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Mutual waterworks support system based on Japanese earthquake disaster experience

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Abstract

Japan is one of the most earthquake-prone countries in the world, as well as experiencing other natural disasters arising from its geography, physiography and weather. The country has frequently experienced major disasters and it has been pointed out that it could be struck by large-scale earthquakes in the future, in areas such as the Nankai trough and Chishima trenches, and directly below Tokyo. Against this backdrop, the Japan Water Works Association (JWWA) has used its organizational strength to develop a mutual support system for recovery from disasters. In this paper the mutual support system's mechanism is described with an explanation of how JWWA developed it through its activities in recent disasters like the Great East Japan and Kumamoto earthquakes, in 2011 and 2016 respectively.

Key words: disaster, disaster restoration, emergency recovery, emergency water supply, mutual support system, resilient water supply system

INTRODUCTION

Japan is one of the most earthquake-prone countries in the world. It is also exposed to other types of natural disaster including typhoons, heavy rain, and cold waves due to its geographical, physiographical and meteorological conditions. Major disasters are common and include the Great East Japan Earthquake in 2011 with a magnitude of 9.0, the greatest recorded in Japan. Together with the associated large tsunami, it caused thousands of casualties and severe structural damage across a vast area. It has been pointed out that Japan could be struck by large-scale earthquakes in the future, in areas such as the Nankai trough and Chishima trenches, and directly below Tokyo. According to simulations carried out by Japan's national government, the Nankai trough megathrust earthquake – M8 class earthquake and large tsunamis exceeding 20 m – could cause up to 323,000 deaths. The maximum possible economic loss would be approximately 170 trillion yen for assets and 45 trillion yen for production and service degradation (Cabinet Office Government of Japan 2018).

Against this backdrop, the Japan Water Works Association (JWWA), the largest water-related organization in Japan, has developed a mutual support system for disaster recovery using its organizational strengths. During recent major earthquakes, JWWA has provided support including emergency water supplies and water supply system restoration, and made significant contributions to the rapid supply of drinking water in disaster areas and the recovery of facilities (Table 1).

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Table 1 | Damage and responses to recent major earthquakes

	Casualties and buildings damaged	Major damage to water supply	JWWA support
Great Hanshin Earthquake January 17, 1995 M7.3, Max. seismic intensity scale[a] of 7	1. Casualties Deaths: 6,434 Injuries: 43,792 2. Buildings damaged Complete collapse: 104,906 Half collapse: 144,274 Partial collapse: 390,506	1. Water suspended: Approx. 1,266,000 households (in 17 cities and towns) Maximum period of water suspension: Approx. 3 months 2. Pipe damage: Distribution pipe repairs: 2,283 Feeder pipe repairs: 89,584	Number of supporting water utilities Water supply: 156 Restoration: 43 Total number of water trucks: 14,073 Total number of support staff: 41,486 Activity period: 39 days
Chuuetsu Earthquake October 23, 2004 M6.8, Max. seismic intensity scale of 7	1. Casualties Deaths: 68 Injuries: 4,795 2. Buildings damaged Complete collapse: 3,175 Half collapse: 13,810 Partial collapse: 104,510	1. Water suspended: Approx. 130,000 households (in 40 cities, towns, and villages) Maximum period of water suspension: Approx. 1 month 2. Pipe damage: Distribution/feeder pipe repairs: 486	Number of supporting water utilities Water supply/ restoration: 63 Total number of water trucks: 1,031 Total number of support staff: 2,270 Activity period: 39 days
Chuuetsu Offshore Earthquake July 16, 2007 M6.8, Max. seismic intensity scale of 6-upper	1. Casualties Deaths: 15 Injuries: 2,345 2. Buildings damaged Complete collapse: 1,319 Half collapse: 5,621 Partial collapse: 35,070	1. Water suspended: Approx. 60,000 households (in 4 cities and villages) Maximum period of water suspension: 20 days 2. Pipe damage: Distribution/feeder pipe repairs: 736	Number of supporting water utilities Water supply/ restoration: 112 Total number of water trucks: 3,751 Total number of support staff: 6,606 Activity period: 20 days
Great East Japan Earthquake March 11, 2011 M9.0, Max. seismic intensity scale of 7	1. Casualties Deaths and missing: 22,199[b] 2. Buildings damaged Complete collapse: 121,781 Half collapse: 280,962 Partial collapse: 744,530	1. Water suspended: Approx. 2,570,000 households (in 19 prefectures) Maximum period of water suspension: Approx. 7 months 2. Pipe damage: Transport/distribution pipe repairs: 6,984 Feeder pipe repairs: 6,932	Number of supporting water utilities Water supply/ restoration: 562 Total number of water trucks: Approx. 13,800 Total number of support staff: Approx. 44,500 Activity period: 152 days
Kumamoto Earthquake April 14, 2017 M7.3, Max. seismic intensity scale of 7	1. Casualties Deaths: 267 Injuries: 2,804 2. Buildings damaged Complete collapse: 8,673 Half collapse: 34,726 Partial collapse: 162,479	1. Water suspended: Approx. 450,000 households (in 34 cities, towns, and villages) Maximum period of water suspension: Approx. 3.5 months 2. Pipe damage: Distribution pipe repairs: 1,071	Number of supporting water utilities Water supply: 100 Restoration: 93 Total number of water trucks: Approx. 1,650 Total number of support staff: Approx. 9,800 Activity period: 68 days

