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Research and development on water supply technologies in JWRC

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ABSTRACT

The Japan Water Research Center has adopted a research model for large water supply technology projects whereby participants from industry, water utilities, and academia work in close cooperation. Using this trilateral research framework, the JWRC has been pursuing the development of water supply technology from various angles for the last 20 years. Major topics have been new water purification technologies as exemplified by membrane filtration and pipeline technology directed at leakage prevention, earthquake proofing, and countermeasures against water quality deterioration in pipes. The current paper gives an overview of the research framework and major R & D projects implemented by the JWRC. Ongoing projects and future outlook are also mentioned.

Key words | *e-water*, joint research and development, membrane filtration, pipeline technology, water purification technology, water quality degradation

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INTRODUCTION

Ever since the introduction of modern water supply systems in Japan, slow sand filtration and rapid sand filtration have been used as the main water purification methods. However, with progressive aging of facilities, a large number of decrepit installations are now due for renewal, and suitable water treatment methods matched to local conditions in the respective area must be developed and implemented. In some areas, sophisticated water purification facilities employing ozone and activated carbon are already in operation, and membrane filtration technology is spreading. With regard to pipeline technology, research is directed at developing solutions in the areas of leakage prevention, earthquake proofing, and countermeasures against water quality deterioration in pipes. In the past, public water utilities, academic institutions, and private enterprises separately carried out R & D projects in these areas, but eventually an integrated framework was created for coordinating research and development by the three participating sectors, namely the industry, utilities, and academia. This is aimed at increasing efficiency and producing comprehensive results. The current paper will provide an overview of past and present water supply technology research in Japan, with particular focus on the role of the Japan Water Research Center (hereinafter abbreviated as JWRC).

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WATER SUPPLY HISTORY AND FUTURE TASKS

Water supply systems have a very long history, which is understandable because humans always need water for purposes such as drinking, hygiene, and fire fighting. It is generally believed that the earliest organized water supply systems were constructed in ancient Roman times. Gravitation was used to transport water from the source to other areas, but there were no provisions for purification. In the period between the third century B.C. and the third century A.D., a total of eleven aqueducts made of stone were constructed. With regard to purification, a discovery made in 2005 in a rural area of China reportedly led to the excavation of a water purification facility dating from the Ming period, more than 400 years ago. Besides ceramic water pipes, a number of basins possibly used for purification were lined with earth having a high concentration of aluminum, as well as layers of sand, gravel, and charcoal. It is thought that aluminum could have been employed as a coagulant and charcoal for water purification.

In Japan, conduit facilities to transport water from sources to city areas began to be built about 400 years ago in present-day Tokyo. By the 18th century, six such facilities existed which were among the largest of their kind worldwide. A modern-style pressurized water supply system was established for the first time in Yokohama in 1887. It comprised 44 kilometres of conduit and employed slow sand filtration. About a hundred years later, in the 1980s, water supply coverage in all of Japan exceeded 90 percent (see Figure 1). Currently, the water supply coverage rate in Japan stands at more than 97 percent, which means that almost the entire population has access to running water. The aim of development therefore has shifted to the updating and optimization of facilities and the construction of higher-level water supply systems.

Water purification in Japan was implemented in Yokohama and later in Tokyo and other areas and was originally based on slow sand filtration methods imported from the U.K. More efficient rapid sand filtration techniques were developed in the U.S. In Japan, it was employed for the first time in 1912 in the city of Kyoto and spread quickly after that. From the year 1990 onwards, small scale purification plants started to implement membrane filtration, and in 2007, a large scale membrane filtration facility with a daily treatment capacity of 80,000 cubic metres has been taken into operation in Tokyo.

The development of water supply technology now faces a number of new challenges. Changing water quality in source areas requires purification methods that are optimized for local requirements. Pathogenic microorganisms have emerged that are resistant to chlorine disinfection. In order to respond to consumer needs for safe and palatable water, countermeasures against odor-causing compounds must be found and implemented. An increasing number of decrepit facilities must be updated or replaced, and functionality must be improved. To meet these challenges and serve society as a whole, research on water supply technology must aim for high-performance solutions.

In the field of pipeline technology, equipment manufacturers have been developing materials with better properties, new types of joints. R & D efforts must now mainly be directed at leakage prevention, earthquake proofing, and countermeasures against water quality deterioration in pipes.

