(2) Increasing the fuel storage capacity by adding or updating fuel storage facilities
(3) Deployment of Fuel Supply Vehicle in order to make refueling by Waterworks Bureau staff more efficient
(4) Establishing relationships with other cities in Japan and gas stations concerning fuel supply

By appropriately combining these measures, it is possible to operate the emergency power generation equipment stably even if a long-term blackout occurs.

This paper describes a basic concept of the time required for operating when a blackout happens, and the facilities which require the installation of equipment as countermeasures against a long-term blackout. In addition, we will show examples of three measures we have put into effect.

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INTRODUCTION

The Sendai City Waterworks Bureau has taken various steps to create a disaster-resilient water supply, for example, reinforcing water pipes against earthquakes and enhancing cooperation with other cities and associations based on our experiences in the Miyagi Oki Earthquake (1978) and the lessons learned from the Kobe Earthquake (1995). By implementing these measures, our total water management system has steadily developed so that all water facilities can be used flexibly and efficiently on a day-to-day basis as well as in times of disaster in order to provide customers with a stable water supply.

On March 11, 2011, the GEJE, the most powerful earthquake (Mw 9.0) ever recorded in the country struck. There was no major damage to Sendai City's purification plants or distribution reservoirs, but the transmission main pipe of Miyagi Prefectural Bulk Water Supply broke, and the water supply to Sendai City was cut off. Furthermore, a long-term blackout occurred over a wide area, including Sendai City, which was caused by breakdown in power generation facilities and transmission network of power companies. At Sendai City Waterworks Bureau, a lot of facilities became uncontrollable and unobservable because of the lack of fuel for emergency power generation equipment. These troubles occurred at same time, resulting in suspension of service to a maximum of 230,000 households, or about 50% of water service users in the city. At the time, the Sendai City Waterworks Bureau did not have enough human resources and we were not able to provide customers with a water supply, despite the support of many other cities.

THE POLICY FOR INSTALLATION EQUIPMENT FOR COUNTERMEASURES AGAINST LONG-TERM BLACKOUT

Before the GEJE, emergency power generation equipment for up to 24 hours operation time at the time of a blackout were installed at all water purification plants (excluding small-scale plants) and facilities owned by the Sendai City Waterworks Bureau, that are greatly influenced by blackout according to Design Criteria for Water Supply Facilities edited by JWWA. However, at the time of the GEJE, we lacked fuel due to long-term blackout occurred extend to 98 hours.

At Sendai city's water purification plants, we attempted to procure fuel to continue water purification; however it was difficult to do so because of the disorder caused by the disaster. In fact, we were able to continue water purification thanks to the timely cooperation of local gas stations and the support from various associations.

However, in water distribution facilities with emergency power generation equipment such as pump stations, there were too many facilities subject for refueling and a shortage in human resources. As a result, of all the 95 water distribution facilities, 60 with emergency power generation equipment have been unobservable and uncontrollable.

Therefore, Sendai City Waterworks Bureau considered extending the operation duration of the emergency power generation equipment based on the experiences of the long-term blackout and difficultly procuring fuel during the GEJE.

At the time of the disaster, about 80% of the commercial power supply was restored (the number of cases within the electric company's jurisdiction) in 72 hours, and a fuel supply vehicle had arrived adequately within 72 hours. Therefore, in main purification plants and important water facilities, we have been proceeding with replacement or extension of fuel storage facilities, changing oil type and so on to keep emergency power generation equipment operating continuously for 72 hours from the

previous maximum duration of 24 hours. As for other facilities, we decided to install equipment as a countermeasure against a blackout longer than 24 hours based on the existing policy, because these facilities usually have small-capacity emergency power generation equipment that can be supplied fuel by Waterworks Bureau staffs (Figure 1).

Definition of the Operating Time in a Blackout

The operating time in a blackout was defined as "the required time to maintain the function of the water facility, not the time of continuous operation at the rated output". In the calculation for the fuel storage amount, previous to the GEJE we calculated based on the fuel consumption of emergency power generation equipment at rated output conventionally. But in recent cases, in accordance with the aforementioned definition, the calculation is carried out based on the fuel consumption of the maximum power demand of a facility.

Selection of Important Water Facilities

Important water facilities were selected in consideration to the following points.