[a]Seismic intensity describes the scale of the ground's motion locally, and varies with distance from the epicenter and local geology. The scale has 10 degrees (0 [imperceptible], 1, 2, 3, 4, 5 lower, 5 upper, 6 lower, 6 upper, and 7). Seismic intensity is measured with an intensity meter, of which more than 4,300 have been installed around Japan.
[b]Including associated deaths and Injuries: 6,230.

MECHANISM OF MUTUAL SUPPORT FOR EARTHQUAKE EMERGENCY RESPONSE

Structure of JWWA

JWWA, a Public Interest Incorporated Association, was established in May 1932 with the aim of spreading modern water supply and the sound development of water supply technologies in Japan.

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As of March 2018, JWWA had 1,359 utility members, 362 individual members and 567 associate members (water related companies).

JWWA has seven regional and 51 prefectural branches (Figure 1), the secretariat being managed by the branch's lead-utility. JWWA members belong to local branches and get involved in branch activities. Each branch has regional characteristics and develops activities in close cooperation with JWWA Headquarters, such as information sharing, training courses and emergency response drills.

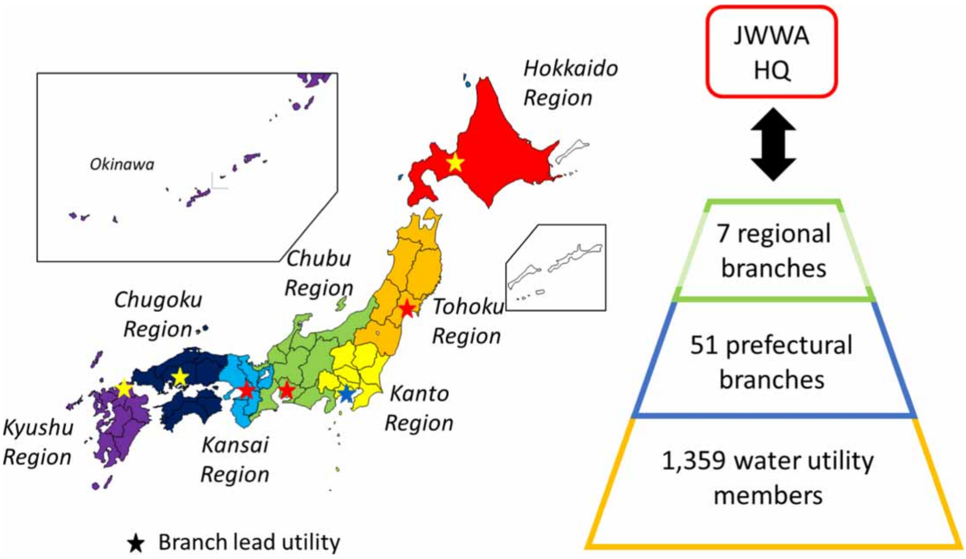

Figure 1 | Structure of JWWA.

Establishing rules for the mutual support system

Based on JWWA members' support activities following the Great Hanshin Earthquake in 1995, JWWA published the 'Report on Emergency Earthquake Response', to meet growing demand for the provision of specific mutual support procedures in emergencies. The report enabled smooth support activities, which were effective following the Chuuetsu Earthquake in Niigata in 2004 and its offshore counterpart in 2007.

