Smart Water Management and Usage Systems for Society and Environment

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OVERVIEW: Water is essential to our way of life and international water-related issues include its short supply and uneven distribution. How to use water in a way that is in harmony with nature and the water cycle and how to reduce the emission of greenhouse gases associated with water treatment are also of concern. To resolve these issues and establish infrastructure for water that is safe and gives users easy access to water and confidence in its quality, Hitachi has proposed the "intelligent water system" concept. This concept aims to perform comprehensive management of the water cycle at a regional or city level based on the ideas of harmony, sustainability, and self-reliance by adopting more intelligent individual technologies including water recycling and other water treatment technologies, information technology, and monitoring and control technology, and by implementing water cycle traceability in a way that treats the water cycle as a "flow of both water and information."

INTRODUCTION

THE 21st century has been called the "water century" with water demand continuing to rise as the world's population grows, and with fresh water in rivers, lakes, and similar making up no more than 0.01% of all the world's water, the imbalance between supply and demand caused by the uneven distribution of water resources has become severe. Accordingly, there is an

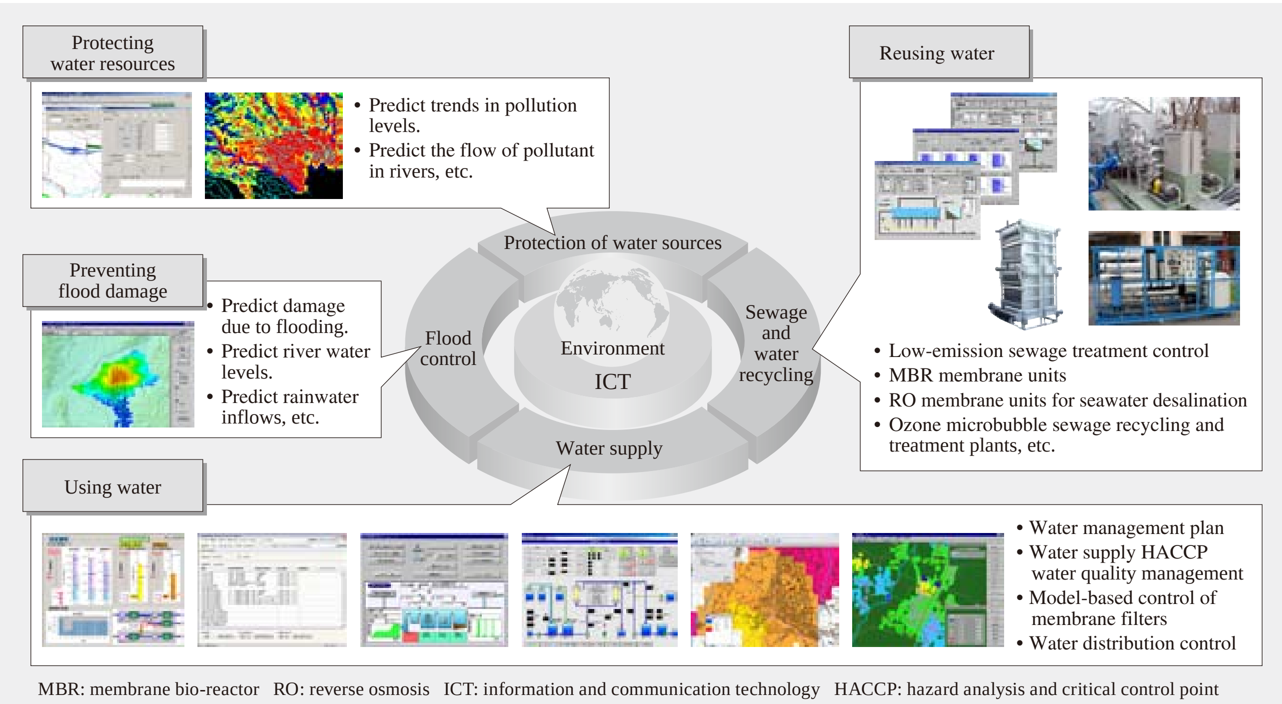

Fig. 1—Overview of Intelligent Water System.
Water management can be performed at a city or regional level in a way that takes account of both people and the natural environment by utilizing ICT and core technologies such as mechanical, electrical, IT (information technology), monitoring and control, and other equipment.

even greater need to provide reliable supplies of clean water that meet demand in a way that takes account of the global environment.