1) Distribution reservoirs have a capacity of more than 2,000 m^3
2) Pump stations send water to distribution reservoir has a capacity of more than 2,000 m^3
3) Water receiving facilities from Miyagi Prefectural Bulk Water Supply
4) Emergency water supply facilities with emergency shutoff valve or motorized valve
5) Facilities have a water supply area including a disaster center hospital
6) Composite facilities in which distribution reservoir and pump station
7) Fixed Wireless Access radio relay and base stations
8) Other facilities role of disaster recovery and water distribution control

As these facilities are necessary for water distribution control and disaster response, we decided to install equipment as countermeasures against a blackout more than 72 hours.

Selection of Engine Type for Emergency Power Generation Equipment

Gas turbine power generation equipment and diesel power generation equipment are mainly used for emergency power generation equipment. Focusing on the fuel consumption rate, the rate of the gas turbine type is about two times higher than the diesel type for the same output. Therefore, in the 11 facilities which had gas turbine power generation equipment, we decided to replace gas turbine type with diesel type to improve fuel consumption. The benefits included in the change to diesel type were not only the improvement of the fuel consumption rate, but also the diversion of the existing fuel tank when altering the oil type and replacing with smaller tanks when improving the fuel consumption rate.

However, large-capacity diesel type needs water cooling equipment which may break down if frozen or when water shortages occur. Furthermore, as the ventilation equipment is large in scope, we decided to install diesel power generation equipment to facilities of small or medium-capacity with maximum power demand of up to 750kVA. For the larger water facilities, we also decided to install gas turbine power generation equipment which can operate stably and have excellent load fluctuation resistance.

