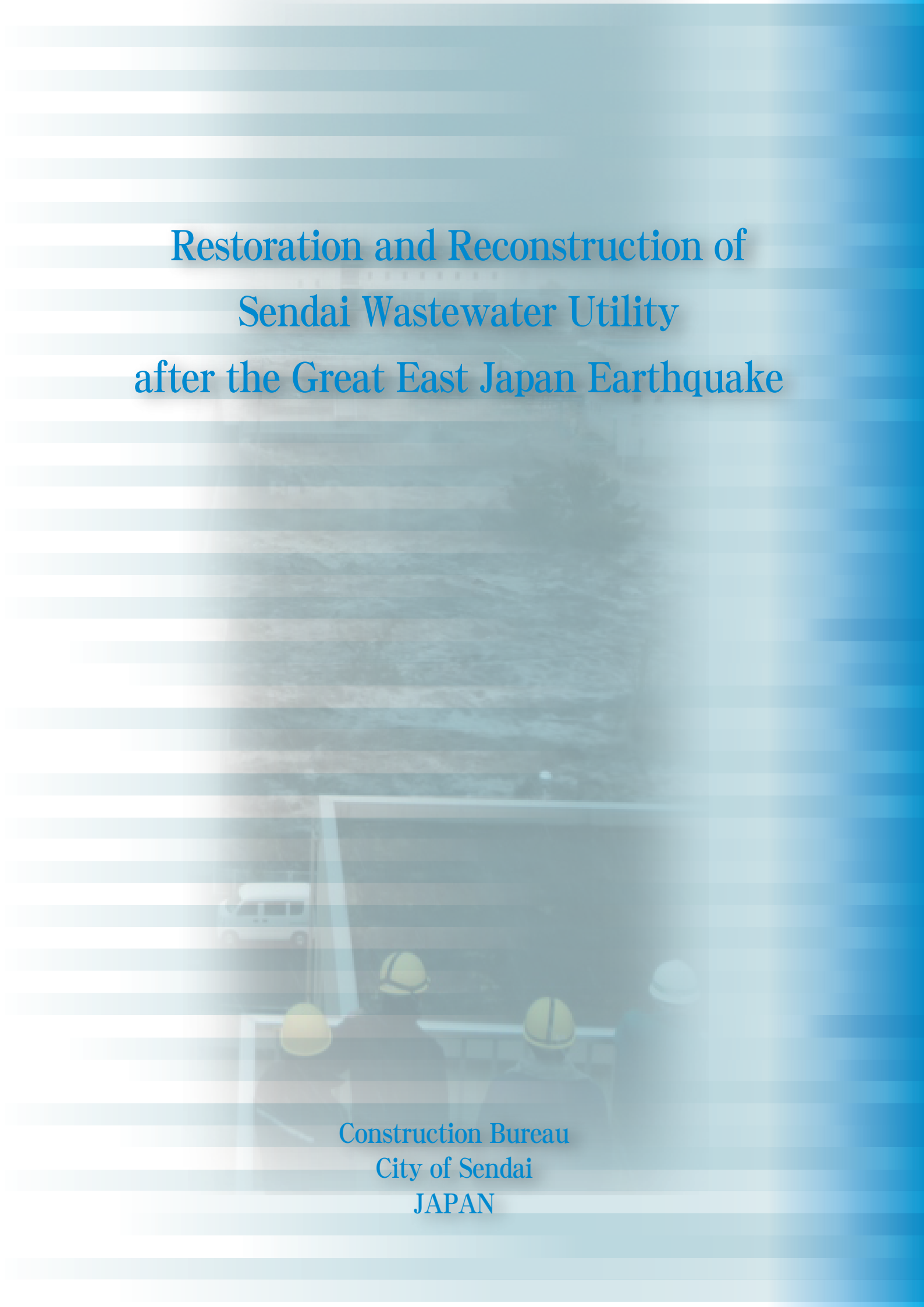
Restoration and Reconstruction of Sendai Wastewater Utility after the Great East Japan Earthquake



Construction Bureau
City of Sendai
JAPAN

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Greetings

The March 11, 2011 Great East Japan Earthquake and ensuing tsunami left an unprecedented amount of damage in the Pacific coastal area of Japan.

In Sendai City, the earthquake and tsunami seriously affected citizen's lives. Almost all essential utilities in the city were disrupted, and the traffic network, including roads and railroads, was broken. Energy, including gasoline, and daily commodities were in short supply.

In terms of the sewage works, the earthquake and tsunami have caused damage to sewerage facilities in the whole city. In particular, Minami-Gamo Wastewater Treatment Plant, which had been treating roughly 70% of the city's wastewater, was devastated by the over 10-meter tsunami. As a result, there were concerns about wastewater overflow in the urban area, but thanks to the construction of the sewer pipe which enabled treated sewage to flow naturally to the sea even during the power outage, citizen's cooperation in conserving water, and emergency operations by dedicated subcontractors and city workers, sanitary conditions were maintained.

When construction began on Sendai's sewage works in 1899, it was only the third sewer system in the nation. Since then, construction has continued over its long history of over 110 years. The fact that we were able to maintain sanitary conditions and the basic operations of the sewer system during this disaster, which was the biggest crisis in the history of the sewer system, is a testament to the work of our predecessors. I have a heartfelt respect for them.

