Damage of water works facilities caused by the Great East Japan Earthquake and future problems for reconstruction in Otsuchi Town

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INTRODUCTION

The Great East Japan Earthquake caused a major disaster due to the tsunami and aftershocks, which were associated with the Tohoku Earthquake off the Pacific coast that occurred on March 11, 2011. The hypocenter of the Sanriku Coast on the Pacific Ocean was one of the largest observed in Japan with a magnitude of 9.0. Table 1 overviews the earthquake. Figure 1 shows Epicenter Map in the Off-Sanriku Region. The tsunami resulting from this earthquake caused major damage. In addition, liquefaction, ground subsidence, and collapse of buildings resulted in severe damage. According to the summary of damages[1)], the death toll (human damage) was 15,892 and 2,573 were missing as of August 10, 2015, but the numbers are still rising even four years later. This paper discusses the damage to water works facilities, current reconstruction efforts, and the future challenges in Otsuchi Town.

Table 1 Overview of the 2011 Tohoku Earthquake off the Pacific Coast

Description	The 2011 Tohoku Earthquake
Date and time	March 11, 2011, 14:46:18.1
Coordinate and depth	North latitude 38°06.2’ East longitude 142°51.6’ 24 km
Magnitude	9.0 (moment magnitude) (the largest observed in Japan)

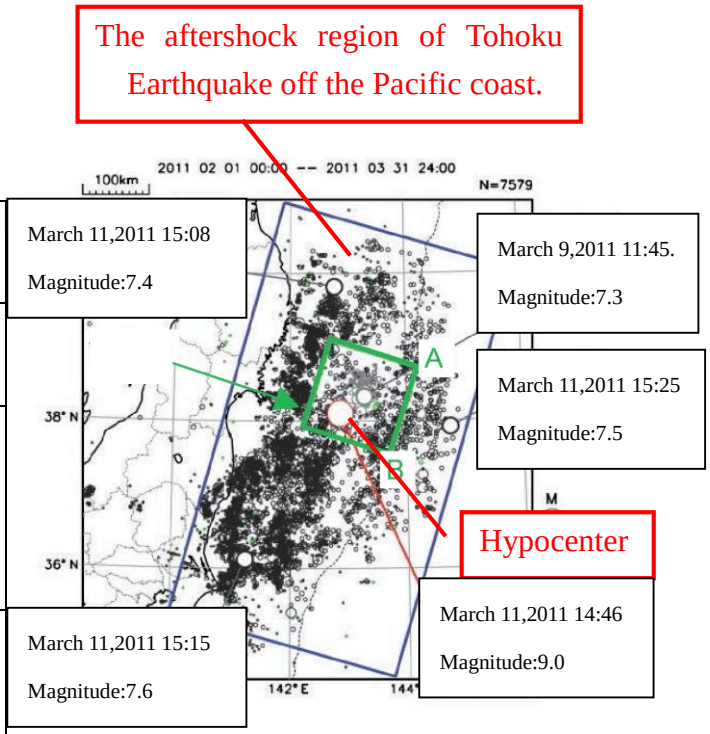

Figure 1 Epicenter Map in the Off-Sanriku Region[2)]

DAMAGE BY THE DISASTER

Damage in Otsuchi Town

Otsuchi Town in the Iwate Prefecture, which is located north of Kamaishi City on the Pacific Ocean, was one of afflicted areas by the Great East Japan Earthquake (Figure 2). Prior to the earthquake, it had a population of 15,276. The local water utility served 13,961 residents and two small water utilities with a total average daily supply of 6,973 m^3 of water.

The Great East Japan Earthquake devastated coastal cities due to the associated tsunami, including a long-term disruption to the water supply. The majority of Otsuchi Town residents lived along the coast. The toll included 809 dead, 423 missing, (as of June 1, 2015)[4], and 4,167 houses destroyed (as of May 31, 2011). The earthquake itself caused little damage compared to the accompanying tsunami, which caused massive flooding that was responsible for most of the damage.

