# Hitachi Review

Volume 64 Number 9 December 2015

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# Water Industry Solutions for Ongoing Development of Social Infrastructure

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Hitachi Review
Volume 64 Number 9 December 2015

## From the Editor

Water is essential to life and its importance goes without saying. Yet access to safe drinking water is far from universal, with many areas also lacking sewage systems and other sanitation infrastructure. Japan, too, faces a number of challenges, including the replacement of aging water and sewage infrastructure, and the transfer of industry skills.

Hitachi's Social Innovation Business operates globally, supplying safe and reliable social infrastructure that is enhanced by the use of information technology (IT). Included in this business is Hitachi's water infrastructure business, which draws on close to a century of experience to supply products and services for a wide variety of fields, encompassing the conservation of water sources, flood control, water supply and sewage systems, wastewater treatment, and water production or recycling.

Hitachi is also actively marketing its water industry solutions, which seek to provide comprehensive answers to the many challenges facing the water industry. These activities extend beyond the water industry itself to also include using IT and control to deliver innovations in water treatment and distribution, responding to various types of emergencies, and optimizing energy use by coordinating operation with the electric power infrastructure. Starting with our solutions for the water industry, Hitachi believes that, by helping to improve people's daily lives and overcome the challenges facing cities and catchments we can optimize all aspects of the infrastructure of society and support ongoing development.

With reference to these background factors, this issue of *Hitachi Review* describes recent activities by Hitachi that involve the use of water industry solutions to contribute to the ongoing development of social infrastructure.

This issue's Expert Insights is an article contributed by Professor Hiroaki Furumai of the Graduate School of Engineering, University of Tokyo. In Technotalk, we invited Professor Seiichi Shin of The University of Electro-Communications to participate in a discussion on the use of IT and control for innovation in the water industry. The discussion also touched on social infrastructure security.

In Overview, we present a summary of our water industry solutions along with a review of current trends in Japan and elsewhere. Subsequent articles cover a wide range of topics, presenting the latest technologies for water supply, sewage, wastewater treatment, operation and maintenance, and so on, along with examples of how these are benefiting our customers.

I hope that this issue of *Hitachi Review* will prove useful to people everywhere who are involved in social infrastructure, not just the water industry.

Editorial Coordinator,
"Water Industry Solutions for Ongoing Development of Social Infrastructure" Issue

**Takahiro Tachi**

Chief Engineer
Water & Environment Solutions Division
Infrastructure Systems Company
Hitachi, Ltd.

# Water Industry Solutions for Ongoing Development of Social Infrastructure

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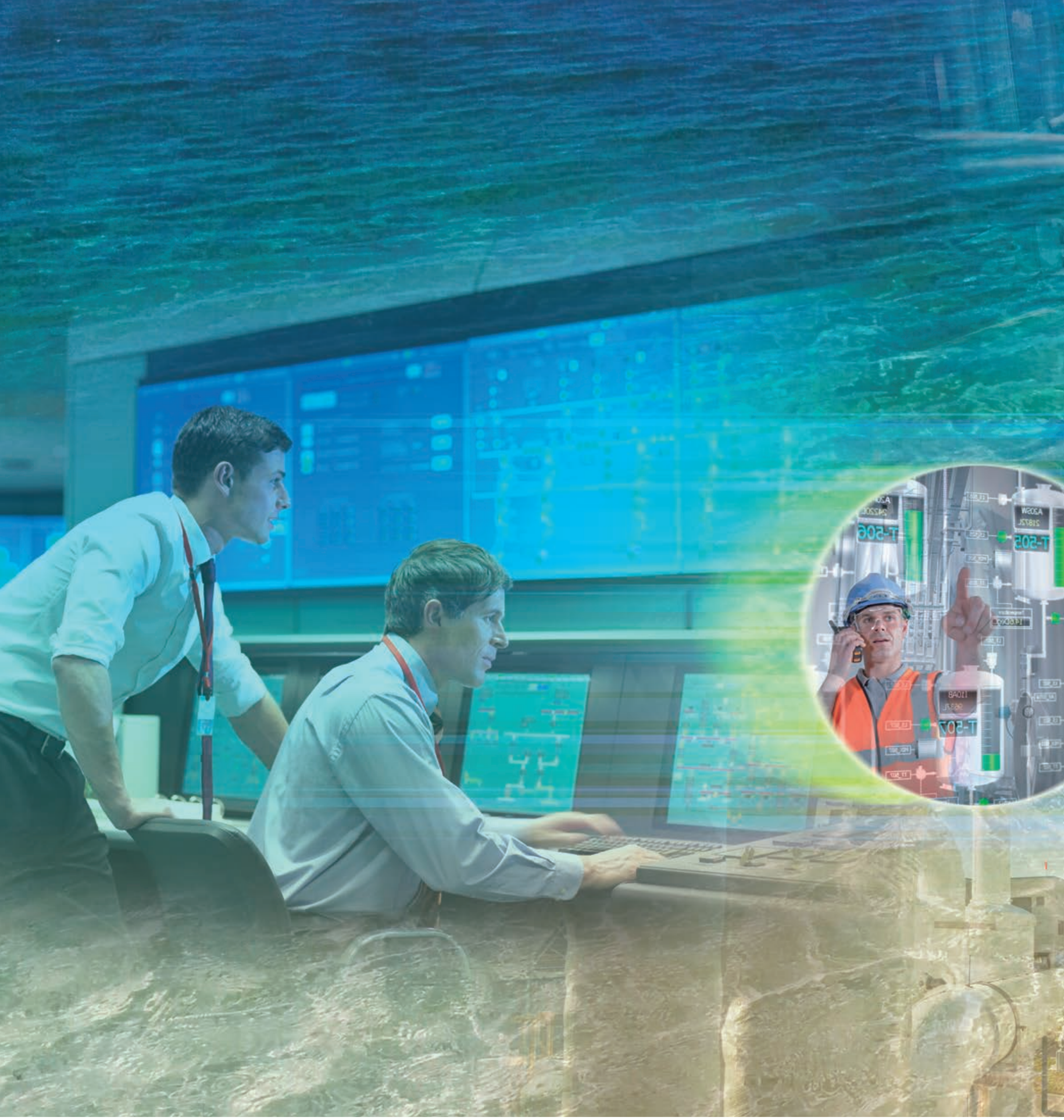


# Water Industry Solutions for Ongoing Development of Social Infrastructure

Not only vital for life, water is also a critical and essential service within the infrastructure of society, being essential to industrial production and other forms of economic activity.

While Japan has built up an advanced level of water infrastructure underpinned by extensive water resources and technical capabilities, the challenge for the future is to maintain this infrastructure.

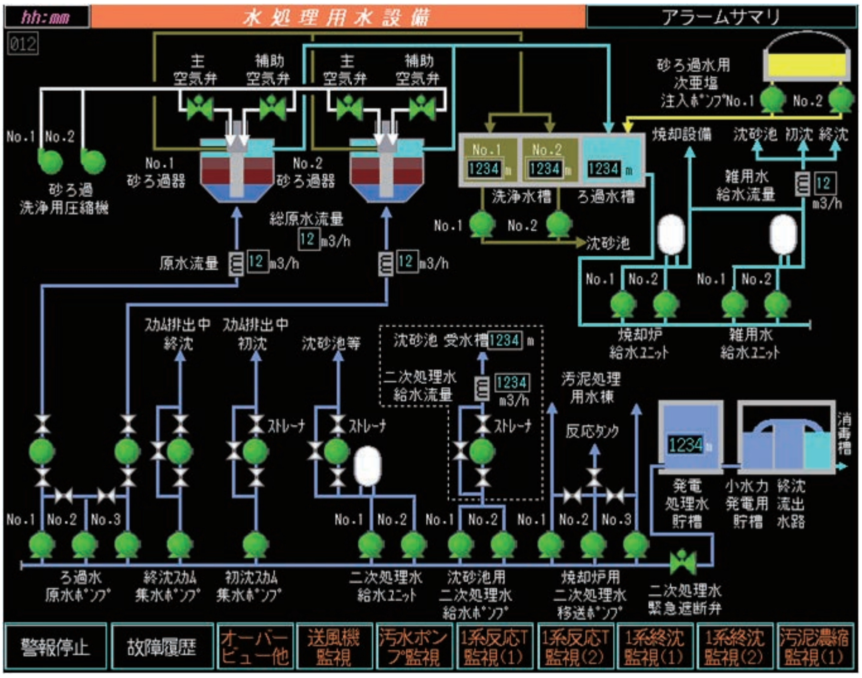
Overseas, meanwhile, the challenge many areas face is how to overcome water shortages driven by environmental, economic, and other factors.

Having for many years been a supplier of products, systems, and services for the water industry, Hitachi is responding to new challenges arising in Japan and elsewhere with water industry solutions based on its accumulated experience and advanced technology.

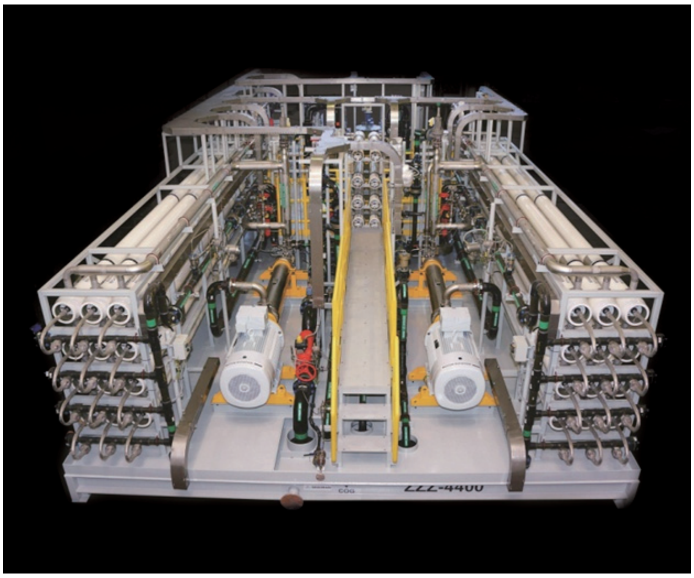
Hitachi intends to contribute to the ongoing development of social infrastructure by establishing a healthy and efficient water industry.

Seawater desalination plant (top) and
drinking water bottling plant (bottom) in the Maldives


Web services displayed on a tablet
(Left: graphics screen, right: alarm messages)




Touch panel display mounted on controller panel that includes functions for monitoring other facilities



Reverse osmosis (RO) unit for oil & gas floating production, storage and offloading systems (FPSOs)

“Navigation system tool” that uses augmented reality (AR) to support operation and maintenance

Expert Insights

# Sustainable Forms of Water Use Systems

**Hiroaki Furumai, Dr. Eng.**

Professor, Research Center for Water Environment Technology, Graduate School of Engineering, University of Tokyo

Doctor of Engineering, University of Tokyo
After positions that included Associate Professor, Department of Civil Engineering Hydraulics, Kyushu University; Associate Professor, Department of Civil and Urban Engineering, Ibaraki University; Associate Professor and Professor, Department of Urban Engineering, University of Tokyo, he took up his current position in 2006.
His other roles include Board of Director of IWA; IWA Fellow 2010; Chairman of IWA Japan national committee; President of the Japan Society on Water Environment; Chairman, Research committee on nonpoint source pollution; Editorial committee members of Water Research, Urban Water Journal, Hydrological Research Letters, and Journal of Climate Change; Chairman, Editorial committee of Journal of Japan Water Works Association; Technical committee member of Japan Sewage Works Association; and Chairman, Research committee on asset management of the Institute of Electrical Engineers of Japan.
His specialty is urban environmental engineering.

The Basic Act on Water Cycle was enforced in July 2014 and the cabinet decision on the Basic Plan for Water Cycle was made in July 2015.

The aims of the Act and the Plan are to maintain and restore a sound water cycle, and to achieve sound progress on the socioeconomic state of the nation and bring greater stability to our way of life by undertaking comprehensive and consistent measures in relation to the water cycle within watersheds.

The next step is for the “water cycle council” established for each watershed to start formulating the watershed water cycle plan. To ensure a sound water cycle within watersheds, it is stipulated that storage, infiltration, replenishment, and retention of water should be handled in a sound manner, and that efficient systems should be constructed for water use in urban areas.

When considering future water use systems, it is essential to be cognizant of the Basic Strategy for Urban Regeneration based on the Act on Special Measures Concerning Urban Regeneration that was partially amended in August 2014. Urban regeneration needs to be undertaken with consideration for what form urban structure will take in 50 or 100 years’ time. Based on the assumption of a falling population due to aging and the low birth rate, it also needs to take account of a wide range of viewpoints, including compacting cities, securing a high quality of life, developing cities that are resilient to disaster, and are attractive, reducing the environmental loads and living in harmony with nature.

Put another way, taking account of the future urban structure, there is a need to ensure that the manmade parts of the water cycle (water supply and sewerage systems) co-exist harmoniously within the natural water cycle. To achieve safe and reliable water use in urban areas together with a sound water environment and waterfronts that are pleasant and peaceful, we need to find appropriate answers to the questions of how to maintain sufficient quantity and good quality of water in cities, and how we should be getting along with water.

Since 2009, I have been conducting a project of the Core Research for Evolutional Science and Technology (CREST) under the strategic basic research program of the Japan Science and Technology Agency (JST). The objectives of the project are to predict the future quantity and quality of water resources in the Arakawa watershed under climate change, and to study possible sustainable systems of urban water use that encourage effective use of the self-owned water resources in cities such as groundwater, rainwater, and reclaimed water. Through this research we have found that, to optimize urban water cycle and water use systems, it is essential that those who are responsible for managing the rivers, groundwater, water supply, and sewerage and have a practical involvement, share information on water resources and water use within the watershed. Then they should identify sustainable ways of using water, and to adopt these as common goals. To support the building of a consensus among these stakeholders, we have developed a tool to generate various scenarios for water use systems using multi-objective optimization algorithms that consider a wide variety of indicators.

Rather than optimizing the individual systems managed within single municipalities, the tool transcends administrative borders to consider water supply and sewerage systems across the entire watershed. I anticipate that the developed tool will be used to explore and develop sustainable water use systems, examining a variety of water use scenarios. I also think that it is now time to propose how our research outcomes can be incorporated and reflected in the creation process of the above-mentioned watershed water cycle plan.

Technotalk

# Accelerating Fusion of IT and Control to Deliver Innovation in Water Industry

**Seiichi Shin, Dr. Eng.** Professor, Control Systems Program, Department of Mechanical Engineering and Intelligent Systems, Graduate School of Informatics and Engineering, The University of Electro-Communications
**Hiroto Yokoi** Senior Researcher, Process Engineering Research Department, Center for Technology Innovation – Materials, Research & Development Group, Hitachi, Ltd.
**Hideyuki Tadokoro, P.E.Jp** Senior Manager, Public Control Systems Engineering Department, Electrical Equipment Information & Control Systems Division, Omika Works, Infrastructure Systems Company, Hitachi, Ltd.
**Toshihiko Nakano, Ph.D.** General Manager, Security Center, Strategic Planning Division, Infrastructure Systems Company, Hitachi, Ltd.
**Takahiro Tachi** Chief Engineer, Water & Environment Solutions Division, Infrastructure Systems Company, Hitachi, Ltd.

*Thanks to a variety of technical innovations over time, the water infrastructure that forms an essential underpinning of society has achieved dependability along with safety and security. Outside Japan, there remain regions beset by water scarcity. In Japan, meanwhile, problems are emerging as a result of the changing social environment, which includes an aging population and declining birth rate. Hitachi supplies numerous products, systems, and services for the water industry that extend from watershed management to flood control, water supply and sewage, water recycling, and waste water treatment. By supplying solutions for the water industry based along these lines, Hitachi is helping overcome the challenges facing water infrastructure in Japan and elsewhere, including improving efficiency and reducing labor requirements for operation and maintenance, expanding the geographical coverage of services, and ensuring the security essential to IT.*

## Challenges for Social Infrastructure and Demands on Use of IT

**Tachi:** Information technology (IT) and control technology are used in a variety of ways by social infrastructure, including water infrastructure.

Consumers may not be aware of it when they see the taps and drains in their homes, but both water supply and sewage are made possible by the support of IT and control technologies, electrical equipment, and other such infrastructure.

**Shin:** There are very few countries in the world where it is safe to drink the water straight from the tap. While this is something we take for granted here in Japan, we should also bear in mind that underpinning this convenience is the role played by advanced control systems and information systems that have been built on the skills of experienced engineers and the efforts of water utilities and suppliers such as Hitachi.

**Tadokoro:** Having constructed this social infrastructure to such high standards, the challenge now facing Japan is how to maintain it into the future.

To ensure the continuity of social infrastructure, it is vital to work through the P-O-M cycle of planning, operation, and maintenance. While greater use is being made of IT in my own field of operations, there are still many aspects of maintenance that rely on work done by human beings. With the number of skilled staff set to fall in the future, there is a need to also use IT to perform maintenance more efficiently, and to collect and analyze the data associated with operation and maintenance (O&M) to optimize upgrade planning.

There is also a need to think about water and the environment in broader terms with a view to achieving efficient management of the circulation of water throughout a catchment. A key aspect of Hitachi's focus on its Social Innovation Business is the "symbiotic

**Seiichi Shin, Dr. Eng.**

**Professor, Control Systems Program, Department of Mechanical Engineering and Intelligent Systems, Graduate School of Informatics and Engineering, The University of Electro-Communications**

Following positions as tutor at the University of Tokyo in 1980, doctorate in engineering (University of Tokyo) in 1987, Associate Professor at the University of Tsukuba in 1988 and Associate Professor at the University of Tokyo, he took up his current appointment in 2006. Other roles have included President and Fellow of The Society of Instrument and Control Engineers (SICE), President of the Control System Security Center (CSSC), and chairman of the judging panel for the Japan Management Association Good Factory prizes.

autonomous decentralized" concept. This is a system concept for maintaining overall sustainability by having multiple systems that operate autonomously to fulfill their own respective functions also work together in mutual harmony and in an optimal way. Our long-term aim is to create a "symbiotic autonomous decentralized" infrastructure that encompasses not only water supply, sewage, and rivers and other environmental water, but also other social infrastructure.

**Nakano:** Greater use of IT, including open technologies, is essential for interlinking and coordinating social infrastructure. Also vital is the assessment of cybersecurity risks and the implementation of countermeasures, including for control systems. In this regard, of particular note over recent years has been the International Electrotechnical Commission (IEC) 62443 international standard for control system security. It stipulates the security programs required for compliance at each level, covering management and operation, systems, and components. In addition to participating in the standardization process, Hitachi has also developed the HISEC 04/R900E controllers that were among the first to obtain Embedded Device Security Assurance (EDSA) certification to minimize the risk of network-based cyber-threats.

In the case of critical systems, we also supply unidirectional routers that physically block access from the external network, and a system for identifying unauthorized personal computers (PCs) and forcibly excluding them to prevent security threats that issue from devices connected to the network without authorization. By taking these active steps to maintain security in control systems, we are helping to build social infrastructure that utilizes IT while also ensuring a secure environment.

## Hitachi Solutions Contributing to Innovation in the Water Industry

**Tachi:** As you noted earlier, the water sector faces numerous challenges, including aging facilities and the retirement in large numbers of experienced workers here in Japan, and physical and economic water shortages evident when we look overseas. Hitachi is marketing its solutions for the water industry globally in order to help overcome these. Can you tell me about any specific initiatives of this nature involving IT and control technology?

**Tadokoro:** In my area, we are engaging in collaborative creation with customers to develop new control technologies that involve greater integration and coordination with IT. Examples aimed at dealing with the challenge of combining energy savings with efficiency and security of supply include the supply of a water distribution control system that performs realtime analysis of data from sensors in the distribution pipe network for optimal control of parameters such as distribution pump pressures, and a water operations planning system that predicts water demand based on factors such as the air temperature, weather, and day-of-week to formulate operational plans for water intake and pumping. In other words, to achieve sustainable progress, we are seeking to use new control technologies to contribute to the entire water supply and distribution network. In a practical manifestation of the "symbiotic autonomous decentralized" concept, we are seeking to commercialize demand response control to cut or shift peaks in the consumption of electric power without compromising the reliability of the water supply by harmonizing the operation of water and electric power infrastructure.

In the field of sewage treatment, we are participating in the Breakthrough by Dynamic Approach in Sewage High Technology (B-DASH) Project of the Ministry of


**Hiroto Yokoi**

**Senior Researcher, Process Engineering Research Department, Center for Technology Innovation – Materials, Research & Development Group, Hitachi, Ltd.**

Joined Hitachi, Ltd. in 1995. Having previously worked on research into water treatment for the nuclear power industry, he is currently engaged in the research and development of treatment and control technologies for water and sewage.
Mr. Yokoi is a member of The Society of Environmental Instrumentation Control and Automation (EICA).



**Hideyuki Tadokoro, P.E.Jp**

**Senior Manager, Public Control Systems Engineering Department, Electrical Equipment Information & Control Systems Division, Omika Works, Infrastructure Systems Company, Hitachi, Ltd.**

Joined Hitachi, Ltd. in 1982. Having previously worked on the development and design of digital instrumentation and control systems and the design of water and sewage monitoring and control systems, he is currently engaged in the development and design of information and control systems for water and sewage and in overseas business activities.
Mr. Tadokoro is a member of The Institute of Electrical Engineers of Japan (IEEJ) and the SICE.

Land, Infrastructure, Transport and Tourism by trialing a water treatment control technique that uses IT-based predictive control to save electric power while maintaining the quality of the treated water.

In the case of pipe network maintenance, we are researching condition-based maintenance (CBM) techniques that utilize IT through our participation in the Rainbows Project, a joint research project on the reconstruction of water distribution networks run by the Japan Water Research Center.

**Yokoi:** In the Research & Development Group, we are focusing on research and development (R&D) work aimed at ensuring the safety and reliability of water. Two aspects of safety and reliability are "appropriate operation" and the "health of equipment." In terms of operation, we have been among the first to develop and supply water safety management systems that support the introduction and operation of Water Safety Plans in accordance with guidelines issued by agencies such as the World Health Organization (WHO) or Ministry of Health, Labour and Welfare.

In terms of equipment health, meanwhile, we have also developed abnormality prediction techniques that utilize adaptive resonance theory (ART) to categorize equipment condition and identify changes. Hitachi has already successfully applied ART in a condition monitoring system for thermal power plants that automatically identifies problems with plant operation.

We are currently using this technology to develop a system for detecting potential faults based on the operating history of pumps at water treatment, seawater desalination, and other such plants. If successfully implemented, the system will not only prevent shutdowns due to pump faults but also reduce maintenance costs without compromising the health of equipment by determining the best time to upgrade equipment.

**Shin:** When thinking about how to pass on technical skills, in addition to utilizing sensors and other IT to enable operation and maintenance to be conducted on the basis of data, we also recognize the importance of documenting practices in manuals. Future manuals will need to go beyond text to include the use of video to demonstrate operating procedures.

The use of three-dimensional (3D) mapping techniques for piping and other equipment at a plant also offers scope for improvements in maintenance efficiency.

**Yokoi:** To support safe and efficient maintenance and inspection at plants and other workplaces, Hitachi supplies a remote work instruction system that uses augmented reality (AR) and 3D data processing techniques. We are also working on the R&D of techniques for generating 3D map data from images with the aim of using these technologies to support O&M in water-related applications.

There is scope for the use of image processing techniques not only for monitoring but also in maintenance. In one example, we are helping pass on skills by developing a system for tablets that displays an inspection or operation procedure to the user when he/she points the camera at an AR marker indicating an inspection site.

**Tadokoro:** We also see potential for utilizing technologies such as sensing and the Internet of Things (IoT) and presenting information over a wider scope and in greater detail as a means of achieving the best possible O&M. In the case of sensing, we have developed a water leak management system that helps with the problems associated with water leaks in emerging economies by combining sensor data, asset information, and hydrological simulation techniques for piping networks to identify locations where the volume of water loss is high.

**Tachi:** To ensure the safety and reliability of water, work on the international standardization of things like abnormal event detection processes and crisis

**Toshihiko Nakano, Ph.D.**

**General Manager, Security Center, Strategic Planning Division, Infrastructure Systems Company, Hitachi, Ltd.**

Joined Hitachi, Ltd. in 1980. He is currently engaged in the development of security for social infrastructure systems. Dr. Nakano is a member of the IEEJ.

**Takahiro Tachi**

**Chief Engineer, Water & Environment Solutions Division, Infrastructure Systems Company, Hitachi, Ltd.**

Joined Hitachi, Ltd. in 1984. Having previously worked on the development of exhaust gas catalysts, techniques for recycling waste, and on secondment to the Japan Water Research Center, he is currently engaged in the water industry in Japan and overseas and in R&D management.
Mr. Tachi is an expert member of the International Organization for Standardization (ISO) Technical Committee 224, Working Groups 7 & 9, and a member of the EICA and the Catalysis Society of Japan (CATSJ).

management of water and wastewater is being undertaken by agencies such as the International Organization for Standardization (ISO). Hitachi is participating along with Japanese agencies in technical committees that are working on the collation of guidelines for things like the procedures to follow in a crisis, how to detect water quality events, and decision-making processes. We aim to continue making a contribution internationally, including in the field of safety standards, by incorporating Japan's water and wastewater management techniques and knowledge of crisis management in response to natural disasters into our proposals.

## Use of Social Infrastructure Security to Help Ensure the Safety and Security of Water

**Tachi:** As mentioned in an earlier discussion, security measures are essential to the achievement of more advanced social infrastructure. I would like to ask Professor Shin, who is President of the Control System Security Center (CSSC), to update us on what is happening in this field.

**Shin:** The CSSC is involved in R&D, training, awareness-raising, security certification, and other activities aimed at maintaining security and providing measures for dealing with cyber-threats against the control systems used for important social infrastructure, such as water, electric power, and gas.

As Dr. Nakano noted earlier, the IEC 62443 standard specifies security requirements for three separate layers, namely management and operation, technology and systems, and components and devices. Security certification is also dealt with in terms of these three layers. In the case of management and operation, the Japan Institute for Promotion of Digital Economy and Community (JIPDEC) provides a cybersecurity management system (CSMS) certification service for information security systems at organizations that deal with control systems. At CSSC, we launched the EDSA security certification program for embedded control system components in 2014 to cover components and devices, and we plan to commence a pilot certification service for technology and systems in 2015. This will make Japan the only country in the world with a comprehensive certification regime for control system security. Utilizing knowledge that you have shared in your role as a member of the CSSC, I look forward to Hitachi providing safety and security to the water industry throughout the world.

**Nakano:** In addition to ensuing that systems are robust, another factor vital to keeping important water infrastructure safe in this era of open systems is that the systems are capable of an accurate and timely response to threats and to other aspects of the ever-changing social environment.

To provide solutions that satisfy this requirement, Hitachi believes it is vital to incorporate "adaptivity," "responsivity," and "cooperativity" into the security measures for social infrastructure. "Adaptivity" means working through the plan, do, check, act (PDCA) cycle to make ongoing enhancements to preemptive countermeasures and defenses against ever-changing threats and other aspects of the social environment. "Responsivity" means accepting that security incidents such as attacks or disasters are inevitable and strengthening training exercises and incident response measures to minimize subsequent damage and to shorten the time it takes to recover. "Cooperativity" means strengthening countermeasures by standardizing situation assessments through the sharing of security information between organizations in order to establish defenses and minimize damage based on obtaining security-related information in a timely manner. Establishing security measures based on these three elements that cover both physical and cybersecurity and include both system management and operation will be essential to social infrastructure in the future.

**Yokoi:** In the case of techniques for physical security, Hitachi supplies technology for using finger veins to perform biometric authentication; systems able to coordinate multiple cameras and track suspicious individuals not only by their faces but also by the color of their clothes, the features of objects they are carrying, and the routes they follow; and explosive detection systems that incorporate mass spectrometers. A recent focus has been the development of security systems that do not compromise user convenience, such as by performing identification as they operate a touch panel or pass through a gate.

**Tadokoro:** For control security, we are increasing the level of security by adopting a philosophy of defense in depth that combines multiple layers of defense, including component-level countermeasures such as one-way routers that block unauthorized access, system-level design practices such as the use of white lists to only permit pre-approved access, and physical authentication systems.

**Tachi:** Because water is a part of the social infrastructure on which lives depend, particular consideration needs to be given not only to efficiency but also to safety and reliability. In addition to taking account of security, Hitachi is accelerating the fusion of IT and control technology and putting its comprehensive capabilities to work on helping overcome the challenges facing the water industry, both in Japan and elsewhere. Thank you for your time today.

Overview

# Water Industry Solutions for Ongoing Development of Social Infrastructure

Takahiro Tachi
Naotoshi Chiba
Takashi Tanaka

## MAINTAINING A HEALTHY WATER ENVIRONMENT

PEOPLE'S daily lives and corporate economic activity are supported by a variety of social infrastructure. Included in this is the water infrastructure, which along with being important because it is vital for life, also faces a variety of challenges that need to be overcome, including how to maintain a healthy water environment and ensure efficient water distribution.

Hitachi operates its Social Innovation Business, which seeks to transform social infrastructure by making the most of information technology (IT), and its work on overcoming the challenges of the water industry (water industry solutions) forms a part of this business. Specifically, by supplying products, systems, and services, Hitachi is working to overcome challenges such as conserving water sources, flood control, water supply and sewage, supplying water as a resource (producing or recycling water), and wastewater treatment.

There has been interest in recent years in using the interoperation of different forms of social infrastructure as a way of making more efficient use of energy and other resources, one example being the study of how to coordinate water and electric power to make efficient use of electricity.

This article gives an overview of this issue of *Hitachi Review* and looks at trends in the water industry in Japan and elsewhere. It also presents examples of water industry solutions that contribute to the ongoing development of social infrastructure.

## WATER IN JAPAN AND ELSEWHERE

### Current Status of Water and Water Resources

While the total global volume of water amounts to 1.4 billion $km^3$, only 0.01% of this is believed to be fresh water suitable for drinking or use in daily life(1). Moreover, this fresh water is unevenly distributed, with a number of communities suffering from water scarcity, particularly in low-latitude (equatorial) regions.

There are also the issues of water shortage and pollution that accompany economic development and rising living standards. In terms of the volumes of water taken for human use in different parts of the world, rapid rises are anticipated in places like Asia in particular, with the total estimated to grow by 30% between 2000 and 2025(2).

In Japan on the other hand, while there has been little sign of worsening water scarcity over recent years beyond a few isolated exceptions, if agricultural imports are thought of as representing an indirect import of water, then the country is not unaffected by overseas water shortages. There have, however, been frequent instances of localized heavy rainfall or flood damage, meaning there is a need for water resource management that includes storm water.

### Trends in Water Industry

The size of the global water industry is predicted to grow from 36.2 trillion yen in 2007 to 86.5 trillion yen in 2025(1). Nearly 90% of this is accounted for by water supply and sewage, of which 40 to 50% is estimated to involve management and operations. The remaining 10% or more is made up of seawater desalination, industrial water, and recycling, all markets that are expected to grow.