We are deeply committed to the restoration of our sewage works based on the Sendai Wastewater Utility Earthquake Disaster Reconstruction Promotion Plan drawn up in March 2012. Full recovery will require tremendous amounts of time and money, but we will make use of the national relief system for disaster recovery and the national government grant for reconstruction. In addition to restoring the system to its previous state, we will implement projects with the utmost concern for disaster prevention and the environment, aiming to become a "disaster-resistant and environmentally-friendly city of a new level."

More specifically, we are constructing a third Minami-Gamo Trunk Sewer to reduce the risk of wastewater overflow in the city. Also, based on the recommendation of the Panel on the Reconstruction Policy of Minami-Gamo Wastewater Treatment Plant, we are reconstructing the plant with solar and other renewable energy systems and tsunami countermeasures. We intend to promote these projects in order to become a model of earthquake and tsunami countermeasures for both domestic and overseas sewerage facilities.

This report documents conditions after the Great East Japan Earthquake and our recovery and reconstruction efforts. I hope it will be helpful for disaster responses in the future, and I offer my deepest thanks to all who have supported our city.

March 2013

Emiko Okuyama
Managing Director, Sendai Wastewater Utility
(Mayor of Sendai)

Infographic Topping

– Recovering Situation of the Sewerage Facilities in Sendai after the Disaster –

Minami-Gamo Wastewater Treatment Plant

Panoramic view (before the disaster)

Panoramic view (after the disaster)

Before the disaster

The moment hit by the tsunami

Wall surface of the blower room

Inside of the blower room

The Nishihara Rainwater Pumping Station

Agricutural Wastewater Facilities（The Sanbonzuka Clean Center）

Septic Tanks（surfaced or upset by liquefaction）

Fukuoka, Izumi

Imozawa, Aoba

1. Outline of Sendai Wastewater Utility

In 1891, Sendai began the precise survey necessary to create a sewage works plan, and in 1899 began construction on the third sewer system in the nation (after Tokyo and Osaka). At that time, due to the discharge of untreated domestic wastewater into rivers and irrigation ditches, the rapid urbanization of the surrounding areas was polluting the rivers, and the drainage conditions in areas without sewer systems were worsening by the year. For this reason, in 1957 a 20-year sewage works plan covering 3,900 hectares was developed. The discharge of untreated wastewater into rivers and irrigation ditches was ended, and wastewater was collected and treated at Minami-Gamo Wastewater Treatment Plant.

In 1972 the plan was revised to include an area of 8,419 hectares and upgrade the treatment plant. Subsequent revisions and mergers with neighboring municipalities have brought the current area to 18,437 hectares. We are working towards the goal of flush toilets in every house in Sendai, and after reconsidering the division between centralized and decentralized treatment from the standpoint of optimization, in 2004 the combined septic tank operations were transferred from the Environmental Bureau.

The Construction Bureau now operates all sewage treatment projects, and the coverage rate of sewage treatment facilities is 99.5%. Moreover, based on our city's ordinance that prioritizes the natural environment (Ordinance for the Protection of the Clear Waters of the Hirose River), the Hirosegawa Wastewater Treatment Plant established an effluent quality standard of BOD 3mg/l and has adopted advanced sewage treatment.

Miyagi Prefecture also experiences frequent earthquakes. In 1978 a magnitude 7.4 earthquake occurred off the coast of this prefecture, and Sendai was seriously damaged by a 5 quake on the Japanese earthquake scale. Pumping stations were heavily damaged and due to widespread power outages, emergency river discharge and other measures were taken. In addition, this earthquake led to a review of the structure of manholes and the promotion of private electric generators. Moreover, the Great Hanshin Earthquake in 1995 and the Niigata Chuetsu Earthquake in 2004 led to recognition of the need for seismic strengthening of pipelines and to its promotion, mainly by the rehabilitation method.

Along with advanced land use in the city center and urbanization of the surrounding areas came repeated flood damage in 1986, 1990 and 1994. New countermeasures against flooding in urban areas were sought, and we have been tackling rainwater challenges including improvement of the combined sewer system, main storm sewers, and pumping stations. Moreover, Sendai has been preparing comprehensive rainwater countermeasures including quick drainage of rainwater, runoff control and countermeasures for an emergency occurring in rainy weather.

2. Damage to Sewerage Facilities and Initial Response

At magnitude 9.0, the earthquake that occurred off the Sanriku Coast on March 11, 2011 was the largest earthquake in Japan's recorded history and the fourth largest in the recorded history of the world.

The violent shaking and the giant tsunami triggered by the earthquake led to a great number of deaths, injuries and missing persons along the coast from the Tohoku region to the Kanto region.

In Sendai City, a maximum seismic intensity of 6 upper (on the Japanese scale with a maximum of 7) was recorded in Miyagino Ward. Nine hundred seventy-nine people died and 30 were missing as of December 2012. In addition, there was enormous damage including slope failures, collapsed roads and buildings, and disruption of vital utilities.

(1) Outline of the earthquake

Earthquake name: 2011 Earthquake off the Pacific Coast of Tohoku

Date and time of occurrence: March 11, 2011 at 2:46 p.m.

Epicenter: Off the Sanriku Coast (about 130km east-southeast of Oshika Peninsula; depth about 24 km)

Magnitude: 9.0

(2) Outline of the largest aftershock

Earthquake name: 2011 Earthquake off the Pacific Coast of Tohoku

Date and time of occurrence: April 7, 2011 at 11:32 p.m.