However, the activities arising from the two Chuuetsu earthquakes highlighted some issues requiring attention. These included the need for cooperation with national and prefectural governments, the development of a flexible response system related to the magnitude of the damage, and a way to support small water utilities. Therefore, in order to enhance the support system, an 'Earthquake Emergency Response Manual' (the Manual) was created in December 2008. It was based on knowledge collected from stakeholders including members of water utilities, national and prefectural governments, and related organizations. A revised Manual was produced in March 2013 using lessons learned from the Great East Japan Earthquake (March 2011) and has been in full use since then.

JWWA HQ disaster response

If an earthquake with a seismic intensity exceeding '5-upper' occurs, and extensive support is thought necessary, JWWA establishes a Disaster Relief Headquarters (HQ) within 24 hours. HQ collects and shares damage information, and secures coordination between the disaster area and supporting water utilities.

If the earthquake intensity exceeds 6-upper, or if thought necessary by the director-general of HQ, an assistance team is sent to the disaster area. They collect the information necessary for early stage emergency water supply and recovery activities – e.g., areas and numbers of households without

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water, and the locations of hospitals, evacuation centers, etc., as well as damage to core water facilities – and provide liaison and coordination for support activities.

Water utility disaster responses

The water utilities affected contact their prefectural branch's lead-utility as quickly as possible, to report damage status and whether support is required. Neighboring water utilities, the prefectural lead-utility and regional branch prepare to provide support on the basis of the seismic intensity level so that information collection, etc., can start on demand (Table 2).

Table 2 | Relief system preparation states (JWWA 2013)

State	Established when	System
Precaution	There has been an earthquake of intensity '5-lower'	The water utility collects information on the disaster status and contacts utilities in the disaster area.
Warning	There has been an earthquake of intensity '5-upper'	In addition to collecting information and making contacts, staff of neighboring water utility and prefectural lead-utility are ready to be sent to the disaster area, if requested by the water utilities.
Emergency	An earthquake of intensity '6-lower' or above has occurred.	In addition to the above, staff are ready for immediate dispatch, if requested by the water utilities.

Figure 2 shows the full procedure from a request for support to dispatching staff. Depending on the amount of damage and the extent of the support request, the JWWA's branch system plays the central role in establishing support.

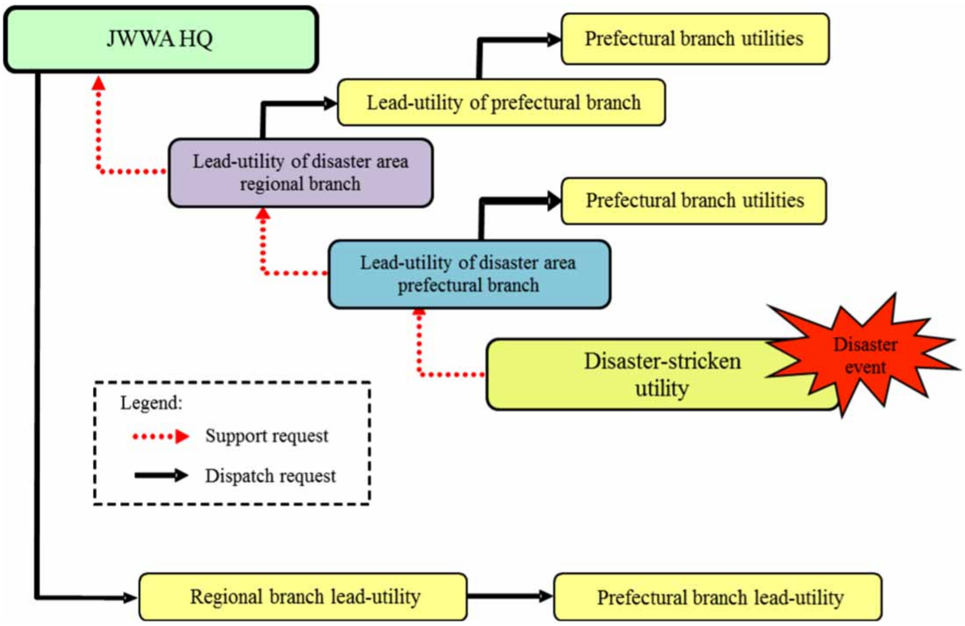

Figure 2 | Support Request Flow at JWWA (JWWA 2013).