In Japan, a society in transition toward a shrinking population, the requirements are for safe and reliable water supplies and sustainability of water resources. The facilities and other infrastructure built during the “construction era” are now coming due for refurbishment but this needs to be done in a way that deals with the challenges of tight economic conditions and a shortage of experienced technical staff due to the aging population. These factors make it essential that business operation is efficient.

The water supply and sewage sector is an industry segment that places a high burden on the environment in terms of reducing emissions of greenhouse gases, and the issue of how to create a low-carbon society while also maintaining the health of natural water resources also looms large.

In response to these challenges, Hitachi has proposed the “intelligent water system” concept as a way of contributing to the water environment around the world based on the hardware and software it has built up through its past and present activities and its operational technology and other know-how.

This article describes Hitachi’s technology and business development efforts aimed at implementing smart water usage management systems together with its plans for the future.

CHALLENGES FOR WATER USE AND INTELLIGENT WATER SYSTEM CONCEPT

Water is present in the environment in the form of a cycle that includes water resources, water use (domestic water supplies and commercial uses such as irrigation and industrial water supplies), and recycling (sewage, recycled water) and water management also includes flood control (preventing flood damage). Also, because the water cycle is spread geographically over catchments and cities, its stakeholders include citizens, industry, agriculture, and the need to protect biodiversity and other aspects of the natural environment. Accordingly, in addition to specific individual technologies, what is also important is to combine these technologies so that they function as a system (see Fig. 1).

Trends and Issues for Water Use Management Systems in Japan

In Japan, the current level of availability for water supplies is about 97% and for sewage services is about 70%, giving the country a high level of water management infrastructure by world standards. A look at Japan’s water balance sheet shows that the country is well endowed with water resources with an average water resource endowment (rainfall less evaporation) of 410 billion m^3/year being set against usage of only 83.4 billion m^3/year (based on consumption in 2005) thanks to the widespread adoption of water-conserving appliances in the home, improvements in the proportion of industrial water that is recycled, and a reduction in the land area used for paddy fields[1].

However, issues that remain of concern include: (1) the effect of factors such as greater rainfall variability or global warming, (2) the need for safe and palatable water and rich water environments, (3) the aging of facilities installed during the era of rapid economic growth, (4) the weak financial condition of organizations and human resource shortages, and (5) how to reduce emissions of greenhouse gases associated with water supply and sewage business operation.

Trends and Issues for Water Use Management Systems Overseas

Water has a fundamental role in our way of life, and problems with both the quantity and quality of water are coming to a head due to factors such as population growth and increasing water pollution around the world. The “World Water Vision” published by the World Water Council in 2000 forecasts that about 4 billion people or approximately half the world’s population would be facing “water stress” by 2025. It also forecasts that the trend toward more frequent water shortages would intensify due to global warming.

When a comparison is made of the proportional distributions of population and water resource endowment, it is clear that Asia including the Middle East is short of water with a low water resource endowment (36% of world’s total) relative to its population (approximately 60% of the world’s people).

These regional water infrastructure needs are not uniform and can be categorized into the following three levels based on the level of infrastructure.

(1) Level 1: No infrastructure

The lack of water supply and sewage infrastructure causes problems with hygiene and environmental degradation, creating demand for the provision of water supply systems.

(2) Level 2: Infrastructure development stage

Problems include increasing water pollution due to urbanization and how to ensure the quality of water used for agricultural, together with demand for the provision of sewage systems.

(3) Level 3: Operational management and upgrade stage

The acquisition of new water resources is made necessary by rapid urbanization and industrialization while the cost of building and operating water use management infrastructure becomes an issue. The requirements include technologies for desalination, sewage and waste water, and maintenance management.