Epicenter: Off the coast of Miyagi Prefecture (40km east of Oshika Peninsula; depth about 66km)

Magnitude: 7.2

(3) Damage to facilities and initial response

The Great East Japan Earthquake caused widespread pipeline breakage and accompanying road subsidence, manhole uplift due to liquefaction, and in hilly residential areas, breakage of pipelines and collapse of waterways due to landslides. Furthermore, Minami-Gamo Wastewater Treatment Plant and other sewerage facilities in the coastal area were severely damaged by the tsunami. The pillars and walls of the main pumping building were destroyed, rendering it unusable, and equipment was inundated, broken and washed away.

In restoring damaged facilities, Sendai adopted a policy of keeping influence on civil life to a minimum. The emergency response was conducted so as to allow the continuous use of toilets and maintain sanitary conditions by avoiding sewage overflows in the city. On that basis, we addressed the preservation of public water quality (in accordance with environmental standards) afterwards.

① Damage to pipeline infrastructure

Thanks to the support of 12 municipalities, including Tokyo, over a period of about a month, we were able to complete a survey of damaged pipeline infrastructure in seriously affected areas. Then, although we were able to continue sewer service, it took nine months of further investigation to get a full picture of the damages. In the end, out of about 4,500km of pipeline, about 100km were found to be damaged, and have been restored.

Regarding the sewer pipe bridge over the Hirose River, one of the two pumping pipes developed a leak, but by concentrating the flow of sewage through the other pipe, we prevented the leakage of sewage.

As of October 31, 2012

Ownership	Pipeline type	Total pipelines (km) 2009	Surveyed pipelines (km)			Damaged pipelines at the end of Jan. 2013 (km)*
			Primary survey (visual inspection from road surface)	Secondary survey (visual inspection from inside manholes)	CCTV inspections	
Public sewerage	Combined	590	590.0	38.5	35.1	30.1
	Separate sewer	2,830	2,792.8	150.5	67.0	54.7
	Separate rainwater	1,042	1,030.3	28.6	10.9	9.0
	Total	4,462	4,413.1	217.6	113.0	93.8
Other		116	111.9	13.1	12.9	8.3
Grand total		4,578	4,525.0	230.7	125.9	102.1

*Length of damaged pipelines is the full length of the spans that contain damaged portions.

The chloroethene pipe broken by the earthquake

The floating manhole by liquefaction

② Damage to pumping stations and wastewater treatment facilities

Out of 330 pumping stations and wastewater treatment facilities, including manhole pumping stations, 48 facilities were damaged by the earthquake and 50 were damaged by the tsunami. Damage from the tsunami was especially heavy, and most of the affected facilities were devastated. During the emergency restoration, due to power outages and fuel shortages, at the main pumping stations, it was very difficult to secure water pumping functions using emergency power generators. In addition, out of 1,153 septic tanks, 128 were found to be damaged by the earthquake.

In particular, at Minami-Gamo Wastewater Treatment Plant, which treats approximately 70% of Sendai's wastewater, most equipment was rendered unusable by the tsunami, and civil engineering facilities were rendered unusable by rubble.

This plant was originally designed to take advantage of the landscape, enabling effluent to flow naturally down a simple treatment route. Therefore, even in this situation, we were able to receive sewage from the city, treat it by sedimentation and disinfection, and discharge it using the emergency effluent gate. This greatly contributed to continuation of sewage service and conservation of a hygienic environment in the city.

Damage Situation of the Minami-Gamo Wastewater Treatment Plant

The moment hit by the tsunami

The 3rd pumping building with the wall curved by the tsunami

Damaged incinerator

The damaged primary sedimentation tank

Damage Situation of the Pumping Stations

The Imaizumi Pumping Station tilted by the earthquake

The Nishihara Pumping Rainwater Station covered by the debris after the tsunami

As of October 31, 2012

Ownership	Facility type	Number of facilities	Damaged facilities			Facilities where temporary functions were secured
			Earthquake	Tsunami	Total	
Public sewerage	Wastewater treatment plants	5	3	1	4	3
	Pumping stations, etc.	239	43	14	56	51
	Subtotal	244	45	15	60	54
Other	Clean centers	18	3	8	11	10
	Relay pumping stations	68	0	27	27	22
	Subtotal	86	3	35	38	32
Total (Collective)		330	48	50	98	86
Sewage treatment plants		【 23】	【 6】	【 9】	【15】	【12】
Pumping stations		【304】	【41】	【41】	【82】	【72】
Publicly-owned-and-managed septic tanks		1,153	126	2	128	128
Grand total		1,483	174	52	226	214

3. Restoration Policy for Minami-Gamo Wastewater Treatment Plant

Minami-Gamo Wastewater Treatment Plant is located less than a kilometer from the coast, and is thus at risk for tsunami damage. In addition, the entire facility has sunk about 60cm, putting it at increased risk of inundation and overflow during rain and high tide. It was necessary to undertake a high-level, specialized investigation into reconstruction at a new site, taking into consideration the subsidence of civil engineering facilities, earthquake and tsunami countermeasures, and the strengthening of functions. Because of this, we formed a committee of experienced researchers and practitioners, who proposed the following restoration policy:

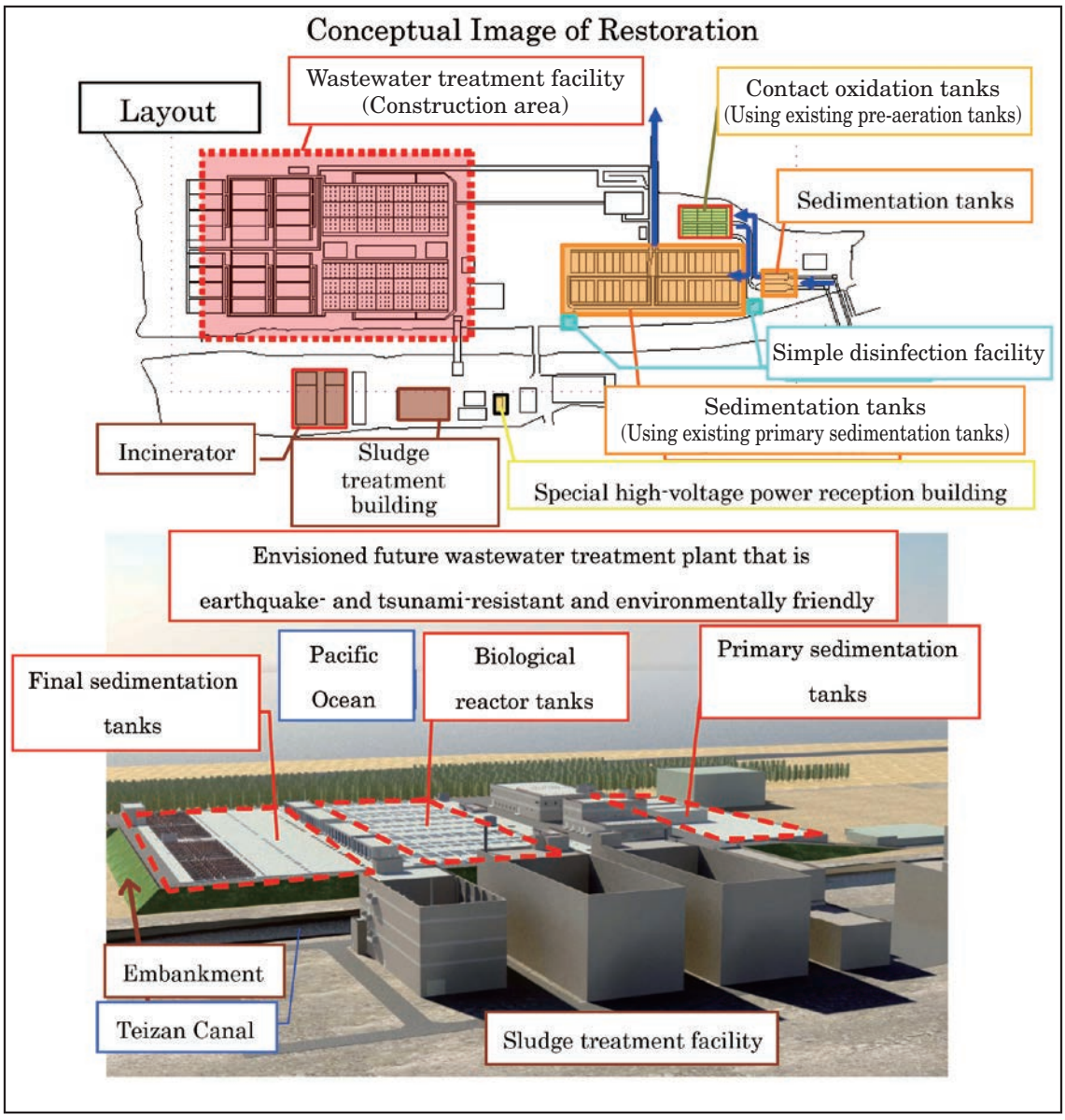
1. As restoration of water treatment facilities will take five years, steps should be taken to improve the quality of treated water during the period of temporary treatment. Considering what it is presently possible to introduce to the facility and the cost of maintenance and management, we believe it will be practical to adopt contact oxidation.
2. Minami-Gamo Wastewater Treatment Plant's characteristics, deriving from the geography between the city and the treatment plant, allow for the preservation of simple treatment functions without power through the gravity flow of water downslope. This is extremely beneficial from the standpoint of crisis management in a disaster and maintaining public sanitation, and thus we believe it is desirable to preserve these characteristics during restoration.
3. Considering the ability to preserve simple treatment functions through the gravity flow of water downslope, the location relative to the sludge processing facility, the amount of time needed for restoration, and the cost of the project, we believe that rather than relocating or decentralizing the water treatment facility, it will be logical and economical to restore the facility on its current site or in the vicinity.
4. In order to prevent destruction of the structure by a tsunami and to design for the preservation of functioning equipment, it will be necessary to adopt tsunami countermeasures, such as raising the height of the facility using the height of the recent tsunami as a reference, and covering the roof. Additionally, measures should be taken to protect workers in a tsunami, such as building appropriate evacuation spots.
5. After considering tsunami countermeasures, construction time, project cost, and maintenance and management, we believe it will be logical to restore the wastewater treatment facility on its current site, indicated on the separate map.
6. In order to secure electric power in a disaster and reduce the burden on the environment, we recommend introducing energy-saving equipment and solar power and small hydroelectric power generation. Furthermore, new technologies for the recycling of resources at the sewage works, energy saving, energy generation, and reducing the burden on the environment should be introduced in the mid to long term after determining the effect on business, including a cost-benefit analysis.

After reviewing the committee's proposals, the city decided to build a new wastewater treatment facility on the current site, aiming for completion by March 2016. The features of the new facility are as follows:

(1) Like the previous facility, the structure will allow for simple treatment (sedimentation, disinfection, discharge), even if power is lost in a disaster, through the gravity flow of water downslope.

(2) While preserving the previous function, each tank will be double-layered or deepened to increase its height, making the facility resistant to tsunamis.