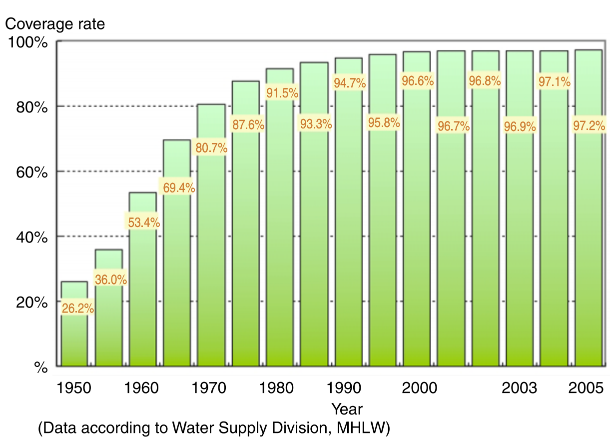

Figure 1 | Development of water supply coverage rate in Japan.

INDUSTRY-GOVERNMENT-ACADEMIA RESEARCH PROJECTS MANAGED BY THE JWRC

What is the JWRC?

The JWRC is a non-profit public organization which contributes to the development of water-related technology in Japan by conducting information collection, research, and development activities in the overall field of waterworks.

In 1988, an organization called the Japan Pipe Systems Research Center was established with the objective of promoting joint research and development by parties involved in the field. This was followed by the forming of the Japan Water Treatment Process Association in 1991. In 1996, these two organizations merged to become the Japan Water Research Center (Fujiwara 2003).

Via research projects pursued jointly by public water utilities, universities and other research organizations, and private sector companies, the JWRC is currently involved in the development of membrane filtration and other treatment technologies as well as in projects related to proper pipeline management. As technical supports, the JWRC has undertaken technologically evaluation, performance surveys and functional diagnosis of water supply facilities and a JWRC standard for membrane filtration modules has been prepared.

Another field of activity is the publication of manuals, guidelines, and study reports, and the organization of symposiums, seminars, and other events. The dissemination of information via various channels will contribute to the development of high-quality water supply systems for future generations. The most prominent undertaking along these lines is the International Symposium on Water Supply Technology which has been held every three years since its inception in 1988. It is recognized as one of the major international events in Japan focusing on water supply technology. The most recent one was the 7th Symposium that took place in November 2006 in Yokohama. For the first time, the International Water Association (IWA) acted as a supporting sponsor, and more than 100 overseas researchers from 30 countries attended the event, which had about 1,000 participants including the delegates from Japan. Invited guests included the IWA president Dr. Garman and many other leading experts both from Japan and abroad. Lectures, research paper presentations, panel discussions, and various exhibits brought the participants up to date with latest developments in water supply technology as well as management issues. Some outstanding papers from the symposium were also selected for inclusion in this publication.

Introduction of the industry-government-academia research model

In the conventional framework, basic research is being carried out independently at universities and other academic institutions, while companies develop facilities, and water utilities tend to be internally focused on operation and management technology. In order to consolidate these separate activities, the JWRC introduced a new research framework in 1991 aimed at consolidated development of water supply technology. In this model, funding relies in part on scientific research grants from the Ministry of Health, Labour and Welfare (MHLW), and in part on the research budgets of private companies. Large projects can be undertaken because the three sectors mentioned above operate in a cooperative relationship. The academic sector continues to carry out basic research, but field experiments and applied testing can be handled by companies specializing in the respective area. This allows the development of highly practical technologies and results in higher technological standards. Membrane filtration is a representative example of the success made possible by this approach. Research has been translated directly into practical application, and the technology is now being used in many of the water purification plants all over Japan. This industry-government-academia research system may be unique to Japan, but it must be a method well suited to Japanese society as it makes use of their characteristics and covers each other's weak points.

Structure and achievement of the industry-government-academia research model

As mentioned above, the JWRC plays an integrating role for public water utilities, universities and other research organizations, and private sector companies, resulting in an R & D model suitable for large projects (see Figure 2). In terms of personnel, funds, and research scope, projects that would be beyond the reach of each individual sector become feasible. For example, the recently completed *e-Water* project was realized with grants and industry funds amounting to about six million USD. As many as 15 academic institutions, 25 large and medium scale water utilities, and 37 water consultants and manufacturers took part.