"Intelligent Water System" Concept

Hitachi has been contributing to water and the environment in a variety of ways including both services and mechanical, electrical, IT (information technology), monitoring and control, and other equipment. Seeking to solve the problems described above, Hitachi has proposed the "intelligent water system" concept. The concept seeks to make smart use of water in a way that takes account of both people and the natural environment, both by making individual technologies smarter in fields such as water treatment, IT, and monitoring and control and also by combining these in systems to optimize the overall operation at a city or regional level. To this end, Hitachi aims to implement systems based on a platform of "water cycle traceability" that utilizes ICT (information and communication technology) to monitor the status of water quality, water quantity, and other environmental factors and treats water resource management as a flow of both water and information.

In addition to taking the form of a cycle that is spread over a wide geographic area, water use management systems need to take account not only of human activity, but also of a wide variety of other stakeholders including the natural environment. For this reason, these systems need to be able to harmonize the water needs of stakeholders spread across an entire catchment, ensure that they are a sustainable part of the infrastructure of society, and be self-reliant while taking account of the burden they place on the environment.

For these reasons, the "intelligent water system" concept utilizes water cycle traceability to achieve healthy water resources and implement water use management systems that exhibit "harmony," "sustainability," and "self-reliance" (see Fig. 2).

SPECIFIC TECHNOLOGIES FOR SMART WATER USE

Water Treatment Systems

Hitachi's involvement in the field of water treatment systems includes commercializing services based on the key technologies for smart water use which include recycling techniques that allow cyclic use of water and seawater desalination which helps mitigate the uneven distribution of water supply and demand.

(1) MBR and MBR-RO systems

MBR (membrane bio-reactor) water treatment systems combine biological processes with membrane separation and commercial applications continue to grow because of their role as a key technology for implementing reliable water recycling and reuse in places where water shortages are acute. Unlike the

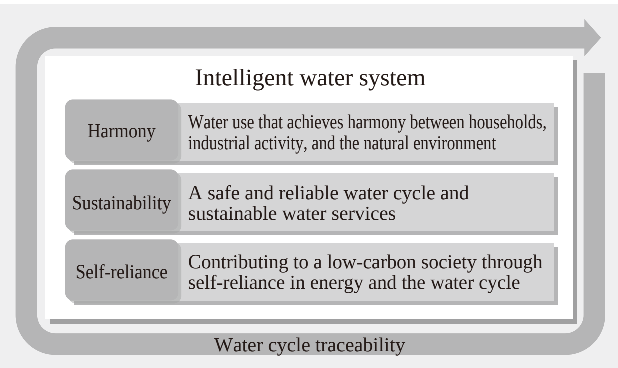

Fig. 2—Intelligent Water System Concept.
The concept utilizes water cycle traceability to implement water use management systems that exhibit "harmony," "sustainability," and "self-reliance."

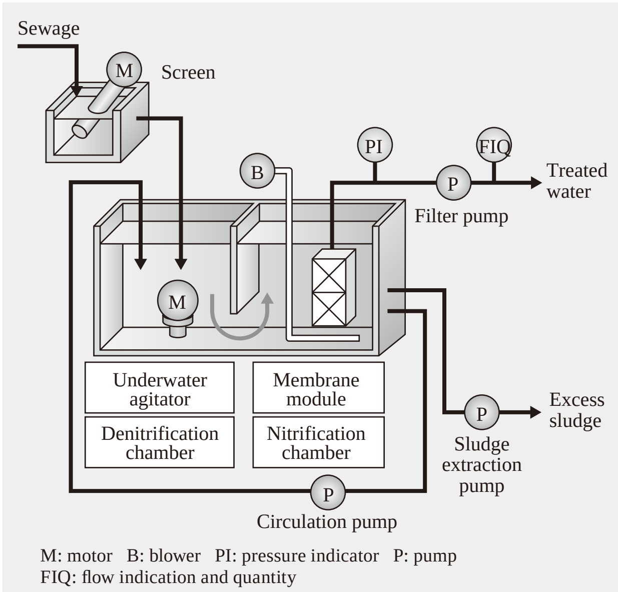

Fig. 3—Standard Flow for MBR System.
The bio-reactor chambers used for advanced processing consist of denitrification and nitrification chambers with the membrane unit being located in the nitrification chamber.