After receiving a support request, the prefectural branch's lead-utility asks nearby water utilities to help. If the level of support available within the prefecture is insufficient, the lead-utility seeks support from the regional branch.

When massive damage has occurred that cannot be handled within the region, additional support is requested from other regional branches through HQ.

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Emergency water supply and restoration

For emergency water supply and facility restoration, a water supply headquarters is established within the water utility in the disaster area, using the standard model described in Figure 3. Support is provided by emergency water supply and restoration teams consisting of staff from supporting water utilities.

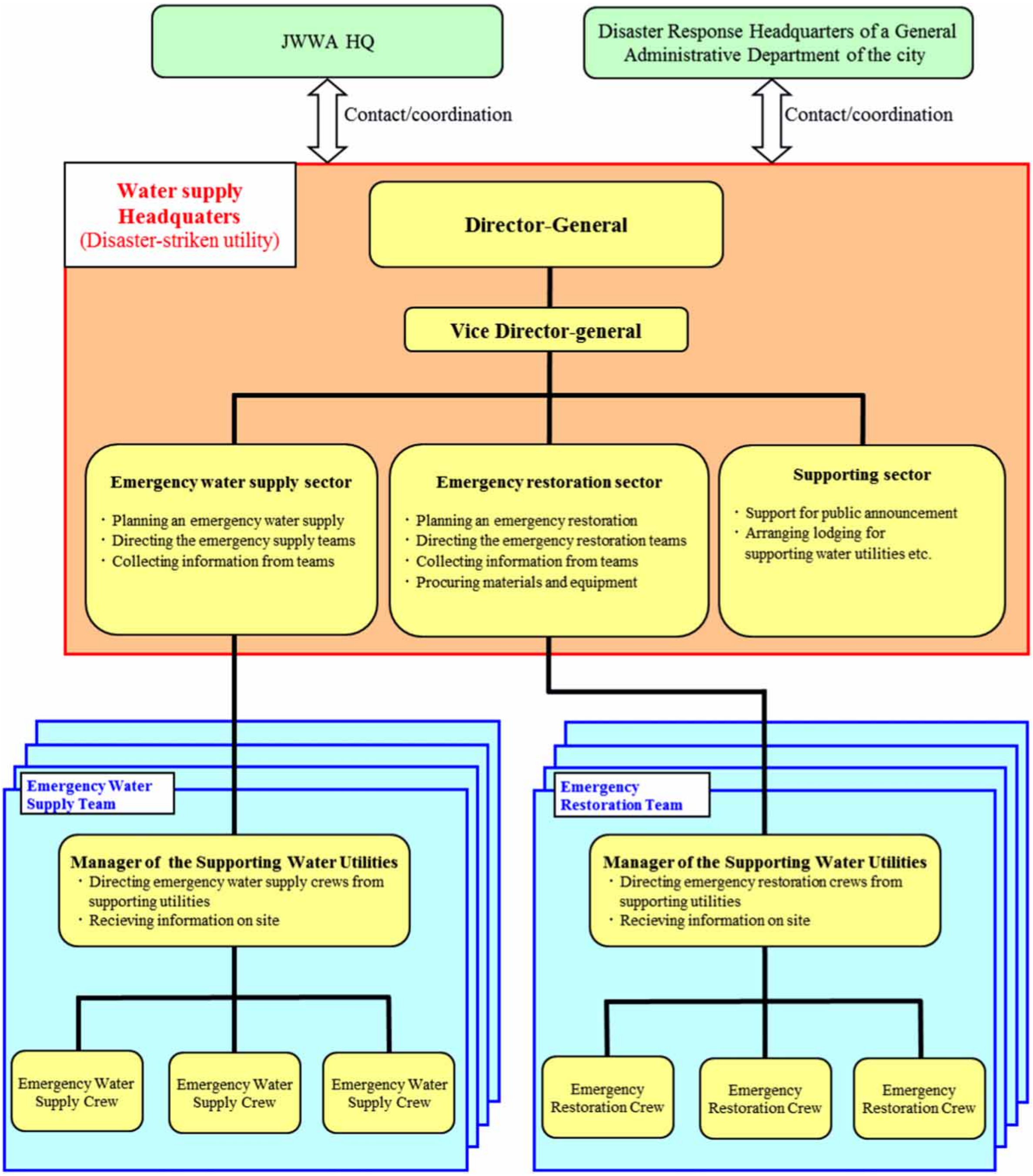

Figure 3 | Sample Configuration of Water Supply Headquarters (JWWA 2013).