There is a lot of competition in the utility operations sector of the market for water supply and sewage from local and European companies, among others. This means that there is potential for Japanese companies with little overseas experience to expand their activities gradually by building up experience over all areas of activity, including design, construction, and maintenance management, as they

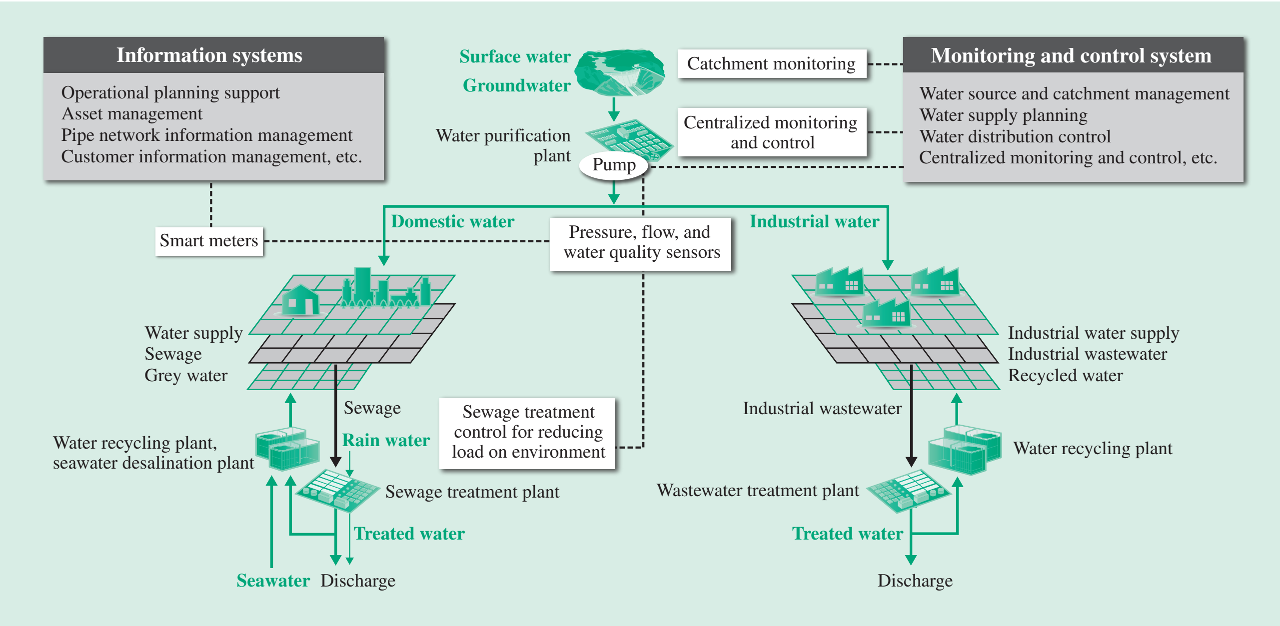



*Fig. 1—Examples of Intelligent Water Systems.*
*The integration of information and control systems with water treatment systems helps optimize the water cycle within cities and catchments.*

develop an understanding of the challenges facing each country or region and contribute to their solution. There is also scope for Japanese companies to draw on their expertise in membrane-based treatment and efficiency improvement to play a part in the markets for seawater desalination and water re-use, which are expected to grow.

In Japan meanwhile, with water supply coverage having reached 97.7% of the population as of the end of FY2013, and with the equivalent figure for sewage being 77.0%, these markets now primarily involve the replacement of existing equipment or its maintenance and management. A variety of challenges need to be confronted if water supply and sewage assets are to be passed on to the next generation in a healthy condition. These include the appropriate replacement and maintenance of aging equipment, the transfer of skills from the large number of experienced staff approaching retirement, improvements to operational efficiency by consolidating activities and covering larger areas, and dealing with the fall in water demand resulting from the shrinking population and changes in lifestyle.

It was against this background that the Ministry of Health, Labour and Welfare published its New Water Supply Vision in March 2013, and the Ministry of Land, Infrastructure, Transport and Tourism published its New Sewerage Vision in July 2014, which included their long term visions for water supply and sewage, strategies for overcoming challenges, and the division of responsibilities between the parties concerned. Furthermore, the Basic Act on the Water Cycle was enacted in April 2014 to ensure that policies relating to the water cycle are pursued in a comprehensive and consistent manner.

Table 1. Components of Intelligent Water Systems
*Hitachi intends to work on implementing the "intelligent water" concept through the interoperation of various technologies, systems, and services.*

| Field | Typical systems or services | Typical benefits |
|---|---|---|
| Operations | • System planning and engineering<br>• Operation planning support system<br>• Asset management (EAM)<br>• Pipe document and drawing management<br>• Customer data management<br>• Billing management<br>• Use of smart meters | • Operational efficiency<br>• Investment smoothing<br>• Service improvement |
| Water supply | • Catchment simulation<br>• Water supply (planning)<br>• Water distribution control | • Stable supply of water<br>• Reducing load on environment |
| Flood control | • Flood simulation<br>• Rainwater drainage | • Safe water environment |
| Water treatment control | • Monitoring and control<br>• Water safety management<br>• Operations outsourcing service | • Reliability improvement<br>• Efficiency improvement |
| Water treatment facilities | • Water purification plant<br>• Sewage treatment plant<br>• Wastewater treatment plant<br>• Membrane filtration plant<br>• Seawater desalination plant | • Reliability improvement<br>• Efficiency improvement |

EAM: enterprise asset management

## OVERVIEW OF WATER INDUSTRY SOLUTIONS

Hitachi offers water industry solutions as a means of contributing to the ongoing development of social infrastructure by overcoming the challenges facing the water industry. Its aim is to provide comprehensive solutions by combining various products and systems as appropriate and integrating them with services such as maintenance and operations.

Hitachi proposed the Intelligent Water System concept to represent its basic approach to the appropriate management of water resources and water-related infrastructure across entire cities or catchments, and to undertaking system-wide optimization. This involves seeking to overcome challenges by putting information and telecommunications technology and control technology to work over a wide area, and seeks to help with things like reducing the load on the environment as well as improving reliability and the efficiency of operational management. Fig. 1 and Table 1 show examples of the components of such systems.

## WATER INDUSTRY SOLUTIONS IN JAPAN

This section describes work aimed at overcoming the challenges facing water supply and sewage in Japan from three perspectives.

(1) Contribution to water safety and reliability

The water supply in Japan delivers water that is safe to drink directly from the tap, 24 hours a day and 7 days a week. One of the technologies Hitachi supplies to help ensure safe water quality is a system that automatically modifies treatment plant control of dosing for chemicals such as flocculants in response to sudden changes in the quality of intake water, without relying on manual intervention by experienced staff. This is helping deal with the falling number of such skilled staff by expanding the range of conditions under which the control system can operate.

For water quality analysis, Hitachi is working on the development of small sensors that can perform on-site multi-factor testing of water quality in realtime. By enabling a response to sudden changes in water quality, this should help ensure a safe water supply.

The failure of infrastructural equipment can have serious consequences for both the public and industry. In order to respond quickly to failures that result from aging and other factors, Hitachi is currently developing a fault prediction and recovery support technology that performs statistical analysis using adaptive resonance theory (ART)[(a)] and operational data from plant and equipment. Hitachi is also strengthening cybersecurity for control systems and supplying physical security technologies that prevent the unauthorized intrusion of people or objects into the water infrastructure.

The Great East Japan Earthquake has prompted measures to improve the resilience to disaster of social infrastructure, and Hitachi has responded by developing and testing temporary emergency sewage infrastructure for use in times of disaster, including high-speed coagulation sedimentation[(b)] or membrane bioreactors (MBR)[(c)].

Work is also underway on the international standardization of control security and of crisis management for water and sewage. Hitachi is participating in this work through an industry-government-academia partnership, and is taking steps to acquire compliance certification.

(2) Contribution to efficiency and reducing the load on the environment

Other challenges include protection of the environment, energy efficiency, and operational efficiency. Hitachi is helping water utilities improve the efficiency of their routine operations by supplying a water supply planning system.

For asset management, Hitachi is helping to improve maintenance efficiency and reduce infrastructure replacement costs by developing technology for things like estimating the distribution of water leaks or using life cycle cost analysis as a basis for assisting with water pipe replacement.

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(a) Adaptive resonance theory (ART)
ART is a self-organizing neural network model (a type of information processing model) used for category learning without learning from sample patterns (without a "teacher"). What normally happens with neural network learning is that learning new input patterns results in a loss of past memory (categories), and conversely that placing an emphasis on retaining past memories is detrimental to new learning. ART avoids this problem by comparing and classifying the consistency of input and memory against reference parameters and then adaptively generating and expanding categories based on the result. It has attracted attention in recent years in pattern recognition and classification model applications.

(b) High-speed coagulation sedimentation
A water treatment system that speeds the rate of sedimentation by adding two different flocculants during the coagulation sedimentation process (the agglomeration and sedimentation of colloidal particles and suspended solids).

(c) Membrane bioreactor
An advanced water treatment system that combines biological treatment with the use of a membrane to separate solids and fluids. An issue with the previous activated sludge method of biological treatment was the large size of the equipment needed for the removal of sludge from the final settling ponds where it forms as sediment after the action of microbes on the sewage in the reaction tanks. In contrast, rather than working by sedimentation, the membrane bioreactor method uses a membrane filter with microscopic pores to separate out the sludge. This reduces the equipment size and improves the quality of treated water.

In the case of sewage and wastewater treatment, Hitachi is reducing the load on the environment and boosting efficiency in terms of both water treatment and operational control, including by installing an anammox treatment system that uses an inclusive immobilization technique(d) to treat industrial wastewater, and trialing a new operation control technique for denitrification.

(3) Contribution to utility operations and maintenance

Hitachi is contributing to operations through public-private partnerships (PPPs) with water utilities that take on a variety of forms, including partial outsourcing, full outsourcing, and private finance initiatives (PFIs).

A 20-year PFI project that includes on-site electric power generation has been running at the Asaka Water Purification Plant / Misono Water Purification Plant of the Bureau of Waterworks Tokyo Metropolitan Government for nearly 11 years, and Hitachi intends to continue striving to contribute to these plants through its involvement in the project. Also in progress is a PFI project that combines both the construction and ongoing maintenance management of a water treatment plant at Yubari City in Hokkaido that uses the membrane filtration method(e).

The introduction of inspection, equipment management, and other systems that use mobile devices is also boosting maintenance and management efficiency. By introducing new products and systems to improve the efficiency of services, and by taking advantage of the synergies that arise from incorporating improvement ideas obtained through this work into technology developments, Hitachi is seeking to supply high-quality, comprehensive solutions (see Fig. 2).

## SOLUTIONS FOR GLOBAL WATER INDUSTRY

Water problems are global challenges that are closely interlinked with the problems of food and energy, and the competition to acquire water business markets is intensifying, involving not only private-sector companies but also national and other government agencies.

Given these circumstances, Hitachi is accelerating its activities aimed at overcoming the challenges of the global water industry through joint ventures such as public-private partnerships and collaborations with other companies from Japan or elsewhere. The following sections describe some examples.

(1) Water supply and sewage

Hitachi is helping rationalize the overall operations of water supply and sewage in the Maldives through its participation in the running of Male' Water and Sewerage Company Pvt. Ltd. (MWSC). MWSC currently operates eight seawater desalination plants that use reverse osmosis (RO) membranes(f) to

(d) Anammox treatment system using an inclusive immobilization technique
An advanced treatment system capable of reliable denitrification with smaller space and energy requirements through the use of inclusive immobilization carriers in which anaerobic ammonium oxidation (anammox) microbes that remove nitrogen from sewage are immobilized in a polymer.

(e) Membrane filtration method
An alternative to the previous rapid filtration method, which combined coagulation, sedimentation, and filtration, this technique uses membrane filtration for continuous water purification. It is entering wider use as a safe and reliable water purification technique that can also deal effectively with pathogenic protozoa that have resistance to the widely used chlorine disinfection of water supplies. Membranes in a variety of materials and forms are used, each of which has different characteristics.

(f) Reverse osmosis (RO) membranes
These are membranes with microscopic pores (diameter of 1 nm or less) that allow water to pass but not impurities such as salt. If water with different concentrations of salt is separated by an RO membrane, the process of osmosis would normally cause water to flow from the low- to the high-concentration side. This can be reversed, however, by raising the pressure on the high-concentration side above the osmosis pressure, thereby causing water to flow to the low-concentration side. This principle of reverse osmosis is used with water treatment membranes for applications such as seawater desalination.

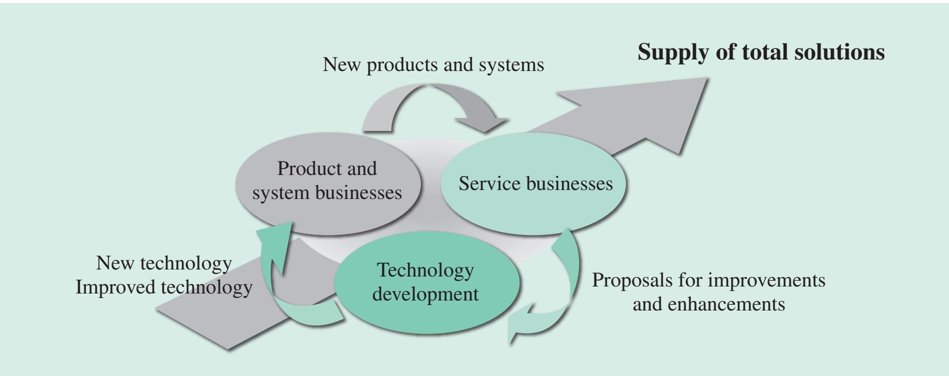


*Fig. 2—Overview of Coordination between Technology Development, Product and System Businesses, Service Businesses.*
*Hitachi aims to supply high-quality service solutions by coordinating the operation of these different businesses.*

*Fig. 3—Hitachi's Participation in Water Business in Maldives.*
*Hitachi is participating in the operations of Male' Water and Sewerage Company Pvt. Ltd. in the Maldives. The drinking water bottling plant is located next to the seawater desalination plant.*

produce fresh water from groundwater drawn from on-site wells. This process is subject to rigorous water quality management to ensure a safe water supply to the 110,000 population of the island of Male'. The desalinated water is also shipped and sold as bottled water to enhance people's way of life (see Fig. 3). Hitachi intends to continue helping to overcome the challenges associated with water in the Maldives, and to put this experience to use in other activities.

(2) Large seawater desalination projects

Hitachi is focusing on the seawater desalination business as one way to overcome water shortages. There are concerns about places around the world that suffer from physical water scarcity, particularly in equatorial regions, and places that suffer from water scarcity for economic reasons due to a surge in demand for water resulting from population growth or economic development. While seawater desalination is one effective way of dealing with this, its challenges include improving energy efficiency and reducing the cost of construction and operation.

Hitachi is participating in the Mega-ton Water System(g) project of the Japanese Cabinet Office's Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program), and the Project on Water-saving Recycling Systems(h) of the New Energy and Industrial Technology Development Organization (NEDO), which are public-private-academia collaborations engaged in the development and testing of large seawater desalination plants, a market that is expected to grow in the future. The projects have succeeded in cutting costs and improving energy efficiency by 30% or more compared to previous seawater desalination systems. This includes a system that helps reduce the load on the environment by reducing the concentration of salt in discharged water by incorporating certain processes used in sewage treatment for use in seawater desalination. There is scope for this system to be deployed at water treatment plants designed for use in regions of water scarcity.

In May 2015, Toray Industries, Inc. and Hitachi signed a memorandum of understanding with Saline Water Conversion Corporation, a seawater desalination company, and Abunayyan Trading Company Limited, a water and energy business, both of Saudi Arabia, to conduct trials of the Mega-ton Water System. By drawing on experience gained from the development of advanced technologies, such as low-pressure RO membranes that help conserve energy and the use of a two-stage design for the RO membrane pressure vessel to make systems more efficient, the aim is to

(g) Mega-ton Water System
One of the projects undertaken as part of the FIRST Program that ran from FY2009 to FY2013. Aimed at helping overcome worsening water problems around the world, the project involved the research and development of core technologies for large, low-cost seawater desalination systems that are energy efficient and place a low load on the environment. A total of 31 organizations participated, including universities and private-sector companies such as Hitachi and Toray Industries, Inc., and the project achieved its research goals. A pilot plant demonstration is planned to commence in 2015 based on the results of the Mega-ton Water System project.

(h) Project on Water-saving Recycling Systems
A project that ran from FY2009 to FY2013 with the aim of developing technologies that can help reduce the load on the environment in energy-efficient ways to enhance further Japan's strengths in water treatment and water resource management techniques. The project developed technologies associated with the water cycle, including innovative membrane separation, energy-efficient membrane bioreactors, separation and recovery of valuable metals and toxic substances, and the highly efficient decomposition of persistent materials. It also included conducting trials and surveys aimed at deploying water resource management techniques in Japan and elsewhere.

build a large seawater desalination plant (in the one million $m^3$/day range) in the near future that features a low load on the environment and low cost.

(3) New business development

Hitachi is working on collaborating with non-Japanese companies to improve and expand its solution marketing capabilities.

Hitachi signed a memorandum of understanding with the water treatment company, Veolia Water Solutions & Technologies SA, in April 2014 relating to the companies working together on water infrastructure projects. The intention is to organize joint ventures on a project-by-project basis for water and sewage treatment, seawater desalination, and other such projects in Middle East, Africa, and Asia. It will also provide opportunities for utilizing Veolia's know-how and sales channels for engineering, procurement, and construction (EPC), as well as operation and maintenance (O&M).

In January 2015, Hitachi acquired Aqua Works and Engineering Pte. Ltd., a Singaporean water treatment equipment and engineering company. This will strengthen overall marketing capabilities in the Southeast Asian region by combining Aqua's water landscaping equipment, such as fountains and pools, with the RO membrane systems of Hitachi Aqua-Tech Engineering Pte. Ltd.

Elsewhere, water treatment for the oil and gas industry is another sector where Hitachi is engaging in new initiatives. With environmental regulation of the oil and gas industry becoming progressively stricter, one of the challenges faced by the industry is how to treat the water produced as a byproduct of oil and gas extraction.

Meanwhile, there is growing demand for sulfate removal units (SRUs) for use with waterflooding, a technique for increasing oil production by injecting pressurized water into oil-bearing strata. The technique requires the elimination of sulfates because of the role they play in the formation of scale (sediment). Another market is that for water treatment equipment used in applications such as offshore oil fields, where special specifications apply because of limitations on things like installation space and power supply.

Hitachi is working on new initiatives that draw on its extensive knowledge of water treatment technology to supply solutions to the challenges specific to the oil and gas industry.

## CONTRIBUTING TO SUSTAINABLE WATER THAT IS SAFE AND RELIABLE

This article has given an overview of trends in the water industry in Japan and elsewhere, and Hitachi's involvement in water industry solutions. Based on its many years of experience and extensive track record, Hitachi intends to continue contributing to the ongoing development of social infrastructure, including safe and reliable water.

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Featured Articles

# Water Distribution Solution for More Efficient Operation of Water Supply

Shinsuke Takahashi, Ph.D.
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Takeshi Takemoto
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*OVERVIEW: The water industry is facing major changes in its business environment, including a rising need to replace aging equipment set against falling demand and revenue due to the declining population. One factor seen as critical to achieving ongoing progress under these conditions will be to reduce costs further by improving the efficiency of capital investment and operations. In response to these challenges, Hitachi is working on research and development and supplying solutions that facilitate greater operational efficiency, including energy-efficient water supply operation systems and water distribution control systems that help in ways that include reducing electricity costs and the load on the environment. The solutions that Hitachi is currently developing with the aim of making further efficiency gains, including by reducing capital investment and operating costs, are a water supply operation technique that can cut or shift peak demand for electric power, a technique for reducing capital investment by determining the appropriate time to replace water pipes, and a leak distribution estimation technique that reduces management costs by improving the productivity of leak surveys.*

## INTRODUCTION

THE water industry is facing major changes in its business environment, including a rising need to replace aging equipment set against falling demand and revenue due to the declining population[1]. There is also demand for measures to make equipment more resilient in light of the experience from the Great East Japan Earthquake, and for measures that can cut or shift peaks in electric power consumption in response to power shortages. One factor seen as critical to achieving ongoing progress under these conditions will be to reduce costs further by improving the efficiency of capital investment and operations.

In response to these challenges, Hitachi is working on research and development and supplying solutions that facilitate greater operational efficiency, including energy-efficient water supply operation systems and water distribution control systems that help in ways that include reducing electricity costs as well as the load on the environment. This article describes three examples of new research and development that are the latest initiatives by Hitachi in this field (see Fig. 1). One is a water supply operation technique that can reduce electric power costs by providing an electric power demand response (DR) function or by accepting requests to cut or shift peaks in electric power consumption. The others are a technique based on the evaluation of life cycle cost (LCC) that reduces capital investment by determining the appropriate time to replace water pipes, and a leak distribution estimation technique that reduces management costs by improving the productivity of leak surveys.

## WATER SUPPLY OPERATION AND PLANNING TECHNIQUE WITH ELECTRIC POWER DR FUNCTION

DR has attracted attention in recent years as a way to control the consumption of electric power during periods of peak demand to ensure a reliable supply[2]. DR is an incentive scheme that encourages users to reduce their demand when needed to maintain the balance of supply and demand. DR comes in the form of both tariff-based and incentive schemes. Tariff-based schemes use electricity pricing options to encourage users to shift peak demand, such as critical peak pricing and time-of-use (TOU) tariffs that vary

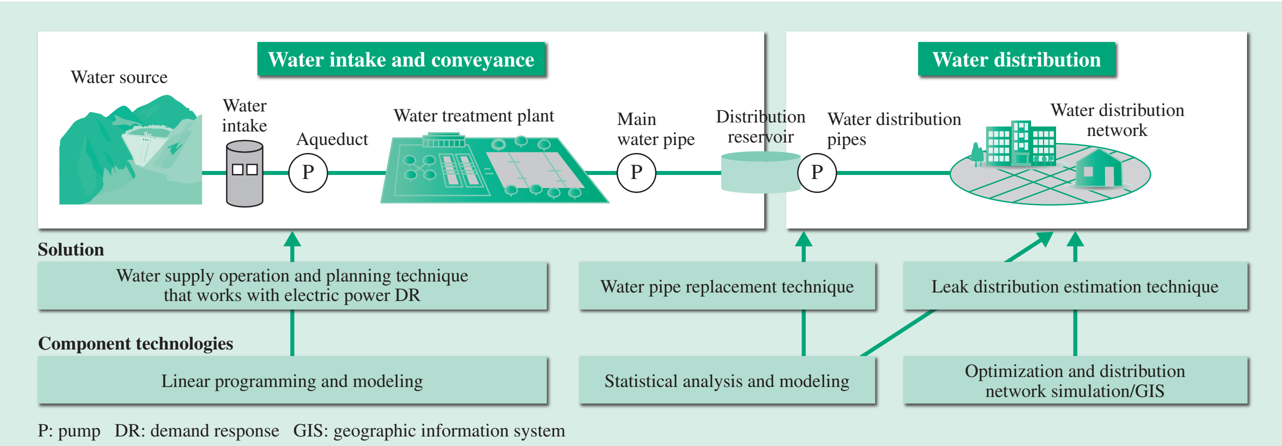



*Fig. 1—Water Distribution Solution for More Efficient Operation of Water Supply and Individual Technologies.*
*To deliver solutions that enhance operational efficiency, Hitachi is working on the research and development of a water supply operation and planning technique that works with electric power DR, a technique for determining when to replace pipes, and a leak distribution estimation technique.*

depending on the time of day. Incentive schemes such as load control programs request users to reduce their power use at times when the supply of electric power is constrained and pay them for doing so in the form of a bonus. Hitachi has developed a water supply operation technique that reduces electricity costs by earning these incentives.

## Water Supply Operation Technique

The water supply operation technique consists of an operation mode that seeks to smooth electric power use in ways that cut the basic tariff by cutting or shifting demand peaks (that is, by smoothing demand across the course of a day), and a DR operation mode that earns incentives by reducing demand in response to requests (see Fig. 2). Water supply systems use a large number of distribution reservoirs to buffer the gap between demand for water and the supply from the water treatment plants. Furthermore, falling demand in recent years means there are a significant number of distribution reservoirs with excess capacity. This means that peaks in electricity demand can be shifted or cut by taking advantage of this unused water storage capacity to shift the timing of conveying pump operation.

Minimizing electric power consumption as far as possible during demand peaks or during time periods specified in DR requests requires well-formulated operating plans to ensure that pump operating times do not overlap. It also requires risk management to ensure that the water levels in distribution reservoirs do not fall below their lower limits. The first of these challenges is met by using mathematical programming called minimum-maximum (min-max) optimization

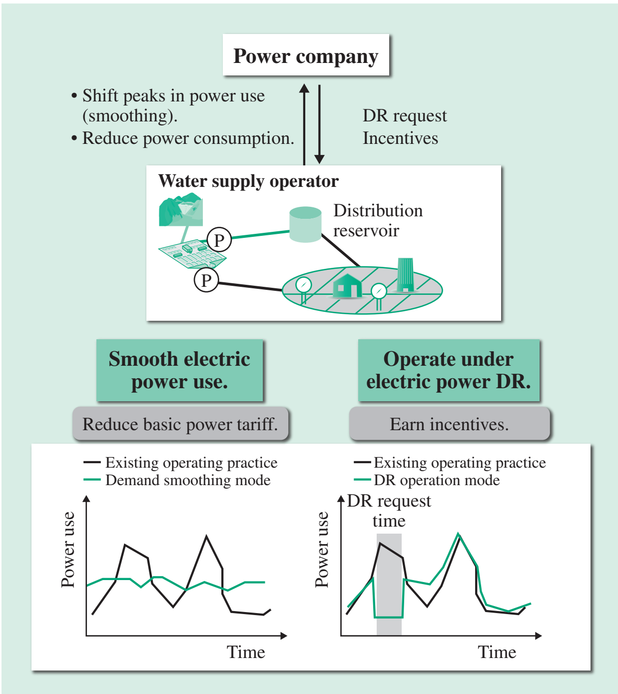



*Fig. 2—Water Supply Operation and Planning Technique.*
*The water supply operation and planning technique provides an operation mode for smoothing the demand for electric power over the course of a day to reduce the basic power tariff, and an electric power DR operation mode that earns incentives by reducing demand in response to requests.*

to produce detailed pump operating plans. For the second challenge, low water level limits are set so as to retain a 12-hour buffer of water supply in the event of a problem such as a conveying pump failure, and the pump operating plans are formulated in a way that ensures these limits are not violated. These practices

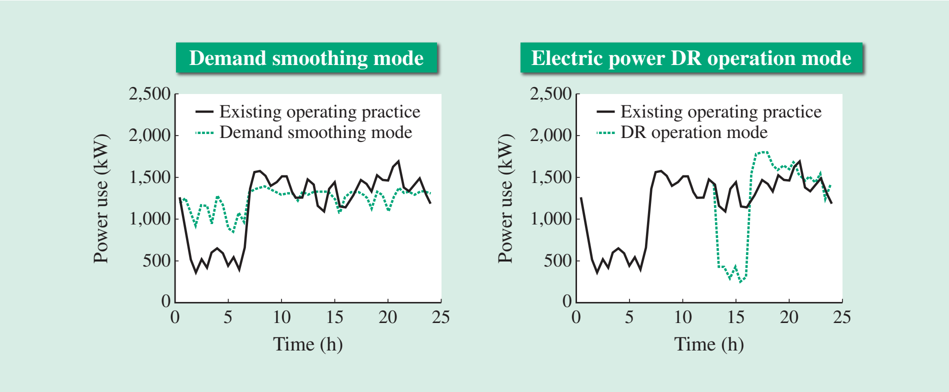



*Fig. 3—Benefits of Using Water Supply Operation to Manage Electric Power.*
*The graphs show the benefits of using the demand smoothing and DR operation modes to manage electric power use.*

ensure the maximum possible power savings and maximize the incentive income and the reduction in power costs.

### Benefits of Electric Power Management

Hitachi assessed the benefits of using the techniques it developed for electric power management at a medium-sized water distribution system serving a daily water demand of approximately 60,000 $m^3/d$ (see Fig. 3). The operating plans covered not only the conveying pumps, but also the intake pumps that made up a large proportion of power consumption.

In power smoothing mode, the new system succeeded in reducing peak daily demand by approximately 20%, from 1,726 kW under existing practices to 1,374 kW. In DR mode, peak demand during the time period covered by DR requests (1 PM to 4 PM) was reduced by approximately 70%, from 1,550 kW under existing practices to 460 kW. It is also possible to operate using both modes at once. It is anticipated that using these operation modes will reduce annual electric power costs.

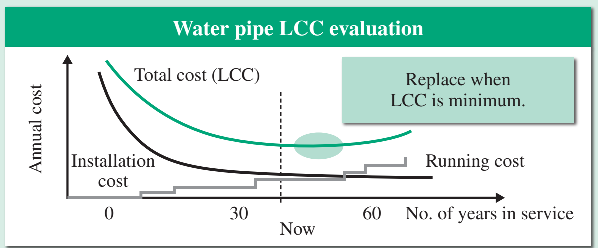
## WATER PIPE REPLACEMENT TECHNIQUE BASED ON LCC EVALUATION

### Water Pipe Replacement Technique

Hitachi has implemented a technique that evaluates the LCC of water pipes to calculate the best time to replace them (see Fig. 4). The "installation cost" means the cost of replacing water pipes spread across the number of years they will be in service, and the "running cost" means the total cost of operation spread across the number of years in service. This latter includes the cumulative total of repair costs, compensation for service outages or flooding, and the cost of water lost through leaks. The LCC is the sum of the installation cost and running cost. The installation and running costs respectively decrease and increase the longer the pipes are in service. Accordingly, the best time to replace the water pipes is after the number of years of service that minimizes this sum. Because it is likely that the LCC will depend on the type of pipe (pipe material, diameter, and so on) and the conditions in which it is used (soil and ground conditions, and so on), it is necessary to calculate an LCC curve and optimal replacement timing separately for each case (pipe type and conditions).

### Example Assessment

The LCC curve and optimal replacement timing were calculated using actual data on water leak incidents. For the running cost calculation, the average cost of a leak incident, including the cost of repairs and water loss, was calculated from historic data and the total cost was obtained by multiplying this by the total number of leak incidents. This "total number of leak incidents" was determined by summing up the leak incident rates (number of incidents per year for a unit length of pipe) for each type of pipe (pipe material, diameter, and number of years in use), which were




LCC: life cycle cost

*Fig. 4—Technique for Determining when to Replace Water Pipes Based on LCC Evaluation.*
*The technique determines the best time for replacing water pipes in order to minimize their LCC.*

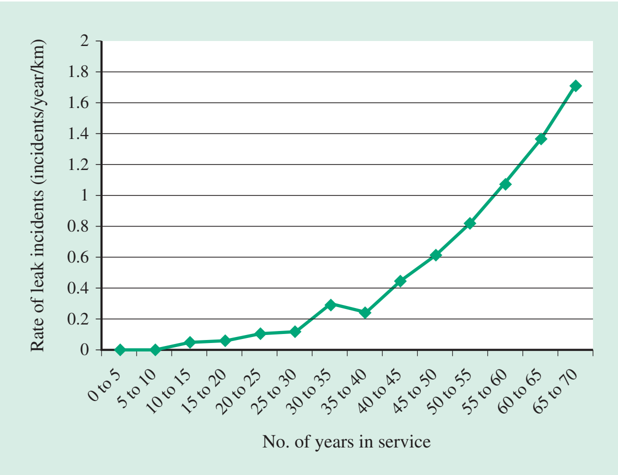



*Fig. 5—Results of Leak Incident Rate Calculation.*
*The graph shows the rate of leak incidents (incidents/year/per km) plotted against the number of years in service.*

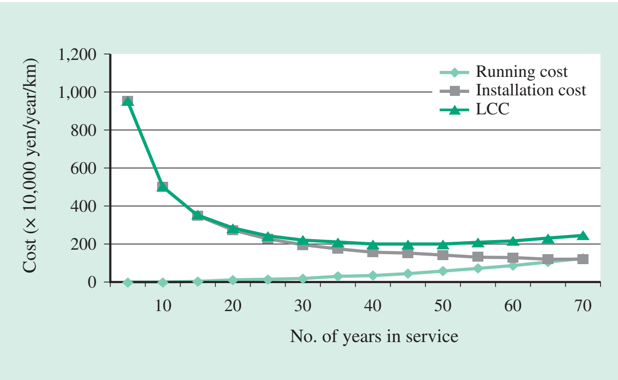



*Fig. 6—Results of LCC Calculation.*
*The LCC is the sum of the installation and running costs.*

determined from historic leak incident data. Fig. 5 shows an example leak incident rate calculation for 75-mm pipe made of rigid polyvinyl chloride (VP). The calculation used actual data for the first 40 years of use and a predictive formula(3) for subsequent years.