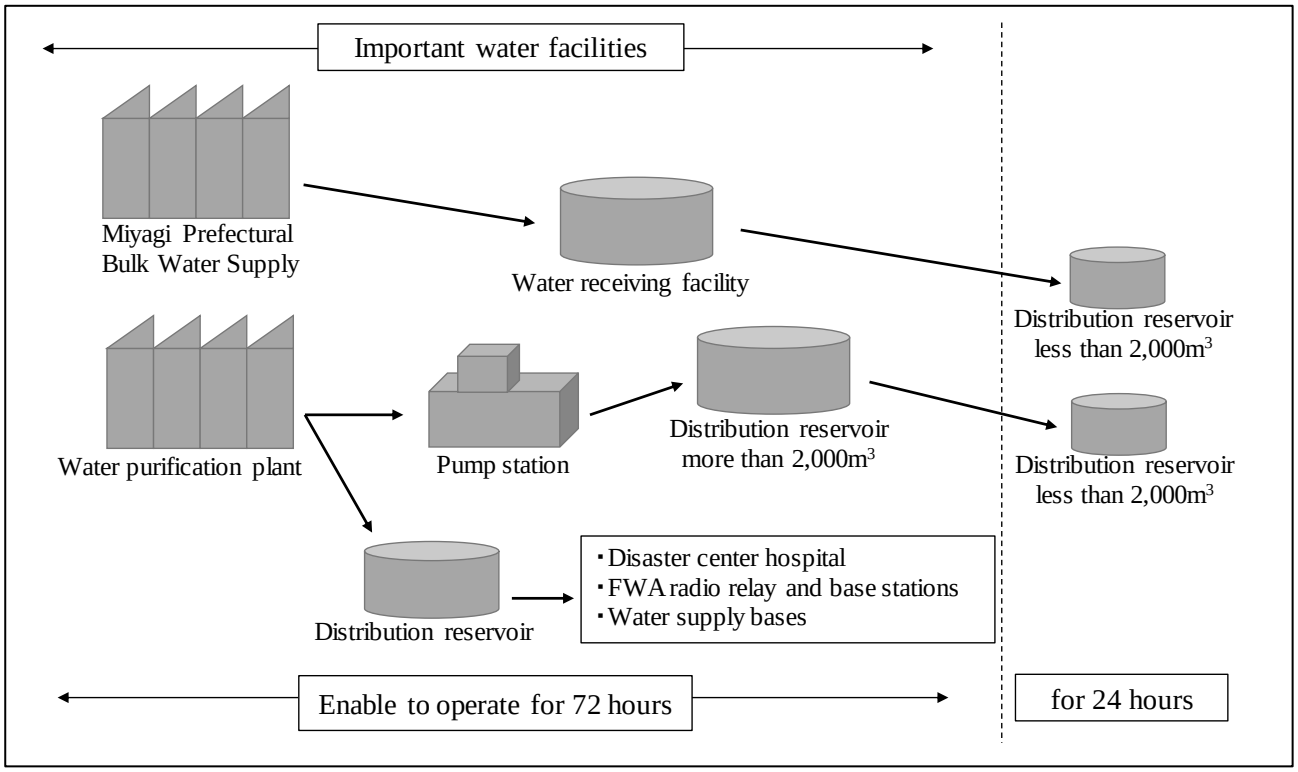

Figure 1. Overview operations for a blackout

Installation of Fuel Storage Facilities

If the capacity of the existing fuel storage does not meet operating time for a blackout, we increase the amount of fuel storage capacity. However, in the water facilities where replacement or extension of fuel storage facilities is difficult owing to lack of space for installation and inferior cost-effectiveness, we reconsider the load capacity and conduct examinations to improve efficiency for operation of emergency power generation equipment in the future.

Deployment of Fuel Supply Vehicle

There are some important water facilities which are required to have 72 hours of operation time during a blackout that have no pumps etc. with large load capacities, and have a fuel tank with less than 100-liters of capacity. In addition, for water facilities that do not correspond to important water facilities, we decided to install equipment as a countermeasure against a blackout of more than 24 hours. For these facilities, we deploy a Fuel Supply Vehicle which enables Waterworks Bureau staff to refuel during a disaster themselves, as replacement or extension of fuel storage facilities is not an economical countermeasure.

EXAMPLES OF THE CONSTRUCTION WORK AGAINST A LONG-TERM BLACKOUT

Sendai City Waterworks Bureau conducts various projects as a countermeasure against a long-term blackout. Among them, three examples which have been carried out after the GEJE are shown below. (The underlined parts are points of modification).

The Upgrade of Emergency Power Generation Facilities in Fukuoka Water Purification Plant

- Specifications of the existing facilities
  - Generator: Gas turbine generator
  - Oil type: Kerosene
  - Rated output: 625 kVA
  - Fuel consumption: approx. 350 L/ h
  - Fuel storage facilities: Underground tank 10,000L + Service tank 490L
  - Operation time: approx. 30 hours
- Specifications of the new facilities
  - Generator: Diesel generator
  - Oil type: Gas oil
  - Rated output: 625 kVA
  - Fuel consumption: approx. 139 L / h
  - Fuel storage facilities: Underground tank 10,000 L + Service tank 950L
  - Operation time: Approximately 78 hours

Since Fukuoka water purification plant is one of the main water purification plant, we changed the gas turbine power generation equipment to diesel power generation equipment for more than 72 hours operation time. We also replaced the underground tank and service tank at the same time.

The Expansion Works of Underground Tank in Kunimi Water Purification Plant

- Specifications of the existing facilities
  - Generator: Gas turbine generator
  - Oil type: Kerosene
  - Rated output: 500 kVA
  - Fuel consumption: approx. 255 L / h
  - Fuel storage facilities: Underground tank 9,000L + Service tank 950L
  - Operation time: approx. 39 hours
- Specifications of the new facilities
  - Generator: Gas turbine generator
  - Oil type: Kerosene
  - Rated output: 500 kVA
  - Fuel consumption: approx. 255 L/ h
  - Fuel storage facilities: Underground tank (9,000L + 10,000L) + Service tank 950L
  - Operation time: approx. 78 hours

Also, Kunimi water purification plant is one of the main water purification plant, we installed an additional 10,000 liter underground tank for more than 72 hours of operation time.