(3) The burden on the environment will be reduced by introducing solar power and small hydroelectric power generation. These will also be used as an emergency power source in a disaster.



4. Sendai Wastewater Utility Reconstruction Plan

(1) Goal of the Plan and Policy for the Recovery of the Wastewater Utility

① Restoration of Minami-Gamo Wastewater Treatment Plant

Based on the proposal of the Minami-Gamo Wastewater Treatment Plant Restoration Policy Investigation Committee, the water treatment facility will be restored to be disaster-resistant and environmentally-friendly on its current site by March 2016.

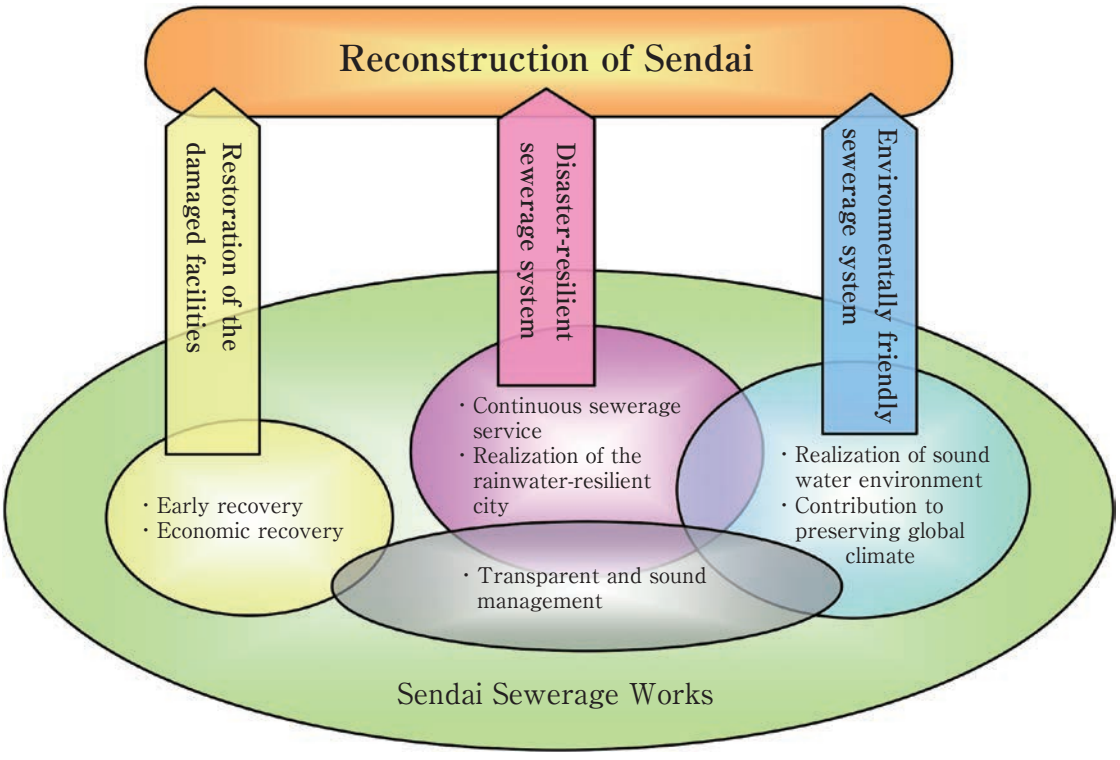
During restoration, the characteristic that allowed simple processing even without power through the gravity flow of water downslope, which was effective in crisis management and maintenance of public sanitation during the disaster, will be preserved. Moreover, in order to secure electricity in times of disaster and reduce the burden on the environment, energy-saving and solar and small hydroelectric power generation will be implemented.

② Construction of Minami-Gamo Trunk Sewer 3

In order to be able to continue sewerage services even during a disaster, we will improve the earthquake resistance of sewage works facilities. As the main project, in addition to strengthening the earthquake resistance of Minami-Gamo Trunk Sewers 1 and 2, we will construct Minami-Gamo Trunk Sewer 3, which will serve a complementary role to these important trunk sewers.

③ Countermeasures against inundation

In order to realize a city that is equipped to handle rainwater, we will construct rainwater drainage facilities (main storm sewers, stormwater pumping stations, stormwater reservoirs, etc.) using national reconstruction grants, develop an inundation hazard map, and subsidize the construction of a stormwater runoff control facility.



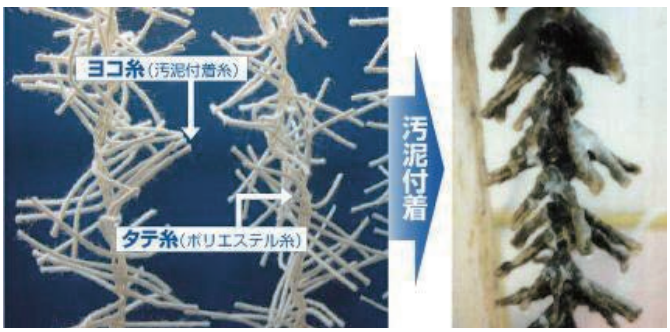
5. Temporary Water Treatment by Contact Oxidation

Because restoration of water treatment facilities will take place over several years, from the point of view of preservation of water quality in neighborhoods using public water, improving the quality of effluent was an issue. Therefore, a treatment method was investigated that would meet the upper limit of the temporary effluent standard of BOD60mg/l proposed by the National Sewerage Disaster Countermeasures Committee of the Ministry of Land, Infrastructure, Transport and Tourism. This method uses existent water treatment facilities (pre-aeration tanks, primary sedimentation tanks) that are not impacted by the restoration.