Table 2 overviews the seismic ground motion due to the 2011 Tohoku Earthquake measured at Kamaishi City[5]. (Note that the data from Kamaishi City is shown because the observation data from Otsuchi Town is not available.) Figure 3 shows photographs of the damage in Otsuchi Town.

Table 2 Overview of the seismic ground motion at Kamaishi City

Instrumental seismic	5.74
Maximum acceleration (gal)	741.56
Maximum velocity (kine)	29.09

(Measured on March 11, 2011 at 14:46)

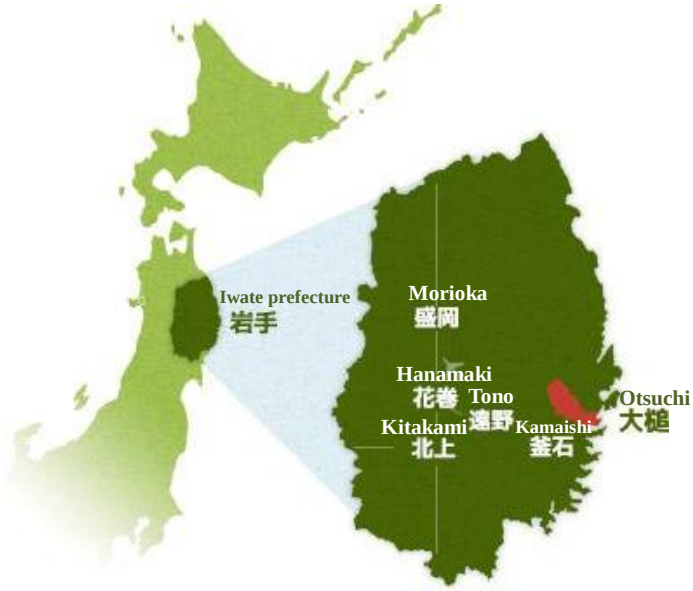

Figure 2 Location of OtsuchiTown[3].

Figure 3 Aerial view of the center of Otsuchi Town(left) before and (right) after The Great East Japan Earthquake.

Damage to the Water Works Facilities

Figure 4 shows damage to the water works facilities. Figure 5 shows damage to the main pipelines. The water works facilities in Otsuchi Town sustained the following damage:

- Household effect: 5,605 households experienced an interruption with their water supply[6)]
- Water purification plant: The tsunami hit the water source (well) for the Ogakuchi pumping station within the water purification plant, raising its water level. Although tsunami damage was not inflicted, if the water level had risen another 40 cm, the water purification plant would have been completely shut down. The non-utility generation facility was also spared damage. These facts made the water purification plant the center for water supply activities after the earthquake.
- Pumping station damage : Three booster pumping stations were completely shut down.
- Distribution pipes damage: 58 km of 107 km of water transmission (delivery) pipes were nonoperational.
- Population served: The number of people served by the water supply was reduced from 13,961 to 9,418. (Note that currently 9,676 residents are being served and the number is gradually increasing.)

Figure 4 Damage to (left) the water purification plant and (right) the Namiita pumping station .

Figure 5 Damage to the pipelines. (left) Broken main pipelines near the coast was washed away and (right) a damaged stop valve with water flowing out.

Emergency water supply

The emergency water supply activities for Otsuchi Town can be summarized as follows:

- Start date of emergency water supply: March 17, 2011
- Number of days that emergency water was supplied: 90
- Number of emergency water supply locations: 17, including a water utility plant as the main location
- Total number of water supply tank vehicles: 425
- Water supplied: 2,305 m^3
- Supplying agency: The emergency water supply was provided primarily by the 48 water utilities belonging to the Japan Water Works Association (43 utilities belonging to the Kansai branch and 5 utilities belonging to the Tohoku branch).

Because emergency water supply personnel could not find accommodations within Otsuchi Town, they were based in Morioka City, which is more than 100 km away, and commuted daily.