Fig. 6 shows the LCC curve for 75-mm VP pipe. The minimum LCC occurs at 40 years. In other words, the best time for replacement is after 40 years of use. This same procedure can be used to calculate the optimal replacement timing under various different conditions. In this case, leaving the pipes in use for five or 10 years longer than the optimal time results in LCCs that are roughly 2 to 3% or 6 to 8% higher respectively. This demonstrates that deferring replacement for any longer (10 years or more) is undesirable because of the increased cost.

While this example produced a result that was close to the statutory durable life, depending on the type of pipe and conditions of use, it is likely that there are pipes that can last longer than this. This means there is scope for reducing the capital and maintenance costs for water pipes by using the same evaluation method to identify such pipes and then allowing them to remain in use for longer periods of time.

## TECHNIQUE FOR ESTIMATING WATER LEAK DISTRIBUTION

To deal with leaks more efficiently, it is important to identify those parts of the water network in which leaks are most frequent. To minimize capital investment and improve leak management productivity, the number of sensors, field tests, and other resources required for this identification process needs to be kept to a minimum. Accordingly, Hitachi has developed a technique for estimating the distribution of leaks in the water distribution network by performing a hydrological analysis (pipe network calculation) using data from a limited number of flow and water pressure sensors located at different parts of the network and asset data such as the degree of obsolescence of the water pipes (see Fig. 7). This works by virtually

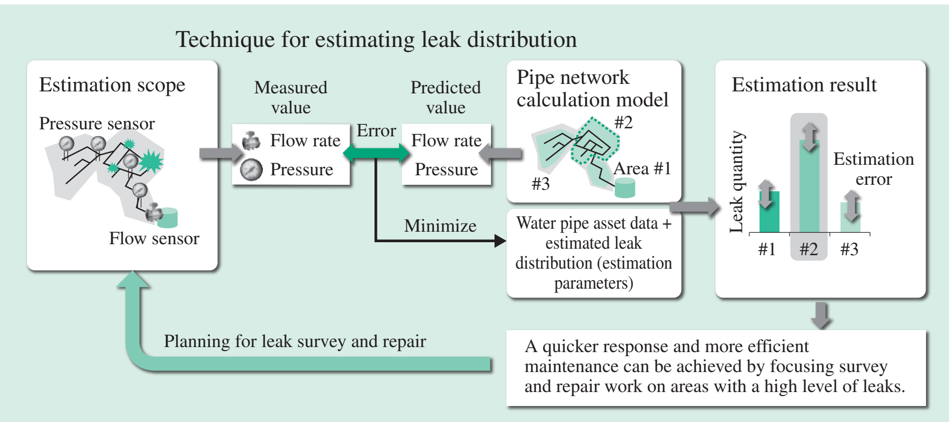



*Fig. 7—Technique for Estimating Leak Distribution.*
*The distribution of leaks on the water pipe network is estimated from water pipe asset data and pipe network calculations.*

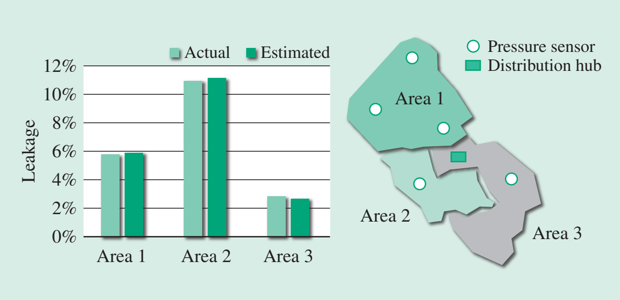



*Fig. 8—Results of Estimating Leak Distribution.*
*The graph shows the actual and estimated values for leaks in each of three virtual areas as a percentage of the total water supply across all three areas.*

dividing the network up into a number of small areas and estimating the volume of leaks in each area. The technique estimates the unknown parameters that specify the geographical distribution of water leaks by performing a hydrological analysis such that the estimated pressures match the actual measured pressures. It uses asset data to determine how the likelihood of a water leak occurring varies across the region, and uses this to estimate the distribution of leaks. This reduces the number of parameters to be estimated and improves the reliability of the result.

A test that simulated actual field conditions demonstrated that the technique could estimate the quantity of leaks to an accuracy of ±2% of the total volume of water supplied by the network (see Fig. 8).

A cost-benefit analysis was also performed for a water distribution network with 300 km of pipe and leakage of around 20% (see Fig. 9). The new technique worked by splitting the above network up into five large district metered areas (DMAs) and then further dividing each of these into three virtual areas, giving a total of 15 virtual areas for the purposes of leak management. The two existing methods involve using and not using DMAs respectively. The former method splits the network into 15 DMAs for leak management and the latter method manages the entire network as a single undivided area. The management cost in Fig. 9 consists of the sum of all costs associated with leak management, including capital investment for things like establishing the DMAs and installing sensors, leak survey costs, and the cost of water lost due to leaks. The results show that the management cost for the new technique is approximately 10% lower than the existing method using DMAs. This was because the new technique requires less capital investment for splitting the network into DMAs.

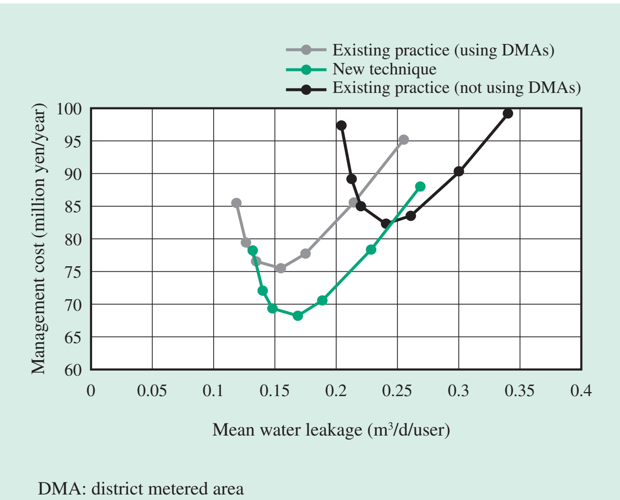



*Fig. 9—Estimated Cost-benefit of Investment.*
*The graphs show a comparison of the management costs for the new technique and existing practices.*

## CONCLUSIONS

This article has described a number of initiatives aimed at improving the operational efficiency of water distribution networks. These initiatives include a water supply operation technique that works with electric power DR and can be used to cut or shift peaks in power demand, a technique for determining when to replace water pipes based on LCC evaluation, and a technique for estimating the distribution of water leaks.

Hitachi intends to boost its contribution to the operation and planning of water supply systems by continuing to enhance and deploy these techniques. Hitachi also intends to continue developing new solutions that deliver further operational improvements by reducing things like capital investment and energy use through the effective coordination and harmonization of geographically distributed water supply systems.

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Featured Articles

# Monitoring and Control Systems and Information Processing Systems to Support Safe Water Supply Operation

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Tadao Watanabe
Tatsuhiko Kagehiro, Ph.D.
Koji Kageyama, Ph.D.
Yukako Asano, Ph.D.
Hideyuki Tadokoro, P.E.Jp

*OVERVIEW: An important part of the social infrastructure, water supply, is moving from an era characterized by expansion in scale to one based on maintenance and management, leading to growing expectations for the use of ICT to provide safe and rational management. While ICT development in the water industry has pursued objectives that include safe water quality and reliable water supply, advances in information infrastructure and the growing diversity of control network systems in recent years have also created an urgent need for measures to deal with the security risks associated with IT equipment. Taking note of the future spread of the IoT and changes in the structure of society, Hitachi is developing monitoring and control systems and information processing systems to overcome these challenges. This article describes diagnostic control techniques that contribute to the safety of equipment and water quality, and technologies for information system security and physical security.*

## INTRODUCTION

WATER supply is a vital part of the infrastructure of society, with coverage in Japan reaching 97.7% of the population as of the end of 2013[(1)]. In addition to strengthening the provision of safe water quality and reliable water supply, maintaining high-quality water services in the future will also require measures for dealing with things like demographic changes and advances in information infrastructure.

According to the National Institute of Population and Social Security Research, the population of Japan is already on the decline, with a forecasted fall from 127.24 million in 2013 to 86.74 million in 2060[(2)]. Looking to the long term, this means that there will be a need to rationalize operation and maintenance to cope with falling demand. Another concern is the difficulty of maintaining safe water quality during adverse circumstances, such as water quality incidents, if knowledge of how to maintain services is not passed on due to the diminishing number of skilled staff. Meanwhile, with the Tokyo 2020 Olympics estimated to attract around five million domestic and overseas visitors[(3)], along with controlling demand for water at particular times and places, ensuring the physical security of facilities also poses a challenge.

In terms of information infrastructure, there is scope for the rationalization of maintenance by taking advantage of the growing prevalence of the Internet of Things (IoT), for example, to utilize functions such as automatic meter reading, remote equipment diagnosis, and efficient control systems. On the other hand, this

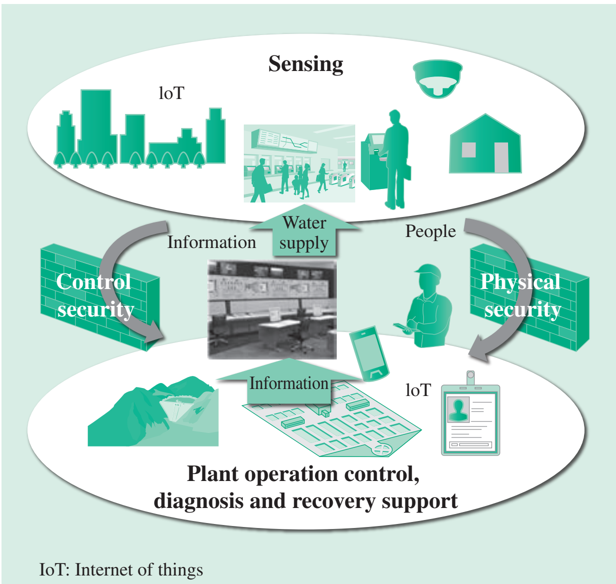


*Fig. 1—Monitoring and Control Systems and Information Processing Systems to Support Safe Water Supply Operation.*
*Advances in information infrastructure are recognized as enabling the rationalization of water supply maintenance and management. In parallel with this is the growing importance of supporting security measures for data and people.*

results in an increase in information security risks. Accordingly, the National Center of Incident Readiness and Strategy for Cybersecurity has listed water as one of the 13 key infrastructure sectors and is looking at what actions can be taken(4), also prompting the publication of the Information Security Guidelines for Water Industry(5) by the Ministry of Health, Labour and Welfare. Similarly, a report by the Industrial Control Systems Cyber Emergency Response Team (ICS-CERT)(6) has noted a rapid rise over recent years in the frequency of cyber-attacks on water control systems in the USA, concluding that there is an urgent need for information and control security measures (see Fig. 1).

Given this background, Hitachi is working on the development of safer water supply systems, meaning systems that ensure the safety of everything from the water itself to plants and information. From among these, this article looks specifically at technologies for operation and control of water treatment, on-site multi-factor water quality measurement, support for fault prediction and recovery, control security, and physical security.

## DIAGNOSIS AND CONTROL FOR SAFETY OF PLANT AND WATER QUALITY

Water quality incidents continue to occur with some frequency, including a large formaldehyde spill into the Tone river system that occurred in 2012. Working through the plan, do, check, act (PDCA) cycle to make continuous improvements is an effective way to ensure that the safety of the water supply is maintained at a high level. Examples of “planning” that form part of the routine operation of water treatment include planning for the safety of water and water quality testing. Operation control, equipment inspection and faultfinding in accordance with these plans are examples of “doing.” “Checks” are conducted on the supplied water and remedial is action taken if necessary. Finally, “action” refers to the periodic review of these activities and the consequent updating of “plans.” The following sections describe information and communication technologies (ICT) that facilitate the PDCA cycle.

### Risk Assessment and Monitoring and Control of Treatment Plants

The primary purpose of water safety planning is to consider the potential risks that exist across the entire process and decide in advance on what actions to take when harm occurs. The New Water Supply Vision published by the Ministry of Health, Labour and Welfare identified taking account of natural weather events in risk management as an important factor for ensuring the safe supply of water, in consideration of the increasing frequency of events such as drought or heavy rain in recent years.

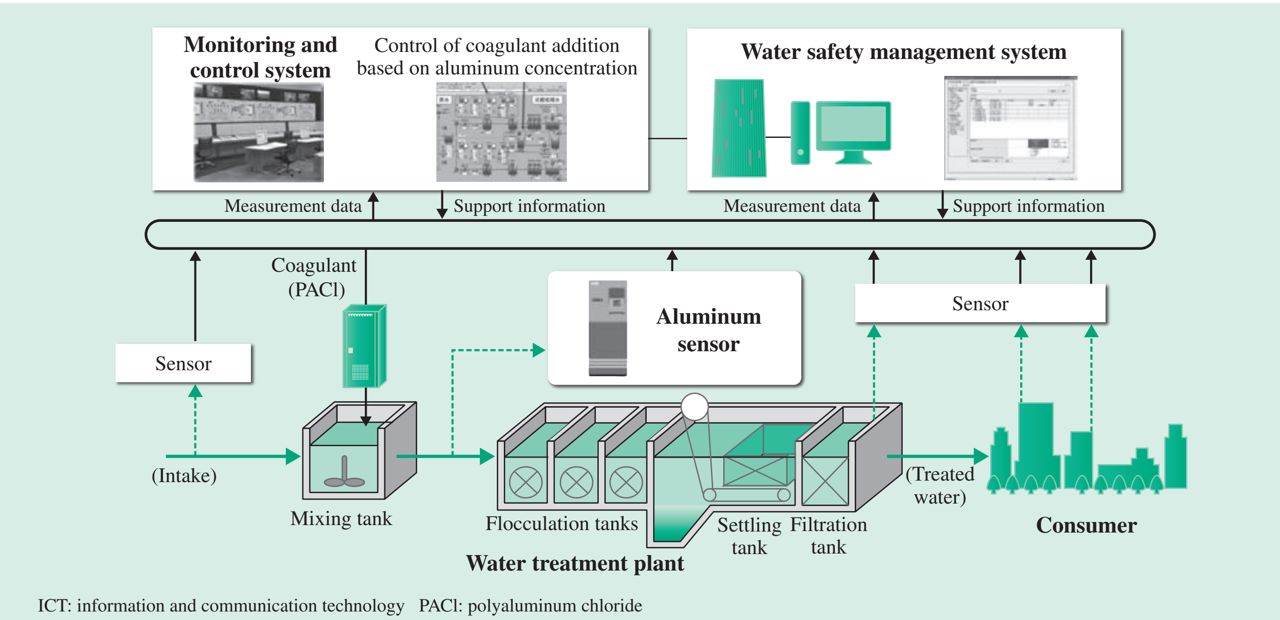


*Fig. 2—Operational Support for Water Treatment Using ICT such as Monitoring and Control, etc.*
*Using ICT to measure the aluminum content of the water being treated and convert it into an indicator shortens the delay time for feedback control. The water safety management system supports risk assessment and response measures using monitoring information that includes water quality from initial intake to the consumer.*

Hitachi supplies systems for planning (the "plan" of PDCA). These are intended to improve accountability and pass on know-how by using reaction models and pipe network models to provide quantitative criteria for whether or not to take actions.

Also, in the case of treatment plant operation (the "do" of PDCA), manual intervention based on the experience of skilled staff has an important role to play, especially during natural disasters when non-standard operation is called for. With the decreasing number of such experienced treatment plant staff, Hitachi supplies a control system that performs chemical dosing automatically in response to sudden changes in the quality of intake water (see Fig. 2).

A feature of this system is that it controls the dosing of coagulant based on the concentration of aluminum in the small flocs in which the flocculation process has not sufficiently advanced, measured immediately downstream of the mixing tank (flocculation is the process whereby the addition of a coagulant causes suspended solids to come out of suspension and form flakes called "flocs"). A trial performed using actual intake water demonstrated that the system can shorten the feedback time and minimize the deterioration in the quality of treated water when sudden fluctuations in water quality occur. Because aluminum coagulants such as polyaluminum chloride (PACl) and high basicity PACl account for more than 80% of coagulant use at water treatment plants in Japan, the system has potential for widespread use.

## On-site Multi-factor Water Quality Measurement

Compact instruments for certain types of water quality measurement have appeared on the market in recent years, thereby enabling regular on-site measurement. Nevertheless, there are still a large number of measurements that require complex manual operations by specialist staff, or that require samples to be sent to specialist measurement agencies, meaning it is difficult to identify sudden changes in water quality for all types of measurement.

For these reasons, Hitachi has been working with Professor Miyake's group at the University of Tokyo, with support from the Core Research for Evolutional Science and Technology (CREST) program of the Japan Science and Technology Agency (JST), to develop a multi-factor water quality measurement system that can be used on-site to enable regular multi-point monitoring that is both automatic and realtime[7]. This water quality measurement system controls the flow of liquid through

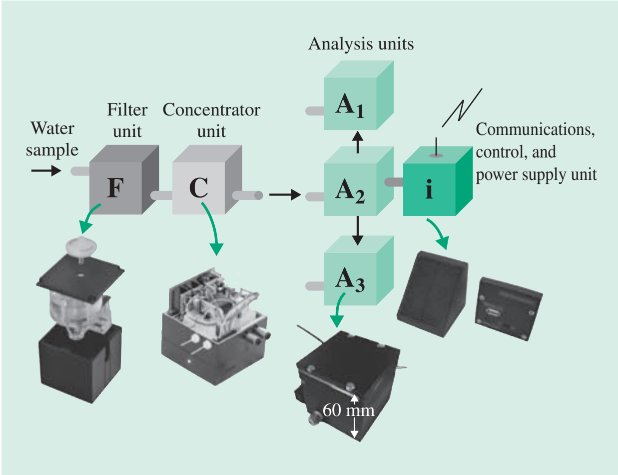


*Fig. 3—On-site Multi-factor Water Quality Measurement[7].*
*The system components include a filter unit, a concentrator unit, analysis units for performing each measurement, and a communications, control, and power supply unit.*

a micro-channel to enable measurement to be performed using minute amounts of sample and reagents (chemicals required for measurement), to obtain results rapidly, and to improve the repeatability of measurements.

The system is made up of the various individual units required for measuring water quality. These include a filter unit for removing impurities from the water (when necessary); a concentrator unit for increasing the concentration of the water sample (when necessary); analysis units for performing each of the measurements; and a communications, control, and power supply unit that controls the other units and can transmit the measurement results (see Fig. 3). Units have been developed to test for residual chlorine and nitrate nitrogen, and to perform bacteria counts, with further units to be added. The standard size for each unit is 60 mm cubed.

The compact design of the measurement system makes it easy to install on-site. Furthermore, by speeding up and automating the measurement process, it can be used for realtime multi-point monitoring, making it possible to respond to sudden changes in water quality. In doing so, it makes it possible to provide a reliable supply of water that is safe and trustworthy.

## Support for Fault Prediction and Recovery

Failures in water infrastructure equipment and machinery due to aging or other reasons can have severe consequences for the public and for industry. The challenge that must be overcome to prevent this is to predict faults before they happen and then respond before problems become serious.

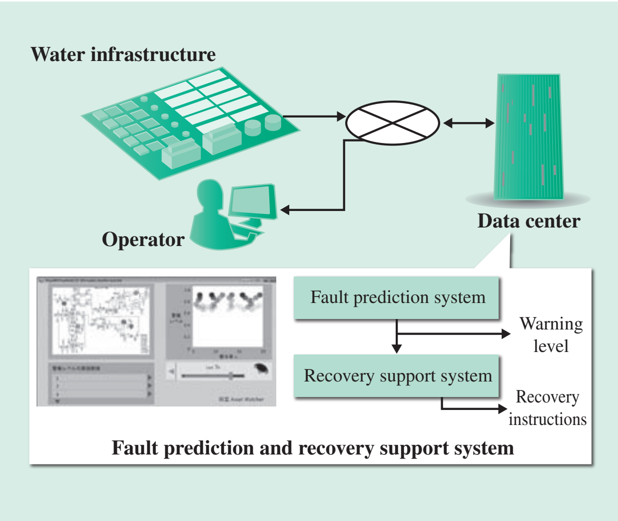


*Fig. 4—Structure of Fault Prediction and Recovery Support System.*
*The system uses big data analytics to analyze plant operational data and predict faults, infer the underlying cause of predicted faults, and output instructions on how to recover.*

In response, Hitachi is currently developing a fault prediction and recovery support technique (see Fig. 4) that is based on operational data from plants and equipment and that incorporates two specific techniques. The first of these involves statistical analysis using adaptive resonance theory (ART). A feature of this technique is that it can identify the warning signs of potential faults at an early stage by detecting small deviations from normal behavior based on the relationships between a large number of input variables.

The second is a semantic network technique that can infer the underlying cause of these warning signs from the plant flowchart and suggest ways of restoring normal operation. This means the operator can be quickly presented with instructions on what to do to prevent the fault from occurring.

Used together, these techniques can prevent plant and equipment failures. In addition to preventing the faults themselves, this also minimizes the detrimental effects on other equipment or on the operation of the overall system.

Hitachi has already applied these techniques to water treatment and seawater desalination plant data, and demonstrated their ability to predict things like damage to pump bearings or fouling of RO membranes. There is also scope for putting these broadly applicable techniques to use for other water industry equipment, such as enabling pre-emptive measures for dealing with abnormalities in sludge-based sewage treatment systems or problems with water quality.

## HITACHI'S SECURITY TECHNOLOGIES

Advances in networking and other ICT have enabled the monitoring and control systems, namely, supervisory control and data acquisition (SCADA) or distributed control system (DCS), for water supply infrastructure to be put together in a variety of configurations, and have contributed to improvements in operational efficiency at water utilities. For example, monitoring and control systems that operated on a standalone basis in the past can now be linked together to provide centralized information and seamless operation and management across multiple facilities. The problem that comes with moving away from previous systems with closed networks, however, is the need to deal with the security risks resulting from this greater diversity and sophistication of system configurations.

Measures for the physical security of water supply facilities is also important given their role as critical infrastructure. Preventing access by unauthorized people and unwanted material requires consideration as to what is the best combination of physical security techniques to suit the nature of facility operations, including the movement of people and material during emergency situations as well as routine operation.

The following sections describe the work Hitachi is doing on control security, the security features of the monitoring and control system, and physical security technologies.

### Hitachi's Work on Control Security

Taking note of the characteristics of infrastructure that remains in operation for long periods of time, and also of developments in the area of cyber-threats, Hitachi has adopted what it calls the "H-ARC concept," which identifies three specific security requirements for social infrastructure, namely that it be "adaptive," "responsive," and "cooperative"(8). This H-ARC concept provides the basis for thinking about monitoring and control systems from implementation to operation.

Along with industry-specific standards for electric power, petrochemicals, and railways, work is proceeding on developing the IEC 62443 international standards covering all aspects of control security.

The IEC 62443-1-x series of standards deal with common concepts and terminology, the IEC 62443-2-x series with security policies and organizational management systems for organizations that own control systems, the IEC 62443-3-x series with technology requirements for system developers, and the IEC 62443-4-x series with control equipment security requirements for equipment manufacturers.

To ensure ongoing control system security, it is essential to work through the PDCA cycle to adapt to changes such as monitoring and control system configurations and the security requirements for each system. To achieve this, the Cyber Security Management System (CSMS) Conformity Assessment Scheme provides a framework that supports the PDCA cycle. CSMS certification is the control systems equivalent of the Information Security Management System (ISMS) specified for information systems in ISO/IEC 27001. The Japan Institute for Promotion of Digital Economy and Community (JIPDEC) published certification criteria based on IEC 62443-2-1 in April 2014[9] (see Fig. 5).

Hitachi has been a member of the Control System Security Center (CSSC) ever since it was first established in March 2012 as a public-private-academia partnership for strengthening the security of control systems that underpin social infrastructure, with involvement that includes research and development. Backing up this involvement, Hitachi has been developing in-house support structures that extend beyond incorporating security technologies into Hitachi's product range (the control system and control equipment covered by IEC 62443-3-x and IEC 62443-4-x) to also encompass assistance for control system owners such as water utilities to obtain CSMS certification. In the future, Hitachi intends to continue contributing to the provision of sustainable social infrastructure that can be used with confidence.

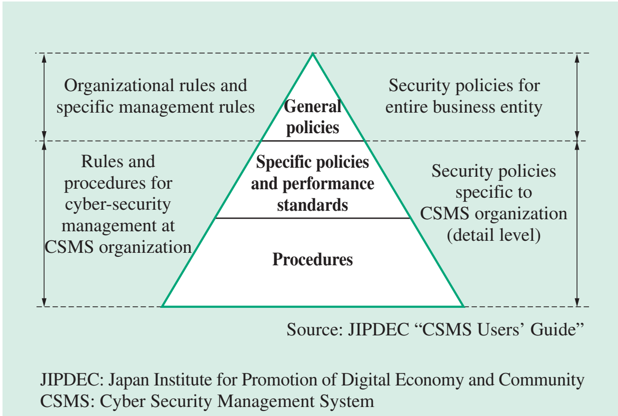


*Fig. 5—Overview of CSMS Certification.*
*The security policies of the individual organizations that operate control systems link in with the security policies and other information management rules of the higher level organizations. The formulated security policies must be approved by the relevant administrator.*

## Security Features of Monitoring and Control System

Hitachi's monitoring and control system for water supply and sewage has been designed to incorporate an extensive range of security functions that take account of the increasingly diverse aspects of operational and management safety. The following section describes two such enhanced functions: a user management function and an anti-virus feature that works based on a whitelist.

### User Management Function

The user management function assigns detailed permissions to each user of a monitoring and control system and controls their use. It consists of the following three function groups (see Fig. 6).

(1) The user authentication function prevents unauthorized access to the control system by using login ID and password to verify identity.

(2) The user access control function can specify the scope of operations available to each user. It has predefined permissions set for each category of user within the operation and management team, including operation administrators, regular operators, and contract operators, and can be managed from within the monitoring and control system. Different access levels are assigned to different users, for example, a regular operator is only permitted to operate equipment and modify settings whereas an administrator is also able to modify control parameters. It also provides an emergency login function that is able to temporarily

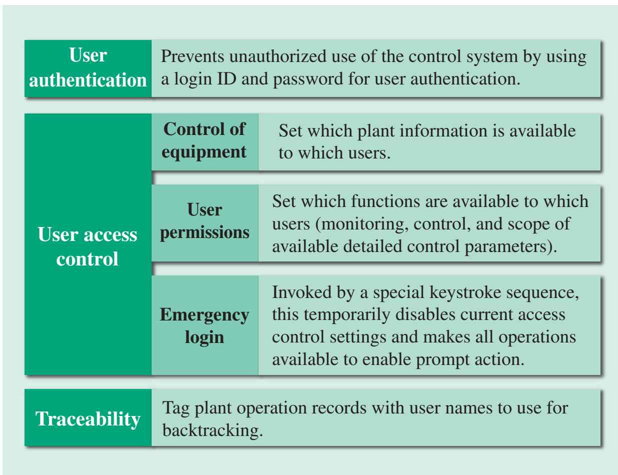


*Fig. 6—Monitoring and Control System User Management Function.*
*To reduce security risks associated with control system operation and management, Hitachi's monitoring and control system includes security functions that are tied to user authentication.*

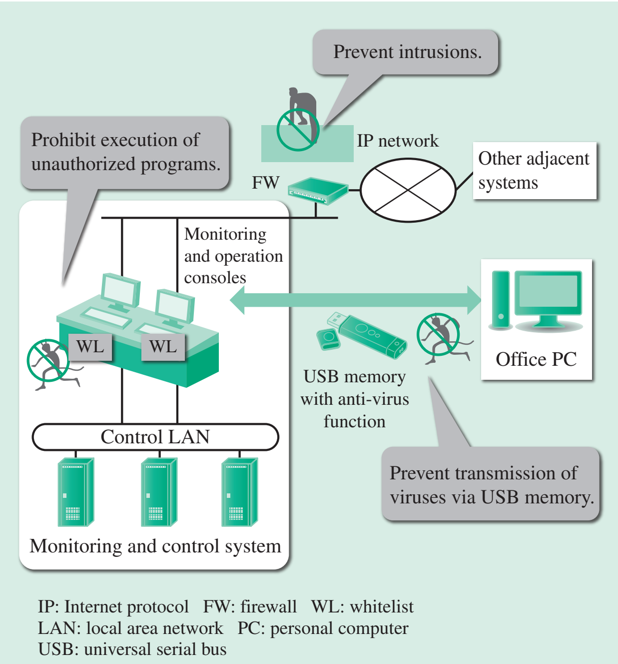


*Fig. 7—Security Features Provided by Monitoring and Control System.*
*The monitoring and control system provides security features to suit different aspects of operation and management.*

disable access controls. This is invoked by a special keystroke sequence that disables access control to make it possible for every operation and management staff member to operate the system in case of disaster.

(3) The traceability function links user IDs and console data to a facility's operational records to enable backtracking to determine whether instructions issued to the plant were appropriate.

**Whitelist Anti-virus Feature**

There have been cases in recent times of monitoring and control systems being infected by computer viruses, a consequence of factors such as the use of universal serial bus (USB) memories to copy data from monitoring and control systems and the ease of interconnecting with other adjacent systems[10]. Once an infection is present, it poses a problem for the operation and management of water facilities, and given the potential for unanticipated problems, it can take a long time to remove the virus and restore the system to normal operation. To deal with this risk, the monitoring and control system provides an anti-virus feature that works based on a whitelist. This works by restricting execution to only those programs designated on a whitelist in advance as permitted to run on the system, thereby preventing the execution of any intruding virus program that does not have permission.

The benefits of this approach compared to the blacklist method are that it consumes less central processing unit (CPU) time in the monitoring and control system and that it avoids the need for an Internet connection for updating virus definitions. It also helps prevent zero-day attacks and attacks from unknown viruses.

The monitoring and control system provides strong security features designed for use with operation and management. In addition to its whitelist anti-virus feature, these include compatibility with a firewall and USB memories equipped with security features (see Fig. 7).

## Physical Security Technologies

Because water treatment plants are a critical part of the social infrastructure and play an important public role, the impact on the public of a terrorist attack or similar incident would be large. To minimize damage by protecting facilities against vandalism or terrorist activity while still maintaining continuous 365-day operation, the following three measures are vitally important.

(1) Preventing intruders from entering facilities

(2) Preventing people from bringing in dangerous goods

(3) Identifying causes and minimizing damage if an incident does occur

The following sections describe technologies owned by Hitachi (see Fig. 8).