Fig. 4—Membrane Unit for MBR.
The two-stage membrane unit with a membrane area of 400 m² can produce about 250 m³/d of treated water.

activated sludge process used in the past, a feature of these systems is that, because the membrane unit performs membrane filtering immersed inside a bioreactor chamber, they do not require as much space and can produce treated water suitable for reuse with only simple maintenance (see Fig. 3).

The membrane unit used in Hitachi's MBR system (see Fig. 4) is an immersible flat membrane type with a microfiltration membrane made of PVDF (polyvinylidene fluoride) and a pore diameter of 0.1 µm. It has demonstrated an ability to remove fecal bacteria and other microorganisms as well as viruses smaller than the 0.1 µm pore diameter through contaminant adhesion and other effects.

Hitachi has deployed its MBR systems primarily in the Middle East where water shortages exist and is using the systems to recycle water for irrigation, industrial, and other uses. Progress is also being made on the application of MBR-RO (reverse osmosis) systems in cases when recycled water requires a high level of water quality such as when used as a supplementary water supply for area cooling. In MBR-RO systems, MBR-treated water is further treated using an RO membrane to eliminate ions from the water. A water recycling business using an MBR-RO system commenced in Dubai in August 2008 and is producing recycled water for sale.

(2) Seawater desalination system

Seawater provides the main source of domestic water in places such as the Middle East, North Africa, and islands and the widespread adoption of seawater desalination systems has made these essential for maintaining the safety and security of daily life and uninterrupted industrial activity. Seawater desalination systems include evaporation methods such as MSF (multi-stage flash) and membrane methods such as RO. While evaporation methods were more common to begin with, greater use of membrane methods in recent years means that use of the two methods is now roughly equal.

Hitachi manufactures an RO system for seawater desalination as well as the RO membrane unit used in the MBR-RO system described above and in January 2009 brought Singapore company Aqua-Tech Engineering and Supplies Pte. Ltd. into the Hitachi Group to provide production, sales, and maintenance services for RO membrane units. The aim was to establish a unified organizational capability for supplying plant that extends from the production of fresh water by desalination of seawater through to sewage and industrial waste water treatment and supply of recycled water.

The RO membrane units for seawater desalination include an RO module, high-pressure pump, cartridge filter, energy recovery unit, booster pump, and operation panel and their water production capacities have been standardized together with the pre-treatment system in a range from 200 to 2,000 m³/d (see Fig. 5).

Information and Control Systems

In the field of information and control systems, Hitachi is working on the implementation of smart water use management systems that use ICT and control technology to improve the intelligence of water-related activities including medium- to long-term plans for water treatment facilities and day-to-day operation.

Fig. 5—RO Membrane Unit for Seawater Desalination.
The water production capacities of these units have been standardized together with the pre-treatment system in a range from 200 to 2,000 m³/d.

(1) System for predicting changes in water pollution

The formulation of appropriate plans for water treatment facilities that take account of medium- to long-term changes in water pollution has an important role in enabling the medium- to long-term sustainability of a harmonious water cycle. To this end, the use of a database of environmental information about water resources in the catchment supports plans such as for providing water treatment facilities or introducing advanced treatment processes.

This system considers the medium- to long-term population of the catchment and urban activity (changes in land use, mining and manufacturing production, agriculture, etc.) to predict future changes in the degradation of the quality of water resources. The pollution load evaluation module divides the entire catchment area into a mesh to estimate how THMFP (trihalomethane formation potential) and four other water quality criteria will change with time (see Fig. 6).

(2) Water supply management system

This system is used to formulate water production plans for water supply systems that include multiple water sources and water treatment plants. It utilizes capabilities such as the buffer function of reservoirs and the flexibility within the water distribution system to operate water treatment plants efficiently. The aim of the water management system is to make the water business sustainable by improving the efficiency of day-to-day water production and to help achieve energy self-reliance by operating the business in a way that takes account of its impact on the environment.