RECONSTRUCTION PLAN

Designing the Reconstruction Plan

Developing a reconstruction activity was a time-consuming endeavor due to the tsunami-induced damage to the booster pump stations and main pipelines. The Master Plan for Water Works Facilities Reconstruction was formulated in September 2012 using the guiding concept "to prepare for an unexpected disaster and develop sustainable water works facilities" in response to the experiences of the Tohoku Earthquake. Staff from the City of Kobe involved in the disaster and reconstruction activities after the Great Hanshin/Awaji Earthquake in 1995 helped draft the Master Plan. The initial plan has been modified twice to align the reconstruction of the water works facilities with the overall reconstruction plan for Otsuchi Town. Table 3 shows the overall reconstruction plan for Otsuchi Town.

Table 3 Overall reconstruction plan for Otsuchi Town

Item		Guiding principle
Tsunami damage prevention	Facilities	Build tsunami barriers, evacuation routes, and evacuation centers.
	Operation	Conduct disaster prevention education and strengthen disaster prevention system.
Land use		Basic principle is to move to higher ground. A maximum height of 20 m of soil is to be laid on areas that were hit by the tsunami in 2011.
Transportation system		Secure alternate routes if major roads are damaged.

Initial Plan

(1) Fundamental Concept in Building Water Works Facilities in Otsuchi Town

- Main pipelines are not to be built in designated flood-prone areas in the new tsunami barrier plan.
- Elevated water reservoirs and existing pumping stations are to be eliminated in tsunami-inundated areas. A gravity flow system that does not rely on an electrical power supply is to be used.
- An emergency water supply is to be secured by providing non-utility generation facility, emergency stop valves, earthquake-proofing pipes connecting to schools, etc.

(2) Examples of the Initial Plans

i. Move important water works facilities out of designated flood-prone areas or consolidate and discontinue these facilities.

- Example (Figure 7 A): Three afflicted pumping stations will be decommissioned to reduce the operating budget and maintenance costs. New reservoirs are to be built on elevated grounds.

ii. Build a system that will maintain its water supply capability even against a giant tsunami

- Example (Figure 7 B): Construction of main pipelines systems along National Route 45, Prefectural Route Kirikiri Kamaishi, and Town Route Kirikiri Namiita.

Although water supply pipes are not typically built along National Routes and other major roads, this Master Plan, which was devised in close cooperation with the authorities for national and other routes, enables main pipelines to be built alongside major roads (National Routes) outside flood-prone areas. As seen in this example, this Master Plan follows an unconventional and rational approach to prepare for disasters.

iii. Eliminate areas where water pressure is insufficient or water cannot be supplied due to the way water supply lines and facilities are built in high-altitude areas where people have relocated.

iv. Build emergency water supply centers.

- Example (Figure 7 C): Schools for grades 1 to 9, Ando pumping station, Akahama new r eservoir, etc.

Revised Plan

The estimated budget for the water works facility reconstruction (the amount from the design consultation in fiscal year 2013) was 3,012,000,000 yen. A 2013 review revised the reconstruction plan for the water works facilities to align the plan with the overall reconstruction plan for all of Otsuchi. The current plan is to be completed in 2018. Table 4 shows the changes to the reconstruction plan.

Table 4 Changes to the reconstruction plan

	Changes to the plan for Otsuchi Town	Changes to the plan for the water utility
(i)	Set up efficient and strategic management and operation of facilities and infrastructure considering future maintainability to realize a sustainable and compact community. The altitude of elevated land is also to be reviewed.	Terminate the plan to build reservoirs in elevated areas, and alter the plan to distribute water from the water sources owned by the water utility.
(ii)	Build a disaster-proof community while considering the traditional ways of Otsuchi Town.	The water source for Otsuchi Town exists only in the Machikata district. Emergency preparedness is strengthened by constructing bypass pipes in the Kirikiri district and Namiita district to form a loop.