For close liaison and coordination between the emergency teams and the water supply headquarters, one supporting water utility is assigned as manager. This 'managing' utility is of similar size to the disaster-stricken utility.

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RESPONSES AND LESSONS FROM RECENT MAJOR DISASTERS

Response to the great east Japan earthquake (2011)

Damage status

The Great East Japan Earthquake – magnitude 9.0 – on March 11, 2011, caused more than 19,000 casualties and 2,000 people are still missing in 2018 (FDMA 2018). The disaster combined earthquakes, a tsunami, and radioactive pollution, and affected a huge area, causing massive damage to infrastructure including water supply and sewerage systems, roads, electricity and gas lines. Water supplies were suspended to up to 2.57 million households served by 264 utilities in 19 prefectures.

Around 57% of the water supply was restored in a week and 90% by the end of March (approximately three weeks). In the most severely damaged area, however, supply suspension continued for much longer – up to seven months (Figure 4).

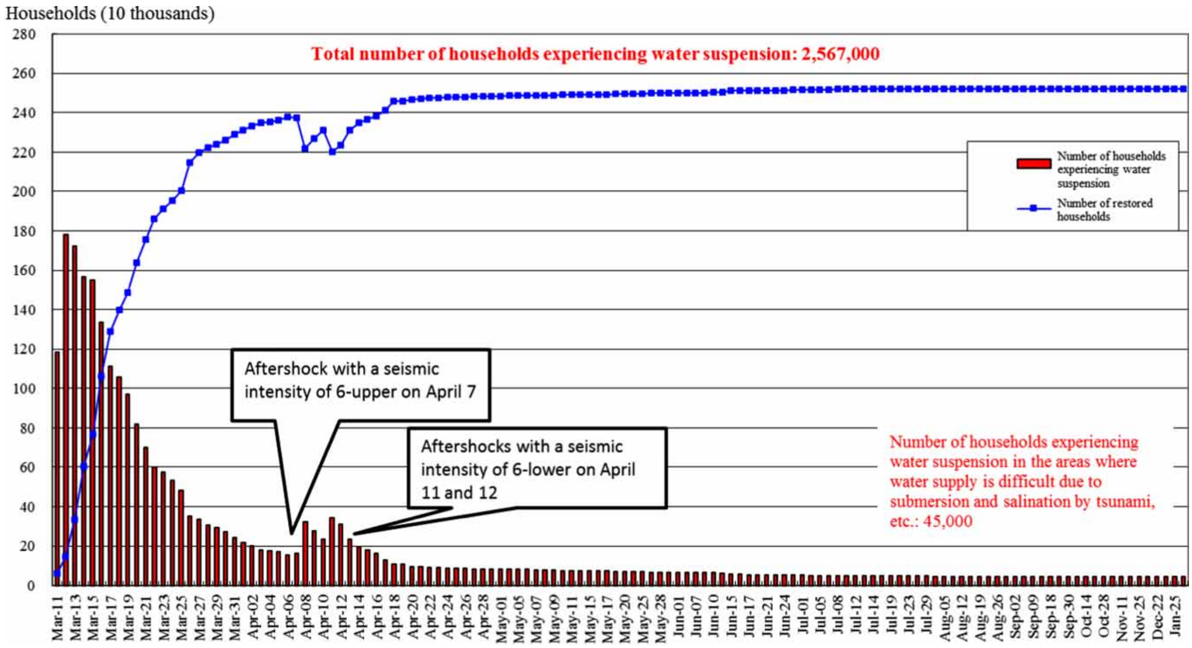

Figure 4 | Numbers of Households with Water Supplies Suspended and then Restored after the Great East Japan Earthquake (MHLW 2013).

The number of areas where water supplies were suspended also increased due to supply interruption from bulk water suppliers, and intake submersion and salinization by the tsunami, and radioactive contamination, all of which posed new challenges in disaster recovery.

JWWA support

Immediately after the Great East Japan Earthquake, JWWA established an 'earthquake' HQ and conducted support activities in liaison with its local branches and related organizations, including the Ministry of Health, Labor and Welfare. The HQ operated round the clock until 6 April (nearly one month). In total around 480 people worked there for 152 days until it was disbanded on August 10. While operating, HQ dispatched assistance teams to Iwate, Miyagi, and Fukushima prefectures, which suffered the worst damage, and around 210 staff members collected information and helped with coordination.