Table 1 (Fujiwara *et al*. 2006) lists the major projects undertaken by the JWRC using this research model since the early 1990s. In the field of water purification, the development of membrane filtration technology was a highlight, while pipeline diagnosis technology formed another area where notable success was achieved.

DEVELOPMENT AND DEPLOYMENT OF WATER SUPPLY MEMBRANE PURIFICATION TECHNOLOGY

Conventional water purification systems mainly rely on sand filtering for solid-liquid separation. The technology in this area

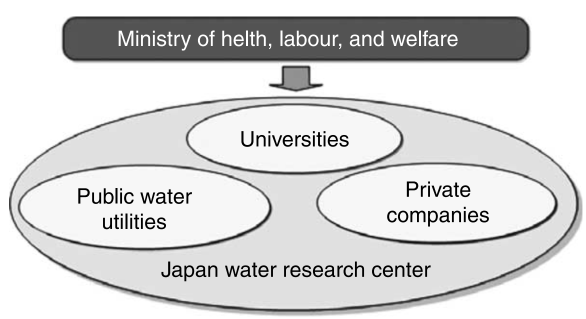

Figure 2 | Organization of joint research model.

Table 1 | Research & development projects

Year	Project Name	Contents
1991 ~ 1993	MAC21	R&D on Applied Technology of the MF / UF Membrane, Pilot Plant etc.
1994 ~ 1996	Advanced-MAC21	R&D on Applied Technology of the NF Membrane, Pilot Plant etc.
1997 ~ 2001	ACT21	R&D on High-efficiency Water Purification Technology
2002 ~ 2004	*e-W*ater	R&D on Sustainable Water Purification Technology
	Epoch	R&D on Movement of Suspended Solid in Pipeline
2005 ~ 2007	*e-Wate*r II	R&D on Advanced Water Purification Technology
	New Epoch	R&D on Pipeline Diagnosis Technology

is mature and well established and has shown many good results. On the other hand, membrane technology can be seen as a new approach to separation that attempts to duplicate the separation functions of living organisms. The evolution of materials technology has enabled the development of practical membrane separation techniques, and their application to the water supply field has already become a reality. Because costs have dropped significantly along with technological progress, it is to be expected that membrane filtration systems will spread further and find wide acceptance in the near future.

Superior characteristics of membrane filtration, such as reliable turbidity separation, potential for automated operation, and easy maintenance prompted the JWRC in the early 1990s to begin researching possible applications in the water supply field. Thanks to the results of joint industry-government-academia projects fostered by the JWRC under the direction of the MHLW, membrane filtration technology was quickly accepted and implemented by many water supply utilities in Japan. The history of these research projects is traced below.

MAC21 project (1991–993)

The MAC21 project (*M*embrane, *A*qua, *C*entury *21*) demonstrated that membrane filtration (micro filtration, ultra filtration) can be extremely effective in removing suspended solids and bacteria, and that micro filtration and ultra filtration are suitable techniques for water purification applications. It was shown that multiple process steps involving flocculation, sedimentation, and sand filtration could be replaced by a single membrane filtration step.

Based on the results of this project, the MHLW approved membrane filtration as a purification system for drinking water. The Japan Water Treatment Process Association (later JWRC) used data from the MAC21 project to compile *Guidelines for the Introduction of Membrane Filtration at Small Scale Water Utilities* and a *Manual for the Maintenance of Membrane Filtration at Small Scale Water Utilities*. Thus it can be said that the implementation of membrane filtration began with small scale water utilities (Hayashi 2003).

Advanced MAC21 (1994–1996)

Following the MAC21 project, another three-year plan named "Development of New Advanced Water Purification Systems Using Membrane Technology" (Advanced MAC21) was formulated. The new project aimed at establishing methods for removing substances not adequately dealt with by conventional water purification methods, such as trihalomethane precursors, trace chemicals, odor-causing compounds, and viruses. To achieve these goals, research on the combination of micro filtration and ultra filtration with ozone-activated carbon processing and on nano filtration (NF) was carried out.