In formulating this plan, the residents' opinions were incorporated and the reconstruction plan for the water works facilities was reviewed in light of changes in the overall reconstruction plan for Otsuchi Town. Revisions include building looping water supply pipe systems instead of reservoirs on elevated land. This flexibility in the plan is one of the characteristics of the Otsuchi Town reconstruction projects.

Figure 6 shows designed cutaway drawing in Otsuchi town. Figure 7 shows the revised plan for the Otsuchi Town water supply system. There are two major changes:

i. Terminate the plan to build reservoirs on elevated land. Instead water is to be directly supplied from the existing water source (Figure 7 D)

ii. Construct bypass pipes in the Kirikiri District (Figure 7 E)

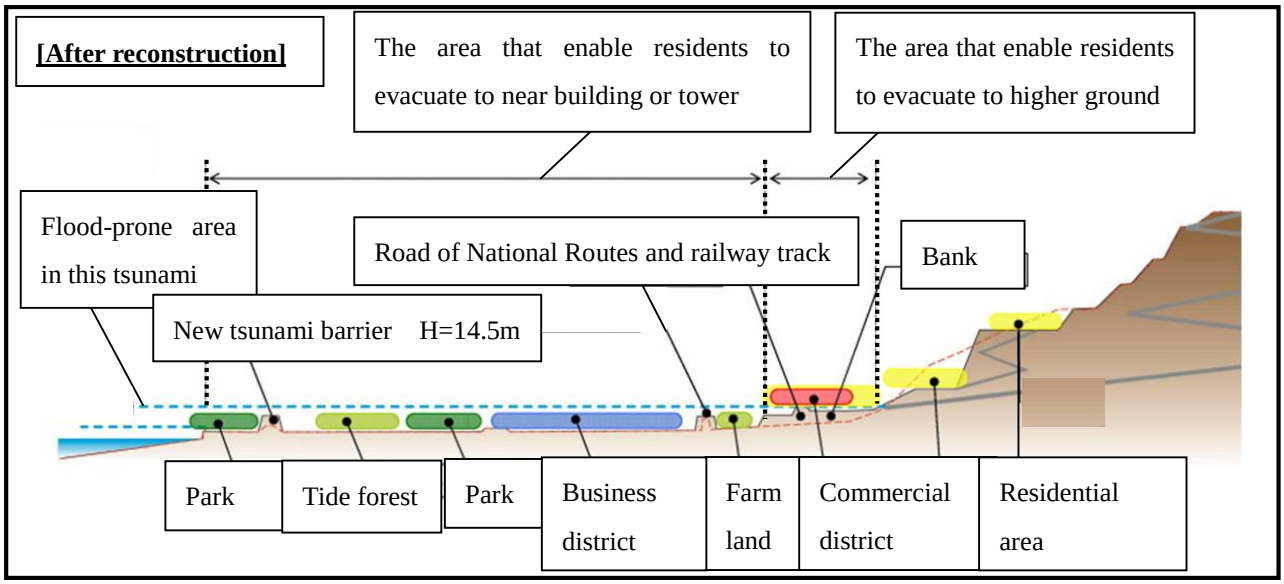

Figure 6 Designed cutaway drawing in Otsuchi town.