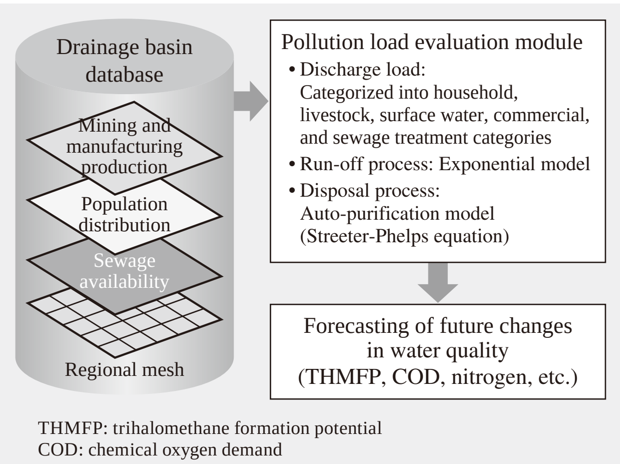

Fig. 6—Structure of System for Predicting Changes in Water Pollution.
The system produces quantitative estimates of future changes in water quality based on predictions and land use over an entire catchment area.

Operational plan formulation calculates the optimum plan within the constraints which include compliance with water privileges and wholesale contracts, upper limits on the range of variation in flow rates so that the treatment process and pumps can operate more steadily, and upper and lower limits on reservoir levels. Because there are a number of performance indicators including economics, stability, and reduction in environmental impact, these cannot be compared easily and objectives may conflict with each other. To take account of these trade-offs and formulate a superior overall plan, Hitachi uses the multi-objective optimization method (see Fig. 7). This provides a means of formulating operation plans that provide stable operation while also taking account of energy costs and the burden on the environment.

(3) Water distribution control system

Appropriate management of the pressure in a water distribution system is an essential aspect of service sustainability which not only provides a consistent level of service but also helps reduce water loss through leakage, improve the proportion of revenue-earning water, and save energy.

The best way to achieve this is to use pumps, valves, and other equipment to boost or reduce the pressure so that the pressure distribution across the entire water distribution network is kept as uniform

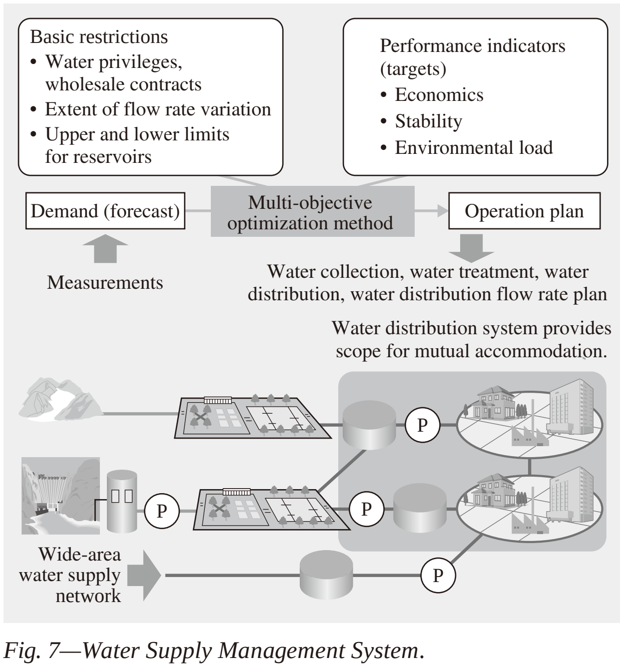

Fig. 7—Water Supply Management System.
A superior overall plan was able to be formulated by using the multi-objective optimization method to consider the trade-offs between different objectives.