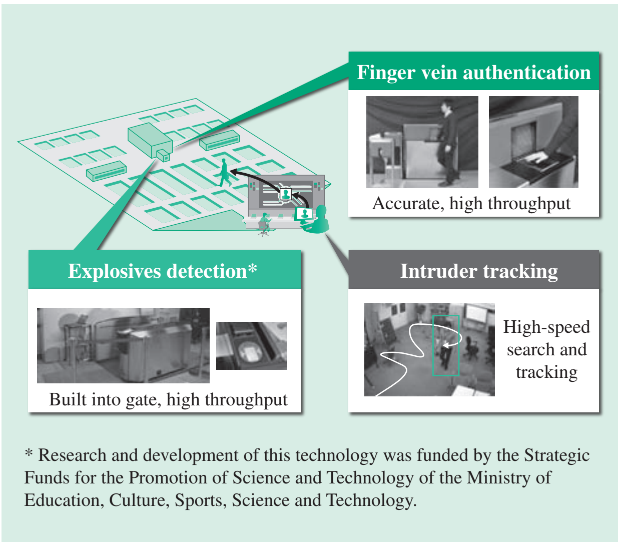


*Fig. 8—Physical Security Technology for Social Infrastructure.*
*Hitachi is developing systems for responding to incidents when they happen as well as preventing intruders or people from bringing dangerous goods into its facilities.*

The prevention of intruders (1) requires monitoring of facility surroundings and verifying identity at entrances and exits. While it is standard practice to use cards for premises access control, even tighter control can be achieved by using biometric information for personal identification. Examples of biometric information include fingerprints, irises, faces, voiceprints, genetic markers, and finger veins. Among these, finger vein patterns, in particular, do not change with age and are difficult to counterfeit due to being located inside the person's finger. Hitachi has commercialized personal authentication systems that use finger vein patterns and deployed them for premises access control systems. To improve convenience without compromising accuracy of identification, Hitachi has also prototyped touch panel and walk-through finger vein authentication systems. These provide strict control while also reducing staff workload by providing "unconscious authentication" (without the user being aware) and greater throughput.

To prevent people from bringing in dangerous goods (2), such as explosives or dangerous chemicals, it is necessary to conduct bag and body checks. The problem with this is that performing such checks manually on all operating staff is not practical due to the time it would take. It is possible, however, to detect dangerous goods with a walk-through system by fitting security gates with a dangerous goods detection system that has a built-in mass spectrometer. These systems blow air at workers that is then drawn in, concentrated, heated, and injected into the mass spectrometer. This can identify any material adhering to the worker by providing a mass spectrum of the microscopic particles collected from them.

To identify the cause and minimize damage if an incident does occur (3), it is necessary to collect image data, such as from surveillance cameras located around the periphery of the facility or images captured when people enter the site, and to search this huge repository of images for clues so that prompt action can be taken. To this end, a high-speed image search engine that can search for similar images in large amounts of image data is used to identify useful images from fragmentary data in a process called similar image search. This makes it possible to quickly discover unauthorized people or goods and enables action to be taken to minimize damage.

The safety of water treatment facilities can be further ensured by building integrated physical security systems that use these technologies in tandem.

## CONCLUSIONS

This article has described monitoring and control systems and information processing systems that support the safe operation of water supplies. These have included technologies for information system security and physical security, and diagnostic and control techniques that contribute to equipment security and water quality while also allowing for the future spread of the IoT and changes in the structure of society. While these are primarily targeted at water and sewage systems, the technologies are also recognized as having growing potential for future use in tandem with other social infrastructure for purposes such as maintaining systems in good condition and providing operational support. Hitachi intends to continue contributing to society through the development of superior, original technology and products and by offering solutions.

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Featured Articles

# Case Studies of Solutions Based on Water Operation and Facility Management Systems for Water Business

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*OVERVIEW: The "New Water Supply Vision" published by Japan's Ministry of Health, Labour and Welfare in March 2013 identified the issues and policies that those involved in the industry should be dealing with in terms of "safety," "resilience," and "sustainability." The water industry in Japan faces numerous challenges, including a dwindling number of technical staff, aging infrastructure, and the drop off in infrastructural efficiency due to the declining population. Drawing on its experience in manufacturing, Hitachi supplies a wide variety of solutions that incorporate its highly reliable products, systems, and technologies. This article describes case studies involving the installation of systems for overcoming the challenges faced by water distribution networks.*

## INTRODUCTION

THE "New Water Supply Vision" published by Japan's Ministry of Health, Labour and Welfare presented specific views on what form water infrastructure should take under the headings ("perspectives") of safety (ensuring the safety of water supplies), resilience (ensuring water supply security), and sustainability (ensuring the sustainability of the water supply system), and encouraged industry participants to adopt these as shared objectives.

It also presented "implementation approaches," namely internal approaches, collaborative approaches, and approaches that demands new ideas.

Fig. 1 shows the initiatives being undertaken by Hitachi in response to these "perspectives" and "implementation approaches" of the New Water Supply Vision, and the associated technologies.

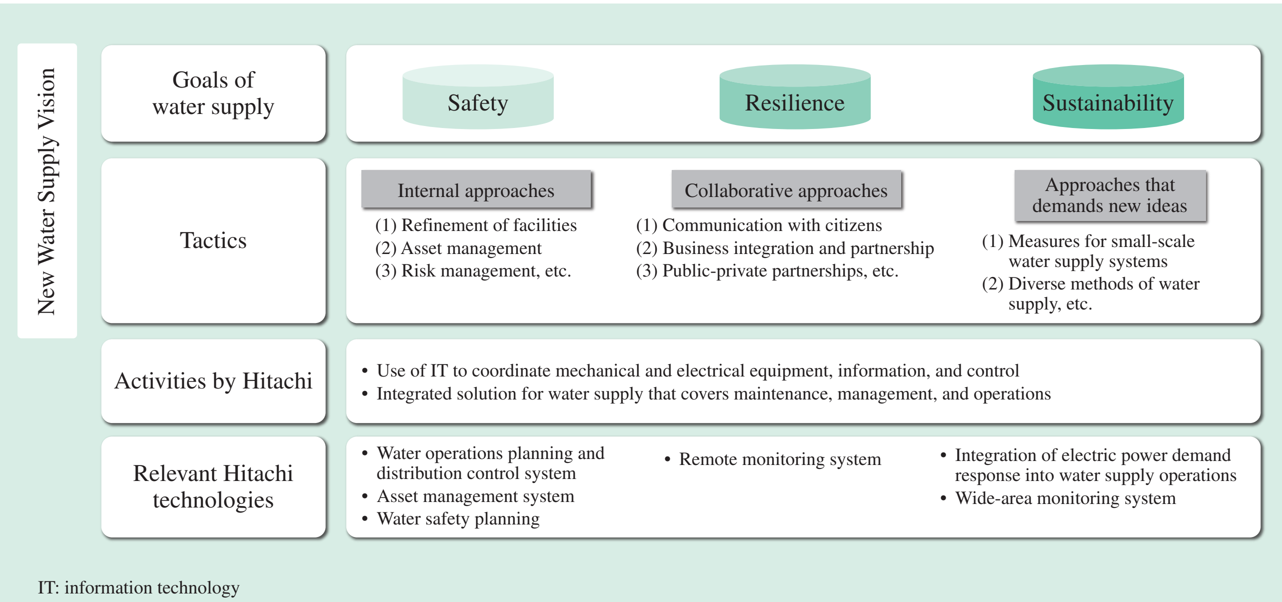


*Fig. 1—Tactics and Hitachi's Activities.*
*Hitachi supplies IT-based solutions for realizing the ideals set for water supply in the New Water Supply Vision.*

Hitachi has a track record of supplying systems that make use of information technology (IT) and the analysis of operational data to enable the efficient control of water infrastructure and to improve its energy efficiency, and for the use of simulations for know-how transfer, personnel training, and improvements in organizational capabilities.

This article describes two case studies involving the installation of water distribution systems that help enhance the water infrastructure, progressively expand its geographical coverage, and make its maintenance more efficient.

## INTEGRATED WATER MANAGEMENT SYSTEM SUPPLIED TO OSAKA MUNICIPAL WATERWORKS BUREAU

### Overview of Water Supply in City of Osaka

Osaka's water infrastructure has a history that dates back 120 years to 1895 when it became the fourth city in Japan to introduce a modern water supply system. During this time, the city has upgraded the treatment technologies used at the water treatment plants responsible for supplying water, ensuring trust in its water supply as well as its safety through measures such as its water distribution network, which supplies water treated using advanced treatment techniques achieving complete coverage of the city in 2000. Subsequently, it installed the Integrated Water Management System in 2014 to further boost the efficiency of water infrastructure operation (which had become an issue of concern) and to establish a comprehensive emergency management infrastructure, expand geographical coverage, and improve energy efficiency. Hitachi already had a track record of supplying the City of Osaka with hardware (monitoring and control systems) and software (systems that use control and simulation techniques) for its water supply infrastructure. This section describes the Integrated Water Management System, which utilizes technologies for the integration of these information and control functions.

### Features of Water Infrastructure in City of Osaka

The water supply system for the City of Osaka currently consists of three water treatment plants (Kunijima, Niwakubo, and Toyono), nine water distribution stations, and two pumping stations for boosting water pressure. The network covers 5,000 km of water pipes with work in progress to enable the redistribution of capacity between treatment plants.

Prior to the introduction of the Integrated Water Management System, the three treatment plants each prepared their own operating plans and handled their own demand forecasting and water distribution planning.

This meant that information needed to be shared between operating staff to enable capacity redistribution between plants.

### Integrated Water Management System

Located at the Kunijima Purification Plant and designed to provide centralized demand forecasting and data collection throughout the City of Osaka, the Integrated Water Management System provides "total" integrated system operation extending from intake to distribution, together with efficient operational management that includes information sharing between water treatment plants. The main functions of the Integrated Water Management System are as follows.

(1) Demand forecasting

To maintain the smooth operation of the three water treatment plants, the system uses statistical analysis to predict water demand based on variables such as the weather, day of the week, and maximum temperature. Among these variables, it also considers the proportion of water carried by each section of the water distribution network ("distribution ratios"), taking account of factors such as changes to the network. The predictions are produced in 30-minute increments covering the next two days, and are sent to the existing monitoring and control systems at the water treatment plants on a daily basis.

(2) Centralized management of water flows within city

This function performs centralized management of water flows within the city and enables capacity reallocation in the event of an emergency by taking account of factors such as loss of distribution capacity at the water distribution stations and other infrastructure.

(3) Water treatment plant reporting

This function receives important data such as water volume and quality measurements from the management systems at the three water treatment plants and uses it to produce combined reports for the plants.

To implement these functions, the Integrated Water Management System is made up of water treatment monitoring consoles for each treatment plant, water system operation consoles and servers that handle functions such as operational demand forecasts, and IT connections to the existing water treatment management systems, distribution management

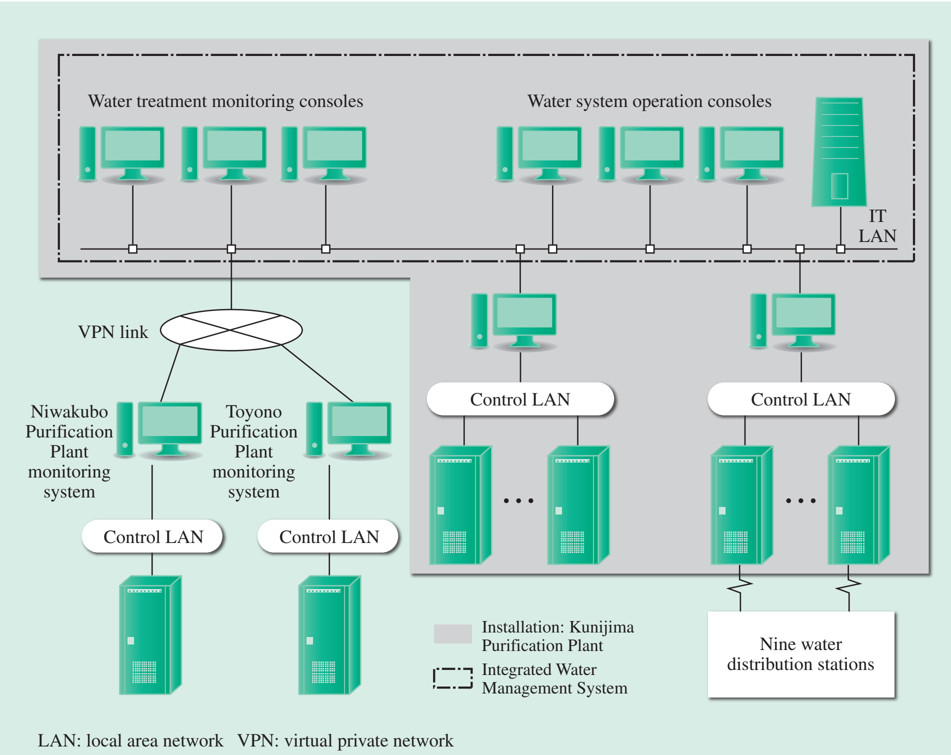


*Fig. 2—Block Diagram of Integrated Water Management System.*
*The Integrated Water Management System handles demand forecasting for the entire City of Osaka and sends its predictions to the existing systems via a communication network.*

systems, and distribution station monitoring systems (see Fig. 2).

## Demand Forecasting Technique

This section summarizes how the Integrated Water Management System forecasts demand (see Fig. 3).

The technique is based on statistical analysis and uses the following three steps to predict demand.

(1) Predict daily demand for the entire city
(2) Predict daily demand for each section of the water distribution network
(3) Predict demand for each section of the water distribution network in 30-minute increments

Each step is described below.

The starting point for predicting daily demand for the entire city (Step 1) is the "week-day/fine-weather demand" obtained by statistical analysis. This is then modified to allow for the relevant variables, namely the weather, maximum temperature, whether demand is different from usual, and the day-of-week. The weather and maximum temperature are entered based on the weather forecast. Days when demand is different from usual are those that have non-standard demand patterns, such as the New Year holiday period. The correction coefficients used for this purpose are also obtained by statistical analysis of past demand data.

Next, to predict daily demand for each section of the water distribution network (Step 2), the demand

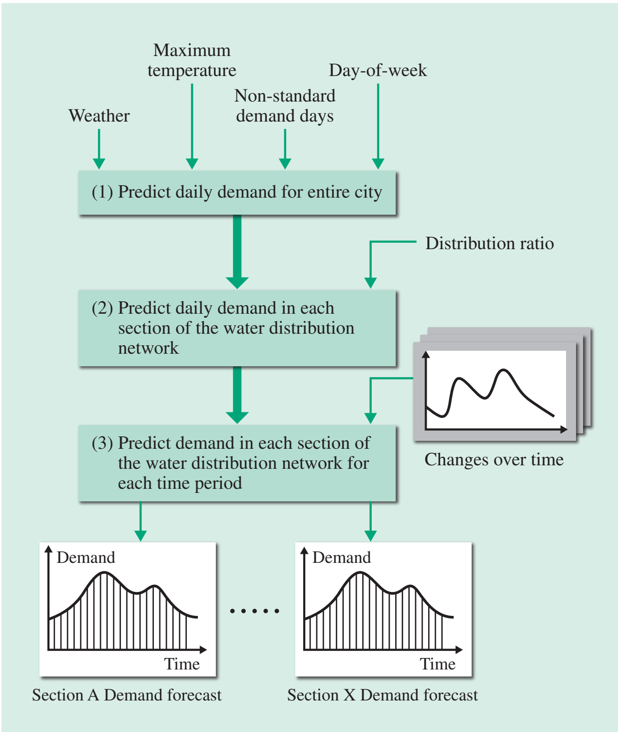


*Fig. 3—Demand Forecasting Calculation.*
*The calculation consists of three steps and predicts water demand in each section of the water distribution network for each time period. To keep up with changes over time, periodic automatic updates are made to the corrections for weather, maximum temperature, non-standard demand days, and day-of-week, and the distribution ratios for each section of the water distribution network.*

obtained by Step 1 is divided between the different sections of the network. This is done using distribution ratios obtained by statistical analysis of past data. The resulting demands are then used to predict demand for each section of the water distribution network in 30-minute increments (Step 3). The estimated variation in demand over time used for this purpose is updated by a learning algorithm using actual data.

The correction coefficients for weather, maximum temperature, non-standard demand days, and day-of-week are periodically revised based on actual data to keep up with changes over time. These revisions are performed annually for the weather, maximum temperature, and non-standard demand days, and weekly for day-of-week. Similarly, the distribution ratios for each section of the water distribution network are updated daily to account for any changes to these sections.

To reduce operator workload, the prediction process is automatic, as are the revisions to correction coefficients and distribution ratios.

### Field Testing of Demand Forecasting

After verifying the data acquired from field testing and tuning the system, the error in daily demand predictions for the entire City of Osaka was less than 2% on average for domestic water and less than 3% on average for industrial water (over the period when data verification was being performed). Having achieved this level of accuracy, the system commenced operation.

## WATER INFRASTRUCTURE MONITORING SYSTEM SUPPLIED TO NIIHAMA CITY WATERWORKS BUREAU

### Overview of Water Supply in Niihama City

The water supply system in Niihama City was commissioned in 1954 and has been operating ever since. A series of six expansion projects were undertaken during this time to ensure that consumers could remain confident of the safety of the water while also increasing the number of people being supplied and the water distribution network coverage area. (The

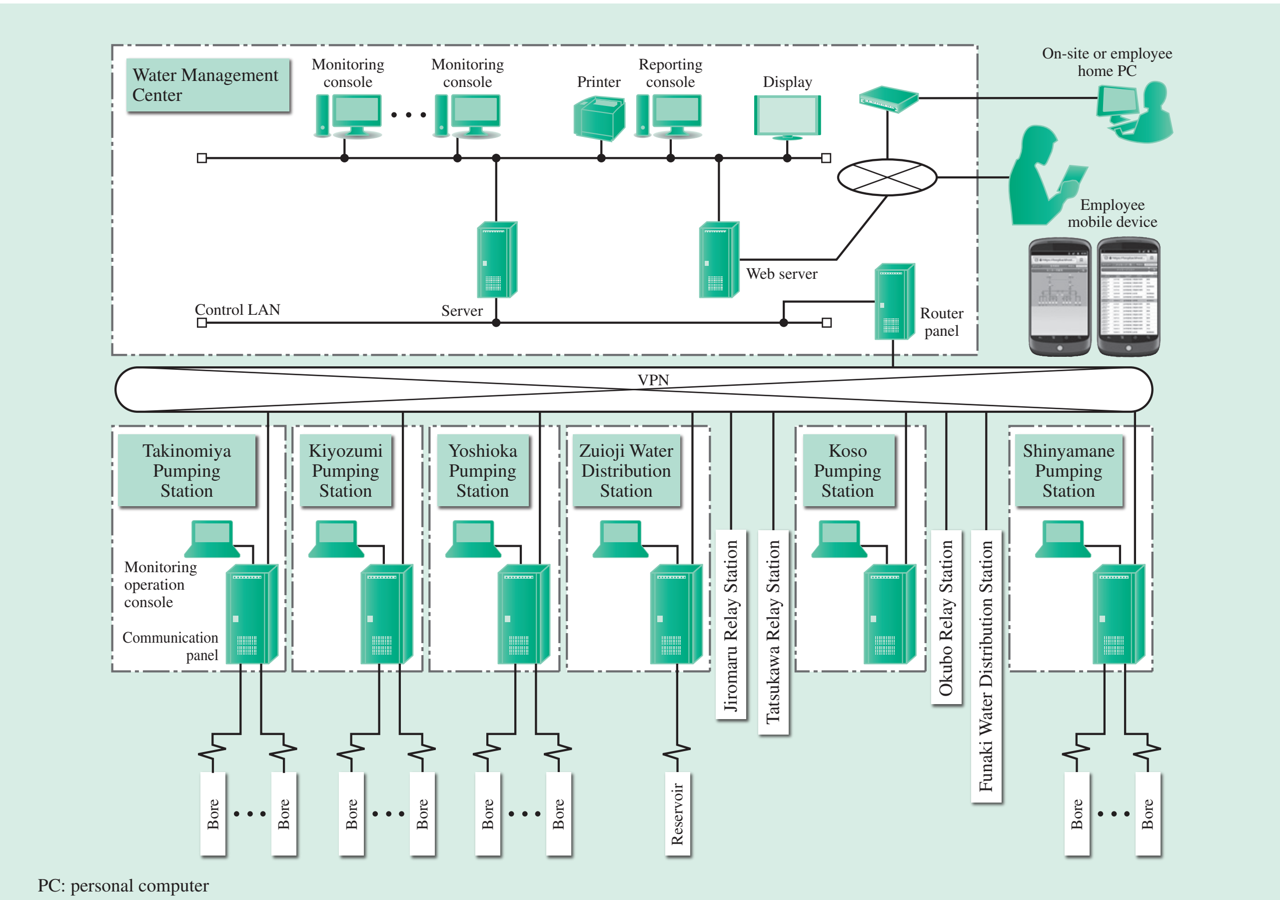


*Fig. 4—Block Diagram of Water Infrastructure Monitoring System.*
*As water is supplied to the city from bores spread over a wide area, the Internet and other IT is used to provide a wide-area monitoring system.*

network currently serves 120,000 consumers, with a planned maximum daily supply volume of 56,300 $m^3$.)

Niihama City sources all of its water from the ground via bores. These bores are spread around the city, and while this means that each bore does not need to produce a large volume of water, the downside is that all of the water needs to be pumped to the final reservoir.

The city completed its Water Management Center in FY1996 to centrally manage this entire infrastructure.

Since then, the infrastructure administrators have been progressively downsized, leading to the installation in April 2014 of a Water Infrastructure Monitoring System intended to provide more reliable and efficient infrastructure operation and more efficient administration, issues that had become matters of concern.

## Features of Water Infrastructure in Niihama City

The water supply system in Niihama City consists of 22 bores scattered over a wide area of the city, 10 main or relay pumping stations, nine reservoirs, and 21 water quality and flow monitoring stations installed at the network edge. This entire infrastructure operates automatically (unmanned). A feature of the system is that the main pumps and relay pumps use significant amounts of electric power to pump water from the bores via the pumping stations to the reservoir.

Prior to the installation of the Water Infrastructure Monitoring System, the procedure when an equipment problem occurred was for the person on duty to notify the infrastructure administrator by telephone. The administrator would then need to go to the Water Management Center to find out what was happening on the network.

## Water Infrastructure Monitoring System

The Water Infrastructure Monitoring System is installed at the Waterworks Bureau itself, and the system enables the water supply infrastructure to be monitored remotely (not just at the Water Management Center) using a smartphone or tablet via the Internet (see Fig. 4).

Furthermore, a variety of water level control setting combinations (“patterns”) for daytime and nighttime operation can be stored to avoid having to change individual pump control settings each time. The aim of this function is to shift daytime power consumption to the night when tariffs are lower.

The system is also designed to have a comprehensive range of simulation functions for checking operating water levels in advance to test the daytime and nighttime “patterns” (see Fig. 5).

## Web-based Monitoring with Tablets

This section describes the web-based monitoring system included in the Water Infrastructure Monitoring System. This web-based monitoring system, which is

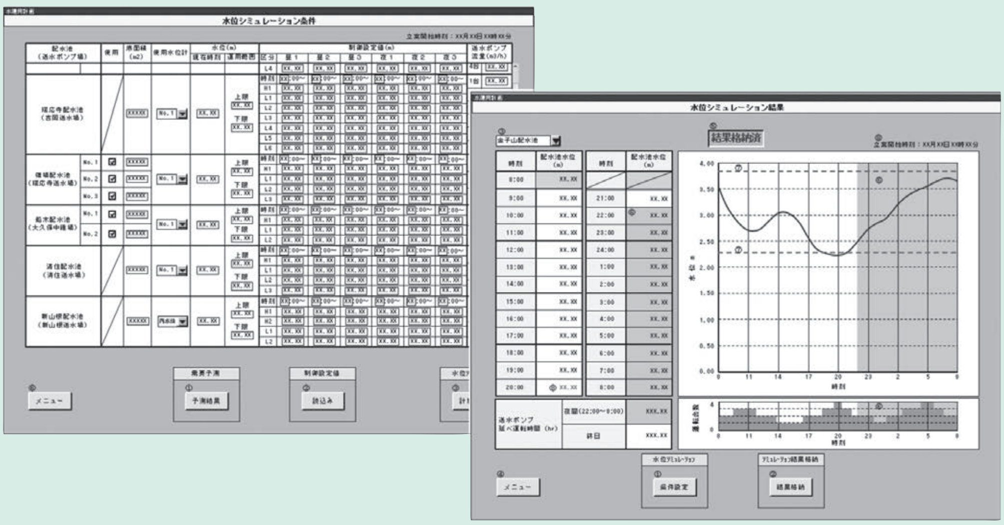

*Fig. 5—Water Level Simulation Screen.*
*Water level settings are specified for daytime and nighttime operation, and simulations are used to perform advance checks of the changes in water level.*


*Fig. 6—Web Services Displayed on a Tablet.*
*The web screens display the same graphics and alarm messages as the monitoring consoles at the Water Management Center. They also use familiar touchscreen operations such as pinch-out and swiping.*

part of Hitachi's information and control systems is used to display the same graphics screens, alarm messages, and other content as the monitor consoles at the Water Management Center on a smartphone or tablet connected via the Internet. Although these devices have small screens (5 to 8 inches), screen display can be enlarged using typical touchscreen operations such as pinch out.

This web-based monitoring system can also detect equipment alarm signals and forward these to infrastructure managers via e-mail. On receiving such an e-mail, an infrastructure manager can check the details of the alarm message and the status of the equipment and use this as a basis for decision-making, such as deciding on the initial response (see Fig. 6).

## CONCLUSIONS

This article has described two case studies involving the installation of water distribution systems that help enhance the water infrastructure and progressively expand its geographical coverage, objectives that were highlighted in the New Water Supply Vision.

The future possibilities for water distribution systems include operational functions that provide a boost to energy efficiency by coordinating the planning of water supply from water treatment plants or reservoirs to optimize overall operation.

Also anticipated is a growing need for energy optimization achieved through integration with power system infrastructure, such as operational functions that cut peak power demand or help reduce costs through use of a demand response regime that is expected to be introduced in the wake of electricity market liberalization.

Hitachi intends to adopt an earnest approach to the challenges facing customers and other parts of society, and to contribute to the safety, resilience, and sustainability of the water infrastructure through the supply of tailored solutions and the development of technology based on technologies already acquired.

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Featured Articles

# Operation & Maintenance and Service Solutions for Water Utilities Based on Public-private Partnerships

Hidenori Hasuka
Takeshi Kurotsu
Takuya Ando
Akimasa Izumiyama

*OVERVIEW: The water utilities in Japan continue to face extremely difficult business conditions that include a shrinking customer base and revenues due to the falling population, growing demands for the upgrading of water infrastructure, and a fundamental review of resilience in light of the Great East Japan Earthquake. One of the ways to overcome these circumstances is to make use of public-private partnerships in their business operations. If these utilities that in the past have primarily been operated by local governments instead adopt in their business operations practices that take advantage of the technical capabilities and other know-how of private-sector businesses, there is scope for strengthening the fundamental operating capabilities of the water industry, including providing higher quality services and cutting costs. Based on many years of experience in supplying products, after-sales services, and technology development to the water industry, Hitachi is contributing to the creation of sustainable water operations by supplying public-private partnership solutions such as PFIs and full operation and maintenance outsourcing.*

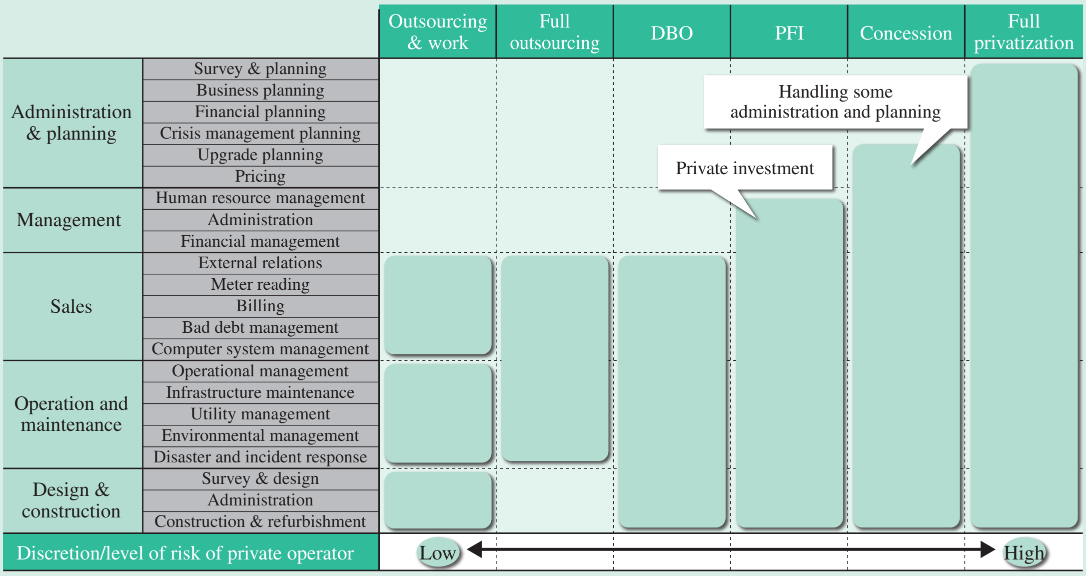
## INTRODUCTION

AFTER reaching a peak of 128.06 million in 2010, the number of people living in Japan has now started to decline, with demographic projections indicating that the population will fall to 86.74 million in 50 years and 42.86 million in 100 years' time[(1)]. This is a major problem for the water industry, because it means a shrinking customer base and falling revenues as well as problems with skills transfer due to an aging workforce and worker shortages, challenges that are already a reality for many water utilities.

On the other hand, it is anticipated that demand for large-scale upgrades to aging water infrastructure will peak during the 2020s and 2030s, requiring water utilities to increase their budgets and embark on planned refurbishments. Other factors that are exacerbating the conditions facing water utilities include calls for a fundamental review of seismic resilience and disaster management prompted by the experience of the Great East Japan Earthquake[(2)].

Despite these business conditions, the utilities still need to maintain water supplies that deliver water of the stipulated quality when and where needed, in the required volumes, and at an appropriate price. The New Water Supply Vision published by the Ministry of Health, Labour and Welfare in 2013 specified policies for achieving the desirable attributes for water supplies in 50 or 100 years' time, namely safety, resilience, and sustainability[(3)]. As described above in this article, ensuring sustainability is a particularly important objective for achieving healthy and reliable water supply operation, even under circumstances that require skills transfer and improved revenues. One way to achieve this is through public-private partnerships. If water utilities that in the past have largely been operated by the public sector (local governments) instead adopt practices that take advantage of the technical capabilities and other know-how of private-sector businesses, this has the potential to help strengthen the fundamental operating capabilities of the water industry by providing higher quality services and cutting costs.

This article describes operational examples involving public-private partnerships that form part of Hitachi's promotion of its water industry solutions for a wide variety of challenges, proprietary support tools that help enhance the efficiency of this work, and likely future developments.




Source: Prepared by Hitachi based on "Guidelines on Comparative Study of Different Types of Water Industry Partnerships Including Private Sector" published by the Water Supply Division, Health Service Bureau, Ministry of Health, Labour and Welfare

DBO: design, build, operate PFI: private finance initiative

*Fig. 1—Hitachi's Public-private Partnership Business Models.*
*Hitachi acts as a "best partner" supplying solutions to water utilities in a wide variety of forms, ranging from partial to full outsourcing and including DBO, PFI, and concession arrangements.*

## ACTIVITIES BY HITACHI

The legal framework facilitating public-private partnerships has been progressively strengthened with a growing diversity of available business models that includes the recognition in 2011 of concession arrangements (private operation of public services) whereby private sector businesses can take responsibility for operating services, including fee collection. This wide diversity of business models for public-private partnerships includes partial outsourcing, whereby the private company undertakes a limited range of activities such as managing operations; full outsourcing, whereby the private company undertakes a wide range of operation and maintenance tasks not limited to operational management only; Private Finance Initiatives (PFIs) whereby the private company undertakes everything from design, construction, and financing of facilities through to their long-term post-construction operation and maintenance; and the concession arrangements referred to above (see Fig. 1).

Based on many years of experience in supplying products and systems to the water industry, along with after-sales services and technology development, Hitachi is involved in a wide variety of activities aimed at establishing sustainable water supplies, ranging from partial outsourcing to PFIs[4], [5].