Accordingly, as a measure to improve the quality of effluent at Minami-Gamo Wastewater Treatment Plant by degrees, we decided to implement mid-level treatment through contact oxidation using string media. This is the first large-scale facility in Japan to adopt this method for use in sewage works.

Facility Outline

- Treatment process: Biological Contact Oxidation using a bio film method with string media (68 units/tank)
- Design flow: 300,000m^3/day (average flow in good weather)
- Design influent BOD: 177mg/ℓ Design effluent BOD: 60mg/ℓ
- Hydraulic retention time: 50 min.
- BOD volumetric loading: 5.2kg-BOD/m^3/day
- Ventilation equipment: GM Blower (260Nm^3 x 400Kw x 2 units)
- Pre-aeration basin: Width 5m × Length 59.2m × Depth 4.25m × 4 channels × 2 pools (Volume: 102,000m^3)



Sludge attached to string media


Biological Contact Oxidation

6. Restoration Cost of Sewerage Facilities

(1) National disaster recovery project system and disaster assessment

When public facilities are damaged in a disaster such as an earthquake or flood, a fixed percentage of the cost of recovery can be obtained from the national government through the national disaster recovery system. In this system, an assessment officer from the appropriate government ministry* and an observation officer from the Ministry of Finance receive a damage report from the applicant (Sendai City) and conduct a disaster assessment in order to confirm the damage conditions, determine if the facilities meet the requirements for support, and determine the cost of the recovery project (assessed amount).

*Public sewage works and urban discharge facilities are under the jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism; agricultural wastewater projects are under the jurisdiction of the Ministry of Agriculture, Forestry and Fisheries; and septic tanks are under the jurisdiction of the Ministry of the Environment.

(2) Damage situation of sewage works facilities from the perspective of cost

The cost of damage was estimated based on viewing some of the damaged facilities, and was subsequently determined through detailed surveys, plans and disaster assessments.

① Cost of damage to sewage works facilities

The damage incurred in the disaster by sewage works facilities under the jurisdiction of Sendai City reached over 72.5 billion yen (cost of recovery), or 40% of the total damage to city-owned essential utilities (water, gas, sewage, etc.) of 168 billion yen. Sewage works facilities throughout the city were damaged, but damage in the coastal area (Minami-Gamo Wastewater Treatment Plant over 57.5 billion yen; pipelines in the Arahama and Gamo areas over 6.2 billion yen; demolition of facilities over 1.9 billion yen, etc.) accounted for 90% of the total.

② Results of disaster assessments

Due to the huge scale of the damage in this disaster, between May 2011 and February 2012, a total of 14 disaster assessments were carried out: eight for public sewage works, three for urban discharge facilities, two for agricultural wastewater facilities, and one for septic tanks, debris removal, and demolition of facilities. As a result, the assessment rate (assessed amount/amount requested) was 99.65%, and we will be able to receive a great amount of support from the national government for recovery.

6. Restoration Cost of Sewerage Facilities

Cost of damage to sewage works facilities in the Great East Japan Earthquake based on results of disaster assessment

[Total(as of Dec.31,2012)] Unit: 1,000 yen

Assessment	Locations	Amount requested	Assessed amount	Assessment rate	Amount covered
Public sewage works facilities	131	69,060,877	68,811,726	99.64%	67,794,870
Urban discharge facilities	16	747,282	746,897	99.95%	735,868
Agricultural wastewater facilities	16	884,967	880,939	99.54%	855,114
Projects under the Ministry of the Environment	32	2,173,919	2,172,434	99.93%	2,172,434
Total	195	72,867,045	72,611,996	99.65%	71,558,286

*Amount covered: Assessed amount-miscellaneous construction expenses (independently borne expenses)
**Amount subject to change as construction progresses

7. Current State of Restoration and Reconstruction (as of Aug. 15, 2013)

(1) Restoration works

1) Outline

Construction on the majority of damaged sewage works facilities will be completed by March 2014, and they will resume normal functioning. The following facilities are exceptions:

- Minami-Gamo Wastewater Treatment Plant (restoration work to be completed in March 2016)
- Facilities located in land-readjustment project areas and in Designated Disaster Risk Areas within the tsunami-affected area.

Facility type	Business type		Pipelines and facilities in need of restoration [a]	Fully-restored pipelines and facilities [b]	Restoration ratio [c=b/a]
Pipelines	Public sewerage	Regular assessment	36.9km	30.9km	83.6%
		Negotiated design	48.6km	0.0km	0.0%
		Total	85.5km	30.9km	36.1%
	Urban discharge facilities		0.19km	0.02km	7.6%
	Agricultural wastewater facilities		1.94km	0.53km	27.3%
	Total		2.13km	0.55km	25.8%
Pumping stations	Public sewerage		52	46	88.5%
	Urban discharge facilities		3	3	100%
	Agricultural wastewater facilities		27	12	44.4%
	Total		82	61	74.4%
Treatment facilities	Public sewerage	Other	3	3	100%
		Minami-Gamo WWTP	1	0	30.6%
		Total	4	3	75%
	Agricultural wastewater facilities		11	7	63.6%
	Total		15	10	66.6%
	Publicly-managed septic tanks		128	128	100%

*Pipelines and facilities in need of restoration differ from initial numbers due to new damage confirmed during construction, the aggregation of treatment areas, etc.