The project resulted in *Preliminary Guidelines for the Implementation of Advanced Filtering Techniques* and *Preliminary Guidelines for Water Purification and Sludge Treatment Using Membrane Technology*. These two publications were later amalgamated into a *Manual for the Introduction of Advanced Membrane Filtration Technology in Water Purification Facilities*. The project findings led to membrane filtration being positioned as an advanced processing technology that goes beyond the mere removal of soluble substances.

ACT21 (1997–2001)

The next project entitled "High-Efficiency Water Purification Technology: *A*dvanced aqua *C*lean *T*echnology for *21*st century" (ACT21) ran over the course of five years, 1997 through 2001. While the main focus of the project was on purification methods providing higher efficiency, the development of technology that could be applied to the new field of membrane filtration was also one of the aims (JWRC 2002).

A noteworthy aspect of this project was its case study orientation. Membrane filtration facilities for two actual purification plants with a planned treatment capacity of 40,000 cubic metres per day and 110,000 cubic metres per day were designed, taking the water quality of the respective raw water into consideration. Aspects such as quality of finished water, installation space requirements, equipments initial and maintenance costs were subject to a comprehensive analysis and compared to conventional rapid sand filtration. The resulting data in turn became the basis for R & D carried out during the subsequent *e-Water* project, aimed at the development of membrane filtration technology for large and medium scale purification plants.

e-Water (2002–2004)

"Research on Sustainable Water Purification Technology: *E*nvironmental, *E*cological, *E*nergy saving and *E*conomical *Water* purification system" (*e-Water*) was aimed at securing a proper water environment for the 21st century. Some goals of the project were the development of energy-saving water purification technologies, reduction of sludge, effective use of water resources and other approaches intended to prevent global warming and sustain a proper water circulation. High-capacity membrane filtration technology played an important part in this scheme.

As the results of earlier projects including MAC21, Advanced MAC21, and ACT21 had shown, membrane filtration is an effective way of providing *Cryptosporidium* control in small scale water purification plants, and implementation of this technology was progressing at a favorable pace. However, medium and large scale plants were still struggling with implementing suitable anti-*Cryptosporidium* measures, in particular in instances with low water temperature and low turbidity. At such plants, the review process regarding the introduction of membrane filtration was still in the initial stages.

To facilitate the introduction of membrane filtration at medium and large scale water purification plants, the new project aimed at developing technology for safe and reliable membrane filtration of large treatment capacities (50,000 to 200,000 cubic metres per day). As a result of this research, a set of *Guidelines for the Introduction of Membrane Filtration at Large Scale Water Purification Plants* was issued. In addition, *Technical Reference Materials for the Introduction of Membrane Filtration at Large Scale Water Purification Plants* were also made available, providing various data and case examples both from Japan and overseas (JWRC 2005*a*).

Originally, the U.S. and Europe were ahead of Japan regarding research and development in the field of membrane filtration. However, since the industry-government-academia research model was implemented, the results of the large scale research projects related here have propelled Japan to the forefront in this field, and the number of purification plants that have implemented membrane filtration is now the highest worldwide.

In 1993, when MAC21 was concluded, there were only seven installations of membrane filtration in Japan (600 cubic metres per day). These increased year by year, reaching 586 plants with a total treatment capacity of 750,000 cubic metres per day in March 2007 (see Figure 3).

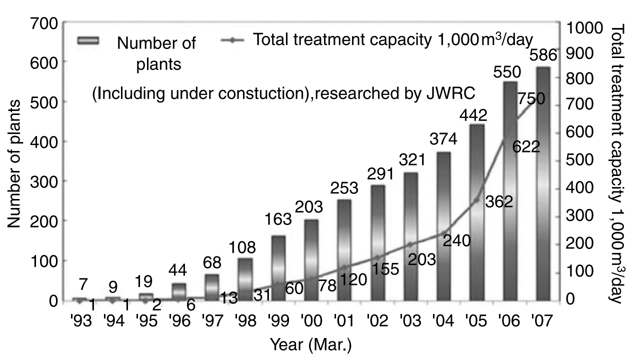

Figure 3 | Membrane water purification plants in Japan.

Plants rated for 40,000 to 80,000 cubic metres per day are now being built on an ongoing basis, and the trend towards larger capacities is expected to accelerate further.