## EXAMPLES OF OPERATION & MAINTENANCE AND SERVICE SOLUTIONS

### Renovation Project Related to Power Facilities to Asaka Water Purification Plant / Misono Water Purification Plant (PFI Project with Bureau of Waterworks Tokyo Metropolitan Government)

The main objectives of this project include installing an on-site power generation plant that can act as a countermeasure against disaster by providing a backup power supply for the water treatment plants, and improving energy efficiency by installing a co-generation system as an environmental measure. Since April 2005, Hitachi has been operating a PFI business that encompasses the construction and operation of the on-site power generation plant and a sodium hypochlorite production facility, and utilization of the soil produced as a byproduct of water treatment (see Table 1). The system supplies approximately 110,000 MWh of electric power and 25,000 GJ of steam annually. The sodium hypochlorite production facility has an annual production of approximately 600t-$Cl_2$, and approximately 7,000 t-wt a year of byproduct soil is recycled.

This fiscal year will be the project's 11th, halfway through the contract period. Drawing on the knowledge

Table 1. Overview of PFI Project with Bureau of Waterworks Tokyo Metropolitan Government
*The table lists the main elements of the PFI project for the Asaka and Misono Purification Plants.*

| | |
|---|---|
| **Project name** | Renovation Project Related to Power Facilities to Asaka Water Purification Plant / Misono Water Purification Plant |
| **Operator** | Asaka Misono Utility Services Corporation |
| **Contract period** | April 1, 2005 to March 31, 2025 |
| **Project type** | BOO |
| **Description** | (1) Construction and operation of on-site power generation equipment (co-generation system). The system supplies heat and power during routine operation and power during emergencies.<br>(2) Construction and operation of sodium hypochlorite production facility, and supply of sodium hypochlorite. In the event of a disaster, production of sodium hypochlorite using stored stocks of salt, power from on-site power generation plant, and treated water.<br>(3) Utilization of the soil produced as a byproduct of water treatment. |

BOO: build own operate

Table 2. Overview of Yubari City PFI Project
*The table lists the main elements of the PFI project for construction and operation of the water treatment plants.*

| | |
|---|---|
| **Project name** | 8th expansion program for Yubari City water infrastructure through a PFI arrangement |
| **Operator** | Yubari Reisui Co., Ltd. |
| **Contract period** | April 1, 2012 to March 31, 2032 |
| **Project type** | BTO |
| **Description** | (1) Design and construction of Asahimachi water treatment plant (planned treatment capacity 3,100 $m^3$/day) and Shimizusawa water treatment plant (planned treatment capacity 4,100 $m^3$/day)<br>(2) Partial upgrade of mechanical, electrical, and instrumentation equipment for off-site facilities (distribution reservoirs, pumping stations, etc.)<br>(3) Management of facility operation and maintenance<br>(4) Water meter reading, billing, and customer relations, etc. |

BTO: build transfer operate

gained during this time, particularly experience from the Great East Japan Earthquake, Hitachi is continually striving through this work to contribute to the resilience and sustainability of these water treatment plants.

## PFI Project in Yubari City, Hokkaido

### Adoption of PFI Project

With more than 40 years having passed since the completion of the Asahimachi and Shimizusawa water treatment plants (in 1967 and 1969 respectively); the aging of equipment at these two critical facilities in the water infrastructure of Yubari City was becoming increasingly apparent. The sustainability of water services had become a major issue for the city, which anticipated a falling income from water rates and a need for plant downsizing due to the shrinking population. Accordingly, as part of its plans for its 8th expansion program, Yubari City decided in July 2010 to upgrade and rebuild its water infrastructure through a PFI arrangement.

Subsequently, Yubari Reisui Co., Ltd., a company set up by Hitachi and two other investors, signed a contract with Yubari City in March 2012 and the project got underway in April of that year. This was the first PFI project for water in Hokkaido and, at that time, only the second in Japan to combine the construction and operational management of a water treatment plant in a single package.

### Project Overview

The project involved not only the construction of new water treatment plants at the sites of the existing Asahimachi and Shimizusawa plants and taking responsibility for their operation and maintenance, but also managing the operation and maintenance of the existing plants during the period prior to completion of the new plants (see Table 2).

The plan involved downsizing the combined capacity of the Asahimachi and Shimizusawa plants from 18,320 $m^3$/day to 7,200 $m^3$/day and adopting the membrane filtration method of water treatment that can efficiently remove protozoan pathogens and other harmful substances.

### Project Progress

Responsibility for managing the operation and maintenance of the existing plants commenced from the outset of the project. This included taking active steps to improve efficiency, including the installation of a plant and asset management system (described below) and an inspection system based on the use of portable tablets. This work is continuing to proceed smoothly.

Work on the design and construction of the Asahimachi and Shimizusawa water treatment plants is also proceeding smoothly in the lead up to the commissioning stage (see Fig. 2).

## Continuation of Operation & Maintenance and Service Business

This section describes a public-private partnership that continued after the expiry of the contract period.

### Tagajo City (Miyagi Prefecture) Full Outsourcing Contract

Hitachi had already been active at this site providing operational monitoring, plant inspection, utilities

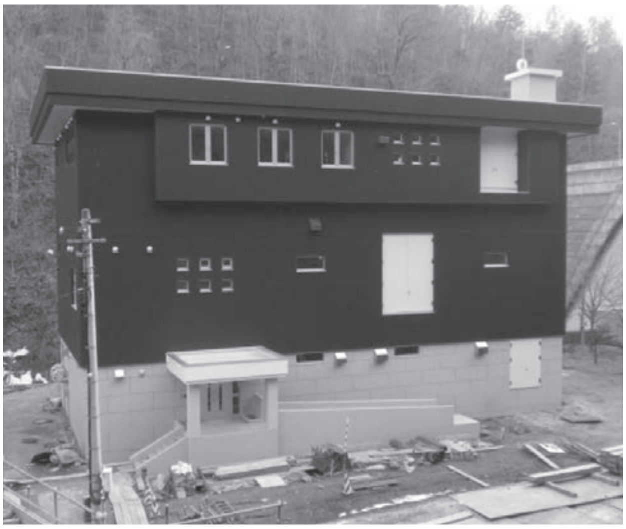


*Fig. 2—Shimizusawa Water Treatment Plant Under Construction (March 2015).*
*The compact design includes housing the settling ponds and membrane filtration equipment in the water treatment building (three above-ground and one basement floor).*

procurement, water quality testing, and minor repairs for the five years from April 2010 to March 2015 under an earlier contract for full outsourcing of operation and management of the Suenomatsuyama water treatment plant and other facilities. During this period, efforts had been made to improve operational efficiency by installing an inspection system using portable devices, batch mail delivery, and a water demand prediction system that helps overcome differences in staff experience level when planning water treatment volumes.

Hitachi also contributed to recovery work after the city suffered significant damage from the Great East Japan Earthquake, providing support for emergency water supplies and emergency recovery work. In particular, Hitachi played a substantial role in work such as providing water supplies to the city, and the ongoing supply of fuel for on-site generators, a commodity that was in short supply.

Having won a renewal of the full outsourcing contract for a further five years from April 2015, Hitachi will continue making contributions to the city.

**Operational Monitoring for Daito City (Osaka Prefecture) Waterworks and Sewerage Bureau**

Hitachi commenced a partial outsourcing project for operational management of water distribution stations at this site in FY2003.

Since FY2009, Hitachi has also been providing ongoing services that include operational monitoring of water distribution, routine inspections, and water quality monitoring. After the expiry of this contract in FY2014, Hitachi was awarded a new five-year contract commencing in FY2015, becoming better placed to take advantage of the innovative ideas of a private-sector company. This project is recognized as an example not only of providing ongoing benefits to the city but also of contributing to advances in the field of public-private partnerships.

## TECHNOLOGIES THAT FACILITATE OPERATION & MAINTENANCE AND SERVICE SOLUTIONS

The adoption of tools that facilitate operational efficiency, including but not limited to the management of human resources at each site, is essential to the provision of efficient, high-quality service solutions. The following sections describe some of the technologies and systems that underpin Hitachi's service solutions.

### Equipment and Asset Management System

Asset management is an essential part of ensuring the sustainability of water supply operations[6]. In the process of collating this management data, the management and analysis of routine inspection results and maintenance records is an important aspect of operation and maintenance. Hitachi has an equipment and asset management system that provides the tools for performing this work. Based on a journal for each item of equipment, these tools can manage the operating life, maintenance plan, and inspection and maintenance records for each item in a database. The data can also be used for spare parts management, location management, and statistical analysis. Furthermore, with its item update tool, new site-specific data fields ("items") can be added as required after the system has been installed, allowing its use to be tailored to suit the differing requirements of different sites (see Fig. 3). The technology has been installed to assist with operation and maintenance work at the Yubari City PFI project where it is used as a database for maintenance work and for data evaluation. Being cloud-based, the system reduces the risk of data loss in the event of a disaster and is a useful tool for data sharing.

Currently, Hitachi is considering whether to customize the technology to provide tools for micromanagement (evaluation) of equipment health, operating life, risk, and life cycle cost (LCC) as part of an asset management implementation.

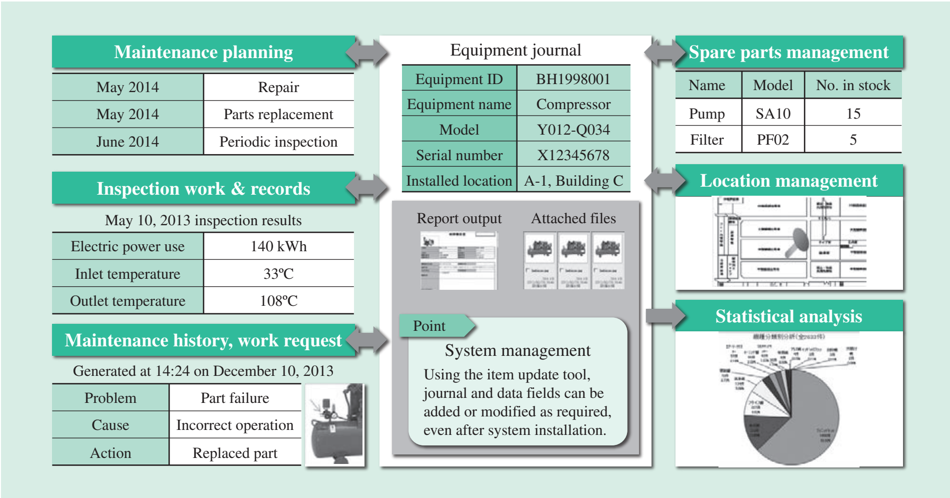


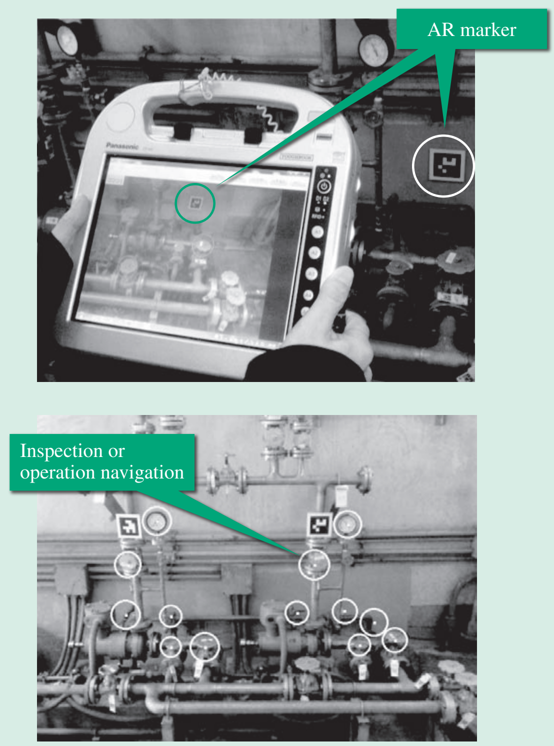

*Fig. 3—Functions of the Equipment and Asset Management System.*
*To allow use to be tailored to suit the differing requirements of different sites, additional data fields can be added as required after the system is installed.*

## Use of AR Technology to Support Operation and Maintenance

Skills transfer is a major challenge for the water industry. While staff training plays a fundamental role in overcoming this problem, because training requires adequate staffing and long periods of time to achieve, there is also a demand for support tools that can provide effective ways to implement skills. In response to this challenge, Hitachi has developed a “navigation system tool” that uses augmented reality (AR) to support operation and maintenance.

AR is a generic term for the use of information and communication technology (ICT) to overlay digital information on the real world. It works by displaying information linked to specific coordinates (which are determined using techniques such as markers or image processing) on top of the camera images of that location (that is, by overlaying image data onto the real world), putting the five human senses of sight, smell, hearing, touch, and taste to work and augmenting reality with additional information. Hitachi has developed an inspection navigation system that uses AR to help inexperienced staff perform operation and maintenance work correctly.

Workers invoke the system after selecting the work they intend to perform. When the worker points the camera on the back of the tablet at an AR marker indicating an inspection site, the system provides a realtime overlay that gives instructions on what to do and which items to inspect (see Fig. 4). The worker then taps the inspection item on the overlay display to enable the performance of tasks such as entering the inspection results using intuitive operation of visible prompts. Which of the three available input methods (tapping, selecting, or entering numeric data) to use can be selected based on the type of equipment being inspected. After entry of the inspection results for the specified items has been completed, the system indicates what to inspect next. It also displays a completion screen to indicate when all inspections




AR: augmented reality

*Fig. 4—AR Inspection Navigation System.*
*When the camera on the back of the tablet is pointed at an AR marker indicating an inspection site, the system assists inexperienced workers by providing a realtime overlay that gives instructions on what to do and which items to inspect.*

have been completed. The adoption of this technology has the potential to enable "skill-free" operation and maintenance in which even inexperienced workers can operate or work on equipment correctly.

## CONCLUSIONS

This article has described Hitachi's work on public-private partnership solutions for the water industry, examples of these solutions, and operation and maintenance technologies that support this work.

To keep water supply infrastructure in good condition, Hitachi intends to continue contributing to the provision of resilient and sustainable water supplies through the supply of water industry solutions in its role as a "best partner" to water utilities.

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Featured Articles

# Control Technology, Advanced Treatment Processes, and Next-generation Systems for Sewage and Wastewater

Masahiro Goto
Ichiro Yamanoi, Dr. Energy Science
Yousuke Hanamoto
Yuya Kimura, Dr. Eng.
Kazuichi Isaka, Dr. Eng.

*OVERVIEW: A backlog of work on the enhancement and development of urban infrastructure, which has failed to keep pace with rapid population increases and urbanization in various parts of the world, has resulted in severe problems for society due to such environmental issues as aquatic degradation, unreliable water and electric power supplies, atmospheric pollution, noise problems, the generation and dumping of large quantities of waste, and traffic congestion. Through the integration of various elements, including operational control of sewage and wastewater, simplification of existing treatment techniques and improvements in their energy efficiency, advanced treatment systems, and next-generation technologies, Hitachi is contributing to the sustainable development of social infrastructure by supplying solutions for the water industry that improve the operation of its infrastructure at the city and regional level.*

## INTRODUCTION

THE sewage and wastewater produced by people's daily activities is normally purified by treatment systems that operate at the municipality, water basin, or work site.

Hitachi is developing technologies for sewage treatment systems in accordance with its Environmental Vision 2025. Hitachi sees these latest sewage and wastewater treatment technologies as effective ways of minimizing the emission of greenhouse gases and the generation of solid waste, and of contributing not only to maintaining and improving the environmental state of waterways in order to provide a richer way of life, but also to supporting emergency response and recovery activities at disaster sites.

This article describes Hitachi's activities in this field with a particular focus on control techniques for sewage and wastewater treatment, advanced treatment processes, and technologies for next-generation systems.

## DEMONSTRATIONS INVOLVING USE OF ICT TO IMPLEMENT EFFICIENT OPERATIONAL CONTROL OF NITRIFICATION

### Overview of Demonstrations

The infrastructure that treats the sewage produced by domestic and business activities faces a wide variety of challenges. These include aging equipment, financial difficulties, energy efficiency, water quality management, staff shortages, declining populations, and the need to cover wider geographical areas. With the aim of dealing with energy efficiency and water quality management in particular, Ibaraki Prefecture and Hitachi commenced "demonstration of efficient nitrification control with information and communications technology (ICT)" for improving the control of nitrification. This research was contracted by the National Institute for Land and Infrastructure Management as part of the Breakthrough by Dynamic Approach in Sewage High Technology Project (B-DASH project) of the Ministry of Land, Infrastructure, Transport and Tourism. The work involves the collection and verification of operational data from a number of water treatment lines at the Kasumigaura Sewage Treatment Plant in Ibaraki Prefecture (with a treatment capacity of approximately 6,500 $m^3$/day).

### Overview of New Control System

Fig. 1 shows an overview of the newly developed control system. The system controls the treatment process to improve the efficiency of nitrification (part of the nitrogen treatment process) and achieve both energy efficiency and water quality management. To save power by reducing blower output (airflow rate), a downstream dissolved oxygen (DO) sensor was installed along with upstream and mid-point ammonia sensors. In addition to predictive and feedback (FB) control (FB control works by making corrections based on the deviation between the actual and desired output), the system also features the use of a treatment characteristics model for feedforward (FF) control. This combination of FB and FF control is intended to help maintain stable operation by responding quickly and appropriately to changes in the incoming sewage flow rate and concentration. Furthermore, FF control uses a treatment characteristics model that provides information on the blower output required for nitrification treatment. Because this treatment characteristics graph can be updated automatically based on the measurements from the ammonia sensors, the accuracy of the predictive model can be maintained automatically. The treatment characteristics graph also functions as a way of indicating the treatment characteristics of the activated sludge (microbes). This improves the efficiency of maintenance by making possible the early identification of changes in the behavior of the microbes or trends in treatment problems.

## Progress of Demonstrations

Trial operation commenced in January 2015. Fig. 1 shows how the aeration airflow varies over time under the new control system and constant-DO control respectively. The new control system has a lower airflow than constant-DO control at all times of the day. The aeration airflow during the trial was 85.9%, with the FY2014 results showing a 14.1% reduction in airflow compared to constant-DO control while still keeping the concentration of ammonia in the treated water to 0.3 mg-N/L. The trial is continuing in FY2015 to verify the reliability of the system over long-term use.

The new monitoring and control system incorporates advanced control functions and is particularly effective when used with blowers that have a high level of controllability. Accordingly, it is anticipated that using this technology when upgrading monitoring and control systems, blowers, and other equipment will deliver improvements in energy efficiency and water quality management.

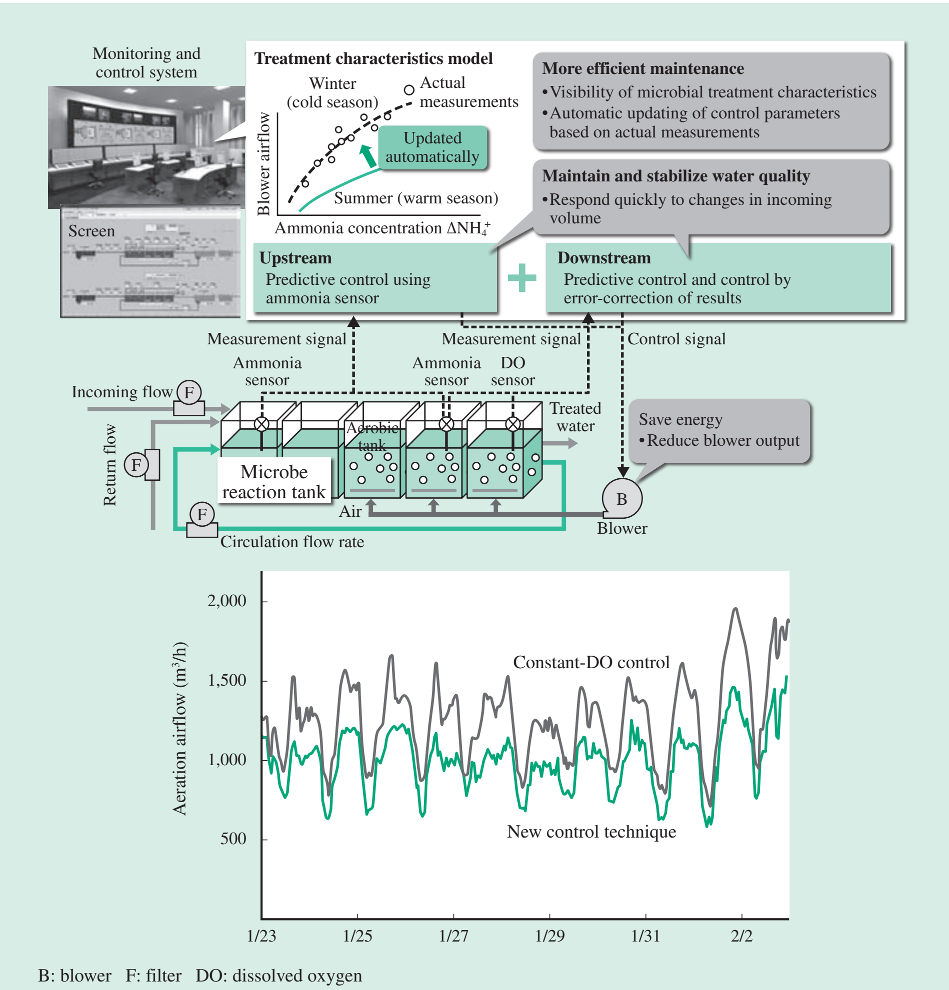


*Fig. 1—Overview of New Control System (Top) and Graph of Variation in Aeration Airflow over Time (Bottom).*
*The results for FY2014 indicated a 14.1% reduction in aeration airflow without compromising the quality of treated water. The trial is continuing in FY2015 to verify the reliability of the system over long-term use.*

## DEVELOPMENT OF TECHNIQUES FOR IMPROVING ENERGY EFFICIENCY OF MEMBRANE BIOREACTORS

### Development of Techniques for Improving Energy Efficiency of Membrane Bioreactors

Membrane bioreactors (MBRs) consist of a waste water treatment process with activated sludge in tanks for biological treatment, and a micro filter for separating suspended solids and other pollutants, to gain clear treated water. Furthermore, one of the major benefits of MBRs is that they are far smaller in size than conventional methods. Hitachi markets smaller-scale MBRs in the Middle East area. As a part of national projects coordinated by the New Energy and Industrial Technology Development Organization (NEDO) and the Japan Science and Technology Agency (JST), research and development work aimed at providing energy saving solutions has been conducted since FY2009, especially on the reduction of aeration, which accounts for 60% of system energy consumption for aeration during the membrane surface cleaning and biological treatment process as stated above. The newly developed techniques reduced membrane cleaning and thus achieved a reduction of system power energy consumption per cubic meter of treated water of 0.4 kWh.

The aeration unit employed for membrane surface cleaning is installed at the bottom of the membrane unit, which consists of a series of membrane sheets. The shear stress, which is generated by the air-liquid two-phase flow in the channels between the membrane element panels, works effectively for membrane surface cleaning, thereby realizing a continuously filtering cleaning process. In these projects, a new type of aeration tube, which is orthogonally oriented to the element panels, was developed (see Fig. 2). This aerator uniformly distributes bubbles into the channels between membrane element panels to increase the efficiency of membrane surface cleaning. Consequently, the aeration flow rate for membrane surface cleaning is reduced by 30%. In addition, intermittent aeration (see Fig. 3) was found to increase the velocity differential between bubbles and liquid phase (see Fig. 4), and promote turbulence around bubbles (in the boundary layer of bubbles), especially in the wake, with computational fluid dynamics (CFD). The larger velocity differential increases shear stress in the wake of bubbles compared to conventional continuously aerating operation, and thus cleans the membrane surface more efficiently. And the validation experiment shows that this aeration process substantially decreases the rate of trans membrane pressure (TMP) (see Fig. 5). As shown in the result of this experiment, the intermittent aeration method achieves further reduction of the aeration rate. The combination of the newly developed aerator and intermittent aeration process was confirmed to eventually reduce membrane cleaning aeration and the system energy consumption per cubic meter of treated water to achieve 0.4 kWh.

In the future, Hitachi plans to assess possible energy saving methods on other equipment (including aeration blowers for biological treatment and circulation pumps) as well, to realize further energy

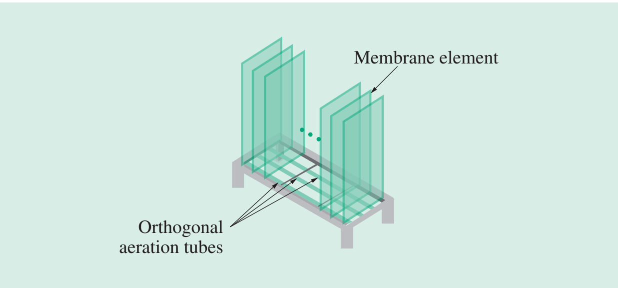


*Fig. 2—Membrane Elements and Orthogonal Aeration Tubes.*
*The orthogonally aligned aeration tubes uniformly distribute bubbles into the channels between membrane element panels.*

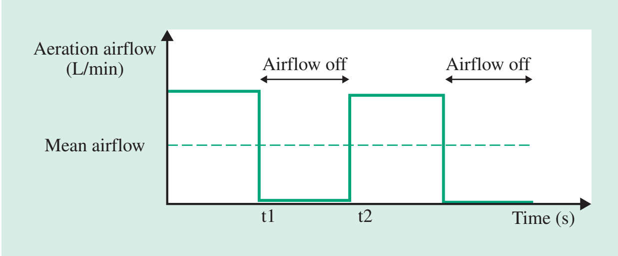


*Fig. 3—Intermittent Aeration Process.*
*Aerating and halting intermittently reduces the amount of aeration while the airflow is off.*

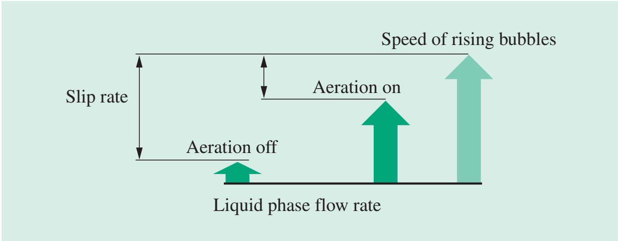


*Fig. 4—Velocity Differential between Bubbles and Liquid Phase.*
*Change of liquid phase velocity generates larger velocity differential, and larger shear stress around the bubbles to further efficiently clean membrane surface.*

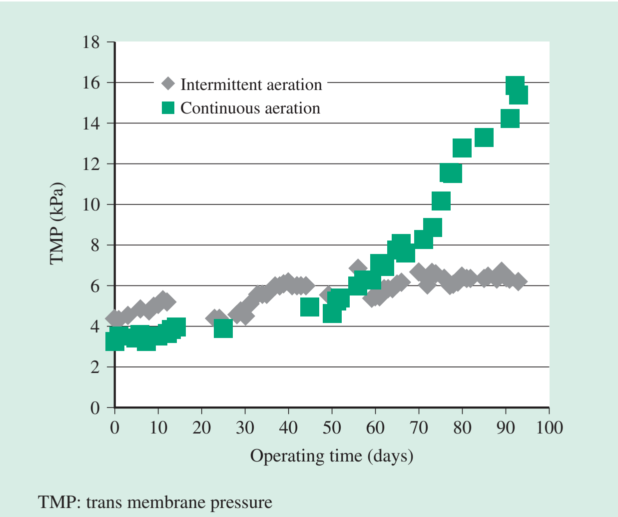


*Fig. 5—TMP Trends in Conditions of Continuous and Intermittent Aeration.*
*The intermittent aeration process greatly improves the efficiency of membrane surface cleaning to substantially decrease the TMP rate.*

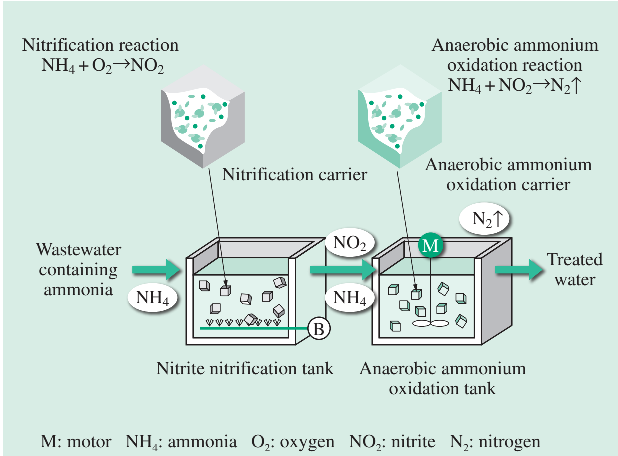


*Fig. 6—Overview of Anaerobic Ammonium Oxidation Treatment System Using Inclusive Immobilization.*
*Nitrifying bacteria contained in inclusive immobilization carriers are added to the nitrite nitrification tank to oxidize half of the ammonia to nitrite. Similarly, anammox bacteria contained in inclusive immobilization carriers are added to the anammox tank to perform denitrification of ammonia and nitrite.*

efficiency improvement aiming at 0.3 kWh or lower for the system energy consumption per cubic meter of treated water.

## NITROGEN TREATMENT SYSTEM USING ANAEROBIC AMMONIUM OXIDATION

A variety of industries produce nitrogen-rich effluent, including inorganic chemical and semiconductor manufacturing and livestock. To prevent eutrophication and other forms of pollution of enclosed waterways such as harbors or lakes and marshes, the regulation of nitrogen effluent has been getting progressively stricter, including the introduction of the seventh total emission control standard in 2014. The nitrogen treatment technique currently in widespread use employs activated sludge for biological nitrification and denitrification. This consists of a nitrification process that uses nitrifying bacteria to oxidize all of the ammonia ($NH_4$) in wastewater to nitrate ($NO_3$), followed by a denitrification process in which nitrifying bacteria convert this nitrate and organic matter to nitrogen gas ($N_2$).

An alternative to this, devised in the 1990s, is the anaerobic ammonium oxidation (anammox) reaction that enables more energy-efficient water treatment. This reaction relies on autotrophic anammox bacteria to convert a quantity of ammonia and approximately 1.3 times that quantity in nitrite ($NO_2$) to nitrogen gas. Its advantages include not requiring organic material and the fact that roughly half the ammonia in the wastewater is converted directly to nitrogen gas without being oxidized, thereby reducing the energy used for the nitrogen treatment. Nitrogen treatment systems that use this reaction (anammox treatment systems) have two tanks, with the addition of a nitrite nitrification tank in which roughly half the ammonia is oxidized to nitrite located upstream of the anammox tank. A feature of Hitachi's anammox treatment system is its use of an inclusive immobilization technique. This involves immobilizing the anammox bacteria and other active microbes in a polymer gel that acts as a carrier (see Fig. 6). Because the active microbes are present in this carrier in high concentration, they can be expected to provide reliable treatment performance and a fast treatment rate. The effectiveness of the system has already been demonstrated in experimental trials using actual wastewater, where benefits included a reduction of approximately 50% in energy use compared to previous methods and reliable long-term performance[(1)].

Hitachi also supplied equipment for the treatment of wastewater at a chemical plant that manufactured ammonia in 2013 (see Fig. 7). At about 100 $m^3$, the reaction capacity of the anammox was among the largest in Japan. The anammox treatment systems that use inclusive immobilization are at the leading edge, with few examples in operation anywhere in the world. The following section describes one example[(2)].