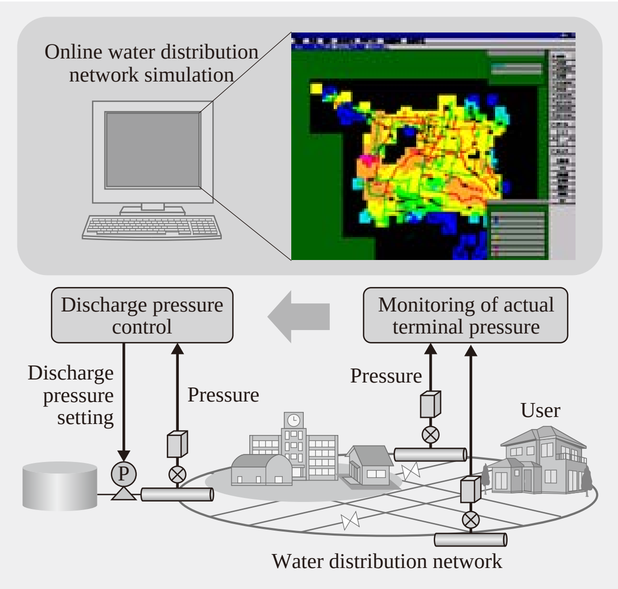

Fig. 8—Water Distribution Control System.
The system simulates the water distribution network in realtime using a GIS (geographic information system) and online pressure and flow measurements to calculate optimum pump discharge pressure and flow rate settings.

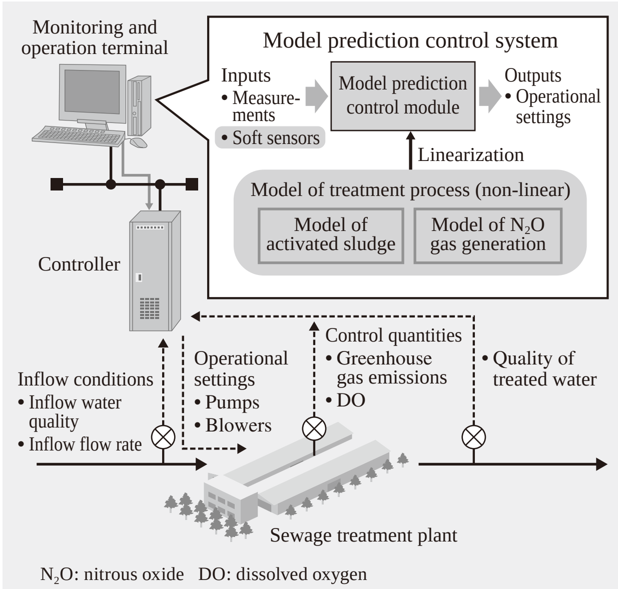

Fig. 9—Role of Low-emission Sewage Treatment Control System.
The sewage treatment plant can be operated so as to reduce its overall greenhouse gas emissions by calculating a model using the plant's inflow conditions and control quantities.

as possible. Although standard practice is to record pressure gauge measurements at various reference points across the network and set pump discharge pressures, degree of valve opening, and other settings to fixed values or time-dependent patterns based on experience, maintaining a uniform and appropriate level of pressure is not always easy.

In response, Hitachi has devised a control system that uses online water network analysis to determine the distribution of flow and pressure across the entire water distribution network in realtime and calculate the optimum values for pump discharge pressures, valve openings, and other settings based on current conditions (see Fig. 8). By updating pipe location data as changes are made to the pipe network, the system can keep up to date with changes in the water distribution network and provide optimum pressure control at all times.

(4) Low-emission sewage treatment control system

In addition to maintaining the quality of discharged water, sewage treatment operations also need to reduce their impact on the environment in the sense of achieving energy self-reliance. To meet this demand, Hitachi is developing a model-based control system that can both reduce emissions of greenhouse gases and maintain discharge water quality by performing online calculation of a linear model of the water treatment process.

The two main technical features of the system are: (a) its use of soft-sensor technology to remove the need for COD-Cr (chemical oxygen demand—chromium) measurements (in which potassium dichromate is used to determine the chemical oxygen demand), and (b) its use of a model to calculate the volume of N_2O (nitrous oxide) gas (which has approximately 310 times the global warming potential of carbon dioxide) released from activated sludge so that account can be taken of the N_2O produced by the treatment process when determining the reduction of greenhouse gas emissions (see Fig. 9).