PIPELINE TECHNOLOGY RESEARCH AND DEVELOPMENT

The JWRC's involvement with pipeline technology research began with a study about diagnosing the degree of decrepit in asbestos cement pipes. Work has expanded to cover topics such as pipeline information management, quake-proofing, direct water service without receiving tank, residual chlorine concentration control, pipeline diagnosis, and renewal planning.

Epoch project (2002–2004)

The *Epoch* (*E*ffective water use in *P*ipeline *O*peration *C*onsidering *H*igh quality) project which started in 2002 focused on technology for preventing water quality degradation in pipes. Some of the results are listed below (Fujiwara 2007).

(1) Investigation on causes of suspended solids.

Water quality degradation in pipes is caused by an increase in suspended solids. An inquiry regarding causes of suspended solids in pipes was conducted among water supply utilities in Japan, and at the same time a large scale distribution test pipelines (pipe diameter 100 to 150 mm, DIP) was constructed to examine the conditions under which red or turbid water occurs in pipes. As a result, locations where suspended solids or other water quality degradation is likely to occur were identified, and it was shown that the concentration of suspended solids tended to be high in such locations also during normal operation.

(2) Clarification on movement of deposits/suspended solids.

Movement tendencies of suspended solids were examined through tests conducted mainly at the above mentioned test pipelines. By inspecting points where deposits dispersed or accumulated, it was established that the flow velocity at which deposits begin to move is 0.6 metres per second. From the tests, an equation for estimating the flow behavior of deposits at branch points was deduced. Calculations made using this equation and actual test data showed a good match (see Figure 4). Contrary to common assumptions, high-density substances (2.4 to 3.2 grams per cubic centimetre) such as sand or iron rust has a tendency to move in the branch-off direction rather than in the straight direction (see Figure 5).

(3) Development of facilities to remove deposits/suspended solids.

Taking the characteristics of deposits/suspended solids into consideration, R & D work was carried out to find ways of improving water quality and minimizing cleaning water volume. Various kinds of removal devices were explored, and an efficient strainer system capable of successfully reducing the amount of water required for pipe cleaning was developed.

(4) Research on energy saving technology.

In order to use potential energy of water efficiently the possibility of using an inline hydraulic turbine to generate

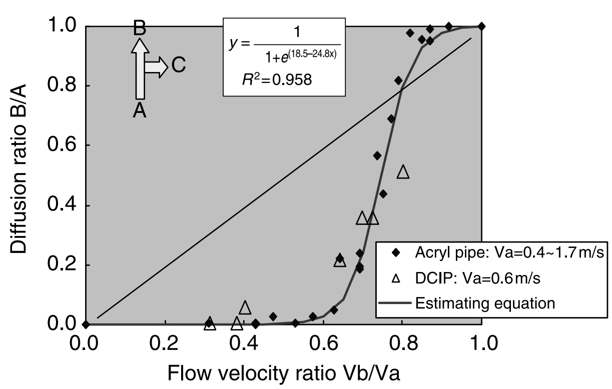

Figure 4 | Diffusion ratio at branch Sand in T branch φ150 × φ100).

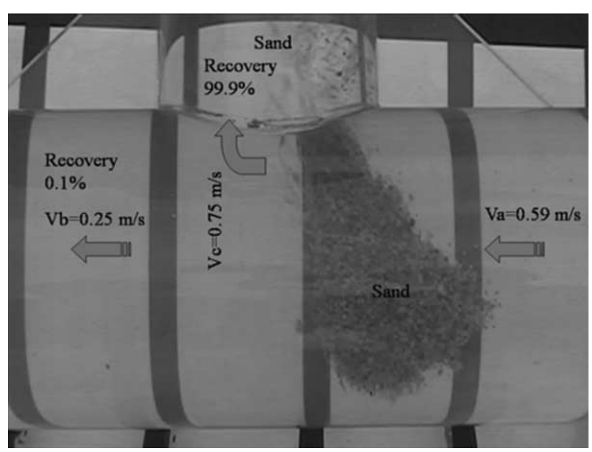

Figure 5 | Experiment on T branch (φ150 × φ100).

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electricity driven by surplus pressure was explored. Data regarding the long-term performance of such a device and possible benefits were collected, and an introductory manual was compiled which explains in easy terms how to plan for and implement the use of inline hydraulic turbine in pipelines (JWRC 2005*b*).