The wastewater at this site has an ammonia concentration of approximately 700 mg-N/L, with

*Fig. 7—Supplied Treatment System.*
*Hitachi supplied a nitrogen treatment system that uses the anammox reaction to treat wastewater from a plant that manufactures ammonia.*

approximately 100 to 400 mg/L of methanol included to provide the organic matter. It has been reported that methanol is very detrimental to both the nitrification and anammox bacteria used in anammox treatment systems. Accordingly, an upstream denitrification tank and biochemical oxygen demand (BOD) oxidation tank for removing methanol were fitted in the upstream part of the anammox treatment system (see Fig. 8). All of the tanks other than the downstream denitrification tank are supplied with carriers that use inclusive immobilization to contain the bacteria required for their respective functions.

The upstream denitrification tank and BOD oxidation tank eliminate all of the methanol from the wastewater. After this treatment, the wastewater continues to the nitrite nitrification tank where approximately half of the ammonia is converted to nitrite. The ammonia and nitrite contained in the wastewater discharged from this tank is then converted to nitrogen gas in the anammox tank. The mean total nitrogen concentrations of the inflow and outflow of the anammox tank are 676 mg/L and 110 mg/L respectively, indicating removal of more than 80% of the nitrogen. To date, the plant has already maintained reliable nitrogen treatment performance for more than a year. Hitachi believes this ongoing reliable performance demonstrates the validity of the development work to date.

## SEWAGE TREATMENT USING MFCs

Sewage is treated by a biological process using activated sludge, and organic matter in the sewage is decomposed by microbes. An issue with this method is the disposal of the excess sludge that accumulates due to the multiplying number of microbes. While it can be disposed of as industrial waste, this accounts for approximately 20% of operating costs. This has created demand for a new treatment technique that reduces the quantity of sludge produced by sewage treatment.

Hitachi is developing a new sewage treatment system that incorporates a microbial fuel cell (MFC) into the sewage treatment system. This not only reduces sludge production by more than 30%* compared to previous treatment methods, it also generates "eco-power" to supply some of the on-site loads such as lighting.

* Estimate by Hitachi based on comparison with previous oxidation ditch method.

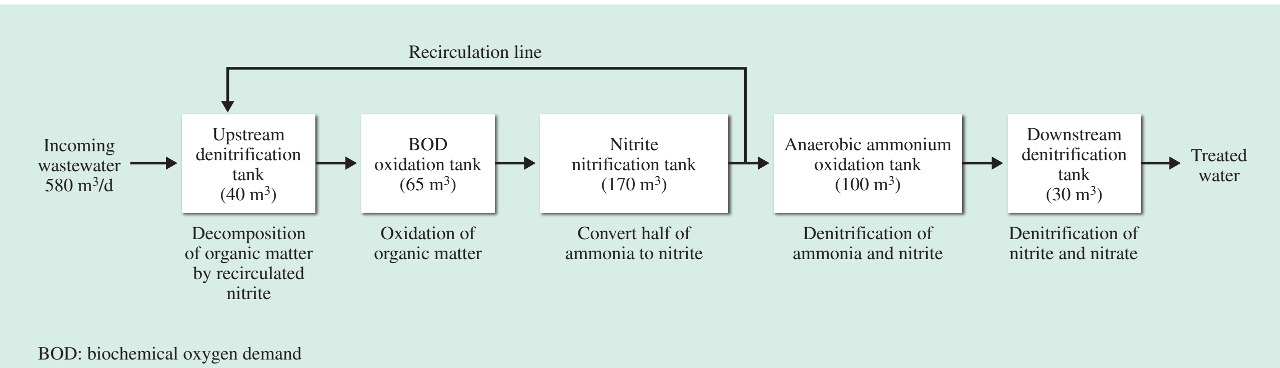


*Fig. 8—Flow of Wastewater at Treatment Plant that Uses Inclusive Immobilization.*
*The diagram shows the flow of wastewater through a treatment system with a rated flow rate of 580 m$^3$/day. The methanol present in the wastewater is removed in the upstream denitrification tank and BOD oxidation tank. Nitrogen removal involves first converting half of the ammonia in the wastewater to nitrite in the nitrite nitrification tank, followed by the denitrification of ammonia and nitrite in the anammox tank. The downstream denitrification tank then eliminates some of this residual nitrite and nitrate together with the added organic matter.*

This groundbreaking technology reduces the volume of sludge produced by using an MFC to recover the electrons and hydrogen produced by microbes in the process of decomposing organic matter in the form of electrical energy, thereby inhibiting microbe multiplication. The anode is submerged in the wastewater and the cathode is located on the treatment tank wall with an oxygen-permeable waterproof layer. The electrons produced by microbes as they decompose organic matter are collected by the anode. At the cathode, which has an oxygen-permeable film with a catalyst coating, water is produced by the reaction on the catalyst of hydrogen ions with the oxygen passing through the film[3]. In other words, the principle of operation of the MFC is that it generates electric power and produces water through the reverse electrolysis of water. (see Fig. 9).

Whereas microbes normally use the electrons freed by the decomposition of organic matter to drive their own multiplication, this process is impeded due to some of these electrons being captured by the anode. As a result, less sludge is produced.

The challenges associated with the development of a sewage treatment system that incorporates an MFC are to conduct system evaluation using actual wastewater, to significantly reduce the cost of the anode and cathode, and to increase electrode size from several centimeters to about 1 m.

As it works toward commercialization, Hitachi has been seeking to identify and overcome the challenges by conducting continuous long-term trials using wastewater obtained from a municipal sewage treatment plant. One of the factors in the high cost of the cathodes is the platinum (Pt) commonly used as the catalyst required by the reaction[4]. In response, Hitachi has reduced the cost of the cathode to roughly one-quarter the previous cost by adopting a carbon cathode that does not contain Pt. Continuous testing using this cathode demonstrated its ability to process the organic material contained in wastewater reliably and for long periods of time, while also generating electric power at a rate, albeit small, of 8.8 mW per square meter of electrode. Measuring effluent chemical oxygen demand (COD) concentration, an indicator of how much organic matter is being decomposed in the wastewater, the technique achieved a mean value of 9.7 mg/L, which represents water quality similar

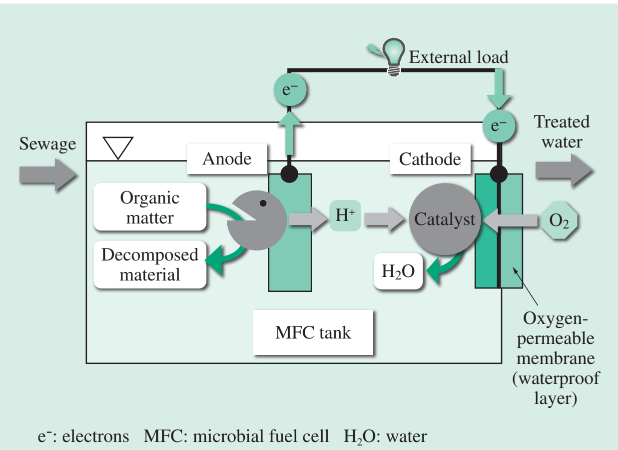


*Fig. 9—Decomposition of Organic Matter and Electric Power Recovery Using MFC.*
*Electrons released by the decomposition of organic matter are collected by the anode, while oxygen permeates through the cathode to react with hydrogen on the catalyst to form water.*

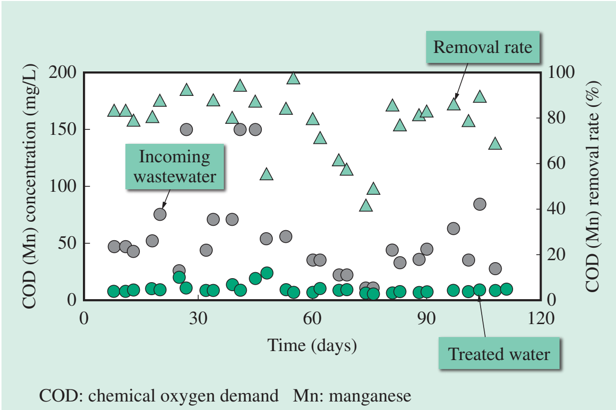


*Fig. 10—Evaluation of Sewage Treatment Performance on Benchtop Pilot Plant.*
*The benchtop pilot plant has demonstrated reliable treatment performance over long-term operation, as measured by COD. The quality of treated water is equivalent to existing wastewater treatment plants.*

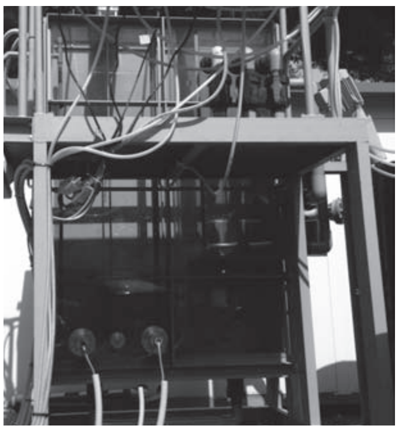

*Fig. 11—Pilot Plant Using Large Anodes and Cathodes.*
*A pilot plant fitted with four large anodes and cathodes (1,000 × 250 mm) has been installed at a sewage treatment plant and commenced operation.*

to that at existing wastewater treatment plants (see Fig. 10).

Hitachi has also been developing large anodes and cathodes suitable for a full-scale plant, and has succeeded in building prototypes with sizes in the 1-m range. A pilot plant that uses these large anodes and cathodes has been built and installed at the abovementioned municipal water treatment plant (see Fig. 11). Hitachi is currently commencing continuous operation trials using actual sewage to verify the effectiveness of the technique by evaluating how well it decomposes organic matter, reduces the production of sludge, and generates electric power.

## CONCLUSIONS

Hitachi intends to continue offering new ways in which it can play a part in maintaining and improving wholesome water environments, and achieving the sustainable development of water infrastructure that reduces the load on the environment.

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Featured Articles

# Work on Reconstruction of Electrical Systems at Sendai's Minami-Gamo Sewage Treatment Center Following Great East Japan Earthquake

Yasuhiro Kato
Akihiro Yamada
Kazushi Nozawa
Akihiko Okada

*OVERVIEW: Many of the sewage treatment facilities sited along the Pacific coast of Tohoku suffered serious damage from the Great East Japan Earthquake. This damage was considerably worse than expected and is taking a long time to recover from. Hitachi has been involved in work on electrical equipment for improving the water quality of treated sewage at the Minami-Gamo Sewage Treatment Center in Sendai City from the period immediately after the earthquake right up to the present day, the final fiscal year of the designated "concentrated reconstruction period" (FY2011 to FY2015). This article describes this involvement and what has been learned from the knowledge and experience gained through this work in terms of how best to enable electrical equipment to cope with disasters.*

## INTRODUCTION

SENDAI City's Minami-Gamo Sewage Treatment Center located on the Pacific coast suffered devastating damage from the tsunami that followed the Great East Japan Earthquake that struck at 2:46 PM on March 11, 2011 (see Fig. 1)[(1), (2)].

Reconstruction work is still ongoing and is scheduled for completion in March 2016[(3), (4)].

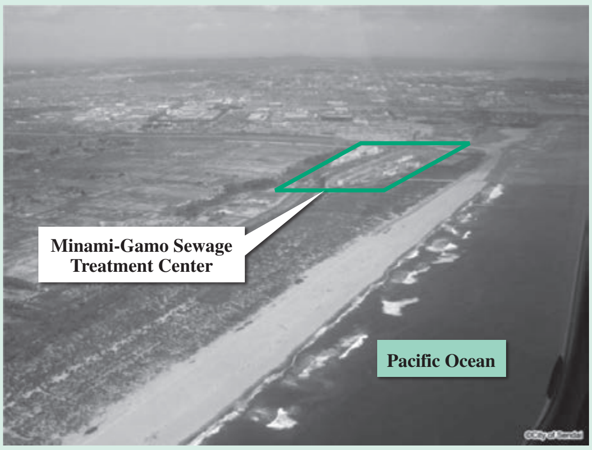



*Fig. 1—Aerial View of Minami-Gamo Sewage Treatment Center. The Minami-Gamo Sewage Treatment Center, shown here after the earthquake, is located on the Pacific coast. Among the damage caused by the tsunami was the washing away of the coastal forest.*

This article describes the work Hitachi has been undertaking since immediately after the earthquake on assisting with damage assessment surveys of electrical and instrumentation equipment and on restoring these systems. It also describes the Koriyama Monitoring Center, the design of which draws on this experience and seeks to spread the risk in the event of another disaster.

## FACILITY OVERVIEW AND DAMAGE SITUATION

With a capacity of 398,900 $m^3$ per day, the Minami-Gamo Sewage Treatment Center treats approximately 70% of sewage from Sendai City. Treatment is performed using the standard activated sludge method, with the resulting sludge then being concentrated, dried, and incinerated. Most electrical equipment at the facility was supplied by Hitachi.

The maximum height of the tsunami when it struck the coast was about 10.5 m, and about 4.0 m in the vicinity of the Teizan canal that flows through the site. At the water treatment facility located between the coast and canal and the extra-high voltage electrical room located adjacent to the canal, foundation piles, earthwork walls, and buildings were damaged by the impact force of the tsunami and from uprooted trees and other floating debris. This rendered the electrical equipment located outside or on the ground floor or

*Fig. 2—Damage Survey in Progress.*
*Conducting the survey on a site still bearing the scars of the disaster was a difficult task.*

basement of buildings unusable due to flooding or to being washed away.

Of the 1,486 items of electrical and instrumentation equipment that had been supplied to the Minami-Gamo Sewage Treatment Center, 966 items (65%) were assessed as being a total loss or partially damaged.

## WORK ON MINAMI-GAMO SEWAGE TREATMENT CENTER RECONSTRUCTION

### Support for Damage Assessment Surveys

A post-earthquake on-site survey commenced on March 28 in response to a request issued on March 24 by Sendai City and Japan Sewage Works Agency, a public organization. The subsequent assessment report was submitted on April 11. To ensure consistency with other disaster response agencies (local government) in matters such as decision-making procedures and reporting, a second round of surveys commenced on May 9, with a final report submitted on June 6. A total of 504 people were involved in conducting the electrical and instrumentation equipment survey over a 35-day period, with that number rising to around 600, including those involved indirectly in tasks such as finding and collating existing equipment drawings.

Along with the difficulty of obtaining gasoline, food, and drinking water, the survey also faced difficult sanitary challenges with the site still bearing the scars of the recent disaster (see Fig. 2).

### Measures Aimed at Progressive Improvement in Quality of Discharged Water

Because it was recognized that the water treatment facility had suffered such severe damage due to the disaster that it would take around five years to fully restore operation, an emergency restoration of operation was undertaken with reference to the content of the Ministry of Land, Infrastructure, Transport and Tourism's "Second Proposals of Technical Committee on Earthquake and Tsunami Countermeasures for Sewerage Systems"[3], with the aim of progressively improving the quality of discharged water (see Fig. 3).

Specifically, prior to full restoration of operation, the plan was to first achieve BOD* of 120 mg/L using sedimentation and disinfection, followed by BOD in the 60- to 15-mg/L range using a combination of biological treatment, sedimentation, and disinfection. The reconstruction of electrical equipment was also scheduled to satisfy this plan.

**Work on Sedimentation and Disinfection**

Work on installing temporary electrical equipment started on April 21, with a temporary switchboard (electrical control panel supplying equipment that included four automatic dust extraction systems and 36 sludge scraping machines) installed on May 2, a temporary distribution panel on May 9, and a backup high-voltage (6 kV) electrical system on May 12. These enabled operation to restart on May 19.

To process the sludge removed from the simple treatment process, an alternative controller held at the factory was used to restore makeshift operation by replacing the earthquake-damaged HISEC-R600 controller in the sludge processing building. This enabled a resumption of sludge drying using the centrifugal dryers.

Subsequently, automation of the sodium hypochlorite injection system (automatic control using a temporary inlet flow gauge) was achieved during July.

**Work on Biological Treatment, Sedimentation, and Disinfection**

To commence operation of the interim treatment facility using the contact aeration process, a power system of about 1,500 kVA was needed to provide electric power to equipment such as the blowers that deliver the air for aeration.

As the site was still running on emergency backup power (up to 2,000 kW) at this time, a temporary standard 2,000-kVA generator able to operate continuously (24 hours a day) and outdoor fuel tanks with sufficient capacity for around 72 hours of continuous operation (approx. 33,000 L) were procured. Once these had been registered with the

* Abbreviation of "biochemical oxygen demand." The amount of oxygen required by microbes to breakdown organic material and other pollutants in the water.

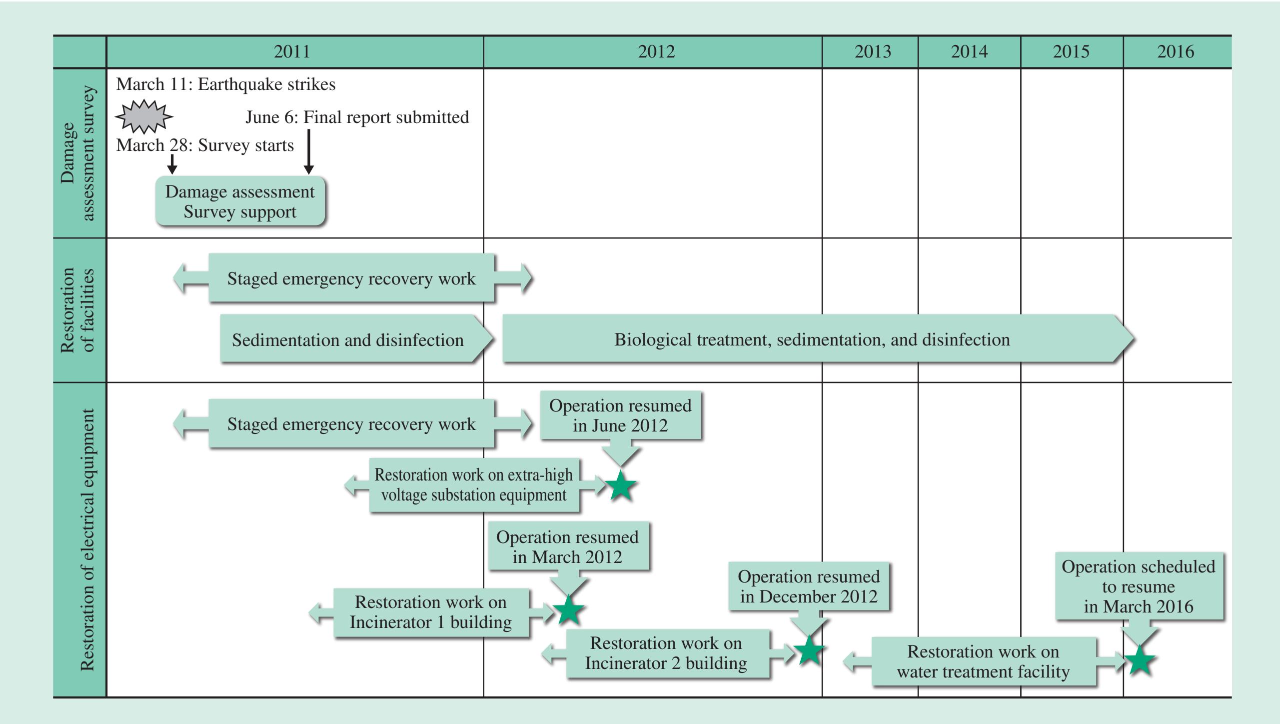



*Fig. 3—Work on Minami-Gamo Sewage Treatment Center Reconstruction.*
*Reconstruction work has been ongoing since the immediate aftermath of the disaster.*

authorities and subjected to inspection, operation of the interim treatment facility using the contact aeration process was able to commence in February 2012.

## Work on Full Restoration of Extra-high Voltage Substation Equipment

The gas-insulated switches (GISs) that had been located on an outdoor, above-ground compound were deemed irreparable due to the ingress of seawater, so the gas was recovered from the tanks and the units were removed and disposed of on September 20. On the other hand, it was decided to take the transformers that had escaped damage due to water ingress back to the factory for refurbishment, and work commenced on their removal. In April of 2012, the replacement GISs were delivered to the site together with the refurbished transformers that had been cleaned, dismantled, had their radiators replaced, and repainted. After testing, adjustment, and a voluntary pre-operational inspection had been completed, supply of extra-high voltage electric power went live on June 12, more than a year after the earthquake (see Fig. 4).

## Work on Full Restoration of Sludge Incinerator

The ground floors and underground floors of the sludge incinerators located on the landward side of the water treatment facility were flooded and suffered water damage.

As was the case with the simplified operation of the water treatment facility, restoring the incinerators used to dispose of the dried sludge was an urgent priority. Demolition of Incinerator 1 commenced in August 2011 and it went back into service in March

GIS: gas-insulated switch

*Fig. 4—Fully Restored Extra-high Voltage Substation Equipment (GIS).*
*By locating structural components on a raised embankment, the restored GISs are located about 10 m above the ground line.*

2012 at the same time that the routine operation of the emergency backup generator was restored. Similarly, demolition of Incinerator 2 commenced in February 2012, and following its complete reconstruction, went back into service in December of the same year.

For the reconstruction of the sludge processing building, because the damaged HISEC-R600 controller in the ground-floor low-voltage electrical room was a discontinued product, a system-compatible HISEC-R700 was used instead to avoid any impact on the overall system.

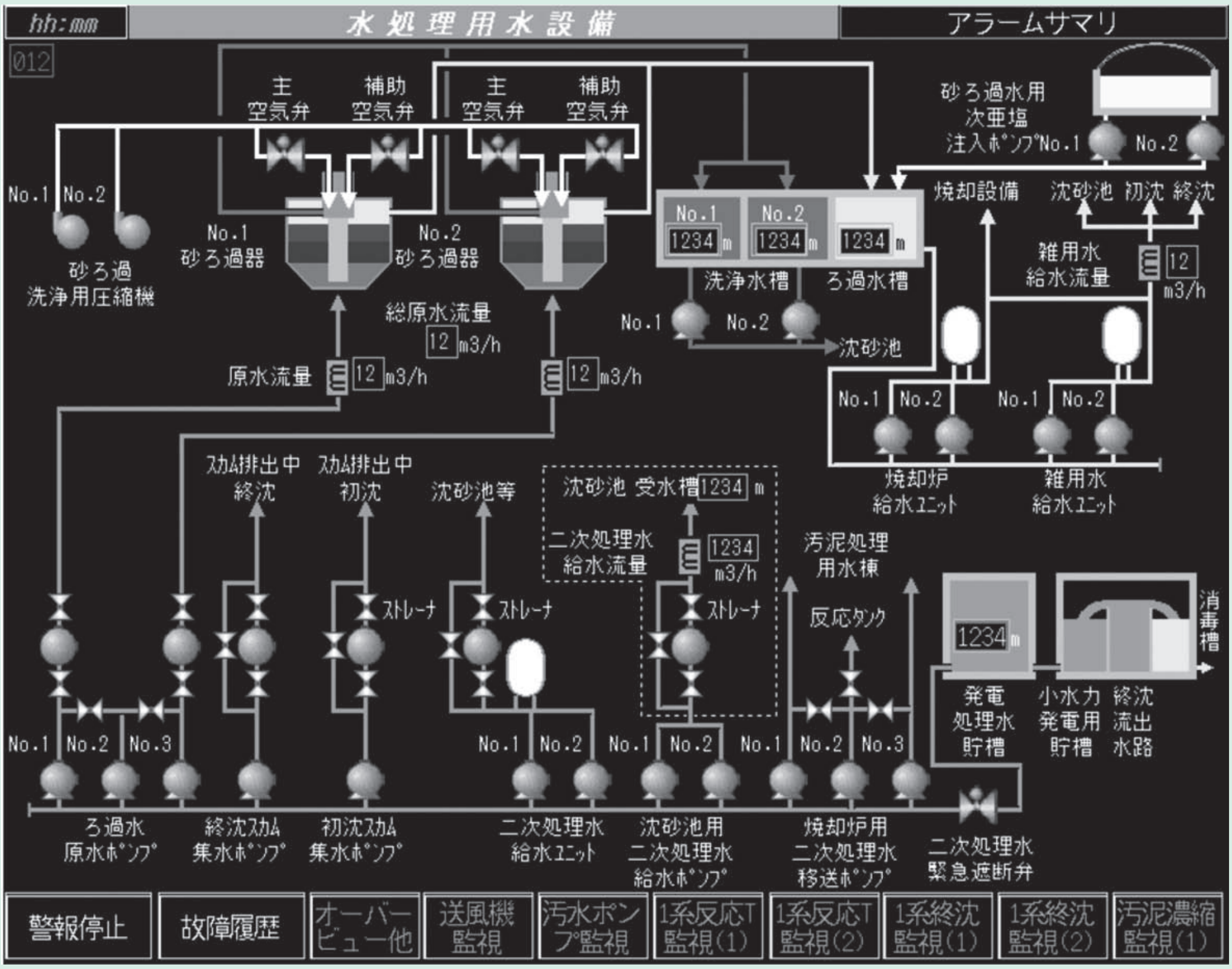
### Work on Full Restoration of Water Treatment Facility

The full restoration of the water treatment facility was undertaken using a different process than before, including the use of a deep-layer reaction tank.

Because the associated earthworks and mechanical equipment involved nine projects spread across seven companies, Hitachi coordinated its design, fabrication, and installation activities across the group to coordinate work on the different projects as they proceeded in parallel and to keep them on schedule.

To allow for future functional enhancements, Hitachi took the proactive step of adopting the latest XR1000H controller for the monitoring and control system.

In adopting the latest controller, Hitachi also gave adequate consideration for undertaking this work in ways that maintain compatibility with the existing Hitachi's central monitoring and control system located on the second floor of the administration building where it escaped damage, and the HISEC-R700 controllers used on parts of the site that had already




LCD: liquid crystal display

*Fig. 5—Screen for Monitoring Other Equipment (Example).*
*In addition to the monitoring and operation of equipment controlled by the controller, the LCD touch panels can also be used for process monitoring of other associated equipment.*

been restored to operation, such as the extra-high voltage substation equipment and on-site power generation equipment.

One of the features of the monitoring and control system is a function for monitoring other equipment.

In terms of monitoring other equipment, this function provides liquid crystal display (LCD) touch panels on the exterior of the XR1000H controllers located in each electrical room that can be used to monitor other associated equipment as well as to monitor and operate the equipment controlled by the controller. This enables workers to obtain the required information on the spot even if they lack a portable tablet or are not in telephone contact with the central control room (see Fig. 5).

Work is also proceeding on providing energy-saving and energy-generating infrastructure at the new water treatment facility by installing photovoltaic- and microhydro power-generation equipment.

## REMOTE MONITORING AND CONTROL SYSTEM FOR SENDAI CITY KORIYAMA MONITORING CENTER

The sewage and storm water pumping stations in Sendai City are divided up into a northern sector (20 stations) and a southern sector (16 stations), with centralized monitoring and control performed at the Rokuchome Monitoring Center.

Based on the experience of the Great East Japan Earthquake, upgrade work on the Koriyama Monitoring Center was completed in FY2014, including a broadband Ethernet link connecting the Rokuchome Monitoring Center and Koriyama Monitoring Center that allows centralized monitoring and control to be performed at both centers. The monitoring and control database for the southern sector pumping stations (server for southern sector clients) was installed at the Koriyama Monitoring

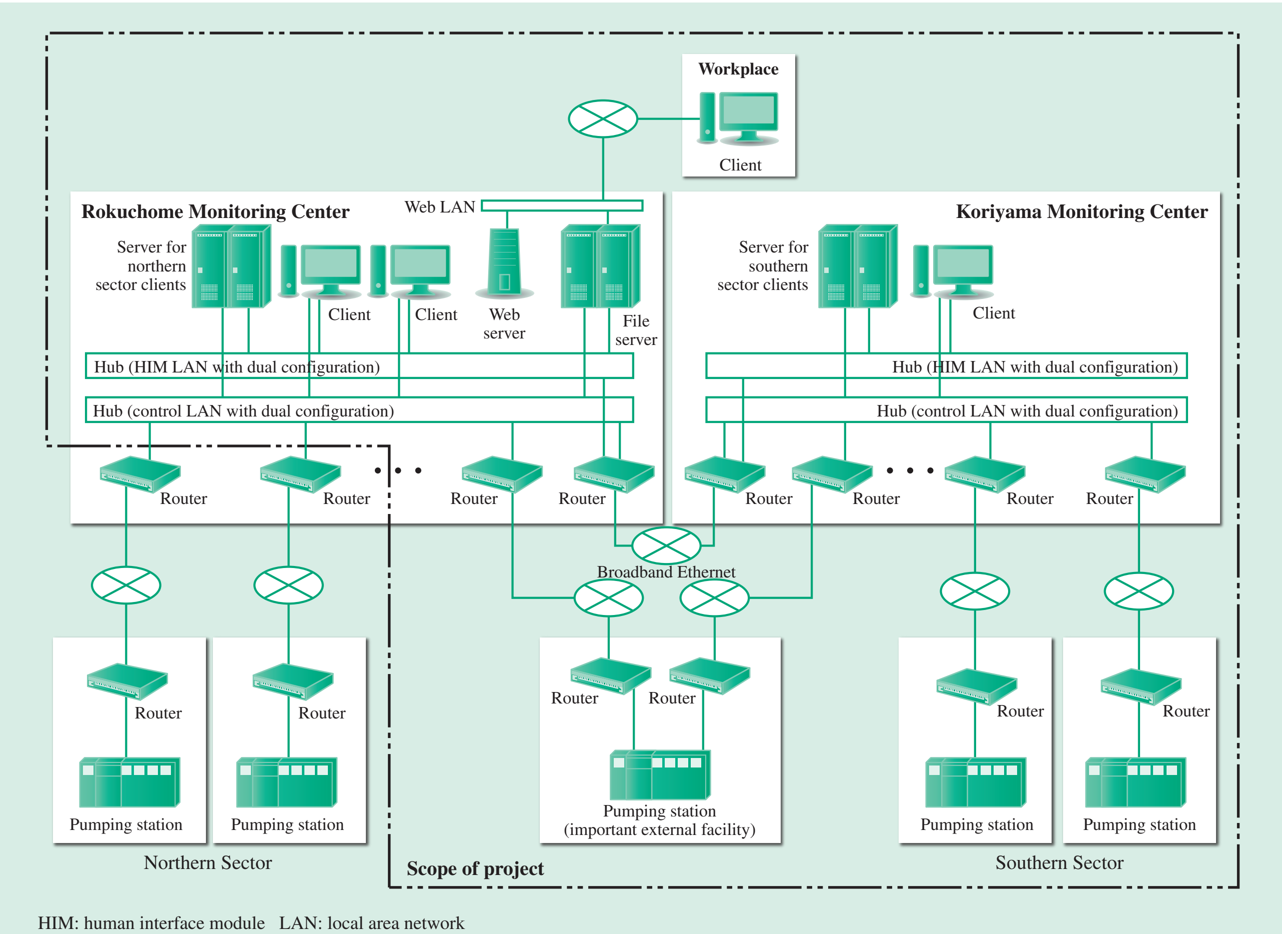



*Fig. 6—Remote Monitoring and Control System.*
*In addition to allowing monitoring and control from both the Rokuchome Monitoring Center and Koriyama Monitoring Center, the broadband Ethernet connection has also enabled the monitoring and control database (client/server) to be installed at both centers to spread the risk.*

Center to spread the risk between the different data management facilities (see Fig. 6). Similarly, to improve reliability, a dual system configuration is used for data transmission to the two monitoring centers from three important external facilities.

## ELECTRICAL EQUIPMENT ABLE TO COPE WITH DISASTERS

Based on the lessons learned from this experience, Hitachi has considered how to make electrical equipment that is resilient to disasters (minimizing or eliminating damage).