In relation to emergency water supplies, around 41,000 people from 552 water utilities nationwide were involved from immediately after the earthquake until HQ disbandment. At the peak,

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approximately 350 water trucks were dispatched to the disaster areas. Emergency restoration support involved 3,500 staff from public water utilities – i.e., excluding those from private companies.

The 552 water utilities involved comprise approximately 40% of the 1,348 utility members of JWWA (March 31, 2011). Of those involved in emergency water supply in the disaster area, 90% were JWWA members, and in emergency supply restoration 70%.

This shows clearly the benefit of mutual support.

Lessons learned

Recovery support activities over the very large area concerned exposed some challenges. For example, in the initial response stage, activities were chaotic because the coordination system was poor due to communication blackouts over wide areas, and there was massive damage in the cities where the lead-utility, which played the central role in the support system, is located. The very extensive damage caused by the tsunami, and the radioactivity issues lengthened support activities, making it increasingly difficult to maintain support standards.

As a result of the above, the 'Manual' rules were revised – e.g.:

a. **Measures for extension of the area and period of support**
   For the logistics of support utilities from distant locations, a 'relay water utility' was defined, to serve as a temporary destination when information on the disaster area is inadequate. It provides places for support vehicles to park and for support teams to rest.
   In addition, when long-term activities are unavoidable, a 'support base water utility' is defined, to provide water supply stations and places to stay.
b. **Measures for reducing early confusion**
   The effectiveness of communication using satellite telephones and email was recorded. Various types of contact forms were also defined for efficient information exchange, as confusion often occurs about information exchange in the initial support stages.
c. **Measures for conducting field operations efficiently and effectively**
   A 'Field Operation Manual' was created summarizing the specific operations to be conducted by staff of both the disaster-stricken water utilities and those utilities supporting them, in time sequence.

Responses to the Kumamoto Earthquakes (2016)

Damage status

The Kumamoto Earthquakes occurred on April 14, 2016 (foreshock, magnitude 6.5) and April 16 (main shock, magnitude 7.3). They caused more than 3,000 casualties, the total and half collapse of approximately 200,000 houses, and massive damage to infrastructure, including the water supply and sewerage systems (Cabinet Office Government of Japan 2018). Some 33 water utilities in seven prefectures suffered water supply suspension to around 446,000 households. The damage in and near Kumamoto City, the epicenter, was particularly severe.

The number of water supply suspensions peaked on April 16, the day of the main shock. In Kumamoto City, which has the largest population in the district, up to 326,000 households lost their water supplies. Abstraction from the Kengun Service Reservoir, the most important supply source, restarted on April 17 and the 800 mm service pipeline was restored on April 21. At the end of April (within approximately three weeks), around 93% of distribution was recovered (Figure 5).

JWWA support

JWWA established an earthquake HQ immediately after the foreshock on April 14, and began support activities.

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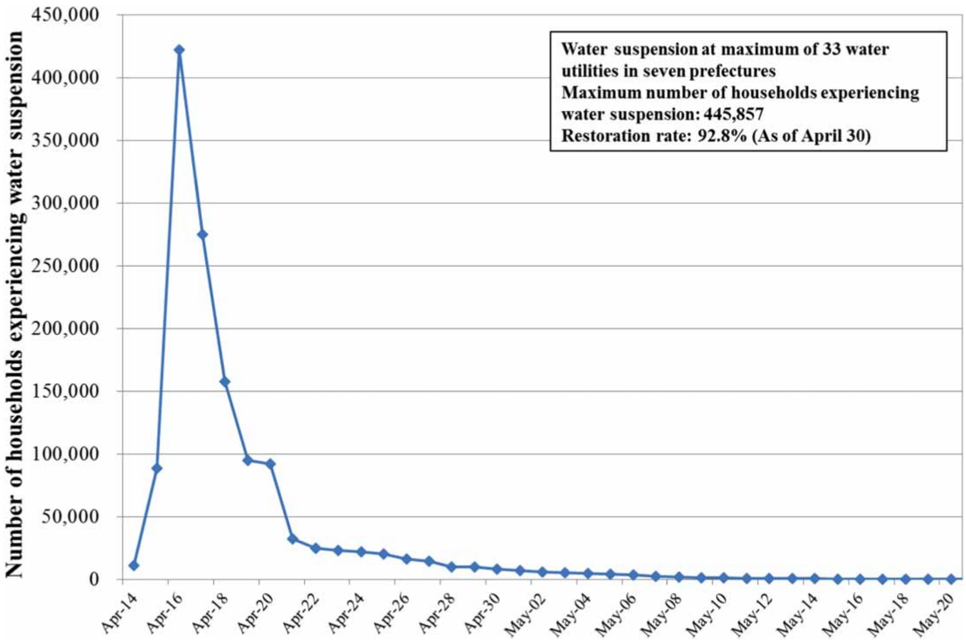