Figure 2. The expansion works in Kunimi Water Purification Plant

The Upgrade of Emergency Power Generation Equipment in Tsunakizaka Water Supply Pump Station

- Specifications of the existing equipment
  - Generator: Gas turbine generator
  - Oil type: Kerosene
  - Rated power: 875 kVA
  - Fuel consumption: approx. 439 L / h
  - Fuel storage facilities: underground tank 13,000L + service tank 950L
  - Operation time: approx. 32 hours
- Specifications of the new facilities
  - Generator: Diesel generator
  - Oil type: Gas oil
  - Rated output: 875 kVA
  - Fuel consumption: approx. 190 L / h
  - Operation time: approx. 73 hours

As the Tsunakisaka water supply pump station sends water to a distribution reservoir with a 10,000m^3 capacity, therefore it classed as an important facility and requires installation of equipment as a countermeasure against a blackout more than 72 hours. As the rated output of the existing generator is 875kVA, we should install gas turbine power generation equipment and increase the fuel storage capacity if we stick to our policy. However, since the requisite capacity of an additional tank is 18,000 liters, we judged that it is not possible to increase the amount of fuel storage capacity because of insufficient installation space. Therefore, we decided to replace with diesel power generation equipment and change the oil type of the existing tank.

Figure 3. The upgrade construction in Tsunakizaka Water Supply Pump Station

OPERATION METHOD OF FUEL SUPPLY VEHICLE

Summary of Fuel Supply Vehicle

The Sendai City Waterworks Bureau deployed one Fuel Supply Vehicle in 2015. The Fuel Supply Vehicle is a 2-ton vehicle which runs on diesel fuel, and is mounted with a 950 liter diesel fuel tank.

The Fuel Supply Vehicle can be operated under a general driver license and without a hazardous materials officer's license in Japan. The implementation of the Fuel Supply Vehicles enabled Waterworks Bureau staff to transport and refuel a large amount of fuel themselves.

We refuel the Fuel Supply Vehicle at a gas station or from the service tank of an important facility having an underground tank using an oil feeding pump. Since the oil feeding pump is battery-driven, we can refuel even during a blackout.

Fuel Supply Training

In order to perform swift refueling in times of disaster, Sendai City Waterworks Bureau carries out fuel supply training using the Fuel Supply Vehicle once every half a year. In fuel supply training, training participants go around important water facilities subject to refueling by the Fuel Supply Vehicle when a long-term blackout occurs. Training is performed by Waterworks Bureau staff members that belong to sections responsible for patrols, and emergency restoration of pump stations and distribution facilities in the time of disasters. Through the training, we learn how to drive and operate the Fuel Supply Vehicle.

Figure 4. Fuel Supply Vehicle


Figure 5. Fuel Supply Training

COOPERATIVE FRAMEWORK FOR FUEL SUPPLY

Cooperative Framework with Gas Stations

At the time of the GEJE, we were able to respond to a disaster efficiently thanks to borrowing a Fuel Supply Vehicle, which we didn't possess at the time, and receiving priority when refueling at gas stations. Based on this experience, Sendai City Waterworks Bureau reached an agreement on a "Request for cooperation in providing information and refueling at the time of disaster" with five gas stations nearby mainly water purification plant on March 2014. According to the document, we requested to the cooperation of fuel supply at the time of disaster.

Cooperative Framework with Other Cities

Sendai City Waterworks Bureau has concluded the "Memorandum of Understandings on Mutual Disaster Support" with Niigata City Waterworks Bureau, as there is a low possibility of an earthquake occurrence in both cities at the same time. In this Memorandum, the support city has the role of planning an emergency water supply, early restoration of water services and supplies fuels.

In addition, when support is requested due to a disaster hitting another municipality, we dispatch the Fuel Supply Vehicle for refuel Water Tank Trucks and heavy machinery for emergency restoration, and so on.

CONCLUSION

This paper introduced the construction works and cooperative framework as countermeasures against a long-term blackout in Sendai City Waterworks Bureau passed through the GEJE.

In the future, Sendai City Waterworks Bureau will continue replacing gas turbine type with diesel type, expanding fuel storage capacity, and training for fuel supply using the Fuel Supply Vehicle to ensure 72 hours operation time in important water facilities and 24 hours operation time in other facilities at the time of long-term blackout. In addition, we will continue to reinforce cooperation through agreements with other cities to stably secure fuel.

Furthermore, we will examine issues such as fuel quality control as an increase the amount of fuel stored and measures to improve fuel consumption by intermittent operation of emergency power generation equipment linked to execution and suspension of pump and so on.

Through the activities described above, we aim to construct a disaster-resilient waterworks system for continuous a supply of "water of life" to citizens.