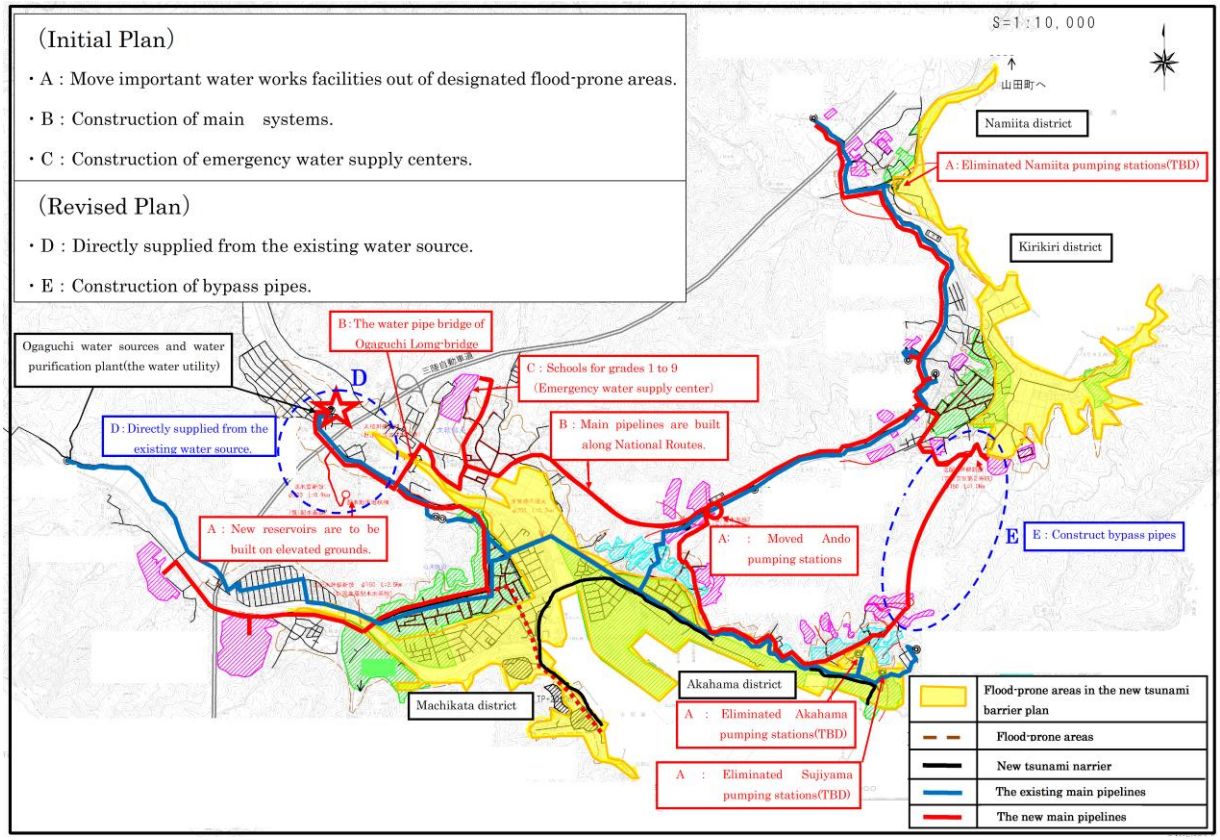

Figure 7 Revised plan for the Otsuchi Town water supply system.

CURRENT STATUS OF THE RECONSTRUCTION PROJECTS, CHALLENGES, AND COUNTERMEASURES

Current Status of the Reconstruction Projects

(1) Coordination with Other Construction Projects

Reconstruction projects are ongoing. The peak activity is in a three-year period from 2015 to 2017, in which many redevelopment and mass-relocation projects will commence. These activities must be coordinated with other reconstruction projects by national, prefectural, and municipal governments as well as those of the Japan Railway.

(2) Increased Activities after the Earthquake

- Field responses for the reconstruction projects (including CMR, meetings with contractors, and operation of valves)
- Changes to the overall plan for special evaluation, release of suspension, various applications, etc.
- Evaluation and inspection associated with the applications to construct water supply equipment

(3) Staffing

Various staffing issues have emerged. Table 5 shows the number of water utility staff. While the number of dispatched and temporary staff for the entire town has increased drastically after the earthquake, only one full-time engineer has been added to the staff. Due to this shortage of engineers, Otsuchi Town has been unable to assign its own staff to lead the water works facilities reconstruction projects. Additionally, only about one week of overlap is allocated between old and newly dispatched staff. The lack of a proper turnover results in newly dispatched staff members with insufficient knowledge of the activities under the previously dispatched staff.