HITACHI'S WORK ON NEW WATER USE MANAGEMENT SYSTEMS

Hitachi is utilizing its previously developed technologies and working with Kogakuin University, The University of Tokyo, and Tohoku University on the development of the IISS (integrated intelligent satellite system) regional water resource management system as part of the "Innovative Technology and System for Sustainable Water Use" research topic of the Japan Science and Technology Agency's (JST) 2009 Core Research of Evolutional Science & Technology (CREST) program (see Fig. 10).

The IISS is a satellite system that combines water, energy, and information. The system aims to improve treatment performance and operational efficiency through the development of new technology and involves the distributed installation of medium-sized or small water recycling facilities depending on the size of the area covered. Specifically, it has the following three objectives.

(1) To achieve harmony with the water quantity and quality needs of stakeholders by adopting technologies that allow the operation of water recycling facilities distributed across multiple locations to be coordinated in an organic way

(2) To make the individual water recycling facilities a sustainable part of the social infrastructure by using innovative membrane technology that can provide low-cost water treatment

(3) Improve self-reliance in a way that takes account of the burden on the environment through technologies able to utilize renewable energy, advanced processing technologies for waste water and sludge.

Hitachi believes that this research and development can help resolve the water shortage problems being experienced globally due to factors such as sudden changes in climate or population growth.

In parallel with this research and development work, Hitachi is also working toward implementing practical water use management systems that utilize ICT based on its "intelligent water system" concept. These systems involve formulating operational plans that look at water supply, sewage, and water recycling from a broad regional perspective and are oriented toward macro- as well as micro-optimization. Water cycle traceability involves the acquisition and

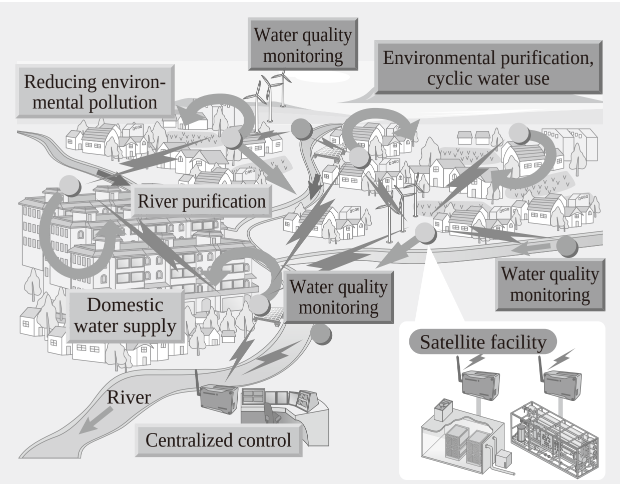

Fig. 10—Overview of IISS (integrated intelligent satellite system) Regional Water Resource Management System.
The system aims to improve treatment performance and operational efficiency through the distributed installation of medium-sized or small water recycling facilities depending on the size of the area covered.

prediction of time-series data about the quality and quantity of water required by users and the quality and quantity of discharged water. In parallel with this, Hitachi is also considering incorporating calculations of the quality and quantity of water able to be processed by water treatment facilities that take account of factors such as the water distribution network and how the water is physically distributed. By implementing this system, Hitachi aims to provide all water users with safe water at low cost in a way that places less of a burden on the environment.

CONCLUSIONS

This article has described Hitachi's technology and business development efforts aimed at implementing smart water usage management systems together with its plans for the future.

Although Japan is said to be blessed with abundant water, this is mainly due to the water management infrastructure built up during the "construction era." If one allows for the concept of virtual water, Japan can also be considered to be a major water importer. Accordingly, in addition to maintaining a safe and reliable water cycle in Japan through appropriate maintenance and equipment upgrades, the country can also be said to have an obligation to apply the technologies and know-how it has built up domestically to contribute globally.

Based on the principles of "harmony, sustainability, and self-reliance," Hitachi intends to continue contributing to society by supplying water management systems and services that take account of both people and the environment.

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