### Installation Conditions for Electrical Equipment

(1) Install equipment in a location that is higher than the anticipated level of flooding

With the exception of the water treatment facility located on the shoreline, the electrical equipment installed on the second floor or higher largely escaped flooding damage during the disaster. This means it is a good idea to install substation equipment, electrical distribution systems, direct current power supplies, on-site power generation equipment, central monitoring and control systems, and other such equipment above the level where flooding damage is likely to occur (on a higher floor) (see Fig. 7). In the case of the Minami-Gamo Sewage Treatment Center, equipment was installed above the anticipated level of flooding by using embankments to raise the height by 10.4 m.

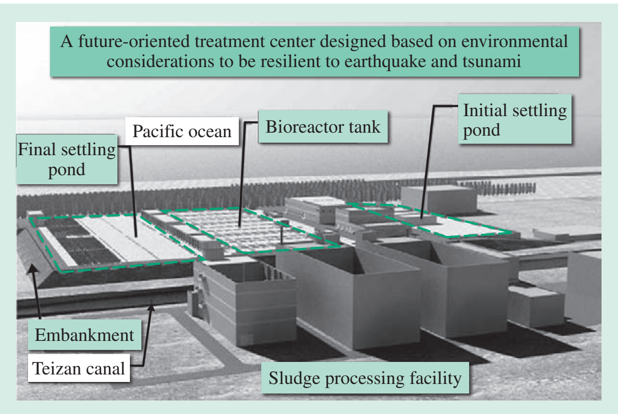



*Fig. 7—Construction of Facilities Above Anticipated Maximum Flood Level.*
*To prevent tsunami damage to structures and avoid loss of equipment and other functions, the facilities were rebuilt on a raised embankment, which in the case of the Sendai City Minami-Gamo Sewage Treatment Center is 10.4 m above ground level.*

(2) Dual routing of power and communications

Because electrical equipment forms part of a system, the effects of a failure in one part spread across the entire system. One practice for preventing this has been to use duplicate power and communication cables depending on the importance of the equipment and to provide multiple routes to keep faults to a minimum by being able to keep the system operating using an undamaged route even if some routes are damaged.

### Quick Restoration of Electrical Equipment

This section describes how to achieve a quick restoration of operation, with reference to onsite-experience with disaster recovery work. This disaster recovery involved working on earthworks, construction, machinery, and electrical equipment in parallel. Of these, electrical equipment is the last to be specified and the last to commence on-site installation.

The requirements for this work are to shorten design and fabrication schedules and to reduce the amount of on-site work such as installation and commissioning.

(1) Shortening design and fabrication schedules

Along with organizational capabilities for tasks such as procuring labor and sourcing parts, the challenges of undertaking recovery work over a long period of time also include the standardization of design drawings across equipment of the same type.

Examples of this include standardizing the electrical specifications (currents, cable connection procedures, and so on) for scraping machines or the valves used in machinery. Because this enables the adoption of standardized practices after the reconstruction and facilitates maintenance and management, it is necessary to deal with machinery and electrical equipment as a single unit.

(2) Reduce volume of installation, commissioning, and other similar work

Because obtaining technical staff and workers is difficult after a large disaster that affects a wide area, Hitachi believes it is important to cut workloads by reducing the number of electrical parts such as cables that need to be installed.

For example, cabling requirements can be reduced by housing controller input and output devices in an auxiliary relay panel that connects to the controller panel via a communications link (see Fig. 8).

Hitachi also believes that future sites of reconstruction work will need to consider things like incorporating input and output devices into on-site operation panels that have been put together based on

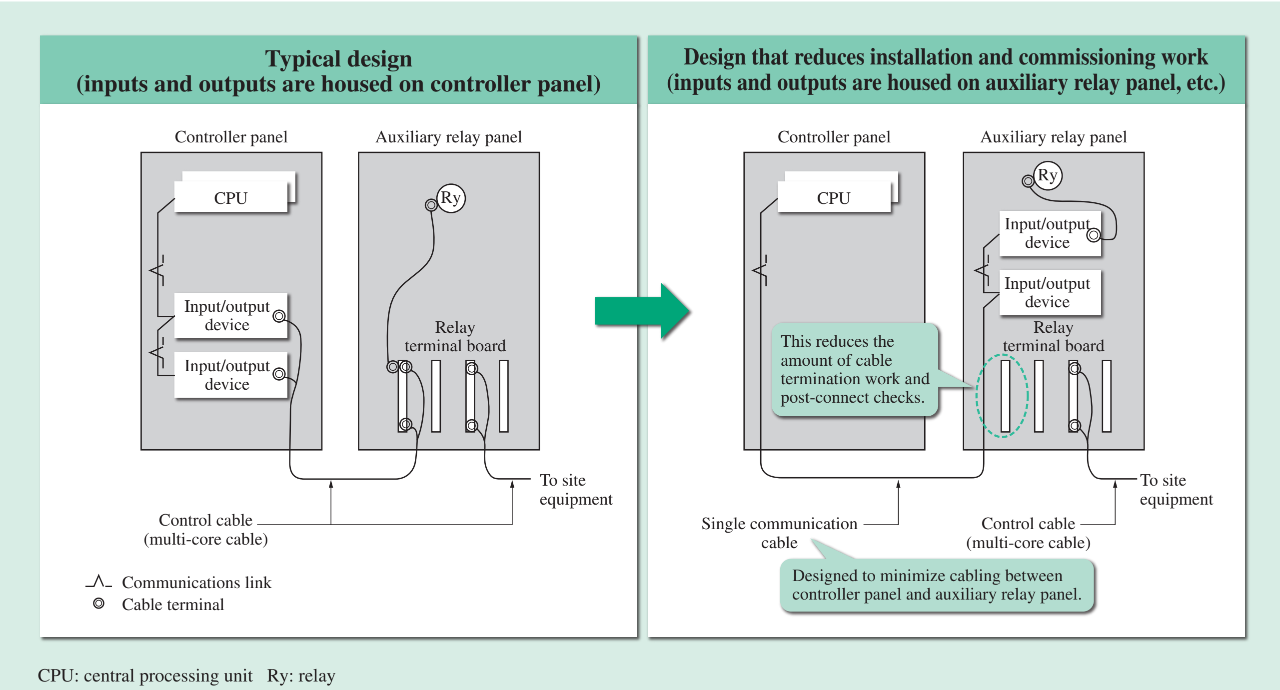



*Fig. 8—Reduced Cabling Design.*
*This is one example of how to enable a quick restoration of operation despite the likely shortage of technical staff after a large disaster affecting a wide area.*

engineering considerations, and the use of portable tablets for on-site operation.

## CONCLUSIONS

This article has described Hitachi's involvement in reconstruction of the Minami-Gamo Sewage Treatment Center in Sendai City from immediately after the earthquake until the present day.

Hitachi intends to continue to fulfill the expectations placed upon it and provide disaster assistance by utilizing the experience and knowledge gained from this involvement and working with local governments affected by disasters.

Finally, the authors would like to express their sincere thanks to everyone who participated so diligently in the reconstruction work, and to the families who provided them with ongoing support, despite themselves being among the victims of the disaster.

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Featured Articles

# Hitachi's Water Business Activities in the Oil & Gas Industry

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*OVERVIEW: Based on a background of growing demand for oil throughout the world, the International Energy Agency has predicted global oil demand in 2015 of 93.6 million barrels per day, an increase of 1.1 million barrels per day. Accompanying this, new requirements are emerging for water treatment, with the injection of water into oil-bearing layers to increase the volume extracted becoming part of conventional oil production practice, and with unconventional oil production from sources such as oil sands or shale oil requiring water-using extraction techniques not used in the past. Given this background, Hitachi is contributing to making the most of limited water resources at oil and gas production sites by supplying solutions to these needs that utilize the extensive water treatment technologies it has cultivated up to now.*

## OVERVIEW OF WATER TREATMENT IN THE OIL & GAS INDUSTRY

THERE is growing demand in the oil and gas industry for water treatment systems that comply with environmental regulations, which are becoming increasingly strict every year, with the treatment of water produced as a byproduct of oil and gas extraction being a particular problem. Furthermore, this increasing requirement for water treatment systems is being driven by economic as well as environmental factors, with large amounts of water being used in recent years as a means for the efficient extraction of limited resources.

In the case of conventional oil production sites, for example, because the pressure in the oil-bearing layers falls the longer a well remains in production, it is common to use "waterflooding" to promote oil extraction by injecting water to maintain this pressure. Waterflooding requires the use of sulfate removal units (SRUs) to eliminate sulfate prior to injection because of the role it plays in scale formation. The injection pumps that pressurize the treated water to high levels are another vital piece of equipment.

Unconventional oil production sites, too, require a variety of water treatment equipment to provide water for extracting the oil from oil sands (which are mined using opencast practices) and steam for the recovery of bitumen by steam assisted gravity drainage (SAGD), or the water used for extracting shale oil or shale gas by fracking.

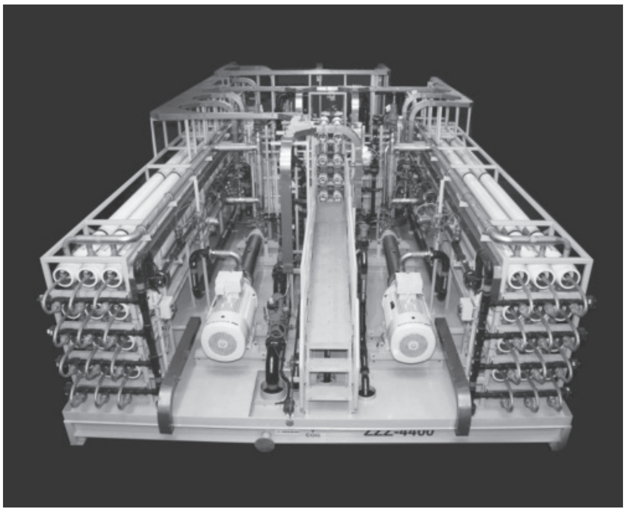
As the water treatment equipment used in the oil and gas industry operates under unusual conditions, it is subject to numerous constraints, such as limits on space and the need for resistance to corrosion, oil, and heat. Accordingly, the industry requires equipment that can satisfy these demands. The water treatment equipment used on offshore oil platforms or floating production, storage and offloading systems (FPSOs), for example, requires special specifications in order to satisfy performance requirements within the very limited space available.

Hitachi has entered this market and is expanding its presence by drawing on its extensive knowledge of water treatment technology to supply solutions that meet the particular needs of various different sites operated by the oil and gas industry. This article describes some of the recent activities of Hitachi, including SRUs, a seawater desalination system for FPSOs (see Fig. 1), and injection pumps.

## OVERVIEW OF SRUS AND HITACHI'S ACTIVITIES

### Need for Sulfate Removal

When seawater is injected into oil wells to improve oil recovery, the ions in the seawater can react with water and clay inside the well to form deposits (scale) that reduce the ability to recover oil by blocking the pores in the well. In particular, there is a need to deal with the sulfate ($SO_4^{2-}$) present in seawater in a concentration of several thousand milligrams per



RO: reverse osmosis
FPSO: floating production, storage and offloading system

*Fig. 1—RO Unit for FPSOs.*
*This RO unit for FPSOs has the capacity to treat 1,200 to 2,226 $m^3$ of water per day. Hitachi has already supplied six of the units, with three more currently in production.*

liter. This sulfate reacts with barium ions ($Ba^{2+}$) and strontium ions ($Sr^{2+}$) in the well to form deposits of barium and strontium sulfate ($BaSO_4$ and $SrSO_4$).

Furthermore, any sulfate that gets into the well is readily transformed into toxic and corrosive hydrogen sulfide ($H_2S$) by the action of sulfate-reducing bacteria, creating an acidic environment in the well and resulting in corrosion of various down-well equipment. Accordingly, the control of sulfate is particularly necessary if seawater is to be used for injection.

### Sulfate Removal Method

Past practice for preventing the formation of scale due to sulfate was to deposit large quantities of scale inhibitor into the well. However, the lack of uniformity in well characteristics makes selecting the best chemical to use and controlling its concentration difficult, so much so that getting the conditions wrong can actually promote scale formation inside the well.

Nano filtration (NF) membranes, a recent development, have attracted attention as a potential technique for removing sulfate from injection water. A feature of NF membranes is that, whereas ions with a single charge can pass through largely unimpeded, the membranes can efficiently separate ions with a double charge. This makes them ideal for the removal of sulfate ions, which have a charge of –2, and when used on seawater with a sulfate concentration of several thousand milligrams per liter, they can reduce the concentration to below 100 mg/L. Because NF membranes are used at much lower pressures and can recover 1.5 to 2 times as much water as the reverse osmosis (RO) membranes used for seawater desalination, they also have potential economic advantages. Furthermore, because NF membranes also filter out microorganisms such as sulfate-reducing bacteria, they can significantly reduce the risk of oil wells being fouled or becoming acidic.

With the technology now starting to be used not only in offshore oilfields such as the North Sea or off the coast of Brazil, but also in onshore fields such as those in the Middle East, the scope of its use is expected to expand rapidly in the future.

### Sulfate Removal System Implementation

Because the condition of seawater varies widely depending on the location and time of year, the choice of pre-treatment system is important for preventing severe fouling of NF membranes and maintaining stable membrane filtration performance. Pre-treatment systems are typically chosen based on the condition of the seawater (presence of organic matter, turbidity, any plankton or other microorganisms) from a range of options that include simple filters, sand filters (such as multimedia filters), and micro-filtration (MF) or ultra-filtration (UF) membrane filters. In particular, membrane filtration has been selected in many recent projects, especially offshore facilities, not just because it is easy to maintain and delivers good water quality, but also for its other advantages that include installation space and equipment weight.

Hitachi is able to draw on its many years of experience with water treatment to supply the right sulfate removal system for each project. By combining these with its information and communication technology (ICT), Hitachi aims to implement systems that satisfy the varying requirements of customers, including for operation and maintenance.

## OVERVIEW OF SEAWATER DESALINATION SYSTEMS FOR FPSOS AND HITACHI'S ACTIVITIES

Hitachi Aqua-Tech Engineering Pte. Ltd. (HAQT) markets seawater desalination systems that feature excellent energy efficiency for a variety of applications. Recent years have seen growing demand for these systems in applications such as offshore oilfields in particular, which are characterized by restrictions such as space and power supply. HAQT has overcome these obstacles by developing technology for more compact and energy-efficient systems, and by equipping them with enhanced corrosion and vibration resistance to enable them to operate on offshore rigs or platforms.

FPSOs have been used by the oil and gas industry for the last 30 years, with many of them currently operating in offshore oilfields. FPSOs are moored on the ocean like a boat, where they receive the crude oil, water and other material produced by an offshore oilfield. The mooring method used depends on the conditions, with multi-point moorings being used in calm waters, and independent moorings being used in waters prone to cyclones or hurricanes. These independent moorings allow the FPSO to be disconnected from the mooring during storms and then reconnected after the bad weather has passed.

FPSOs have the following advantages.

- Can be relocated and reused
- Minimize need for offshore construction, faster startup of production
- Able to be used in a wide range of maritime climates

Moreover, with the advances in moorings and undersea equipment over the last few years, FPSOs can now be used in deeper waters and stronger currents than before.

HAQT supplies seawater reverse osmosis (SWRO) equipment for seawater desalination on FPSOs. This SWRO equipment is commonly used on FPSOs as oil dilution and water treatment systems. The equipment is customized to suit the following conditions.

- Drinking water
- Water for general use
- Cooling water
- Water containing dilute oil

The rinse water used to dilute crude oil in order to remove the salt and water requires a high level of water quality. This rinse water dissolves the salt contained in the crude oil. Because any solids or salt contained in the rinse water will contaminate the crude oil and will need to be removed by subsequent processing, it is necessary to eliminate these impurities beforehand. SWRO systems are primarily used for this purpose as they can produce rinse water on the vessel with consistent quality.

Underpinned by demand from the FPSO market, HAQT supplies products that are customized to suit a wide range of requirements.

## INJECTION PUMPS

### Product Overview

Injection pumps operate at high pressure and are used for waterflooding, a technique classified as a secondary recovery method for the production of crude oil. In contrast to primary recovery, whereby the oil is forced to the surface by the natural pressure of the underground oil-bearing layers, secondary recovery methods are those that increase production volume by forcibly increasing the flow of oil through the oil-

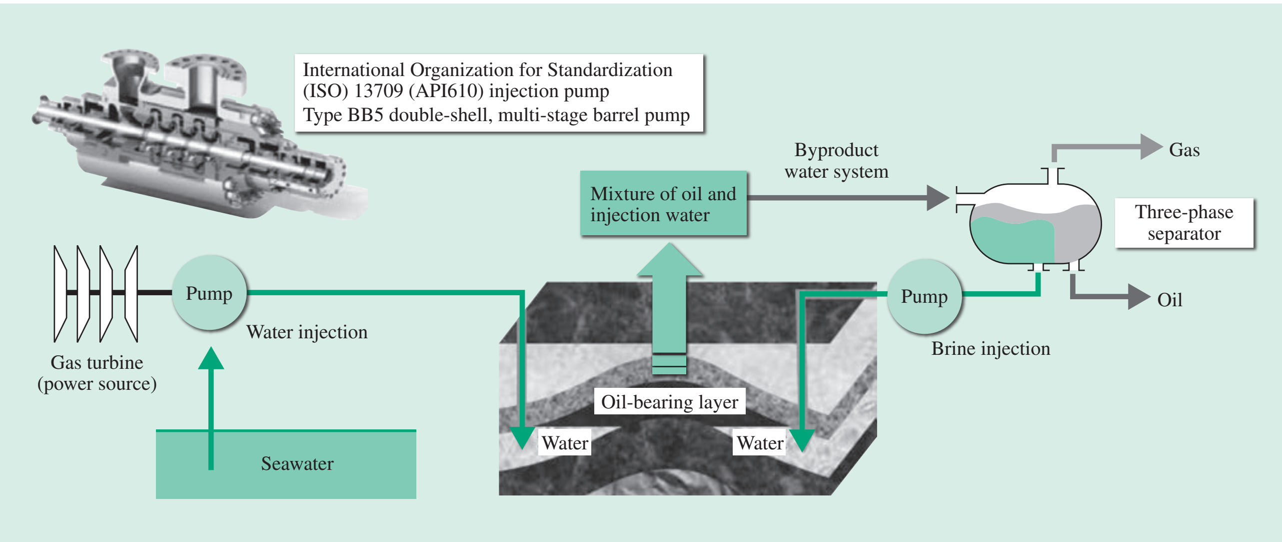



*Fig. 2—Overview of Crude Oil Extraction System Using Secondary Recovery Method.*
*A water injection pump is one that injects a fluid, such as water drawn from the ocean, into the oil-bearing layer. A brine injection pump, on the other hand, is one that re-injects water that has been separated from the fluid mixture extracted from the oil-bearing layer in a three-phase separator. Both types of pump increase production of crude oil by improving the flow of fluid through the oil-bearing layer.*

bearing layers. Waterflooding is one such method and it works by using a pump to inject pressurized water. As primary recovery is typically believed to extract only around 30% of the available oil, the current growth in the international consumption of oil means that the use of other methods such as waterflooding to increase the production of existing oil fields has become an essential addition to the discovery of new fields. Fig. 2 shows an overview of an oil extraction system that uses a secondary recovery method.

In response to this situation, Hitachi has developed and commercialized new injection pumps that feature high reliability and high performance for use in waterflooding. The main features are as follows.

(1) Compliant with International Organization for Standardization (ISO) 13709 (API610) standard

(2) Help reduce life cycle costs (including maintenance) by providing high efficiency and pumping performance thanks to the use of highly accurate computational fluid dynamics (CFD) to redesign the shapes of the impellor and other fluid power components.

(3) High reliability achieved through the use of dual-phase stainless steel that provides both high strength and resistance to corrosion when used to pump seawater.

(4) High level of operational reliability thanks to low-vibration operation achieved through the evaluation and testing of rotor dynamics.

(5) A range of shaft seals and bearings available to suit different conditions, with auxiliary components that feature compact design and long operating life.

### Development Technology for High-performance Fluid Power Components

The BB5 multi-stage barrel pump designed for use as an injection pump contains a large number of fluid power components, including the impellor and diffuser. To achieve high performance, it is important to produce optimal designs for the shapes of these components by determining how they interact with the flow. In addition to using highly accurate CFD to simulate the flow through each of these components (see Fig. 3), a high-performance shape design was achieved efficiently by conducting a systematic study of the sensitivity of performance to the shape of fluid power components using a parameter design based on experimental design methods.

### Summary

These injection pumps have demonstrated both high performance and high reliability, with a discharge pressure of approximately 200 bar (20 MPa), a rated output of 28,000 kW (ISO rating of gas turbine used to drive pump), and a total of more than 13,000 hours of field operation.

Injection pumps are required to operate under a wide range of conditions in terms of both the fluids they are called on to pump and the conditions in the oil-bearing layer. By supplying the oil and gas market with injection pumps that can satisfy diverse requirements with high efficiency and reliability, Hitachi intends to continue contributing to the steady supply of energy.


CFD: computational fluid dynamics

*Fig. 3—Use of CFD to Simulate Flow inside Pump.*
*The figure shows the pattern of flow through the pump, from the inlet channel to the impellor, diffuser, and return. High efficiency is achieved by making full use of highly accurate CFD.*

## CONCLUSIONS

This article has described Hitachi's recent activities relating to water supply in the oil and gas industry. Hitachi has already built up a track record of supplying solutions that satisfy customer needs in a variety of fields. By further boosting its involvement, Hitachi intends to continue contributing to achieving both environmental protection and economic development on a global scale.

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Featured Articles

# Work on Introduction of Water Distribution Control System in Zhejiang Province, China through Public-private Partnership

Masahiro Yabashi, PE-Jp
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Keiji Okuma
Jun Liu
Yineng Gu

*OVERVIEW: Hitachi has undertaken a feasibility study whereby it has participated in a model public-private partnership for the adoption of a water distribution control system already proven through use in Japan by a selected water utility in Zhejiang Province, China. The region covered by the study has a total customer base of 150,000 people with maximum demand of 30,000 m$^3$/day. Based on the results of an on-site survey of the water distribution network and other infrastructure, an investigation was conducted into future problems with low pressure in the distribution network due to increased water demand. The study found that, by formulating a pipe network plan that makes maximum use of the gravity-fed distribution of water from treatment plants, and by undertaking the basic design of the water distribution control system with this plan as one of the design assumptions, it should be possible to achieve a reliable supply of water and the efficient operation of infrastructure. Based on this experience, Hitachi intends to continue contributing to the international deployment of Japanese water technology.*

## INTRODUCTION

THIS article describes an example of the public and private sectors in Japan working together on the international expansion of the water industry that involves work being undertaken in China in support of the management of water distribution by small and medium-sized utilities.

In line with the Chinese government's intention to improve the overall standard of water supplies, a memorandum of understanding was reached between Japan's Ministry of Health, Labour and Welfare and the Ministry of Housing and Urban-Rural Development of the People's Republic of China in May 2008 regarding technical collaboration with Japan on water supply in regional Chinese cities. Based on this agreement, a regional city in Zhejiang Province, China was selected by the Ministry of Housing and Urban-Rural Development to participate in the project. An on-site survey and consultations were held with the main urban water utility in the city in November 2008. This led to a model project that primarily involved support for the management of water distribution in cooperation with a utility that expressed a desire to adopt Japanese technology. The agreement to undertake this project was signed in November 2010.

As regional cities along the Pacific coast of China have been experiencing remarkable economic growth and rising water demand, there is a high level of concern about improving the efficiency of water distribution management and maintaining the reliability of water supplies. To utilize Japanese technology as part of efforts to help overcome these challenges, we proposed a plan for pipe network optimization and prepared a basic design for the installation of a water distribution control system based on a survey of the participating local water utilities. The following sections provide an overview of this work.

## SURVEY METHOD

Three preliminary surveys of the participating region were conducted from November 2008 to February 2010 through collaboration between relevant agencies in China and the Water Supply Division at the Health Service Bureau, Ministry of Health, Labour and Welfare and other public and private sector agencies in Japan[(1), (2)] (see Table 1). Through this process, the participating water utility was selected and work

Table 1. Preliminary Survey and Full Survey of Participating Region
*Surveys and consultancy were undertaken as a public-private partnership with the aim of introducing Japanese water supply technology to regional cities in China.*

| Item | Date | Survey work | Remarks |
|---|---|---|---|
| Preliminary survey 1 | November 2008 | Consultation with candidate utilities in the selected regions | Project for International Expansion of the Water Industry, Water Supply Division at the Health Service Bureau, Ministry of Health, Labour and Welfare |
| Preliminary survey 2 | November 2009 | Presentation of information about Japanese products and technologies to candidate utilities in the selected regions. | Same as above |
| Preliminary survey 3 | February 2010 | Agreement among relevant parties to commence model project for water distribution management at selected participating utility. | Same as above |
| Full survey 1 | June 2010 | Preliminary survey of treatment plants, pumping stations, and other infrastructure at participating utility | In-house survey |
| Full survey 2 | August 2010 | Detailed survey of treatment plants, pumping stations, and distribution pipe networks at participating utility | Water Saving and Environmentally-friendly* Water Recycling Project of NEDO |
| Full survey 3 | October to November 2010 | Additional survey of water treatment plants, pumping stations, water distribution network; relevant parties from Japan and China agree on memorandum of understanding for conducting model project. | Same as above* |
| Full survey 4 | April 2011 | Detailed survey of water treatment equipment | In-house survey |

NEDO: New Energy and Industrial Technology Development Organization
* Water Saving and Environmentally-friendly Water Recycling Project, Research and Development of Water Resource Management Technologies, Demonstration Research aimed at their Deployment in Japan and Overseas, Verification and Feasibility Study of Work on Supporting Energy-efficient Water Distribution Management in Asia (Phase 1) of NEDO

started on the model project for water distribution management, with the districts supplied by the utilities used as the model region.

Since June 2010, with assistance from the New Energy and Industrial Technology Development Organization (NEDO), two full surveys of the water distribution networks and other infrastructure in the model region and two independent surveys to collate the challenges facing water distribution management, now and in the future, have been conducted. Additionally an investigation has been conducted into the best ways to make improvements in response to predicted future increases in water demand(3).

Table 2 profiles the water utility selected for participation in the model project. Although small, the operation of the utility is typical of regional cities, providing 24-hour water supplies with approximately 15% of non-revenue water ratio. However, because the region is experiencing rapid economic growth, increasing demand has been causing problems with low water pressure at the edge of the network. To overcome these, it was decided to assist the utility with a two-stage draft plan involving, (1) Optimization of the water distribution network, and (2) Installation of a water distribution control system.

The surveys of the water distribution network were performed using maps of the water pipe network provided by the participating utility, and a field survey of the entire model region to ascertain conditions on the ground. The pipe network analysis function of

Table 2. Profile of Participating Utility
*A regional city in Zhejiang Province, China that is experiencing rapid economic growth.*

| Item | Value (As of 2010) | |
|---|---|---|
| Customer base | 150,000 | people |
| Supplied area (model region) | 300 | km$^2$ |
| Maximum daily water supply (present day) | 15,000 (approx.) | m$^3$/day |
| Maximum daily water supply (future) | 30,000 (approx.) | m$^3$/day |
| Treatment capacity (future) | 30,000 (20,000 at treatment plant A, 10,000 at treatment plant B) | m$^3$/day |

Hitachi's geographic information system (GIS) based water distribution management system was used to perform pipe network simulations based on the data obtained by the surveys.

On-site surveys were also conducted to obtain information about the water treatment plants and distribution pumping stations, including equipment configurations and operating conditions.

## OPTIMAL PLANNING FOR WATER DISTRIBUTION NETWORK

In addition to collating information about the challenges facing water distribution networks now and in the future, an investigation was also conducted into a plan for optimizing the distribution network to cope with predicted future increases in water demand.

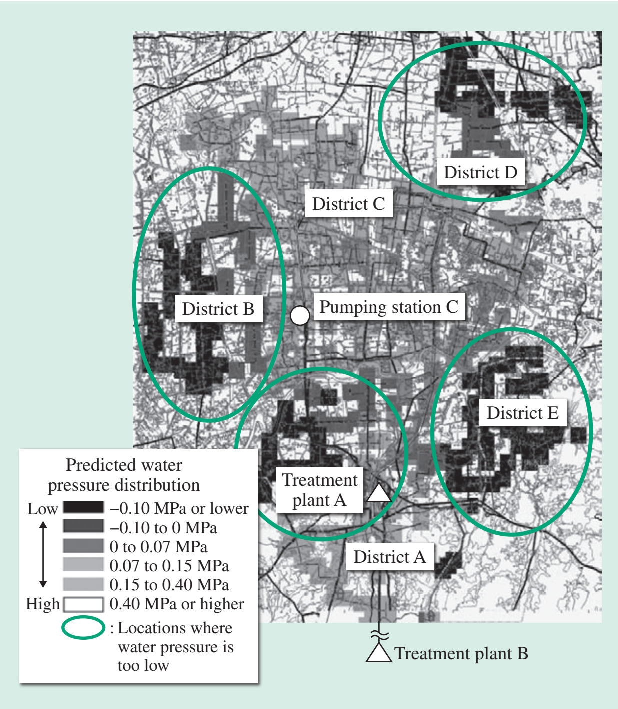


*Fig. 1—Water Pressure Distribution and Future Predictions for Model Region.*
*Pressure shortfalls due to increases in water demand anywhere in the covered regions were predicted based on the use of the distribution network analysis function in Hitachi's geographic information system (GIS) based water distribution management system to simulate the future distribution of water pressure in the pipe network.*

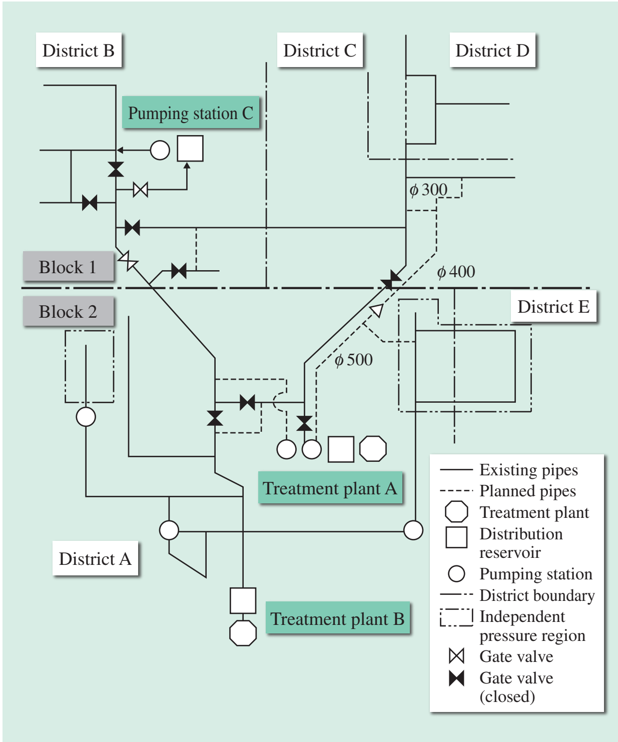


*Fig. 2—Optimal Planning for Water Distribution Networks.*
*A plan that considers both cost reduction and energy efficiency was formulated for optimizing the pipe network to deal with future problems of low water pressure by preventing the water supplies from treatment plants A and B from interfering with each other.*

## Understanding Present and Future Challenges Facing Water Distribution Networks

Apart from a mountainous area in the south, the model region (districts supplied with water by the participating utility) is largely flat. As of April 2011, water distribution to the entire district A, located in the center of the model region, was supplied by pumping from treatment plant A, which is located in the middle of the district. At this time, treatment plant B located in the mountainous area in the south of district A (from which water distribution is gravity-fed) and pumping station C in the nearby district B were both out of service, future plans are based on the assumption that these will resume operation.

A water pressure simulation was performed based on the collected data for the entire water pipe network in the model region. This indicated that, given the current maximum capacity of approximately 15,000 m$^3$/day, low pressure (less than 0.15 MPa) would occur in districts D and E at the edge of the network, a result consistent with the routine water distribution management conditions for the participating utility.