Figure 5 | Number of households suffering water supply suspension because of the Kumamoto Earthquakes (MHLW 2018).

The HQ operated round the clock until April 22 (one week). A total of around 110 people worked there for 30 days, until its disbandment on May 13. (The Kyushu Regional Branch continued to provide support until June 21.)

Assistance teams were also dispatched to the lead-utility of the disaster stricken regional and prefectural branch, Fukuoka and Kumamoto city. About 90 staff from the HQ collected information and helped with local coordination.

Emergency water supply activities involved about 6,100 utility staff from members of JWWA – 100 water utilities – in cooperation with several regional branches. At the peak, up to 96 water trucks operated in the disaster areas. In emergency restoration, around 3,700 water utility staff (excluding a number from private companies) from all seven local branches were involved.

Lessons learned

Several major lessons were learned.

a. Importance of promoting earthquake-proofing of waterworks

Kumamoto City depends entirely on groundwater sources. After the earthquakes, high turbidity was observed in all 96 wells, and the entire water supply was suspended temporarily. As the city had been actively promoting earthquake-proofing of their facilities – 72.4% of trunk mains had been earthquake-proofed by March 2016 – the damage to water supply facilities was relatively minor considering the scale of the earthquakes. Had similar earthquakes occurred in a city with low levels of earthquake-proofing, the damage would have been more serious and it would have taken longer to recover.

Once again the importance of earthquake-proofing was demonstrated.

b. Importance of the system for receiving support

Since the damaged area was limited, Kumamoto City and neighboring cities were crowded with support staff, making it difficult to arrange places for logging, secure storage, parking, etc. This showed that early establishment of a support receipt system in the disaster area is extremely important for smooth operation.

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JWWA compiled the 'Emergency Earthquake Response Special Research Committee – Emergency System Investigation Subcommittee Report' in February 2017 and encouraged all water utilities to prepare support receipt plans, as well as presenting them with items to be considered for inclusion (JWWA 2017a).

c. **Response by small water utilities**

Small water utilities near the epicenter had difficulty establishing an emergency response system due to lack of specialized staff and local private water-related companies, and documents that were not available – e.g., supply network maps.

To cope with this, it is important to promote the preparation of basic documents including facility layout plans, network and emergency water supply station maps, to create a disaster response manual, and train daily staff.

CONCLUDING REMARKS

Water supply coverage is 97.9% in Japan, and high water quality levels are maintained. Most water supply facilities, however, were built in the period of high economic growth in the 1960s and 1970s, and many are aging. People also want water utilities to strengthen disaster measures. To mitigate damage to facilities and minimize the effects on peoples' lives, water utilities across Japan are earthquake-proofing their main facilities. (In March 2017, the earthquake-proof rates for trunk water mains was 38.7%, water treatment plants 27.9%, and service reservoirs 53.3% (JWWA 2017b).)

In addition to 'hard' measures for physical infrastructure, including restructuring aging facilities and earthquake-proofing, it is important to enhance 'soft' measures. This includes strengthening coordination among stakeholders like water utilities, private companies, and government organizations. The total Japanese water utility workforce has decreased by 30% since 1990. Small- and medium-sized water utilities that serve populations of fewer than 50,000 people, account for around 70% of the total and have fewer than 11 staff on average. These utilities have difficulty responding to disasters by themselves and JWWA's mutual support system is especially effective for them.

Based on the Manual, JWWA conducted nationwide emergency response drills (communication, dispatching water trucks to designated places, emergency water supply and restoration exercises, etc.) for the first time in 2018, to strengthen the mutual support system.

Further promotion of disaster prevention and mitigation measures from both the 'soft' and 'hard' viewpoints, is expected to reinforce the resilience of water supply systems and secure the sustainability of water utilities.

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