Other pipeline technology research results

A large number of guidelines and manuals were issued as a result of researching other aspects of pipeline technology (Hirano 2003). These are the *Water Supply Earthquake Countermeasure Manual*, *Manual for Residual Chlorine Concentration Control in Pipelines*, *Manual for Diagnosis and Renewal Planning for Aged Pipelines of Cast Iron, Steel, and High Density PVC*, etc.

ONGOING R & D PROJECTS

Currently, the JWRC is pursuing two research projects, namely "*e-Water II*" concerned with water purification technology and "*New Epoch*" concerned with pipeline technology. Both are three-year projects scheduled to run from 2005 to 2007.

e-Water II Project

The *e-Water II* Project involves research on the following themes:

(1) Research on a suitable purification system in accordance with raw water conditions.

Raw water conditions nationwide are classified into groups based on water quality. They are then, through a water purification system implementing a combination of unit water purification processes, evaluated on such criteria as safety of treated water quality, manageability, economical use of energy, a Life Cycle Assessment taking into account reduced environmental burden, drainage and sludge treatment process, and monitoring and instrumentation systems, and suitable water purification process guidelines are then investigated.

- The classification of treatment systems and the establishment of desirable treated water quality levels
- The study of coagulant dosage, mixing conditions and pretreatment methods with regard to the combination of membrane filtration treatment and iron-based coagulant (Pilot plant experiment)
- Measurement, analysis and evaluation of raw water quality
- Evaluation of treatability in each purification process
- Establishment of Life Cycle Assessment (LCA) technique

(2) Research on odor-causing compounds for safe and palatable water.

Traditionally, 2-MIB and geosmin have been stated as being the representative odorants. However, there are instances where even though these two substances have not been detected in raw water, odors still occur after purification treatment, or at water taps. It may be that odor-causing compounds present in raw water are denatured in the chlorine process, and then form some sort of odorants.

In order to supply safe and palatable water, we are carrying out research which will improve on safety and comfort through such means as promptly detecting unknown odor-causing compounds, changing the method of water intake, and advancing the water purification process.

- Simulation by means of water quality prediction models
- Creation of hazard maps
- Examination of countermeasure technologies against odor-causing compounds (including 2-MIB, geosmin)
- Implementation of online observation experiments using VOC monitoring system

New Epoch project

The *New Epoch* project (R&D on Pipeline Diagnosis Technology) involves research on the following themes:

(1) Research on water quality deterioration in decrepit pipeline and preventive measures.

Using the decrease and disappearance of residual chlorine as a main indicator, investigating methods to diagnose and evaluate the deterioration status of inside the pipes, and developing a pipeline function diagnosis technology in terms of water quality.

- Investigation of the relationship between water quality and decrease in residual chlorine
- Investigation of the relationship between pipeline material and decrease in residual chlorine
- Examination of water quality in actual decrepit pipelines
- Examination of water quality deterioration prevention by improving the Langelier's Index

(2) Research on evaluation technology of decrepitude degree for pipeline.

By making use of statistical as well as physical methods, develop a new evaluation technology to easily and efficiently determine the decrepitude degree of underground pipeline, and consider its application to existing pipeline.

- Study of existing pipeline diagnosis technology
- Examination of evaluation method of decrepit pipeline using statistical method
- Basic research towards no-dig diagnosis such as impact elastic wave method, etc.

CONCLUSIONS

The industry-government-academia research model has shown itself to be a useful framework for carrying out consolidated and effective research on a number of topics in the field of water supply technology. So far, the Japan Water Research Center has been mainly active in the areas of water purification technology and pipeline technology. The results of our work are used widely by water utilities and related businesses in Japan, thereby contributing to the availability of safe and palatable drinking water. We intend to build upon the accumulated knowledge and know-how of experts from the three sectors, namely industry, utilities, and academia. In the near future, the results of projects outlined in this paper will be applied to formulate and establish guidelines for selecting water purification processes which are optimized for the conditions of the respective raw water. We will continue to carry out research on countermeasures for odor-causing compounds in order to supply palatable water, as well as research on pipeline diagnosis technology for systematic and efficient pipeline renewal.

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