The simulation also predicted low pressures would occur throughout the model region in the future, when water demand is forecast to increase to approximately 30,000 m$^3$/day (see Fig. 1). This found that, even with treatment plants A and B both operating, gravity-fed distribution from treatment plant B would be inadequate due to the water supplies from the two plants interfering with each other.

Based on these results, an investigation was conducted into planning how to optimize the distribution network to overcome these problems.

## Investigation into Distribution Network Optimization Plan

To reduce the cost of improvements and encourage energy efficiency, the planning process adopted a policy of avoiding the installation of any additional pumps as much as possible. Specifically, what this meant was to use improvements to the distribution network as the primary way of ensuring adequate pressure, while also seeking to reduce energy use by making maximum use of gravity-fed water distribution from treatment plant B in the mountainous area.

Fig. 2 shows an overview of the plan. The investigation concluded that, in addition to ensuring adequate pressure throughout the model region by dividing the pipe network into blocks (as described below) and other measures based around improving the pipe network, efficient water distribution could be achieved by making maximum use of gravity-fed water distribution.

### Division of Pipe Network into Blocks

To eliminate problems such as interference between water distribution from the two treatment plants as much as possible and take maximum advantage of gravity-fed distribution, the network was divided into blocks, with districts A and E in one block and districts B, C, and D in the other. Under this arrangement, gravity-fed distribution from treatment plant B would supply districts A and E and pumped distribution from treatment plant A would supply districts B, C, and D.

### Pipe Network Improvements

The on-site survey found that parts of the distribution network at the network edge had a tree and branch structure, leading to concerns about such problems as retention of water in the pipes and low water pressure or quality. To minimize these risks and ensure a reliable supply of water, an improvement plan was formulated whereby connections would be created between the pipelines in each system to achieve a loop topography for the edges of the network.

## IMPLEMENTATION OF WATER DISTRIBUTION CONTROL SYSTEM

Having collated the current challenges facing water operation, a draft design for implementing a water distribution control system was collated with reference to future equipment planning and based on the assumption that the above optimization of the water distribution network would proceed.

### Present and Future Challenges for Water Distribution

Based on the results of the on-site survey, it was found that water distribution faces the following present and future challenges.

- Low water pressure and residual chlorine concentration in some areas
- Heavy workload due to manual plant operations (no central monitoring and control system installed)
- Problems with reliability and efficiency due to lack of communications between sites

### Preparation of Draft Design for Water Distribution Control System

A draft design was produced for implementing a water distribution control system to overcome the challenges listed above.

A water distribution control system maintains adequate water pressure in the distribution network for supplying water from the treatment plants and distribution reservoirs to consumers (see Fig. 3). The system considered for this application is based on control of the network pressures by making continuous measurements of water pressure at various points around the pipe network, running realtime simulations utilizing offline data on the pipe network (such as GIS data and billing data), and using these to adjust set-points such as outlet pressure of pumps and valves opening automatically. All of the steps from pressure measurement to control adjustments would be performed automatically.

Taking account of the state of communications infrastructure at the site, it was decided to adopt a system configuration based on the use of the cellular telephone network for monitoring pipe network measurements and an optic fiber network for central

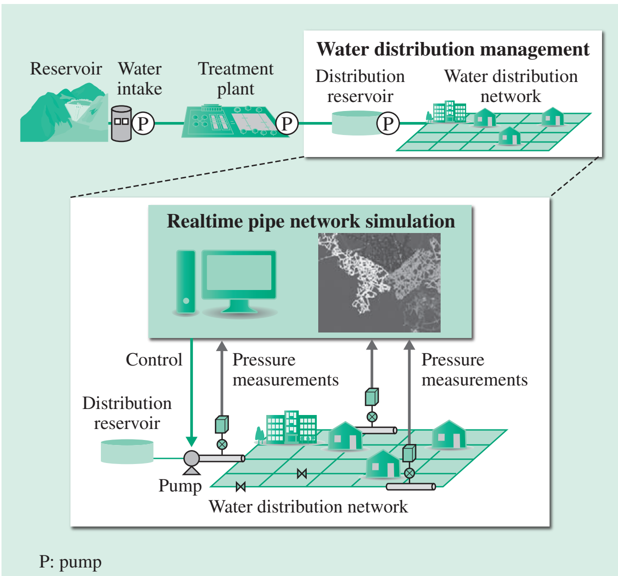


*Fig. 3—Overview of Water Distribution Control System.*
*The diagram shows an example water distribution control system that optimizes water pressure from the treatment plants and distribution reservoirs to consumers.*

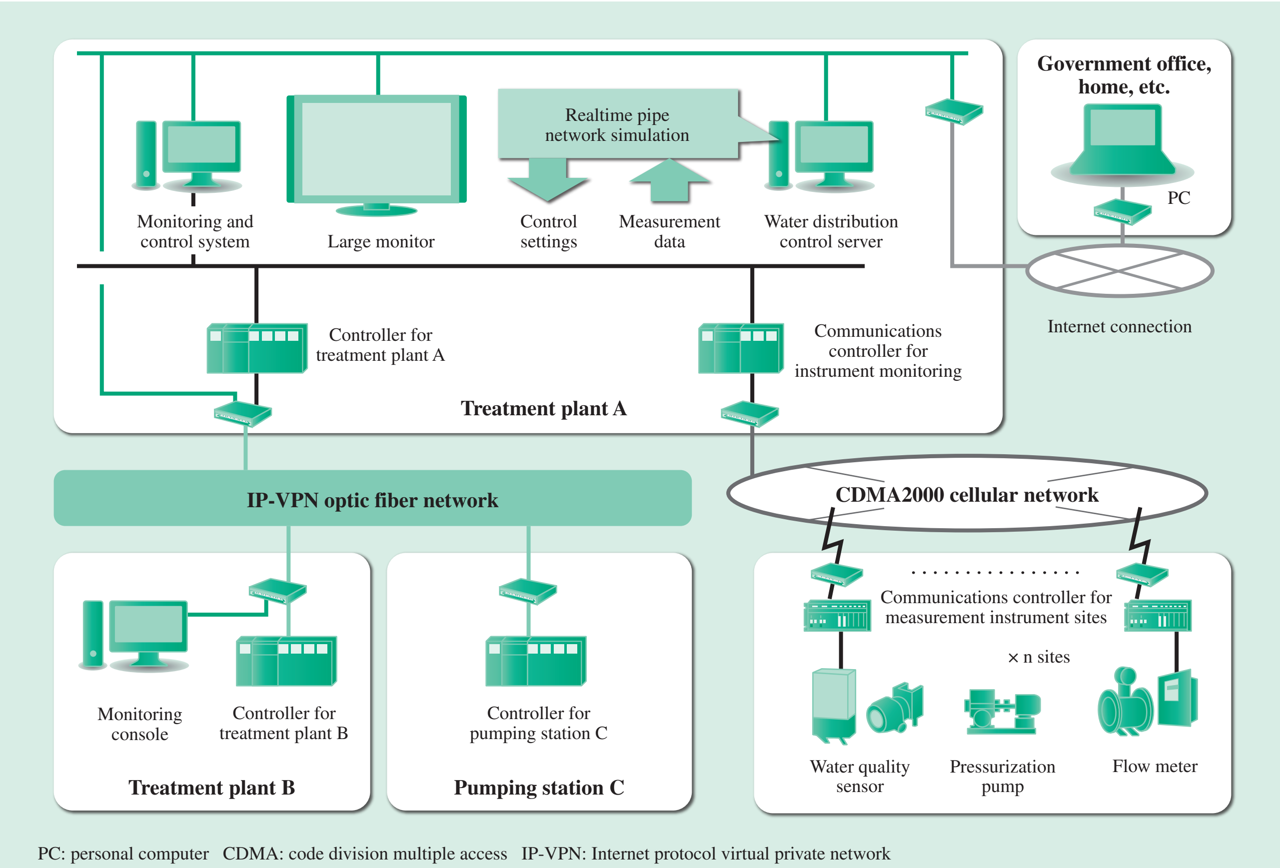


*Fig. 4—Block Diagram of Water Distribution Control System.*
*A water distribution control system was proposed together with a plan for optimizing the water distribution network to deal with future problems due to low water pressure.*

monitoring and control (see Fig. 4). Centralized monitoring should provide both productivity improvements and a faster response to abnormal situations. Along with eliminating low water pressure by coordinating the operation of treatment plant A and pumping station C, it was also anticipated that the system would provide better control in terms of energy efficiency.

Work is proceeding at the site on improving the water distribution network and adopting centralized monitoring and control of the treatment plants, with the adoption of a water distribution control system among the issues being considered.

## FUTURE DEVELOPMENTS

### Use of Water Distribution Control System to Save Energy

Water-related efforts presented in the 12th Five Year Plan of the Chinese government include making progress on public facilities and services, making effective use of water and energy resources, and measures for dealing with water and atmospheric pollution. The customer base for urban water supplies is growing steadily, as is the total volume of water supplied. Along with the provision of services that satisfy this rising demand for water, there is a need for systems that can make effective use of limited water and energy resources while also taking account of environmental protection, including water quality and the atmosphere.

As we estimate that 40% of the power consumed by the water industry is used by pumps for transporting or distributing water, measures for improving the energy efficiency of these pumps will provide major benefits to the industry.

Table 3 lists the primary ways of saving energy in the transportation and distribution of water. While it depends on when equipment is installed, effective methods over the medium to long term include the appropriate management of piping and other infrastructure and improvements in the efficiency of plant and equipment. On the other hand, efficiency improvements achieved through

TABLE 3. Ways of Saving Energy in Water Transportation and Distribution
*Using control of overall operation to improve efficiency is an effective way to achieve better energy efficiency in a comparatively short time.*

| | Challenge | Ways of saving energy | Time scale | Cost | Benefits | Assessment |
|---|---|---|---|---|---|---|
| 1 | Improve efficiency through better management of pipes and other infrastructure | • Repair or replace water distribution pipes to reduce leaks | Long | Medium | Medium | ○ |
| 2 | Efficiency improvements to plant and equipment | • Installation of highly efficient energy-saving equipment (such as pumps)<br>• Use of capacitors to improve power factor<br>• Replacement of existing pipes and valves with low-resistance alternatives | Medium | High | High | ○ |
| 3 | Control of overall operation to improve efficiency | • Control pumps to avoid over-pressure<br>• Detailed control of pump output based on fluctuations in demand | Short | Low | High | ◎ |

control of overall operation can deliver benefits over a comparatively short time period just by installing control equipment, without making major changes to existing infrastructure, meaning it has a good cost/benefit ratio. The installation of a water distribution control system is one such method and it is an effective way to improve energy efficiency across the water distribution system.

Furthermore, because the system can adapt flexibly, from the planning to the design level, to changes such as predicted future increases in water demand, Hitachi believes that it is an effective option for the regional cities of China as the country becomes increasingly urbanized.

### Use as Water Leak Management System

Because the water distribution control system described in this article uses realtime pipe network analysis, it can also be used as a water leak management system with realtime functions. The system has potential applications in supporting leak surveys and countermeasures by using links to asset management data on water piping to identify the risk of water leaks and estimate the likely volume. [The volume of water leaks in each district metered area (DMA) is estimated using Hitachi's proprietary classification method.]

The system also has potential for future use in places like Southeast Asia and India, where dealing with leaks from water pipes is a major challenge.

## CONCLUSIONS

The initial objective of this work was the overseas expansion of the Japanese water industry[4]. Based on a study of the viability of utilizing advanced Japanese technologies in a model region in China conducted through collaboration between the public and private sectors in both nations, it was concluded that the adoption of technologies for supporting pipe network planning and the installation of water distribution control systems have the potential to help improve efficiency of water distribution management and stability of supply in the regional cities of China.

In the future, Hitachi intends to evaluate and verify the markets, profitability, and so on for the systems and planning support technologies described in this article, including in the form of an ongoing integrated business that also encompasses training in operation and management. As China is seeking to improve its technology for operating water utilities as a matter of national policy, Hitachi aims to draw on experience from this work to establish business models that suit the Asian region, and to deploy them more widely.

## ACKNOWLEDGMENTS

This article draws on material from the Water Saving and Environmentally-friendly Water Recycling Project of NEDO. Furthermore, the work also benefitted from advice and support from the Water Supply Division at the Health Service Bureau, Ministry of Health, Labour and Welfare; the Japan Water Works Association; the Federation of Japan Water Industries, Inc., and Pacific Consultants Co., Ltd. The authors would like to express their thanks to all of these agencies involved in the work.

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Featured Articles

# Contribution to and Future Prospects for ISO/TC 224 and ISO/TC 282 International Standardization Activities in the Water Industry

Takahiro Tachi
Naoki Ohkuma, Dr. Eng.

*OVERVIEW: Recent years have seen growing activity on international standardization in the water industry. The ISO/TC 224 technical committee dealing with service activities relating to drinking water supply systems and wastewater systems has already been active for 14 years, over which time its scope of activity has continued to expand. Also expanding is the scope of international standardization initiatives aimed at overcoming societal challenges, such as the ISO/TC 282 committee on water re-use and the ISO/TC 268 committee that deals with sustainable development, including water, within communities. This article describes the current status and future prospects of work on international standardization in the water and related industries with reference to the experience of the authors, who serve on the ISO/TC 224 and ISO/TC 282 technical committees.*

## INTRODUCTION

RECENT years have seen growing activity on international standardization in the water industry. The origins of this activity can be traced back to around 2001, when the International Organization for Standardization (ISO), one of the world's standards bodies, approved the establishment of the ISO/TC 224 technical committee for water supply and wastewater services.

The focus of most past standardization had been on product standards that stipulate things like dimensions and materials or methods of measurement. Recent years, however, have seen the emergence of initiatives for service standardization undertaken from a user's perspective, and the standardization of measures or other activities for overcoming societal challenges in their entirety. In the water industry, ISO/TC 224 is one of the main initiatives aimed at service standardization, and there has also been a widening in the scope of activities aimed at overcoming societal challenges, such as the ISO/TC 282 committee on water re-use and the ISO/TC 268 committee that deals with sustainable development, including water infrastructure, within communities.

Hitachi has been contributing to overcoming global challenges through its participation in a wide range of standardization work in partnership with other interested institutions from both Japan and elsewhere. This article describes the current status and future prospects of work on international standardization in the water and related industries with reference to the experience of the authors, who serve on the ISO/TC 224 and ISO/TC 282 technical committees.

## TRENDS IN INTERNATIONAL STANDARDIZATION FOR WATER

Table 1 lists the main ISO technical committees that deal with water. These are listed in chronological order by date of formation. The committees prior to ISO/TC 224 tended to deal with product standardization and those since with service standardization. In the case of ISO/TC 282, for example, rather than stipulating product specifications for membranes, disinfection systems, and other items used to recycle wastewater, the standardization work focuses on the things that matter to users, such as quality levels and ways of using the water. Rather than supporting existing product markets, these activities can be thought of as being oriented toward the development of new technologies for overcoming problems or the creation of new markets.

TABLE 1. Key ISO Technical Committees Relating to Water (as of September 1, 2015)

*Whereas the focus of standardization work prior to the establishment of ISO/TC 224 was on product standards, since then, the focus has been on service standards and on ways of resolving societal challenges.*

| Committee | Title (Secretariat) |
|---|---|
| TC 5 | Ferrous metal pipes and metallic fittings (China) |
| TC 23/SC 18 | Irrigation and drainage equipment and systems (Israel) |
| TC 30 | Measurement of fluid flow in closed conduits (United Kingdom) |
| TC 113 | Hydrometry (India) |
| TC 138 | Plastics pipes, fittings and valves for the transport of fluids (Japan) |
| TC 147 | Water quality (Germany) |
| TC 223 | Societal security (Sweden) → Merged into TC 292 |
| TC 224 | Service activities relating to drinking water supply systems and wastewater systems - Quality criteria of the service and performance indicators (France) |
| PC 251 | Asset management (United Kingdom) |
| PC 253 | Treated wastewater re-use for irrigation (Israel) → Merged into TC 282 |
| TC 255 | Biogas (China) |
| TC 268 | Sustainable development in communities (France) |
| TC 275 | Sludge recovery, recycling, treatment and disposal (France) |
| TC 282 | Water re-use (China, Japan) |
| TC 292 | Security and resilience (Sweden) |

ISO: International Organization for Standardization TC: technical committee
SC: sub-committee PC: project committee

TABLE 2. ISO/TC 224 Technical Committee Working Groups and Standards (as of September 1, 2015)

*The technical committee has had numerous active working groups since the publication of ISO 24510 to 24512.*

| Working Group | Title | ISO standards (published or under development) |
|---|---|---|
| WG 1 | Terminology | PWI 24513 |
| WG 2 (Disbanded) | Service to users | ISO 24510:2007 (Published) |
| WG 3 (Disbanded) | Drinking water | ISO 24512:2007 (Published) |
| WG 4 (Disbanded) | Wastewater | ISO 24511:2007 (Published) |
| WG 5 | Examples of the application of 2451X Standards | PWI 24514 |
| WG 6 | Asset management | DIS 24516-1, PWI 24516-2, CD 24516-3, PWI 24516-4, 24516-5, 24516-6, CD 24523 |
| WG 7 | Crisis management of water utilities | ISO 24518:2015 (Published) WD 24520, 24525 |
| WG 8 | Onsite domestic wastewater management using low technologies | DIS 24521 |
| WG 9 | Decision support systems | AWI 24522 |
| WG 10 | Flushable products | 24524 |
| WG 11 | Storm water management | 20325 |
| WG 12 | Water efficiency management | 24526 |

WG: working group PWI: preliminary work item AWI: approved work item
WD: working draft DIS: draft international standard CD: committee draft

Water supply and sewage utilities in Japan are largely run by local governments. Accordingly, most of the contributions by Japan to international standardization for water take the form of public-private collaborations.

## INTERNATIONAL STANDARDIZATION OF WATER SUPPLY AND WASTEWATER SERVICES BY ISO/TC 224

### Background and Current Status of Standardization Work

The establishment of the ISO/TC 224 technical committee on “Service activities relating to drinking water supply systems and wastewater systems - Quality criteria of the service and performance indicators” was prompted by a French proposal to ISO in 2001. It has worked on developing voluntary guidelines, primarily through debate on the establishment of performance indicators (PIs) that can provide quantitative yardsticks for assessing water utilities. The ISO 24510 to 24512 guidelines for service PIs that can be used by the operators and users of water supply and wastewater systems were published in 2007[(1), (2), (3)].

A public-private-academia collaboration from Japan actively participated in proposing and critiquing PIs with consideration for their own concerns of maintaining and developing the country’s high level of water supply and wastewater infrastructure. Furthermore, the national standards formulated during this time also cited the international standards.

Work since 2008 has moved on from broad considerations to specific topics, with a series of new working groups (WGs) being set up under the ISO/TC 224 committee. Table 2 lists these ISO/TC 224 WGs and the standards they have produced or are in the process of producing (as of May 1, 2015). While Japan has participated in all of the WGs since 2008, mainly through public agencies, limitations on budget and personnel have presented a challenge. To help overcome this, Hitachi delegated staff to serve on two working groups (WG 7 and WG 9) since 2012 in response to a request from the Japanese committee for water supply issues at ISO/TC 224, and with assistance from relevant local organizations. The following section describes the activities of these WGs.

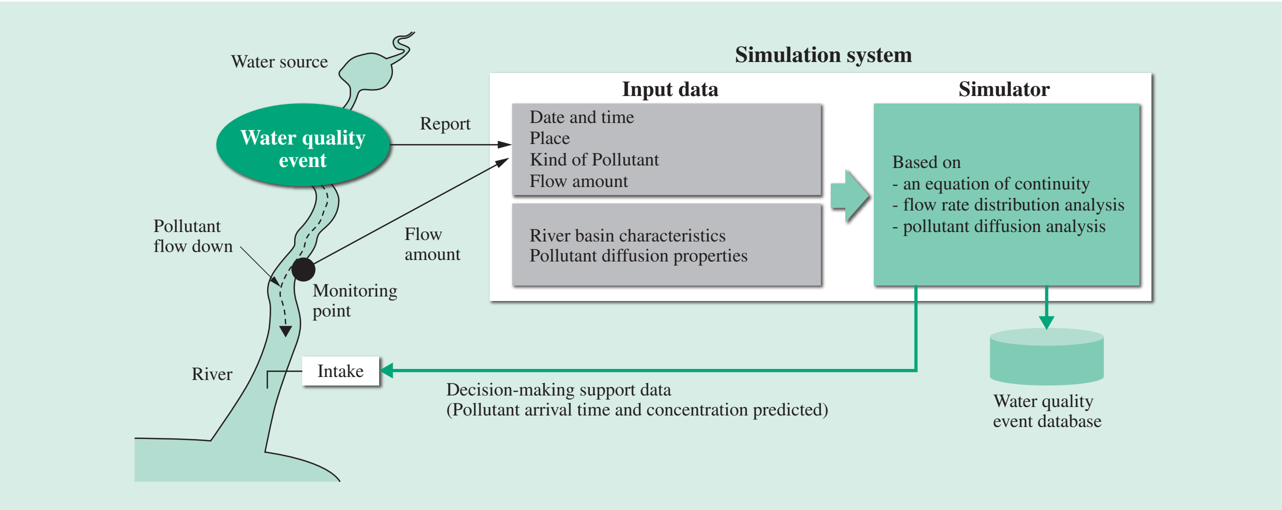


*Fig. 1—Japanese Proposal to ISO/TC 224/WG 9.*
*An example of a water quality event detection system, this river flow simulation technique (a system for calculating the time taken for pollutants to flow downstream, and their concentrations) was presented as a concept not tied to specific products or regions.*

### International Standardization of Processes for Detecting Water-related Events

WG 9 has been active since 2012, working on standardizing the detection of water-related events and the decision making process. Because Japan supplies sensors, monitoring and control systems, and other products that assist with the detection of water-related events, such as water pollution, and has experience with their use, it put forward these as examples of best practices.

Fig. 1 shows one such example submitted by Japan[4]. This is a river flow simulation technique (a system for calculating the time taken for pollutants to flow downstream, and their concentrations) that helps make decisions such as whether to halt the intake of water when a water quality event occurs upstream. While the system is already installed at water utilities in Japan, it was presented as a concept with global applicability that is not tied to specific product requirements or regions.

### Future Prospects

ISO/TC 224 has set up numerous WGs over the 14 years since its formation was first proposed. While the scope of activities to date has involved the formulation of service standards for voluntary adoption by water and sewage utilities, there has been debate on the subject of broadening this to include products and stakeholders. In the future, Hitachi intends to keep watching the unfolding developments and to continue its involvement through Japan's public-private collaboration.

## INTERNATIONAL STANDARDIZATION OF WATER RE-USE BY ISO/TC 282

### Background and Current Status of Standardization Activities

The ISO/TC 282 technical committee for water re-use established in June 2013 is chaired by Israel and has a dual secretariat from Japan and China. It provides a forum for formulating international standards on water re-use, with Japan taking a leading role. Recognizing this, a national coordinating body has been set up under the Director for Watershed Management at the Sewerage and Wastewater Management Department of the Ministry of Land, Infrastructure, Transport and Tourism. The first meeting of ISO/TC 282 was held in Tokyo in January 2014 and the second in Lisbon, Portugal in November 2014.

The first meeting was attended by 10 countries and dealt with establishing the organizational structure of the committee. In addition to approving the establishment of Sub-committee 1 (SC 1: Treated wastewater re-use for irrigation) coordinated by Israel, it also decided to hold votes on setting up Sub-committee 2 (SC 2: Water re-use in urban areas) proposed by China, and Sub-committee 3 (SC 3: Risk and performance evaluation of water re-use systems) proposed by Japan. A vote held in March 2014 approved the establishment of both of these sub-committees. Also at the first meeting, Israel proposed and gained approval for establishing a WG on "Treated Mine Water Use."

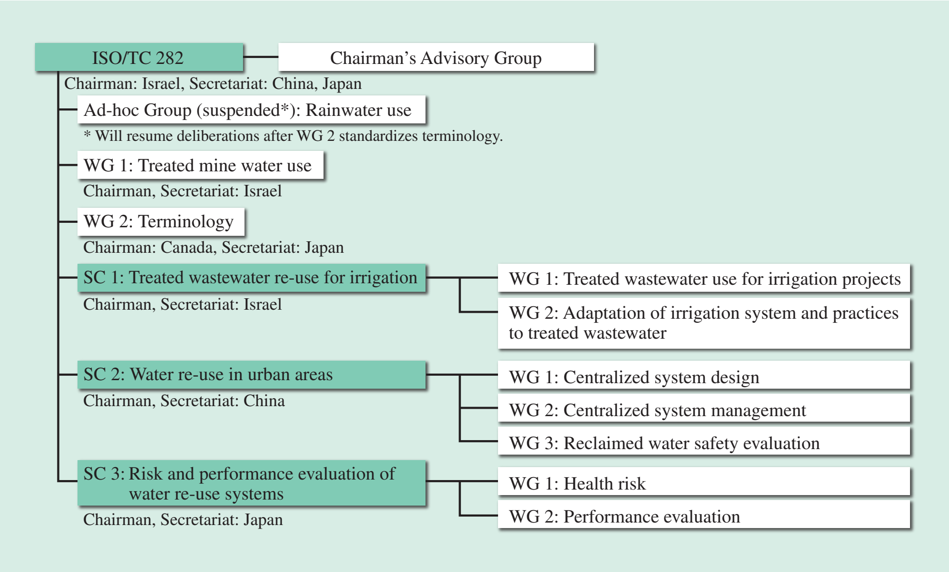


*Fig. 2—Organizational Structure for Standards Development in ISO/TC 282 (Water Re-use) (as of September 1, 2015).*
*The organization is made up of two WGs that report directly to the TC and three SCs. Japan plays a central role in WG 2 (Terminology) and SC 3 (Risk and performance evaluation of water re-use systems).*

At the second meeting, Japan proposed the development of three guidelines on, (1) methods for assessing health risks, (2) grading of water for re-use, and (3) methods for assessing membrane bioreactor (MBR) technology. However, the second and third of these failed to gain approval. Following discussion among the participating nations, however, it was agreed to prioritize standards development for a revised version of the second proposal on water grading, and to undertake a comprehensive revision of the third proposal in the form of guidelines on "methods of assessing treatment techniques for water re-use." The revised and new proposals were submitted in December and approved by a vote held in February 2015. Future work on standards development for these three Japanese proposals will be undertaken by SC 3.

Fig. 2 shows the organizational structure for standards development in ISO/TC 282 (as of September 1, 2015). WG 1, which was proposed by Israel, may in the future be replaced by a fourth sub-committee (SC 4) on industrial water re-use.

## International Standardization of Treatment Techniques for Water Re-use

In January 2014, the Water Reuse Promotion Center and Kyoto University were jointly contracted to undertake a three-year project on "establishing platforms for international standardization and wider adoption of water recycling systems" to provide tools for exports of water infrastructure, the request for which was issued by the Technical Regulations, Standards and Conformity Assessment Policy Division of the Ministry of Economy, Trade and Industry (METI). With the aim of submitting standardization proposals to ISO/TC 282, this project involved preparing draft international standards for methods of assessing the performance of water re-use systems, as well as for membrane-, ultraviolet-, and ozone-based treatment techniques, and the collection of test data on the risk assessment of recycled water using the membrane bioreactor-reverse osmosis (MBR-RO) system of Water Plaza Kitakyushu.

To formulate guidelines on methods for assessing the performance of treatment techniques for water re-use, work is being undertaken in collaboration with the above METI international standardization project. A working draft (WD) was circulated among the participating nations in April 2015, and consultation among the national representatives has been underway since the WG 2 meeting of SC 3 held in Canada in May.

## Future Prospects

Because there is a limited market for water re-use in Japan, Japanese companies working in the field have been seeking to identify markets and establish operations overseas. Having their products and systems appropriately assessed in accordance with ISO standards helps differentiate them from competitors and should lead to a larger share of overseas markets.

Work on developing standards at the ISO/TC 282 technical committee has only just begun. The international standardization of methods for assessing the performance of technologies associated with water re-use can be expected to help improve the water environment around the world and to invigorate Japan's water-related industries.

## INTERNATIONAL STANDARDIZATION OF SMART COMMUNITIES BY ISO/TC 268/SC 1

The over-concentration of populations in cities is giving rise to a variety of societal challenges around the world, particularly in emerging and developing economies. Given that the fundamental solution to these problems lies in the appropriate provision of social infrastructure, concepts such as the smart city and the environmentally conscious city have been put forward as ways of creating a new generation of cities in which this objective has been realized.

It was based on this background that the ISO/TC 268 technical committee was established in 2012 to work on sustainable development in communities. Japan is both the chair and secretary of the first sub-committee (SC 1: Smart community infrastructures), which is working on the standardization of PIs and frameworks for urban infrastructure[5].

Definitions and yardsticks for assessing smart cities and livable communities have not always been clear in the past. Accordingly, ISO/TC 268/SC 1 has adopted a three-tier model of communities (shown in Fig. 3) that defines the scope of standardization in terms of urban infrastructure layers that include energy, water, mobility, and telecommunications. The sub-committee is looking not just at individual infrastructure systems, but also at examples of their interoperation. Its first publication was the ISO TR 37150 technical report, which deals with metrics for smart community infrastructures and was issued in 2014. Similarly, the ISO TS 37151 technical specification on the principles and requirements for performance metrics was issued in 2015[6].

Water supply and sewage are part of the community infrastructure layer and need to interoperate with other forms of infrastructure such as energy and telecommunications. The work being done by ISO/TC 268/SC 1 is also being regularly reflected in other water-related standardization activities, including ISO/TC 224.

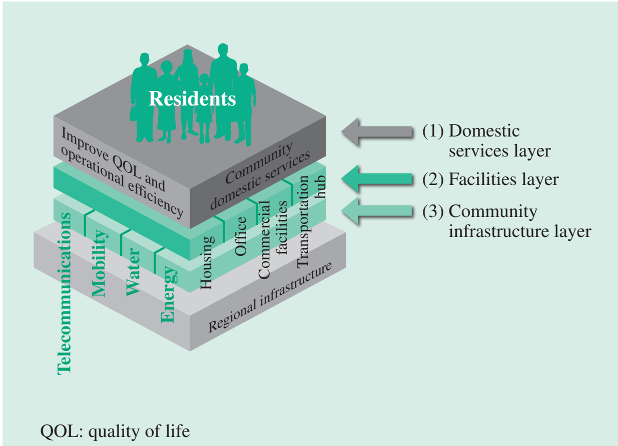


*Fig. 3—Three-tier Structure of Communities.*
*ISO/TC 268/SC 1 is looking at the functions of social infrastructure in communities in terms of a three-tier model. Water and sewage form part of the community infrastructure layer that underpins domestic services and facilities.*

## CONCLUSIONS

International standardization in the water industry has been expanding to also encompass service standardization. Now, 14 years or so after ISO/TC 224 started its work, there is vigorous activity on standardization aimed at dealing with specific challenges such as asset management, crisis management, and reducing the load on the environment. This has spread in recent times to cover users as well as service providers, including starting work on the international standardization of things like which products may be flushed down the drain and the efficient use of water.

It is important to recognize that, rather than the international standardization of technologies as such, work is progressing on the standardization of the business environment to ensure that technologies are used effectively. While this can be expected to open up or expand new markets, there will also likely be cases where reforms will be needed to existing business processes.

Hitachi is working to offer solutions for water and the environment that seek to overcome challenges through the extensive integration of products, systems, and services for the water industry. In addition to incorporating developments in service standardization into these activities, Hitachi also aims to use its work on international standardization through public-private collaborations to help overcome water-related challenges throughout the world.

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