**Fully-restored pipelines and facilities are pipelines and facilities on which construction carried out by the sewage works bureau has been completed.

2) State of Restoration of Minami-Gamo Wastewater Treatment Plant

① Completion date of full restoration

Restoration of the water treatment facility is scheduled to be completed by March 2016. Restoration of the sludge treatment facility is scheduled to be completed by March 2014. Regarding the current state of water treatment, please see "5. Temporary Water Treatment by Contact Oxidation".

② Progress of restoration works

Percent completed: 30.6%

State of restoration of the water treatment facility
(Preparation→Demolition→Reconstruction)

Preparation (Sept. 26, 2012)

Demolition (Mar. 11, 2013)

Reconstruction (June 29, 2013)

(2) Reconstruction projects

In order to reduce the risk of flooding in the eastern part of the city due to land subsidence in the Great East Japan Earthquake, we will rebuild and build new stormwater drainage facilities including main storm sewers and stormwater pumping stations.

1) Outline

Area	Land Subsidence	Main Projects
Gamo, Shiratori	Approx. 50cm	・Nishihara Main Storm Sewer 4 (new) ・Nishihara Rainwater Pumping Station (new) ・Nakano Rainwater Pumping Station (expansion)
East Haranomachi	Approx. 50cm	・East Haranomachi Main Storm Sewer 4 (new) ・Tsurumaki Pumping Station (expansion)
Kasuminome	Approx. 30cm	・Kasuminome Main Storm Sewer 2 (new) ・East Arai Main Storm Sewer (new) ・West Arai Main Storm Sewer (new) ・East Arai Rainwater Pumping Station (new)

2) Status

Construction progress, stage of design, scheduled date of completion, etc.

Area	Land Subsidence	Main Projects
Gamo, Shiratori	Approx. 50cm	・Nishihara Main Storm Sewer 4 (new) : In design stage; construction scheduled to begin in FY 2013. ・Nishihara Rainwater Pumping Station (new): Scheduled to begin operation in FY 2016. ・Nakano Rainwater Pumping Station (expansion): Scheduled to begin operation in FY 2016.
East Haranomachi	Approx. 50cm	・East Haranomachi Main Storm Sewer 4 (new): In design stage; construction scheduled to begin in FY 2013 and be completed in FY 2015. ・Tsurumaki Pumping Station (expansion): In detailed design stage; scheduled to begin operation in FY 2016.
Kasuminome	Approx. 30cm	・Kasuminome Main Storm Sewer 2 (new): In design stage; construction scheduled to begin in FY 2013 and be completed in FY 2015. ・East Arai Main Storm Sewer (new): In design stage; scheduled to order materials in FY 2014. ・West Arai Main Storm Sewer (new): In design stage; scheduled to order materials in FY 2013. ・East Arai Rainwater Pumping Station (new): Scheduled to begin detailed design in FY 2013 and begin operation in FY 2016.

8. Collaborative Research on Algal Biomass

Sendai City, in collaboration with Tsukuba University and Tohoku University, is supporting research and development on algal biomass that produces oil by using the organic matter contained in sewage. Using the damaged Minami-Gamo Wastewater Treatment Plant as a base, by combining the cultivation of two types of algae (Aurantiochytrium and Botryococcus) with the treatment of sewage, we aim to move from sewage treatment that consumes large amounts of energy to the creation of a new recycling system that produces energy.

This collaborative research was selected for a subsidy by the Ministry of Education, Culture, Sports, Science and Technology. Research will be conducted over a period of five years beginning in FY 2012, from basic research in the laboratory to a pilot study in an outdoor facility.

9. Problems Encountered and Lessons Learned in the Disaster

In Sendai's first sewage works plan, finalized in 1957, Minami-Gamo Wastewater Treatment Plant was situated in the coastal area. It was established in conjunction with a trunk sewer (Minami-Gamo Trunk Sewer 1) that, by taking advantage of the elevation differences in the Hirose River terrace on which the city developed, allowed for the natural flow of sewage downslope to the wastewater treatment plant. Simple treatment was carried out at Minami-Gamo Wastewater Treatment Plant from 1964, when it began operation, to 1979, when advanced treatment began. From the flow of sewage into the treatment area to sedimentation, disinfection and discharge, the treatment process was carried out without pumping, through the natural flow of water downslope.

Due to the Great East Japan Earthquake (tsunami and power outages), it was extremely difficult for Minami-Gamo Wastewater Treatment Plant and other sewage works facilities in Sendai to continue normal operations. However, due to the gravity flow of wastewater downslope from the city to the treatment plant, the center was able to continue taking in sewage and discharging into the ocean. As a result, it is worth noting that there were no major overflows in Sendai, and it was not necessary to take measures to restrict the use of the sewage system.

(1) Problems encountered in the disaster

① Stockpiles

In anticipation of an earthquake off the coast of Miyagi Prefecture, we were fully stocked with all the materials and equipment necessary for surveying pipelines, right down to stationery. Because of this, we were able to conduct a survey quickly after the disaster. However, due to power outages and fuel shortages directly after the disaster, it was extremely difficult to secure water-pumping functions at pumping stations. Therefore, additional stockpiles of fuel are necessary to maintain functionality at main pumping stations in a large-scale disaster.

② Care of survey groups from support cities

This was Sendai's first large disaster since the mutual aid agreement between large cities was established after the 1995 Kobe-Awaji Earthquake. Thus, we had never accepted a large-scale support team, and had not prepared accommodations and welfare. In the future, it would be desirable to discuss the scale of a disaster and support systems and be prepared to accept support teams.