Table 5 Number of water utility staff

	Number of staff (engineers)	Town employees	Temporary employees	Dispatched employees	Remarks Entire town
Before the Earthquake	7 (2)	7	0	0	136
After the Earthquake	9 (3)	5	2	2	276

Problems in the Reconstruction Projects

Otsuchi Town is facing three major problems:

(1) Shortage of staff

The number of staff members has increased by three after the earthquake by receiving dispatched staff members from other organizations, including the City of Sakai. However, there is a still a shortage of staffing in light of the amount of work to be done such as construction management for the reconstruction projects, coordination with other reconstruction projects, and coordination with CMR, etc.

(2) Building facilities

Vast financial and human resources are currently being spent on reconstruction projects of facilities. Consequently, updating and expanding the capacity of existing aging facilities (such as reservoirs and pipelines), earthquake proofing, and building of small water supply systems are currently left undone.

(3) Population decline

The decreasing population is a cause for concern over the reduction in the staffing level for the water utility as well as the decline in the service level. The declining population has resulted in a reduced demand for the water supply. In fact, the amount of water supplied in Otsuchi Town has decreased significantly since the earthquake.

Table 6 shows the forecasted water supply revenue in relation to the population decrease.

Table 6 Forecasted water supply revenue in relation to the population decline

	2009	2013	Percentage	Forecast for 2035
Registered population	16,171	12,673	78%	8,916
Households supplied water	5,969	4,549 Note	76%	3,436
Water supply revenue	231 million yen	160 million yen	69%	133 million yen
Large consumers	45	23	51%	No data

Note: The number of Households supplied in the year 2013 include accommodations for 150 reconstruction workers, volunteers, and dispatch staff members. After the reconstruction project is complete, this number is expected to be nil.

Other problems include:

- Operation of the water utility is becoming financially difficult due to the decreased revenue associated with the significant decline in demand for water as well as increased depreciation costs. Actually, average daily supply in Otsuchi town was decreased more than half in two years from 2011.
- The population may not recover according to the plan after the reconstruction projects are complete, further reducing the demand for water.
- The significant decrease in the demand for water may mean that the capacity of the water supply facilities will be too large in the future.

Challenges to problems

This section describes the responses to the three problems.

(1) Shortage of staff

- Accelerate hiring and promotion of staff members, including dispatched workers from the private sector.
- Provide a sufficient turnover between old and new staff members.

(2) Building of facilities

- Selectively choose projects other than reconstruction projects. Implement higher priority projects first and update existing facilities in order to utilize limited financial resources.
- Future projects should be leveling and facilities built for a long operational life to reduce human and financial resources.

(3) Population decline

- Try to bring in and retain large consumers such as marine product processors.
- Incorporate downsizing into future facility updates to reduce cost and improve efficiency.
- To overcome potential financial difficulties with the water supply operations due to the population decline, implement a water rate increase.

CONCLUSIONS

(1) Lessons Learned

- The impact of Great East Japan Earthquake was greater than anticipated, and Otsuchi Town was not properly prepared. To minimize damage, the worst-case scenario must be considered when planning facilities and operations.
- A rational and robust reconstruction plan was drawn against future disasters due to the support and guidance from people with disaster relief experience.
- It is important to review reconstruction plans in coordination with residents' opinions and overall plans.

(2) Remaining Challenges

- Full-fledged recovery of the water supply facilities is lagging compared to the restoration of other earthquake damage due to the delay in developing an overall reconstruction plan for the entire town. Early planning of basic reconstruction principles is desirable in response to a major disaster.
- While the entire nation is experiencing a low birth rate and aging of its population, the population decline may be further accelerated due to a disaster in regions like Otsuchi Town where the total population is small, exacerbating the population decline issue. Hence, after the reconstruction projects are complete, securing human and financial resources will be difficult.

ACKNOWLEDGMENTS

We appreciate the staff who works in water supply utility in Otsuchi town for providing significant information.

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