③ Disaster assessment policy of the Ministry of Land, Infrastructure, Transport and Tourism

We were in communication with the Ministry of Land, Infrastructure, Transport and Tourism about the damage situation, disaster surveys, and the disaster assessment policy beginning directly after the disaster. However, the survey and assessment methods could not be settled upon, and the survey method had to be changed frequently. In order to carry out surveys efficiently, standards should be set and a system established beforehand. There is a need for the parties involved to share their experiences in the future.

④ Emergency contact system with the Prefecture

While there was no major sewage overflow in Sendai following the Great East Japan Earthquake, there was an overflow near a regional sewage treatment plant involving sewage from Sendai. There should have been a discussion in advance about how to minimize damage in a large disaster, but at the time of the disaster no such meeting had been held, and there may also have been deficiencies in the communication system. In the future, there is a need especially for frequent communication with the regional sewage works, agreement on disaster response, and the establishment of a system for cooperation.

⑤ Business continuity plan (BCP)

Sendai Wastewater Utility prepared a wastewater utility disaster response manual in 2006, and from 2010 was also involved in the development of a BCP. Minami-Gamo Wastewater Treatment Plant and the facility management center were able to transition quickly to an initial response. In particular, at Minami-Gamo WWTP, a total of 101 people, including 34 staff members and 67 service contractors, were working at the time of the disaster, but due to their quick response, all people present were able to take refuge before the tsunami hit. Moreover, in order to avoid restrictions on the use of the sewer system and sewage overflows in the city, on March 12, the day after the disaster, they manually opened a gate on a discharge route from the era of simple treatment as a measure to continue the inflow of sewage.

At the same time, with regard to the pipelines, because of delays in revisions to the previously prepared disaster response manual and the development of a BCP, they had to feel their way through the initial response.

At Sendai Wastewater Utility, based on the lessons we have learned, in 2012 we finalized a new BCP for earthquakes and tsunamis and are conducting drills. We are also preparing a BCP for heavy rain.

⑥ Placement of equipment in preparation for an emergency

After the disaster, based on the BCP, we opened the discharge gate at Minami-Gamo WWTP, but because a manual opening had not been anticipated, we were only able to open the gate about 10cm. In a disaster, loss of power and broken equipment are conceivable, so various circumstances must be anticipated and the means for manual operation secured.

In addition, much electronic equipment is placed on the first floor out of convenience, but as there is a fear of water damage in a tsunami, equipment should be placed on a higher floor or measures such as the installation of waterproof doors should be taken.

(2) Lessons learned from the disaster

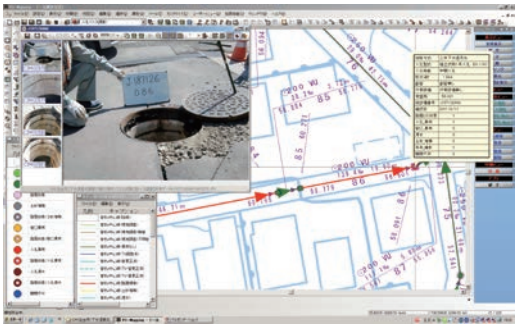
① Securing bypass functionality

Nakano stormwater pumping station is located in the coastal area and pumps stormwater from the northern part of Sendai Port. The facility was inundated by the tsunami and the pumps were damaged to the point that they could not function. However, because a bypass waterway had been

established that allowed for discharge into Sendai Port through the natural flow of water downslope, the station was able to contribute to the relief of flood damage in the city.

At the same time, at Minami-Gamo WWTP, 70% of Sendai's sewage is conveyed by Minami-Gamo Trunk Sewers 1 and 2, which are always filled to capacity. If there were an accident at one of the sewers, the other would not have the capacity to take on additional sewage. For that reason, in order to prepare for future disasters and accidents, we are planning the construction of Minami-Gamo Trunk Sewer 3, which will serve as a bypass for the other sewers.

② Effect of asset management



In the damage survey of pipelines, land subsidence, water retention, and the uplift of manholes are measured and photographed. The result must be used to grasp the damage situation (places and extent), and select the next day's survey location. With GIS and the database of pipeline ledgers and facility ledgers created using asset management, we were able to grasp the damage situation as geographical data, thus making it possible to make quick adjustments and produce visual output. In this way we were able to carry out an effective and efficient survey.

③ Importance of support from other cities

Up until now, when a large-scale disaster has occurred, the major cities in Japan have supported each other and undertaken restoration work. Based on the mutual aid agreement between large cities in times of disaster, four days after the disaster, we undertook the first pipeline survey (visual inspection) with staff from other cities. About a month after the disaster, we had received the support of 1,630 people from 12 cities, and were able to quickly carry out the damage survey of pipelines. After that, we also received the support of staff from other cities in the disaster assessments and recovery construction work.

We also received support from private business associations. In order to plan for the quick recovery of sewage works pipelines and facilities, in 2005 we signed two agreements with these associations: an agreement regarding support for the restoration of sewerage pipelines in a disaster, and an agreement regarding support for the restoration of wastewater treatment facilities in a disaster. Every year, we also cooperated to hold regular disaster drills. Due to these efforts, we were able to swiftly carry out the emergency response after the Great East Japan Earthquake.

Minami-Gamo Wastewater Treatment Plant (Feb. 3, 2015)

Restoration and Reconstruction of Sendai Wastewater Utility after the Great East Japan Earthquake

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